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A DESCRIPTIVE MODEL FOR DETERMINING OPTIMAL HUMAN PERFORMANCE IN SYSTEMS VOLUME III

AN APPROACH FOR DETERMINING THE OPTIMAL ROLE OF MAN AND ALLOCATION OF FUNCTIONS IN AN AEROSPACE SYSTEM

by Harold E. Price and Barbara J. Tabachnick

Prepared by
SERENDIPITY ASSOCIATES
Chatsworth, Calif.
for Ames Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • MARCH 1968

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(INCLUDING TECHNICAL DATA APPENDICES)

By Harold E. Price and Barbara J. Tabachnick

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Prepared under Contract No. NAS 2-2955 by
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A DESCRIPTIVE MODEL FOR DETERMINING OPTIMAL HUMAN PERFORMANCE IN SYSTEMS

Volume I

PART A

A SIMPLE MODEL OF A MAN-MACHINE DEVELOPMENT CYCLE

PART B

A SIMPLE CALCULUS FOR DISCRETE SYSTEMS

Volume II

PART A

SYSTEM DEVELOPMENT ACTIVITIES CONCERNED WITH PUTTING MAN IN AN AEROSPACE SYSTEM

PART B

DEVELOPMENT OF MAN-MACHINE SYSTEMS:
Some Concepts and Guidelines

Volume III

AN APPROACH FOR DETERMINING THE OPTIMAL ROLE OF MAN AND ALLOCATION OF FUNCTIONS IN AN AEROSPACE SYSTEM

Volume IV

A DESCRIPTIVE MODEL FOR DETERMINING OPTIMAL HUMAN PERFORMANCE IN SYSTEMS

Final Summary Report

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AUTHOR'S NOTE

This report presents an approach for determining the role of man and the allocation of functions to man and machines in an aerospace system. An extensive amount of data used in developing this approach are included as technical appendices. The research was sponsored by the National Aeronautics and Space Administration, Ames Research Center, under contract NAS 2-2955.

This effort was greatly enhanced through the interest and support of the technical monitor, Mr. Charles Kubokawa. Any comments regarding this report, or the data contained herein, would be appreciated if directed to:

Mr. Charles C. Kubokawa
Man-Machine Integration Branch
Biotechnology Division
Ames Research Center
National Aeronautics and Space Administration
Moffett Field, California

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1. INTRODUCTION

In every aerospace system development cycle there must be decisions concerning (1) should man be in the system or not, and (2) if he is in the system, what will he do. If one is concerned with obtaining optimal human performance in aerospace systems, then clearly, determining (1) whether man will have a role, and (2) if so, what functions he will participate in are two of the most important decisions in a system development cycle which bear upon this concern. Subsequent activities in system development which are concerned with selecting, job-aiding, training, supporting, and human engineering for man in the system are consequences of the role and allocation of function decisions and cannot make up for bad decisions in these two areas.

Despite the importance of these two decision steps concerning man's performance in the system to be built, there is general concern in the literature and among human factors and biotechnological specialists that we do not now make good allocation of function decisions. Specifically, we are not able now to completely justify a role for man (or no role) in aerospace systems, and we are not able now to adequately justify determinations of what performances should be allocated to men when they are included in the system.

Swain and Wohl (ref. 26) assert:

> A rather stark conclusion emerges: There is no adequate systematic methodology in existence for allocating functions (in this case, test and checkout functions) between man and machine. This lack, in fact, is probably the central problem in human factors engineering today... It is interesting to note that ten years of research and applications experience have failed to bring us closer to our goal than did the landmark article by Fitts in 1951 (p. 9).

Jordan (ref. 14) discusses current problems and efforts to allocate functions between men and machines and arrives at a similar conclusion to that of Swain and Wohl. He presents an analogy in the physical sciences concerned with the concept of "ether" which

> ...played a central role in physical thinking for over a century after having first been introduced as a necessary

> medium for propagating electromagnetic waves. But during all this time all attempts to build and expand upon this concept led to difficulties and contradictions. A century of research on ether turned out to be sterile in that no significant advance was made during that time.

The conclusion which Jordan draws from this analogy is as follows:

> The lesson to be learned from this momentus episode is that when a scientific discipline finds itself in a dead end, despite hard and diligent work, the dead end should probably not be attributed to a lack of knowledge of facts, but to the use of faulty concepts which do not enable the discipline to order the facts properly. The failure of human factor engineering to advance in the area of allocation of functions seems to be such a situation . . .

Jordan's final conclusion is stated as follows: "Herein lies the main future challenge to human factors engineering." (p. 165)

We agree that the problem is not so much a lack of facts as the ability to use these facts. We further assert that the problem usually referred to as "allocation of functions" is in fact two problems in that it is first necessary to determine man's role (or no role) in the system and then to determine which functions should be allocated to man. There are two related needs which must be satisfied to improve this process: (1) there is a need for a public, teachable, generalizable approach for carrying out the determination of man's role and allocation of function decisions in a manner which fits the decisions properly into the total development process, and (2) there is a need for an organization of the supporting data used to make trade-offs in the decision-making process such that data can readily be retrieved when needed. By and large, it appears that much of the data required are available; the problem appears to be that the data are indexed in a manner which makes them relatively inaccessible.

The objective of this report is twofold. First, it is to present a sequence of activities which describes an effective strategy for determining man's role and carrying out the allocation of function decisions. This sequence is intended to be useful as a guide for carrying out these decisions in the

development of any aerospace system. Effort has been made to develop and present a sequence which does not require unusual or unavailable background knowledge or data for its use. Effort has also been made to present a sequence that is amenable to evolutionary improvement. To render the sequence improvable, the rationale underlying its form is presented. The sequence is articulated with the total development cycle model of Report I of this series of reports and thus poses a way of integrating the decision-making activities into the system development cycle to ensure that the allocation decisions help to achieve a system which is optimal as a whole. The second part of the objective of this report is 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. Thus, access to the data is provided in a manner that is compatible with the structure of the sequence.

The body of this report presents: conventions important to the rationale or approach (Chapter 2), an overview of the approach and sequence of activities (Chapter 3), relationship of the sequence of activities to the overall development cycle model (Chapter 4), the activities for determining the optimal role of man (Chapter 5), and activities for determining the allocation of functions to man (Chapter 6). Supporting data for the sequence of activities is provided in Appendices A and B.

This report is number three in a series of three technical reports. The other related reports may be of interest to some users of this report. They are:

I Part A—A Simple Model of a Man-Machine Development Cycle.
Part B—A Simple Calculus for Discrete Systems.

II Part A—System Development Activities Concerned with Putting Man in an Aerospace System.

Part B—Development of Man-Machine Systems: Some Concepts and Guidelines

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2. CONVENTIONS

Certain concepts, assumptions, and definitions germane to the approach advocated are presented in this chapter. These may all be referred to as conventions and are so identified here. Research Report I, A Simple Model of a Man-Machine Development Cycle, presents (Chapter 2) many of the conventions and assumptions underlying the entire research program. Generally the conventions presented here are pertinent to this report only, although a few of the more critical conventions that are presented in Report I that do relate to this report are repeated or restated here. Each convention is numbered and titled and is presented generally in the order in which it is encountered in performing or understanding the sequence of activities described in this report. Thus, it is suggested that these conventions be read prior to reading the rest of this report. However, to assist the reader in referring to these conventions when necessary, they are referenced thoughout the remainder of the report where they apply, and they are listed below in the order in which they are presented in this chapter:

1. Local and Remote Segments
2. Optimal Manned Design
3. Man-Rated Performance
4. Core Performance
5. Roles of Men in Systems
6. Types of Human Performance
7. Personnel Support Systems
8. Man-Machine Comparisons
9. Personnel Products Package
10. Automation
11. Components of Human Performance

Convention 1
Local and Remote Segment

Aerospace systems may be described in terms of the geographical or physical location of the performance units within the total system configuration. It is frequently useful to describe systems, or for that matter any performance units, in terms of whether they are local or remote. Local refers to the immediate mission environment in which the system operates. The actual space vehicle of a space system would be the local segment, for example. Remote refers to some geographical or physical location away from the immediate mission environment, such as the launch area in the case of a space system. Remote systems or performance units also have two further qualifications, as follows:

1. Human beings may always participate in systems at the remote locations, although they may have to be protected and sustained from any hostile environment.

2. Remote systems or performance units require some type of mechanization to permit their interaction with equipment and/or personnel of the local system.

Convention 2

Optimal Manned Design

If man is used in a system concept there is an optimal manned design solution for any set of system requirements, although the optimal manned design solution may not be the best overall system solution. This is not to say that a manned solution is optimal or best; rather it is saying that if a manned solution is a candidate together with non-manned solutions, then the manned solution should be one in which man's role is optimal.

An optimal manned design solution is one in which man has the most responsible/authoritative/acceptable (R/A/A) role which he can perform while also being protected and sustained. Further, the concept for approaching consideration of man's capabilities and limitations should be to design man into the system with the most responsibility, authority, and acceptance feasible within the system requirements and constraints. This concept is based on the following rationale originally developed by Price, Smith and Behan (ref. 22).

1. Historically, the attempt has always been to extend man's capability and usefulness rather than to eliminate man. Developments in the physical sciences have been consistently oriented toward providing man with a better understanding and a better capability to participate in his current environment.

2. Acceptance by human operators within the system will be greater toward the higher responsibility/authority (R/A) roles than toward the lower R/A roles. It is now known that acceptance is definitely negative if human beings are designed into the system at a lesser level of R/A than they are capable of accepting and performing. The result is to reduce system reliability.

3. The higher R/A roles in systems are apt to have more cognitive performance associated with them. These types of performance are where man does excel and where it is difficult and expensive to build equivalent machines.

4. Design decisions concerning the implementation by men or machines for the higher order of R/A roles will influence the requirements for the lesser order of R/A roles. Thus every conceivable means, including utilization of man, must be considered to approach the optimum design solution and reduce the negative consequences of poor design.

5. It is well documented that man is a major component providing consistency in system performance. Since consistency of performance contributes to system performance reliability, man may be viewed as a major contributor to system performance reliability. This concept is based on the assumption that there are different levels of responsibility and authority associated with different types of performance. It also appears (based on the work on this project to date) that the importance attached to any role is dependent on the level of responsibility/authority, and that this is correlated with the degree of acceptance by man of his role in the system. That is, the greater the role man has, the more acceptable that role is to him. In summary, therefore, the optimal role of man is defined as that role which has the most responsible/authoritative/acceptable features feasible.

6. When man is included locally in a system, one of the usual reasons is to have him available to deal with unusual and unforeseen events. It is man's recognized aptitude for reprogramming or redesigning his role on the spot to deal with the unexpected that is so valuable, because it will increase system reliability. However, this is an aptitude of man, not a subsystem output achieved at no cost to the system or system designers. Like all required outputs it is not free but requires inputs. In order to be able to effectively redesign his role, in unusual or emergency situations, two preconditions must exist, and at this point in the design we must determine if in fact they will exist. These preconditions are as follows:

a. The man must understand the overall function of the system, and more specifically the subsystem he is interfacing with, his role in it, and how all automatic functions operate for which he might have to provide total or partial back-up. Where man is not given adequate explanations as to how functions other than his own are performed, particularly machine functions, he will make up his own explanations, as has been pointed out by Firstman and Jordan (ref. 8). These explanations will more than likely be incorrect and, therefore, not an effective tool in an unforeseen situation.

b. Man must be proficient at rapidly solving new and unforeseen problems in the subsystem environment. It has been demonstrated that this capability can be learned. Such capability has been labeled learning how to learn, or more simply as a learning set. However, this ability can be created and maintained only by giving the man the responsibility and freedom to continually try out new tasks and methods. Obviously it is not possible to produce the capability in man to deal with unforeseen events by selection, traditional training methods, or job guides.

Therefore, if man is to be placed in a system, particularly locally, in order to increase system reliability by having him as an

additive for dealing with unforeseen events, it is essential to give him as much responsibility and authority as is feasible. Maximum responsibility and authority are necessary to permit him to develop a learning set so that he will have the capability to deal with unexpected events.

Convention 3
Man-Rated Performance

Many system or function performance requirements may be implemented by solutions involving man as part of the design concept. Such solutions, wherein it is feasible to use man as part of the solution, are called man-rated. Thus man-rated performance is any performance that can be obtained with man as part of the design solution.

The range of human participation in potential man-rated solutions may actually be a continuum; however, it has been found useful to describe this range of participation in three levels of participation which can be identified as manual, mechanized, or manual-automatic. (The term machine-automatic is used where performance is fully automated and performed exclusively by programmed machines—see Convention 10, Automation.)

Manual task performance implies that a man performs the task, that he generates or accomplishes whatever power, energy, or energy transduction is required, and further that he controls the application of power or directs the utilization of the given energy. No assumptions are made about the nature of the task. It may utilize human receptors, or effectors, or both. The definition does not preclude the use of tools (e.g., a chart, a lever, or a telescope) which merely extend man's raw capabilities.

Mechanized task performance implies that a man performs the task, while a machine generates or accomplishes whatever power, energy, or energy transduction is required, but that a man controls the application or directs the utilization of the given energy. Again, no assumptions are made about the nature of the task. In this case, the tool does more than extend man's raw capabilities. Examples are powered flight controls, search radar, a bottling machine, or a desk calculator.

Manual-Automatic task performance implies that a machine performs the task by generating or accomplishing whatever power, energy, or energy transduction is required, and that a man controls, in real time, the application of the power or directs the utilization of the given energy. In manual-automatic

task performance man participates more indirectly. He may determine what is to be done, and perhaps how, as in the use of a digital or analog computer. He usually monitors the output to determine whether it meets certain minimal standards of accuracy. He initiates and may terminate the operation of the automatic device, as in the use of an autopilot or a record changer.

Convention 4
Core Performance

The prominent performances of any complex aerospace system may be described generally by the following seven categories of performance: (1) Sensing, (2) Interpreting, (3) Information Processing, (4) Decision-Making, (5) Controlling, (6) Monitoring, and (7) Information Storage. Since these seven categories of performance generally can be used to describe the prominent performance aspects of any system (or subsystem or function), they may be viewed as "core" performances likely to be found in any system. The term core performance is thus used in this study to encompass these seven types of performance. It may also be noted that core performances, in general, may be implemented by man or machine, or man-machine combinations.

Convention 5

Roles of Men in Systems

Many approaches have been developed for analyzing man's capabilities and limitations with respect to his potential in system performance. Some approaches suggest that man and machines should be compared for system performance, while others suggest that man and machines are not comparable, but are complementary. Some suggest that man should be designed into the system wherever possible, others suggest that man should be designed out of the system wherever possible. There are numerous controversial issues concerning man's capabilities and limitation for system performance. The philosophy adopted here is (1) that man has certain unique performance capabilities which cannot be compared against machines; (2) that many system performance requirements can be obtained either by man, or man-machine design solutions (man-rated), or can be obtained by machine alone (machine-automatic); (3) that if man's inclusion in the system is justified by his performance of mission-critical functions, his utilitarian capability may be exploited for performance of other system tasks which are not cost-effective to automate; (4) that man has certain unique limitations which require some type of personnel support system to accommodate his physical, physiological, and psychological constraints wherever he is used. This philosophy suggests that in order to develop the potential role of man in the system, four questions must be considered:

1. Can man's unique capabilities be significant in the obtainment of the system goals? While it is difficult to categorize man's unique capabilities, they seem to lend themselves to two major groups as follows:

    a. Man has the ability to learn; that is, acquire new knowledge and skills. Man can learn by practice, trial and error, or transfer of previous training. This unique ability to learn and transfer that learning to another situation has important implications for man's potential role in a system.

First, man can perform in many complex system situations if those situations are merely similar to the learning situation; second, man can accomplish deliberate or insightful learning "on-the-job" if the occasion calls for it.

b. Man has the capacity for creative cognition. This unique capability is frequently referred to as the ability to "think," but man's truly unique characteristic is that he is capable of insightful or heuristic thinking. On this basis, it may be said that man is unique in his ability to exercise judgment in unstructured situations, or to form concepts.

2. What system performance could be implemented by man? This question is concerned with either operations or maintenance performance which is basic or clearly related to mission success, and may usually be restricted to core performance activities.

3. If a role for man is justified because of his unique capabilities (question 1) or core performance activities (question 2), What other performance can be assigned to him to fully exploit his utilitarian capabilities? In other words, if man is justified in the system for other reasons, then full advantage should be taken of such things as his flexibility, adaptability, and motor skills, to perform tasks which may be very difficult or costly to automate.

4. Will man's unique limitations constrain his use in the system? This question must consider both system and individual factors such as the following:

a. Man comes in only one physical model and can only be integrated into the system concept as a physical whole with certain general characteristics of size, weight, shape, strength, etc.

b. Man has physiological needs. His performance deteriorates rapidly when these physiological needs, such as nourishment, environmental protection, sleep, comfort, and general health are not satisfied.

c. Man has psychological needs. His performance can change significantly as a result of such psychological variables as motivation, frustration, conflict, fear, etc. Further, his performance usually deteriorates over prolonged periods of high stress or nonactivity.

Answers to the first two questions determine what may be called the basic performance role of man. Answers to the second two questions determine what may be called the complementary and support performance role of man. Thus we may say that man has three potential roles in a system, i.e., basic, complementary, and support.

Convention 6
Types of Human Performance

It was established in the preceding convention (Roles of Men in Systems) that there are three elemental roles of men in systems; viz., basic, complementary, and support. Human performance in systems is usually expressed in other terms such as "operator" or "maintenance." In the context of this report three types of human performance are considered. These are defined as follows:

1. Operator performance refers to human performance which is directly concerned with obtaining the requirements of prime system functions.

2. Maintenance performance refers to performance of humans as "maintenance technicians" wherein they are part of the design concerned with maintaining prime system equipment, support system equipment, or additive (maintenance) system equipment.

3. Support performance refers to human performance which is directly concerned with the maintenance of human performance capabilities and may be either (a) personal maintenance activities, or (b) job-proficiency maintenance activities.

Convention 7

Personnel Support Systems

The concept of a personnel support system was presented in Research Report 1. The essence of that concept is repeated here and extended somewhat for the purposes of this report.

The concept of a personnel support system, that is, a system which provides environmental conditions for men in an operational system, is important in aerospace system development. Men in the local segment of an aerospace system are virtually always exposed to environmental conditions which would degrade the reliability of performance of many functions if support systems were not provided. A support system for the local segment of an aerospace system is called a Human Support System; for the remote segment it is called a Safety and Support System. Either of these personnel support systems includes all of the means justified for inclusion in the system on the basis of requirements for environmental conditions to sustain the reliabilities of prime and additive system means where the means is man.

For this report, personnel support has been further broken down into four areas of concern as follows:

1. Human Maintenance. —This area consists of those performances or devices of an individual vital to his physical and mental well-being such as (a) sleeping, (b) eating, (c) hygiene, (d) exercise, (e) recreation, and (f) housekeeping.

2. Human Monitoring. —This area consists of those performances or devices attendant to the medical and psychological monitoring of the physical and mental well-being of the crew. This includes both diagnostic and therapeutic performance.

3. Life Support. —This area consists of those performances or devices related to maintaining of a life supporting environment in what might otherwise be an environment hostile to human beings. This situation is of course prevalent in the local segment of any aerospace system.

Life support includes: atmosphere supply and composition, temperature-humidity control, pressure control, trace contaminant control, CO_2 removal, water management, and waste management.

4. System Protection—This area consists of those performances or devices related to protecting human beings against system performance or environmental factors which could be damaging or fatal. These factors are such things as acceleration, radiation, magnetics, electrostatics, sonics, and intense illumination.

Convention 8

Man-Machine Comparisons

The following discussion was originally presented by Price, Smith and Behan (ref. 22). Minor alterations have been made.

The literature contains many statements which compare men and machines. These are two very large classes of things. It may be expedient from a political point of view to consider that all men are born equal. However, from a practical point of view, it is not true. Further, shortly after birth they diverge in a variety of ways. Thus, what a particular human being is, what he can bring to a particular system task and the ease with which he can be integrated into that task, are a function of what he was born with and of the sum total of the experience he has had before being assigned to the system. Initial selection is one of the most important processes in filling crew requirements for any responsible system task. One of the problems with a good bit of the data on human performance is the selection of subjects. Frequently, people who are handy at the time the experiment is to be conducted are the subjects used. An example in the area of aviation research is the use of college students to estimate the ability of trained pilots to perform visual perceptual judgments. The subjects used to help make a decision about man's role in a system should always be representative of the population from which the system operators will be drawn.

On the other hand, all machines are not IBM 7090s. Complex electronic equipments of the same series differ among themselves more than do human beings selected and trained to perform complex system tasks (ref. 2, 4, 5, 16, 19, 23, 24, 28). Similarly, the class of machines called computers vary in complexity from the H-W Electronics 15K to the IBM 7090, both of which are classed as general purpose solid state computers. They compare as follows (26).

	HW-15K	IBM-7090
Add Time, microseconds	700	4.4
Storage Cycle, microseconds	16700	2.2
Storage, computer words	4000	17,500
Type of storage	Drum	Core & Drum
Word size	24 binary	36 binary
Buffering	None	MRWC

The upshot of this discussion is that men differ among themselves and that machines of the same class differ among themselves more than do men. The conclusion seems inescapable, except for making the broadest possible comparisons, that when comparing man and machines

one should specify the population from which the man is to be drawn and the specific characteristics of the machine under comparison. No one would argue with the statement that computers can perform arithmetic computations faster than men. On the other hand, some computers perform arithmetic computations faster than other computers.

A second qualification as regards the comparison of men and machines is concerned with preparing the man or machine for use in the system. In the case of the man there are problems of selection, training and pre-operational evaluation. In the case of the machine there are problems of design, construction and pre-operational evaluation. In either case it is necessary to specify intended use, performance criteria and minimum reliability requirements before the chain may be started. In both cases there is considerable interaction between selection and training, in the case of man, and between design and construction, in the case of the machine. In the comparison of man and computers, human training is analogous to computer programming. The human must learn a basic set of mental and physical skills which serve as a foundation for more complex and specialized learning and task performance. The system programs for a computer are analogous to these basic skills of the human. The learning of more complex and specialized task performance, on the part of the human is analogous to the specific—non-system—programs which must be written for the computer. Just as human performance can be modified by training, within the limits of the basic set of skills, so may the computer performance be modified by writing new programs, within the constraints of the available system programs. While the basic skills of the human tend to remain relatively constant, it is possible to modify these, e.g. learning a foreign language. The majority of the change in human task performance is in the specialized tasks. Similarly with the computer, while system programs may be changed, it is specific programs which are continually being written, updated and improved.

A second analogy to the training which humans frequently receive is the modification to change or improve the operating characteristics of machines. A modification to an operating piece of equipment requires that the entire chain of design, construction and pre-operational evaluation begin anew. Modifications usually arise because of inadequacies in the original piece of equipment. Such modifications run the gamut from relatively minor changes to the obsolescence of a piece of equipment, e.g. the AN/FSP-20 radar replacing the AN/FSP-6 radar in the air defense unit. Few of the articles in the literature considered these processes. However, these processes are not accomplished for free, either for man or machine. Preparing either man or machine to fill a role in a system costs money and requires time, talent and facilities.

A third qualification is the requirement for the use of man or a machine. Here one must consider such things as special environments,

space requirements, weight, power, preventative maintenance to maintain reliability (motivation, if one is speaking of humans). In most systems, the human does not need a special environment. However, most complex electronic equipments do need a special environment. In such cases the human operator benefits from the demands of the machine. With the advent of solid state electronics, the demands for a special environment are not so stringent. However, they are not entirely removed.

With the advent of high altitude and space flight, the system itself operates in a highly specialized environment. In such cases man requires that the operational environment be modified to conform to the limits of his ecological constraints. As long as spacecraft are small, with a minimum of electronic gear, the equipment will benefit from the human requirement. But as spacecraft become larger, with more and more electronic gear, the requirements for the special environment will be contributed by both man and machine.

In terms of the capacity and diversity for performance which man offers, he requires relatively little space for most system tasks. This statement assumes that man takes his rest and recreation at a point remote from his system task performance. If the system must also provide for human rest and recreation, then man's space requirements increase considerably. In the case of man there is likely a strong relationship between space requirements in such a situation and the nature and duration of the mission. Space requirements will increase with increased mission duration, up to a maximum, and remain constant thereafter.

Space requirements for a machine are independent of mission duration. These space requirements are composed of that space occupied by the machine as such and the adjacent space required for all maintenance. Despite the enormous strides which have been made in miniaturization and packaging, equipments still require a great deal of space.

Both man and machine place constraints on the system in terms of the weight they bring with them and the power they require for an operation. However, in relation to capacity for performance, man has the edge on both counts. Electronic and other equipments are generally heavy and they require more equipment to supply them with power. Man is light per unit of capability and he requires only about 100 watts of power per day (10). Furthermore, in ground-based systems and short duration flight missions, he brings that power with him. However, in spacecraft with long duration missions, man's quantitative power supply requirements may become formidable. Further, qualitatively, man's power supply requirements are very complex.

In the case of the human performance, reliability is maintained by social custom and constraints. The job that is done, or the position filled, carries with it a certain status or prestige value. If a man occupies a low status position he is encouraged to do well, improve

himself and move up the status ladder. If the man accepts the social context in which the position is found, all is well. If he does not, then coercion or appeals to pride, team fellowship or patriotism may serve as poor seconds. Another way to maintain motivation is through remuneration for services. This is usually in the form of money, which contributes to social status. The crux of the matter is to get the individual to accept the subculture of the system tasks.

A fourth area for consideration is maintenance and repair. Both man and machine place heavy requirements on either a system or its context for maintenance and repair. Data to make trade-offs in this area must be prepared before an adequate comparison may be made.

The foregoing qualifications may be summarized as follows. In considering a trade-off between man and machine, where performance capabilities are not at issue, one should consider:

1. The population from which system operators will be drawn;
2. The specific characteristics of the machines under consideration;
3. The costs of selection and training of humans as compared with the costs of design and construction of equipment;
4. The costs of potential continued training for humans as compared with the costs of potential modification and reprogramming for equipments;
5. Special environmental requirements of man and machine;
6. Space requirements of man and of machine;
7. Weight and power requirements of man and machine;
8. Reliability (motivation) and preventative maintenance;
9. Cost of maintenance and repair.

Convention 9

Personnel Products Package

The concept of a personnel products package was presented in Research Report 1. The essence of that concept is repeated here and extended somewhat for purposes of this report.

The man-related end products of an aerospace system are identified by five categories of things:

1. Selected and trained crew members;
2. Job aids;
3. Materials to maintain reliability of crew performance on the job;
4. Products of human engineering including interface devices, tools and workspace arrangements;
5. Personnel support systems (Human Support System and Safety and Support System).

Taken together, we will refer to all of these end products as a personnel products package, or simply as personnel products. All of these classes of things are installed as physical components in the operational system. All of them relate to man as an implementor of system functions—both prime functions and additive functions. All common man-related end products of aerospace system development cycles fit into one of the five categories.

The above discussion of personnel products was basically taken from Research Report 1. For purposes of the present report it is convenient to consider the Personnel Products Package as two groups; namely, Performance Achievement Products, and Performance Maintenance Products. The Performance Achievement group consists of those elements related to achieving personnel performance or, in other words, how is the potential crew performance capability achieved. The specific elements in this group are (1) Selection, (2) Training, (3) Job Aids, and (4) Human Engineering. The Performance Maintenance group consists of those elements related to maintenance of the capability to perform once the capability has been achieved. The specific elements in this group are (1) job proficiency maintenance, and (2) the

personnel support system (see Convention 7). The listing below summarizes the concept of Personnel Products as used in this report.

Personnel Products Package

Performance Achievement Group

1. Selection
2. Training
3. Job Aids
4. Human Engineering

Performance Maintenance Group

1. Job Proficiency Maintenance
2. Personnel Support System

Convention 10

Automation

Men and machines are not competitors. This statement is paramount when one is concerned with the allocation of a system function for performance by a man or a machine. It is equally poor system design to have a man doing a machine's job or a machine doing a man's job. Also, it is not cost-effective to pursue a man-rated allocation solution when in fact it is impossible or obviously unfeasible. Thus automation possibilities, or a machine-automatic solution (as it is called in this report), should be determined early in the allocation sequence. To avoid the attempt to formulate man-rated allocations where they are entirely inappropriate, there must be criteria by which we can recognize functions which are or are not amenable to human participation at any level. Such criteria, which are only generally available at present, can be stated in terms of the limits of human performance capability so that these limits can be compared with performance requirements implied by functions. Whenever human performance limitations are exceeded and cannot be compensated for by a man-machine design solution, it can usually be recognized immediately.

For clarification, a definition of machine-automatic performance follows: Machine-Automatic task performance implies that a machine performs the task by generating or accomplishing whatever power, energy, or energy transduction is required, and that a preprogrammed feature controls the application of the power or directs the utilization of the given energy. In machine-automatic task performance man participates only at a remote time or place. This is not to be confused with "remote control" in which man may directly control a machine in real time only from a remote location. It is axiomatic that all machine-automatic performance is monitored by man, either during the performance or at some time after the performance is accomplished. Man may thus choose to reprogram the machine, but this is not what is called continuous control.

Convention 11

Components of Human Performance

Human performance may generally be viewed as occurring by the integrated outputs of man's three basic performance components; viz., sensory-perceptual, cognitive, and motor. Since these components also correspond to the basic psychophysical capacities of man, it is important to understand them in the context of man-machine performance. Birmingham and Taylor (ref. 3) have developed a very good discussion of this which follows:

> One of the by-products of engineering psychology is the conceptualization of the human operator and the machine which he controls as the two parts of one over-all man-machine system. Figure (a) shows a paradigm of this concept. [1]
>
> The receptors consist of the sense organs of the body; for example, special cells in the retina of the eye, the organs of Corti in the ear, and the proprioceptors in the muscles, tendons, and joints. It is through the receptor organs that changes in energy in the external environment take effect upon the human organism. Such energy changes which excite receptor cells are called stimuli (S).
>
> But not only is the organism acted upon by the environment—in turn the man modifies the external world through responses (R) of the effector organs. In the human, the effectors consist of muscles and glands, though only the former are directly involved in man-machine system function.
>
> Between the receptors and effectors is shown the central nervous system, which consists of the brain and spinal cord. It is through the activity of this nervous system that thought, judgment, and decision-making arise and learning takes place.
>
> Connecting the three uppermost boxes are lines which represent the peripheral nervous system, with the sensory nerves connecting the receptors to the central nervous system and with the effectors being supplied by the motor nerves. The upper portion of the diagram may be interpreted as indicating that stimulation from the outside leads to nerve impulses going

[1] A modified version of Figure (a), from the original reference is shown in Figure (b). This modified version is somewhat more useful to this study as it shows inputs which may be directly perceived by man, e.g., verbal conversation, in addition to the inputs that the human perceives from the machine and the responses he makes to the machine.

to the central nervous system, where they are rerouted along the motor nerves to the muscles. The latter respond, moving the body or applying force to some object and thus altering in some degree the state of the external world.

The only part of man's environment represented in the diagram is the machine, which is shown in the lower half of the figure. It is through the controls, the levers, knobs, handwheels, and switches that human response takes its effect upon the mechanism. On the other hand, it is through the displays, the dials, light panels, cathode ray tubes, horns, buzzers, and cross-pointer indicators that the operator is presented with information concerning the activities of the mechanism, which is represented in the schema by the box labelled M. Within the box are the vacuum tubes, the amplifiers, the special circuits, the servo motors, the electronic or mechanical computers, and the power drives—in short, those parts of the system which are traditionally of greatest interest to the engineer.

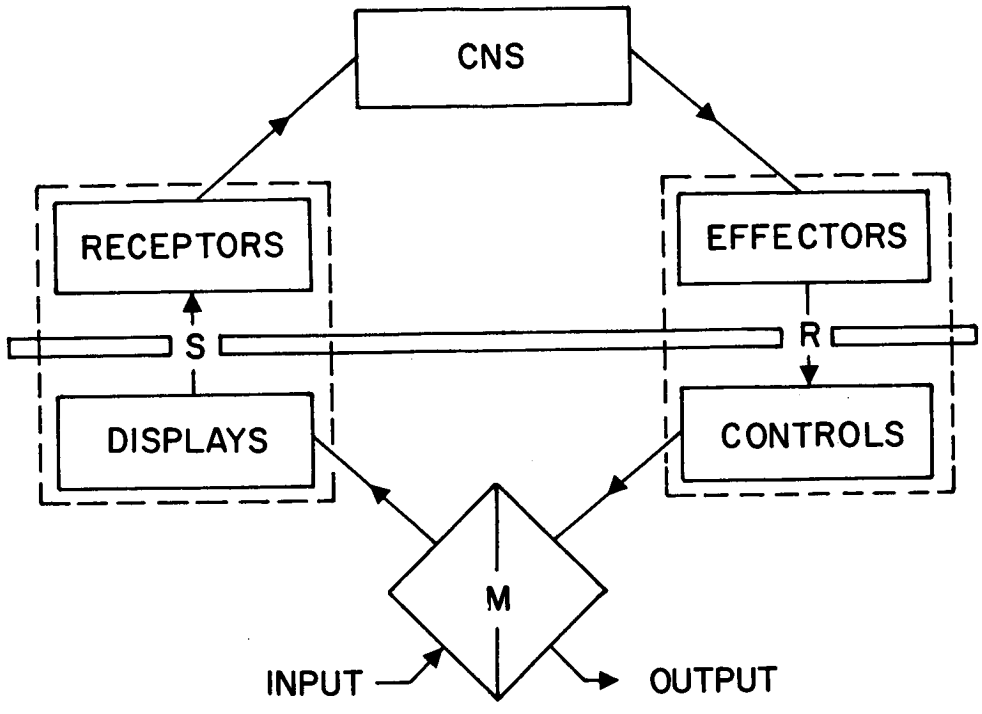


Fig. (a) The man-machine system as represented in Ref. 3.

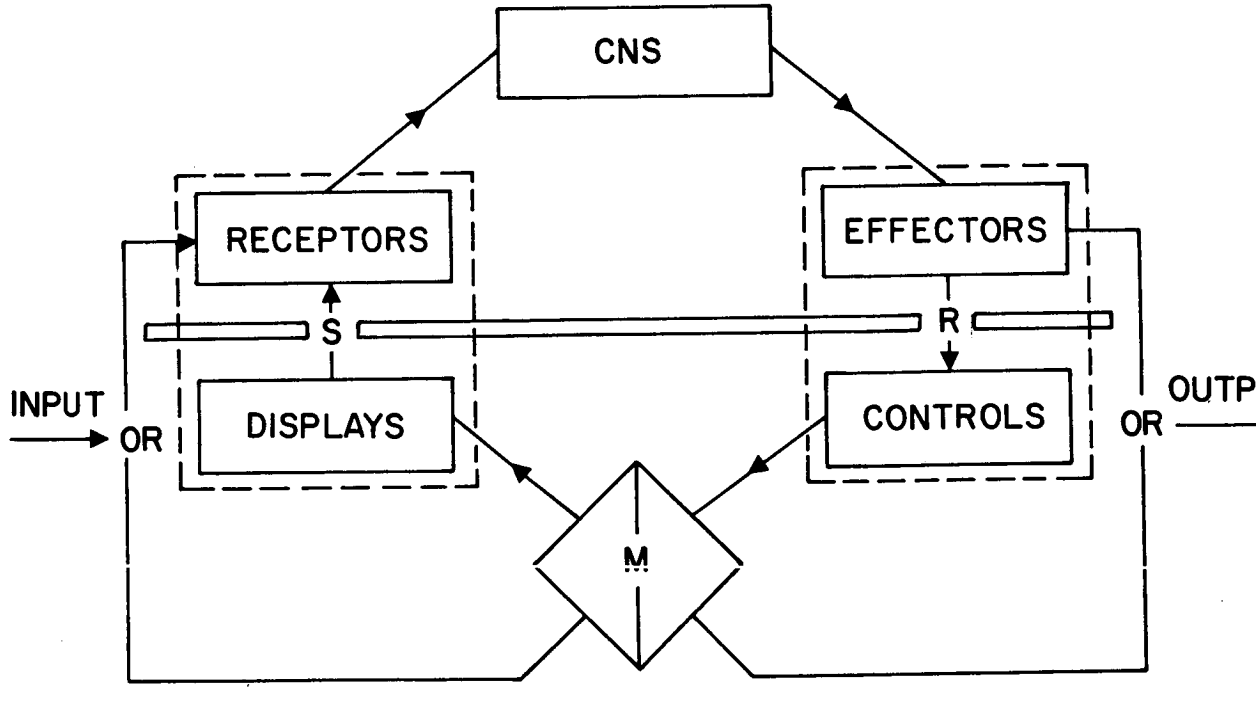


Fig. (b) A modified version of the man-machine system.

3. THE SEQUENCE OF ACTIVITIES FOR DETERMINING THE OPTIMAL ROLE OF MAN AND ALLOCATION OF FUNCTIONS — AN OVERVIEW

Chapter 1, Introduction, stated that an effective strategy is necessary for determining man's role and the allocation of function decisions. The strategy presented here is based on the rationale developed in Chapter 2 that (1) there are indeed two separate aspects to the overall problem, viz., first, determination of man's role in the system, and second, the allocation of functions to man within that role; and (2) that there is considerable data available but there is neither an existing strategy nor an adequate indexing of the data to facilitate their use. The strategy proposed here to be compatible with the above rationale is what might be called a hypothetical-deductive strategy. Other investigators, for example Hopkins (ref. 12) and Lindquist (ref. 17) have also suggested, at least in part, a similar strategy. In principle, it is simply one of using basically qualitative data to hypothesize man's role (or allocation of function) and then using more quantitative data to test the hypothesis. This basic strategy is carried out in two parts; one is concerned with the determination of man's role and the other is concerned with the allocation of functions to man. In either case, the first activity in the sequence is where the "hypothesis" is formed, and the succeeding activities are concerned with testing that hypothesis. Table 1 is an overview of all of the activities for both parts, indicating the order of performance and the outputs of each activity.

TABLE 1

THE SEQUENCE OF ACTIVITIES FOR DETERMINING THE OPTIMAL ROLE OF MAN AND ALLOCATION OF FUNCTIONS

ACTIVITIES FOR DETERMINING THE OPTIMAL ROLE OF MAN

Activity 1
Hypothesize the Potential Basic Role of Man

Outputs

1. Statements proposing unique human capabilities to foster system performance.
2. Statements proposing man-rated core performance to foster system performance.
   a. Sensing
   b. Interpreting
   c. Information Processing
   d. Decision-Making
   e. Controlling
   f. Monitoring
   g. Information Storage

Activity 2
Hypothesize Potential Complementary and Support Role of Man

Outputs

1. Statements proposing utilitarian human capabilities to foster complementary system performance.
2. A check list of personnel support system needs:
   a. Human Maintenance
   b. Human Monitoring
   c. Life Support
   d. System Protection

Activity 3
Review Manned System Solution Feasibility

Outputs

1. Statements identifying suspect areas of compatibility between human variables and system parameters which would eliminate a manned system solution from further consideration.
2. Statements identifying suspect areas of effectiveness or practicality which would eliminate a manned system solution from further consideration.

Activity 4
Develop a Preliminary Crew Concept

Outputs

1. A summary of crew performance in the local and remote segments for operations, maintenance, and support.
2. Estimates of the range of crew size.
3. Summary of concepts for crew performance achievement and proficiency maintenance.
   a. Selection
   b. Training
   c. Job Aids
   d. Human Engineering
   e. Proficiency Maintenance

Activity 5
Analyze Personnel Support Requirements

Outputs

1. Statements and supporting data of personnel support system requirements and development or operational implications.

Activity 6
Review Potential Crew Role for Acceptance and Reliability

Outputs

1. Summary statements of acceptability of manned system concept indicating areas of possible lowered reliability due to unacceptable role requirements.

Activity 7
Synthesize Optimal Crew Role

Outputs

1. Description of an optimal crew role including the crew concept, personnel support requirements, and crew effectiveness.

ACTIVITIES FOR DETERMINING THE OPTIMAL ALLOCATION OF FUNCTION

Activity 8
Establish Feasibility of Man-Rated Allocation

Outputs

1. Statements and rationale supporting the feasibility or unfeasibility of a man-rated allocation for function performance.

Activity 9
Develop Potential Man-Rated Allocations

Outputs

1. Descriptions of alternative man-rated allocations varying in extent of man participation for each function.

Activity 10
Review Allocation Potential Against Psychophysical Capacities

Outputs

1. Statements and data identifying allocations which are unfeasible because of incompatibility with basic psychophysical capacities.

Activity 11
Review Allocation Potential Against System or Function Constraints

Outputs

1. Statements and data identifying allocations which are unfeasible because of system environmental constraints.
2. Statements and data identifying allocations which are unfeasible because of system or function performance constraints.

Activity 12
Review Allocation Potential Against Human Reliability

Outputs

1. Statements and data identifying allocations which are unfeasible because of suspect human reliability.

Activity 13
Synthesize Man-Rated Allocations

Outputs

1. A summary and preferred order of potential man-rated solutions for accomplishment of each function.

4. RELATIONSHIP OF THE ACTIVITIES IN THE SEQUENCE TO THE OVERALL DEVELOPMENT CYCLE MODEL

Research Report IA of this series developed and presented an overall man-machine development cycle. The present report may be used independently, but it has been developed generally with the requirement to support the overall development process presented in Research Report IA. No discussion of the overall development cycle model is presented here and the reader is referred to Report I for the detailed discussion of the model. However, the model, in its diagrammatic form is presented on the following pages to indicate the articulation between the present report and the overall model. The dotted input and output arrows indicate the "loops" relating the activities of this report to the model. The activities of this report which receive inputs from or provide outputs to the model are identified for each dotted arrow. The encircled numbers in the arrow lines are loop numbers which are explained in Table 2 following the model.

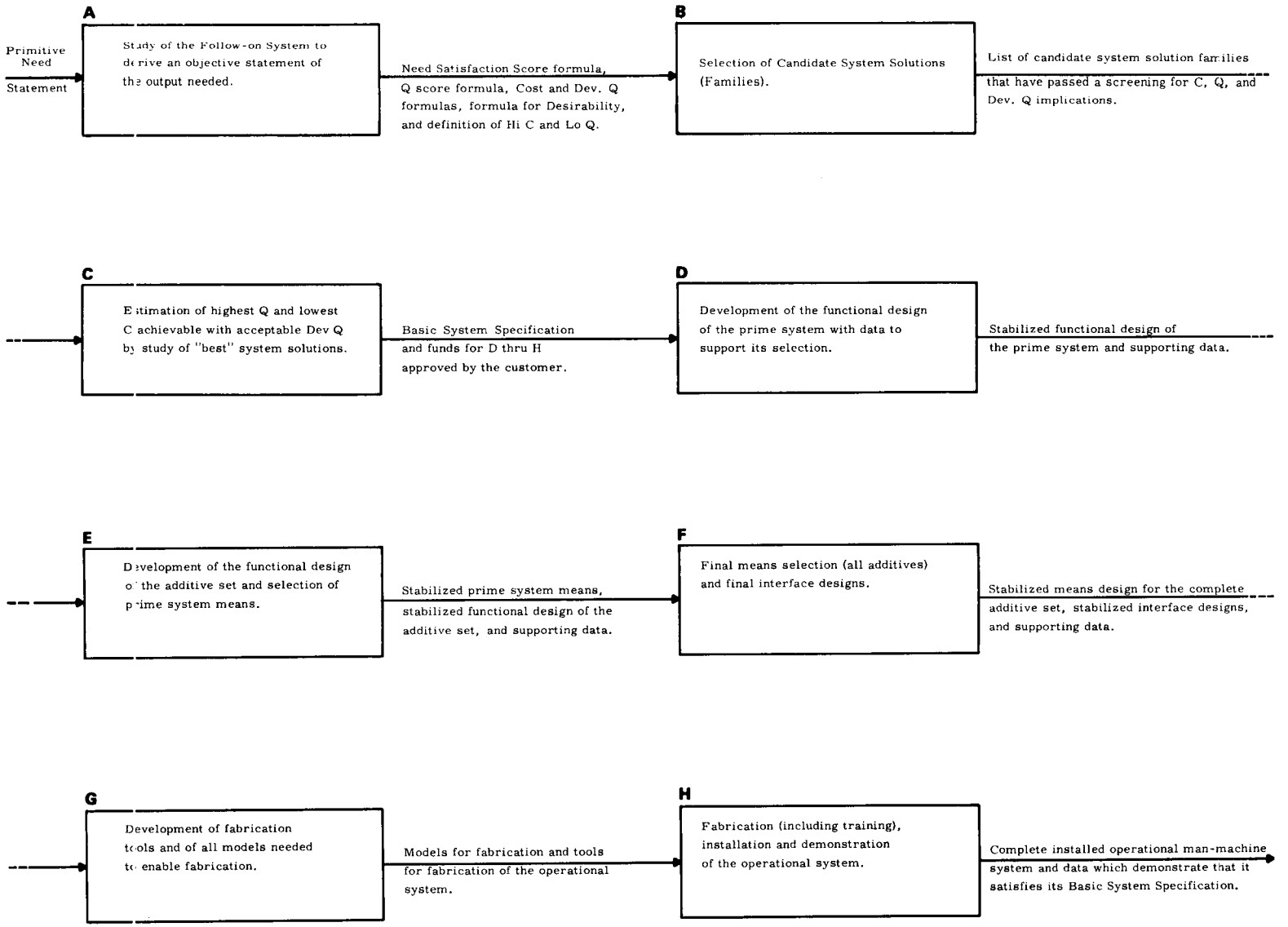


Figure 1. Schematic representation of the index model.

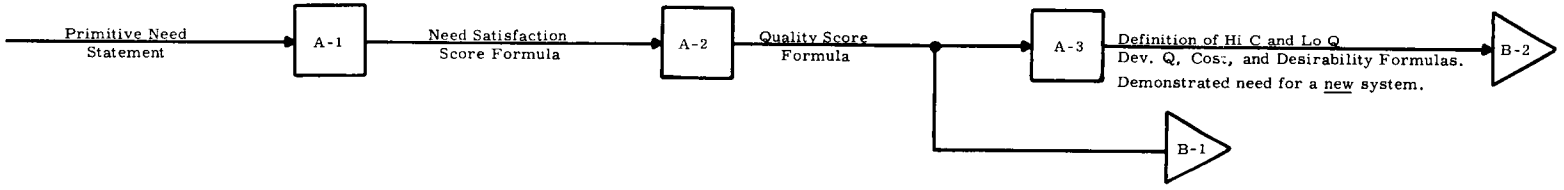
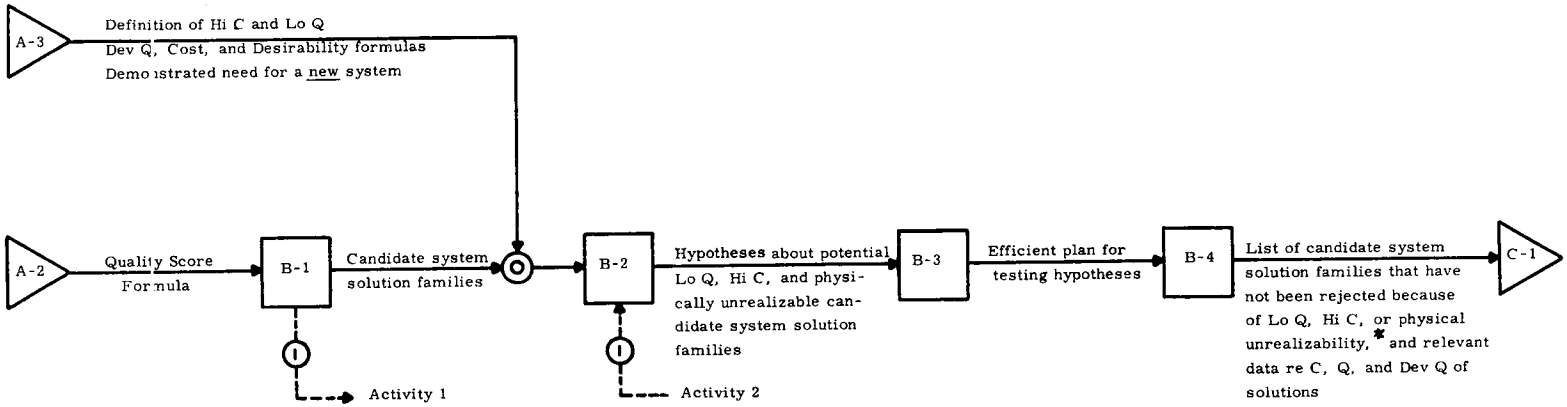
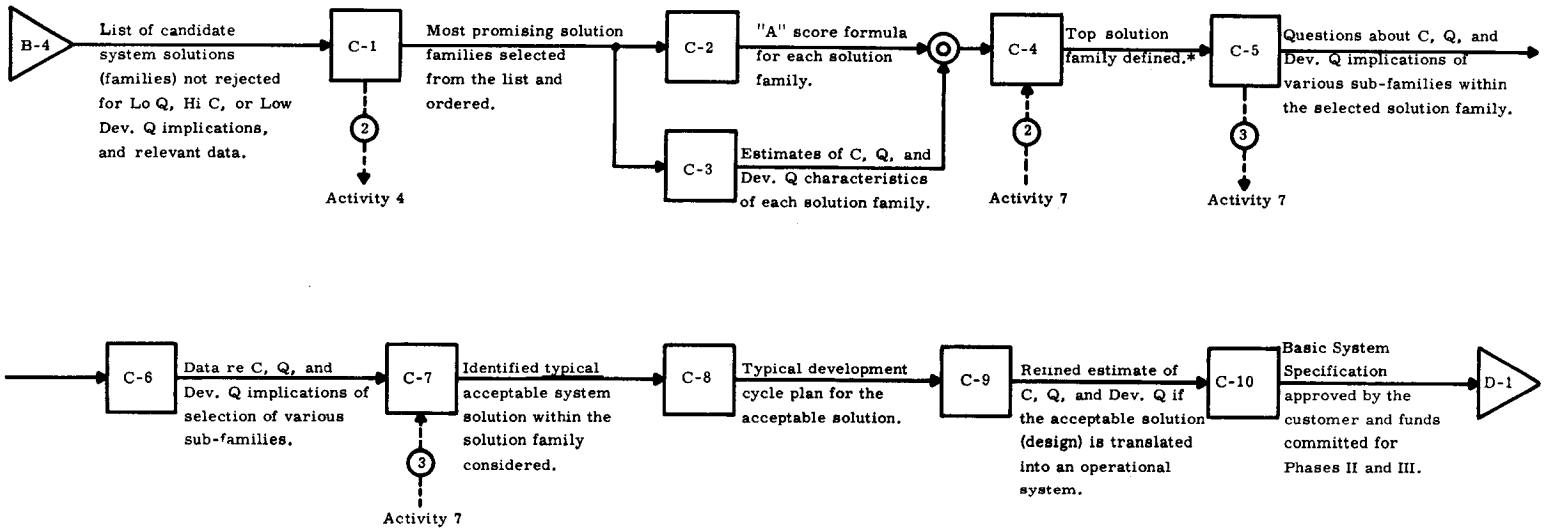


Figure 2. Diagrammatic overview of Function A (Phase I) showing the component activities and their relationships.



* Note: The type of activity sequence exemplified by B-2, B-3, B-4 may be repeated several times in order to shorten the list of candidate solutions sent to C-1. On the other hand, this sequence may be bypassed altogether if the output of B-1 does not need screening.

Figure 3. Diagrammatic overview of Function B (Phase I) showing the component activities and their relationships.



* Note: If it is desired to explore the Cost, Quality space adequately in Phase I, it will be necessary to identify several "top" solution families and to carry out parallel studies by replicating Functions C-5 through C-9 for each family. Such an approach would require comparison of the data for each family in C-10 as a basis for preparing the Basic System Specification.

Figure 4. Diagrammatic overview of Function C (Phase I) showing the component activities and their relationships.

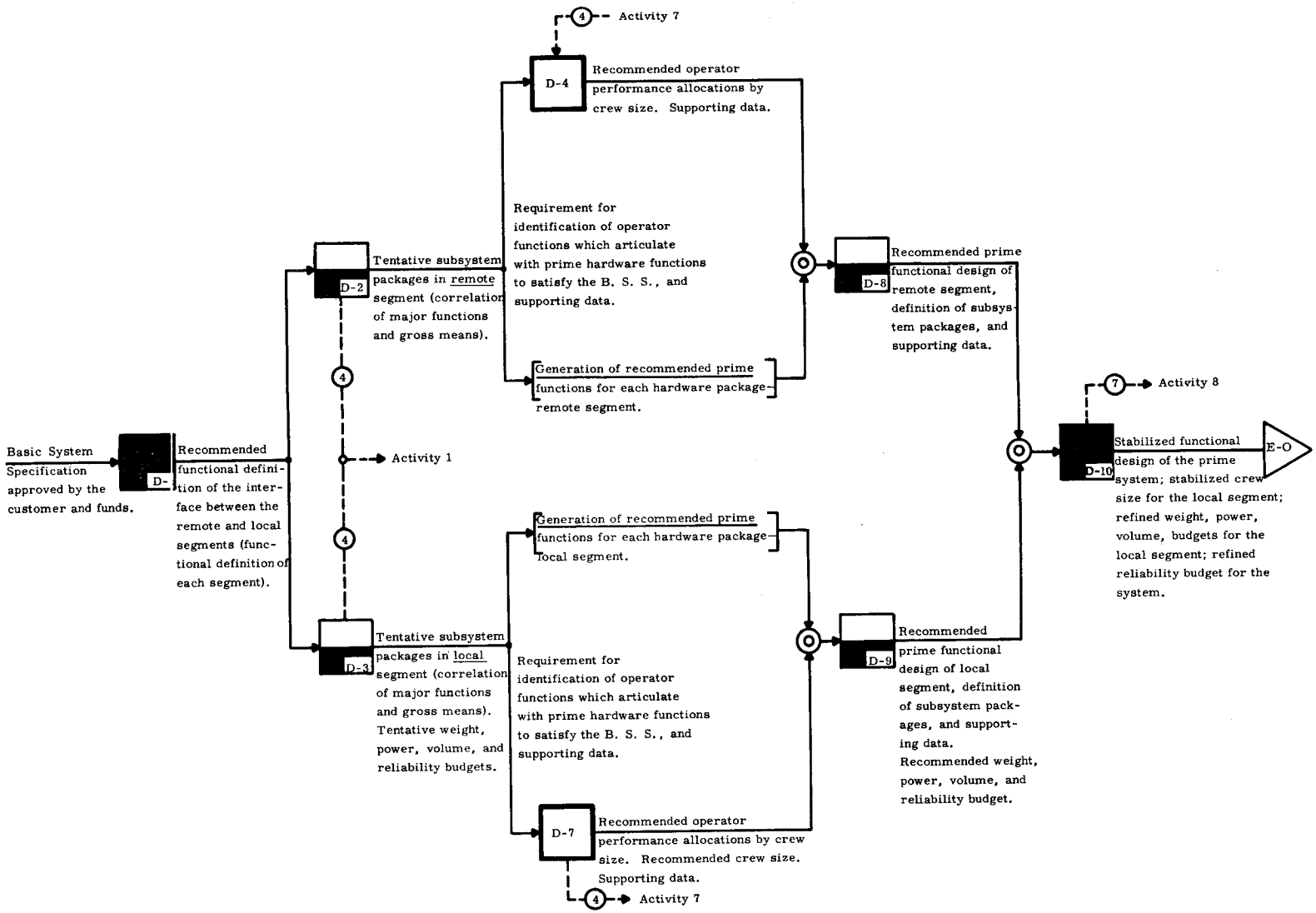


Figure 5. Diagrammatic overview of Function D (Phase II) showing the component activities and their relationships.

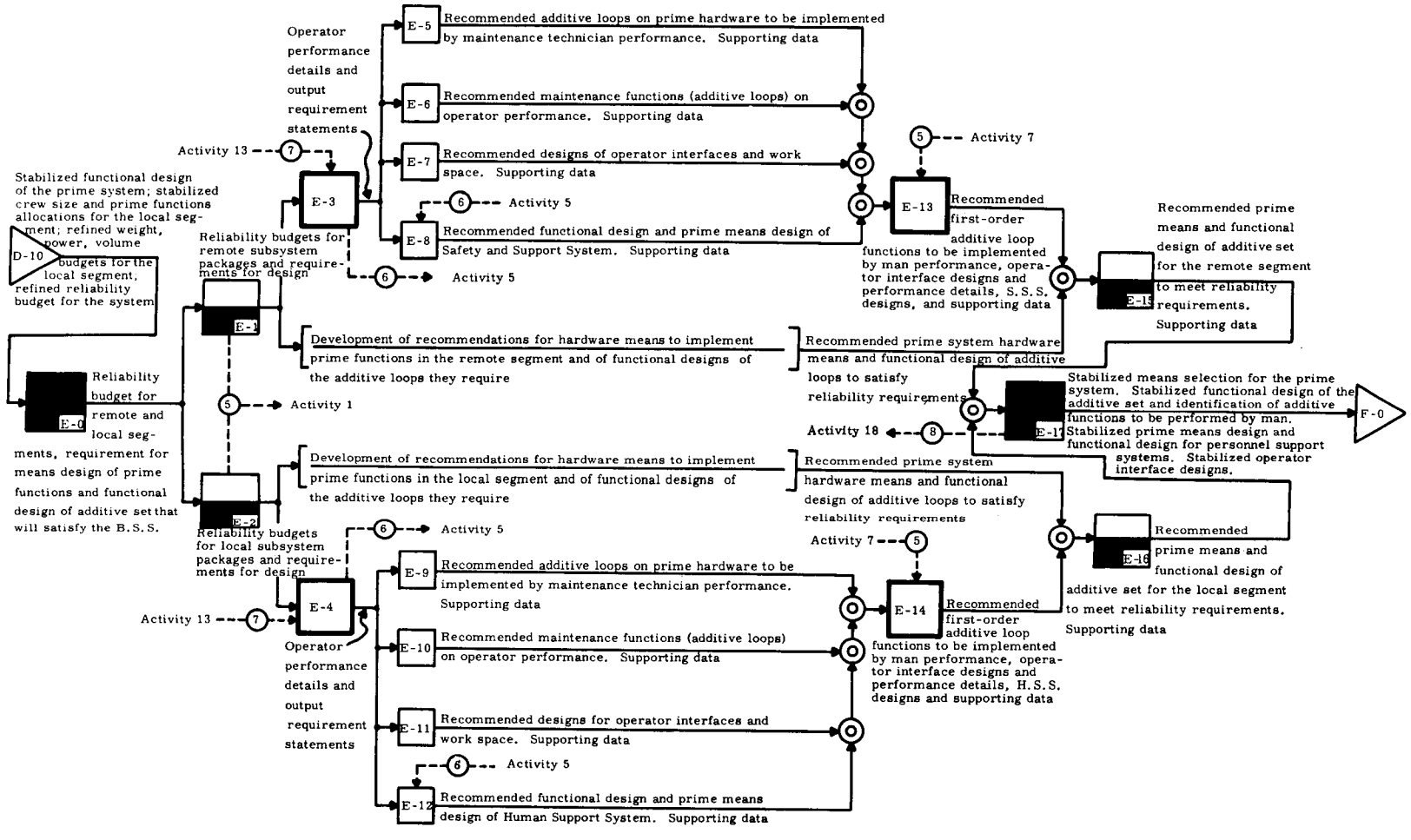


Figure 6. Diagrammatic overview of Function E (Phase II) showing component activities and their relationships.

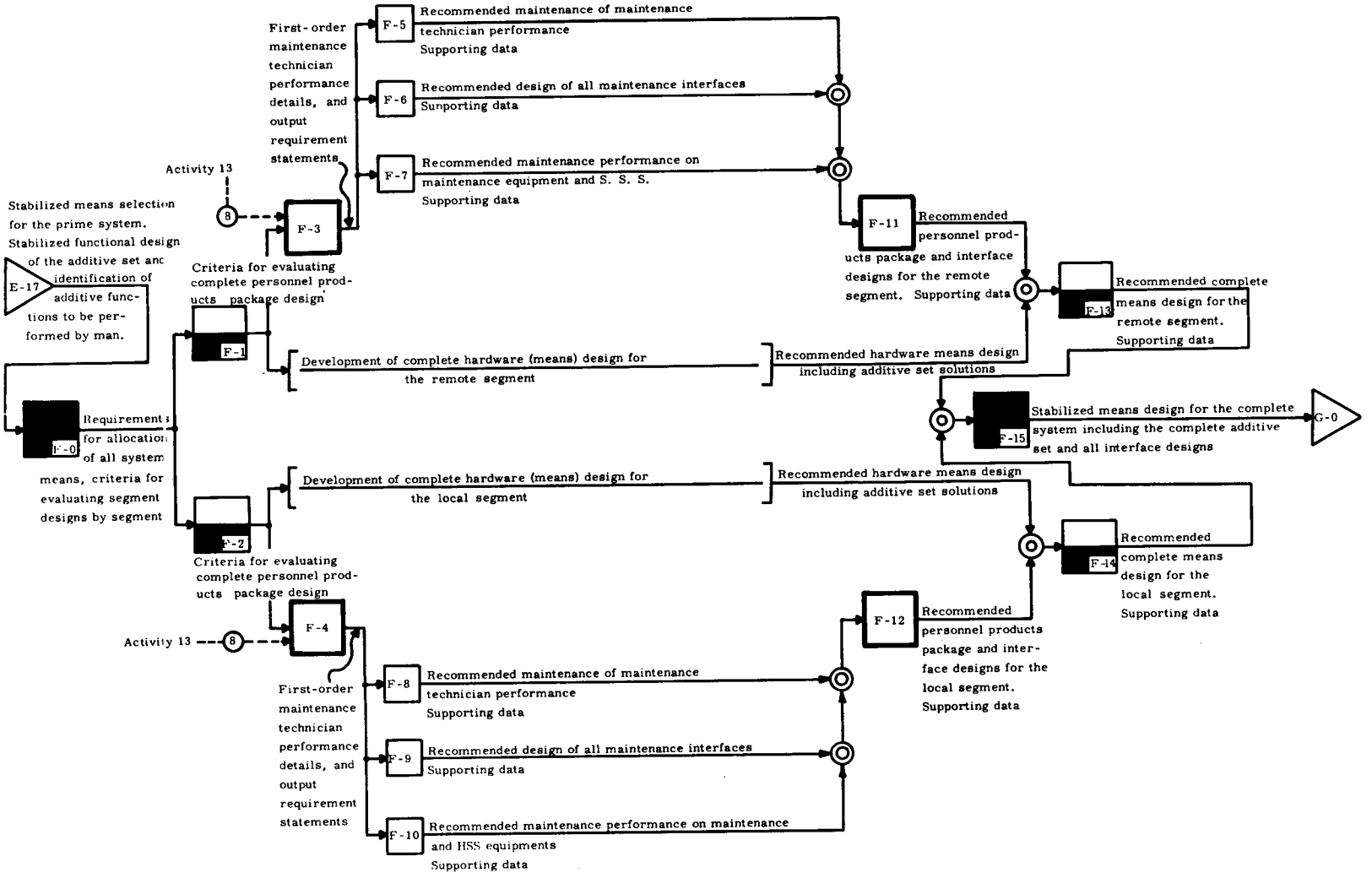


Figure 7. Diagrammatic overview of Function F (Phase II) showing component activities and their relationships.

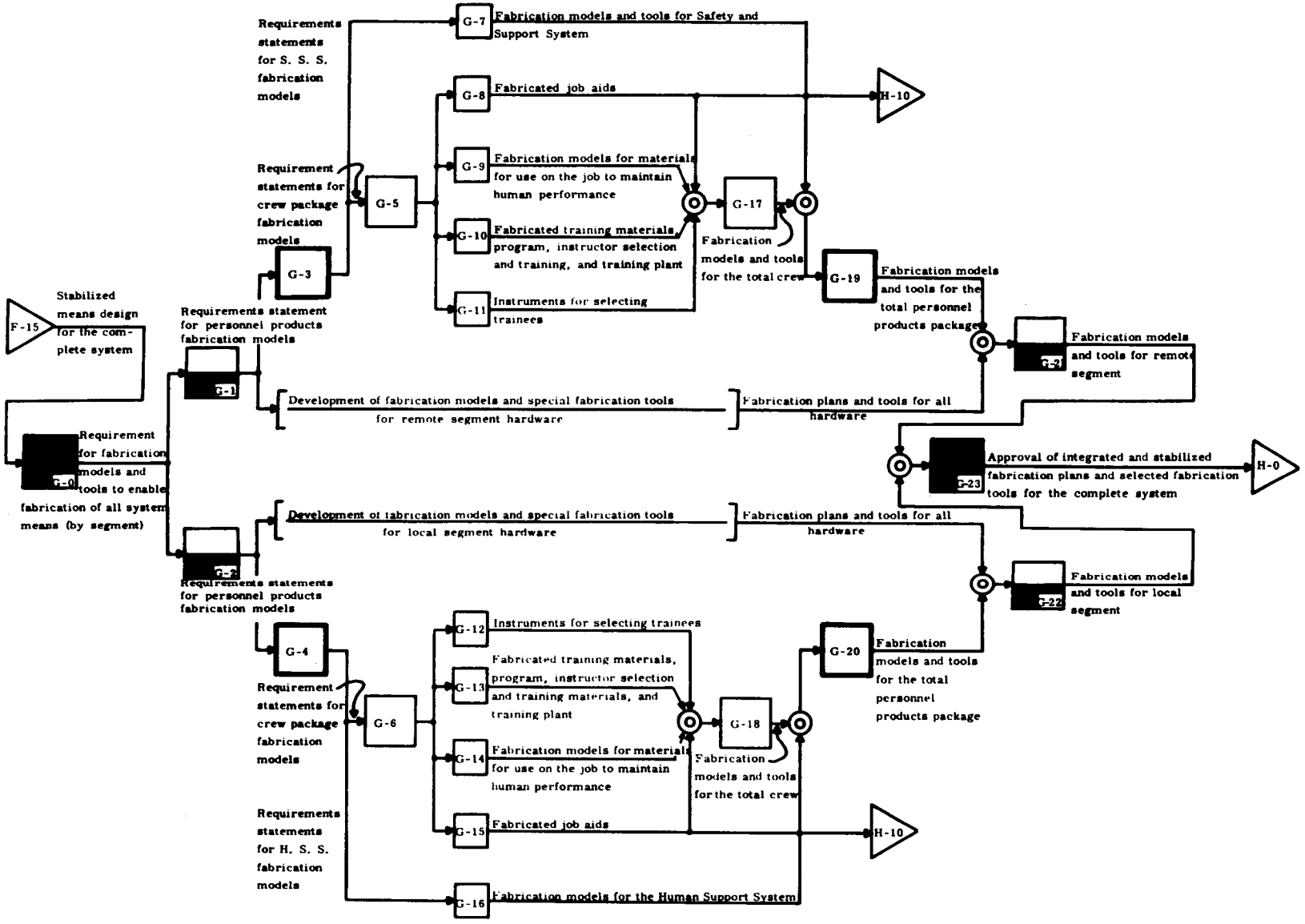


Figure 8. Diagrammatic overview of Function G (Phase II) showing component activities and their relationships.

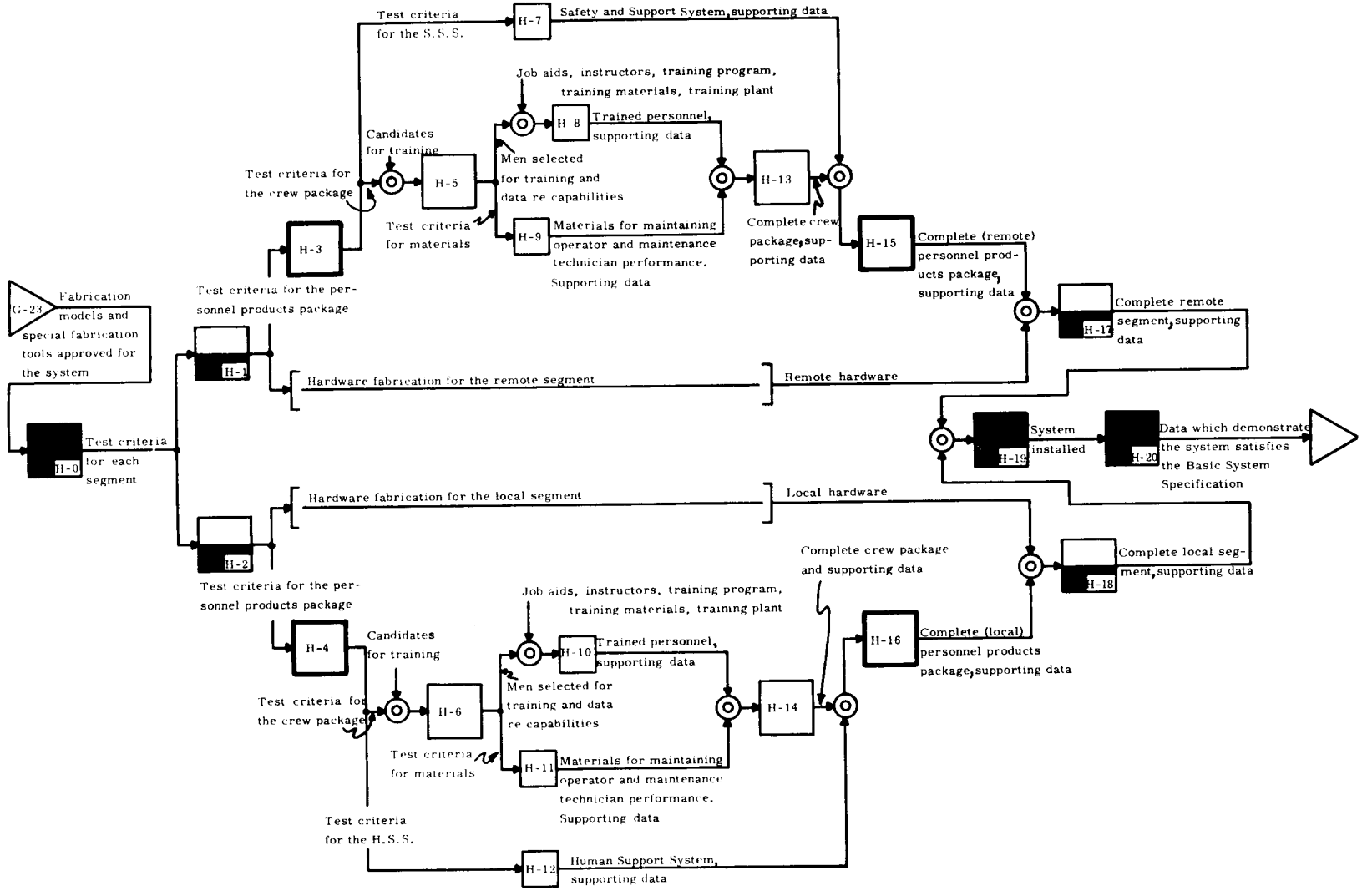


Figure 9. Diagrammatic overview of Function H (Phase III) showing component activities and their relationships.

TABLE 2. INTERACTING LOOPS BETWEEN THE DEVELOPMENT CYCLE MODEL ACTIVITIES AND THE ACTIVITIES OF THIS REPORT.

Loop	From Model Activity	To Sequence Activity	From Sequence Activity	To Model Activity	General Purpose
(1)	B-1	1	3	B-2	Identify Potentially Unsatisfactory Manned System Solutions
(2)	C-1	4	6	C-4	Provide Supporting Evidence for Manned System Concepts for Selection of Top Solution Concepts
(3)	C-5	1-7	1-7	C-7	Provide Additional Data Concerning Man's Role to Refine Candidate Solutions
(4)	D-2 & D-3	8	13	D-4 & D-7	Provide Descriptions of Recommended Operator Performance Allocations
(5)	E-1 & E-2	8	13	E-13 & E-14	Provide Descriptions of Recommended Maintenance and Support Performance Allocations
(6)	E-3 & E-4	5	5	E-8 & E-12	Identify Personnel Support System Requirements for Crew

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5. ACTIVITIES FOR DETERMINING THE OPTIMAL ROLE OF MAN

This chapter contains the activities in support of determining man's role. Each activity starts on a new page and in general is presented according to the following format:

Activity Number and Title

Outputs

(Statements of the expected results from implementing the activity.)

Activity Requirements and Constraints

(Discussion of the need for the output and the effect of low quality, or no outputs, on other activities, activities in the development cycle model, or system development in general. Also discusses any constraints on the output, approach, or data.)

Activity Implementation

(Rationale of the approach and a summary of the separate tasks.)

Task Number and Name. —

Inputs:

(Data required to perform the task. Usually a sample is presented and reference is made to the Appendices for additional data if appropriate.)

Approach:

(Discussion of the procedure to be followed, estimates to be prepared, calculations, etc.)

Documentation:

(A suggested format for documenting the results.)

Activity 1
Hypothesize the Potential Basic Role of Man

Outputs

1. Statements proposing unique human capabilities to foster system performance.
2. Statements proposing man-rated core performance to foster system performance.
   a. Sensing
   b. Interpreting
   c. Information Processing
   d. Decision Making
   e. Controlling
   f. Monitoring
   g. Information Storage

Activity Requirements and Constraints

This activity is concerned with the development of the potential basic performance role of man (see Chapter 2, Convention 5, Roles of Men in Systems), or simply What can man do relative to achieving the underlying goals of the system. The potential basic performance role of man must be developed to establish a basis for evaluating or justifying candidate manned-system solutions developed in the basic model. Further, it is necessary to have the potential basic performance role of man developed before the potential complementary and support role of man can be developed (Activity 2), and before the feasibility of a manned system solution can be evaluated (Activity 3). This activity may also be implemented to refine or more fully develop final candidate solutions.

If the output of this activity is not fully developed, the outputs of the succeeding activities in the sequence obviously will be impaired; but perhaps the most significant consequence would be the unwarranted elimination of a candidate solution for a manned system which was in fact a "good" candidate worthy of further development.

The most serious limitation in implementing this activity is the lack of quantified data available concerning man's performance at the "role" level. There is, however, a good deal of qualitative information which can be used to build a hypothesis for man's role which can be tested as more data and detail are developed.

Activity Implementation

The approach for implementing this activity is in consonance with the basic Hypothetical-Deductive approach described in Chapter 3 and is essentially one of hypothesizing the potential basic performance role of man. Development of the hypothesis is aided by reviewing information concerning man's unique and core performance capabilities for basic system operational or maintenance performance.

Task 1. Development system applications for man's unique capabilities. —

Inputs:

1. System Performance Parameters
2. Unique Human Capabilities Statements and Discussions

These data should describe man's unique capabilities for performance that cannot be duplicated by machines.

Appendix A, Section 2.1 contains some data relevant to this task. Two samples of typical data of this type follow:

Sample 1

Men are needed to make judgments when it becomes impossible to reduce operations to logical, pre-set procedures.	Machines require logical pre-set procedures.

Sample 2

Sinaiko and Buckley, 1957, ref. 25

Capability for Learning

> One of man's most important basic abilities, an attribute that clearly differentiates him from machines, is that he can learn. Given enough time, man can improve his performance in almost any task. In spite of the tremendous value of this ability to acquire better methods and new knowledge and skill, learning takes time. The time required for the learning process will generally vary with the complexity of the material or task he is trying to learn.
>
> Much of human learning involves a trial and error process. If one thing doesn't work, man will try another. The learning process is usually accelerated if there is feedback or knowledge of results. If man gets this kind of information, he can quickly figure out new approaches and drop the old unsuccessful ones and keep the ones that worked. Sometimes, he doesn't need to try every possible approach but can grasp the basic nature of the problem and get the right approach rather suddenly. This is called insightful learning. Most learning is a combination of both trial and error and insight.
>
> The use of simulators illustrates another fact about human learning: men are somehow able to transfer skills acquired in one situation to another similar, but not identical, situation. For example while Link trainers do not duplicate every aspect of flying an airplane, they are useful devices for training principles of cross-country navigation.

Approach:

Each system (or subsystem) performance parameter should be analyzed for potential application of unique human performance capabilities such as learning and creative cognition. In general, statements or discussions of unique human performance capabilities will not be presented in terms specific to any one system, and they must be carefully compared against the specific system requirements with this in mind. The ability to do this, in fact, is perhaps an example of the use of unique human cognitive capabilities by system analysts actually performing this task.

Documentation:

Figure 10 is a suggested format for documenting the results of this task. As each system application of unique human performance capabilities (e.g., judgment) is identified, entries should be as follows:

1. The relevant unique human capability.
2. Indicate whether the performance is operational (O) or maintenance (M) in the local (L) or remote (R) segments.
3. The system application and relevant system parameter.

Task 2. Develop potential man-rated system applications of core performance areas. —

Inputs:

1. System Performance Parameters
2. Statements Concerning Man-Rated Performance of Core Performance Area.

These statements should describe man's capability for performing in each of the following seven areas: (1) Sensing, (2) Interpreting, (3) Information Processing, (4) Decision Making, (5) Controlling, (6) Monitoring, (7) Information Storage.

Appendix A of Section 1 contains a considerable amount of human performance statements organized by core performance areas. The statements are at the beginning of each of the subsections 1.1 — 1.7. A sample of this type of statement from the "data processing" category follows:

> Man is a relatively poor numerical computer under stress, but is unmatched for the more qualitative nonnumerical computations.

Approach:

Man-rated performance areas, as used in this report, refer to those areas of performance where it is feasible for man to participate (see

1	2	3
UNIQUE HUMAN CAPABILITY	O M L R	SYSTEM APPLICATION

Figure 10. Suggested data documentation format for Activity 1A.

1	2	3
PERFORMANCE AREA	O M L R	SYSTEM APPLICATION

Figure 11. Suggested data documentation format for Activity 1B.

Chapter 2, Convention 3, Man-Rated Performance), although he may not participate at all in a specific system application either because the requirements are beyond his capability, or because a manned solution is not cost-effective. The core performance areas (see Chapter 2, Convention 4, Core Performance) are most likely to provide a man-rated performance hypothesis. Thus, the approach for implementing this task should be one of systematically analyzing each system parameter for its principal component performances corresponding to the seven core performance areas, i.e., (1) Sensing, (2) Interpreting, (3) Information Processing, (4) Decision Making, (5) Controlling, (6) Monitoring, and (7) Information Storage; and for each core performance component developing the optimal man-rated system application. Each system application must be developed by analytic comparison of human core performance data and the system performance requirement.

Documentation:

Figure 11 is a suggested format for documenting the results of this task. As each potential man-rated core performance component of a system parameter is identified, entries should be as follows:

1. The relevant core performance area, e.g., sensing.
2. Indicate whether the performance is operational (O) or maintenance (M) in the local (L) or remote (R) segments.
3. The system application and relevant system parameter.

Activity 2

Hypothesize Potential Complementary and Support Role of Man

Outputs

1. Statements proposing utilitarian human capabilities to foster complementary system performance.
2. A check list of personnel support system needs:
   a. Human Maintenance
   b. Human Monitoring
   c. Life Support
   d. System Protection

Activity Requirements and Constraints

Chapter 2, Convention 5, Roles of Men in Systems, presents a philosphy which suggests that there are three potential roles for men; viz., basic, complementary, and support. Man's basic role consists of (1) that performance which demands the unique capabilities of man, and (2) man-rated core performance which is essential to the operation and maintenance of the system. This basic performance role is the principal justification for man in a system. However, the other two roles for man must also be hypothesized, since in one role (complementary) he provides additional performance capabilities, and in the other role (support) he causes subtractive performance requirements.

A complementary performance then consists of that additional performance which may be obtained from man because of his utilitarian capabilities, and support performance consists of that performance which man must provide to support or sustain himself. Thus, the outputs of this activity are required primarily to complete the picture of man's potential role so that manned system solutions can be fully evaluated. This activity may also be implemented to refine or more fully develop final candidate solutions.

If the outputs of this activity are not accomplished, the evaluation of a manned system solution would be biased since all of the potential performance

of man would not have been identified. Man's utilitarian value is frequently exploited as an afterthought in system development even though historically in extant systems in which he has a major role, much of his contribution is due to his utilitarian performance. Also, without the development of personnel support needs at this point, only the good features of a manned system solution are considered without the supporting consequences of man per se.

The principal constraints on the implementation of this activity are (1) a lack of a comprehensive source of data concerning man's general utilitarian capabilities and support requirements, and (2) the difficulty in obtaining historical information concerning man's performance in extant systems which can be applied to new systems under development.

Activity Implementation

The approach for implementing this activity is in consonance with the basic Hypothetical-Deductive approach described in Chapter 3 and is essentially one of (1) hypothesizing the potential complementary performance role of man, and (2) delineating the personnel support system to define man's potential support role. Development of the hypothesis is aided by reviewing information concerning (1) man's diverse capabilities, (2) machine limitations, and (3) personnel support requirements.

Task 1. Develop system applications for man's utilitarian capabilities. —

Inputs:

1. System Performance Parameters
2. Statements Concerning the Diversity of Human Performance Capabilit

This information should suggest man's value for utilitiarian performa simply because he is available.

Appendix A, Section 2.3 contains some data relevant to this task. A sample of a typical item follows:

"If man is already present in a given situation, it may be more economical to use him as a sensor than to provide additional equipment if the sensing requirements are within the range of human sensitivity. This also is related to the desirability of providing a man with enough work so that he will maintain a reasonable level of motivation and alertness." (Ref. 27)

3. Statements and Discussions Concerning Machine Limitations

This information should reveal those performance areas in which machines have limited capability, at least within the foreseeable state of the art.

Appendix A, Section 3.2, contains a limited amount of this type data. Two samples follow:

Sample 1

"Machines generally have limitations in their abilities to adapt to unexpected variations in situations. (Machines typically have to be programmed in advance to perform predetermined activities under certain specified circumstances; where it is difficult or impossible to anticipate various possible circumstances, and to program for such, machines are at a distinct disadvantage to man.)" (Ref. 18)

Sample 2

Krendel and Bloom, 1963, ref. 16

Consistency — An Attribute of Skill

On an intuitive basis it might appear that the performance of machines would always be more consistent than that of men. Interestingly enough, with complex equipments, the opposite is more often the case. Even such relatively simple devices as radar equipment often exhibit surprising variability compared with their human operators. In an unpublished study cited by Chapanis (1959), variations between individual radar sets of the same model were found to be much larger than differences among operators. Indeed, in his studies on detectability on radar scopes, Williams (1949) found so much variability in cathode ray tubes that he could not use electrical measurements of circuit parameters as the independent variables. In the case of entire aircraft

systems the machine variability is, of course, substantial. As a matter of fact, pilots tend to characterize certain of supposed identical individual craft as "mushy" and others as "touchy". In a similar vein, Bray (1958), reports on experiments on interceptor gunnery performances as measured by actual firing on targets. Variability between pilots was normally of little importance compared to variability within and between aircraft; he goes on to state:

> "In other words the hardware varies within itself and from one item of hardware to another so greatly as maintenance and adjustment are normally carried out that the pilot matters little, if at all."

Approach:

Each system (or subsystem) parameter should be analyzed for potential application of utilitarian performance capabilities which man can provide simply because he is present. In general, statements or discussions of utilitarian human performance capabilities will not be presented in terms specific to any one system; hence they must be carefully compared against the specific system requirements with this in mind. In addition, information concerning machine limitations should also be reviewed in order to hypothesize where man utilitarian capabilities might be used instead.

Documentation:

Figure 12 is a suggested format for documenting the results of this task. As each system application of utilitarian human capabilities is identified, entries should be as follows:

1. The relevant human performance capability.
2. Indicate whether the performance is operational (O) maintenance (M) in the local (L) or remote (R) segment.
3. The system application and relevant system parameter.

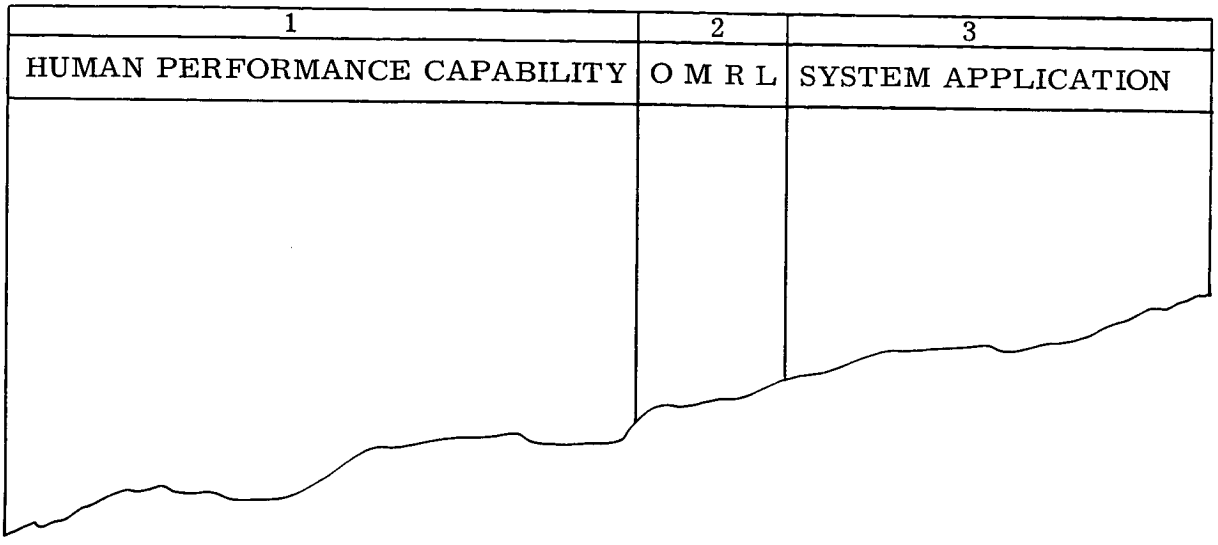


Figure 12. Suggested data documentation format for Activity 2, Task 1.

Task 2. Develop a check list of personnel support system needs. —

a. Human Maintenance
b. Human Monitoring
c. Life Support
d. System Protection

Inputs:

1. System Performance Parameters
2. Basic Personnel Support Check List

Approach:

A personnel support check list such as the one shown in Figure 13 should be reviewed to establish (1) whether the support requirement exists either in the local or remote system, and (2) whether the system concept provides for the support requirement. The concept of a personnel support system is presented in Chapter 2, Convention 7, Personnel Support Systems.

Documentation:

As each personnel support area is reviewed, results should be recorded in a check list format similar to that in Figure 13. If the requirement exists in the local or remote system, this should be identified by check in that column, and the provisions of the system concept to support this requirement should be briefly recorded in a column opposite the relevant requirement.

PERSONNEL SUPPORT SYSTEM NEEDS

PERSONNEL SUPPORT AREA	SYSTEM NEEDS	
	LOCAL	REMOTE
Human Maintenance		
a. Sleeping		
b. Eating		
c. Hygiene		
d. Exercise		
e. Recreation		
f. Housekeeping		
Human Monitoring		
a. Medical Monitoring		
b. Psychological Monitoring		
Life Support		
a. Atmosphere Supply and Composition		
b. Temperature-Humidity Control		
c. Pressure Control		
d. Trace Contaminant Control		
e. CO_2 Removal		
f. Water Management		
g. Waste Management		
System Protection		
a. Acceleration		
b. Radiation		
c. Magnetics		
d. Electrostatics		
e. Sonics		
f. Intense Illumination		

Figure 13. Suggested check list for Activity 2, Task 2.

Activity 3
Review Manned System Solution Feasibility

Outputs

1. Statements identifying suspect areas of compatibility between human variables and system parameters which would eliminate a manned system solution from further consideration.
2. Statements identifying suspect areas of effectiveness or practicality which would eliminate a manned system solution from further consideration.

Activity Requirements and Constraints

The purpose of this activity is to develop a rationale for filtering out candidate manned system solutions that are unworthy of further consideration thus avoiding the consequent development costs. In general, this activity supports Function B of the Development Cycle Model. It is generally more appropriate for the local segment of the system rather than the remote segmen This activity could be bypassed for candidate system solutions which are "designated" to be feasible either by policy, precedence in previous systems, or by mandate (for example, it is mandatory that the commercial supersonic transport be a manned system concept).

The emphasis in this activity is to look at obvious factors which might eliminate any candidate concept from further consideration. In general, obvious factors for eliminating manned system concepts are (1) unique human limitations that preclude feasible protection and sustenance of a crew, or (2) sophisticated state of the art in automation that makes a manned solution impractical, or (3) unreasonableness of a manned solution from the standpoint of cost-effectiveness. This activity is concerned principally with the first factor since it is assumed that this sequence of activities will be implemented by human factors-oriented personnel. However, the second and third factors can be considered pragmatically.

If this activity is not accomplished, "wasted effort" is implied in further developing a candidate system solution which would be established as unfeasible after more detailed analysis.

The principal constraint on the implementation of this activity is one of orientation to the objective of eliminating candidate solutions that are obviously unfeasible, but not to eliminate all suspect solutions. Thus, performance of this activity requires some insight on the part of the performer to seek out the most obvious factors to investigate.

Activity Implementation

The method for accomplishing this activity is basically a technique of (1) insightful identification of suspect factors in a given manned system concept and (2) analyses of these suspect factors with respect to cost, quality, or practicality.

Task 1. Determine and investigate obvious suspect factors of crew support which could justify elimination of a particular manned solution. —

Inputs:

1. System parameters
2. Potential performance role of man from Activities 1 and 2
3. General statements and discussions of human limitations

Appendix A, Section 2.2 contains some general data of this type. Two samples follow:

Sample 1 (Ref. 22)

"Humans are subject to a coriolis effect, motion sickness."

"Machines are not subject to a coriolis effect."

Sample 2

Horst, 1962, ref. 13

Temperamental Factors

> Men differ from machines also with respect to personality or temperamental characteristics. One may facetiously refer to "temperamental" machines, but in general machines do not get angry and avoid performing their functions because they do not care to. Unless there is some mechanical or organic malfunction in the machine, it will not refuse to respond appropriately to its foreman or supervisor who gives it proper instructions. Neither will it try to make its operator think that it is doing a better job than it really is in order to get promoted to more important functions. Unless the machine is ill, it will not fail to cooperate with another machine simply because it does not like the other machine, or because it would prefer to receive from or give to some other kind of machine. These kinds of differences create many problems in the selection and classification of personnel for man-machine systems.

4. General data relating human variables and system parameters

For this activity, these data should be comprehensive rather than detailed, since a more thorough analysis will be conducted in Activity 5. Appendix B contains data of this type, and it is suggested that only those data included under the major system parameter headings should be considered in this activity, unless a particular suspect area obviously should be investigated. Table 3 is a key to these data in Appendix B. Figure 14 is a sample of this type of data.

Approach:

The approach for implementing this task is essentially one of insightful identification and investigation of suspect areas of human limitations, or support requirements, for the particular manned system solution. This can be accomplished in two steps: (1) by utilizing the data describing man's unique limitations (Input data, item 2); and (2) by utilizing the human variable-system parameter data (Input data, item 3). Of course any other

TABLE 3. A KEY TO DATA RELEVANT TO ACTIVITY 3

"REVIEW MANNED SYSTEM CONCEPT FEASIBILITY"

System Parameters by Human Variables Matrix

Human Variables \ System Parameters	S1 ENVIRONMENT	S11 ACCELERATION	S18 ALTITUDE/LOCATION	S19 PAYLOAD	S23 LOGISTICS	S26 PERFORMANCE	S27 MISSION DURATION	S32 EMERGENCY/ABORT/ESCAPE
H1 PHYSICAL								
H2 Shape and Size								
H3 Weight								
H4 Age								
H5 Sex								
H6 Body Position		○						
H7 PHYSIOLOGICAL		○						
H8 Body Systems	○	○					○	
H18 Thermoregulation								
H19 Circadian Rhythm								
H20 Metabolic	○	○		○				
H21 Sexual Drive								
H22 Exertion/Activity Level	○	○		○				
H23 PSYCHOLOGICAL								
H24 Performance Systems	○	○						
H29 Individual Differences								
H30 Social Sensitivities								
H31 Recreation								
H32 ECOLOGICAL	○						○	
H33 Habitability	○	○		○			○	
H34 Physiological Stress/Tolerance	○	○				○		
H35 Psychological Stress						○		
H36 THERAPEUTICS/PROPHYLAXIS								
H37 Psychiatry								
H38 Pharmacology								
H39 PERSONNEL SUBSYSTEM DEVELOPMENT	○						○	
H40 Crew Size					○		○	
H41 Selection/Training								
H42 Human Engineering								
H43 Sustenance	○	○		○	○		○	
H44 Protection	○	○	○					○
H45 Work/Rest Cycles								
H46 Hygiene	○							
H47 LIFE SUPPORT SYSTEM MEANS	○			○				

BIOMEDICAL FUNCTIONS OF
THE TERRESTRIAL ATMOSPHERE

Normal physiologic and psychologic reactions during air breathing maintained up to	10,000 ft
Atmospheric oxygen contribution to respiration	50,000 ft
Air pressure sufficient to keep body fluids below boiling point	63,000 ft
Useful consciousness period of 10 to 12 seconds during hypoxia	65,000 ft
Air density sufficient high to permit ambient air pressurization in aircraft	80,000 ft
Protection against heavy primaries	120,000 ft
Protection against ultraviolet radiation (3000 to 2100 Å)	140,000 ft
Sufficient time to inflate pressure suit upon explosive decompression	150,000 ft
Scattering of visible light	400,000 ft
Propagation of sound waves	400,000 ft
Protection against macro-meteorites	400,000 ft

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

ITEM NO.	SUBJECT AREAS.	SOURCE:
10	SYSTEM - S1, S18 HUMAN - H44	Reference 219, p. 18.

Figure 14. Sample data item for Activity 3.

area that is obviously suspect should be specifically investigated if it might provide justification for eliminating the particular solution.

Documentation:

Figure 15 is a suggested format for documenting the results of this task. Only suspect areas which might justify elimination of a particular candidate solution need be documented. Entries should be as follows:

1. The suspect area of human limitation or support.
2. Any implication for system design to compensate for the suspect area.
3. A conclusion relative to elimination of the solution, e.g., a statement of probability of crew survival.

1	2	3
SUSPECT AREA	SYSTEM IMPLICATION	CONCLUSION

Figure 15. Suggested data documentation format for Activity 3.

Task 2. Determine and investigate obvious suspect areas of overall effectiveness or practicality which could be justification for eliminating a particular manned solution. —

Inputs:

1. System parameters
2. Potential performance role of man from Activities 1 and 2
3. Statements and discussions of machine capabilities

Appendix A, Section 3.1 contains some data of this type. Two samples follow:

Sample 1

"Repetitive Operations. Machines excel in repetitive and routine tasks; unlike humans, machines do not become bored or inattentive." (Ref. 7)

Sample 2

Westbrook, 1959, ref. 28

> We may conclude that certain functions must be done automatically. These include those actions requiring a fast reaction time or where an unfavorable environment for the pilot is inherent. Most actions in the blast-off, exiting and certain re-entry trajectories fall into this category. Certain functions might best be done automatically. Included in these would be continuous, long time, repetitive and boring actions in which the pilot's attention would wander and his performance suffer. An example of this type of action would be continuous, tight, attitude stabilization in space flight.

4. Statements and discussions of man-machine relative effectiveness

Appendix A, Section 4.1 contains data of this type. Two samples follow:

Sample 1

There are great individual differences with respect to how effectively a group of men can carry out a specified performance.	Machines are usually designed to specifications for a particular purpose, so that there will be no great variation among them.

Sample 2

Edwards, 1962, ref. 6

> [The following three virtues of men in competition with computers] ... are crucial for most current man-versus-computer problems in man-machine systems.

The first of these is that in a very important sense men are far more reliable than computers. It has already been pointed out that computers make far fewer mistakes than men. But in general the mistakes computers make either remain unchecked or stop the computer completely. Man, on the other hand, can detect his own mistakes and spontaneously work out a plan to correct them or remedy their effects. Furthermore, once he has learned how to perform a task correctly, man does not repeat and repeat the same error, as will a computer with a broken part. In short, if a little allowance is made for the approximate nature of human reliability, man is far more reliable using any computer yet invented, or any likely to be invented in the near future. Of course, some computers are to a degree self-correcting even now, and most large future computers will embody various kinds of self-correction features. But the versatility of human beings in dealing with error is an extremely remote goal indeed for computer technology. This human reliability characteristic is so important that major systems are likely to continue to include human components for a long time to come for this reason alone.

Perhaps the most practical advantages of men over computers, of course, are in cost and availability. Consider a system which has an expected life of ten years. Over that period, it might cost $120,000 in salary to employ one man to tend the system. The system for personnel support and other indirect personnel costs might over that time cost another $120,000. That puts the cost of one human brain, for many purposes the most effective computer now available, at something like $240,000 over a ten-year period. By contrast, an IBM 709, for many purposes much inferior to the man, costs something like $1,000,000 per year, or more than 40 times as much as the man over the ten-year period. Even if the system were to operate 168 hours per week, which requires at least five men for each operator position, the computer would be much more than 10 times as expensive (since the cost of supporting it would go up with round-the-clock usage). Of course, the 709 can do many things that men cannot do, and vice versa; which is preferable depends on the specific nature of the job to be performed. But the man has a powerful built-in economic advantage, which is not likely to change very much with time.

Availability is important also. There are many men, and at least a third of them can be trained to perform difficult intellectual tasks. There are few computers, and the number of really large ones is unlikely

to become as large as, say, one millionth of the number of men. So men not only are cheaper, they are also easier to obtain.

Approach:

The approach for implementation of this task is again one of insightful identification and investigation of suspect areas of system effectiveness or practicality for the particular manned system solutions. This can be accomplished in two steps: (1) by utilizing data describing machine capabilities (Input data, item 2) and (2) by utilizing data describing relative man-machine effectiveness (Input data, item 3). The comparison of man-machine effectiveness should be tempered by considering individual differences in both men and machines as discussed in Chapter 2, Convention 8, Man-Machine Comparisons. Of course, any other obvious factors of system effectiveness or solution practicality should be investigated if it might provide justification for eliminating the particular solution.

Documentation:

Figure 15 is a suggested format for documenting the results of this task. Only suspect areas which might justify elimination of a particular candidate solution need be documented. Entries should be as follows:

1. The suspect area of effectiveness or practicality.
2. Any implication for system design to compensate for the suspect area.
3. A conclusion relative to elimination of the solution, e.g., a statement identifying an equipment solution that is more cost-effective.

Activity 4
Develop a Preliminary Crew Concept

Outputs

1. A summary of crew performance in the local and remote segments for operations, maintenance, and support.
2. Estimates of the range of crew size.
3. Summary of concepts for crew performance achievement and proficiency maintenance.

    a. Selection
    b. Training
    c. Job Aids
    d. Human Engineering
    e. Proficiency Maintenance

Activity Requirements and Constraints

The basic requirement of this activity is to bring together information thus far developed to provide the basis for answering the two key questions of concern for manned system concept. These two questions are: (1) What part of the total system (local and remote) capability is provided by crew performance? (2) What is the cost for the provision of a crew in the system? The first question should be completely answered during the performance of this activity; the second question can only be partially answered. Cost factors associated with manned system concepts may be generally considered as (1) those concerned with development of crew performance achievement (see Chapter 2, Convention 9, Personnel Products Package), and (2) those concerned with crew support in the operational system. Crew performance achievement costs include the costs of selection, training, job aids and human engineering. In other words, these costs are associated with how the desired crew performance is developed. Crew support costs are concerned with those costs necessary to provide maintenance of the health, welfare and performance capabilities of the crew and proficiency maintenance materials. One factor which is critical in determining both crew performance achievement costs and

crew support costs is crew size. This activity will be concerned with developing an estimate of the range of crew size and delineation of the crew performance achievement concepts. This activity will also include consideration of proficiency maintenance materials (actually this is part of crew support, but it is more logically considered together with crew performance achievement concepts). Crew support system requirements will be developed in Activity 5 which follows.

If the efforts called for in this activity are not provided, the follow-on efforts of Activities 5 and 6 in the sequence will be impaired. Activity 5 is particularly dependent upon an estimate of crew size, whereas Activity 6, concerned with crew role acceptance, is particularly concerned with an integrated definition of anticipated crew performance.

The most difficult aspect of implementing this activity will be the development of time estimates for crew performance. The estimates of crew size must be built up from these data and synthesized with other data concerning work-rest cycles, or duty cycles.

Activity Implementation

The approach for obtaining the outputs of this activity is essentially one of:

1. Integrating the potential crew performance developed in Activities 1 and 2 into local and remote segment performance and organized by operations, maintenance or support;
2. Estimating time of performance for each element of potential crew performance;
3. Delineating performance achievement concepts for each element of crew performance—that is, how will this performance capability be developed in the crew; and
4. Summarizing the crew concept in terms of crew size, crew performance roles, and crew performance achievement techniques. Each of these is considered a separate task and is described in the following sections.

Task 1. Integrate statements regarding potential human performance according to operation, maintenance, and support performance within the local and remote segments. —

Inputs:

Statements of the proposed performance role of man from Activities 1 and 2.

Approach:

The statements regarding the potential performance role of man developed in Activities 1 and 2 should now be integrated into packages describing local segment performance and remote segment performance with all performance statements organized by operations, maintenance, or support within the local and remote segments. The performance statements developed in Activities 1 and 2 were identified with respect to local or remote segment, and operations, maintenance, and support. Thus, this task is simply one of reorganizing these statements.

Documentation:

The results of this task should be documented in a format similar to that shown in Figure 16. The top row (column 1) of the format indicates whether the information applies to the local or remote system and whether it applies to operations, maintenance or support. Each potential crew performance should be recorded in column 2 and the underlying system parameter should be recorded in column 1.

Task 2. Estimate crew performance time for each performance statement. —

Inputs:

Human performance time data for various types of functions.

Approach:

For each statement of potential crew performance, an estimate of the total crew performance time per mission should be developed. These estimates may be developed as the total crew man-hours per mission, or they may be developed as the total crew man-hours required each time the function is performed together with an estimate of the frequency of performance of the function.

Documentation:

The total crew man-hours per mission should be entered in column 4 of Figure 16 for each potential crew performance.

1. Local___ or Remote___ System Operations___Maintenance___ Support___			
2. System Parameter	3. Crew Performance	4. Crew Time	5. Performance Achievement Concept

Figure 16. Suggested data documentation format for Activity 4.

Task 3. Delineate principal performance achievement concepts and proficiency maintenance concept. —

Inputs:

Knowledge of techniques for achieving crew performance potential and proficiency maintenance.

a. Selection
b. Training
c. Job Aids
d. Human Engineering
e. Proficiency Maintenance

Approach:

Each potential personnel performance area should be analyzed (presumably by human factors specialists) and the principal performance achievement concepts delineated as well as the concept for maintenance of proficiency. Principal performance achievement concept, as used here, implies the most important, or critical, technique for achieving the particular crew performance. For instance, all performance may require some training, but the critical performance achievement concept in some areas may be selection (e.g., selection of a physician for medical monitoring performance), job aids (e.g., instructional materials for troubleshooting a piece of equipment), or human engineering (e.g., design of a particular control and display interface between man and machine for remotely controlling an unmanned vehicle). Proficiency maintenance refers to the technique for maintaining proficiency on the job in the operational system. Chapter 2, Convention 9, Personnel Products Package, defines the factors of performance achievement and proficiency maintenance.

Documentation:

The critical performance achievement concept(s) and proficiency maintenance concept for each performance area should be recorded in column 5 of Figure 16.

Task 4. Summarize the crew concept. —

Inputs:

1. Data developed in Tasks 1, 2, and 3 above.
2. Human performance work-rest cycle, or duty cycle, data.

These data may be necessary for estimating the range of crew size.

Appendix B includes some of this type of data.

Approach:

Crew concept as used here means: (1) crew size, (2) crew performance roles, and (3) crew performance achievement requirements. Items 2 and 3 above simply summarize the information developed in Tasks 1 and 3. Estimates of the range of crew size may be relatively obvious, or they may be difficult, depending on the system concept and mission requirement. For example, estimates of the range of crew sizes for aircraft with mission durations measured in hours will be relatively obvious. Estimates of crew sizes for space vehicles with missions extending into months or even years will be more difficult. If necessary, the crew performance time data developed in Activity 2 can be used in conjunction with a timeline analysis technique to obtain a more valid estimate of ranges of crew sizes in complex systems of long mission durations. Hanes and others (ref. 11) provide a good review of different methods of timeline analysis. Also, the problem of crew size estimation is a concern of Activity D-7 of the Development Cycle Model. The important requirement here is to establish a realistic range of crew sizes for the local system so that Activity 5 (Analyze Personnel Support System Requirements) which follows will not be conducted for a range of crew sizes that is impractical.

Documentation:

No particular format is required for documentation since the summarized crew concept is essentially descriptive in nature. However, it

is suggested that the following order of presentation is logical:

1. Range of crew sizes.
2. Crew performance roles.
    - Local System
        - Operations
        - Maintenance
        - Support
    - Remote Systems
        - Operations
        - Maintenance
        - Support
3. Crew performance achievement requirements.
    - Selection
    - Training
    - Job Aids
    - Human Engineering
    - Proficiency Maintenance

Activity 5
Analyze Personnel Support Requirements

Outputs

Statements and supporting data of personnel support system requirements and development or operational implications.

Activity Requirements and Constraints

There are three basic requirements underlying the need for this activity. First, this activity represents the first detailed analysis effort which can be used as a thorough test of the feasibility of the manned system concept under consideration. Feasibility of the concept can be tested from two standpoints; (1) that the crew can be reliably protected and sustained; and (2) that the potential crew performance can in fact be implemented within the constraints of personnel support requirements. Second, personnel support requirements and subsequent means to meet these requirements will have a significant influence on overall system cost-effectiveness. Thus, looking at the personnel support requirements in detail provides a basis for evaluating the cost of a crew concept against the effectiveness of the potential crew performance. Third, identification as early as possible of design development and operational implications necessary to provide personnel support requirements maximizes the probability that an integrated man—machine system design and subsequent operation can be achieved. This activity is thus in direct support of activities E-8 and E-12 of the Development Cycle Model.

If the output of this activity is not developed, it will have an effect on the validity of the final synthesized crew role developed in Activity 7. The quality of the output of this effort also affects other activities in the development cycle model, particularly where cost and quality estimates of manned system concepts are necessary. Further, it is reasonable to expect that because of the importance of safety and survival of the crew that a good quality effort for this activity could prevent or minimize design modification and retrofit later in the system development process.

The primary constraint mitigating against a high-quality output of this activity is the fact that the content data necessary to perform this activity is not generally organized or indexed to be compatible with the procedure for this activity. It should be emphasized that there is a great deal of data available to support the performance of this activity; thus the constraint is not the lack of data, but rather its organization or indexing in the literature. This is the principal reason why an extensive appendix of data to support this activity was prepared for this report.

Activity Implementation

The approach for meeting the outputs of this activity is essentially one of analyzing each system parameter for its effect on personnel support requirements and documenting the results in a manner meaningful to a system designer. Personnel support requirements are defined in Chapter 2, Convention 7, Personnel Support System. However, since, there may be interactions between human variables and also interactions between system parameters, the analysis procedure lends itself to three serial tasks as follows: (1) Analyze a system parameter against human variables for system support requirements; (2) Investigate any identified human variables against other human variables for interactions; (3) Investigate the relevant system parameter against other system parameters for interactions. This sequence of tasks should be continued for all system parameters until all possibilities are exhausted.

Task 1. Determine personnel support requirements and development or operational implications as a function of all system parameters.—

Inputs:

1. System parameters
2. Data describing human support variables as a function of system parameters.

These data should indicate quantitative relationships between human variables and system parameters.

Appendix B contains an extensive amount of these data. Table 4 is a key to the data in Appendix B. Figure 17 is a sample data item showing interactions between:

a. Atmosphere (S2) and sensory/perceptive performance (H25)
b. Atmosphere (S2) and body position (H6)
c. Prolonged linear acceleration (S13) and body position (H6)
d. Prolonged linear acceleration (S13) and sensory/perceptive performance (H25)

Approach:

For each system parameter, an analysis of its effect on human support variables should be conducted. System parameters must of course be specific to the system under consideration. For this report, however, lists of typical system parameters and human variables have been compiled for purposes of indexing the data in Appendix B provided to support this activity. Table 4 is a matrix of the system parameters versus human variables. Thus the data in Appendix B (although certainly not all-inclusive) may be used to implement this task.

Documentation:

Figure 18 is a suggested format for documenting the results of this task. As each system parameter is analyzed, entries should be as follows:

1. The relevant system parameter.
2. Indicate the local (L) or remote (R) segment.
3. The relevant human variable.
4. The specific personnel support requirement.
5. Implications for the development or operational system.
   It is further suggested that each development or operational implication be preceded by a simple two-word code to indicate first whether the implication is development or operational, and, second, whether the implication is for facilities, system equipment, personnel equipment

Table 4. A KEY TO DATA RELEVANT TO ACTIVITY 5—"ANALYZE CREW SUPPORT REQUIREMENTS"
System Parameters by Human Variables Matrix

Human Variables \ System Parameters	S1 ENVIRONMENT	S2 Atmosphere	S3 Toxins	S4 Temperature/Humidity/Ventilation	S5 Noise	S6 Illumination	S7 Radiation	S8 Magnetics/Electrostatics	S9 Biological	S10 Meteorites	S11 ACCELERATION	S12 Weightlessness	S13 Prolonged Linear Acceleration	S14 Vibrations	S15 Rotations	S16 Impact (Deceleration)	S17 Partial Gravity	S18 ALTITUDE/LOCATION	S19 PAYLOAD	S20 Volume	S21 Weight	S22 Power	S23 LOGISTICS	S24 On-board	S25 Resupply	S26 PERFORMANCE	S27 MISSION DURATION	S28 Hours	S29 Days	S30 Months	S31 Years	S32 EMERGENCY/ABORT/ESCAPE
H1 PHYSICAL																				○	○											
H2 Shape and Size		○		○																○	○											
H3 Weight				○								○								○	○								○			
H4 Age		○													○						○											
H5 Sex																				○												
H6 Body Position		○									○		○	○		○																
H7 PHYSIOLOGICAL											○									○	○											
H8 Body Systems	○										○	○		○													○	○				
H9 Cardiovascular		○	○	○	○		○				○	○	○	○	○	○	○	○										○	○			
H10 Digestive																																
H11 Excretory		○	○	○								○									○								○			
H12 Glandular		○		○																								○	○			
H13 Musculoskeletal		○										○	○	○			○												○			
H14 Nervous		○		○		○	○					○	○	○		○	○	○											○			
H15 Reproductive							○							○																		
H16 Respiratory		○	○	○								○	○	○	○			○		○	○							○	○			
H17 Skin		○		○			○																					○				
H18 Thermoregulation		○	○	○		○						○	○		○			○				○						○	○			
H19 Circadian Rhythm																												○	○			
H20 Metabolic	○	○		○							○	○	○	○					○		○							○	○			
H21 Sexual Drive																																
H22 Exertion/Activity Level	○	○	○	○							○	○							○									○				
H23 PSYCHOLOGICAL																																
H24 Performance Systems	○	○		○	○						○	○		○				○										○	○			
H25 Sensory/Perceptive		○	○	○	○	○	○					○	○	○	○	○	○									○			○	○		
H26 Perceptual Motor		○										○	○	○												○		○				
H27 Cognitive		○		○									○			○												○	○			
H28 Motor		○		○									○	○												○						
H29 Individual Differences											○	○	○		○											○		○				
H30 Social Sensitivities																																
H31 Recreation																																
H32 ECOLOGICAL	○																										○					
H33 Habitability	○	○	○	○	○		○				○			○	○		○		○	○	○			○			○	○	○	○		○
H34 Physiological Stress/Tolerance	○	○	○	○	○		○				○	○	○	○	○	○	○	○			○					○	○	○	○			○
H35 Psychological Stress		○		○	○	○	○					○	○	○						○						○		○	○			
H36 THERAPEUTICS/PROPHYLAXIS																																
H37 Psychiatry																																
H38 Pharmacology		○		○		○	○				○	○	○	○		○										○			○			
H39 PERSONNEL SUBSYSTEM DEVELOPMENT	○																										○					
H40 Crew Size		○	○	○																○	○			○	○		○	○		○		
H41 Selection/Training		○		○							○				○					○	○											
H42 Human Engineering						○							○	○						○												
H43 Sustenance	○	○	○	○			○				○								○	○	○		○	○	○		○		○	○		
H44 Protection	○	○	○	○	○		○				○	○	○	○		○		○		○	○		○				○	○				○
H45 Work/Rest Cycles																										○		○	○			
H46 Hygiene	○											○									○	○										
H47 LIFE SUPPORT SYSTEM MEANS	○	○	○	○			○	○			○	○							○	○	○	○		○			○	○	○	○		

OXYGEN AND BRIGHTNESS DISCRIMINATION DURING $+G_z$ AND $+G_x$

Comparison of visual brightness discrimination is shown in figure a for subjects during exposure to $+G_z$ accelerations under three breathing conditions: normal breathing air; 100% O_2; and 100% O_2 with positive pressure. The positive pressure ratio was 0.75 inches of water per G.

a.

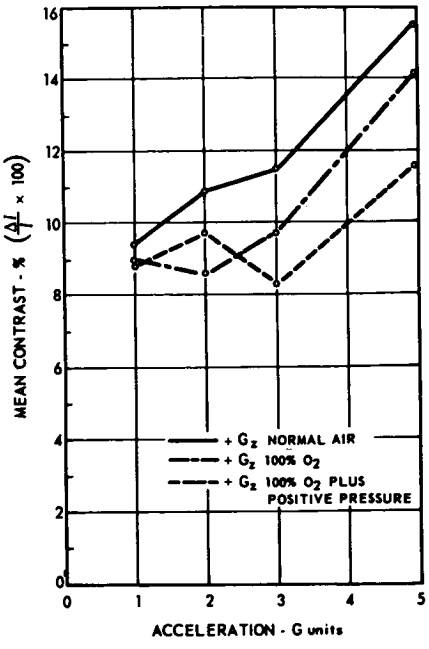
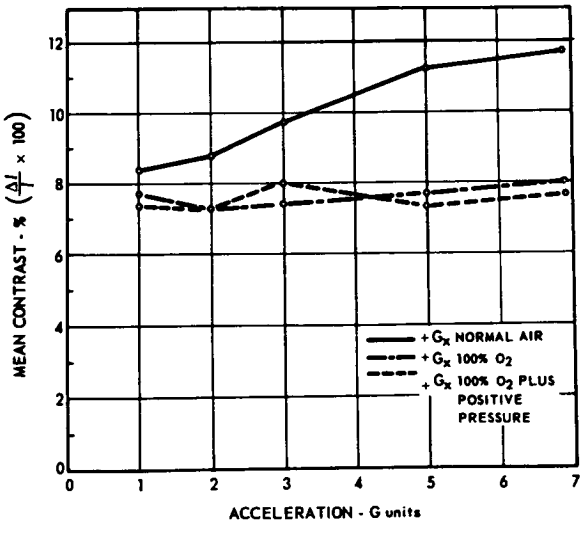


Figure b shows similar data during transverse acceleration ($+G_x$).

b.



ITEM NO.	SUBJECT AREAS:	SOURCE:
491	SYSTEM - S2, S13 HUMAN - H6, H25	Reference 554, p. 45. Based on Reference 120.

Figure 17. Sample input data item for Activity 5.

I	II		III	IV	V
System Parameter	L	R	Human Variables	Support Requirement	Development or Operational Implication

Figure 18. Suggested data documentation format for Activity 5.

supplies, data, personnel, other. It is further suggested that the raw data sources be attached to this form for reference.

Task 2. Investigate potential interactions between the relevant human variable identified in Task 1 and other human variables. —

Inputs:

Data describing potential interactions between human support variables.

These data should indicate quantitative relationships for interactions between human variables.

Appendix B contains data of this type. Table 5 is a key to these data in Appendix B. Figure 17, presented earlier, is a sample data item showing the interactions between body position (H6) and sensory/perceptive performance (H25).

Approach:

For each human variable identified as a function of a system parameter in Task 1 an investigation of its potential interaction with other human variables should be conducted. Table 5 is a matrix of potential human variable interactions developed to index the data provided in Appendix B and may be used to implement this task.

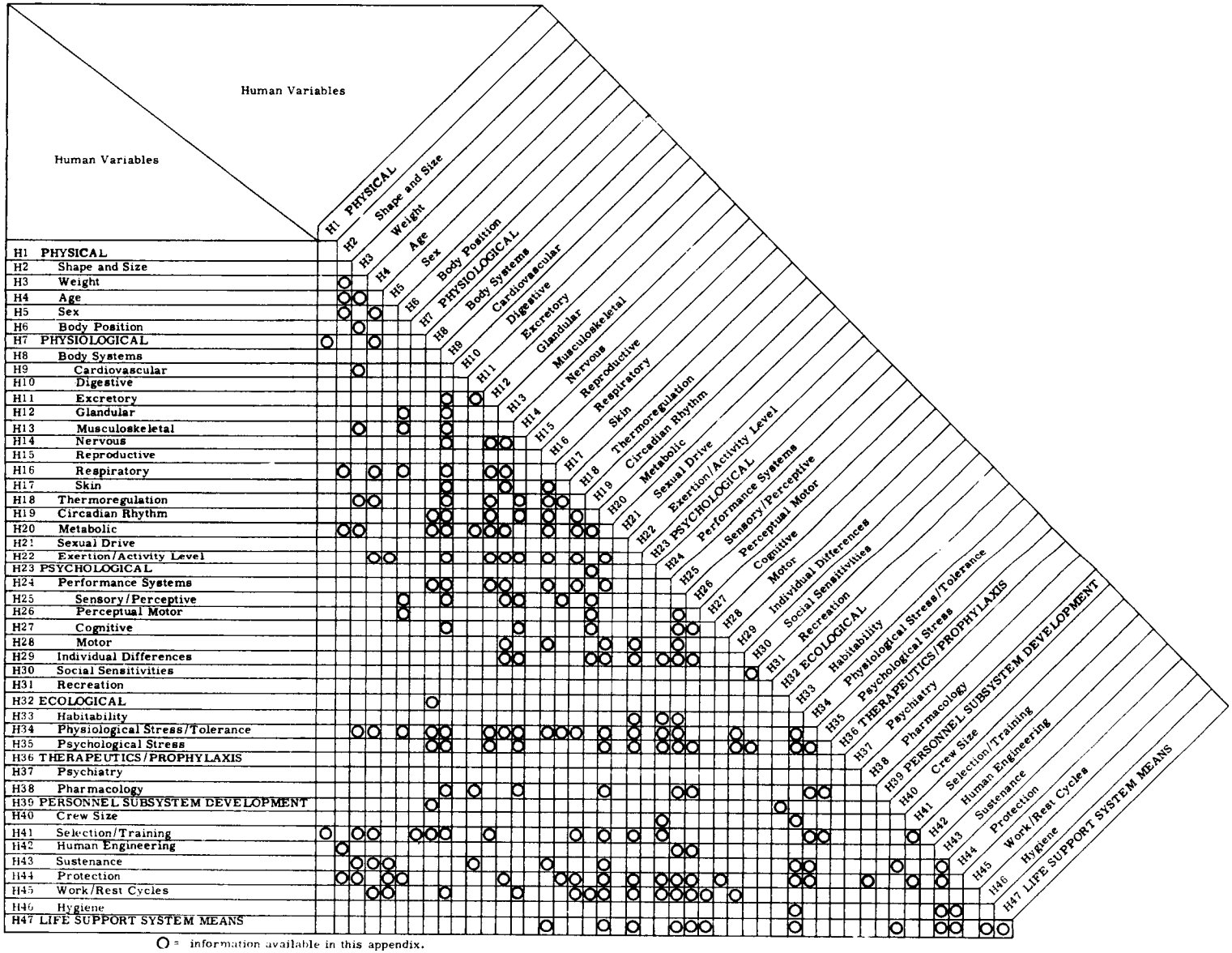
Documentation:

Figure 18 is a suggested format for documenting the results of this task. As each human variable is analyzed, entries should be as follows:

1. No entries.
2. Indicate the local (L) or remote (R) segment.

TABLE 5. A KEY TO DATA RELEVANT TO ACTIVITY 5-"ANALYZE CREW SUPPORT REQUIREMENTS"

Human Variables by Human Variables Matrix



O = information available in this appendix.

3. The relevant human variable vs. other human variable.
4. The specific personnel support requirement.
5. Implications for the development or operational system. It is further suggested that each development or operation implication be preceded by a simple two-word code to indicate first whether the implication is development or operational and, second, whether the implication is for facilities, system equipment, personnel equipment, supplies, data, personnel, other. It is further suggested that the raw data sources be attached to this form for reference.

Task 3. Determine potential interations between system parameters.—

Inputs:

1. Data describing potential interactions of system variables.

These data should indicate quantitative relationship for interactions between system parameters.

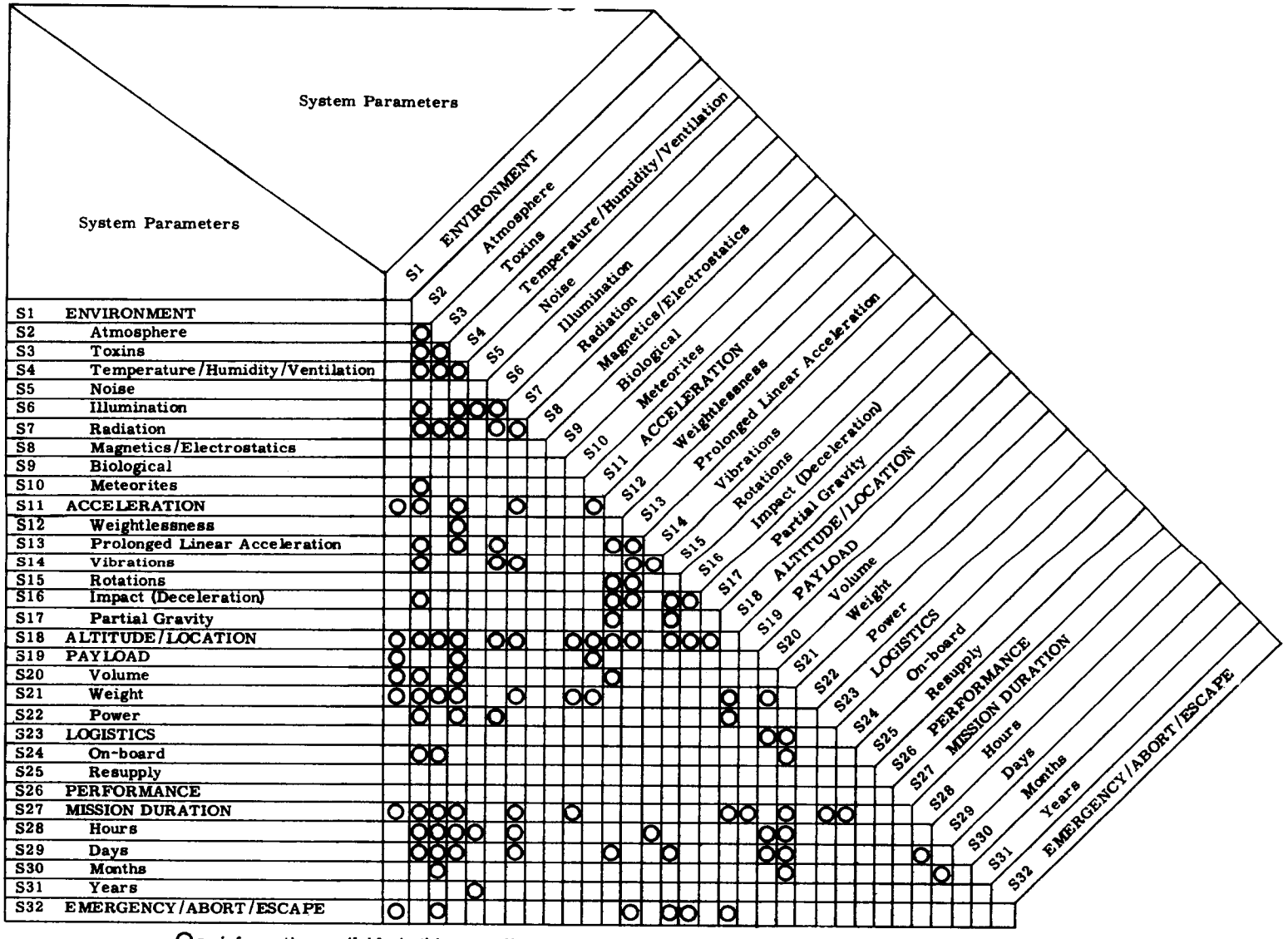
Appendix B contains data of this type. Table 6 is a key to these data in Appendix B. Figure 17, presented earlier, is a sample data item showing an interaction between atmosphere (S2) and prolonged linear acceleration (S13).

Approach:

For each system parameter identified in Task 1, an investigation of its potential interaction with other system parameters should be conducted. Table 6 is a matrix of typical system parameter interactions developed for indexing the data in Appendix B. This table and the data in Appendix B may be used for this investigation. If potential interactions are identified, the new system variable identified as interacting with the system variable of concern should be checked against the total list of system variables provided as an input to Task 1 to insure that the new variable is included on the list of system parameters to be investigated.

TABLE 6. A KEY TO DATA RELEVANT TO ACTIVITY 5—"ANALYZE CREW SUPPORT REQUIREMENTS"

System Parameters by System Parameters Matrix



O = information available in this appendix

Documentation:

Figure 18 is a suggested format for documenting the results of this task. As each system parameter is analyzed, entries should be as follows:

1. The relevant system parameter vs. system parameter.
2. Indicate the local (L) or remote (R) segment.
3. No entry.
4. The specific personnel support requirement.
5. Implications for the development or operational system. It is further suggested that each development or operational implication be preceded by a simple two-word code to indicate first whether the implication is development or operational and, second, whether the implication is for facilities, system equipment, personnel equipment, supplies, data, personnel, other. It is further suggested that the raw data sources be attached to this form for reference.

Activity 6
Review Potential Crew Role for Acceptance and Reliability

Outputs

Summary statements of acceptability of manned system concept indicating areas of possible lowered reliability due to unacceptable role requirements.

Activity Requirements and Constraints

After a potential crew role has been defined (Activities 1 and 2) and this role has been qualified as feasible (Activity 3), the question of what can be done to maximize crew performance reliability in the system must be considered. In general, human performance can be improved by:

1. Selection of individuals for task performance;
2. Motivating the individual;
3. Enhancing the flexibility and adaptability of the individual through training;
4. Modifying the attitudes of individuals toward techniques of task accomplishment;
5. Utilizing social mores to achieve task performance;
6. Human engineering or equipment changes.

The most effective way of enhancing human reliability at the system concept or crew role level of development is to ensure that the potential crew role has a maximally high acceptance value for the crew. Price, Smith, and Behan (ref. 22) have stated that " . . . acceptance factors are most critical and will have a maximum effect on system effectiveness, in the role area. As the design of man's role as a major output of system design . . . it is most important to include acceptance factors at this point. "

If this activity is not accomplished, a potential crew role could be developed which is not optimal and may result in costly retrofit or redesign to accommodate crew acceptance problems.

The most serious constraint in implementing this activity is the fact that very little work has been done relative to acceptance factors and system design, and methods of determining the acceptance value of a given system concept are not adequately developed.

Activity Implementation

Man-machine system design has generally utilized data relative to man's sensory-perceptual, cognitive, and motor capabilities in determining man's role, allocating functions to man or machine, and in designing man-machine interfaces. However, man's motivational system (i.e., acceptance) has not been systematically included in man-machine system design. This is a serious error as a highly motivated man can compensate to a considerable extent for poorly designed equipment to maintain system output. Conversely, a man dissatisfied by a machine function, because of status, economic, or survival fears, or simply a desire to perform the function manually because it is a function man enjoys, may not properly use equipment which has been designed to fit all other criteria. Consequently, the system output may suffer. When determining man's role, acceptance factors are most critical and will have a maximum effect on system-effectiveness. Thus it is important to review the potential role of the crew for acceptance problems.

Task 1. Review potential crew roles for acceptance and reliability. —

Inputs:

1. Potential crew role from Activity 4
2. Principles of acceptance and crew reliability.

These data consist of statements including allocation principles and discussions of system roles which are acceptable to humans, thereby

fostering more reliable crew performance. Additional useful data are concerned with general considerations of human reliability/variability.

Appendix A, Section 4.2 contains some data on human reliability and acceptance. Two samples follow:

Sample 1

> "Men are generally accepting of system roles which give them an opportunity to exercise and, therefore, maintain skills which they feel are important to maintaining their position in the occupational and social status system in which they are immersed." (Ref. 22)

Sample 2

Fitts, 1962, ref. 9

Human Reliability

> . . . Man's performance varies as a function of alertness, fatigue, and stress. Different people vary widely. In the present context, however, one point should be emphasized. Man can often increase his reliability to meet the demands of the task. In driving along a highway at 60 miles an hour, for example, it is obviously desirable to keep the automobile from straying into the opposite traffic lane. In this instance reliability is a life-or-death matter. Fortunately, it is a function which many individuals perform hundreds of times a day with small likelihood of a serious error within their lifetime. Elsewhere, the present author has estimated that, given any two cars which are closing with a speed of 120 miles an hour and must pass with a clearance of 5 to 10 ft, the probability of a head-on collision is somewhere on the order of 10^{-9} or 10^{-10}. The generalizations about reliability hold, however, only if an individual realizes that reliable performance is required — as, for example, in the case of landing an airplane or passing another car . . .

Approach:

Review the crew role for areas where man's potential performance is less than the responsibility or authority he is capable of delivering (see Chapter 2, Convention 2, Optimal Manned Design). More specifically, look for this situation in those areas where automated functions are anticipated and where crew skills are not fully exploited. Acceptance problems are frequently created by the lack of confidence in the reliable performance of hardware in automated functions, and must be considered independently of whether the hardware is in fact ineffective and unreliable. With respect to human skills, the morale of man is frequently lowered if he is not functioning at what for him is a high skill level. Nissen (ref. 21) in his paper on motivation states that "capacity is its own motivation." Consequently, if man's role does not permit him to exercise his capability or capacity he may become frustrated and lose motivation for performing his assigned and expected system functions.

Documentation:

A format such as that suggested in Figure 19 could be used for documenting the results of these activities. Column 1 should identify the system role under consideration indicating whether it pertains to the local or remote system and whether the performance area is operations, maintenance, or support. Column 2 could be used to indicate if the particular role is apparently acceptable or if there are potential problems in acceptability. Column 3 could then be used to record the rationale, or suspect areas, including techniques or system design features which would have to be modified to correct the problem area.

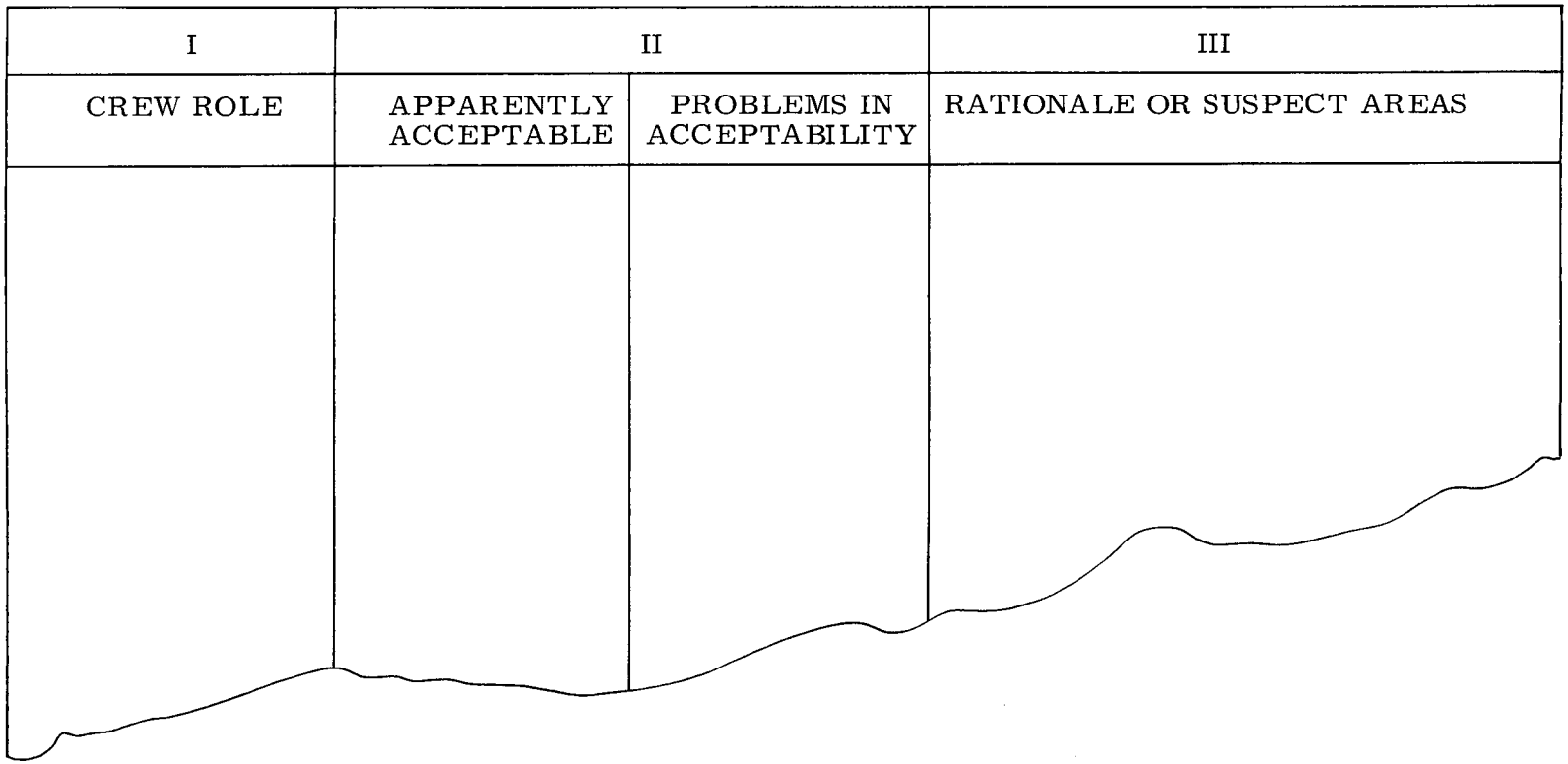


Figure 19 . Suggested data documentation format for Activity 6.

Activity 7
Synthesize Optimal Crew Role

Outputs

Description of an optimal crew role including the crew concept, personnel support requirements, and crew effectiveness.

Activity Requirements and Constraints

This activity is included for the general purpose of reviewing the results of the previous activities, updating them as necessary, and bringing them all together in a package describing the optimal crew role for a particular manned system concept. This activity may not be essential since no new analyses or investigations are being conducted here, but it may be useful, particularly in the case of complex systems where system managers need summary descriptions of the crew role. Information derived and documented during the previous activities will of course be available to support the general summary provided during this activity. This activity is also indicated as a "source" activity where specific questions concerning the crew role may be introduced.

Activity Implementation

Many studies or reports refer to the role of man or the role of the crew in a particular system. Most of these studies or reports, however, do not include a consistent definition or implication of what is meant by the role of man. The only apparent consistency is that they all seem to agree that a description of the role of man provides some general impression of what man will do in the system. For purposes of this report, the crew role is intended to include: (1) information concerned with crew size ranges; (2) potential crew performance; (3) crew performance achievement concepts; (4) personnel support requirements; and (5) crew system-effectiveness. Thus, the procedure for implementing this activity is one of synthesizing the information developed for all of these crew role factors into a summary description which can be titled an optimal crew role. A specific approach to summarizing the

information cannot be described; also the amount of supporting data to be included in the summary is arbitrary. The format suggested under Documentation, below, does provide some guidance as to the order in which the summary may be conducted.

Documentation:

No particular documentation format is necessary to present the results of the synthesized crew role. The following outline, however, does suggest the organization in which the summary should be compiled.

SYNTHESIZED OPTIMAL CREW ROLE

Crew Size

- Local and Remote

Potential Crew Performance

- Local Operations
- Local Support
- Local Maintenance
- Remote Operations
- Remote Support
- Report Maintenance

Crew Performance Achievement Concepts

- Selection
- Training
- Job Aids
- Human Engineering

Crew Support Requirements

- Human Maintenance
- Human Monitoring
- Life Support
- System Protection

Crew System-Effectiveness

- System Capabilities
- System Reliability
- System Cost Factors

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6. ACTIVITIES FOR DETERMINING THE OPTIMAL ALLOCATION OF FUNCTION

This chapter contains the activities in support of the allocation of functions to man. Each activity starts on a new page and in general is presented according to the following format:

Activity Number and Title

Outputs

(Statements of the expected results from implementing the activity.)

Activity Requirements and Constraints

(Discussion of the need for the output and the effect of low quality or no outputs on other activities, activities in the development cycle model or system development in general. Also discusses any constraints on the output, approach, or data.)

Activity Implementation

(Rationale of the approach and a summary of the separate tasks.)

Task Number and Name. —

Inputs:

(Data required to perform the task. Usually a sample is presented and reference is made to the Appendices for additional data if appropriate.)

Approach:

(Discussion of the procedure to be followed, estimates to be prepared, calculations, etc.)

Documentation:

(A suggested format for documenting the results.)

Activity 8

Establish Feasibility of Man-Rated Allocation

Outputs

Statements and rationale supporting the feasibility or unfeasibility of a man—rated allocation for function performance.

Activity Requirements and Constraints

This activity is similar in purpose to Activity 3 in that the primary purpose of the activity is to preclude unnecessary work on the man-rated allocations when they are obviously unfeasible. In this case, however, it is also desirable to determine if man—rated allocations apparently are feasible. Thus, in either case, it is simply necessary to establish a sufficient reason why a man—rated allocation is either unfeasible or feasible. If the evidence supports the position that a man—rated allocation is obviously unfeasible, no additional activities in the sequence are performed. On the other hand, if the evidence supports the position that a man—rated allocation is feasible, then the next succeeding activity can be started immediately. Thus this activity serves as a filter to preclude unnecessary work. The consequences of not performing this activity are simply that additional work may be performed which turns out to be fruitless.

The primary constraint in the implementation of this activity is the insight required of the analyst to identify the suspect factors for investigation. It should also be emphasized that this activity and succeeding ones are concerned with the "allocation of functions" problem and it is therefore assumed that Activities 1 through 7 have previously established the fact that the system will be manned, and that a specific crew role is anticipated. Thus the potential crew role may influence implicitly or explicitly the feasibility of a man—rated function allocation.

Activity Implementation

The general approach for implementing this activity is to review the performance requirements of the function of concern against general statements of man-machine performance capabilities to establish either that the function design obviously should be a machine-automatic allocation, or that the function design can be a man-rated allocation (see Chapter 2, Convention 3, Man-Rated Performance).

Task 1. Determine if the function requirements obviously should be accomplished by a machine-automatic allocation. —

Inputs:

1. Function Performance Requirement and Constraints
2. Performance Capabilities of Machines

Data are needed to indicate those performance areas for which machines are currently superior to man in order to determine that a machine-automatic solution is obviously necessary. This information should also describe some general characteristics of machines which permit them to perform system tasks in a manner which obviously would be unreasonable to expect from humans.

Appendix A, Section 3.1, contains some data of this type. Two samples of typical data of this type follow:

Sample 1

"Repetitive Operations. Machines excel in repetitive and routine tasks; unlike humans, machines do not become bored or inattentive." (Ref. 7)

Sample 2

Westbrook, 1959, ref. 28

We may conclude that certain functions must be done automatically. These include those actions requiring a

fast reaction time or where an unfavorable environment for the pilot is inherent. Most actions in the blast—off, exiting and certain re—entry trajectories fall into this category. Certain functions might best be done automatically. Included in these would be continuous, long time, repetitive and boring action in which the pilot's attention would wander and his performance suffer. An example of this type of action would be continuous, tight, attitude stabilization in space flight.

Approach:

Function performance requirements must be systematically compared against data or state—of—the—art knowledge concerning machine capabilities to determine if the function design allocation is obviously machine—automatic (See Chapter 2, Convention 10, Automation).

Documentation:

Figure 20 is a suggested format for documenting results of this task. The system function should be identified in column 1, the feasibility of a man—rated allocation should be identified in column 2, and the rationale for the judgment should be presented in column 3.

Task 2. Determine if a man—rated allocation appears feasible. —

Inputs:

Statements Concerning Man—Rated Core Performance Capabilities

To establish the feasibility of man participation in any system function, a series of statements concerning performance capabilities of men and machines comparatively and individually can be used.

Appendix A, Section 1.1 through 1.7, contains statements of this type at the beginning of each section. These statements are organized into seven core performance areas; namely,

1. Sensing
2. Interpreting
3. Information Processing
4. Decision-making
5. Controlling
6. Monitoring
7. Information Storage

A sample of this type of data follows:

> Man has the capability for tracking through clutter in a wide variety of situations.

Approach:

Review the functional requirements and constraints against statements concerning man-machine capabilities to determine if man-rated performanc solutions are feasible.

Documentation:

Figure 20 can also be used to document the results of this task. The system function should be identified in column 1, the feasibility of a man-rated allocation should be identified in column 2, and the rationale (identifiying the core performance area) for the judgment should be presented in column 3.

I	II			III
SYSTEM FUNCTION	MAN FEASIBLITY			RATIONALE
	YES	NO	?	

Figure 20. Suggested data documentation format for Activity 8.

Activity 9

Develop Potential Man–Rated Allocations

Outputs

Descriptions of alternative man–rated allocations varying in extent of man participation for each function.

Activity Requirements and Constraints

Earlier, in Activity 6, the problem of crew acceptance was presented and it was stated that acceptance factors are generally related to the responsibility and authority of the crew with respect to system performance. Authority as used here refers to the degree of participation or control that man has in the implementation of any system performance or function performance. Thus man–rated solutions or allocations may require various levels of human participation, from complete participation (manual) to minimum participation (manual–automatic). In other words, there may be several man–rated allocations which will accomplish a given functional performance requirement. Consider, for example, maintenance performance involving a decision–making about a probable failure in any of the following ways:

1. Manual. — By direct observation of the system or environment and/or reference to a maintenance manual (job aid).
2. Mechanized. — By utilization of general purpose test equipment to formulate and test a hypothesis.
3. Manual–Automatic. — By initating and monitoring "built–in" special purpose test equipment which provides a probable answer on the basis of specific input data.

The purpose of this activity is to identify all of those potential man–rated allocations for each functional performance in order that they may be evaluated against each other and against completely machine–automatic solutions for selection of the primary design solution to the function requirement. It is important to emphasize, however, that even man–rated allocations that are not selected as the primary means of implementing the function may be

selected as secondary or tertiary means for backing up the primary design solution. Thus the importance of thoroughly implementing this activity is apparent.

Activity Implementation

The approach for implementing this activity is in consonance with the basic Hypothetical–Deductive approach described in Chapter 3 and is essentially one of hypothesizing the potential man–rated allocations and then testing these hypotheses through the efforts of Activities 10, 11, and 12 which follow. Development of man–rated allocation hypotheses for a particular function is accomplished by reviewing function performance requirements against data concerning human performance capabilities.

Task 1. Develop potential man–rated allocations for each functional performance.—

1. Manual
2. Mechanized
3. Manual-Automatic

Inputs:

1. Man and Machine Capabilities for Core System Performance.

A series of rather detailed discussions of man and machine capabilitie for core system performance are required to develop potential man–rated allocations for all system functions in which human participation has not been eliminated by Activity 8. As before, core system performance refers to: (1) Sensing, (2) Interpreting, (3) Information Processing, (4) Decision Making, (5) Controlling, (6) Monitoring, and (7) Information Storage.

Appendix A, Sections 1.1 through 1.7,contains discussions of man–machine core performance capabilities (following the summary statements

at the beginning of each section) which can be used to implement this activity. A sample of this type of information follows:

Kidd, 1962, ref. 15

Interpreting

Given the fact that signals are available to the operator through his sensory channels, what do we know with respect to their meaning to him? Most of the signals in man-machine system operation are symbolic; that is, they have assigned rather than intrinsic meaning. The problem is whether the intended meaning and the understood meaning are the same. A discussion of this question by Campbell (1958) emphasizes the point that the human operator has certain tendencies to distort the meaning of stimuli, or to assign meaning that was not intended. A part of this distortion originates in the process of identification; that is, the tendencies for redintegration, closure, and the like in response to fragmentary or noisy inputs constitute sources of perceptual errors, as suggested by the Gestalt psychologists.

Closely related, yet generally conceived as a cognitive process, is the mechanism of expectation or cognitive set. People recognize what they expect to recognize. Such expectations can be very general and sustained; they can be established over brief experimental exposure (for example, the Einstellung effect, Luchens, 1942); or they can be imparted symbolically by instructions. Despite man's remarkable capabilities for adaptation or adjustment, there are contrary mechanisms which give both the advantages of continuity and automaticity to certain complex responses (Bahrick and Shelly, 1958) and the disadvantages of rigidity.

There are emotional components involved in the interpretation process also. While "perceptual defense" may be a slightly disreputable concept nowadays (Freeman, 1955), it still appears that our cognitive experiences are influenced by our motives to some extent (Eriksen and Brown, 1956). Thus the individual recognizes, in a meaningful sense, not only what he expects to recognize, but also what he wants or needs to recognize.

2. Human Performance Diversity Data

Because of man's ulititarian performance potential his diverse performance capabilities must be considered as a basis for man-rated allocations for system functions.

Appendix A, Section 2.3 contains some data of this type.

Sample of this type of information follows:

> "Man excels in ability to perform fine manipulation, especially where misalignment appears unexpectedly." (Ref. 30)

Approach:

Each function should be analyzed for potential man—rated allocations. This analysis can be accomplished by systematically reviewing data concerned with (1) man—rated core performance capabilties (Input data, item 1) and (2) human performance diversity (Input data,item 2) against the function performance requirements. Potential allocations at all levels of manned participation (manual, mechanized or manual—automatic) should be developed.

Documentation:

Figure 21 is a suggested format for documenting the results of this activity. Entries should be as follows:

1. Identify the particular function of concern. This may also include more specific identification such as (1) What subsystem, (2) Local or Remote Segment, and (3) Operator, Maintenance, or Support.
2. Specify the type of allocation as manual, mechanized, semi—automatic.
3. Identify the relevant human performance area such as interpreting, if it is one of the core performance areas, or manipulation, if it is one of the general human skill diversities.

4. Describe the allocation solution in terms of the anticipated man and machine performance anticipated.

I. FUNCTION _____

2	3	4
ALLOCATION TYPE	RELEVANT HUMAN PERFORMANCE AREA	RATIONALE OR ALLOCATION DESCRIPTION

Figure 21. Suggested data documentation format for Activity 9.

Activity 10
Review Allocation Potential Against Psychophysical Capacities

Outputs

Statements and data identifying allocations which are unfeasible because of incompatibility with basic psychophysical capacities.

Activity Requirements and Constraints

The purpose of this activity is to test the validity of potential man-rated allocations developed in Activity 9 against human psychophysical capacity criteria. The potential man-rated solutions were developed, or in effect hypothesized, without detailed consideration of basic human capacities. This activity will therefore be a qualifying activity to the extent that potential allocations may be rejected as incompatible to basic psychophysical capacities. It is apparent then that the amount of confidence which can be attached to any potential man-rated allocation is increased in proportion to the amount of effort applied to this activity.

Activity Implementation

Man is frequently conceptualized as consisting of three subsystems (ref. 28, 3) which may be generally referred to as his sensory-perceptual, cognitive, and motor subsystems although different authors use different terms for these things. These three subsystems represent the basic psychophysical capacities of human beings, and are intrinsic to human performance in any potential man-rated solution. These three subsystems then represent three factors which can be used to validate the potential allocation hypothesized in Activity 9. Birmingham and Taylor (ref. 3) developed a somewhat theoretical but relevant discussion of a man-machine system which is presented in Chapter 2, Convention 11, Components of Human Performance for orientation to the rationale underlying this activity.

Task 1. Determine the compatibility of each man-rated allocation with basic human psychophysical capacities. —

Inputs:

Basic psychophysical capabilities and limitations

Inputs needed for this activity consist of quantitative data relative to the psychophysical capabilities and limitations of humans in the three basic areas of human functioning: sensory-perceptual, motor, and cognitive.

Appendix A, Section 2.4, contains a limited amount of relevant data for this activity. A great deal of additional data is available in the psychological and human factors literature, particularly on sensory-perceptual capabilities. Appendix B, areas H24 - H28 may also be used for this activity.

Table 7 is a sample of this type of data.

Approach:

Analyze each man-rated potential allocation for its sensory-perceptual, cognitive, and motor performance requirements. Quantitative performance values should be derived for these component performance requirements. These requirements should then be compared against basic psychophysical capacities to determine areas of suspect or obvious incompatibility.

Documentation:

Figure 22 is a suggested format for documenting the results of this activity. In general, entries are as follows:

1. The system function for which the potential allocations are being tested should be identified.

TABLE 7. MAN'S SENSES AS INFORMATIONAL CHANNELS: A COMPARISON OF THE INTENSITY RANGES AND INTENSITY DISCRIMINATION ABILITIES OF THE SENSES *

Sense	Intensity Range		Intensity Discrimination	
	Smallest Detectable	Largest Practical	Relative	Absolute
Vision	2.2 to 5.7 x 10^{-10} ergs	Roughly, the brightness of snow in the midday sun, or about 10^{9} times the threshold intensity	With white light, there are about 570 discriminable intensity differences in a practical range	With white light, 3 to 5 absolutely identifiable intensities in a range of 0.1 to 50 ml.
Audition	1 x 10^{-9} ergs/cm^2	Roughly, the intensity of the sound produced by a jet plane with afterburner or about 10^{14} times the threshold intensity	At a frequency of 2,000 cps, there are approximately 325 discriminable intensity differences	With pure tones about 3 to 5 identifiable steps
Mechanical vibration	For a small stimulator on the fingertip, average amplitudes of 0.00025 mm can be detected	Varies with size of stimulator, portion of body stimulated and individual. Pain is usually encountered about 40 db above threshold	In the chest region a broad contact vibrator with amplitude limits between 0.05 mm and 0.5 mm provides 15 discriminable amplitudes	3 to 5 steps
Touch pressure	Varies considerably with body areas stimulated and the type of stimulator. Some representative values: Ball of thumb—0.026 erg Fingertips—0.037 to 1.090 ergs Arm—0.032 to 0.113 erg	Pain threshold	Varies enormously for area measured, duration of stimulus contact and interval between presentation of standard and comparison stimuli	Unknown
Smell	Widely variant with type of odorous substance. Some representative values: Vanillin—2 x 10^{-7} mg/m^8	Largely unknown	No data available	No data available

* Mowbray and Gebhard (ref. 20).

2. The potential allocation listed by level of extent of human participation: i.e., manual, mechanized, manual-automatic.

3. Indication by a "yes" or "no" whether human capacities in each of the three functional areas are adequate.

4. Suspect or succeeded human capacities should be explained in this column.

1. FUNCTION _____

2	3			4
	WITHIN HUMAN CAPACITIES			
POTENTIAL ALLOCATION	SENSORY-PERCEPTUAL	MOTOR	COGNITIVE	SPECIFIC CAPACITIES EXCEEDED

Figure 22. Suggested data documentation format for Activity 10.

Activity 11
Review Allocation Potential Against System or Function Constraints

Outputs

1. Statements and data identifying allocations which are unfeasible because of system environmental constraints.

2. Statements and data identifying allocations which are unfeasible because of system or function performance constraints.

Activity Requirements and Constraints

Activity 10 was accomplished to test the validity of potential man-rated allocations with respect to basic human psychophysical capacities. The purpose of this activity is to further test the validity of surviving man-rated allocations against criteria related to environmental and/or performance constraints. The potential man-rated allocations were hypothesized without detailed consideration of specific environmental or performance constraints associated with the particular function. This activity will therefore be a qualifying activity to the extent that potential allocations may be rejected as incompatible with system or functional environment, or performance constraints. For example, man-rated allocations, such as using man to perform discrete manipulations may have survived the test of Activity 9 (Basic Psychophysical Compatibility), but system environmental factors, such as acceleration, could reveal that these manipulations are not feasible in the specific environment in which the function is to be performed. Similarly, function performance constraints, such as duration of a continuous monitoring task, could also justify elimination of a man-rated allocation if a vigilance decrement was likely to occur. The extent of the effort involved in this activity is also related to the validity with which the potential allocations can be accepted.

Activity Implementation

Generally speaking, system or function constraints may be considered as resulting from (1) system environment, i.e., the environment in which the total system is operating, or (2) function performance constraints, i.e., unique task conditions associated with performing the function. Thus the approach for implementing this activity lends itself to two separate investigating tasks wherein the potential man-rated allocations are compared against system environment criteria and function performance criteria for feasibility.

Task 1. Determine the compatibility of each man-rated allocation with system environmental parameters. —

Inputs:

Environmental parameters and their effect on human performance.

These data should relate environmental system parameters to basic human performance.

Appendix B contains an extensive set of data items relating system parameters and human variables which were developed primarily for the analyses of personnel support requirements (Activity 5). System parameters S-1 through S-18, and human variables H-24 through H-28 appear to be most relevant to this activity. Figure 23 is a sample of this type of data.

Approach:

Analyze each potential man-rated allocation for the critical system parameters which affect or will be in effect during the performance of that function. Each of these system parameters should then be investigated against the potential performance allocation to see if they are detrimental to the accomplishment of the performance allocation as hypothesized.

The Critical Effective Temperatures at Which Impairment May Be Demonstrated, According to Various Sources

Name and type of test	Investigator	Temperature (^{o}F)	
		Max. at which performance remains normal	Demonstrable impairment
Typewriter code (scrambled letters)	Viteles	80	87
Morse code reception	Mackworth	87.5	92[a]
Locations (spatial relations code)	Viteles	80	87
Block coding (problem solving)	Mackworth	83	87.5[a]
Mental multiplication (problems)	Viteles	80	87
Number checking (error detection)	Viteles	80	87[a]
Visual attention (clock test)	Mackworth	79	87.5[a]
Pursuit (visual maze)	Viteles	80	87
Reaction time (simple response)	Forlano	93[b,c]	—
Discrimeter (complex response)	Viteles	80	87
Lathe (hand coordination)	Viteles	80	87[a]
Pursuitmeter	Mackworth	87.5	92[a]
Motor coordination	Weiner	64.5[c]	91[a]
Ergograph (weight pulling)	Mackworth	81[d]	85.3[a,d]
Bicycle ergometer (heavy work)	Liberson	64.5[c]	91.5[c]
Weight lifting (heavy work)	N.Y. Ventil. Comm.	64.5[c]	70[c]

[a] Deterioration statistically significant.

[b] Provided wet bulb does not exceed 86°F.

[c] Effective temperature estimated from data in report.

[d] Midpoint of a range of conditions.

Robert M. Gagne, (editor), Psychological Principles in System Development, (c) 1962. Reprinted by permission of Holt, Rinehart and Winston, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
113	SYSTEM - S4 HUMAN - H24	Reference 587, p. 150. Based on Reference 178.

Figure 23. Sample input data item for Activity 11, environmental constraints.

Documentation:

Figure 24 is a suggested format for documenting the results of this task. In general, entries are as follows:

1. The function under investigation should be identified at the top of the table.

2. The potential solution under review with an indication of the extent of human participation; that is, manual, mechanized, or manual-automatic.

3. The relevant constraint, in this case the environmental parameter.

4. Indication of whether the potential allocation is apparently feasible or not feasible because of the effect of the relevant environmental parameter.

5. The rationale or design implication which results.

Task 2. Determine the compatibility of each man-rated allocation with critical function performance constraints. —

Inputs:

Performance constraints and their effects on human performance.

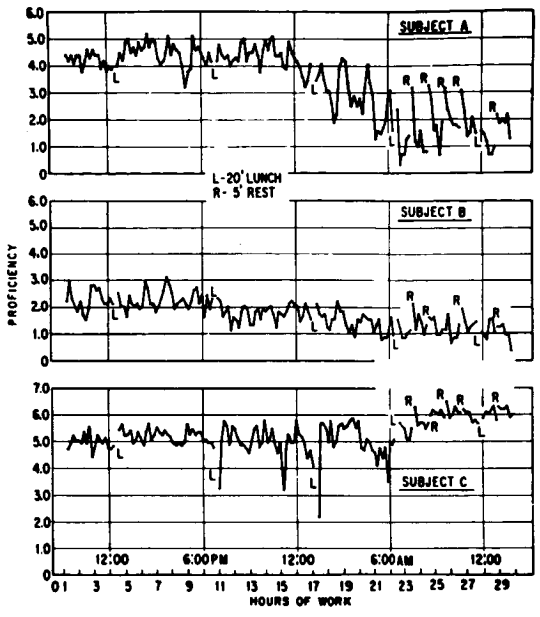
These data should be concerned with interrelationships between functional performance constraints such as confinement and mission duration, and their effect on human task proficiency.

Appendix B contains a limited amount of data of this type. Generally, the data is concerned with system variables S-26 through S-32 and human variables H-23 through H-25. Figure 25 is a sample of this kind of data.

1. FUNCTION _____

2	3	4		5
POTENTIAL ALLOCATION	RELEVANT CONSTRAINT	APPARENTLY FEASIBLE	NOT FEASIBLE	RATIONALE OR DESIGN IMPLICATION

Figure 24. Suggested data documentation format for Activity 11.



Proficiency of three subjects required to perform an exacting operator task for 30 consecutive hours.

The proficiency curves for three subjects are shown above. The curve for subject A closely approximates the mean of the entire group. The initial level of efficiency was maintained for about sixteen hours of work which required the monitoring of several simulated aircraft indicators for thirty consecutive hours. With the exception of short and infrequent periods for lunch, relief, and exercise, the subjects remained at their tasks and were not permitted to sleep. The same figure shows that A and B fall quite short of their initial proficiency levels, whereas subject C achieved a quite different time course of performance.

ITEM NO.	SUBJECT AREAS:	SOURCE:
464	SYSTEM - S28 HUMAN - H19, H26, H29	Reference 219, p. 360. Based on Reference 438.

Figure 25. Sample input data item for Activity 11, nonenvironmental constraints.

Approach:

Analyze each potential man-rated allocation for the critical function performance constraints which will affect or will be in effect during the performance of the function. Each of these performance constraints should then be investigated against the potential performance allocation to see if they are detrimental to the accomplishment of the performance allocation as hypothesized. Hopkins (ref.12) has discussed a technique whereby different man-machine alternatives are qualified by introducing "unfavorable events" that could endanger the mission success. The only events that are considered are those that may be assigned some appreciable probability of precluding successful accomplishment of a major mission requirement if nothing were done to counteract them. This technique could also be used in the implementation of this task.

Documentation:

Figure 24 , the documentation format suggested for Task 1 of this activity, is also appropriate for recording the results of Task 2. The only difference is that entry 3 should now be used for entering the relevant performance constraint instead of the relevant system environmental parameter.

Activity 12
Review Allocation Potential Against Human Reliability

Outputs

Statements and data identifying allocations which are unfeasible because of suspect human reliability.

Activity Requirements and Constraints

This activity is necessary as a final qualification of the potential man-rated allocations remaining after prior qualification for compatibility with psychophysical capacities (Activity 10) and compatibility with system environment and function performance constraints (Activity 11). It is also necessary to evaluate human reliability of the potential allocations so that remaining candidate solutions can be compared against each other. Therefore, it is desirable that the evaluation of human reliability associated with each potential allocation should be expressed in quantitative terms. Two major difficulties exist in implementing this activity. The first is the lack of human reliability data which can be generalized to other task situations. The second is the difficulty of relating individual function reliability measures to overall measures of system-effectiveness which, of course, is desirable.

Activity Implementation

Crew acceptance factors were considered to be the most significant variable affecting crew role reliability (Activity 6); task performance factors, that is, the ability to perform specific tasks accurately and timely, are the significant variables for this activity. For each implied or explicit performance task of each man-rated allocation, it would be desirable to have a measure or prediction of human reliability in the performance of that task. In general, there are three ways in which human performance reliability may be estimated; namely, (1) conduct a study specifically to estimate this value; (2) consider the reliability of performance of the same tasks in other systems; (3) make an

"educated guess" by reviewing human performance reliability in situations as similar as possible, and then interpolating to the situation at hand. The first technique is generally not feasible except for critical performance functions, and of course the second technique is more desirable than the third.

Task 1. Evaluate the human participation in each potential man-rated allocation and estimate the human performance reliability. —

Inputs:

Human performance reliability data for various task situations

These data should indicate error rates or potential for various task performances. A sample of this type of data follows:

Data sample (from the AIR Data Store, referenced in the "Data Provided" Section, below).

IDENTIFICATION/RECOGNITION

Base Time = .25

Time added	Reliability	
		1. Discrimination (Refers, in general, to the separation of one thing (stimulus event) from others.)
0	.9998	a. Heterogeneous (Refers to discriminations made among relatively unique or unlike events.)
3.42	.9987	b. Homogeneous (Refers to discriminations made among relatively similar events.)
		2. Recall (Refers to the retrieval of information from memory. The level of recall, as viewed here, is assumed to be primarily dependent upon the opportunity for learning the material in memory.)
0	.9997	a. Formal (Refers to recall of information for which there has been an opportunity to learn and practice sufficient to attain a high degree of proficiency. This assumes that contingent operations are either unlikely or well learned.)

2.57 .9992 b. Informal (Refers to recall of information for which there has been inadequate opportunity to learn or practice. The major assumption here is concerned with operating contingencies. That is, when operations depend upon uncontrollable external events (enemy action), the opportunity for learning is restricted.)

No attempt has been made to provide data necessary for the accomplishment of this activity although some of the data in Appendices A and B may apply. The following list of references contains guidelines for predicting human reliability, and contains some actual error rate data.

Berry, P. C.; and Wulff, J. J.: A Procedure for Predicting Reliability of Man-Machine Systems. 1960 IRE International Convention Record (New York). Pt. 10, March 1960, p. 112.

Majesty, Melvin S.: Personnel Subsystem Reliability. 1962.

Meister, David: Methods of Predicting Human Reliability in Man-Machine Systems. Human Factors, vol. 6, no. 6, Dec. 1964, pp. 621-645.

Munger, Sara J.; Smith, Robert W.; and Payne, Dan: An Index of Electronic Equipment Operability: Data Store. American Institute for Research, AIR-C43-462-RP(1), Pittsburgh, Pa., January 3, 1962.

Pontecorvo, A. B.: A Method of Predicting Human Reliability. Paper presented at Fourth Annual Reliability & Maintainability Conference, vol. 4, July 1965, pp. 337-342.

Sprunger, J. A.: Human Reliability in Manned Space Problems — Estimation and Verification. Space and Information Systems Division, North American Aviation, Inc., 1963.

Stave, Allan M.: The Quantification of Human Reliability. TIS 65SD216, 1965.

Swain, A. D.: A Method for Performing a Human-Factors Reliability Analysis. N64-17267, 1963.

Swain, A. D.; Altman, J. A.; and Rook, L. W., Jr.: Human Error Quantification. A Symposium held at the Sixth Annual Meeting of the Human Factors Society (New York), Nov. 28-30, 1962. Sandia Corporation Reprint SCR-610, April 1963.

Approach:

Each potential man-rated allocation must be analyzed for its implicit or explicit task performances, and estimates of the reliability of these task performances must be made by comparing the task description to similar task descriptions for which reliability data are available. Where directly comparable performances and data are not available (which will certainly be true in most cases), the contingencies or assumptions affecting generalizations that are made from known data to the system functions should be identified.

Documentation:

Figure 26 is a suggested format for recording the results of this activity. The entries in general are as follows:

1. Identify the function of concern at the top of the table.
2. Identify the potential solution being investigated, column 2.
3. An estimate of human performance reliability, column 3.
4. An explanation of the contingency or assumptions made in the determination of the reliability estimates, column 4.

1 FUNCTION

2	3	4
POTENTIAL SOLUTION	RELIABILITY ESTIMATE	CONTINGENCY

Figure 26 . Suggested data documentation format for Activity 12.

Activity 13
Synthesize Man-Rated Allocations

Outputs

A summary and preferred order of potential man-rated solutions for accomplishment of each function.

Activity Requirements and Constraints

The principal requirement for this activity is to synthesize the results of all the preceding activities concerned with allocation of functions, and present a summary of the final potential man-rated allocations for each system function. In general, the preceding activities have been concerned with developing man-rated allocation hypotheses (Activity 9) and then successively qualifying these hypotheses (Activities 10, 11, and 12) until only potential allocations remain which are acceptable as valid man-rated allocations. This activity is concerned with the presentation of those valid allocations.

Activity Implementation

The approach to this activity is simply one of reviewing the results of all the preceding activities and summarizing or integrating the results into a logical presentation.

Task 1. Synthesize and order valid man-rated allocations and describe these allocations together with concomitant suspect areas. —

Inputs:

Results of Activities 8, 9, 10, 11, and 12.

Approach:

No particular procedure can be recommended for accomplishing this activity other than the suggestion that the results of all of the activities to be synthesized should be reviewed, as the activities are in fact being synthesized.

Documentation:

Figure 27 is a suggested format for documenting the results of this activity. In general, the entries are as follows:

1. The particular function of concern should be identified at the top of the table. This might also be amplified to include the relevant subsystem, local or remote segment, and operational, maintenance, or support performance type.

2. Where a multiplicity of candidate solutions for accomplishing this function remains, these should be listed in the order in which they are preferred as optimal man-rated allocations. Each candidate allocation should be identified as to whether it is considered manual, mechanized, or manual-automatic.

3. Column 3 should contain descriptions of suspect areas and recommendations for coping with these potential problems for each candidate solution.

1 FUNCTION

2	3
CANDIDATE ALLOCATIONS	SUSPECT FACTORS AND RECOMMENDATIONS

Figure 27. Suggested data documentation format for Activity 13.

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7. RESEARCH NEEDS

This chapter identifies research needed either to advance the activity implementation techniques or to develop data to support the techniques. The research needs have been integrated into six separate items. Generally speaking, the first three items are concerned with supporting data research needs and the last three items are concerned with activity technique research needs. The activities which the research will support are identified and some statement of the relative value of each research need is presented.

1. Data Development

All development programs or analytical techniques probably suffer to some extent from a lack of supporting data. The approach proposed here is no different. Lack of supporting data is the primary constraint in the implementation of several activities. It should be mentioned that the problem of the lack of data is of course quite different from the problem of the lack of organization or accessibility of the data which is the concern of research needs.

The particular areas wherein the problem is the lack of data rather than management of the data, and the activities wherein these data are needed, are as follows:

a. Personnel Task Performance Time (Activity 4)

b. Crew Acceptance Principles (Activity 6)

c. Human Performance Reliability (Activity 12)

d. Costs Associated with Achieving and Maintaining Personnel Performance (Activity 7)

In general, the data and associated activities listed above are relevant to that part of the overall approach concerned with the validation of hypotheses concerning man's role and function allocation rather than with forming the hypotheses. In other words, there is more data available for formulating

personnel performance hypotheses than there are for testing these hypotheses. Research programs to develop new data in any or all of the areas thus relate directly to the confidence that can be associated with the analytical derivations of crew roles and function allocations.

2. Data Management

Data management as used here refers to problems of organization, storage, and retrieval of data in those areas where a good deal of data exist but are not readily available to the system designer's needs. Generally speaking, the data management problem applies to data concerned with human performance capabilities, personnel support requirements, and human factors engineering. In other words, comparatively speaking, considerable data exist in the three areas above but are not readily available to the system designer, at least from the viewpoint of design problems. The system designer's problems, and consequent need for information concerning human beings, are in terms of a particular system concept or function with certain system parameters. Thus, the most desirable method of obtaining such information is by system parameters rather than by human variables. In effect, the system designer would like to know for any system parameter what human variables are affected by this parameter and what the implications are for system design. The vast majority of the data reviewed in the development of this report are organized by human variables in the books or reports in which they are found and thus are not directly accessible to the system designer unless he knows inherently which human variables interact with various system parameters. Furthermore, many data items apply to more than one area of concern but these are restricted to a single location if they are presented in a book or research report. The data management research need thus may be interpreted as two research needs, the first being the need for an organization scheme for coding available data and the second a storage and retrieval technique for gaining access to the data.

For this report a considerable amount of the personnel support data was reviewed and prepared as an appendix both to support activities of this report

(primarily Activities 3 and 5), and to illustrate the problems of data management. The first problem of data management, that is, organization, was solved by developing a list of system parameters and human variables to provide a basic matrix for organizing and coding the data. This basic matrix has been presented as Table 4 (p. 77). To solve the second problem of data management, that is, storage and retrieval, a simple method was developed wherein (1) the data are numbered in the appendix as individual items or pages in a random fashion with each new data item receiving the next available accession number, (2) the data were "stored" as a bound volume, and (3) accession lists identifying relevant data items for any pair of cell coordinates of the matrix were prepared. As described in the appendix itself, this technique may be extended one step further by reproducing the data items on "edge-punched" cards for a more convenient random access system. Research to develop more elaborate organization schemes and storage and retrieval techniques can be pursued at virtually any level. Certainly, with respect to storage and retrieval techniques or systems, the state of the art today varies from simple edge-punched cards to elaborate computer-controlled display systems. The sophistication of the storage and retrieval system depends to a great extent on the universality of its use. It is recommended, however, that a more sophisticated organization scheme could be developed similar to the one contained in this report but extended to include not only personnel support data but human performance capability data (such as that contained in Appendix A) and human factors engineering data. It is further recommended that once these schemes are fully developed, random access handbooks (such as Appendix B) and/or simple techniques such as edge-punched cards could be prepared to make a large amount of the readily available data accessible to the general population.

3. Historical Data Compilation

Commensurate with the problem of research data needs is the need for compilation of historical data on past or extant systems. Many times in the conduct of this program, it was apparent that knowledge of decisions concerning role of the crew and allocation of functions in existing systems would

be useful. While this data may generally be available in system-specific documents, it is believed that compilation of this data into a single source would be extremely valuable to the implementation of the approach proposed here. In many cases, in fact, generalizing from a previous or existing system to a new system would have more validity than generalizing from research data to a new system. Thus, it is recommended that a worthwhile research need would be the preparation of a single source of compiled data concerning man's role in the allocation of functions in recent and current complex man-machine systems.

4. Crew Size Estimation

A technique for estimating the feasible range of crew sizes early in the development of aerospace systems would be extremely useful not only for determination of man's role, but for other aspects of the development cycle generally concerned with the identification and selection of candidate system solutions. In particular, this technique would be of value to Activity 4 of the approach proposed here. The crew size directly affects both development and operational costs as well as vehicle and support system equipment designs. Final crew size may be determined at a much later stage in system development, but a technique for estimating a narrow range of crew sizes early in the development cycle would prove extremely cost-effective. It is suggested that this technique could be developed and presented as parametric data in which the critical relevant parameters could be traded off.

5. Man-Rated Allocations Criteria and Techniques

Techniques for establishing the feasibility of a man-rated allocation, (Activity 8) and for developing potential man-rated allocations (Activity 9) generally are not available. In the first case this appears to be a criterion problem basically in that criteria must be developed to apply to given function requirements and constraints to determine if man-rated allocation is feasible. In the second case, a technique is necessary to systematically build potential man-rated allocations. With respect to the latter case, the technique must

produce descriptions of manual, mechanized, and manual-automatic allocations that are feasible for the same function. Research leading to criteria and techniques for screening and developing man-rated allocations will also provide a basis for standardization, or at least consistency with respect to analytical approaches, for allocating functions to man. This, of course, does not mean that empirical methods might not revise allocations based on analytic techniques.

Research leading to man-rated allocations criteria and techniques which are acceptable to system designers would provide two other important contributions; viz., (1) system designers could anticipate the type and format of information they would receive from human factors personnel, and (2) a historical record of the evolution of function allocation would be available for review and use in other systems.

6. Validation of Allocations

Techniques for assessing the validity of potential man-rated allocations are necessary to increase confidence in the hypothesized allocations. Activities 10, 11, and 12, of this report are concerned with the validation of allocations but the research need is basically in the area encompassed by Activity 11 which is concerned with system or function constraints. [1] As mentioned in the discussion of Activity 11, Hopkins (ref. 12) has discussed a technique whereby different man-machine alternatives are qualified by introducing "unfavorable events" that could endanger the mission success. It is techniques such as this which should be more fully developed to test potential allocations and thus increase confidence in the proposed allocation. Here again, as in the previous research need, we are concerned exclusively with analytical techniques rather than empirical techniques. If research leading to more validating techniques was conducted, it would seem reasonable to

[1] Validating techniques which are based on system or function constraints would have more "face validity" and probably would also be more prolific.

expect that potential allocations developed as proposed in this study not only would have more validity but also would be more acceptable to system designers.

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TECHNICAL APPENDIX A
MAN-MACHINE PERFORMANCE DATA

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INTRODUCTION

This appendix contains supporting data for several of the activities described in the body of this report. Each activity description identifies the type of data required to support it and references relevant sections of this appendix. As a summary convenience, Tables 1 and 2 following are presented as a key to match activities within the sequence to the contents of the appendix.

Actual organization of data within the appendix does not follow the activity sequence but is indicated in the Table of Contents. Sets of data are divided into "Statements" and "Discussions" about various aspects of man and machine performance capabilities and limitations. "Statements" refer to general allocation principles, including man-machine comparison lists available in the human factors literature as well as summaries of more lengthy descriptions of men and machines. "Discussions" delve more deeply into the issues raised by the "Statements," giving explanatory details and limitations to the use of the allocation principles. Several human engineering texts, bioastronautics texts and government research reports were used as sources for the appendix.

The data is in no way comprehensive; it serves as a representative set of the kind of data useful in some system development activities. It will be noted that data in certain categories are quite scarce, while in other areas there is plenty of discussion, but disagreement among researchers. In cases of contradictory statements, both sets of data have been included, without comment.

TABLE 1. A KEY TO RELEVANT DATA SECTIONS FOR ACTIVITIES CONCERNED WITH DETERMINING THE OPTIMAL ROLE OF MAN IN A SYSTEM CONCEPT

ACTIVITIES		RELEVANT DATA SECTIONS		
		Statements	Discussions	Appendix B
Activity 1.	Hypothesize the Potential Basic Role of Man			
	A. Unique Human Capabilities Performance	2.1	2.1	
	B. Core (Prime & Maintenance) System Performance	1.1-1.7		
Activity 2.	Hypothesize Potential Complementary and Support Role of Man			
	A. Utilitarian Performance	2.3, 3.2	3.2	
	B. Support System Performance			
Activity 3.	Review Manned System Solution Feasibility			
	A. Machine Capabilities	3.1	3.1	
	B. Unique Human Limitations and System Performance	2.2	2.2	X
	C. Man-Machine System Effectiveness	4.1	4.1	
Activity 4.	Develop a Preliminary Crew Concept			
	A. Summarize Potential Crew Performance			
	B. Estimate Crew Size			X
	C. Estimate Crew Performance Development Requirements			X
Activity 5.	Analyze Personnel Support Requirements			
	A. Analyze System Parameter - Human Variable Interactions			X
	B. Analyze Human Variable - Human Variable Interactions			X
	C. Analyze System Parameter - System Parameter Interactions			X
Activity 6.	Review Potential Crew Role for Acceptance and Reliability	4.2	4.2	
Activity 7.	Synthesize Optimal Crew Role			

TABLE 2. A KEY TO RELEVANT DATA SECTIONS FOR ACTIVITIES CONCERNED WITH DETERMINING THE OPTIMAL ALLOCATION OF FUNCTIONS TO MAN

ACTIVITIES		RELEVANT DATA SECTIONS		
		Statements	Discussions	Appendix B
Activity 8.	Establish Feasibility of Man-Rated Allocation	1.1-1.7, 3.1	3.1	
Activity 9.	Develop Potential Man-Rated Allocations		1.1-1.7	
Activity 10.	Review Allocation Potential Against Psychophysical Capacities	2.4	2.4	
	A. Sensory - Perceptual			
	B. Motor			
	C. Cognitive			
Activity 11.	Review Allocation Potential Against System or Function Constraints			
	A. Environment & Performance			X
	B. System/Function Constraints		2.3	X
Activity 12.	Review Allocation Potential Against Human Reliability		4.2	
Activity 13.	Synthesize Man-Related Allocations			

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MAN-MACHINE PERFORMANCE DATA SECTIONS

1.0 Man - Rated Core Performance

1.1 Sensing

Statements: —

MAN	MACHINE	
"Man is a selecting mechanism and must be set to sense specific items."	"Machines are sensing mechanisms."	ref. 79
"Limited to certain ranges of energy change affecting human senses. Sensitivity: very good."	"Range extends far beyond human senses (X-rays, infrared, etc.). Sensitivity: excellent."	ref. 41
Under favorable conditions absolute thresholds of sensitivity in various modes (visual, audition, tactile) are very low.	Machine's thresholds are generally not as low as human. They may have the same capability but only at great expense.	ref. 111 ref. 36
The human has limited channel capacity.	Machines may have as much channel capacity as can be afforded.	ref. 111
"Not subject to jamming, EMC, etc."	"Generally subject to interference by enemy action and noise."	ref. 111

Man senses many stimuli at once and will therefore select, from a variety of responses available to him, one which is more or less appropriate to the situation. ref. 27

"The ability to detect certain forms of energy, especially very low energy levels which can be detected by humans, but which are not great enough to activate an instrument, is one of man's characteristics." ref. 99

"Man is sensitive to a wide variety of stimuli through the use of the organs of sight, hearing, smell, touch, temperature, pain, taste, balance, and muscle sense (kinesthesis). All of these sensory abilities are used in operating and/or maintaining equipment, though obviously some are used much more than others. In spite of this wide variety in sensitivity, the range and accuracy of sensitivity in any one mode is quite restricted compared to machine "sensing ability." ref. 99

Investigations of machine recognition of written or printed characters or spoken language show how primitive known electronic circuit principles are compared to the nervous system. ref. 95

Human beings are usually superior to machines in perceiving and interpreting sensory information. ref. 114

"Man has excellent signal detection ability and his real-time capacities can be used in sensor systems such as radar, sonar, and infrared; however this usually is one of the least desirable uses of men in systems." ref. 34

Detection of low energy signals in a random signal background appears easier via sound than visually. Combined inputs (sound and visual) indicate some performance improvement. ref. 114

"If man is already present in a given situation, it may be more ecomonical to use him as a sensor than to provide additional equipment if the sensing requirements are within the range of human sensitivity. This also is related to the desirability of providing a man with enough work so that he will maintain a reasonable level of motivation and alertness." ref. 106

"Man is seriously limited with respect to bandpass, channel capacity, and peak power; man is essentially a single channel computer and must accomplish multiple tasks sequentially (i.e., by means of time sharing); his great asset is his capacity for learning and adaptive processes." ref. 34

"The function of human sensing is not used with particular frequency in modern systems, largely because machines can be designed to do a better job." ref. 41

Machines can sense forms of energy that are in bands beyond man's spectrum of sensitivity, such as infrared, radio waves, X-rays, radar wavelength and ultrasonic vibrations. ref. 99 ref. 67

Discussions: —

Wayman and Jones, 1964, ref. 106, p. 145.

Sensing

In deciding whether equipment or personnel should perform specific functions related to receiving inputs, information is needed about:

- the requirements for energy detection and discrimination; and
- the system- and use-determined factors influencing energy detection and discrimination.

Energy detection and discrimination refers to the ability to receive or sense electromagnetic, particulate, and/or mechanical energy without specific regard to signal qualities or informational content. Detection refers specifically to the absolute presence or absence of physical energy, while discrimination refers specifically to the presence or absence of a difference between physical energy levels. The reception of these energies requires the presence of a sensing mechanism which can be affected by the particular type, range, magnitude, and other qualities of the energy. Obviously, both man and equipment are capable of receiving many forms of physical energy. This detection or reception by the senses is prerequisite to discrimination and later processing. System- or use-determined factors may then dictate other uses of equipment or personnel for sensing and may require compromises in the assignment of tasks. In one instance, though limited in detection and discrimination capabilities as compared with a specific equipment sensor, man may be required in the system because of his multipotentiality for sensing many forms of physical energy. In other instances, where detection would be monotonous, hazardous, inefficient, or impossible for man to perform, equipment sensors may be required or desirable. The guidelines which follow serve to structure the man-machine assignment decision with respect to the critical function of sensing.

Wayman and Jones, 1964, ref. 106, p. 146.

Detection and Discrimination

Detection and discrimination of specific physical energies should be performed by equipment sensors, except for the following considerations:

a. If the situation requires the reception of many different types of physical energy in close proximity in time but not simultaneously (such as might be involved in steering a vehicle, where visual, auditory, tactual, and kinesthetic sensing all may be useful for control), the multipotentiality of man's senses may indicate his use for detection and discrimination functions.

b. If high noise levels are present, it may be necessary to utilize man to detect signals. This capability is often associated with detection of signals on cathode-ray tube displays and use of communication equipment.

c. If equipment sensors cannot be designed to provide effective scanning, then it may be necessary to use man. Man, through his ability to direct his attention to various portions of his environment, may provide a more effective means of detection than more highly programmed equipment sensors.

d. If contingencies which may arise in the operation and maintenance of the system cannot be predicted adequately during its design, it may be necessary to include man as a sensor for some back-up functions.

e. If effective equipment sensors cannot be designed, then it may be necessary to use man. For example, man must be included to detect visual signals associated with the use of radar equipment, auditory signals associated with the use of sonar, and wave forms associated with the use of test oscilloscopes. This may, in some instances, involve the detection of low-energy levels which might fail to activate an equipment sensor.

McCormick, 1964, ref. 67, pp. 7-8.

Sensing (information receiving). One of these [four classes of system] functions is sensing, or information receiving. Some of the information entering a system is from outside the system, for example, airplanes entering the area of control of a control-tower operator, an order for the production of a product, the heat that sets off an automatic fire alarm, various cues regarding the presence of schools of fish, and telegraph communications. Some information, however, may originate from inside the system itself. Such information can be of a feedback nature (such as the reading on the speedometer of the action on the accelerator or the feel of a control lever), or it can be information that is stored in the system.

The sensing, if by a human being, would be through the use of the various sense modalities, such as vision, audition, and touch. There are various types of machine sensing devices, such as electronic, photographic, and mechanical. Sensing by a machine in some cases is simply a substitute for the same sensing function by a man. The electronic device in an automated post office which identifies the location of a stamp on an envelope is simply doing the same thing that a man would otherwise do to place the envelope in proper position for canceling the stamp. The sonar used for detecting schools of fish, however, involves "sensing" the fish in a manner that a man is not capable of; men would sense their presence by other means, such as observing gulls dipping to the surface of the water or observing surface perturbations in the water.

Ellis and Ludwig, 1962, ref. 27, pp. 72-73.

SENSORY ABILITY. It is often stated that the human sensing capacities of vision and audition generally surpass those of machines. The sensitivities of these two important sensory modalities of the human organism are frequently cited as challenges to the ingenuity of the instrument maker and the engineer. In the distance receptors of the ear and eye there are artificial considerations which have not been applied in the design of counterpart instruments. We are speaking here of phenomena which are truly unique to the human organism. Examples of such features are, in the eye, the effects of after-images which result from the lag in refocussing, or the perception of the quality "whiteness" as appearing whiter when observed against a black background. Similar phenomena are noted for the ear. These features are consequences of built-in limitations of anatomical and evolutionary origins.

Man is a multi-purpose assemblage of sensory and motor capabilities. These capabilities interact in a way fundamentally similar to the workings of machines which incorporate various feedback schemes, but in a manner much more complex —not more complex in terms of the basic action relationships between error sensing and corrective adjustment, but in terms of concomitancy and sequencing of various acts of both sensory and motor nature. Thus, we are probably justified in saying that man senses not just one stimulus in even the most rigidly controlled experimental situation; he senses many. He will therefore always select, from a variety of responses available to him, one which is more or less appropriate to the situation. Hence, we may say that, quantitatively, the sensing capabilities of human receptors are but approximated, not known.

It follows that the interrelationships between sense modalities are even less capable, at the present, of quantification.

Steinbuch, 1965, ref. 95, pp. 478-480.

Man receives information from the environment by means of receptors. These receptors lie mainly in the retina of the human eye (about 100 millions) and on the basilar membrane of the cochlea of the ear (some ten thousands). The whole surface of the human body is covered by many receptors for pressure, temperature, smell, taste, etc.

Man communicates information to the environment mainly be [sic] using his "effectors", i.e. his muscles, or his glands. Speaking, writing, moving etc. is due to muscular activities. Contrary to this fact, the present automata receive information from the environment in a specially prepared way, for example by teletype, punched cards, by special transducers etc. Machine recognition of written or printed characters or spoken language was seriously considered only a few years ago. The investigations showed how primitive all known electronic circuit principles are, compared to the circuit principles of the nervous system.

Table 1

A Comparison of Some Characteristic Values of Man and Automaton [Partial Table]

	Man (central nervous system)	Automaton (digital computer)
Circuit elements		
type	neurons	diodes, transistors, ferrite cores etc.
number	$1,5 \cdot 10^{10}$	some 10^4
volume	$10^{-8} \ldots 10^{-5}$ cm^3	$10^{-2} \ldots 10^{+1}$ cm^3
Input and output		
type	approx. 10^8 receptors, muscles, glands	teletyping equipment, punched cards equipment etc.
rate	unconscious : approx. 10^9 bit/sec conscious : maximal 10^2 bit/sec	$10^2 \ldots 10^6$ bit/sec

Man and automation use a different way to exchange information. The man uses audible speech, visible writing, gestures, mimicry, etc. Automata use electric impulses whose period is much shorter than those signals of a man and which correspond to a lower level of energy. Since the speed of operation, and the type of input and output signals between man and machine are so different, tasks requiring smooth integration of machine and man cannot be efficiently performed. For this reason it is often preferable to use only machines for tasks that could be better performed by men.

Fig. 1 shows how improper integration of men and machines can lead to loss of time and reliability.

The left side of Fig. 1 shows a situation where a human operator is supposed to turn a switch R when he recognizes the coincidence of signals A and B. This task can be more easily and reliably performed by electromechanical relays. The reliability can be further increased by using electronic switches (e. g. transistors).

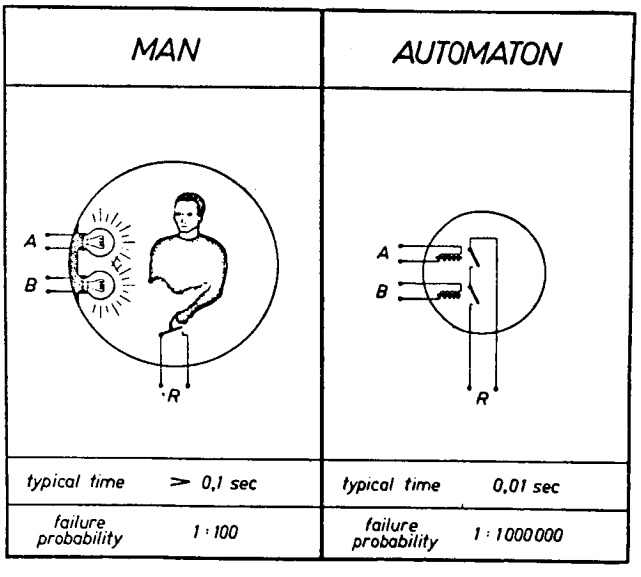


Fig. 1. Response R depending on two signals A and B

Morgan, et al., 1963, ref. 72, pp. 34-35.

[MAN vs. MACHINE]
AS SENSORS

Human sensing is restricted to a relatively narrow range of physical energies. Man's visual sensing is limited roughly to the wavelengths between 300 and 1,050 mμ — an extremely small portion of the electromagnetic spectrum [1]— and his auditory sensing is limited roughly to the frequencies between 20 and 20,000 cps (in many people, the upper limit might be under 10,000 cps). But human sensitivity — in the sense of the minimum energy that man can detect — compares favorably with the sensitivity of machines. This can be seen from the following facts:

a. A man can detect the light of a match 50 mi away on a clear night — energy as little as 2-6 X 10^{-10} ergs (10^{-10} Lamberts).

b. He can detect a sound so weak that it is barely above the level of molecular noise of air — energy as little as 1 X 10^{-9} ergs/cm^2 (0.0002 dyne/cm^2).

c. A man's sensitivity to odors varies enormously with the chemical composition of the odor, but he can detect as little as 2 X 10^{-7} mg/m^3.

Human discrimination — the ability to detect differences in the intensity or quality of stimulation — also compares favorably with that of machines. Under ideal conditions, man can visually detect the following:

a. Differences in wavelength of 1 mμ (10 A).
b. Differences in intensity of 1%.
c. Forms as small as 0.5 sec of arc.

And, under ideal conditions, man can audibly detect differences in frequency of 0.5% and differences in intensity of 7% (0.33 db).

In general, human discrimination becomes relatively better the higher the intensity of stimulation. But, because many instruments discriminate better at low or medium intensities, it is often necessary to design and operate equipments at levels that strike a compromise (and an optimum) between man and machine characteristics. For example,

[1] Reference is made to material elsewhere in the book from which this quotation is taken.

human discrimination of brightnesses, like those presented by PPI targets, is best at relatively high brightnesses, but the physical contrast of targets with their background is better at lower screen brightnesses. As a result, the best screen brightness is one that strikes an optimum compromise between the characteristics of the cathode-ray tube and those of the human eye.

Human beings are usually superior to machines in perceiving and interpreting sensory information, as is indicated by the following:

a. Human beings are good for tasks requiring discrimination of signals in noise (French, 1954). As examples, a radar operator can distinguish real echoes or targets in clutter, and an experienced radio operator can usually make sense out of words being heard through high-background static.

b. Man can identify similar patterns in different situations. This ability, which many situations require, is uniquely human. For example, man can be trained to recognize aircraft silhouettes when the aircraft are at different distances and in different positions. [1]

c. Man can get information out of incomplete or sparse signals. For example: the telegram, "C-m- at ---- F-th-r dy-ng," can be interpreted easily by a man but not by a machine. (This ability to interpret partial information also has its drawbacks. Because of it, man often interprets incorrectly.)

d. Man is selective in his perceptions; he can shut out certain signals and respond to others. As examples, a teletype operator can respond to the clacking of the machine but ignore other noises in his environment, and an air traffic controller can listen to the radio channel that concerns him while ignoring messages coming in over other channels.

Morgan, et al., 1963, ref. 72, p. 26.

SIGNAL DETECTION

The detection of significant low-energy signals appearing against a background of random signals is a vital problem in many situations. For example, the typical search radar

[1] Reference is made to material elsewhere in the book from which this quotation is taken.

presents a polar-coordinate display of an immediate area, and superimposed on all land or sea returns are significant targets plus random returns that are both internal and external to the generating and receiving equipment. Although little systematic work has been done in comparing the ability of the eye and the ear to accomplish this particular task, in general, it appears easier to recognize a complex sound pattern against an altering sound background than it is to recognize an equivalent visual pattern against a visual background.

Work done in the use of combined visual and auditory inputs in sonar and radar indicates some improvement in detection. This relatively minor improvement, however, is a function of many parameters — such as time lag between the different inputs and compatibility of displays — and, under certain conditions, the combined visual and auditory inputs can lead to a serious reduction in detection.

Morgan, et al., 1963, ref. 72, p. 28.

MULTIPLE INPUTS

The senses are being bombarded constantly by multiple inputs. Usually, most of them are irrelevant to the task at hand and, unless consciously noted, are ignored. Of the two most important senses, vision and audition, vision is in the best position with respect to complex stimulation because where one looks and the objects at which one looks are under direct control. Many things might be, and usually are, going on in the peripheral field of vision without intruding upon the central task on which one is concentrating; to all intents and purposes they do not exist. On the other hand, if peripherally occuring events are important to the central task, they can be taken in quickly in successive fixations.

The auditory system is not so constituted and, because it is not, offers some special problems in the realm of multiple inputs. Because these problems have many important practical aspects, they have received considerable attention. Communication systems, for example, are susceptible to interference from overlapping messages, irrelevant atmospheric noise, and the like. These and other types of problems have been scrutinized from many angles, but multiple inputs to other sensory systems by comparison, have been neglected.

Gagne, 1962, ref. 41, pp. 45-46, 60-61.

Sensing

We need spend very little time on this simplest of human functions, not only because it has served us so well already as an example, but also because it is not of tremendous importance in modern complex systems. In our fictitious system, a task which required the individual to report a difference or lack of difference in alignment of two small line segments provides us with a typical example. In general terms, the function is one which indicates the presence or absence of a difference in physical energies. As is well known, such a difference may take the form of light intensity or wave length or wave composition, so far as visual displays are concerned, and comparable differences may be sensed when input is fed through other senses, such as hearing or touch. Considerable quantitative information has been collected concerning these varieties of sensing, particularly for vision and hearing. [1]

As we have said, the function of human sensing is not used with particular frequency in modern systems, largely because machines can be designed to do a superior job. However, the specific variety we have used as an example, visual acuity, is sometimes utilized to good advantage in such tasks as alignment of vernier scales and in aligning instruments such as transits and gun sights. It is difficult, though, to think of an example of the use of brightness or color sensing as a function of a human operator in a system. Similarly, although auditory inputs are often employed in systems both as warning signals and as conveyors of voice communication, the sensing of slight physical differences in sound energy does not often occur as a task for a human operator. Although the mechanisms for sensing are activated in the use of higher functions, sensing itself has extremely restricted employment in systems.

A number of studies of sensing thresholds have shown that filtering conditions have important effects on the exercise of this function; in fact, the various constant errors which occur in psychophysical experiments may be considered to reflect the limitations of the filtering mechanism (compare Woodworth, 1938). The differences in results obtained in psychophysical experiments with trained versus untrained observers are also relevant to the establishment of filtering conditions. Evidently a trained observer does not "sense

[1] Reference is made to material appearing elsewhere in the book from which this quotation was taken.

better" because of his previous training, but he does "attend better" and thus is able to report extremely small physical differences with a high degree of probability. The implication is that certain observational routines may be acquired and stored in long-term memory and that these may facilitate filtering. Although filtering conditions for the sensory function may readily be established by instructions ("As soon as you see a difference in brightness in these two patches of light, press this switch"), these will not be optimally effective in untrained observers.

What about the other conditions for the sensing function? Shunting conditions are readily established by instructions ("Report only a difference in brightness, but not how bright the patch is, or what color it is, or anything else"). As our previous discussion has implied, there are presumably no effects of training on the sensing function; inputs from memory affect the function only indirectly, through their influence on the filtering conditions. From the point of view of systems design, perhaps the most important aspects of conditions for sensing are the minimum display requirements expressed in terms of physical measures. Because the sensing mechanism is the initial avenue for all higher functions, the physical limitations of this function sometimes have an important bearing on equipment design. [1] These limits of sensory functioning are described at greater length[1] . . .

For the sensing function, the limitations of man are quite apparent. The physical-energy changes he can sense are limited to those which affect his receptors of vision, hearing, touch, smell, taste, and so on. [1] In contrast, machines are able to sense changes beyond these limits, in the ultraviolet and infrared regions of the electromagnetic spectrum, above 200,000 cycles in the mechanical spectrum, and so on. Within the limitations of his senses, a man's sensitivity is quite good, since it is known that he can sense very small differences (compare Geldard, 1953). But the number of changes he can respond to at one time is relatively small — that is, his channel capacity is limited. Beyond this, it will be realized that reprogramming man's filtering conditions is a matter readily accomplished by instructions; in a machine, this would be expensive or time-consuming or both.

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[1] Reference is made to material appearing elsewhere in the book from which this quotation was taken.

Sinaiko and Buckley, 1957, ref. 91, pp. 5-6.

Capability for Data Sensing

Man gathers information through his senses: he sees, smells, hears, tastes, and feels pressure or pain. Human senses are stimulated by physical energy. For example, in the visual sense mode, color hue varies with the frequencies of light waves striking the retina of man's eyes; brightness is a function of the energy level of the light waves; saturation corresponds to the homogeneity of the wavelengths.

Human sensory abilities are very complicated. There are definite known limitations, both minimum and maximum, on how much energy is required to produce a sensation. Some sounds are at too low an energy level to be audible while others are too high and may produce injury. Sometimes the senses are unable to distinguish between slightly different energy sources. Even people with normal color vision cannot always discriminate between two very similar colors. Still another aspect of the human senses is that they are limited in terms of speed and capacity.

Human senses tend to be inconsistent. Such things as a man's general health, or fatigue, affect his sensory ability. Background conditions — noise of all types — influence and may adversely affect the senses. Man's ability to gather information about the environment is affected if two or more of his sense channels are stimulated at the same time. The cab driver who is following a World Series game on the radio and, at the same time, trying to respond to traffic lights or other visual signals is experiencing simultaneous sensory stimulation. Further, although he would use different words to describe it, the interaction between the driver's two senses has an adverse effect on his over-all performance. On the other hand, in some cases, sensory interaction may boost performance as, for example, when one receives the same message simultaneously through visual and auditory means.

The human senses rarely operate by themselves. Man usually does more than simply serve as a receiver of information; he acquires data — sounds, smells, sights — and interprets them as they come in. Experience plays an important role here. A traveler passing through the New Jersey meadows does not merely sniff the air and file away the abstract concept, "putrid." Instead, he somehow thinks, "animals" or "down on the farm" or "pigs." The point here is that the boundary between data sensing and data processing (which is treated later in this section) is a fuzzy one.

Man may fail to sense some facts that are present, and he may impose interpretations on what he does sense. His ability to perceive the world in terms of a context is a tremendous advantage because it enables him to get a great deal of information out of a sketchy amount of data. On the other hand it will often get him into trouble because he will "see" things that are not there.

A very important and uniquely human sensory ability is the selectivity man uses in his perceptions. The traffic policeman on a busy corner is literally bombarded with sensations but he is able to filter out the irrelevant and concentrate on things of importance to him. An ambulance siren produces a much different response in the policeman than do truck horns. Similarly, the policeman can "shut out" some visual signals (passing cars or people) and concentrate on others (traffic signals or flashing red lights). This ability to perceive the world in terms of a context often gets man into trouble by causing him to ignore important things, but it also enables him to make order out of chaos.

Finally, another aspect of man as a data sensor is his capacity for getting information out of incomplete or sparse signals. The telegram, "C-m- at ---- F-th-r dy-ng" can be interpreted with little ambiguity, although it occurs in a piecemeal fashion. This ability to interpret partial information also can get man into trouble by causing him to base interpretations on the wrong facts. Optical illusions are examples of a wrong pattern being imposed on partial information.

System Design Implications
[list abbreviated to items concerned with function allocation]

[1] Humans are good for tasks requiring discrimination of signals in noise. For example, a radar observer can distinguish real echoes, or targets, in clutter. And for experienced radio operators, it is usually possible to make sense out of words being heard through high background static.

[2] Man can identify similar patterns in different situations. For example, he can recognize an aircraft silhouette when the aircraft is at different distances and in different positions and attitudes. This is a rather unique ability which many situations require.

Woodson and Conover, 1964, ref. 114, p. 1-27.

[THE HUMAN] AS A RECEIVER

Proper inputs to the senses (seeing, hearing, touch, etc.) result in man's being a highly reliable receiver. His time constants are relatively long, 25 to 150 milliseconds, and his sensitivity ranges are limited, approximately 20 to 20,000 cycles per second in the sound spectrum and from 4000 to 7000 angstrom units in the electromagnetic spectrum. His rate of perceived input seems to be not much greater than 10 successive items per second. His input capacity is easily saturated, and care should be taken to avoid messages to him that are overlapping, competing, or visually and aurally incompatible.

Woodson and Conover, 1964, ref. 114, p. 1-28.

SENSORY CAPACITIES

Under proper conditions of illumination, man can see color, brightness, and form. The range or amplitude over which the eye can function covers more than 8 logarithmic units; i.e., taking the lowest intensity at unity, the highest will have a value of about 100 million. The eye responds to as little as 4 or 5 quanta of energy and under ideal conditions can detect the presence of an object which subtends about a half second of visual angle. This is equivalent to seeing a wire, 1/16 inch in diameter, a half mile away. He can hear, touch, taste, and smell with varying degrees of sensitivity. The energy in 1×10^{-10} erg/sec is enough to cause an auditory response. This is only slightly greater than the energy released by the collision of air molecules in random Brownian movement. The loudest sound he hears, without pain, contains roughly 10 billion times as much energy.

The sensitivity of both the eye and the ear is close to theoretical limits for resolution of a physical system. In fact, there is reason to believe that in some cases of hypersensitivity the person actually hears the sounds produced by the Brownian movement.

PRA, 1960, ref. 3, p. IV - 13.

Sensing

While sensing components of machines have been developed to a high degree of perfection, man can add to systems the cognitive element of perception. Under favorable conditions,

some sensory thresholds of man are exceedingly low. In perceiving patterns of light and sound men can add meaning, e.g., attach values not previously programmed. They are also able to recognize objects and places without a vast amount of preprogramming specifically for the system. An important and unique human sensory ability is the selectivity man uses in his perceptions. Man can be literally bombarded with sensations, but he is able to filter out the irrelevant and concentrate on things of importance to him. While men are subject to illusion, they are relatively invulnerable to such things as electronic jamming. Another capability of man's sensor is his ability to recognize a pattern or receive a message when it is only partially complete. Finally another unique attribute of man is his ability to recognize similar patterns under different conditions. For example, man can recognize a command whether it is written in long hand, typed out, spoken to him verbally, or presented to him on a display.

Grether, 1963, ref. 46, pp. 83-84.

VISUAL CAPABILITIES FOR RECONNAISSANCE:

... Let us examine man's visual capabilities in space, first as they apply to reconnaissance from orbit. Swartz and others (1959) of the Martin Company, working under one of our contracts, have analyzed human visual capabilities for recognition of ground targets from orbit, using both direct vision and magnification by periscope. Recognition, as opposed to simple detection, requires that the target be large enough so that identifying details can be resolved.

It turns out that man has very little capability for visual identification of ground targets from orbit. Even for exceptionally clear atmospheric conditions, the minimum resolvable object length, from a 113-mile orbit, is computed to be 1730 feet for the unaided eye, i.e., no magnification. The only targets the man could recognize are geographical features and very large man-made construction. The situation is improved little, if any, by giving the astronaut magnification, by means of a periscope. As the magnification is increased, so is the rate of image movement. In the restricted field of a periscope, a magnified target moves by so rapidly that the viewer would be unable to evaluate what he sees...

HUMAN CAPABILITIES IN RENDEZVOUS, INSPECTION AND DOCKING:

Human visual capabilities offer much more promise for detecting other objects in orbit, and rendezvousing with

them. This is particularly true for objects in co-planar orbits with slow rates of movement relative to the astronaut's vehicle. A satellite large enough to carry a man, fully illuminated by the sun, and seen against a dark sky background, will be visible at comparatively long ranges (100 miles and more). There are other conditions, however, when the visual sighting range will be quite short. One such condition occurs when the satellite is in the earth's shadow or night-time part of the orbit. Thus, the visual sighting range can vary between wide limits, depending upon the momentary conditions of illumination, background, and other parameters. For cooperative targets the visibility conditions can be greatly improved for the night-time condition by using external lighting beacons.

Even though a target may be well within sighting range, this is no assurance that the astronaut will find it, unless he is given quite exact information, by radar or other means, about the azimuth and elevation of the target relative to his own vehicle. This is necessary to cut down the area he will have to scan by visual search.

After the target has been sighted, the astronaut will need to make various visusal [sic] judgments and decisions if rendezvous, inspection and/or docking operations are to be executed successfully. The visual conditions under which these judgments must be made are quite different from those familiar to people on earth and in aircraft. Baker and Steedman (1961), in our laboratory, have conducted experiments to determine how accurately people can make judgments of motion, size, and distance of targets under darkroom conditions closely resembling the visual conditions in space. ... The observers were required to judge whether the target was moving toward or away from them. These data show that this judgment can be made with 90 percent accuracy when the target has moved relatively short distances. Similar threshold data have been obtained for several other types of visual judgments an astronaut might be expected to make in rendezvous, inspection, and docking operations.

1.2 Interpreting

Statements: —

MAN	MACHINE	
"Able to use perceptual constancies; i.e., the spatial redundancy in the real world to "recognize" objects and places and thereby simplify otherwise very complex situations."	"Zero, or very limited ability to use perceptual constancies."	ref. 111
"Man has high tolerance for ambiguity, uncertainty and vagueness."	"Machines are highly limited by ambiguity and uncertainty in the input."	ref. 79
"Man can interpret an input signal accurately even when subject to distraction, high noise or message gap."	"Machines perform well only in a clean environment."	ref. 79
"Man may introduce errors by identification, redintegration or closure."	"Machines do not utilize these processes."	ref. 79
"Expectation or cognitive set may lead an operator to see what he expects to see."	"Machines do not exercise these processes."	ref. 79

Man excels in locating and recognizing patterns, and making generalizations about them. He can perform many tasks which require use of this ability. ref. 34 ref. 114

Man has the "ability to recognize objects and places despite varying conditions of recognition." ref. 74

Man has the "ability to select own inputs." ref. 74

"Use man for tasks requiring the discrimination of signals in noise." ref. 72

"Use man where the task requires pattern discrimination in a changing field." ref. 72

"Use man where discrimination must be made between multiple inputs." ref. 72

While both man and machine are currently capable of recognizing patterns from prescribed universes, only man can currently discern relational pattern among items from non-prescribed universes. ref. 27

" . . . the human operator has certain tendencies to distort the meaning of stimuli, or to assign a meaning that was not intended." ref. 59

Discussions: —

Swain and Wohl, 1961, ref. 99, p. 24.

Ability to perceive patterns and generalize about them, even though the patterns may change in size or position or may be partly masked by noise. However, this ability (perceptual constancy) as it applies to certain types of activities is often difficult to learn. Interpretation by human operators of patterns of lights sometimes required by certain computer programs may be extremely difficult to learn. Waveform analysis is considered by most maintenance technicians to be the single most difficult perception required in test and checkout, and differences of opinion often exists between technicians in interpreting waveforms. Therefore, it is ordinarly (sic) advisable to search for ways to avoid waveform or light pattern analysis, especially where relatively low-skilled personnel may be employed. However, if data can be encoded and displayed in such a way that the personnel can use their perceptual capability to the maximum (i.e., if adequate "pictorial" or familiar "patterned" displays are used), then they will be very good at sizing up complex situations quickly. This latter ability is especially important in complex fault location problems.

Unpublished paper; Psychological Research Associates:

Function: Pattern Recording and Self Switching

Requirement	Obtaining information frequently requires sorting out many overlapping noise spectrums, selecting one spectrum (pattern) and amplifying (sharpening) while dampening (leveling) other patterns. Many shifts of this kind required, can not be predicted.
Example	Cocktail party, many people talking, much noise, there is useful information, but from shifting sources, parts of room and at varying intensities and tone.

Man	Can detect patterns in mass of inputs, amplify desired inputs and negatively adapt (dampen) to others. Can then easily select another pattern and dampen (amplify) these inputs, dampen remainder and record.
Machine	Unable to instantaneously switch patterns to record through use of selective dampening and amplification. Will either record all inputs at same intensity (i.e., noise) or only one pattern.
System Design Implication	Man excels, usually used. At least one major military data processing system is replacing machine unit for detecting and recording patterns with men.

Edwards, 1962, ref. 26, pp. 94-95.

> Psychologists and computer experts would . . . list pattern recognition, particularly visual pattern recognition, as an important capability in which men far excel computers. A great deal of research on how to make machines recognize patterns is in progress. The fundamental difficulties result from the fact that men recognize patterns in spite of transpositions, rotations, translations, and many other varieties of systematic and random distortion. Machines cannot do nearly so well: it is a great achievement that Selfridge (1955, 1956, 1959) has been able to train machines to recognize Morse code sent by human operators. Note the use of the word "train." The assumption underlying almost all attacks on the pattern recognition problem is that the complex structure of equivalence classes of stimuli necessary for pattern recognition must be learned, rather than built into the machine. There are even some comparatively unsuccessful attempts to train machines by means of reward and punishment, in the absence of any specified structuring of the machine (Friedberg, 1958). At any rate, the problem of pattern recognition is very far indeed from being solved, in spite of the strident newspaper stories concerning various pattern recognition programs which appear from time to time. Until it is solved, computers will be unable to interpret complex visual displays such as aerial photographs, will be unable to recognize spoken words, will have difficulty recognizing longhand, and in general will be markedly inferior to men in a crucially important technological skill. But this deficiency may well not exist 15 years from now, in view of the rapid rate of progress now being made in research on mechanical pattern recognition.

Edwards, 1962, ref. 26, p. 95

> A major virtue of men is that they have a high tolerance for ambiguity, vagueness, and uncertainty. Men are able to detect what other men mean through the smog of what they say, and they customarily do so and behave accordingly. Such tolerance for ambiguity is based on a life-long history of experience with ambiguity and on the ability to argue by analogy from one's own purposes to those of other people. Neither of these characteristics seem likely to be available for computers in any near future. So long as computers cannot tolerate and exploit ambiguity, they cannot be given major executive responsbilities unsupervised; social control is usually based on vague mandates which permit wide but not unlimited latitude in interpretation (for example, platforms of political parties). This means that man-machine systems will necessarily continue to have men with veto power over computer-generated decisions, rather than vice versa.
>
> One reason why men are good at tolerating and exploiting ambiguity is that they can effectively translate uncertainty into probability—another task in which men far excel computers. Consider the statement, "Before you go to bed tonight, you will consume a bottle of beer." Presumably that statement is neither impossible nor certain. A computer could probably go no farther; a man can attach a number to the statement which represents his evaluation of its probability of being correct. Such numbers are, it turns out, excellent guides to action; men can accurately translate uncertainty into probability. Computers, on the other hand, are far superior to men in taking probabilities and payoffs and computing from them the best course of action. These considerations suggest that a military-information processing system which must cope with relatively unreliable data (such as a sonar system) might profitably use human operators as transducers for probabilities. These probabilities could be entered into a computer, which would then compute the optimal course of action in the light of them. No such system now exists, but it seems entirely possible that there might be one ten years from now.

Ellis and Ludwig, 1960, ref. 27, p. 73

> Perceptual Ability. "Man excels at comprehending complex data presented pictorially or symbolically." This statement is progressively weakened by almost daily reports in the technical journals concerning new achievements in electromechanical pattern recognition. In the mechanization of these processes, ordering schemes are brought to bear in the form of rapid discriminative subroutines. Given an

experimental library (mechanical memory) of vast dimensions such as that envisioned by present computer technology, and access speeds such as those within our grasp and presently employed, we are quite able to match or exceed human competence in these matters. Mechanized sensing and information transmission now depend upon the presence or absence of atomisitic (sic) elements in the stimulating source.

However, it should be noted that while both man and machine are currently capable of recognizing patterns from prescribed universes, machines (unlike man) can not yet discern relational patterns among items from non-prescribed universes.

Wayman and Jones, 1964, ref. 106, pp. 153-154

Interpretation

Interpretation of complex physical energy inputs should be performed by personnel.

a. Interpretation, as used herein, refers to the capacity to recognize or ascribe meaning, contextual relations, or organization to sensed energy. As such, it represents a first level of processing. Of course, any equipment transformation involving transducing, filtering, or amplification functions can be thought of as interpretation in the sense of simple processing of signals. However, the concern here is with situations which involve more complex signal transformation and organization.

b. Because of his capabilities for attending to selected portions of his environment, detecting many forms of physical energy, ascribing meaning to them based on past experience, and responding with appropriate actions, man is more effective than equipment in many situations where transformation of inputs is required. This is most evident in the perception of patterns and recognition of these patterns in new or unusual stimulus situations. For example, this includes the capabilities of man to interpret wave forms on cathode ray tube displays, interpret radar and sonar display, etc. Examples of how this perception of patterns or relationships can be transferred from one situation to another are evidenced in man's ability to steer vehicles under varying environmental conditions.

c. Some limitations of human interpretive abilities should be noted:

(1) Past perceptual experiences influence present interpretation and, conversely, current interpretive activities influence stored events and change them both qualitatively and quantitatively.

(2) The reliability and content of signal interpretation is particularly susceptible to emotional and intellectual errors (both constant and sporadic), as well as physical degradation (decreased sensitivity because of sensory fatigue, etc.). This problem of attaining and maintaining reliable and valid human interpretation of physical energy can be mitigated by adequate design engineering (e.g., information displays), personnel training (including practice and training support documents and materials), and on-the-job proficiency reinforcements, training and proficiency exercises, etc.)

Firstman and Jordan, 1962, ref. 31, p. 12.

In perception the human has distinct advantages over machines:

Humans perceive patterns, not isolated bits. These patterns are not restricted to one sensory modality, but may include some or all of them. The operator hears a strange sound and detects an unusual odor in conjunction with a change in rate or degree of vibration in a machine. He senses from this pattern that something is wrong and he will stop the machine before it destroys itself. The human can perceive the pattern of an airplane blip through noise far more effectively than can the tracking program of the SAGE computer. Similarly he is able to see patterns on oscilloscopes. Man can also perceive patterns of events occurring over time and thereby anticipate events; this is behind much of his ability to learn.

Fitts, 1962, ref. 33.

Perceptual Capacities

Human preception (sic) is based on unique organizing and selecting processes. Man organizes his visual world, for example, into objects, into figure and background, into meaningful shapes and contours. He recognizes the faces of his friends, interprets printed and handwritten symbols, and performs a myriad of other similar classification functions. His ability to use language is certainly one of his most remarkable abilities. Many of man's unique perceptual abilities have been used routinely by system designers, and occassionally some unique human perceptual ability finds a new system use. As an illustration, it has recently been found that a man can listen to the video signal from a radar antenna and identify many of the characteristics of the target source. It has also been discovered that he can look at two photographs in a "blink comparator" and almost immediately pick out the

one target in a large area which is new or which has changed position.

Gagne, 1962, ref. 41, pp. 46-49, 55.

Identifying

A much more important and widely used function than sensing is the function of identifying. [An example of an identifying function is one in which]...the human operator is asked to "report," by pressing one of five buttons, which of five wave-form patterns is being displayed. This kind of function is perhaps the most ubiquitous in which human beings engage, whether in their daily lives or in the context of systems operation. A stock clerk identifies merchandise; a pilot identifies panel instruments; an office manager identifies his staff; an equipment repairman identifies the parts of equipment with which he deals; a file clerk identifies file cards. Learning the names for and locations of the various controls of a machine, or the words to be used in verbal communication within a system, are examples of this function. In identifying, the human operator makes a number of different responses to a number of different classes of stimulation. The transformation which takes place from input to output performs the specific function of identifying (distinguishing among) different input qualities. In more traditional psychological language, this is the function of perception.

A particular case of the identifying function must be recognized, in the situation which requires the identification of only two input classes, as opposed to three or more. For example, we may want to require an operator to report the presence of a "blip" on the oscilloscope face. But this means that we expect him to distinguish a blip (a small bright patch having certain size limits) from that large class of other small bright patches, the "noise" in the machine. In such a form, this function is often called detection. Although it may be said to have a certain simplicity in this form, since the inputs to be distinguished are only two, the function is still basically one of identifying, that is to say, of making different responses to different classes of input. In all probability, the conditions for generation of this function are basically the same, whether we are dealing with twenty input classes or only two.

Filtering Conditions. In getting the operator to report certain classes of input qualities, one must utilize a set of instructions which prevent the reporting of other input qualities (since such reporting would contribute "noise" to the

next input). If we require the identifying of changes in wave amplitude and frequency, for example, this may mean that we do not want the reporting of changes in wave brightness, or its position on the scope face, or its "thickness" as a line, or any of a number of other qualities it may possess. If the input is Morse code, we want the human operator to identify the particular combinations of sound that are used to make letters and words, but not such other stimulus qualities as signal speed or loudness. Instructions, as well as memorial inputs from previous instructions, define the identifications required.

Shunting Conditions. Another purpose of instruction is, of course, to shunt out the employment of higher-level functions on the part of the human operator. The task may be one which requires him to perceive but not to interpret. For example, if he is asked to identify five different wave forms, this may imply that he is asked not to report any of several meanings of these wave forms, such as their possible means of generation or their implications as inputs for the next stage of the system. Reporting such meanings may be easy or hard for the individual. But if the designed task calls for identification only, then the shunting conditions must also be designed to keep the individual functioning at this level, or else his output will be likely to contain errors as well as noise.

Memorial Inputs. Obviously the filtering and shunting conditions of such a task are carried as programs (or sets) in the short-term memory, after having been established by instructions. The long-term memory, on the other hand, provides the "models" of wave forms with which the external inputs are compared and which thus make possible the differentiation of output that is required in five different responses (for example, pushing five different buttons).

The nature of these stored models is an interesting and remarkable matter. As is well known, the physical nature of the input may vary over a relatively wide range without disturbing the identifications which are made. This is what is meant, in its broadest sense, by perceptual constancy, and it is a property which has not yet been built into a machine, except in the most limited sense. As a simple example, it is evident that a human being can readily identify the digits 0 1 2 3 4 5 6 7 8 9, whether they are printed, stamped or written, and even when they are subject to wide variations in size, stroke width, or other changes in form. Up to the present, at least, there must be a close physical resemblance between two digits for a machine to be able to "recognize" them as the same; for a man, the physical resemblance required varies over a wide range. Because of such models in long-term memory, a photograph of an object is

an input equivalent to the direct sight of the object itself; a chord in the key of F is equivalent to the same chord in the key of G; a round knob among a group of square knobs is identified regardless of changes in its size. In a more complex setting, a ground radar return may make possible the identification of objects such as railroads, bridges, and bodies of water as equivalent to those depicted on a printed map.

Identification routines, or models, are chiefly acquired by a process of learning . . .

Identifications are sometimes put together to form sequences of action, rather than being acquired one at a time in any order. Such sequences are usually referred to as motor skills, or perceptual-motor skills. In a common example, reading out loud from a printed page, the individual must identify each word in the sequence by making a response appropriate to it (that is, by pronouncing the word) and then going on to the next. Of course, an entire sequence of this sort may also be committed to memory, in which case the input for each identification becomes, not the printed word itself, but the sound of the previous word uttered by the speaker. Similarly, in a skill such as bicycle riding the input for each successive identification (such as pushing downward on the left pedal) is a complex which includes both the currently present external stimulus situation and the proprioceptive feedback from the movement just previously made (extending the right leg). When the human individual is required in a systems context to track a continuously moving display element, such as a spot on an oscilloscope, he is similarly required to use the identifying function in response to an input that includes both the current position of the spot and the feedback from his previous movement, in a continuous action sequence.

Identifying is a function at which man currently excels the machine. Primarily, this is because the stimuli to be identified can vary over a wide range in their physical dimensions, as well as in the context in which they are imbedded, without producing errors in identification. In other words, the models man can learn and store are extremely "flexible." Machines have not yet been designed which can perceive inputs of such variability in a reliable fashion. Instead, the routines that function as models for the machine must have relatively fixed patterns. When these routines can be unvarying, but are composed of long sequences (as, for example, in certain types of tracking), a machine can readily outperform a man. Long sequential routines require fairly lengthy periods of practice on the part of a human being.

Interpreting

In many system instances, the most important function performed by the human being is interpreting. Here the individual makes outputs which, in effect, place inputs into categories whose basis is their effects rather than their appearances. In other words, interpreting is a matter of identifying the meaning of inputs. Suppose that our human operator, seated at his console containing oscilloscope and response buttons, is given the task of reporting whether a blip on his scope represents a friendly or a hostile aircraft. He cannot, of course, decide on the basis of its appearance, since this is not distinguishable from that of other blips. Instead, he may have to decide primarily on the basis of certain rules which form a part of the memorial input in this case — the blip is approaching from the northeast, flying at a certain altitude and with a certain speed, following no previously reported "track," and so on.

The contrast between identifying and interpreting is well exemplified in the task of aerial photo-interpretation. The initial part of this task is one in which the human being identifies objects such as piles, bridges, buildings, or lakes. But in interpreting the photograph, he takes another step as well. He interprets an airplane as a "combat aircraft," or a building as a "power plant," or a tank as a "water tank." It should be noted that he is not able to do this on the basis of the appearance of these objects (a water tank may be indistinguishable in appearance from a fuel tank) but only by making inferences about the expected effects of the actions they lead him (or others) to take. In other words, he begins to work with "if-then" relationships, which can be approximately illustrated by the statement "If it is a power plant, then I should see transmission lines." Psychologists have given this kind of behavior many names, including "expectancy," "hypothesis-using," and "thinking." In interpreting, the human being identifies inputs in terms of their expected effects. Interpreting thus involves a choice among "courses of action" available through memorial inputs.

The minimal display conditions required for interpreting are determined by the fact that the function of identifying must precede the interpretation itself. In the case of the task of interpreting a blip on an oscilloscope, for example, the human operator must have been able to identify the northeast approach, the altitude, the speed, and the type of track followed in order to be able to make the interpretation required. In the photo-interpretation task, he must be able to identify transmission lines, transformers, and a number of other objects to perform the interpreting adequately. Unless the required objects are displayed, and unless they can be identified by the human observer, correct interpreting cannot be accomplished.

Shunting and Filtering Conditions. At this level of human functioning, shunting conditions are not required. The channels are open, and the human operator is being asked to function in a manner which he seems to prefer and at which he often excels.

Filtering conditions, however, are quite as essential with this mode of functioning as with others. Instructions are used to "set the problem," or, in other words, to tell the human operator what to look for. If he has the task of reporting enemy aircraft, he must be instructed, in effect, not to report such things as the volume of traffic on local airways, or the fact that a scheduled commercial airliner is ten minutes late, or a whole host of other interpretations which he is perfectly capable of making. Sometimes he may have time to make such interpretations, to attend to such inputs; but on those crucial occasions when the load is heavy, filtering will be essential to the prevention of errors.

Ordinarily, as we have said, filtering conditions are established by means of instructions which activate sets carried in short-term memory. There are occasions, however, on which system functioning may depend upon the discovery of suitable filtering conditions by the human operator himself. For example, suppose the task to be performed were that of interpreting an aerial photograph of enemy territory for "military significance." In such a case, it is perhaps not possible, or at least not desirable, to specify by instructions "what to look for." The individual will likely proceed by developing a number of filtering conditions of his own — he will adopt his own sets by giving himself instructions. He may try several of these self-instructions in a row before finding some which make it possible for him to perform the task successfully to his satisfaction. Such self-instructions appear to be equivalent to what a number of psychological investigators call "strategies" (see for example Bruner, Goodnow, and Austin, 1956). System development procedures are sometimes designed to take advantage of the highly adaptive characteristics of human beings in discovering their own best filtering conditions. We shall have occasion to return to this point in a later discussion of "system learning."

Memorial Inputs. Short-term memory provides, as we have said, the sets which determine filtering. There may also be brief sequential routines, actually a part of the filtering mechanism, which determine certain sequences of behavior. For example, such a routine might read: "First, check the altitude, next the range, and finally the speed." Such routines must of course contain a limited

number of steps if they are to remain within the limitations of the short-term memory. In any case, it can be seen that their function is to provide for the filtering of inputs in a certain order.

One kind of input from long-term memory is a familiar one: the models which make identification possible. The individual, it is often said, must perceive the situation before he can interpret it. We have already emphasized this point. If the human operator is being asked to report "enemy attack," he must be able to identify such things as altitude, range, speed, and nature of track. This means he must possess a mechanism which compares the actual inputs with models available in his long-term memory. Similarly, the photo-interpreter must be able to identify, on the basis of stored models, power transmission lines, transformers, and many other objects, in order to make the interpretation, "power plant."

The second type of stored input is new. It consists of the rules by means of which objects, regardless of appearance, are classified into categories of "expected effects." They are the action categories which are so essential to interpreting. In landing a large aircraft, the pilot perceives instrument indications of a number of aspects of the plane's performance, or even more immediately, in terms of the courses of action available to the pilot himself. Thus an overly high altitude may "mean" the alternative courses of action of nosing down or making another landing approach. The rules that define these courses of action are available to the trained pilot from his long-term memory. These rules can be expressed as verbal statements; whether they are stored in this form or some other is a matter psychologists argue about, but which need not concern us here. Similarly, the photo-interpreter who has identified a "pile" has in his memory a whole set of rules which determine a number of courses of action, such as "Look for vehicle tracks" or "Look for nearby chimneys," which enter into the process by means of which he arrives at the interpretation "coal pile" that is the output response. It may be noted, too, that these stored rules are not necessarily of an all-or-none sort; rather, they frequently represent probabilities and have been studied as such by a number of investigators (see Gagne, 1959).

Interpreting in Sequence: Dynamic Decision Making. It is not at all uncommon for interpreting tasks to occur in sequential form. The step-by-step nature of problem

solving has frequently been emphasized (see for example Johnson, 1955), as well as the fact that the information available for each later step is likely to be contingent on the consequences of earlier ones. In a task of equipment troubleshooting, for example, the initial interpretation may lead the individual to check an input voltage; his next step is an interpretation of symptoms which include the initial information plus this voltage reading. At each step of the way, the input to the human problem solver is changing, because of his own actions, and continues to do so until he is able to make the final interpretation that locates the malfunctioning part. Aerial photo-interpretation also frequently proceeds in this sequential fashion (Gagne, 1954).

Obviously, this kind of dynamic decision making requires successive reprogramming, at each step of the way, of the filtering conditions in short-term memory. Thus at each new stage the individual must provide his own instructions to establish the filtering set which tells him "what to look for." This kind of flexible reprogramming constitutes one of the most striking characteristics of human functioning, and one which distinguishes it markedly from that of most machines. In performing in this manner, the individual must have available in his long-term memory the variety of "filtering rules" necessary and relevant to the problem to be solved. Choosing among them is the major task accomplished by interpretation. The rules themselves then come into play in determining the particular filtering set employed in the next stage of the problem; they are self-instructions, or programs.

A more complex form of dynamic decision making occurs when the feedback loop from the preceding action step involves interacting with another person. In such circumstances the input situation for each step in the sequence becomes highly variable and unpredictable, since it depends not solely on the effects of the individual's own output, but also on that of the second individual. Suppose that two air-traffic controllers must share the task of guiding traffic into an airfield, having as a primary display two PPI (Plan Position Indicator) radarscopes displaying the same information. This is a "load-sharing" task, and it is obvious that each decision made by individual A will result in an action that changes the input for individual B. In periods of heavy traffic, such a system could presumably not be operated without some externally imposed filtering instructions concerning the sector, range circle, or destination to be covered by each controller (Kidd and Hooper, 1959). However,

even when this has been done, the task is one in which frequent interaction is required between the individuals, in the sense that each new situation for decision making is determined in part by the preceding action of the other person. The possibility of flexible programming is obviously a necessary condition for successful operation of this type of system.

Inventing. We have seen that the high adaptability of human beings is exhibited in their capability for frequent reprogramming of the filtering (as well as shunting) conditions applicable to the transformation of inputs into outputs. There is also another, and even more striking, way in which the flexibility of human behavior is demonstrated. This is in the invention of new rules. It is reasonable to suppose that "having a new idea" is fundamentally a matter of using old rules (ideas) in utterly new situations. The history of science contains many examples in which a principle from one sphere of knowledge is transferred by analogy to another sphere, with the result that the entire outlook on the second problem is changed, the problem is "redefined," and a great upsurge of novel theory results. Invention also occurs with some frequency in other areas of human activity as well, and its occurrence as a requirement in certain systems cannot be overlooked. A successful leader is often an inventive leader, in the sense that he achieves new solutions to problems of social interaction and group productiveness. Military tactics and strategy also require new solutions for new situations if they are to remain successful.

Inventing occurs when the individual makes an interpretation of inputs in accordance with a set of rules which he has not previously applied to the situation or to similar situations. Thus, for the individual, every "original" solution of a problem is, in a sense, an invention. Whether or not it is an invention in a broader social sense of course depends upon whether other people have previously made the same interpretation. Much of the evidence about inventing is anecdotal (see for example Platt and Baker, 1931). It is interesting and suggestive, but of limited scientific usefulness. "Brainstorming" (Taylor, Berry, and Block, 1958) is a technique which was designed to stimulate invention in group situations, and its encouragement of "wild ideas" is a feature which suggests a possibly new experimental approach to the topic.

A number of varieties of interpreting can be performed better by machines than by human beings.

Complex and lengthy sequences of rules can readily be designed into a machine, and tasks such as computing can be performed in a fraction of the time required by a man. Computers can be designed also to include probabilistic rules, and such interpretation can often better be done by a machine than by human beings. The filtering of inputs, however, can be easily reprogrammed in man, whereas this is difficult in a machine. In addition, it has been found desirable in a number of instances to permit human beings to develop their own filtering rules, and this sort of "adaptation" may be shown to improve man's performance. Can machines invent new ways of using rules? Perhaps they will be able to someday, although as yet their performance in this function is distinctly limited. The kind of task at which man clearly excels, compared with present-day machines, is one which requires interpreting of inputs which require complex identifications in the first place. Aerial photo-interpretation, for example, is such a task. Perhaps a machine could be designed to follow the rules required in deciding that a picture contains an "aluminum plant"; but a human being would first have to identify the objects in the photograph which enter into these rules. When these functions are used together in a man, we have a task which appears to be peculiarly a human one, and which can on occasion use man's capabilities to the limit. Another kind of human function which reveals man's remarkable capabilities is that of dynamic decision making, in which input changes at each step of an interpretation sequence produce reprogramming of the individual's filtering sets. The facility and rapidity with which such changes can be brought about stand in marked contrast to the capacities of a machine.

Gagne, 1962, ref. 41, pp. 62-63.

Coding

There are many varieties of coding tasks in systems. Characteristically, the input comprises stimulus patterns which must be identified in terms of outputs designed to be employed as inputs to the next link in the system. Suppose, for example, that the operator must receive messages through headphones in Morse code and transform these messages into typed English sentences for transmittal to the next system component (which in this case is another human being). Clearly these activities utilize the function of identification. Filtering sets must be established by instructions which insure that the individual will attend only to certain kinds of auditory sounds received through the headphones and ignore the noise. The individual must utilize some stored models which represent the pattern of dots and dashes he hears in order to identify them as letters and words. There is also a second stage to this task, which also has the characteristics of identifying: the words must be transformed into an output which involves the use of a typewriter. There is thus a motor skill required, and the sequential routines involved in typing must also be available to the individual through his long-term memory.

If we look a little more closely at this total task, we can see that the first stage of identifying (transforming Morse code into English prose) can be more efficiently accomplished by interpreting. In fact, this is what usually happens if we give an individual enough practice at receiving code (as Bryan and Harter (1899) suggested many years ago). As practice continues, the experienced code receiver begins to be able to anticipate whole sequences of dots and dashes, because he is interpreting the message in accordance with well-practiced "rules" of English prose. This methods turns out to be more efficient for several reasons. The human message receiver can perform accurately even when subjected to rather extreme distractions; he can receive even when the noise level is very high; and he can receive when there are gaps in the message. These facts have some particular significance for the system design decision as to how the human operator can best be employed in this coding task. If the Morse code can be depended upon to provide a relatively constant physical input, a machine can readily be used to translate these fixed patterns into English letters and words. However, if reception is going to be characterized by frequent noise and lapses, a human being may be needed to

perform both the identifying and the interpreting required for producing reliable (and meaningful) English prose.

The second stage of this task, the typing, presents a somewhat different picture. The input in this case will be meaningful English sentences supplied by the individual to himself. He must now identify the letters and spaces which make up these sentences in terms of responses made to the keyboard of the typewriter. In order to do this, he must have acquired the sequential routines that constitute the basis for this motor skill. This, of course, is well within his capabilities; after sufficient practice a high degree of typing proficiency can be attained. Thus, if a human individual has been chosen to do the interpreting task of the first stage, he can readily be used to perform the identifying (motor skill) function required at the second stage. The crucial decision has therefore already been made, and can be seen to characterize a wide variety of coding tasks. When inputs can have a fixed relationship to outputs, a machine can perform the entire coding operation very well indeed. In contrast, when inputs must be identified which are variable in their physical dimensions; or when they must be interpreted, because inferences about meaning have to be made to fill gaps; then the task is one at which a human being excels.

Another Example of Coding. Let us change the situation a little, so that we can look at another coding task. Suppose we set our operator-console subsystem the task of reporting "deviant courses" of aircraft which are being tracked by radar and displayed as a track of points on a scope face. What we want the subsystem to do is to identify as "deviating" or "nondeviating" from preplanned courses the tracks of a number of aircraft shown on the scope. Obviously there are several ways of going about this. One may think of doing it, for example, by requiring the human being to report the specific variables of speed, heading, and altitude to a computer, by punching them in a set of buttons. The computer then compares these variables with a set representing the preplanned course stored in its memory. When the task is designed in this manner, we are requiring the use of the identifying function of the human being, in a relatively simple and straightforward way. He identifies the speed of a given track, making his output by punching buttons. Similarly, he identifies heading and altitude, by comparisons of the display dimensions in each case with models stored in his long-term memory. But depending on the situation, the computer may have been given a difficult, or even impossible, task. What ranges of variation in speed, heading, and altitude is it going to report as "deviating"?

What combinations of these variables is it going to choose to distinguish "deviating" from "nondeviating"? Can it take account of, and ignore, certain gaps in the information it receives, certain errors made by the human operator, or the presence of occasional "noise"? Of course, this depends on the nature of the operating situation, as we have said.

Suppose the task were performed by a man-machine display combination in a different way. This time the machine will take note of and measure the speed, heading, and altitude of the tracked aircraft. This it can do quite well because these variables are relatively "fixed" in character; they are definite physical variables which can be fed to the machine as inputs that do not change significantly in their other dimensions. The machine will then display a track for the aircraft in question, plotted out on a visible screen. At the same time, it will also display the preplanned track of the aircraft, taken from its memory. The display as a whole, then, will be one which shows the human operator the two tracks simultaneously, each in its dimensions of speed, altitude, and heading. Now the human being is confronted with the necessity of using his identifying function in a way that will exploit it effectively. He can ignore small changes, gaps, noise, and other variations in input in perceiving the patterns which he reports as "deviating" or "nondeviating." Once he has acquired the proper models, he will be able to perform such a task with a high degree of efficiency. Furthermore, his performance can be easily reprogrammed: if the task demands that he ignore speed on a particular occasion or for a particular aircraft, a filtering set established by instruction enables him to do this easily without loss of effectiveness. On the whole, then, this can be seen to be a much more efficient arrangement than that previously described. The machine is being asked to do what it can do best: sensing, measuring, and perhaps computing, such things as speed, altitude, and direction. And the human being is being required to perform the kind of function at which he excels: identifying patterns of stimulation that are subject to variation in a number of dimensions, but which must be reported as equivalent despite these variations.

Gagne, 1962, ref. 41, pp. 65-66.

Scanning and Detection

Scanning and detection together provide... [an] example of a subsystem task in which the human observer plays a prominent part. Suppose we ask our observer to report the presence of buildings in a relatively unpopulated area

which is being scanned by radar mounted in an aircraft and displayed on a scope. The aircraft approaches the area and flies over it at a height of 30,000 feet, and the human observer is required to report as soon as possible the position of each building he can identify. The radar picture on the scope changes with each sweep, so that the terrain features become increasingly clear as the aircraft gets closer to the area. The scanning and detection task begins at a distance of 20 miles.

Anyone who has observed a terrain picture on a radar scope will realize at once that the basic identification function being utilized in this task is one which requires a model by means of which "buildings" and "things that are not buildings" can be distinguished. It is the kind of model which bears little resemblance to that used in viewing an aerial photograph, for example. Buildings are distinguished in radar returns on the basis of brightness and shape differences, but they are recognized as buildings only after the human observer has had considerable experience in viewing such returns. Furthermore, the variations in these dimensions as well as in the background against which they occur are quite extensive, particularly since each successive antenna sweep brings an altered picture. Fundamentally, then, this task uses the identification function, requiring output responses which indicate the presence or absence of buildings. (As we previously pointed out, the identification of a single category of input from all others is usually called detection.)

But obviously something else has been added to this task which makes it different from simply "looking at a radar picture." It is performed under pressure of time. And in order that it be performed efficiently under these conditions, a sequential routine called "scanning and search" has been added. This routine is an essential part of the filtering conditions—by means of it, the individual continues to "tell himself" where to look and what to look for throughout the whole operation. Scanning and search routines may be carried in short-term memory, as is usual unless they are extraordinarily lengthy. They may be reprogrammed; for example, one might need to give the instruction, "Look in the northwest quadrant." If there is a requirement that filtering routines be particularly systematic (as is true, for example, in airplane "spotting"), they may be practiced and stored in long-term memory. In any case, scanning and search frequently are preliminary to, and coupled with, detection.

Scanning and search routines as a prelude to detection have often been taught successfully to military personnel who must carry out missions in the dark (compare Sharp, Gordon, and Reuder, 1952). In this case an initial act of sensing some change in visual stimulation (a movement in the dark) puts into operation a systematic routine of observing "out of the corner of the eye" in order to bring to bear on the situation the more sensitive extrafoveal receptors. Such routines must be deliberately trained, because they are directly opposite to those used in daytime vision, when the "natural" thing to do is to look at the object foveally. The function ultimately employed is again one of detection, in which the individual attempts to identify "a moving thing" or perhaps "a moving enemy soldier" against a background of nonmoving shapes.

Gagne, 1962, ref. 41, p. 69.

Troubleshooting—

[One example of an "intellectual" task which utilizes the function of interpreting]...is troubleshooting, or the diagnosing of malfunctions. While this kind of task occurs most frequently as a part of system maintenance, as opposed to system operations, it is important to recognize that troubleshooting in a more general sense is not confined to maintenance. In many instances, the operation of modern systems requires this kind of task as an integral part of "running" the system, or of "putting it into operation." Strategic missile systems provide an example. While the popular image of the "operation" of such a system may conceive of this as beginning at the time the missile leaves the launching pad, military users of such missiles are well aware that the major portion of system operations takes place on the ground minutes, hours, and even weeks before the time of launching. The missile and its components are "checked out" in many different ways during these periods of time, and even the final countdown before launching may be considered to be a standardized checkout procedure. Checking out equipment is a task of troubleshooting.

Pickrel, 1962, ref. 77, pp. 142-143.

Man as an Observer and Interpreter

Earlier justifications for space flight generally implied observation, for economic purposes in determining the presence of materials, for scientific purposes in noting that a nearby planetoid would make an excellent manned space station, for military purposes

in studying an agressor's territory below. Preprogrammed cameras are excellent observers but they are not as good as man, just as manned aircraft can perform with greater precision than pretargeted missiles. Man uses his memory to store information about target characteristics. He observes the terrain for underlying patterns that indicate these characteristics. He defers decision-making until more relevant information is obtained and improves his decisions then accordingly. The ability to screen and categorize information, and test the compatibility of different solutions to known realities is one way of describing man's exploratory processes. Man's senses can be extended by hardware, but the hardware is not a substitute. This is not an argument that man should always be present.

Kidd, 1962, ref. 59, pp. 163-164.

Interpreting

Given the fact that signals are available to the operator through his sensory channels, what do we know with respect to their meaning to him? Most of the signals in man-machine system operation are symbolic; that is, they have assigned rather than intrinsic meaning. The problem is whether the intended meaning and the understood meaning are the same. A discussion of this question by Campbell (1958) emphasizes the point that the human operator has certain tendencies to distort the meaning of stimuli, or to assign meaning that was not intended. A part of this distortion originates in the process of identification; that is, the tendencies for redintegration, closure, and the like in response to fragmentary or noisy inputs constitute sources of perceptual errors, as suggested by the Gestalt psychologists.

Closely related, yet generally conceived as a cognitive process, is the mechanism of expectation or cognitive set. People recognize what they expect to recognize. Such expectations can be very general and sustained; they can be established over brief experimental exposure (for example, the Einstellung effect, Luchins, 1942); or they can be imparted symbolically by instructions. Despite man's remarkable capabilities for adaptation or adjustment, there are contrary mechanisms which give both the advantages of continuity and automaticity to certain complex responses (Bahrick and Shelly, 1958) and the disadvantages of rigidity.

There are emotional components involved in the interpretation process also. While "perceptual defense" may be a slightly disreputable concept nowadays (Freeman, 1955), it still appears that our cognitive experiences are influenced by our motives to some extent (Eriksen and Brown, 1956). Thus the individual recognizes, in a meaningful sense, not

only what he expects to recognize, but also what he wants or needs to recognize.

Grether, 1963, ref. 46, pp. 83-84.

VISUAL CAPABILITIES FOR RECONNAISSANCE:

...Let us examine man's visual capabilities in space, first as they apply to reconnaissance from orbit. Swartz and others (1959) of the Martin Company, working under one of our contracts, have analyzed human visual capabilities for recognition of ground targets from orbit, using both direct vision and magnification by periscope. Recognition as opposed to simple detection, requires that the target be large enough so that identifying details can be resolved.

It turns out that man has very little capability for visual identification of ground targets from orbit. Even for exceptionally clear atmospheric conditions, the minimum resolvable object length, from a 113-mile orbit, is computed to be 1730 feet for the unaided eye, i.e., no magnification. The only targets the man could recognize are geographical features and very large man-made construction. The situation is improved little, if any, by giving the astronaut magnification, by means of a periscope. As the magnification is increased, so is the rate of image movement. In the restricted field of a periscope, a magnified target moves by so rapidly that the viewer would be unable to evaluate what he sees.

1.3 Information Processing

Statements:—

MAN	MACHINE	
"Speed of reinstatement of rule sequences relatively low (as in computing)"	"Speed of using rule sequences high (e.g., computing)."	ref. 41
"Limits to length of sequential routines fairly high, but time-consuming to train."	"Potential limits of length of routines very high."	ref. 41
Easy to reprogram, does not require extensive or precise preprogramming.	Difficult to reprogram.	ref. 41 & 91
"Computation is weak and relatively inaccurate; optimal theory of games strategy cannot be routinely expected."	"Can be programmed to use optimum strategy for high-probability situations."	ref. 36

Man is able to handle a great variety of different information processing tasks.	ref. 33
Man can use raw information immediately without coding, punching or similar operations.	ref. 91
Man is a relatively poor numerical computer under stress but is unmatched for the more qualitative nonnumerical computations.	ref. 114
"Man has great versatility in handling many different input and output codes; however he is a relatively slow information processor and is being replaced by machines in many clerical tasks."	ref. 34
"Design the man-machine system so that the bandpass required of the man never exceeds three radians per second."	ref. 12
"Design the man-machine system so that the transfer function required of the man is, mathematically, always as simple as possible, and, wherever practicable, no more complex than that of a simple amplifier."	ref. 12

Humans are relatively poor, with respect to machines for performing routine, repetitive tasks. ref. 105

Humans are relatively poor, with respect to machines for computing and handling large amounts of stored information. ref. 105

Humans are relatively poor, with respect to machines for ability to reason deductively (i.e., to use rules for processing information). ref. 105

"Computations. Machines designed to perform specific computing operations are more efficient than man." ref. 27

"Machines generally are better in their ability to count or measure physical quantities." ref. 67

"Machines generally are better in their ability to process quantitative information following specific programs." ref. 67

"...any high-volume information-processing task in which the rules for processing are simple and easy is just right for machine performance. And tasks which are not of this nature can often be made so by appropriate redefinition." ref. 26

Machines are capable of handling highly complex operations (i.e., doing many different things at once). ref. 99

"Machines excel in ability to repeat operations very rapidly, continuously, and precisely the same way over a long period." ref. 114

Machines are better able to apply deductive reasoning, such as recognizing stimuli as belonging to a general class (with specified characteristics). ref. 67

"Machines excel in performing complex and rapid computation with high accuracy." ref. 114

Discussions:—

Morgan, et al., 1963, ref. 72, pp. 35-36.

Man vs. Machine as Data Processors:—

Man has certain advantages and disadvantages as compared with computers. His access time (speed of recall) is slow compared to that of a computer, but he is able to recall generalized patterns of previous experience to solve immediate problems. As yet, no computer can do this. Man learns to do numerical computations, but in the main his time constants are such that he is a relatively poor numerical computer—especially under stress. He is, however, the only available computer that can solve problems by logical induction.

In general, man is superior to data-processing devices in the following respects:

a. For most tasks, he does not need extensive preprograming. Through further learning, he constantly develops and modifies his own programs. His previous education has already "programed" him.

b. He is more flexible; he can deal with unforeseen situations.

c. He can exercise judgment because he can selectively recall relevant facts and methods of solving problems.

d. He does not require special coding of messages; the information does not have to be transformed into digital form. He does, however, perform better when information is presented in certain forms than when it is presented in others.

On the other hand, data-processing devices are superior, in general, to human beings in the following respects:

a. They can store much more data accurately. A computer can store thousands of items of information that no human being could possibly remember.

b. They can compute answers with much greater speed and accuracy. A computer can do accurately, in a few seconds, computations that would otherwise require many man-months.

c. They can sort and screen data faster, rejecting all data that are not in a desired class and leaving the final judgment among the remaining alternatives to a human operator.

d. They are usually more reliable for routine decisions—decisions that are always made in the same way according to some rule.

e. They are less subject to fatigue, prejudice, and other transitory factors that distort man's judgments and decisions.

PRA, 1960, ref. 3, p. IV-13.

Data Processing and Selection:—

Man cannot be expected to follow optimum strategy (as in a theory of games) but through the exercise of critical discrimination, particularly in situations where alternatives cannot be specified in advance, they more than make up for the machine's superior ability to select efficiently from preprogrammed material. Perhaps man's most valuable asset as a system component is his ability to think. Among the types of thinking operations people perform are calculation, quantitative and qualitative estimations, comparative judgement, translation, coding, inductive and deductive reasoning, abstraction and conceptualization, memorization and recall, prediction, and decision making. The exercise of man's thinking ability allows him to use the most appropriate course of action in ambiguous situations. It is important to remember that extensive preprogramming of man is not required for him to perform in many ways. For example, if a task requires integration, man soon starts acting as an integrator, if differentiation is called for that also can be supplied. In addition, men can be expected to select and report incidental information which is related to system effectiveness.

McCormick, 1964, ref. 67, pp. 8-9.

Information processing and decision. Information processing embraces various types of operations performed with information that is received (sensed) and information that is stored. The identity and nature of such operations as far as human mental processes are concerned are not yet well understood; in many respects the human mind must still be considered as a "black box." The information processing by machine components must presently be programmed in some way—by either simple or complex methods, including computers; computers are being developed, however, that can be thought of as "learning" from their own "experience" and thus generating artificial intelligence.

Although it is not feasible to categorize all types of information-processing operations, a few might be mentioned, especially those which are fairly clearly identifiable. There is, for example, an operation of information retrieval. For people, this is the process of recalling to mind, when appropriate, the stored (learned) information.

In a machine component, it would consist of the selective retrieval of information, when needed, such as the sorting of punched cards on a particular item of information, the following of a specified program by a computer (which would retrieve the specified information as necessary from, say, tapes or cards), or the following by an automatic machine tool of the "model" in reproducing standard parts. Recognition is the function of identifying, or recognizing, some object or other stimulus as being the same as some previously experienced object or stimulus. This is related to the information-retrieval function, since retrieval would occur when there is recognition of the object or other stimulus. There are also various kinds of arithmetic and mathematical operations, including addition, subtraction, multiplication, integration, and differentiation, as well as others; for machine components most information operations would be arithmetic and mathematical. The process of reasoning is of course a very dominant ability of human beings, although (as indicated above) computers are being developed to perform some learning and reasoning functions. Evaluation is essentially a judgmental function, usually involving an appraisal of various considerations in the light of certain specified or nonspecified standards or criteria.

The result of a series of information-processing functions is the making of a decision which serves as the basis for subsequent action. A decision (in the context of a man-machine system) is a determination with respect to a succeeding act or series of actions or, in some cases, the absence of an act. Decisions can range in their complexity from those that are virtually automatic or predetermined by the situation to those that are based on a variety of considerations and involve the estimation of risks and the weighing of different values in arriving at a course of action.

For human beings, it should be pointed out that these several types of information-processing functions usually are not distinguishable, even where all, or several, occur in the same situation. In fact, such processes cannot be directly observed, but rather can only be inferred from some end result, specifically from some subsequent action that is taken by an individual or from some response that the individual makes.

Swain and Wohl, 1961, ref. 99, p. 29.

Handling of highly complex operations (i.e., doing many different things at once. Fitts et al. (1951) state that when man has to employ his highest intellectual abilities, he is essentially a one-channel computer - he can work effectively at solving only one problem or attending to one thing at a time. Only when he achieves very high degrees of skill can he work on more than one thing, and then only by rapidly shifting back and forth.

The machine, however, is limited only by the capacity built into it.

Gruber, 1961, ref. 47, p. 115.

Types of Human Information Processing:—

While "information processing" refers broadly to the entire stimulus-response complex, it may also be viewed in terms of the nature or degree of perceptual-integrating activities involved in the information processing. From the latter viewpoint, human information processing may be classified into the following types:

1. Where the human is essentially a relay. In this case there is virtually a one-to-one correspondence between the signal received and the subsequent response. Cortical involvement is at a minimum. An example would be the task of teletypewriting an already prepared message.
2. Where the human acts as an encoder. Here there is a transformation of the input signals such that the response output may be either qualitatively and/or quantitatively different from the input. Cortical involvement may vary widely, depending upon the task; however, the minimum degree of involvement would usually exceed that of the relay situation. The task of keying a code number to represent address information would be an example.
3. Where the human is an evaluator. This is the decision-making type of situation. Responses, when made, represent a choice based on an interpretation of the input information. The response may also be the result of past inputs or experiences and/or a consideration of future contingencies. An example would be the functions performed by the weapon selector in modern military systems.

Information-Processing Capacity:—

The information-handling capacities of the human operator are typically defined in terms of the speed and accuracy of task performance or in terms of the amount of information transmitted per second. By "information transmitted" is meant the number of binary decisions (bits) involved in the information processing.

It should be noted that specific values for the capacity of the human to process information are dependent upon many situational variables. These variables, some of which will be discussed later, make the enumeration of values for the capacity of the human channel rather specific to the conditions under which the measurements were obtained.

For situations where the input information varies along a single dimension (such as color, brightness, loudness, pitch), and the task requires an absolute judgment about the stimulus in terms of this dimension, the human is capable of processing approximately 3 ± 1 bits of information per stimulus event * (Attneave, 1959 and Quastler, 1955). That is, the human can identify absolutely only between 4 and 16 steps along any single sensory dimension. While some differences do exist between the sensory channels in this respect, the interesting feature is the similarity of the results obtained with different input channels. In the applied situation, the relevant conditions are usually not limited to that of a unidimensional input requiring an absolute judgment.

The addition of other dimensions to the stimulus will increase the amount of information transmitted (or the capacity of the human channel) in absolute-judgment situations; however, the increase resulting from adding dimensions is at an apparently decreasing rate of change (Miller, 1956). That is, the channel capacity is not the sum of the independent capacities for, say, two dimensions separately, but something less than this sum. The addition of a third dimension increases capacity also, but the amount of increase is less than the amount of increase observed when the second dimension was added, and so on for further dimensional additions. It should be mentioned that, while the addition of stimulus dimensions does increase the total capacity of the human channel, the accuracy with which judgments are made decreases with respect to any particular dimension.

The capacity of the human channel to transmit information under conditions of immediate memory is apparently independent of the amount of information represented by the memory units or items (Miller, 1956). Immediate memory conditions are situations in which a person receives a sequence of stimuli before making a response. While immediate memory is of finite length (usually ranging between 5 to 9 items), the information content of the memory material can be increased without affecting the memory span. That is, it makes little difference in this situation if the stimulus material is sequences of decimal numbers or words from a 1000-word vocabulary.

With regards to the upper limits of human information transmission, 30-35 bits/sec seems a reasonable estimate (Quastler, 1955). Such information transmission occurs in the oral reading of English text when the vocabulary contains

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* Absolute judgment refers to a categorization of identification of the stimulus itself as opposed to a comparative judgment, in which the stimulus is evaluated relative, in some respect, to another stimulus.

approximately 1000 words and the reading rate is 200 words per minute.

Sinaiko and Buckley, 1957, ref. 91, pp. 6-7.

Capability for Data Processing:—

In addition to his ability to act as a data sensor, man processes information: he can think. When information has been received through his senses, man may perform various operations upon it: he stores, modifies, combines, sorts, and rearranges. This capability is the most important single human characteristic of man as a system component. Because the area of human thought is perhaps the most complicated and least well understood in psychological science, not much beyond a general description of man's data processing characteristics can be given. Also, the very richness and variety of man's ability to handle and utilize information makes it almost impossible to characterize completely. Among the types of thinking operations people perform are: arithmetic calculations, quantitative and qualitative estimations, comparative judgment, translation, coding, inductive and deductive reasoning, abstraction and conceptualization, memorization and recall, prediction, and decision making. These processes range in complexity from a child counting his fingers to Professor Einstein contemplating the infinite nature of the universe.

A major characteristic of man as a data processor is his flexibility. First, people do not require extensive or precise preprogramming. Men can deal with changing situations and unforeseen problems in the absence of a specific program. (Actually, previous experiences lead to the developing of "programs" which can be utilized in new situations.) Unlike a computer, man can constantly develop and modify his own programming: he learns the great flexibility of the human as a data processor is another related point. Not only can Johnny read and understand the comics but he applies the same rules for decoding printed symbols to such diverse materials as telephone directories, TV commercials, crossword puzzles, racetrack tote boards, and Sunday school hymnals. The flexibility of thought makes improvisation another uniquely human characteristic. Solutions to complex problems attempted by people may go down many avenues. The number of different ways an idea can be expressed in words—consider this paragraph as an example—is a case in point.

Judgement is another ability that man as a data processor can exercise. Probably this skill comes

from man's long-term storage (memory) and his ability to selectively recall relevant facts at the right time. Few people, if any, remember everything they see or hear but an amazingly large amount of material can be recalled years after it has been acquired. In exercising judgement an experienced operator makes decisions in new situations which resemble, but are not exactly the same as, earlier experiences he has had. Civil Aeronautics Administration air controllers are faced with dozens of potential violations of air space regulations every day, none of which is exactly like any other. Good controllers draw on their previous experience and are able to resolve these problems accurately and quickly. Man can grasp complex situations—he can see the "big picture"—and make decisions about appropriate courses of action.

System Design Implication:—

1. Take full advantage of man's versatility as a data processor. While modern electronic computers can do in minutes what people at desk calculators take days or years to do, computers are relatively inflexible. Computers do not think. Machines, at best, can only carry out instructions of men. And, finally, cost and space factors involved in most computers can be staggering. This point can be summed up by a comment of Dr. Arvid W. Jacobsen, (1954) Director of Wayne University's computation laboratory. He says, "...Any attempt to build a machine that could operate at even a moron level of intelligence would call for an expenditure of billions of dollars and parts and equipment covering hundreds of square miles."

2. Since his speed, accuracy, and capacity differs widely with particular data processing tasks, a man should be assigned to system tasks with careful selectivity. For example, a man is not very effective in performing routine calculations. He is rather slow and likely to make errors. His memory for large bodies of concrete facts and details is not very reliable. He should be replaced, or supplemented by automatic devices, in performing tasks like these.

3. The fact that extensive preprogramming of man is not necessary is important for more than cost considerations. It also means that man can deal with unforeseen situations. In a sense, man is a general purpose computer with an almost unlimited number of programs available. Moreover, he can select from his own repertoire of programs, change programs or modify his program in the middle of an operation, and even invent new programs—all as the situation and the mission require. He can see the "big picture;" he can correct his own mistakes.

On the other hand, all this flexibility leads to an increased possibility of error and variability. Also, while preprogramming in the usual sense of having to foresee, define, and "wire in" all conceivable program steps and eventualities is not necessary, some training time is required.

4. The fact that man does not require that information be coded into a digital or some other form tends to cut down time and expense of system operation. Man can utilize raw information immediately without coding, punching, or similar operations. He can use verbal, numerical, and immediate sensory data without coding delay, or at least after a rapid recording of his own, as in the case of a language translation.

5. While humans can use information presented to them in a variety of ways, some are definitely more effective than others. The form that information takes can influence the speed and accuracy of human performance. For example, if the man in a system has as his major job the making of tactical decisions or control decisions of some kind, there should be a careful study of what information he requires to make these decisions. The aircraft pilot, for example, is not really interested in how many gallons of fuel he has left in his tanks, but in the amount of time he can still fly. Thus, this is the information that should be presented to him. He can then give his attention to his main job and not be compelled to compute miles or minutes per gallon of fuel. In addition to considering the form in which the information presented will be phrased, attention should also be given to the detail in which it should be presented. For example, the pilot may be interested in flying time left to go, but should this be presented in hours, half hours, minutes, or seconds?

6. Man and the computer are not deadly rivals. The computer can take over a great many of man's chores, especially the more routine ones and man can be freed to devote more of his time and energy to his specifically human activities of planning, supervision, and creative thought. Man and the computer (in fact man and any machine) should be thought of as team members rather than competitors. Each has certain strengths and weaknesses. Effective systems design should compose the team so as to have each team member compensate for the other's shortcomings. This is done, for example, in the case where the computer is used to make routine calculations which a man needs to make overall decisions or where the computer is used to make rough sorts among a large number of alternatives when the man is assigned the job of making the final decision among the screened alternatives remaining.

Woodson and Conover, 1964, ref. 114, p. 1-29.

Computational Ability:—

Man learns to do numerical computations, but in the main his time constants are such that he is a relatively poor numerical computer when under stress. No computer can match him, however, for the more qualitative, nonnumerical computations.

These characteristics are common to all men in some degree. It must be remembered that men differ widely in their capacities, body sizes, training, and skills. Until "quality control" is utilized in the acceptance of new models of the human being, the engineer should design equipment which can be used adequately by any member of the population likely to use it.

Man's performance usually tends to deteriorate as a function of time on the job. This is seldom a result of physiological tiring per se. It results, rather, from boredom, inattention, and lack of motivation. Care should be taken in designing the man's job so that he is not forced to operate near his maximum load limits for very long. In addition, control over his ambient environment must be exercised. Tolerance to a single stressful condition may be exceeded when several environments interact at the same time. Design for the "normal" whenever possible, and this will allow the operator to perform more nearly to the specifications you expect of him.

Fitts, 1962, ref. 33.

Man's Versatility:—

In marked contrast to his limited information-handling rate is man's ability to handle a great variety of different information-processing tasks. The number of different functions which a man is capable of performing almost defies enumeration, and undoubtedly is one of his greatest assets as a system component. Man's versatility even poses a considerable danger to system design, since it is always a temptation to assign to a man any and all miscellaneous functions which are left over after most of the rest of the system has been designed, assuming that after a short learning period he will be able to handle all such "simple" tasks equally well. In this connection, it is important to remember that although man is extremely versatile, and can, in fact, learn to perform a great number of different functions, he nevertheless performs some of these functions much better than others. As an

illustration, his information-handling rate in bits per second varies by a factor of at least five to one depending on how input and output information is coded. Thus man's information-handling capacity is usually poor when a binary code is employed, and is substantially higher when a large alphabet such as the alpha-numeric English alphabet is employed. As a further illustration, a typist, who uses all ten fingers, one at a time can transmit information at a considerably higher rate than can a telegraph operator who uses only a single key; and a stenotype operator, who uses five fingers in many combinations, can record information at even higher rates. This ability to handle information at higher rates when using more complex input and output codes is one of the interesting ways in which the conditions required for optimum human performance differ significantly from the requirements of a machine such as a digital computer.

Birmingham and Taylor, 1954, ref. 12, p. 7.

A Basic Principle of Control Design:—

In contrast to the poor performance of complex tasks hypothesized for the human operator is the fact that machines can be built to perform intricate computations with remarkably high precision and low variability. It is true that stability and accuracy are not obtained without effort, but for such tasks as double or triple integration and/or differentiation it seems unquestionable that electronic or mechanical components can be made to be more precise and repeatable than man.

If this is the case, and if precision is required, it follows that when a man-machine system must integrate, differentiate, or perform other higher-order computations, these should be supplied by the nonhuman components of the system whenever possible. This is tantamount to saying that the human should be required to do no more than operate as a simple amplifier. Broadening this somewhat, adding to it a statement as to human bandwidth, and phrasing it as a general design principle, the following emerges: Design of the man-machine system so that (1) the bandpass required of the man never exceeds three radians per second and (2) the transfer function required of the man is, mathematically, always as simple as possible and wherever practicable, no more complex than that of a simple amplifier.

Wayman and Jones, 1964, ref. 106, p. 155.

Generalized Processing:—

Generalized information processing and decision making should be performed by personnel where:

a. Pattern perception is important (especially where patterns may change in size, position, or energy configuration (types and strength levels) under different conditions.

b. Long-term storage of information is required.

c. Insight, discovery, or heuristic problem solving is required.

d. Decision making and learning in a complex changing situation are required.

e. Ability to improvise and adopt flexible procedures is important and, within the state of the art, cannot be built into a machine program.

f. Number of low-probability events which might occur is high and the cost or capacity of machine programming is exceeded by the requirement.

g. Inductive reasoning is required, i.e., a requirement exists for generalizations to be made from the specific events.

Wayman and Jones, 1964, ref. 106, pp. 155-156.

Specialized Processing:—

Specialized information processing and decision making should be performed by equipment where:

a. Deductive logic can be programmed.

b. Speed and amount of memory search or entry (storage) is an extensive requirement.

c. Highly complex computations or logical operations are involved.

d. Short-term storage and retrieval of large amounts of data is required.

e. System functioning requires extremely short time lags between scheduled events.

f. Many routines, channels, and memory areas must be utilized simultaneously (parallel operation).

g. A high degree of repetitiveness and routine is involved in the sequence of tasks or events.

h. Events are unambiguous and probable but can be expected to occur only infrequently, e.g., as in monitoring of equipment readiness.

i. Reduction of the over-all amount of work load and activity for personnel can be expected and provided within system cost parameters.

Swain and Wohl, 1961, ref. 99, p. 28.

Computing ability. In the maintenance field, technicians make errors even in the simplest conversions of data requiring no more than simple arithmetic. Humans, and this includes average maintenance technicians, are poor at quickly performing highly complex calculations. And some calculations, for example, higher order integrations pertinent to some types of fault anticipation, are beyond the capability of humans. However, machines are limited by the rules of operation that are built into them. In some cases, humans can arrive at an adequate answer more quickly by a series of approximations that drop out unnecessary precision. This ability helps account for the greater speed of the abacus operator over a calculating machine operator for certain classes of calculations.

Swain and Wohl, 1961, ref. 99, p. 29.

Deductive reasoning ability. Machines are much quicker and more reliable than humans in identifying a specific item as belonging to a large inclusive class and in using rules for processing information. If the test and checkout operation can be programmed 100%, then a machine can be built to perform the operation rapidly and accurately with perfect repeatability. However, and this is often overlooked, procedures can be built to enable the human to follow the rules efficiently, though less rapidly and with a small but finite probability of error.

1.4 Decision Making

Statements:—

MAN	MACHINE	
"Man can make inductive decisions in novel situations; has the ability to generalize."	"Machines have little or no capability for induction or generalization."	ref. 79
Man does not always follow an optimum strategy.	Machines will always follow the strategy which is built into them.	ref. 111, 36
"Man will require a review or rehearsal period before making decisions based on items in memory."	Machines go directly to the item in memory required for the decision.	ref. 79

Man is capable of integrating a large amount of information gathered from experience and bringing it to bear in a novel situation. ref. 79

"Where the decision-making process is dependent upon maximum flexibility, assign it to the human in the system." ref. 90

"Where the decision involves the consideration of a situation context in which the weightings of the factors involved vary in accordance with the context, assign it to the human in the system." ref. 90

"Where the decision-making couples active hypothesis formulation with inductive reasoning, assign it to the human in the system." ref. 90

"[Humans]...may be reprogrammed by self-instruction following input changes contingent on previous response (dynamic decision making)." ref. 41

"When all the alternatives cannot be specified in advance, true decision making is required and presumably this can only be done by human beings." ref. 109

"...the human, if his presence is required at all in airborne weapon systems, is there to make decisions of a complexity for which, although theoretically possible, it would be very difficult, costly, and cumbersome to build a 'machine'." ref. 111

"Once we understand better how man uses heuristic procedures... [in making decisions], we may be able to devise similar machine programs." ref. 33

[Man]... "learns to make decisions in the face of excess, missing, or unreliable information." ref. 33

"Where the decision-making process is dependent upon complex procedures requiring a large number of differentiations or integrations, assign it to the computer." ref. 90

"Where the decision-making process is dependent upon infallible memory with its precise source accurately tagged (and ignoring display potential), assign it to the computer." ref. 90

"Where the decision involves contextless deductive reasoning, assign it to the computer." ref. 90

"Where the decision involves inductive reasoning of a straightforward nature, assign it to the computer." ref. 90

"Where the decision-making involves prediction of the future and if the weightings of the variables involved are known, assign it to the computer." ref. 90

Discussions:—

Tolcott and Chenzoff, 1961, ref. 103, pp. 116-119.

One of the key problems for a system design is the allocation or decision functions between men and machines. To state this problem in more specific terms, the designer must select the decision-making steps which can and should be pre-programmed for machine execution and those steps which should be taken by humans operating at various levels within the system...

"RATIONAL" DECISION MAKING

In approaching the problem of decision making in specific relation to system design, one must first identify the steps required to be taken in any decision process, insofar as the decision might be termed "logical" or "rational." Recent work in the field of decision theory (Chernoff and Moses, 1957) is valuable in helping to identify these steps. It is recognized that, in many decision situations, one or more of the steps may be performed unconsciously, in a matter of split seconds, or well in advance of other steps. Moreover,

certain steps may first be carried out on a trial basis, and then revised after their implications have been evaluated but before an action choice has been implemented. These identifiable steps in the logical decision process are as follows and are discussed in detail in the following sections:

- Predict contingency probabilities and determine reliability of the predictions.
- Identify action alternatives and constraints (rules of the game).
- Develop an outcome matrix and assign utilities to the outcomes.
- Determine an appropriate risk philosophy.
- Develop a set of decision rules (strategy).
- Interpret information entering the system.
- Review decision rules, and modify them if necessary.
- Implement the action choice.

• Predict contingency probabilities and determine the reliability of the predictions. Essentially, this step is concerned with identification of the relevant events which will demand that action be taken, and the estimation of the likelihood of their occurrence. In the development of a weapons system, for example, preliminary planning requires that the system planner and designer interpret intelligence information to be able to estimate future enemy capabilities and intents related to the purpose of the system, and plan the system design around these preliminary estimates. However, once the system is in use, information entering the system may indicate that these estimates must be revised in the light of recent experience, and that the decision rules based upon them must also be revised accordingly. Thus, the prediction of contingency probabilities is an on-going process involving, initially, the system planners and designers and, ultimately, the users.

As the contingencies begin to occur with some significant frequency, it becomes possible to determine how reliably they can be identified by the man-machine elements in the system. This type of information plays an important role in the continual improvement of decision-making rules or strategies.

• Identify action alternatives and constraints (rules of the game). The rational development of decision rules demands the explicit identification of the action choices available to the decision maker, and the significant characteristics of these action alternatives. Among the most critical characteristics are: (a) lead time required between action choice and implementation (e.g., time required to achieve a desired level of alert status), (b)

estimated success of the action (e.g., reliability and "kill" probability of weapon systems), and (c) rules or constraints related to the use of particular action choices (e.g., conditions under which an irreversible action would be taken).

Again, this step must be performed in advance by the system planner and designer, but with recognition of the fact that the action choices available to the user may be restricted or augmented during the operation of the system.

• Develop an outcome matrix and assign utilities to the outcomes. The outcome matrix is simply a table showing every possible combination of contingency and action. The assignment of a value (or loss) to each possible outcome, perhaps the most critical step in the decision process, is a uniquely human function, depending on individual motivations, goals or sets of values. To the extent that a commonly agreed upon criterion (or criteria) for "success" can be established, it is possible in some situations to arrive at a commonly accepted set of utilities for the outcome matrix. However, in most real systems, success may be measured by several criteria, and agreement on their relative importance may be difficult to achieve. Human value judgments tend to vary considerably both among individuals and within an individual from time to time, and are often based on factors of which the individual himself is unaware.

It should be pointed out that even when system goals or criteria for success can be agreed upon, the task of attaching utilities to the action-contingency combinations called "outcomes" is not a simple one in most practical situations. One must also consider the probability that a desired consequence (i.e., one which furthers the goals of the system) will result from each of the possible outcomes. This is one of the most difficult sets of estimates that a rational decision maker operating in a real-life situation has to make.

In a complex military system, where consistency of behavior among many individuals is usually essential, utilities must be established which are in accord with the system goals, and these utilities must be made explicit and communicated to all persons playing a significant decision-making role in the system. Even more important, it must be recognized that events may require that the utilities be changed. For example, accidental destruction of a friendly aircraft during tense peacetime conditions probably represents a greater loss than it would during a "hot" war. The authority to make (and revise) these value judgments must be clearly allocated

to specific individuals, and the values they assign to various outcomes must be communicated throughout the system.

• Determine an appropriate risk philosophy. Risk philosophy, described in some detail in the literature on decision theory, is essentially the nature of the gain-loss balance which a person finds acceptable over a period of time. Minimizing the maximum loss ("minimax") represents one risk philosophy: minimizing the average loss, another. Experimental studies of gambling behavior indicate wide differences among individuals in preferred risk philosophies. Recognition that these differences may be important in military situations is suggested by evidence that different selection criteria are applied, for example, to fighter pilots as compared to bomber pilots. Further research is needed to determine whether significant relationships can be found between measurable personality characteristics, risk philosophy and performance in other types of military decision-making situations.

• Develop a set of decision rules (strategy). On the basis of the steps described here, decision theory provides techniques for selecting an optimum set of rules or strategy in advance as an aid to rational decision making. It should be noted that many of the steps (e.g., assignment of values to outcome, adoption of risk philosophy) depend primarily on subjective human judgment, while others (such as determination of prediction reliability and after-the-fact estimates of contingency probability) are more objective in nature and can be at least aided, if not entirely accomplished, by automatic data-processing techniques. In theory, it would be possible to devise equipment which will actually compute the best set of decision rules for some systems, provided all the factors discussed above are explicitly identified and entered into the computer. If mixed strategies are desired, several alternative sets of rules could be computer-generated.

Such pre-planned decision rules, whether or not they are automatically developed, should be formulated in terms which relate specific informational inputs to specific action choices (e.g., if an air or space vehicle with a set of characteristics a, b, c,...,n is detected, take action X). They should also be responsive to changes in utilities, risk philosophy, estimates of contingency probability, etc., which might be introduced by human monitors.

However, such a system would ignore the possibility of unanticipated contingencies, or contingencies whose probability of occurrence had been estimated to be so low that economic considerations had forced the designer to omit

them from consideration. Since unanticipated or low-probability events must be considered by the user of the system, humans are normally assigned additional functions, as is next described.

• Interpret information entering the system. In many highly automated systems, humans are assigned the task of monitoring information simply as a back-up to the equipment. Although this may be desirable because of equipment unreliability, it does not fully exploit human capabilities, and in many instances it induces boredom with consequent degradation of performance. Humans can serve several useful functions (related to the interpretation of information) which are either beyond present computer capabilities, or else would require unrealistically complex equipment:

a. They can evaluate narrative information (such as intelligence reports) and "structure" or code it for machine processing, particularly if they are trained as specialists in limited areas of interest.

b. They can recognize unanticipated or low-probability events which their data-processing equipment has not been programmed to handle, particularly if they are alerted to the possibility that unusual events might occur. Further, they can attach confidence levels to their reports of these events.

c. They can recognize patterns of events (both temporal and spatial) which would require complex electronics to be recognized automatically.

This is not to say that they would necessarily perform these tasks well. There are likely to be wide individual differences in effectiveness due to training, experience, distortion of memory, tolerance to stress, level of motivation, and other personal idiosyncrasies, as well as to social factors which depend on the group organization. But in conceptualizing a system, the tasks mentioned above should be recognized as potentially important human operations, with implications for the design of equipment to facilitate them.

• Review decision rules, and modify them if necessary. When information entering a system suggests the occurrence of unexpected or abnormal contingencies, or the sudden availability of new action alternatives, the decision rules may have to be modified. When humans are included in military decision systems to provide "flexibility," it is because of their capability of accomplishing this function.

Its effective accomplishment, however, demands that utilities be assigned to any new set of outcomes which become possible (see "Develop an outcome matrix..." above). The assignment of new utilities is likely to be overlooked in the stress of the situation, unless careful training has emphasized the importance of this step. As discussed above in "Develop a set of decision rules..." it may some day be possible to perform the actual computation of the decision rules automatically.

•Implement the action choice. In decision systems where the stakes (i.e., potential loss due to wrong action) are high, one or more humans are usually interposed between the selection of an action according to the decision rule, and the implementation of the action choice. In concept, at least, if the decision rules have been formulated in advance by the process described here, it is hard to visualize what additional contribution can be made by a human at this last stage. In practice, however, it is almost certain that many of the action steps will have been performed by individuals with access only to limited information (i.e., information relevant only to their subsystem values and goals). These individuals therefore cannot be expected to have either the same information or the same set of values as the chief of the next higher order system. And since many decisions made at the subsystem levels have important implications for the higher-order system, a pre-action review is often justified.

The schematic in Fig. 2 presents a graphical restatement of this discussion.

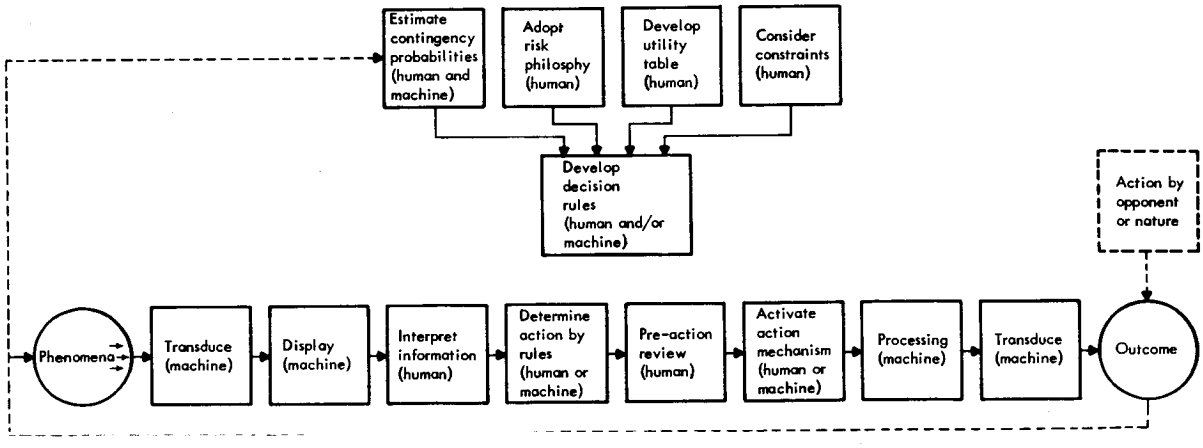


Fig. 2 —- Schematic diagram of steps in rational decision process.

THE FUTURE

Humans will continue to be utilized in several roles which are essential in the decision-making process. These include:

a. estimation of the likelihood of future contingencies
b. assignment of values (or losses) to each possible outcome
c. establishment of a risk philosophy
d. recognition of indications of low-probability events (or those which cannot be handled by the equipment)
e. review of selected actions before they are implemented (where the stakes are high).

McCormick, 1964, ref. 67, pp. 8-9.

Information processing and decision. Information processing embraces various types of operations performed with information that is received (sensed) and information that is stored. The identity and nature of such operations as far as human mental processes are concerned are not yet well understood; in many respects the human mind must still be considered as a "black box." The information processing by machine components must presently be programmed in some way—by either simple or complex methods, including computers; computers are being developed, however, that can be thought of as "learning" from their own "experience" and thus generating artificial intelligence.

Although it is not feasible to categorize all types of information-processing operations, a few might be mentioned, especially those which are fairly clearly identifiable. There is, for example, an operation of information retrieval. For people, this is the process of recalling to mind, when appropriate, the stored (learned) information. In a machine component, it would consist of the selective retrieval of information, when needed, such as the sorting of punched cards on a particular item of information, the following of a specified program by a computer (which would retrieve the specified information as necessary from, say, tapes or cards), or the following by an automatic machine tool of the "model" in reproducing standard parts. Recognition is the function of identifying, or recognizing, some object or stimulus. There are also various kinds of arithmetic and mathematical operations, including addition, subtraction, multiplication, integration, and differentiation, as well as

others; for machine components most information operations would be arithmetic and mathematical. The process of reasoning is of course a very dominant ability of human beings, although (as indicated above)computers are being developed to perform some learning and reasoning functions. Evaluation is essentially a judgmental function, usually involving an appraisal of various considerations in the light of certain specified or nonspecified standards or criteria.

The result of a series of information-processing functions is the making of a decision which serves as the basis for subsequent action. A decision (in the context of a man-machine system) is a determination with respect to a succeeding act or series of actions or, in some cases, the absence of an act. Decisions can range in their complexity from those that are virtually automatic or predetermined by the situation to those that are based on a variety of considerations and involve the estimation of risks and the weighing of different values in arriving at a course of action.

For human beings, it should be pointed out that these several types of information-processing functions usually are not distinguishable, even where all, or several, occur in the same situation. In fact, such processes cannot be directly observed, but rather can only be inferred from some end result, specifically from some subsequent action that is taken by an individual or from some response that the individual makes.

Thomas, et al., 1961, ref. 102, p. 12.

Design Aspects of the Method. In devising... [a mathematical model for allocating decision making (assessments) among men and machines] it was assumed that the designer of a man-machine system can obtain or estimate the values of certain system parameters. These parameter values, together with an acceptable probability of control, the tolerance limits, and magnitudes of corrective actions, are then used in the model to determine the time interval between Type I assessments. * From this assessment cycle time, the designer could determine the minimum and maximum extents to which machine assistance apparently is required. In this case, the underloading on the humans may serve as a threat to the maintenance of system performance at the desired probability level. On the other hand, very short assessment cycle times may indicate that most, and perhaps all, of the assessment functions would have to be accomplished by

*Type I assessment indicates whether or not the actual state of the system lies within the tolerance limits of the desired state at a specified time.

machines. Various supplementary tasks that are assigned to the human operators in the control subsystem can also be included in the analysis of the burden on the operators. At this stage of the analysis, all of the special details of the particular system being designed are combined with relevant human-performance data to evaluate and optimize the design.

Unpublished paper, Serendipity Associates:

Fogel (1961) states that "The only true justification for including man in a system in modern equipment lies in his unique value as a decision-maker." Shapero (1961) disputes this by stating that "common home thermostats 'decide' when to turn the furnace on and when to turn the furnace off though the homeowner decides upon the temperature criterion the thermostat employs for its decision." The thermostat in this example, however, can more appropriately be considered a controller than a decision-maker. In a later section, Shapero recommends consideration of a criterion for determining whether man is required in a system function, such as "...when all of the alternatives can be preprogrammed in advance, machine capabilities can be used on the basis of cost and weight, etc." Conversely, when all of the alternatives cannot be specified in advance, what we might call true decision-making is required, and presumably this can only be done by human beings. Thus, the thermostat in the example above is simply sensing the existence of a pre-established condition, and then exercising a preprogrammed control command to the furnace.

Fitts, 1962, ref. 33.

Use of Heuristic Procedures

Many of the complex problems encountered in everyday life are such that analytic solutions have not yet been found. Examples include certain kinds of transportation, scheduling and personnel assignment problems, where the only sure way to find an optimum is systematically to try all possible combinations. In circumstances where he is faced with problems of this sort, man usually finds moderately efficient solutions. In their daily affairs executives, commanding officers, and business managers make a great many decisions of this sort. We do not yet have a very good understanding of the kinds of heuristics which people employ in solving such complex problems. Once we understand better how man uses heuristic procedures, we may be able to devise similar machine programs. In the meantime, however, it is often convenient to use people when heuristic methods are necessary. Thus the

scheduling of work on production problems, where deadlines must be met and unexpected contingencies are likely to be encountered, is often a function which is assigned today to an experienced human manager (although the manager may use a computer to assist him in reaching decisions).

Woodson and Conover, 1964, ref. 114, pp. 1-27.

AS A COMPUTER OR EVALUATOR

Man is an exceptionally good evaluative computer. From intermittent information on a PPI display he is able to estimate courses, velocities, times, and points of interception with considerable accuracy. Man is able to make decisions based on past experience and patterns of visual or auditory inputs. He is the only available computer able to solve problems by logical induction.

Williams, et al., 1956, ref. 111, p. 29.

Decision-Making and Boolean Algebra

It seems to be commonly agreed that the human, if his presence is required at all in airborne weapon systems, is there to make decisions of a complexity for which, although theoretically possible, it would be very difficult, costly, and cumbersome to build a "machine." Without anticipating the answers to be discovered to the questions posed earlier about the division of function between man and machine, it seems reasonable to accept the proposition that the human will be required at least to act as a decision-maker. In this capacity, he will be called upon to maximize, at any given time, perhaps the probability of success of the mission, perhaps the probability of safe return of the aircraft, perhaps some other probability. In general these decisions will require time depending upon their complexity (the number of subsidiary decisions required in their achievement, the number of alternative courses of action available, etc.).

Fitts, 1962, ref. 33.

Smoothing, Filtering, and Extrapolating: Dealing With Unreliable Information

Throughout his lifetime, man selects and smooths information, estimates probabilities, anticipates alternative outcomes, and in various other ways learns to make decisions in the face of excess, missing, or unreliable information. These abilities have many implications with respect to functions which he can perform in complex systems.

Many of the perceptual functions discussed in the previous section involve selecting, smoothing, or filling gaps in information. Man is able to perform such functions by virtue of his knowledge of the statistical properties of noise and of coherent signal sequences. Thus, man's knowledge of the redundancies of the English language helps him to converse with a friend in the presence of acoustic noise. He can reconstruct a jumbled English message, detect the possible presence of a submarine amidst a great many other water noises, and make intuitive estimates of probabilities. Since many modern man-machine systems must operate in environments that degrade information, man's ability to function effectively in the face of uncertainty often enables him to make an important contribution to the continued functioning of such systems.

Kelley, 1961, ref. 58, 1. 121.

Actually, man plays two quite different roles with respect to the control system: (1) he supplies the system input and (2) he may serve as an element of the system. The first role is outside the control-system loop, and derives from the human goal or purpose which provides the reason for the system's existence. As previously noted, his function could be described as that of control-system director. The director of a control system is a decision maker. His principal task is to decide what it is the system should do. In this position, man is the representative of the user of the system, whether that user is a person, group, or organization. Although the director's decisions may be automated or programmed in various ways, the ultimate decisions are always traceable to man. Man cannot, in principle, be replaced in his function as a control-system director. Sometimes, the same person is both the director of the control system and an element in that system—as, for example, an aircraft pilot. More significant, perhaps, is the fact that control system with its director may also be an element in a larger control system....

The characteristics of man that are important in considering his role as a control-system element tend to be different from those important to a control-system director. The control-system director will usually need to understand the goal of the system, and the factors that may affect its realization. He makes decisions, exercises judgment, and carries responsibility for what the system does. The most relevant research areas concerned with this control-system role are therefore those of decision making and (sometimes) leadership.

Gagné, 1962, ref. 41, pp. 51, 52.

Interpreting in Sequence: Dynamic Decision Making. It is not at all uncommon for interpreting tasks to occur in sequential form. The step-by-step nature of problem solving has frequently been emphasized (see for example Johnson, 1955), as well as the fact that the information available for each later step is likely to be contingent on the consequences of earlier ones. In a task of equipment troubleshooting, for example, the initial interpretation may lead the individual to check an input voltage; his next step is an interpretation of symptoms which include the initial information plus this voltage reading. At each step of the way, the input to the human problem solver is changing, because of his own actions, and continues to do so until he is able to make the final interpretation that locates the malfunctioning part. Aerial photointerpretation also frequently proceeds in this sequential fashion (Gagné, 1954).

Obviously, this kind of dynamic decision making requires successive reprogramming, at each step of the way, of the filtering conditions in short-term memory. Thus at each new stage the individual must provide his own instructions to establish the filtering set which tells him "what to look for." This kind of flexible reprogramming constitutes one of the most striking characteristics of human functioning, and one which distinguishes it markedly from that of most machines. In performing in this manner, the individual must have available in his long-term memory the variety of "filtering rules" necessary and relevant to the problem to be solved. Choosing among them is the major task accomplished by interpretation. The rules themselves then come into play in determining the particular filtering set employed in the next stage of the problem; they are self-instructions, or programs.

A more complex form of dynamic decision making occurs when the feedback loop from the preceding action step involves interacting with another person. In such circumstances the input situation for each step in the sequence becomes highly variable and unpredictable, since it depends not solely on the effects of the individual's own output, but also on that of the second individual. Suppose that two air-traffic controllers must share the task of guiding traffic into an airfield, having as a primary display two PPI (Plan Position Indicator) radarscopes displaying the same information. This is a "load-sharing" task, and it is obvious that each decision made by individual A will result in an action that changes the input for individual B. In periods of heavy traffic, such a system could presumably not be operated without some externally imposed filtering instructions concerning the sector, range

circle, or destination to be covered by each controller (Kidd and Hooper, 1959). However, even when this has been done, the task is one in which frequent interaction is required between the individuals, in the sense that each new situation for decision making is determined in part by the preceding action of the other person. The possibility of flexible programming is obviously a necessary condition for successful operation of this type of system.

Swain and Wohl, 1961, ref. 99, p. 27.

Ability to reason inductively, that is, to make generalizations from specific observations. Along with judgment, this is perhaps man's greatest claim to fame. It is especially important in troubleshooting. But one of the reasons the inductive ability is so important is that the manual programming provisions (in the forms of maintenance instructions and graphic aids) are inadequate to the job, that is, they fail to provide adequate support for human deductions, especially in troubleshooting. Since the generalizations made by technicians are so often incorrect, the best test and checkout situation perhaps should require as little as possible of man's inductive ability.... (this does not necessarily mean to automate.)

Wayman and Jones, 1964, ref. 106, p. 155.

Generalized Processing

Generalized information processing and decision making should be performed by personnel where:

a. Pattern perception is important (especially where patterns may change in size, position, or energy configuration (types and strength levels) under different conditions.

b. Long-term storage of information is required.

c. Insight, discovery, or heuristic problem solving is required.

d. Decision making and learning in a complex changing situation are required.

e. Ability to improvise and adopt flexible procedures is important and, within the state of the art, cannot be built into a machine program.

f. Number of low-probability events which might occur is high and the cost or capacity of machine programming is exceeded by the requirement.

g. Inductive reasoning is required, i.e., a requirement exists for generalizations to be made from the specific events.

Specialized Processing

Specialized information processing and decision making should be performed by equipment where:

a. Deductive logic can be programmed.

b. Speed and amount of memory search or entry (storage) is an extensive requirement.

c. Highly complex computations or logical operations are involved.

d. Short-term storage and retrieval of large amounts of data is required.

e. System functioning requires extremely short time lags between scheduled events.

f. Many routines, channels, and memory areas must be utilized simultaneously (parallel operation).

g. A high degree of repetitiveness and routine is involved in the sequence of tasks or events.

h. Events are unambiguous and probable but can be expected to occur only infrequently, e.g., as in monitoring of equipment readiness.

i. Reduction of the over-all amount of work load and activity for personnel can be expected and provided within system cost parameters.

1.5 Controlling

Statements. —

MAN	MACHINE	
Generally not good at tracking although may be satisfactory where situation requires frequent reprogramming; can change tracking properties to produce best attainable system performance in any situation. Is best at position tracking with changes under 3 radians per second.	Good tracking characteristics easy to obtain for limited set of requirements, etc.; to track well in all conditions considerable complexity required. Properties fixed in each range.	ref. 111, 36
Man can generate only relatively puny force, and cannot exert a large amount of force smoothly.	Machines can generate and exert considerable force in a highly controlled manner—smoothly and precisely.	ref. 105, 67

Man has the capability to act as an intermittent servo in the performance of a number of different systems or equipments. ref. 79

Man is better suited to situations where alternative modes of operation are likely to be required. ref. 79

Man has the capability for tracking through clutter in a wide variety of situations. ref. 74

There is good reason to examine man's contribution to space ship control, since they are aboard it and available for use. ref. 64

"Human controllers will probably continue to be replaced in many systems by automatic feedback control systems; however he can develop very high levels of skill." ref. 34

The responsibility for test system control is to be given to the operator, so that he and the system (i.e., automatic checkout equipment) can function most effectively. ref. 30

Man can guide and control equipment performing constructive operations to a degree that cannot be done any other way, since constant modifications and adjustments in the general method of performing any operation will be required to meet the conditions that prevail. ref. 1

Intermittent operation of equipment is possible if man is present as a controller and actuator through time to make the on-off decisions. ref. 77

"When the identifications involved in tracking can be reduced to simple inputs varying in a single dimension, it is obvious that machine performance can easily be made to exceed that of a human operator." ref. 41

"Exerting large amounts of force smoothly and precisely. The... human is no match in strength for even the simplest lifting or moving devices, and his control movements with large objects tend to be erratic and subject to oscillation, especially when the emphasis is on speed." ref. 99

Discussions:—

PRA, 1960, ref. 3, p. IV-12.

Controlling

While man possesses many alternative modes of operation, when his size and weight are considered in relation to machines, for most specific modes of operation machines outstrip men. Machines can perform routine repetitive tasks without decrements due to boredom and fatigue. They can perform many different things simultaneously without man's physiological limitations. Machines can be built to respond much more quickly to control signals and can apply great forces smoothly and precisely. The ability of man to make control movements is limited in both power and speed. One advantage of using man's motor capability however, is his ability to change both position and location with relative ease.

Gagne, 1962, ref. 41, pp. 67-68.

The tracking of a continuously moving target is a kind of task which has occurred with some frequency in military systems. This is the task which characterizes antiaircraft gunnery, for example, and, in a somewhat more complex form, aerial gunnery. The function utilized in tracking is obviously identification, and the models involved pertain to the "sighting picture" provided by the reticle, or gunsight, which displays the target in reference to the positioning of the gun, usually represented as the intersection of cross hairs. The directions of movement of the control (the output) reflect the identification of a variety of different positions of the target in the field of the gunsight. The task is one in which successive pictures are reacted to (identified) one after another by movements which blend into each other and form a more-or-less continuous movement.

In this kind of tracking task, the sequence of movement required is not only variable but unpredictable from one moment to the next. This is in contrast with a motor skill like that involved in rendering a particular composition on a piano, in which the sequence of movements is entirely determined by the sequence of notes. Consequently, the models of primary importance to the tracking task are those which represent relationships between target position at any given moment and direction and speed of movement of the control handle (or wheel). However, since the input to tracking performance also includes kinesthetic feedback from the just-previous movement, it is impossible to provide for the learning of wholly adequate models except by giving practice with the use of the specific control used in the actual task. This is the reason for the insistence upon "realistic" representation of control pressures and movements in training devices and simulators for tracking tasks such as gunnery and aircraft maneuvering. It is noteworthy, however, despite the correctness of this position, that models acquired for identification of the sighting picture alone (without accompanying kinesthetic feedback) may nevertheless have the most marked effects on tracking performance. Studies of flexible gunnery, for example, have shown the critical importance for good tracking of training in recognition of correct sighting pictures (compare Goldstein and Ellis, 1956).

When the identifications involved in tracking can be reduced to simple inputs varying in a single dimension, it is obvious that machine performance can easily be made to exceed that of a human operator. Extensive training in sighting-picture models can thereby be avoided. But the primary reason for machine excellence in tracking is one

of speed, ... The human individual's time of reaction (not less than 1/4 second for each identification) presents a definite limitation to his tracking performance, as a number of studies have shown (compare Fitts, 1951). This speed is slow indeed, compared to what can be accomplished with the use of such mechanisms as servomotors and analogue computers. Since the demand for speed in gunnery has greatly increased in recent years, it is not surprising to find that this kind of task is to an increasing degree performed by machines, without the participation of the human operator.

The task of flying an airplane constitutes an interesting and instructive example of tracking. The tracking required for control and maneuver of the plane in flight have long ago been taken over by machine (except, of course, for small private aircraft). Even before the automatic pilot was extensively used, it became apparent that the identifications required in the course of flight were being made with reference to instrument readings, which represent extremely simple models for the human being and, in fact, could readily be reduced to single-dimension inputs to a machine. The "seat of the pants" soon became unnecessary as a source of input for the identifications made in controlling the aircraft. The situation in landing the aircraft, however, is quite a different one. Here the identifications required are based upon models with a variety of "built-in" variations, of the sort that are used by human beings in perceiving distance. Automatic landing of airplanes can presumably be accomplished, but only when the input variables which establish the requirements for the plane's performance can be specified with great precision. Again we can realize that this particular tracking task is performed better by a human operator because of his ability to acquire and store complex models (of distance) which are applicable to a great variety of specific situations.

Morgan, et al., 1963, ref. 72, p. 36.

[MAN VS. MACHINE] AS CONTROLLERS

In this role, man also has his capabilities and his limitations. He can push buttons and pedals, turn knobs, throw switches, and operate various other kinds of controls, provided such controls do not impose tasks that exceed his capabilities. Some of these can be listed as follows:

a. The forces that human operators can exert are limited. *

* Reference is made to other portions of the book from which this quotation is taken.

b. Human operators are relatively slow in moving controls, as compared with machines. Also, compared with machines, human movements involve considerable time delay between the time the decision is made to move the control and the time the movement is initiated. * Thus, when controls should be operated with little delay and with great speed, machines are superior to human beings.

c. Man is also limited in the kinds of movement he can make. He can reach in some directions and not in others, and he can reach or extend his limbs only for limited distances. *

d. The precision with which man can apply a given force to a control is also limited. If asked to maintain a certain pressure on a control, the actual pressure will oscillate around the desired pressure and will approximate the desired pressure with some average (or constant) error.

e. The time during which man can apply a force is limited.

f. Man, as a controller, is easily overloaded.

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* Reference is made to other portions of the book from which this quotation is taken.

Pickrel, 1962, ref. 77, p. 142.

MAN AS A CONTROLLER AND ACTUATOR THROUGH TIME

The problem of creating a reliable hardware system to meet the gross control requirements and combine the adjustments and timing of earth and lunar take-offs and landings (these are intermittent operations) with changing vehicle dynamics is very complex. Intermittent operation of equipment is possible if man is present to make the on-off decisions. This is the way an aircraft pilot makes use of his automatic pilot. He accomplishes the gross control requirements manually when changing power settings during take-off and landing. He constantly refines the degree of power, its direction, and the timing for its exertion. He trims the ship and turns to the general heading desired, thus meeting gross guidance requirements. Then he engages or re-engages his automatic pilot. A practiced person can sense changing control requirements and react to them within half a second. A machine like an adaptive servo can meet this need, but only slowly. The pilot must often fly the aircraft manually and serve as its guidance

system. In spacecraft, man's muscle power can be of real importance in orienting reaction jets, generating electrical power, and braking or accelerating inertial wheels. His ability to perform will also make him useful as an observer and interpreter.

Woodson and Conover, 1964, ref. 114, pp. 1-27 and 1-28.

[MAN] AS A CONTROL MECHANISM

Man's transfer function within a control system is highly dependent upon what is expected of him. In hovering a helicopter he does a remarkable job of maintaining a fixed position which would require the solution of some nine simultaneous equations if done by a computer. In flying an airplane, the pilot is faced with the task of simultaneously responding to several instruments which give him the results of his control movements. Given the usual lag in the system, the likelihood of his anticipating the results of his control movements—so as to pull out exactly on the target—is very remote. If "anticipatory" circuits are used in the system to display the effects of the control movements in advance, his job can be done with extreme precision.

For these and other similar tasks, such as maneuvering a space vehicle, it is desirable to use electronic aids to integrate and differentiate for man—and use him as a simple amplifier in the system. Man's motor output seems to have a band width of about 10 cycles per second and a "natural" periodicity of about 1/2 to 1 cycle per second. Care should be taken to avoid putting him in a system with a resonant frequency which will be amplified by this 1/2-to-1-cycle oscillation tendency.

MOTOR RESPONSE

Man can talk, push buttons, use hand cranks or joysticks. He can point, write, push pedals, and so on. All of these outputs are usable and have been used in man-machine systems. It must be remembered that his motor performance characteristics vary considerably, depending upon the mode of response. The design engineer can use these characteristics in two ways: (1) to provide those movement characteristics which are desired as input to the controls, and (2) to eliminate those movement characteristics which are undesirable.

Licklider, et al., 1957, ref. 64, p. 111

> Although the primary functions of the men aboard the [space] ship are to conduct the reconnaissance and the exploration and to report the progress of the expedition via radio and television to eager listeners and viewers in every part of the world, we shall try to concentrate on the design of the control system of the space ship. In doing that, we shall be turning our backs on requirement areas in which human capabilities are unchallenged—turning to face problems that are in many respects better attuned to automatic than to manual control. There is nevertheless good reason to examine the contributions the men may be able to make to the control of the space ship: they are (by assumption) aboard it and available for use, and we can save a ton of expensive fuel every time we eliminate a pound of unnecessary equipment.

Sinaiko and Buckley, 1957, ref. 91, pp. 8-9.

> Capability for Motor Activity
>
> In addition to data sensing and data processing, man also performs certain motor activities. He can move his arms, legs, hands, and do other muscular actions. Speech also included here.
>
> These motor activity capabilities enable man to act upon the environment by manipulating controls, changing his position and location, transmitting information verbally to other men, and by lifting and moving objects. As in the case of man's data sensing and data processing capabilities, the motor capabilities of man are rarely used in isolation.
>
> The ability of man to make movements is limited in both power and speed. There are weights he cannot lift, physical forces he cannot overcome. There is a time delay between the instant when he decides to make a movement and the time the movement occurs. Man is also limited as to the kind of movements he can make. He can reach in some directions and not in others, and there are limits to the distances he can reach or extend his hand. The consistency with which man can apply force is also limited; if asked to maintain a certain pressure on a control, for example, the actual pressure maintained will oscillate around the desired pressure. The muscular aspects of speech activity also limit human performance. The speaker fatigues, cannot exceed certain rates of speech, cannot maintain absolute precision in sounds, and cannot exceed certain decibel levels.

Sinaiko and Buckley, 1957, ref. 81, pp. 12-13.

> Man can also serve as a system component in a role whose complexity is somewhere in between those of the plane commander and the radar operation. For example, there is his role as a controller. In this role he may be the helmsman on a ship, or a radar tracker, or an elevator operator, or a process controller in an industrial plant. Here his task is a continuous one but the task involved is the same throughout. He is in a sense acting as a simple servo-mechanism. Just as the thermostat acts on the basis of the discrepancy between the desired heat and the actual heat in its job of controlling the heat in a house, the man who is controlling a submarine's depth acts on the discrepancy between the actual depth and the desired depth. He watches the actual depth on a display, and modifies the depth with a control. This kind of task has been given the general name of "tracking." It involves man in the system as a continuous control element, and gives him the task of making continuous control adjustments. Note that here man is using his data sensing capacities in one continuous loop.
>
> Man can also override his own actions when crucial events occur. For example, if an operator working at a routine assembly task noticed a fire in the plant, he would probably stop production but, more important, he would report the fire.
>
> The preceding examples have shown how man can perform several kinds of tasks simultaneously or in rapid succession, and keep them all integrated. He can direct his own effort. He can shift his attention rapidly from one task to another, or he can concentrate his attention to a very narrow aspect of the total situation, or he can distribute it over many aspects of the situation, giving only a minimal amount of attention to each. There is, however, a limit to all this. There is a point at which the addition of tasks and responsibilities outstrips man's versatility. In this case, something gets neglected. While this is not a desirable situation, it is at least a point in his favor that man, as compared to a machine, will not simply go on functioning blindly until he breaks down, but will probably attempt to focus his effort on the most critical tasks in the situation, thus saving the situation to some degree. But total breakdown can eventually happen to man in this kind of stress.

Kelley, 1961, ref. 58, p. 121.

> Actually, man plays two quite different roles with respect to the control system: (1) he supplies the system input and (2) he may serve as an element of the system. The first role is outside the control-system loop, and derives from the human goal or purpose which provides the reason for the system's existence.... Sometimes, the same person is both the director of the control system and an element in that system—as, for example, an aircraft pilot. More significant, perhaps, is the fact that control systems are frequently arranged hierarchically, and a given control system with its director may also be an element in a larger control system.
>
> As a control-system element, man can be, and frequently is, replaced. The control-system element to replace him should be selected with reference to the total requirements of the system, and the special characteristics of discrete mechanical and human components.
>
> The characteristics of man that are important in considering his role as a control-system element tend to be different from those important to a control-system director...
>
> The control-system element fulfills different kinds of requirements. His relevant characteristics are usually classified as "skills."* The principal matters of concern here are how good his "sensors" are, how quick his reactions, and how skilled his control manipulations. A discussion of the characteristics of man as a control-system element requires an article in itself. The following are some of his outstanding traits: (Chernoff and Moses, 1957)
>
> 1. Man's sensory and perceptual characteristics are of major importance in his usefulness as a control-system element. He can detect signals well and can perceive patterns of events that cannot yet be detected mechanically.
>
> 2. Man can perform transformations on signals reaching him. Some of these can be described usefully in engineering and mathematical terms. Man can amplify, multiply, integrate, or differentiate input signals, or sum two separate signals. He can combine these operations effectively in performing a meaningful task, such as controlling a vehicle or interpreting a radar signal.

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* See Section 7, "Human Skills as Systems Considerations."

3. Man can learn complex input-output relationships, acquiring through training the capacity to perform a desired transformation. He can also modify this transformation as circumstances require. He thus forms an extraordinarily flexible control-system element, more adaptive than any "adaptive controller" in the breadth of changes he can make in his signal-transmission characteristics.

4. Man's principal drawbacks are that he is slow to react, imprecise and, in many applications, expensive. Where speed and precision in producing a completely definable transfer function are the principal system requirements, man usually forms a poor, if not completely unusable, control-system element.

Despite his limitations, in many systems man still forms the finest control element available. Perhaps someday the control system containing a human element will be a rarity. The control-system director would then be the sole focus of attention in human-factors engineering. But if this is to happen, it will be a long time from now.

Krendel and Bloom, 1963, ref. 61, pp. 31-33.

Adaptability to Control Dynamics

Adaptation, which in our usage is the process by which the human operator compensates for changes in the requirements of his task, has long been recognized as an important attribute of human motor behavior without explicit formulation. For example, Bartlett (1948), has stated that all forms of skilled performances possess an "outstanding character of rapid adaptation." He cites experimental work on the "sense" or direction of movement in the manipulation of controls as follows:

> "It is possible to alter the sense of the manipulatory movement during the course of the experiment without the knowledge of the operator. Nearly everybody now makes a greater amount of error. But the increase is significantly greater in some cases than in others. Some operators make the display the 'key', and are delicately perceptive of any change in visually presented motion. These are readily adaptable, changing an upward into a downward bodily action very often without at all definitely knowing what they have done. Others make their 'key' the feel of the movement itself, and for these the required adaptation is relatively difficult."

The need for rapid adaptation by aircraft pilots can be understood in terms of capabilities and tactics of modern high performance aircraft which result in large changes in controlled element dynamics. The static and dynamic response characteristics of aircraft control systems are in general functions of time, mass loading, and flight conditions. The extension of the operating flight regime of modern military aircraft has resulted in ever wider variations in these characteristics. A number of examples from operational or combat conditions provide illustrations of these changes in dynamics. Thus:

1. The release of bombs will shift the center of gravity of the airplane and thus change controlled element dynamics.

2. A jet penetration requires the airplane to pass through atmosphere of rapidly changing density with changes, albeit no radical changes, in the aircraft's dynamics.

3. Combat damage to control surfaces, structure, hydraulic system and so forth will change the aircraft's response in an unpredictable fashion.

In some cases it is possible to minimize these changing characteristics mechanically by the use of high gain feed back loops. Whitaker, Yamron, and Kezer (1958), however, point out that in an increasing number of cases, the required aerodynamic control moments and power are not available due to the limits imposed by other aspects of aircraft design. In other cases, it is possible to compensate for these changing characteristics by preprogramming adjustments in the control system parameters. If sufficient information about the airplane's flight characteristics is available these adjustments can be scheduled to take place based on measured flight condition; for example, when altitude or Mach number reach a certain value, the gain of a servo amplifier could be increased or decreased by a predetermined amount. Rath (1958) assesses the difficulty of such open loop adjustments and points out that if the scheduled adjustment is not precisely correct due to poor data, miscalculation, some unforeseen changes in aircraft configuration, or even component aging, the adjustment might well lead to a poorer system response. He, therefore, presents the case for a closed loop type of adjustment which would continue adjusting until the desired response was reached.

The Adaptive Optimizing Human

The adaptive capabilities of human operators has been put on a quantitative basis by a recent study by McRuer and

Krendel (1957) which reviewed the body of data on manual closed loop control. By examining the measured linearized transfer functions which describe human control behavior under various experimental conditions, the authors were able to detail and delimit human adaptive, optimizing behavior. The essential results are that there exist a limited number of transfer function forms which the human pilot can generate. The selection of the form is adapted to the particular control dynamics with which the pilot is confronted. Thus, on an intuitive level, it is clear that a pilot adapts his control behavior differentially to a sensitive high performance aircraft from his control behavior in flying a sluggish aircraft. Within a particular form which the pilot has adapted, he may optimize his behavior by effectively varying the parameters which describe the transfer function he has generated. Thus, although many pilots can fly high performance aircraft, some fly better than others. These superior pilots have optimized their behavior within the following constraint: fly a high performance aircraft.

1.6 Monitoring

Statements: —

MAN	MACHINE	
"Can monitor low-probability events for which, because of the number possible, automatic systems would not be feasible."	"Program complexity and alternatives limited so that unexpected events cannot be adequately handled."	ref. 36
"Men are poor monitors of infrequent events or of events which occur frequently over a long period of time."	"Machines can be constructed to detect reliability in frequent events which occur frequently over a long period of time."	ref. 79
Can detect masked signals effectively in an overlapping noise spectrum on displays such as radar and sonar.	Not very good at detecting signal in noise when spectra overlap.	ref. 36

By being alert for changes, human beings can frequently anticipate undesirable conditions. ref. 27

"Man can function very effectively as a monitor of complex systems if given proper information and displays; the importance of this role will probably increase." ref. 34

"Man has excellent signal detection ability and his real-time capacities can be used in sensor systems such as radar, sonar and infrared; however this usually is one of the least desirable uses of men in systems." ref. 34

"If man is already present in a given situation, it may be more economical to use him as a monitor than to provide additional equipment, provided the monitoring tasks are properly designed to compensate for man's limited capabilities." ref. 106

If man is to serve as an emergency backup (to automatic monitoring equipment), it may be necessary to assign manual tasks which could be better performed by machine, simply to keep the man aware of what is happening in the system. ref. 98

Detection of low energy signals in a random signal background appears easier via sound than visually. Combined inputs (sound and visual) indicated some performance improvements. ref. 72

"If at all possible, the computer rather than a man should have primary responsibility for maintaining vigilance and detecting when, after a period of inactivity, some system action is required." ref. 26

"Machines generally are better in their abilities to monitor for prespecified events, especially when infrequent (but machines cannot improvise in case of unanticipated types of events)." ref. 67

Humans are relatively poor, with respect to machines, for monitoring other men or machines. ref. 105

Where possible, equipment should be designed to monitor men and stop; or give a warning whenever operators make mistakes. ref. 72

"Long-term monitoring of specific physical energies generally should be performed by equipment sensors." ref. 106

Discussions:—

Swain and Wohl, 1961, ref. 99, p. 27.

Monitoring Other Men or Machines.

A great deal of research evidence (both experimental and field observational) collected by North American and British researchers shows that man is a poor monitor of infrequently occurring events as well as frequently occurring events over a long period of time (McGrath, et al., 1959)—Man becomes distracted or just bored. The evidence is so overwhelming that Fitts, et al. (1951) have declared that machines should monitor humans rather than vice versa. This principle has important implications for the design of semi-automatic equipment... A corollary to the above principle is that man should not be the sole check on the accuracy of his work."

Wayman and Jones, 1964, ref. 106, pp. 147 & 150.

Monitoring

Long-term monitoring of specific physical energies generally should be performed by equipment sensors.

In addition to his unsuitability for the detection of electromechanical energies per se, man is typically a poor monitor of infrequently occurring events or events occurring over long periods of time. He is easily distracted and he may become bored or fatigued. Again, as with detection, there may be conditions which require the use of man for monitoring in spite of these limitations. Thus:

a. If signals must be detected in high noise environments, then it may be desirable to use man for monitoring. In operational situations, this applies mostly to cathode-ray tube displays such as radar displays, auditory equipment associated with sonar, and external communications equipment. In maintenance situations, this capability is most relevant in the use of test oscilloscopes.

b. If the unpredictability of the signal makes it difficult or impossible to use an equipment sensor, then it may be necessary to use man. For example, the visual and auditory capabilities of man may be useful when it cannot be predicted:

(1) Where the signal will occur, although some notion may be had of when it will occur;

(2) When the time of onset will be, although the position in space of the signal is predictable;

(3) Whether something is going to occur.

Again, these involve the multipotential capabilities of man's senses where the complexity or the unpredictability of the input situation makes it difficult or impossible to use equipment sensors.

c. If equipment cannot be designed to handle monitoring requirements, then it may be necessary to use man.

Gagne, 1962, ref. 41, pp. 66-67.

> [A]...relatively common kind of task that involves the function of detection is called monitoring. A monitoring task is one that requires detection of events which occur at relatively rare, randomly distributed intervals over a lengthy period of time. The events may be the appearance on the display of an object which must be reported, or they may be out-of-tolerance conditions of the equipment. The human individual may be required to detect one or a number of different events, when and if they occur, during the same time period.
>
> The basic function utilized in monitoring tasks is detection, and this means that the individual must have available the models required. If he is to report the appearance of a blip on an oscilloscope, he must have the model which distinguishes the blip from noise. Or, if he must detect out-of-tolerance readings on twelve gauges, he must have the model for each of these. However, since the events he is looking for are infrequent and sporadic, a monitoring task is not easy for a human being to perform with high efficiency over periods of time greater than half an hour or so. Scanning and search routines become excessively tiresome and subject to inhibition. Attention is said to wander; that is, the sets for filtering which are held in short-term memory tend to fade away, and the inputs to be detected are missed (compare Deese, 1957).
>
> There are two general ways of effectively designing a monitoring task assigned to a human operator. One is to establish the necessary models in long-term memory and to depend upon a strong alerting stimulus (like a loud noise or a bright light) to take the place of filtering conditions. This method is often used with danger signals. The maintenance of filtering conditions within the individual becomes unnecessary with this method, since the warning signal is strong enough to capture the attention and to block the reception of all other inputs for a time. The second way is to provide for the occurrence of events at frequent enough intervals so that the filtering sets are in a sense "reinforced" and thus maintained (compare Garvey, Taylor, and Newlin, 1959). A human operator who must watch for the appearance of a blip representing an aircraft in an isolated portion of the earth may be looking for something which seldom happens. A satisfactory way to maintain the filtering conditions necessary for such detection is to increase the frequency of the events—that is, the blips. This can be done by deliberately designing the machine to "help out" the man, by including a program which simulates the occurrence of blips (representing aircraft) at relatively

frequent intervals. By thus insuring the maintenance of filtering sets, the efficiency of the human operator can be substantially raised.

Actually, as the work of Mackworth (1958) and others has shown, monitoring is not the kind of task which human beings perform well, except under the conditions described in the previous paragraph. The equipment designer needs to consider the instances in which the machine can be built to perform this function, which is the case when the events to be detected can be reflected as changes in single physical variables. In contrast, when these events partake of the perceiving of forms and patterns varying widely in their physical dimensions, the detection may have to be done by a man. In such cases some provision must be made for insuring the maintenance of sets for filtering.

Swain, 1964, ref. 98, p. 254.

Be Sparing in The Use of Man as a Monitor

Man is an unreliable monitor. The more passive his role in a system the more he tends to withdraw from the system by letting his attention wander or even by going to sleep. If it is desirable that man serve as an emergency backup, then he should be given tasks to keep him aware of what is happening in the system so that he can take over when needed. It may be necessary to give him these tasks even though they could better be done by a machine.

An example from the log of one human factors specialist will help illustrate the human monitor problem. The initial design of a fully automatic missile fire control system had displays showing the status of the various fire control functions. But if a man were not continually following the change in status, it would take him from several seconds to several minutes to determine the status of some functions. And yet, in case of a malfunction of certain automatic equipment, the operator would have to act almost immediately to prevent severe damage to equipment or loss of the missile. Therefore, the firing system had to be redesigned with some manual functions even though these functions could be performed automatically with more speed and greater reliability.

Swain and Wohl, 1961, ref. 99, p. 25.

Ability to detect signals (including patterns) in high noise environments. In the test and checkout situation, this ability is related mostly to the use of the test oscilloscope and various types of operational cathode ray tube

displays. One shortcoming to this human ability is the human tendency to fill in gaps in the displayed information on the basis of expectancies. When these expectancies are not valid, the technician may see something that is not there, or may miss out-of-tolerance indications not in line with his erroneous expectancy. This human limitation applies mostly to monitoring tasks, somewhat less to routine maintenance tasks, and least to fault location tasks where he knows something is wrong and is searching for out-of-tolerance indications.

Morgan, et al., 1963, ref. 72, pp. 37 & 39.

Although many machines are made completely automatic, men often should be used to override the machine to meet emergencies or situations requiring judgments for which the machine has not been programmed. For example, the decision was made to include a pilot in a new, and virtually automatic, interceptor aircraft. Although most aspects of the typical mission could be handled automatically, or from the ground, it was felt that a human pilot —riding as a passenger most of the time—could exercise judgment in selecting modes of operation for automatic elements in the system. Also, in the event of a failure or other emergency, the man could override the automatic controls (Seamans and Pickford, 1956).

Harmon and King, 1961, ref. 48, pp. 7-8.

There is one question concerning vigilance which has been attacked experimentally; the problem of attention to infrequent signals as, for example, when a radioman on watch must detect at long intervals an occasional call to his own ship among a multitude of other messages. The evidence from studies dealing with such situations indicates that, under these conditions, vigilance tends to be lowered, with attendant likelihood that the crucial message will be missed, in its entirety or in part. Research has been performed on maintaining operator vigilance by filling in such blank intervals with some type of "dummy" message—additional research devoted to discovery of other methods of maintaining vigilance is in order.

Kidd, 1962, ref. 59, pp. 162-163.

[An]...area of increasing relevance to system design concerns the phenomenon of attention. Since it is not possible here to review the literature on this topic, it will suffice to point out that interest in attention is currently going through a revival under the heading of vigilance research. The problem, stated briefly, is how to insure the attention

of an operator to the highly infrequent signals of a monitoring task. At first, this seems to be the opposite of the sensory-capacity problem: the distinction between too much and too little sensory input. However, there is reason to believe that altogether different psychological processes are involved in the two types of task. For vigilance, one of the most promising explanations appears to be a hypothetical inhibition-arousal mechanism, based on the notion that any reiterative repetition of either a stimulus or response raises the detection and elicitation thresholds respectively for all stimuli and all responses (that is, induces a state of somnolence or fatigue). The organism (operator) is either aroused "all over" or, in a sense, encapsulated "all over." This effect appears to depend on the heterogeneity of the stimulus-response pattern; the more heterogeneity, the greater the arousal.

The third question relevant to the identifying function concerns perceptual interference: the detection of signals in noise. Noise is here used in its broadest sense, as a background stimulus which can mask a critical signal, whether the signal be visual, auditory, tactual or some other. The problem of masking of signals by noise has often been studied as a problem in sensing, in which the basic determining factor is the similarity (psychophysical) between the signal and the noise stimuli. However, when the task is one of detection (in the sense of identifying a particular signal), humans have a remarkable capacity for selectivity. Somehow, they are able to do a remarkable job of preventing extraneous material from becoming an interference to the detection task. Often very minute and fractionated cues presented against a heavy background of noise are all that is necessary to enable a person to reconstruct a complex picture. For equipment design, however, the question exists as to how to enhance a man's ability to abstract the signal from the noise components of his stimulus environment; or, secondarily, how to minimize the noise itself.

Morgan, et al., 1963, ref. 72, p. 26.

SIGNAL DETECTION

The detection of significant low-energy signals appearing against a background of random signals is a vital problem in many situations. For example, the typical search radar presents a polar-coordinate display of an immediate area, and superimposed on all land or sea returns are significant targets plus random returns that are both internal and external to the generating and receiving equipment. Although little systematic work has been done in comparing the ability of the eye and the ear to accomplish this particular

task, in general, it appears easier to recognize a complex sound pattern against an altering sound background than it is to recognize an equivalent visual pattern against a visual background.

Work done in the use of combined visual and auditory inputs in sonar and radar indicates some improvement in detection. This relatively minor improvement, however, is a function of many parameters—such as time lag between the different inputs and compatibility of displays—and, under certain conditions, the combined visual and auditory inputs can lead to a serious reduction in detection.

Morgan, et al., 1963, ref. 72, p. 39.

MEN FOR FAULT LOCATION

Machines, no matter how reliable, break down, and men are required to find, and do something about, the cause of breakdown or malfunction. To assist men in doing this, equipment should be designed, whenever possible, so that human beings can interrogate it and determine the fault in it. For example, long-distance transmission of TV programs is accomplished by a system of 107 microwave relay towers spanning the United States. The major role of men in this system is to monitor and maintain the outputs of the relay towers. Because many of the towers are located in remote and inaccessible areas, and because breakdowns occur too infrequently to justify crews at each site, automatic trouble-indication equipment has been designed to enable engineers to interrogate remote towers and to diagnose breakdowns before dispatching repairmen.

Morgan, et al., 1963, ref. 72, p. 37.

MACHINES TO MONITOR MEN

Where possible, equipment should be designed to stop, or to give a warning, whenever operators make mistakes. The following are some examples of such designs:

a. The "dead-man" switch on a railway locomotive automatically brings the train to a halt whenever the engineer, for any reason, takes his foot off of it, thereby indicating that he is no longer in control of the locomotive.

b. In a master distribution system for a television network, an operator at a control console is supposed to

switch connections without error and at precisely the correct times. The task of the operator is to connect incoming programs (black buttons) with the proper outgoing lines (white buttons). To eliminate the possibility that two incoming programs might be switched to a single outgoing line, the console is so wired that, if two black buttons are depressed at the same time as a white one, no switching can occur, and the operator is warned, by a signal, that an error has been made (Collins and Hofmann, 1957).

1.7 Information Storage

Statements: —

MAN	MACHINE	
"Man has excellent long-term memory for related events."	"Machines can have this property, but are very expensive."	ref. 79
"Man is not well adapted to high speed accurate search of large volumes of information."	"Computers are built to do just this."	ref. 79
"Man has extremely limited short-term (buffer) memory for factual material."	"Machines may have as much buffer memory [as] can be afforded."	ref. 79
"Limitation to rule storage not known."	"Limits of rule storage ("logic") quite high."	ref. 41
"Man has the ability to improvise and exercise judgment based on long-term memory and recall."	"Machines do not possess these properties; they are best at routine functions."	ref. 79

"Memory. Man is reasonably efficient in tasks requiring long-term memory." ref. 27

" The storage capacity of the human nervous system is larger than the capacity of all existing automata. The access time of this human storage of information is normally shorter than the access time of comparable mechanical storage devices." ref. 95

"Man has good long-term memory for generalized experience, but rather poor immediate memory for most sensory functions. This is especially so in audition. His access time is slow, compared with that of a computer, but he is able to recall generalized patterns of previous experience to solve immediate problems. As yet, no computer can do this." ref. 114

Humans excel in the ability to store large amounts of information for long periods and to remember relevant facts at the appropriate time. ref. 99

"Humans are generally better in their abilities to retrieve pertinent information from storage (recall), frequently retrieving many related items of information; but reliability of recall is low." ref. 67

Men have greater accessibility to items in storage since they can get at a single memory in many different ways. ref. 26

"Man has a very limited short-term (buffer) storage capacity; however once learning has taken place man is usually able quickly to call up the desired information or to reinstate a skill whenever it is needed." ref. 34

Short-term memory imposes certain limitations on the man's capacity for processing information, and may introduce various distortions. ref. 48

Computers excel men in long-term storage of immense amounts of information, and can reproduce it extremely accurately. ref. 26

"Machines are generally better in the abilities to store coded information quickly and in substantial quantity (for example, large sets of numerical values can be stored very quickly)." ref. 67

"Storing and recalling large amounts of precise data for short periods of time. Especially in the computer field, there are requirements for short-term storage of information ("scratch pad" data), followed by complete erasure of the data in preparation for another task. Machines excel at this; humans not only have difficulty memorizing large amounts of information, but their recall is oten spotty, and they have difficulty in completely erasing information in short-term storage." ref. 99

Discussions: —

PRA, 1960, ref. 3, pp. IV-13 to IV-14.

Storing

In general, machines far surpass men in serving a storage function. Information can be stored in

machines for infinitely long periods of time, and when required can be erased completely from a machine's memory. A machine's channel capacity can be arbitrarily large, but man's ability to recall relevant facts at an appropriate time from a large amount of information stored in memory for considerable periods is a valuable adjunct to the system. It is this capability of man which allows him to exercise judgment. An amazingly large amount of information can be stored for years and recalled by an experienced human being when he is required to make decisions in situations which are similar to earlier experiences which he has had.

Steinbuch, 1965, ref. 95, pp. 478-479.

An essential feature of all "functions of intelligence" is the storage of information. In man we have to distinguish two different principles of storage: short-term storage, e.g. applied in mental arithmetic for storing provisional results, and long-term storage, e.g. for learning languages, writing, or manual skills etc. The storage of information in the nervous system is a result of changes at the synapses. On the other hand, the storage of information used in automata depends on the hysteresis of ferromagnetic materials, e.g. of iron, nickel etc. The storage capacity of the humen nervous system is larger than the capacity of all existing automata. The access time of this human storage of information is normally shorter than the access time of comparable mechanical storage devices.

Table 2
Comparison of Some Characteristic Values
[Partial Table]

Storage	Man (central nervous system)	Automaton (digital computer)
principle	changes in synaptic connections	hysteresis of magnetic materials
capacity	(?) 10^{9} ... 10^{13} bit	10^{5} ... 10^{8} bit
access time	10^{-2} ... 10^{+1} sec	10^{-8} ... 10^{+2} sec

Swain and Wohl, 1961, ref. 99, p. 25.

Ability to store large amounts of information for long periods and to remember relevant facts at the

appropriate time. This ability is related to the human's superior ability to use judgment, to improvise, and to respond appropriately to low probability occurrences. The human is said to be capable of storing from 1.5 million to 100 million binary bits of information. The largest computers available for test and checkout fall far short of this capacity. Man's memory of facts is less reliable than machine's, but he does fairly well at remembering principles, strategies, contingencies, and other rules and their applications provided that he has been properly taught.

Edwards, 1962, ref. 26, p. 101.

[A] common function is goal-setting for searches. Computers very often solve problems by means of directed search through a very large set of possible solutions. Searches should usually be guided by hypotheses concerning the most fruitful places to search first — that is, by using heuristic principles; it is arbitrary whether searching continues until a solution is found or whether it stops after the most likely possibilities have been searched. A computer program can induce these heuristic principles from experience with the problems, but more often in practical applications men will supply computers with heuristic principles to guide search. Little use of this sort of technique has so far been made in military-information processing systems, but they will obviously be very important, for example, in the design of systems for processing the immense volumes of information which will be generated by reconnaissance satellites.

Edwards, 1962, ref. 26, p. 94.

Many computer experts agree that the most important respect in which men excel computers is in the accessibility of the items in storage. Men can get at a single memory in many different ways; in particular, they can recover memories on the basis of similarity alone. Computers, by contrast, have no such efficient cross-indexing. If they did, it would be possible to write programs which rely on the computer to locate and produce any item in memory without specific instruction concerning where that item is. At present, no such procedure is possible. Cryogenic computers will have capabilities of this sort which excel those of current computers, but they will still be much inferior to the capabilities of men.

Wayman and Jones, 1964, ref. 106, p. 156.

Long-Term Storage and Retrieval

Long-term storage and recall of meaningful material of considerable contextual complexity should be performed by personnel when:

a. Retention of abstract and symbolic material and its selective recall for a wide variety of applications is required.

b. Modification of retained material in the direction of new learning about a constantly changing environment is required.

c. Judgment in situations is required where all the relevant factors cannot be clearly specified in advance.

d. Self-modifying behavior based upon retention of experienced events is required.

Conditions for Employment of Personnel for Processing Functions

If personnel are used to perform information processing functions, then the information characteristics, rate, storage, and retrieval requirements must lie within human capabilities.

Harmon and King, 1961, ref. 48, p. 9.

Short-term memory refers to the temporary storage of information for relatively immediate use. The problems which it raises are closely akin to those of immediate memory span, only here the situation is complicated by the rapid and continuous input of information. As far as communication is concerned, the short-term memory imposes certain limitations upon the man's capacity for processing information; it may also introduce various distortions like those mentioned in connection with perception, above. Kay (1960) has described some experiments illustrative of the limitations of short-term memory. He concludes that we do not yet have accurate knowledge of the extent of these limitations, nor what, if anything, can be done about them. The question has a very obvious bearing upon standards of speed and accuracy which can realistically be demanded in communications. Research here is lacking.

Fitts, 1961, ref. 33.

> One of man's most serious limitations in handling information arises from his very limited buffer storage (or immediate memory) capacity. Thus, a task as simple as remembering a telephone number long enough to complete the dialing operation overtaxes the memory of a large proportion of people — i.e., they must refer back to the telephone book before completing the dialing. Man's ability to understand conversation, to recode information for more effective transmission, to look ahead and use anticipation while driving in traffic, and even his ability to learn simple associations, is seriously restricted by the amount of readily available information that he can retain in immediate memory. It should be noted, however, that this limitation definitely does not apply to man's capacity to retain information in long-term or permanent storage — as, for example, the ability of a test pilot to recall information needed in an emergency situation, or the ability of a chess player to recall some strategy employed in a championship match which he observed many years before.

Wayman and Jones, 1964, ref. 106, p. 156.

> Short-Term Storage and Retrieval
>
> Storage of large amounts of data and recall for short periods of time should be performed by equipment when:
>
> a. Information is low in meaningfulness to the human, even though it may ultimately be useful to him.
>
> b. Encoding or identification for library search can be simpler than the symbolic processes utilized by humans for the purpose of recall.
>
> c. Rapidly committing large amounts of information to storage is required, since humans often cannot recall information and apparently cannot completely erase learned material — a factor which sometimes creates considerable unreliability and lack of validity in operator performance.

PRA, Unpublished paper.

> Function: Data Recording and Storage
>
> Requirements
>
> Ability to accurately record and store large quantities of technical detailed data.

Example

Record weapon system engineering documents for later transmittal.

Man

Limited memory capacity with some inaccuracies. Slow. Storage not permanent. Number of channels that can record simultaneously limited and they will affect (interfere) with each other, though occasionally this is beneficial for augmenting a weak signal (e.g., by watching lips and listening may collect adequate data when either channel separately below threshold and will not record).

Tends to process data regardless of need or desirability for processing. Some inaccuracies produced in data processing due to biases and experiences (e.g., optical illusions).

Machine

Able to accurately and rapidly store vast amounts of data for long periods of time. Can record on many channels simultaneously without interference. Does not process data unless instructed to do so.

System Design Implications

Data recording and storage best done by machine, or by man-machine system with man used for pattern or criticality recognition and data selection.

2.0 Human Capabilities and Limitations

2.1 Unique Human Capabilities

Statements: —

MAN	MACHINE
Men are needed to make judgments when it becomes impossible to reduce operations to logical, pre-set procedures.	Machines require logical pre-set procedures. ref. 27
Man is frequently capable of inventing expedient alternatives or repairs in emergencies.	Programming a machine for corrective or alternate action in all conceivable emergencies generally not feasible. ref. 27
"Man can override his own actions should the need arise."	"Machines can only do what they are built to do." ref. 79
"Man can modify his performance as a function of experience; he can learn to learn."	Trial and error behavior is not characteristic of machines." ref. 79
"Able to use temporal redundancy or sequential dependencies in real world; i.e., able to respond to situation as if it were more or less stable or dependable."	"Tend from instant to instant to behave as if the state of the world were independent of previous and subsequent states." ref. 111
"Use of novel rules possible (inventing)."	"Limited in use of novel rules." ref. 41

Man has the ability to learn from experience (so that he improves his own performance and thereby is more effective in achieving system tasks). ref. 31

Man is able to reason, make subjective evaluations, and weigh various considerations that cannot be programmed in advance. ref. 67

"Man has unique ability to act adaptively in situations involving risk and uncertainty." ref. 34

Man excels in applying originality in solving problems: i.e., alternate solutions." ref. 114

"Man is neither rapid nor always reliable in using logical or deductive procedures; however he has great ingenuity, can exercise judgment in situations where rules for action are incomplete, and he can make good use of approximate and heuristic methods." ref. 34

"...a man landing on the moon is better equipped to decide what to observe and sample than are we back here on earth, blindly sending up a machine to reach and grasp for whatever it can. Man can look and think." ref. 82

Significant human capabilities which cannot be duplicated by a machine in so small and reliable a package include selection among alternative ways of achieving a mission. ref. 79

"By using judgment, man can evolve and modify performance criteria, select relevant inputs, decide between programmed and impromptu responses, etc." ref. 70

Man can implement different modes of behavior and thus effect the diverse requirements which judgment may dictate. ref. 70

"Man excels in ability to exercise judgment where events cannot be completely defined." ref. 114

Man has the ability to handle unexpected events without previous experience or "programming."

Man is necessary wherever the form, and/or content of all of the inputs cannot be specified... wherever the assumption concerning the relationships between inputs and outputs are subject to re-examination and restructuring in the operational context. ref. 88

Man is mandatory to perform management and control tasks which require judgment as opposed to decision making. ref. 79

Man can make subjective estimates and evaluations. ref. 67

Man can develop entirely new solutions. ref. 67

Discussions:—

Price, et al., 1964, ref. 79, p. 24.

What systems performance requires man? It is assumed that there are some types of performance which must be implemented by man, at least within the present state-of-the-art. In a report titled An Approach to Functions Analysis and Allocation, Shapero, Rappaport and Erickson (1961) develop a criterion for deciding when man is required in the system. They assert:

> "In any system (or function) of human design, man is necessary wherever the assumptions concerning the relationships between inputs and outputs are subject to re-examination and restructuring in the operational context."

This criterion is restated "in a more limited form for use in analyzing functions... (page 21)as follows: In any system (or function) of human design, man is necessary wherever the form, and/or content of all of the inputs and outputs cannot be specified."

We do not necessarily believe that this is the sole criterion, or that there is in fact a simple single criterion, but criteria can be developed to determine when man is required for system performance. For example, the lesson of the Mercury program can be stated as a criterion for human participation. In any system (or function) of human design, man is necessary wherever an automated performance possesses a high likelihood of failure or malfunction during the period of mission accomplishment.

Firstman and Jordan, 1962, ref. 31.

Man's complementarity to the machine stems from his being intelligent; regardless of whatever capabilities machines have, they are not intelligent. By "intelligence" two basic abilities are understood: the ability to learn from experience (so that man improves his own performance and thereby is more effective in achieving the system tasks), and the ability to function in novel situations unanticipated by the system designers (commonly called the ability to improvise).

Man thus complements machines by being able to compensate for two general weaknesses found in the design of machines or machine systems: a) failure to

design a machine to do tasks that in operation are found necessary, and b) inability of the machine to do or to do well that which it was designed to do. Because of these weaknesses, a machine often becomes a useless hulk, if an intelligent human operator is not available to fix and improvise.

Human intelligence also often enables operators to learn to use the machines in the field more efficiently than anticipated. Operators learn shortcuts, devise new techniques, suggest new designs and procedures, etc.; in other words, with experience men learn to use equipment more efficiently than it is possible to conceive of without experience. For these reasons, it is unprofitable to set up a complex system without men assuming key and responsible roles in it. This, in essence, is what underlies the concept used almost universally to characterize the human operator—flexibility.

Sinaiko and Buckley, 1957, ref. 91, p. 9

Capability for Learning

One of man's most important basic abilities, an attribute that clearly differentiates him from machines, is that he can learn. Given enough time, man can improve his performance in almost any task. In spite of the tremendous value of this ability to acquire better methods and new knowledge and skill, learning takes time. The time required for the learning process will generally vary with the complexity of the material or task he is trying to learn.

Much of human learning involves a trial and error process. If one thing doesn't work, man will try another. The learning process is usually accelerated if there is feedback or knowledge of results. If man gets this kind of information, he can quickly figure out new approaches and drop the old unsuccessful ones and keep the ones that worked. Sometimes, he doesn't need to try every possible approach but can grasp the basic nature of the problem and get the right approach rather suddenly. This is called insightful learning. Most learning is a combination of both trial and error and insight.

The use of simulators illustrates another fact about human learning: men are somehow able to transfer skills acquired in one situation to another similar, but not identical, situation. For example, while Link trainers do not duplicate every aspect of flying an airplane, they are useful devices for training principles of cross-country navigation.

Fitts, 1962, ref. 33.

Adaptation and Learning

Closely related to man's versatility is his capacity for learning new skills, for long-term retention of important information, and for adaptation to the particular requirements of a new task or a new environment. This aspect of human capacity is so well-known that it hardly warrants further discussion. However, a few special characteristics of man's learning processes and their implications for system design do need to be emphasized.

In a system task, man tends to optimize his performance with respect to the requirements of the system, provided only that he is given proper feedback—i.e., has available information regarding the system input and system output which he needs in order to search for an optimum. Thus, rather than asking, "What is man's transfer function in a closed-loop system?" it is more appropriate to ask, "What are the limits within which man can change his transfer function in accordance with the demands for system optimization?"

PRA, 1960, ref. 3, p. IV-14.

Learning

One of man's capabilities which markedly differentiates him from machines is his ability to learn. Given enough time and practice on almost any task which is within the general capabilities of human beings, man will learn to become extremely proficient at this task. His learning ability also is important in emergency situations since much of man's learning is through trial and error. When faced with the necessity to do something, man will continually try alternative means for accomplishing a function or task if the system is partially degraded or for some reason the preferred method will not work. Man's ability to learn and his capability for transfer of learning have important implications on the utilization of him as a system component. Man can perform in many complex system situations if those situations are merely made similar to situations which he has already learned, and a maximum amount of transfer can occur. In many situations it is simpler to redesign a task to take advantage of man's learning than to design a machine to accomplish the same task.

Morgan, et al., 1963, ref. 72, p. 28.

LEARNING

Machines can store (remember) or record items of information fed into them, but human beings are far more capable than machines of changing their behavior (learning) on the basis of past experience. Man can learn in one or all of the following ways:...

a. By practicing a skill over and over again until it becomes ingrained (Example: learning to typewrite.)

b. By trial and error, in which the man attempts various solutions to a problem and adopts the one that succeeds. (Example: solving a difficult puzzle.)

c. By transfer of previous training. (Example: after a brief explanation, a person with training in radio can understand the principles of radar.)

Swain and Wohl, 1961, ref. 99, p. 26.

[Man has the] ability to profit from experience, that is, to modify responses on the basis of prior events. Although some machines are said to be able to learn, this ability in machines is rudimentary. It is not used to its maximum in the maintenance or maintenance design situations because of lack of a formal organization and procedure for incorporating and disseminating the body of maintenance knowledge. Without such formal recording and dissemination, this knowledge cannot be applied to the test and checkout situation for either design or use.

Ellis and Ludwig, 1962, ref. 27, p. 73.

PREDICTION. "By being alert for changes, human beings can frequently anticipate undesirable conditions." The statement is no doubt true. It no longer, however, applies uniquely to human beings, for adaptive systems, or systems exhibiting "intelligent" behavior, have usurped another niche in provinces formerly enjoyed only by organisms. The designers of so-called adaptive systems refer to "goal-oriented" behavior—toward the achievement of an objective by the machine system.

Wayman and Jones, 1964, ref. 106, p. 140.

Ability to Arrive at New and Completely Different Solutions to Problems

The human can employ originality in putting to use incidental intelligence picked up during his training or experience. Unfortunately, he sometimes may try the novel when the usual would be more appropriate. This partly explains the often-observed tendency for the technician to "tinker" and for the operator to "over-adjust" rather than follow the prescribed procedures. Probably a more complete explanation should also refer to the usual inadequate design of procedures.

Firstman and Jordan, 1962, ref. 31, p. 11.

It is fair to state that as yet it is not known how to use the human operator optimally; he has many untapped potentials that are relatively unpredictable at a concrete level. For example, the ACE field survey clearly showed that man's ingenuity in getting his equipment to work is frequently underestimated.

Most of the operator's capabilities are not comparable to a machine's capabilities, but complementary to them.

Ellis and Ludwig, 1962, ref. 27, pp. 68 & 69.

Evaluation

Evaluating, or summation of the judgment processes basic to complex response, consists of several processes forming a mental activity complex. First, perception defines the object, message, or circumstances of immediate concern. Experience facilitates perception in that it enriches perceptual scope and possibly short-cuts the perceptual process. Habitual patterns of thought also affect the process, as well as categorization within the limits of individual experience. Similarities are sought between the item of momentary interest and those previously encountered within the individual's experience, either through direct exposure or via the recorded experiences of others.

The distinctive quality of human performance in the solution of complex problems is as yet unparalleled (with the exception of certain iterative problem-classes) by machines. We are presently unable to provide accurate descriptions of human thought processes and attach to them such labels as "reasoning," "judgment," and "selective recall." Conventionally, we reserve the use of

such labels for the generalized description of inadequately understood human thought processes. Despite this lack of precision in definition, it is clear that the human organism enjoys certain capabilities not as yet embodied in other machines. A suggested, though inexhaustive, list of these capabilities follows:

(a) Extracting something recognizable from a dynamic environment because it has been previously experienced. In psychological idiom this capability is referred to as stimulus generalization;

(b) Discerning poorly defined, unquantized, and frequently irrelevant items of information, and subsequently having such items "on call" selectively;

(c) Perceiving analogous behavior in dissimilar systems without change in the fundamental receptor structure;

(d) Self-assessment or, in the system idiom, determination of a gross approximation to the state occupied;

(e) Utilizing information which is qualitative in nature, and further assigning such qualitative information relational positions (upon a continuum of uncertain dimensions);

(f) Using a nonrigorous language structure, i.e., nonrigorous in the sense that there is no isomorphic relationship between symbol and designatum;

(g) Synaesthesia, i.e., concomitant sensation (in certain instances of an altogether subjective nature) of experiencing data in terms of another sense than the one actually being stimulated, as in color hearing, in which sounds seem to have characteristic colors. These phenomena are not clearly understood, but to the extent that they are operable they serve as stimulus reinforcement means (they function as built-in sensory redundancy);

(h) Operating conceptually in "universes" not apparent as a direct result of experience; i.e., conceptualization of geometries not locally Euclidean, spaces of power greater than that of the continuum, etc.

Swain and Wohl, 1961, ref. 99, p. 25.

Ability to use judgment. It is difficult to define "judgment" though we all seem to know what it is. Perhaps man's superior ability to use judgment is related to his ability to handle concepts, ideas, and other data which are not easily quantified, and to arrive at a decision on the basis of some unspecificable comparison of nebulously defined alternatives, even when the situation is unique. Machines are not very efficient at the kind of selective, long-term storage needed in handling unique problems, and they cannot be fed any variables that cannot be encoded. Thus, judgment is very important where the population of events cannot be completely defined.

Fitts, 1962, ref. 33

Contingent Programing

Most of what has been said in this section in regard to some of the unique capabilities of man in performing system functions can be summarized under the general heading of contingent programing. The implication is that where contingencies cannot be completely anticipated, and thus where situations are likely to arise calling for judgment, for selectivity in processing information, for the use of estimates of probabilities, or for the devising of novel procedures, it is probably desirable to have people around who can change the rest of the system in accordance with their best judgment. This does not mean, of course, that system designers and computer programers should not make every effort to anticipate contingencies and to provide computer programs and mechanical devices for changing system characteristics under such novel circumstances. It is even desirable to attempt to provide adaptive mechanisms for handling certain classes of situations the exact nature of which cannot be anticipated. At present, however, there appears to be a definite limit to the extent to which we can turn over such reprograming functions to adaptive mechanisms. In summary, man may be expected to try to change his own behavior, relative to fixed system characteristics, and also to try to change the rest of the system, in both instances so as to maximize overall system performance.

Judgment

Immediately prior to World War II, the author was involved in the development of tests for selecting aviation cadets. As a preliminary step in determining the abilities needed for success in pilot training, we interviewed experienced Air Corps pilots, and also analyzed reasons given by instructor pilots for eliminating cadets from pilot training.

Both studies suggested that one of the most important traits of a good pilot was the ability to exercise good "judgment" in emergencies. Later research clearly confirmed this conclusion. However, the nature of good judgment, and the development of measures of this ability, still remain something of an unsolved problem. Good judgment involves more than following a prescribed rule (deductive reasoning). It is more than the ability to remember and use practical information. It involves not only the ability to think clearly and logically, and to apply relevant previous experience, but also the ability to estimate probabilities and eventualities, to evaluate alternatives, and to perceive what is relevant in novel situations. In analyzing a critical situation afterward, it may appear that men may not always use the best possible judgment in critical situations. However, they nevertheless do remarkably well in such circumstances. They bring previous experience to bear on unique situations. They improvise, see relationships, select appropriate procedures, and usually arrive at decisions within the time and environmental limitations of the particular problem facing them at the moment. As a result, we often decide to include men in new systems because we assume that they will be able to react intelligently to situations which cannot be anticipated at the time the system is designed. Some recent progress has been made in writing adaptive computer programs and in designing adaptive control systems that can change their characteristics so as to optimize their performance in response to unpredicted environmental changes; however, man is still the chief component that is employed to provide judgment in novel situations.

Morgan, et al., 1963, ref. 72, pp. 37-38.

MEN TO MONITOR MACHINES

Although many machines are made completely automatic, men often should be used to override the machine to meet emergencies or situations requiring judgments for which the machine has not been programed. For example, the decision was made to include a pilot in a new, and virtually automatic, interceptor aircraft. Although most aspects of the typical mission could be handled automatically, or from the ground, it was felt that a human pilot—riding as a passenger most of the time—could exercise judgment in selecting modes of operation for automatic elements in the system. Also, in the event of a failure or other emergency, the man could override the automatic controls (Seamans and Pickford, 1956).

Sinaiko and Buckley, 1957, ref. 91, p. 13.

> Man's ability to sense, to make decisions, and to take action simultaneously and successively has been described. It is important, however, to recognize other human characteristics which affect these things. A man's emotional state or his adjustment to the physical environment or his state of health all may affect his performance as an integrated unit. For example, the radar operator who has family problems may fail to detect targets; or, an underwater demolition swimmer may, under strong patriotic motives, perform superhuman tasks that he himself never believed possible. In summary, man operates as an integrated unit and this is both an advantage and a disadvantage. In a positive sense, man has unequalled versatility; on the negative side, he is not a consistent unit.

Fitts, 1962, ref. 33.

> Use of Heuristic Procedures
>
> Many of the complex problems encountered in everyday life are such that analytic solutions have not yet been found. Examples include certain kinds of transportation, scheduling and personnel assignment problems, where the only sure way to find an optimum is systematically to try all possible combinations. In circumstances where he is faced with problems of this sort, man usually finds moderately efficient solutions. In their daily affairs executives, commanding officers, and business managers make a great many decisions of this sort. We do not yet have a very good understanding of the kinds of heuristics which people employ in solving such complex problems. Once we understand better how man uses heuristic procedures, we may be able to devise similar machine programs. In the meantime, however, it is often convenient to use people when heuristic methods are necessary. Thus the scheduling of work on production problems, where deadlines must be met and unexpected contingencies are likely to be encountered, is often a function which is assigned today to an experienced human manager (although the manager may use a computer to assist him in reaching decisions).

2.2 Unique Human Limitations

Statements: —

MAN	MACHINE	
Men may become angry and avoid performing their functions because they do not care to.	Unless there is some mechanical or organic malfunction in the machine, it will not refuse to respond appropriately to proper instructions.	ref. 49
"Men are subject to anxiety about their safety and about conditions of their environment."	"Machines do not consider safety or aspects of their environment."	ref. 79
"Man is dependent upon his social environment, both present and remembered."	"Machines have no social environment."	ref. 79
"Interpersonal problems develop among humans."	"No interpersonal problems among machines."	ref. 79
"Man saturates quickly in terms of the number of things he can do and in the duration of his effort."	"Machines can do one thing at a time so fast that they seem to do many things at once, for a long period of time."	ref. 79
"Man's diurnal cycle imposes cyclic degradation of behavior."	"The machine cycle may be longer than 24 hours."	ref. 79
"Performance may deteriorate with time; usually recovers with rest."	"Behavior decrement relatively small with time; wear maintenance and product quality control necessary."	ref. 36
"Human performance is degraded by long duty periods, repetitive tasks and cramped or unchanged positions."	"Machines may be built which are less affected by long duty periods, perform routine repetitive or precise tasks well, but some are restricted as to position (orientation)."	ref. 79
Human performance is degraded by fatigue and boredom.	Machine performance is degraded only by wearing out or by lack of calibration.	ref. 111

"Much of human mobility is predicated on gravity."	"Machines may be built which perform independently of gravity."	ref. 79
"Humans have low toleration for g-forces."	"Machines are unaffected by g-forces."	ref. 79
"Humans are subject to a coriolis effect, motion sickness."	"Machines are not subject to a coriolis effect."	ref. 79

"Man comes in only one physical model — whole. From a design point of view, man can only be integrated into the system concept as a whole man with certain general characteristics of size, weight, shape, strength, etc." ref. 79

"Man performance potential costs: There is a definite price to pay for providing and maintaining reliable performance potential in man. These costs are measurable in terms of training; maintenance of human proficiency; manuals, handbooks, instructions and other job guides; and protection and sustenance requirements of human beings." ref. 79

"Man has certain physiological needs. Man's performance deteriorates rapidly when certain physiological needs, such as nourishment, sleep, comfort, and general health are not sufficient." ref. 79

"Man has certain psychological needs. Man's performance usually deteriorates over prolonged periods of high stress or nonactivity; man's performance also changes significantly because of such psychological variables as motivation, frustration, conflict, fear, etc." ref. 79

Men require motivation so that their interests are concurrent with the goal of the systems they are part of. ref. 31

Man's sensitivity to changes in his overall environment can affect many aspects of his behavior in unpredictable ways. ref. 31

Humans are vulnerable to errors through perceptual distortions. ref. 48

Man should be eliminated where environments are physiologically damaging, unnecessarily dangerous, physically uncomfortable, or tend to reduce motivation and alertness. ref. 105

Discussions: —

Firstman and Jordan, 1962, ref. 31, pp. 15-16.

Human Individuality. Perhaps the most annoying limitation of the human operator is that he is not a machine; that is, he has a mind of his own and interests of his own, which may be independent of or in opposition to the aim or goal of the system he is a part of. Hence, when one is primarily interested in getting a job done with a minimum of external entanglements it is understandable that machines are considered preferable to men—machines do not need to be motivated. But again, motivating men is the price one has to pay in order to have an operator that functions as an all-purpose calculator and generally can take over and do the job when preplanning is found to be deficient.

Sinaiko and Buckley, 1957, ref. 91, pp. 10-11.

Physical and Psychological Needs

There are certain physiological needs of human system components that must be satisfied or their performance will be degraded. Food, sleep, maintenance of health, and waste elimination are critical human physiological needs. In addition to these, there are certain psychological needs which have effects on system design. Discussion of the area of human personality is not appropriate here. However, such things as morale, motivation, and job satisfaction definitely affect overall system capability and they should be considered by the designer of man-machine systems.

System Design Implications

1. If system tasks performed by men are of long duration — more than the customary eight-hour shift — provisions made for meeting physiological needs assume special importance. (Of course, regardless of mission duration, human needs are always present and they must be met.)

2. Morale is adversely affected by routine, repetitive tasks. Most men tend to lose interest and

become bored in such situations. Their work becomes less efficient. If possible, repetitive tasks should be done by machines instead of men. Where a task must be done by a man, other functions (perhaps even unnecessary ones) can be added to break up the monotony.

3. People tend to become anxious — and their work suffers — if they lose, or think they lose, control over their own safety. Windows giving pilots access to the outside world may be necessary to maintaining a sense of control although they may not be necessary for actually flying the aircraft. In this connection, the case of the dentist's drill is interesting. It has been found that patients feel less anxiety when they are given a device enabling them to signal the dentist when to stop drilling temporarily and that this makes the whole session go more smoothly.

4. Men's psychological needs are sometimes very subtle but they can be affected by the system designer. For example, from the point of view of the efficiency of a system it might seem desirable to have a TV camera watch men to see that they maintain their work pace. However, this might seriously affect morale and all production could stop.

Sinaiko and Buckley, 1957, ref. 91, p. 13.

Man's ability to sense, to make decisions, and to take action simultaneously and successively has been described. It is important, however, to recognize other human characteristics which affect these things. A man's emotional state or his adjustment to the physical environment or his state of health all may affect his performance as an integrated unit. For example, the radar operator who has family problems may fail to detect targets; or, an underwater demolition swimmer may, under strong patriotic motives, perform superhuman tasks that he himself never believed possible. In summary, man operates as an integrated unit and this is both an advantage and a disadvantage. In a positive sense, man has unequalled versatility; on the negative side, he is not a consistent unit.

Harmon and King, 1961, ref. 48, pp. 6-7.

Perceptual Distortions

Beyond a doubt, this area comprises one of the most prolific sources of error as far as the human component in communications systems is concerned. The human link in

the chain is particularly vulnerable here, for error tendencies, both in the transmission and the reception of messages, operate upon meaningful (plain language) and meaningless (cipher) material alike — although more strongly, it would appear, upon the former type of content. As usual, most of the available research deals, not with communication specifically, but with more general problems of the accuracy of perception. Campbell (1958) has recently reviewed the literature from the standpoint of communications systems.

Transient failure of the perceptual process, due to causes within or without the individual, may produce gaps in the message set or received. Such gaps may be serious enough in themselves, but they are outweighed by another source of error which seems to be inherent in the perceptual (and memory) function itself, the tendency to "structure" or organize information. Many leading principles of perceptual organization are known, and their effectiveness in inducing false or inaccurate perceptions has been demonstrated. Thus output, if imperfect, will tend to be "shorter, simpler, and less detailed than input" (Ibid, p. 342). It will tend to be unconsciously altered to conform to the expected message, to previous messages, to the attitudes of the receiver, and even to the desires attributed to the ultimate recipient of the message ("desire to please the receiver"). Inasmuch as tendencies like these have been shown to be significant determiners of perception in relatively neutral, laboratory situations, it would seem that their investigation as sources of error in communication should be of paramount importance.

Horst, 1962, ref. 49, p. 234.

Temperamental Factors

Men differ from machines also with respect to personality or temperamental characteristics. One may facetiously refer to "temperamental" machines, but in general machines do not get angry and avoid performing their functions because they do not care to. Unless there is some mechanical or organic malfunction in the machine, it will not refuse to respond appropriately to its foreman or supervisor who gives it proper instructions. Neither will it try to make its operator think that it is doing a better job than it really is in order to get promoted to more important functions. Unless the machine is ill, it will not fail to cooperate with another machine simply because it does not like the other machine, or because it would prefer

to receive from or give to some other kind of machine. These kinds of differences create many problems in the selection and classification of personnel for man-machine systems.

Firstman and Jordan, 1962, ref. 31, p. 11.

As a functioning mechanism, man is constant; he is supplied "as is." Training and education can be conceived as techniques of changing man, but the changes introduced are not radical. On the other hand, one of man's primary characteristics is his variability. Human variability may be thought of as inter-individual and intra-individual differences. The former, differences among individuals, are obvious and widely observed. Perhaps more important and difficult to cope with are intra-individual differences, that is, differences within an individual. These in general result from man's sensitivity to changes in his over-all environment, a sensitivity that can affect many aspects of his behavior in unpredictable ways.

Both types of variability must be accounted for in any discussion of human performance. This, perforce, needs to be done implicitly; statements of general characteristics will be tempered by them.

Swain and Wohl, 1961, ref. 99, p. 27.

Performance of routine, repetitive, precise tasks.

Man is notoriously prone to commission of errors in such operations. As in monitoring tasks, he becomes easily distracted, or he may perform some non-prescribed action out of sheer boredom. However, if the task is sufficiently repetitive that it can become automatized, then the operator's involvement in, and awareness of, what he is doing can be reduced to a minimum, and he is free to think of other things. This is one explanation for the compatibility of many persons to extremely routine assembly line work. In the military test and checkout situation, this high degree of repetitiveness and restriction in work assignment are seldom to be found except in some depot operations. Consequently, it is a safe generalization that machines are superior to humans in the performance of most routine, highly repetitive, and precise tasks.

2.3 Human Performance Diversity

Statements: —

MAN	MACHINE	
"Man can develop a high flexibility for task performance."	"Machines are inflexible in a task performance situation."	ref. 79

"Man is a highly versatile component. He can fulfill a wide range of functions that usually require very complex and large mechanical or electronic counterparts. Some of man's versatile capacities cannot be duplicated by non-human components." ref. 91

"Compared with machines, men are generalists or jacks-of-all-trades. This versatility is extremely useful but, at times, it can be troublesome because of man's somewhat unpredictable nature." ref. 33

One allocation principle might be: use man for as many different functions as is feasible, provided first, that these can be performed with the required speed, accuracy, etc., and second, that the functions are performed at such times so as not to overload man's information handling rate. ref. 27

"Flexibility. Humans possess a degree of flexibility of action which may protect them against total system failure. Programming of a given machine for corrective or alternate action in all conceivable emergencies is not generally feasible. However, man is frequently capable of inventing expedient alternatives or repairs in such situations." ref. 114

Man is very flexible and can perform well in many different jobs if his limitations are not overlooked. As the requirements placed on him become more complex, however, this same flexibility may result in a decrement to the system's performance. Use the machine to relieve the man of as many routine jobs as possible, but use the man to supply the judgments and flexibility of which machines are incapable. ref. 72

"Use man where his flexibility will be required in unforeseen situations." ref. 72

"Use man where the sensing and reporting of incidental intelligence is expected in the course of a mission having other objectives." ref. 72

Man has the ability to make and report observations on his own performance; observations on system performance; observations of a scientific nature; and incidental intelligence. ref. 79

"As a system component, man selects from his abilities the one most appropriate to the situation he is in and he acts accordingly." ref. 91

"Man can change his own operating characteristics so as to optimize system output in terms of some specified criterion." ref. 34

"Man can develop a "behavioral strategy" when no optimum strategy can be specified." ref. 79

Man can apply principles to solutions of varied problems. ref. 67

Man can adapt physical responses (within reason) to variations in operational requirements. ref. 67

Human adaptability allows organization of the system structure by selection and use of machine outputs best suited for control purposes. Setup of an internal organization effects highly efficient use of any coherence in the presented stimuli. ref. 70

Human adaptability allows adjustment, within the system structure as organized, of transfer characteristics to forms appropriate for control. ref. 70

There is good reason to examine the contribution of man to space ship control, since they are aboard it and available for use. ref. 64

"If man is already present in a given situation, it may be more economical to use him as a monitor than to provide additional equipment, provided the monitoring tasks are properly designed to compensate for man's limited capabilities." ref. 106

"If man is already present in a given situation, it may be more economical to use him as a sensor than to provide additional equipment if the sensing requirements are within the range of human sensitivity. This also is related to the desirability of providing a man with enough work so that he will maintain a reasonable level of motivation and alertness." ref. 106

"The idea of using men as back-up systems for computer functions is very widely applied; most manned space vehicle designs are designed that way. There is some question whether in many applications it might not be cheaper and just as effective to have the man perform the function in the first place." ref. 26

Man is required to perform preventative maintenance, troubleshoot and repair machines by problem solving; compensating for inadequate design; and selecting an appropriate alternative means. ref. 79

"Man is valuable as a technical troubleshooter. He can better assure the reliable operation of all equipment on the mission by on-the-spot checking, repairing, and replacing of faulty equipment." ref. 1

Man must be capable of taking over in cases of machine failure or destruction. ref. 48

The addition of man to a spacecraft system will assure high reliability by his abilities to operate, manually override, maintain and repair vital spacecraft functions. ref. 1

All of man's outputs, as a transmitter, are motor responses, and these are relatively slow and low-powered. ref. 114

Within its limitations, the human body is the most efficient instrument for such motor activity as grasping, stacking and placing objects, calibration and adjustment of instruments, and application of screwdrivers, etc. ref. 31

"Man excels in ability to perform fine manipulation, especially where misalignment appears unexpectedly." ref. 114

Discussions: —

Gagne, 1962, ref. 41, p. 62.

We ... note that tasks, forming as they do the parts of system operations, do not hold a one-to-one correspondence

with human functions. There are tasks which utilize a single human function in their performance, and there are tasks which utilize several functions. Man is a relatively versatile "package." It is not surprising, therefore, that he is used to carrying out a great variety of tasks, which are typically designed to "fit in" with the functions of machines, rather than being designed specifically to conform to the conditions of the separate human functions.

There appear to be certain typical kinds of task situations in which man is used as a part of a subsystem, and these have come to be called by special names. It is doubtful that these tasks have any more general significance than that they occur frequently in many different systems. But each of them reflects the employment of human capabilities in a manner which exploits one or more of the advantageous features of human functioning.

Horst, 1962, ref. 49, p. 233.

Versatility. Although it is possible to design machines which can perform many different kinds of tasks, most men can perform more different kinds of tasks than machines can. However, in the development of a system one is ordinarily not concerned with the construction of versatile machines; similarly, one does not typically require men to do many different kinds of jobs, even though they may be capable of them. In a different sense, though, versatility is a most significant kind of characteristic of the personnel components of a system. Most men can do some things better than they can do other things, even though they can do a number of things reasonably well and perhaps only a few things not at all well. What is important in developing the logic of personnel selection and classification is that one man can do task a better than tasks b or c , whereas another can do b better, and another can do c better. The personnel selection and classification problem arises in part from this lack of correspondence between the relative abilities of men for different kinds of activities. In the design of machines for a system, the procedure is to design the machine specifically for what it is supposed to do, and in general there is no concern about how many other tasks it can perform or how well it can perform them.

Fitts, 1962, ref. 33.

Man's Versatility

In marked contrast to his limited information-handling rate is man's ability to handle a great variety of different

information-processing tasks. The number of different functions which a man is capable of performing almost defies enumeration, and undoubtedly is one of his greatest assets as a system component. Man's versatility even poses a considerable danger to system design, since it is always a temptation to assign to a man any and all miscellaneous functions which are left over after most of the rest of the system has been designed, assuming that after a short learning period he will be able to handle all such "simple" tasks equally well. In this connection, it is important to remember that although man is extremely versatile, and can, in fact, learn to perform a great number of different functions, he nevertheless performs some of these functions much better than others. As an illustration, his information-handling rate in bits per second varies by a factor of at least five to one, depending on how input and output information is coded. Thus man's information-handling capacity is usually poor when a binary code is employed, and is substantially higher when a large alphabet such as the alpha-numeric English alphabet is employed. As a further illustration, a typist, who uses all ten fingers, one at a time, can transmit information at a considerably higher rate than can a telegraph operator who uses only a single key; and a stenotype operator, who uses five fingers in many combinations, can record information at even higher rates. This ability to handle information at higher rates when using more complex input and output codes, is one of the interesting ways in which the conditions required for optimum human performance differ significantly from the requirements of a machine such as a digital computer.

Cooper, et al., 1963, ref. 24.

Translated into terms of system operation, taking advantage of man's flexibility provides capability for making missions more versatile, recallable, and less vulnerable. In addition he has the advantages of being able to return the vehicles for re-use.

He is more versatile because he can

(1) Select targets of opportunity readily;
(2) Easily re-program for alternate targets;
(3) Strike against mobile targets either as a platform against strategic orbital bombing systems or enemy mobile launchers;
(4) Sense and process information not programmed for in the available hardware;
(5) Provide for mission alternatives in single envelope, such as
    (a) Reconnaissance with strategic capability,

(b) Defensive with strategic capability, and
(c) Early warning with strategic capability.

Further he is recallable since he

(1) Can delay system arming, and
(2) Can return system with no danger to population.

Also he is less vulnerable, in that he

(1) Can take evasive action;
(2) Can provide ECM measures when needed;
(3) Can take defensive action;
(4) Can strike against enemy counteroffensive in order to protect system and to provide partial prime mission.

Sinaiko and Buckley, 1957, ref. 91, p. 7.

A major characteristic of man as a data processor is his flexibility. First, people do not require extensive or precise preprogramming. Men can deal with changing situations and unforeseen problems in the absence of a specific program. (Actually, previous experiences lead to the developing of "programs" which can be utilized in new situations.) Unlike a computer, man can constantly develop and modify his own programming: he learns. The great flexibility of the human as a data processor is another related point. Not only can Johnny read and understand the comics but he applies the same rules for decoding printed symbols to such diverse materials as telephone directories, TV commercials, crossword puzzles, racetrack tote boards, and Sunday school hymnals. The flexibility of thought makes improvisation another uniquely human characteristic. Solutions to complex problems attempted by people may go down many avenues. The number of different ways an idea can be expressed in words — consider this paragraph as an example — is a case in point ...

Since his speed, accuracy, and capacity differs widely with particular data processing tasks, a man should be assigned to system tasks with careful selectivity. For example, a man is not very effective in performing routine calculations. He is rather slow and likely to make errors. His memory for large bodies of concrete facts and details is not very reliable. He should be replaced, or supplemented by automatic devices, in performing tasks like these ...

The fact that extensive preprogramming of man is not necessary is important for more than cost considerations. It also means that man can deal with unforeseen situations.

In a sense, man is a general purpose computer with an almost unlimited number of programs available. Moreover, he can select from his own repertoire of programs, change programs, or modify his program in the middle of an operation, and even invent new programs — all as the situation and the mission require. He can see the "big picture;" he can correct his own mistakes.

Swain and Wohl, 1961, ref. 99, p. 25.

Ability to improvise and adopt flexible procedures. The human can reprogram easily and quickly and can vary performance tolerances quickly. He can acquire new methodological know-how simply by reading printed verbal procedural directions. Human flexibility helps avoid complete breakdown in emergencies. Thus, if high degrees of flexibility are required for test and checkout operations, then the technician should play a large role in accomplishing them. However, he would have to be a relatively highly skilled technician, unless the flexibility could be designed into written procedures for him to follow.

Unpublished paper, Psychological Research Associates.

Man is, essentially, a general purpose computer with an almost unlimited number of programs. He can switch programs, or modify them, in the middle of an operation. He can also devise new programs for himself, while operating, if the program he's using does not produce adequate results (involving learning and the ability to deal with unique data and situations). This characteristic also results in some inconsistency. Man is not passive; he is able to query data sources by designing necessary and appropriate outputs when more data is required.

Fitts, 1962, ref. 33.

Implications for the Role of Man in Space Flight

Once the decision is made to build a manned space vehicle, much can be gained by using the crew to perform as many different functions as is feasible, since in many instances an additional function assigned to the crew results in a saving in weight. Thus one rule-of-thumb for assigning functions to human space crewmen might be: use man for as many different functions as is feasible, provided first, that these can be performed with the required time, accuracy, and other tolerances, and second, that the function is performed at such times that man's

information-handling rate will not be overloaded by this additional assignment of responsibility. This principle must certainly not be applied uncritically. As an illustration, men should probably not be required to perform functions where it is essential to remember to perform an operation at a precisely specified time, or where a very fast reaction time is essential in responding to an infrequent and unexpected event.

Many possibilities are open to the designer, due to the large amount of time available in space flight, for using crewman to perform functions where high precision is required. As mentioned previously, a man is seriously limited with respect to the frequencies that he can cope with in a closed-loop control system. Thus, he cannot directly stabilize a highly underdamped system which tends to oscillate at frequencies above several cycles a second. However, a man can easily cope with disturbances whose rates are substantially less than one cycle per second, especially if he is provided with a properly "quickened" display, and if he can anticipate the time of onset of the disturbance. A man can even control a pure inertia system (such as a space vehicle) in three dimensions, provided the rates are sufficiently low in each dimension. As a further illustration, it is conceivable that a number of relatively simple (essentially paper-and-pencil) navigation procedures might be employed by a man in space flight, provided there were sufficient time to complete and check the computations before action had to be taken.

Man's ability to use general-purpose equipment, such as test instruments, for checking out electrical and mechanical systems, for making observations, or for computing purposes can possibly be exploited in space systems, even though these procedures might be highly inefficient if time were at a premium.

Lastly, of course, it should be mentioned that many of the points which have been emphasized in regard to man's versatility, his adaptive capacity, and his capacity for improvising and devising heuristic procedures, apply also to his potential role as a space scientist. Scientific work is highly creative in nature. A scientist is not just a person who makes routine observations in a fixed pattern — such forms of data collection can often be performed faster and more accurately by automatic devices. A scientist, rather, is a person who uses current information in forming hypotheses, who searches for new information on the basis of contingencies which have arisen in the course of his previous

investigations. In space flight, where the time for communications is lengthened and the time required for a return trip is great, the availability of a trained scientist who can make on-the-spot decisions based on current information may lead to savings worth years of time and millions of dollars, provided space systems are designed so that man's full potential as a creative scientist can be exploited.

McRuer and Krendel, 1962, ref. 70, pp. 1117-1118.

Within the confines of physical constraints present in a given application, human adaptability includes:

1) Organization of the system structure.
   a) Selection and use, as feedback quantities, of those sensible machine outputs best suited for control purposes.
   b) Setup of an internal organization (equivalent to the construction of several signal-processing paths within the human) which effects highly efficient use of any coherence in the presented stimuli (system forcing function and feedbacks).

2) Adjustment, within the system structure as organized, of transfer characteristics to forms appropriate for control.

The attributes of judgment, multimode behavior, and adaptability in a control system component allow the design of systems of great reliability and versatility. By using judgment, the man can evolve and modify performance criteria, select relevant inputs, decide between programmed and impromptu responses, and so forth. A multimode capacity enables the man to implement different modes of behavior and thus to effect the diverse requirements which judgment may dictate. To design such control systems, engineering descriptions of the critical component, man, are needed.

Unpublished Paper, Serendipity Associates.

SELECTING

Man cannot be expected to follow optimum strategy (in a theory of games sense) but through the exercise of critical discrimination, particularly in situations where alternatives cannot be specified in advance, they more than make up for the machine's superior ability to select efficiently from preprogrammed material. The exercise of discrimination allows

man to choose the most appropriate course of action in ambiguous situations. If a task requires integration, man soon starts acting as an integrator, if differentiation is called for, that also can be supplied. In addition, man can be expected to select and report incidental information which is related to mission objectives.

Swain and Wohl, 1961, ref. 99, p. 26.

Ability to handle low probability alternatives (i. e., unexpected events). However, the technician may not always use the optimum strategy in fault location related to a rare symptom of equipment malfunctioning. In fact, he generally tends to try several strategies which have worked before for more familiar events, and he tends to repeat unsuccessful strategies or just "Easter egg" (Bryan et al., 1955, 1957, and 1959). This characteristic is not restricted to relatively unskilled technicians. If low probability events can be programmed into a machine, the machine will be more efficient because there is no forgetting. However, if there are a large number of low probability events (the usual situation in test and checkout operations), then the storage capacity required to handle them poses problems for the machine. On the other hand, properly designed manual test and checkout procedures can increase markedly the facility of the average technician to respond to the unexpected.

Sinaiko and Buckley, 1957, ref. 91, p. 13.

Man can ... override his own actions when crucial events occur. For example, if an operator working at a routine assembly task noticed a fire in the plant, he would probably stop production but, more important, he would report the fire.

... man can perform several kinds of tasks simultaneously or in rapid succession, and keep them all integrated. He can direct his own effort. He can shift his attention rapidly from one task to another, or he can concentrate his attention to a very narrow aspect of the total situation, or he can distribute it over many aspects of the situation, giving only a minimal amount of attention to each. There is, however, a limit to all this. There is a point at which the addition of tasks and responsibilities outstrips man's versatility. In this case, something gets neglected. While this is not a desirable situation, it is at least a point in his favor that man, as compared to a machine, will not simply go on functioning blindly until he breaks down, but will probably attempt to focus his effort on the most critical tasks in the situation, thus saving the situation to some

degree. But total breakdown can eventually happen to man in this kind of stress.

Sinaiko and Buckley, 1957, ref. 91, p. 12.

Coordinated Action

Man behaves as an integrated unit. His many capabilities work in combination and concurrently. At the same time he is sending information, a man may also be processing information and performing certain motor activities. As a system component, man selects from his abilities the one most appropriate to the situation he is in and he acts accordingly. He can operate in a simple or in a very complex manner.

An example of human coordinated action in a relatively simple situation is the job of a radar operator whose task is to detect targets and report their presence to his supervisor. The radar operator watches his scope and performs a more-or-less systematic scanning action with his eyes. A suspected target — which looks like a bright spot of light — has to be distinguished from random noise. Upon deciding that a target is real, the operator then communicates with his supervisor. How the radarman does this depends on several things. If he is inexperienced, he might leave his station, walk to the CIC Officer, tug at the latter's sleeve, and report the target. Or, the radarman can relay the target information over a telephone. Still another situation, in which the safety of the shop might depend on his making an accurate report, might find the radar operator using a special "condition red" buzzer signal to alert everyone. The point here is that even a simple human task includes integrated action: data sensing (seeing the target), data processing (evaluating the target, applying rules for determining his next step), and motor activity (calling the supervisor).

The task of the radar operator, with all of the coordinated action it requires, is, however, relatively simple when compared to the job of business executive, a ship captain, or a plane commander.

Firstman and Jordan, 1962, ref. 31, p. 13.

An important aspect of man's flexibility is his ability to "degrade gracefully." Machines can function in their prescribed manner. If they are overloaded or if any other thing goes wrong in their environment, they tend to become ineffective and often destructive. Men, however, can compensate and modify their performance so that although they might not do a good job, they can continue to function in a

limited fashion. Whereas a machine generally turns out a good product or a useless product (or none), man usually can turn out at least a poor but nevertheless acceptable product under adverse conditions. Moreover, a man is to some extent selfcorrecting; ordinarily he can detect a deficiency and improve or correct his performance.

Harmon and King, 1961, ref. 48, p. 6.

Attention ... should be called to certain consequences of automation in all fields of activity including communications. As machines take over more and more of the routine tasks hitherto performed by man, the human operator is left increasing freedom and greater responsibility for the decision-making aspects of his task. At the same time, especially in military situations, he must be capable of taking over in cases of machine failure or destruction (as in combat). This perhaps calls for some upgrading of personnel as task requirements change. Certainly it underlines the need for periodic review and revision of selection criteria if the communications system is to maintain maximal reliability.

Westbrook, 1959, ref. 109, p. 8.

Performance of certain projected military space missions, nebulous though they may be, will require judgment characteristics that can only be provided by the human. Certain difficult tracking and judgment tasks such as moon landing are especially suitable for the human. Finally the use of man to eliminate some of the complexity of the control system and to perform repair of the remaining equipment will be required to make extended space missions feasible.

Once the need for a man is established for a given mission either as a flight control element or for another reason, the whole mission must be examined to determine where man could be used. Highly desirable reductions in weight of equipment and increases in probability of success will result from this approach.

Thus man has a place in certain missions not merely on the basis of curiosity or even as a scientific observer but on sound engineering reasons as a flight control element.

Amorelli, et al., 1964, ref. 1, pp. 22-23.

What, then, is man's contribution to the space mission? The spacecrewman provides a tool by which mission success can be assured. Man's ability to operate, override, maintain, and repair are the means. It is unrealistic to assume

that the space vehicle's reliability without man will be significantly more reliable than past missile developmental programs, yet reliability requirements are much greater.

Design implications of this concept of man and mission success are several. First, and most important, is that a system in which man is included should be designed to utilize his capabilities to the fullest. It would be foolish to design a fully automatic system where man is merely a passenger. If nothing else, the crewman can provide manual override for most functions and reduce the quantity of redundant equipment.

Second, serious consideration should be given to providing additional interchangeable spares, rather than redundancy, as the approach to increased reliability. Using this concept can simplify the design, reduce weight, and considerably offset the penalties for life support imposed by man.

Third, the question of which performs more efficiently — man or machine — is academic. The important idea is to put them both in an orbital space station or on the moon, and eventually use them for interplanetary or even interstellar exploration. However, there are important relationships between man and machine. These relationships involve designing and planning space mission operations that constantly consider the human element, yet minimize initial weight and bulk, and strive for more efficient power utilization. Since there is presently no precise equation for optimizing a system in which both man and machine operate at their most effective levels, many interrelated factors remain uncertain and unanswered. Thus, functions must be postulated which, under present technology, are most effectually carried out by man. However, the ultimate balance between man-performed and machine-performed functions cannot be predicted until engineering development and biotechnical knowledge become more sophisticated.

Licklider, et al., 1957, ref. 64, p. 111

Although the primary functions of the men aboard the [space] ship are to conduct the reconnaissance and the exploration and to report the progress of the expedition via radio and television to eager listeners and viewers in every part of the world, we shall try to concentrate on the design of the control system of the space ship. In doing that, we shall be turning our backs on requirement areas in which human capabilities are unchallenged — turning to face problems that are in many respects better attuned to automatic than to manual control. There is nevertheless good reason

to examine the contributions the men may be able to make to the control of the space ship: they are (by assumption) aboard it and available for use, and we can save a ton of expensive fuel every time we eliminate a pound of unnecessary equipment.

Bamford, 1959, ref. 9, p. 56.

One of the most fundamental decisions to be made by the planner of a man-machine system is the allocation of its functions between crew and residual system. For any given mission, or required correspondence between the system's output and its environmental input, the functions which are allocated to the crew are those which the latter must perform in order for the system's mission to be realized ...

Two kinds of gains may be realized by allocating certain of the functions of a man-machine system to its crew: the operational capability, reliability, and availability of the system may be augmented by the use of human components; and through such use net savings may be effected in weight, volume, power, maintenance, and other hardware costs. These gains are the factors of human utility to the system. They are the factors which the system planner must weigh against the corresponding factors of human cost in deciding the complementary roles of man and machine.

Swain and Wohl, 1961, ref. 99, p. 26.

Ability to Perform Fine Manipulations

This superiority of man is especially important in assembly-disassembly operations, fault correction (e.g., soldering, replacing tubes, etc.) and in the fine adjustments required in calibration and alignment. Machines built to perform this type of manipulation are frequently extremely costly and complex. However, precise manual adjustments often must be aided by a machine, for example, a receiver tuning device or a torque wrench with a readout in foot-pounds. And those manipulations involving complex eye-hand coordination are difficult to learn to a high skill level.

Firstman and Jordan, 1962, ref. 31, p. 12.

Within its limitations, the human body is the most efficient instrument for motor activity. The hands can grasp a larger variety of objects and move them in a greater variety of ways much more efficiently than any one kind of machine. The human sense of balance is unmatched for stacking objects, placing objects on shelves and platforms, etc. Aided

by the eyes, human fingers are unmatched for fine calibration and adjustment of instruments as well as for application of screwdrivers and the other hand tools used to repair or replace parts of a machine.

Woodson and Conover, 1964, ref. 114, p. 1-27.

AS A TRANSMITTER

Man can utilize the outputs of another man or piece of equipment in a system and transmit these as inputs to other men or other pieces of equipment by voice link, knobs, push buttons, switches, and so on. All of man's outputs are motor responses, and these are relatively slow and low-powered. For steady-state conditions, his output in highly developed skills (typing, or playing a musical instrument) seems to be limited to approximately 25 bits per second (6 or 7 letters or notes per second). Maximum human capacity is about 40 bits; the probable operating rate for typical unskilled tasks may be around 2 bits per second.

Steinbuch, 1965, ref. 95, pp. 479-480.

Man and automaton use a different way to exchange information. The man uses audible speech, visible writing, gestures, mimicry etc. Automata use electric impulses whose period is much shorter than those signals of a man and which correspond to a lower level of energy. Since the speed of operation, and the type of input and output signals between man and machine are so different, tasks requiring smooth integration of machine and man cannot be efficiently performed. For this reason it is often preferable to use only machines for tasks that could be better performed by men.

Unpublished Paper, Psychological Research Associates.

Function: Reliability and Maintenance

Requirement

Must perform system design functions for extended periods of time far removed from base, without any external maintenance.

Example

Observe activity in foreign rocket engine laboratories and test facilities.

Man

High reliability and long life. Self maintaining, utilizing widely available materials. But physiological needs and rigid physical environment requirements (moderate temperatures, low radiation, etc.) plus large size make concealment difficult. Performance somewhat variable due to health, fatigue, etc. Performance also variable across individuals (not well standardized).

Machine

Reliability low if instrument at all complex. Needs outside maintenance. Often easier to conceal due to miniaturizing.

System Design Implications

Function can not be performed by machine alone because of maintenance problem. Need man, or machine-augmented man where machine utilized for conceal advantages, and ability to tolerate greater environmental extremes.

2.4 Basic Psychophysical Capabilities and Limitations

Sensory — Perceptual: —

Mowbray and Gebhard, 1958, ref. 73, pp. 2-5.

TABLE 3. A SURVEY OF MAN'S SENSES AND THE PHYSICAL ENERGIES THAT STIMULATE THEM

Sensation	Sense Organ	Stimulated By	Originating
Sight	Eye	Some electromagnetic waves	Externally
		Mechanical pressure	Externally or internally
Hearing	Ear	Some amplitude and frequency variations of the pressure of surrounding media	Externally
Rotation	Semicircular canals	Change of fluid pressures in inner ear	Internally
	Muscle receptors	Muscle stretching	Internally
Falling and rectilinear movement	Semicircular canals	Position changes of small, bony bodies in the inner ear	Internally
Taste	Specialized cells in tongue and mouth	Chemical substances dissolvable in saliva	Externally (contact)
Smell	Specialized cells in mucous membrane at the top of the nasal cavity	Vaporized chemical substances	Externally
Touch	Skin mainly	Surface deformation	On contact
Vibration	None specific	Amplitude and frequency variations of mechanical pressure	On contact
Pressure	Skin and underlying tissue	Deformation	On contact
Temperature	Skin and underlying tissue	Temperature changes of surrounding media or of objects contacted	Externally and on contact
		Mechanical movement	
		Some chemicals	
Cutaneous pain	Unknown, but thought to be free nerve endings in the skin	Intense pressure, heat, cold, shock and some chemicals	Externally and on contact
Subcutaneous pain	Thought to be free nerve endings	Extreme pressure and heat	Externally and on contact
Position and movement	Muscle nerve endings	Muscle stretching	Internally
	Tendon nerve endings	Muscle contraction	Internally
(kinesthesis)	Joints	Unknown	Internally

TABLE 4. MAN'S SENSES AS INFORMATIONAL CHANNELS: A COMPARISON OF THE INTENSITY RANGES AND INTENSITY DISCRIMINATION ABILITIES OF THE SENSES

Sense	Intensity Range		Intensity Discrimination	
	Smallest Detectable	Largest Practical	Relative	Absolute
Vision	2.2 to 5.7×10^{-10} ergs	Roughly, the brightness of snow in the midday sun, or about 10^9 times the threshold intensity	With white light, there are about 570 discriminable intensity differences in a practical range	With white light, 3 to 5 absolutely identifiable intensities in a range of 0.1 to 50 ml.
Audition	1×10^{-9} ergs/cm^2	Roughly, the intensity of the sound produced by a jet plane with afterburner or about 10^{14} times the threshold intensity	At a frequency of 2,000 cps, there are approximately 325 discriminable intensity differences	With pure tones about 3 to 5 identifiable steps
Mechanical vibration	For a small stimulator on the fingertip, average amplitudes of 0.00025 mm can be detected	Varies with size of stimulator, portion of body stimulated and individual. Pain is usually encountered about 40 db above threshold	In the chest region a broad contact vibrator with amplitude limits between 0.05 mm and 0.5 mm provides 15 discriminable amplitudes	3 to 5 steps
Touch pressure	Varies considerably with body areas stimulated and the type of stimulator. Some representative values: Ball of thumb—0.026 erg Fingertips—0.037 to 1.090 ergs Arm—0.032 to 0.113 erg	Pain threshold	Varies enormously for area measured, duration of stimulus contact and interval between presentation of standard and comparison stimuli	Unknown
Smell	Widely variant with type of odorous substance. Some representative values: Vanillin—2×10^{-7} mg/m^8	Largely unknown	No data available	No data available

Table 4. (continued)

Sense	Intensity Range		Intensity Discrimination	
	Smallest Detectable	Largest Practical	Relative	Absolute
Smell (continued)	Mercaptan (C_2H_5SH)—4 x 10^{-5} mg/m^3 Diethyl/Ether ($C_2H_5OC_2H_5$) 1.0 mg/m^3			
Taste	Widely variant with type and temperature of taste substance. Some representative values: Sugar—0.02 molar concentration Quinine Sulfate—4 x 10^{-7} molar concentration	Not known	No data available	No data available
Temperature	Sensation of heat results from a 3-second exposure of 200 cm^2 of skin at rate of 1.5 x 10^{-4} gm-cal/cm^2/sec	Pain results from a 3-second exposure of 200 cm^2 of skin at a rate of 0.218 gm-cal/cm^2/sec	No data available	No data available
Kinesthesis	Joint movements of 0.2 degree to 0.7 degree at a rate of 10 deg/min can be detected. Generally, the larger joints are the most sensitive	Unknown	No data available	No data available
Angular acceleration	Dependent on the type of indicator used 1. Skin and muscle senses 1 deg/sec^2 2. Nystagmic eye movements 1 deg/sec^2	Unconsciousness or "blackout" occurs for positive "G" forces of 5 to 8 G lasting 1 second or more	No data available	No data available

Table 4. (continued)

Sense	Intensity Range		Intensity Discrimination	
	Smallest Detectable	Largest Practical	Relative	Absolute
Angular acceleration (continued)	3. Oculogyral illusion 0.12 deg/sec^2	Negative forces of 3 to 4.5 G cause mental confusion, "red-vision" and extreme headaches lasting sometimes for hours following stimulation		
Linear acceleration	In aircraft—0.02 G for accelerative forces and 0.08 G for decelerative forces	For forces acting in the direction of the long axis of the body, the same limitations as for angular acceleration apply	No data available	No data available

TABLE 5. A COMPARISON OF THE FREQUENCY RANGES AND FREQUENCY DISCRIMINATION ABILITIES OF SOME OF THE SENSES

Sense	Wavelength or Frequency Range		Wavelength or Frequency Discrimination	
	Lowest	Highest	Relative	Absolute
Vision				
Hue	300 mμ	1,500 mμ	At medium intensities there are about 128 discriminable hues in the spectrum	12 to 13 hues
Interrupted white light	Unlimited	At moderate intensities and with a duty cycle of 0.5, white light fuses at about 50 interruptions per second	At moderate intensities and with a duty cycle of 0.5, it is possible to distinguish 375 separate rates of interruption in the range of 1 to 45 interruptions per second	No greater than 5 or 6 interruption rates can be positively identified on an absolute basis
Audition				
Pure Tones	20 cps	20,000 cps	Between 20 cps and 20,000 cps at 60 db loudness, there are approximately 1,800 discriminable steps	4 to 5 tones
Interrupted white noise	Unlimited	At moderate intensities and with a duty cycle of 0.5, interrupted white noise fuses at about 2,000 interruptions per second	At moderate intensities and with a duty cycle of 0.5, it is possible to distinguish 460 separate interruption rates in the range of 1 to 45 interruptions per second	Unknown
Mechanical vibration	Unlimited	Unknown, but reported to be as high as 10,000 cps with high intensity stimulation	Between 1 and 320 cps, there are 180 discriminable frequency steps	Unknown

TABLE 6

CHARACTERISTICS OF THE SENSES

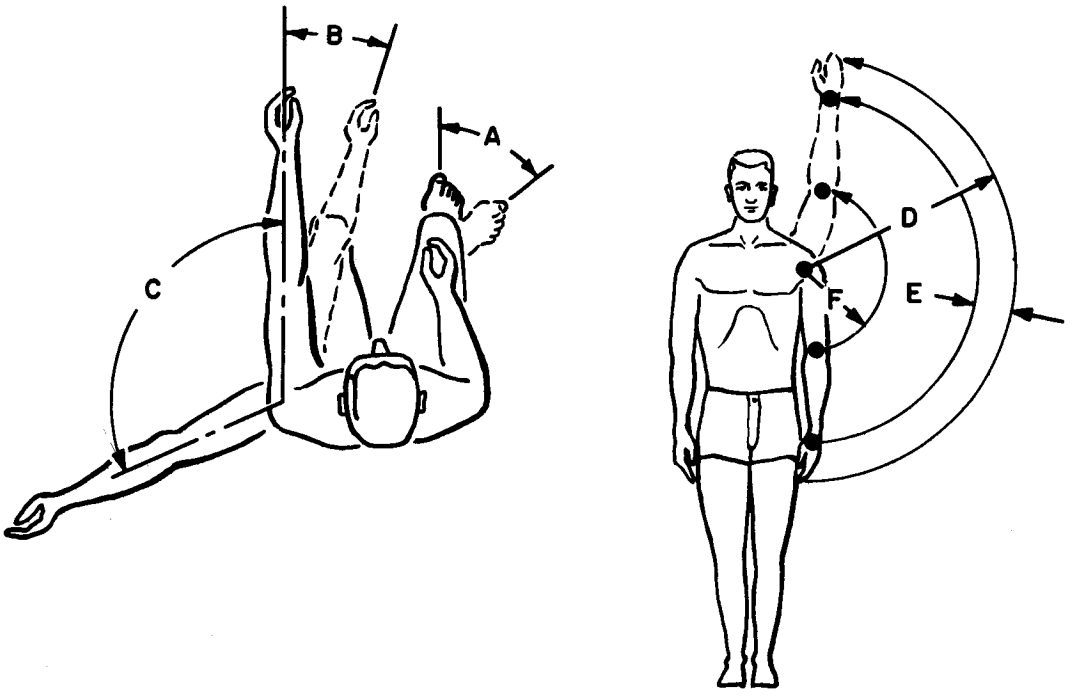
Parameter	Vision	Audition	Touch	Taste and Smell	Vestibular
Sufficient stimulus	Light-radiated electromagnetic energy in the visible spectrum	Sound-vibratory energy, usually airborne	Tissue displacement by physical means	Particles of matter in solution (liquid or aerosol)	Accelerative forces
Spectral range	Wavelengths from 400 to 700 mu. (violet to red)	20 cps. to 20,000 cps.	> 0 to < 400 pulses per second	Taste—salt, sweet, sour, bitter. Smell—fragrant, acid, burnt, and caprylic	Linear and rotational accelerations
Spectral resolution	120 to 160 steps in wavelength (hue) varying from 1 to 20 mu.	~3 cps. (20 to 1000 cps.) 0.3 percent (above 1000 cps.)	$\frac{\Delta pps}{pps} \cong 0.10$	——	——
Dynamic range	~90 db. (useful range) for rods = 0.00001 mL to 0.004 mL; cones = 0.004 mL to 10,000 mL	~140 db. 0 db = 0.0002 dyne/cm^2	~30 db. .01 mm to 10 mm	Taste $\cong$ 50 db 3×10^{-5} to 3% concentration quinine sulphate. Smell = 100 db.	Absolute threshold $\cong 0.2^{\circ}$ / sec/sec
Amplitude resolution $\frac{\Delta I}{I}$	contrast = $\frac{\Delta I}{I}$ = .015	.5 db (1000 cps. at 20 db or above)	~.15	Taste $\cong$ .20 Smell: .10 to 50	~.10 change in acceleration
Acuity	1° of visual angle	Temporal acuity (clicks) $\cong$0.001 sec.	Two point acuity = 0.1 mm (tongue) to 50 mm (back)	——	——
Response rate for successive stimuli	~0.1 sec	~0.01 sec (tone bursts)	Touches sensed as discrete to 20/sec	Taste ~ 30 sec Smell ~20 sec to 60 sec	~1 to 2 sec nystagmus may perist [sic] to 2 min after rapid changes in rotation
Reaction time for simple muscular movement	~0.22 sec	~0.19 sec	~0.15 sec (for finger motion, if finger is the one stimulated)	——	——

Table 6 (continued)

Parameter	Vision	Audition	Touch	Taste and Smell	Vestibular
Best operating range	500 to 600μ (green-yellow) 10 to 200 foot-candles	300 to 6000 cps. 40 to 80 db	——	Taste: 0.1 to 10% concentration	~1G acceleration directed head to foot
Indications for use	1. Spatial orientation required. 2. Spatial scanning or search required. 3. Simultaneous comparisons required. 4. Multidimensional material presented. 5. High ambient noise levels. (Javitz, 1961)	1. Warning or emergency signals. 2. Interruption of attention required. 3. Small temporal relations important. 4. Poor ambient lighting. 5. High vibration or G forces present. (Javitz, 1961)	1. Conditions unfavorable for both vision and audition. 2. Visual and auditory senses. (Javitz, 1961)	1. Parameter to be sensed has characteristic smell or taste. (i.e. burning insulation).	1. Gross sensing of acceleration information.
References	Baker and Grether, 1954 Chapanis, 1949 Woodson, 1954 Wulfeck, et al., 1958	Licklider, 1951 Licklider and Miller, 1951 Rosenblith and Stevens, 1953 Stevens and Davis, 1938	Bekesy, 1961 Jenkins, 1951	Pfaffman, 1951	Wendt, 1951

Motor. —

PRA, 1959, ref. 4, pp. 9-16.



Arm and Foot Movement Limits

Motion	Description	5%ile	50%ile	95%ile	Range (95% of sample)
A	Foot rotation* (side to side)	No data available	78°	No data available	46° - 110°
B	Arm rotation* (side to side)		48°		30° - 66°
C	Arm rotation* (side to side)		134°		100° - 168°
D	Arm reach radius**	27.7"	30.0"	32.3"	No
E	Wrist reach radius**	7.0"	7.6"	8.2"	data
F	Elbow reach radius**	16.5"	18.0"	19.4"	available

*Air Force personnel.

**Industrial workers.

Tuttle, et al., 1950, ref. 104.

Table 7. Grip Strength and Endurance for 200 Men.

	Right hand		Left hand	
	Average	SD	Average	SD
Average maximum strength (lb)	108	21	95	18
Average strength-endurance index	62	12	55	10

Webb, 1964, ref. 107, p. 264.

Table 8
FORCES EXERTED ON HAND CONTROLS

Controls designed to be actuated by human force should be operable by the weakest individuals of the using population but able to withstand the maximum force the strongest individuals of the using population can apply. The tables show the maximum forces (measured in pounds) exerted on vertical or horizontal handgrips by male college students, tested in a seated position.

Vertical Handgrip

Right Arm						N = 55	Left Arm					
Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.		Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.
Push	60	34	92	150	38		Push	60	22	79	164	31
	90	36	86	154	33			90	22	83	172	35
	120	36	103	172	43			120	26	99	180	42
	150	42	123	194	45			150	30	111	192	48
	180	50	138	210	49			180	42	126	196	47
Pull	60	24	63	74	23		Pull	60	26	64	110	23
	90	37	88	135	30			90	32	80	122	28
	120	42	104	154	31			120	34	94	152	34
	150	56	122	189	36			150	42	112	168	37
	180	52	120	171	37			180	50	116	172	37
Left	60	20	52	87	19		Left	60	12	32	62	17
	90	18	50	97	23			90	10	33	72	19
	120	22	53	100	26			120	10	30	68	18
	150	20	54	104	25			150	8	29	66	20
	180	20	50	104	26			180	8	30	64	20
Right	60	17	42	82	20		Right	60	17	50	83	21
	90	16	37	68	18			90	16	48	87	22
	120	15	34	62	17			120	20	45	89	21
	150	15	33	64	18			150	15	47	113	27
	180	14	34	62	24			180	13	43	92	22
Up	60	20	49	82	18		Up	60	15	44	82	18
	90	20	56	106	22			90	17	52	100	22
	120	24	60	124	24			120	17	54	102	25
	150	18	56	118	28			150	15	52	110	27
	180	14	43	88	22			180	9	41	83	23
Down	60	20	51	89	21		Down	60	18	46	76	18
	90	26	53	88	20			90	21	49	92	20
	120	26	58	98	23			120	21	51	102	23
	150	20	47	80	18			150	18	41	74	16
	180	17	41	82	18			180	13	35	72	15

Source: Hunsicker (1955)

Table 8-Continued

Horizontal Handgrip

Right Arm -- Wrist Pronated						N = 30	Left Arm -- Wrist Pronated				
Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.	Direction of force	Elbow angle (deg)	Percentiles 5th	50th	95th	S. D.
Push	60	40	94	156	36	Push	60	33	86	138	35
	90	25	65	100	24		90	27	60	93	28
	120	23	46	70	15		120	17	43	71	17
	150	18	40	66	18		150	15	37	69	18
	180	17	32	59	12		180	12	32	59	13
Pull	60	13	37	50	16	Pull	60	20	39	64	18
	90	14	32	54	13		90	17	37	63	18
	120	13	26	43	10		120	12	30	56	14
	150	12	29	48	10		150	15	32	52	13
	180	11	28	48	12		180	16	34	61	r5 [sic]
Left	60	19	41	72	19	Left	60	20	42	66	15
	90	12	31	64	15		90	17	38	60	12
	120	9	26	53	13		120	17	34	53	8
	150	9	21	39	11		150	17	31	54	11
	180	10	19	34	7		180	15	28	41	8
Right	60	16	48	73	18	Right	60	18	36	51	15
	90	16	39	59	15		90	11	27	54	11
	120		34	47	11		120	10	22	39	10
	150	18	32	45	7		150	9	23	53	16
	180	16	31	57	13		180	10	20	49	13
Up	60	23	49	79	20	Up	60	22	57	100	22
	90	28	69	112	29		90	37	77	123	24
	120	41	91	138	30		120	45	91	145	30
	150	43	99	165	38		150	58	100	159	32
	180	35	95	156	35		180	47	101	171	
Down	60	23	61	158	35		60	18	74	139	35
	90	22	83	142	35		90	23	75	136	34
	120	37	92	161	35		120	29	75	148	
	150	40	90	154	34		150	39	79	136	19
	180	41	87	143	31		180	34	76	138	31

Source: Hunsicker (1957)

Woodson and Conover, 1964, ref. 114, pp. 6-19 and 6-20.

REACTION TIME

The speed with which we may react to a stimulus is, among other things, dependent upon:

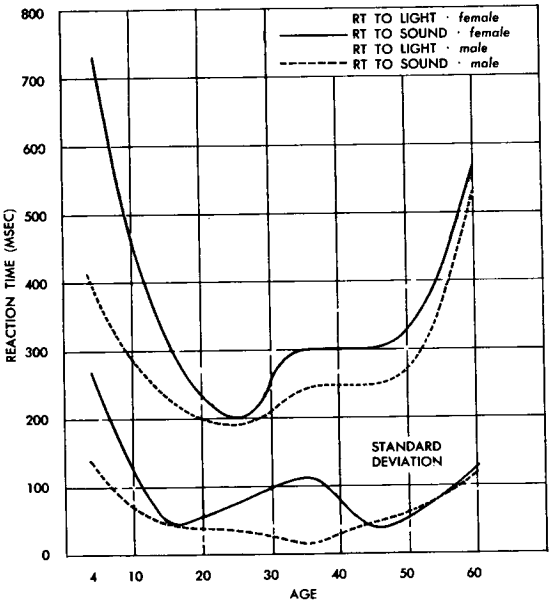
The sense to which it is presented — auditory reaction time (RT) is faster than visual RT (see graph below).

Stimulus intensity — greater stimulus intensities, up to a definite limit above threshold, decrease RT; above the limiting intensity, no reduction in RT may be expected.

Practice — simple RT may be reduced as much as 10 per cent by practice.

Preparedness — "ready" signals reduce RT.

Motor unit responding — right hand and foot are faster than left, for right-handed people.



Age and sex.

Complexity — reaction time may be simple, as when a key is pressed in response to a light, or complex, as

when a key is pressed only when a red, rather than an alternative green light, is flashed. The latter is complex, because a discrimination or judgment must be made before the reaction. An estimate for simple and complex RT can be obtained from the following formula:

$$RT \text{ (in milliseconds)} = 270 \log_e (n+1)$$

where n represents the number of discriminations required before reacting.

RT's to discrete, isolated stimuli have considerable variability. The minimum RT variability one may expect can be expressed in these terms: 50 per cent of the RT's in a set of responses will fall within a $\pm$15-millisecond range around the average RT of the set. Mean simple RT's do not often go below 150 milliseconds, even under the most favorable conditions. When responses are made at regular intervals to an external "pacing" stimulus or to one's own previous action (as in tapping), however, variability can be tremendously reduced and RT's can be as low as or lower than 100 milliseconds.

Speed of Perception -to-Action:

Brain perception of what eye sees	0.1	sec	
Brain recognition	0.4	sec	
Decision	4 - 5.0	sec	
Motor Response	0.5	sec	
Vehicle Reaction	2 +	sec	
	7 - 8.0	sec	Total

Cognitive. —

Ellis and Ludwig, 1962, ref. 27, pp. 74-75.

COMPUTER CHARACTERISTICS. Three papers are combined into a section entitled "Human Beings as Computers" in IRE Transactions, Vol. EC-6 (1957), pp. 190-202. These articles probably provide the best estimates currently available of certain computer-oriented characteristics of man.

Their most salient propositions can be summarized as follows:

(a) The human central nervous system is composed of about 10^{10} neurons, each of which acts, relating a

neuron to a component, as a distributed repeater.

(b) The principal function of the central nervous system is similar to that of computer for an enormously complex, multiple closed-loop (between 10^3 and 10^6 loops) servosystem.

(c) The output side of a neuron is called an axon. The principle axon connections number about 2×10^6 from each eye to the brain, about 5×10^4 from the ears to the brain, and about 10^6 from the remainder of the body of the brain.

(d) To date, there is no known transfer function covering all effective connections between neurons (these connections are called synapses). It is known, however, that all synapses behave as nonlinear filters and that, in general, beat-frequency coding is present.

(e) On the level of production of biochemical tools to sustain life (subconscious nervous control, chemical control, and metabolic coordination), man processes an estimated 3×10^{24} bits of information per day. The general pattern for these computations is contained in a "blueprint" of between 10^5 and 10^9 bits of non-redundant information. "Blueprintwise," man is only one or two orders of magnitude more complex than a bacterium.

(f) Current estimates place the quantity of information simultaneously storeable in the conscious human memory between 1.5×10^6 and 43×10^9 bits. The smaller number represents about 1000 times the complexity of the multiplication table, and the larger number represents the storage over 80 years of a person with perfect memory who receives from his environment and actively processes about 25 bits per second for 16 hours per day. A "reasonable" capacity is usually estimated to be about 10^8 bits.

3.0 Machine Performance Generalizations

3.1 Machine Capabilities

Statements: —

MAN	MACHINE	
Man has a built-in response latency, about 200 micro-seconds in a go/no-go situation.	Machines need not have a response latency. Can respond very quickly and consistently to control signals.	ref. 111 105 67

Machines can maintain performance over extended periods of time (machines typically do not "fatigue" as rapidly as humans). ref. 67

"Machines have a greater insensitivity than man to extraneous factors." ref. 99

"REPETITIVE OPERATIONS. Machines excel in repetitive and routine tasks; unlike humans, machines do not become bored or inattentive." ref. 27

"SIMULTANEOUS ACTIONS. Machines can be devised to carry on a greater number of simultaneous activities than man." ref. 27

Functions which must be done automatically include actions requiring a fast reaction time, or situation where an unfavorable environment for the pilot is inherent. ref. 109

Discussions: —

Edwards, 1962, ref. 26, pp. 92-94.

> It has ... been pointed out that the fundamental virtues of computers are speed and accuracy. The performance of many individually easy information-handling tasks, time after time and without error, is not at all easy for men; it is what computers do best. Consequently, any high-volume information-processing task in which the rules for processing are simple and

easy is just right for machine performance. And tasks which are not of this nature can often be made so by appropriate redefinition ...

The search process, important though it is for any logical operations the computer might wish to perform, contains a serious flaw: most search problems lead to unreasonably large sets of things to search. Even a safe can be made computer-proof by adding a few additional numbers to the combination. The key to getting around this is what has come to be called heuristic programming ...

Another task in which computers excel men is long-term storage. They remember immense amounts of information, and can reproduce it extremely accurately. It is seldom desirable for a man to commit something to memory if he can conveniently use a machine — perhaps as simple a one as paper and pencil — to remember for him ...

The other ways in which computers excel men as technical assistants mostly reflect human imperfections from which computers are free. Among them are: emotional attack on problems, slow speed of learning and necessity for repetition, egotism and unwillingness to be treated as a slave, laziness, and dishonesty. Note that illness is not listed; computers are often exasperatingly "sick" — which means that they do not give the right answer, for no easily discernible reason.

Finally, man-machine systems exist for human purposes, not the other way around. No matter how skillfully a machine can achieve an end, that end is a human end, not a machine end. This characteristic of computers is in principle unnecessary, but in practice it seems unlikely that men will make any serious attempt to liberate this powerful race of willing slaves.

Swain and Wohl, 1961, ref. 99, p. 29.

Responding quickly to control signals. Machines have microsecond lags, whereas the shortest which can be expected from man is about 200 milliseconds, and this only if he is set to make a movement upon the receipt of a GO/NO-GO signal. If a decision is required, the human response time increases rapidly. Moreover, man becomes fatigued rapidly under conditions requiring a series of rapid decisions. Speed, then, is one of the primary qualities of machines.

Swain and Wohl, 1961, ref. 99, p. 29.

> Insensitivity to extraneous factors. Machines have a greater insensitivity than man to extraneous factors. They have no moral problems. They do what they're told to do. Perhaps this is at once the machine's greatest advantage and its greatest disadvantage. The advantages tend to be emphasized by design engineers, especially those who have seen equipment misused in the field. The disadvantages tend to be emphasized by field personnel, especially those with high levels of skill who see aspects of this skill being replaced by machines.

Ellis and Ludwig, 1962, ref. 27, p. 73.

> PREDICTION. "By being alert for changes, human beings can frequently anticipate undesirable conditions." The statement is no doubt true. It no longer, however, applies uniquely to human beings, for adaptive systems, or systems exhibiting "intelligent" behavior, have usurped another niche in provinces formerly enjoyed only by organisms. The designers of so-called adaptive systems refer to "goal-oriented" behavior — toward the achievement of an objective by the machine system.

Westbrook, 1959, ref. 109, pp. 7-8.

> We may conclude that certain functions must be done automatically. These include those actions requiring a fast reaction time or where an unfavorable environment for the pilot is inherent. Most actions in the blast-off, exiting and certain re-entry trajectories fall into this category. Certain functions might best be done automatically. Included in these would be continuous, long time, repetitive and boring action in which the pilot's attention would wander and his performance suffer. An example of this type of action would be continuous, tight, attitude stabilization in space flight.

3.2 Machine Limitations

Statements: —

"Machines generally have limitations in their abilities to adapt to unexpected variations in situations. (Machines typically have to be programmed in advance to perform predetermined activities under certain specified circumstances; where it is difficult or impossible to anticipate various possible circumstances, and to program for such, machines are at a distinct disadvantage to man.)" ref. 67

"Machines generally have limitations in their abilities to learn, or modify, behavior on the basis of experience." ref. 67

"Machines generally have limitations in their abilities to reason, make subjective evaluations, and weigh various considerations that cannot be programmed in advance." ref. 67

"Machines generally have limitations in their abilities to improvise." ref. 67

"Machines generally have limitations in their abilities to use uncoded information. (Machines require information in coded form; humans can utilize much information in uncoded form.)" ref. 67

Discussions: —

Krendel and Bloom, 1963, ref. 61, p. 27.

Consistency — An Attribute of Skill

On an intuitive basis it might appear that the performance of machines would always be more consistent than that of men. Interestingly enough, with complex equipments, the opposite is more often the case. Even such relatively simple devices as radar equipment often exhibit surprising variability compared with their human operators. In an unpublished study cited by Chapanis (1959), variations between individual radar sets of the same model were found to be much larger than differences among operators. Indeed, in his studies on detectability on radar scopes, Williams (1949) found so much variability in cathode ray tubes that he could not

use electrical measurements of circuit parameters as the independent variables. In the case of entire aircraft systems the machine variability is, of course, substantial. As a matter of fact, pilots tend to characterize certain of supposed identical individual craft as "mushy" and others as "touchy". In a similar vein, Bray (1958), reports on experiments on interceptor gunnery performances as measured by actual firing on targets. Variability between pilots was normally of little importance compared to variability within and between aircraft; he goes on to state:

> "In other words, the hardware varies within itself and from one item of hardware to another so greatly as maintenance and adjustment are normally carried out that the pilot matters little, if at all."

The significant value of man in terms of his ability to increase system reliability — measure of consistency of system output — has been dealt with by McRuer, Ashkenas, and Krendel (1959), in connection with the current manned vs unmanned space craft controversy; and Anderson (1958), has presented a quantitative discussion of the increased system reliability afforded by the use of manned space vehicles in comparison with unmanned vehicles.

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4.0 System Effectiveness Considerations

4.1 Man-Machine Effectiveness

Statements: —

MAN	MACHINE	
May be able to perform better in certain cases of transient overload than machine; i.e., may be able to tolerate temporary overloads without complete disruption. Man's performance degrades gracefully.	May break down completely if overloaded; i.e., information handling capacity fixed: overload leads to disruption of system.	ref. 111
Man is reasonably reliable. He can add reliability to system performance by selection of alternatives.	Machines are reliable only at the expense of increased complexity and cost; then only for routine functions.	ref. 111
Man can detect his own mistakes and correct them.	. . . computers make far fewer mistakes than men, their mistakes generally either remain unchecked or stop the computer completely.	ref. 26
If one part of the nervous system fails, correct functioning of the whole system will be restored by use of other parts of the nervous system.	Electronic systems at the present state of knowledge will malfunction even if only a single circuit element fails.	ref. 95
"Relatively inexpensive for available complexity and in good supply; must be trained."	"Complexity and supply limited by cost and time; performance built in."	ref. 36
"Light in weight and small in size for function achieved; low power requirement, less than 100 watts."	"Equivalent complexity and function would generally require radically heavier components and enormous power and cooling resources."	ref. 36

"Easy to maintain with minimum of "in task" extras."	"Maintenance problem becomes disproportionately serious as complexity increases."	ref. 36
"Nonexpendable and interested in personal survival; emotional."	"Expendable and unconscious of personal existence; will perform without distraction from problems arising outside of task."	ref. 36
"Performance may deteriorate with time; usually recovers with rest."	"Behavior decrement relatively small with time; wear maintenance and product quality control necessary."	ref. 36
Total available manpower is limited.	Within wide limits, the problems of raw materials from which to produce machines within a system are not crucial.	ref. 49
It is difficult to predict how and to what extent men's functions can be modified (through training and experience).	Machines are often modified so as to change or improve their functioning.	ref. 49
It is difficult to determine how well individuals are meeting the specifications of their job activities.	There are reasonably straightforward procedures for determining how accurately machines meet their performance specifications.	ref. 49
It is not typical that men leave the system because of wearout or because new and better types are required.	Turnover is a result of replacement due to wearout or development of better machines.	ref. 49
For any particular function there is a definite limit to how well or how much of something a person can do.	These limitations are often greatly exceeded by machines.	ref. 49
There are great individual differences with respect to how effectively a group of men can carry out a specified performance.	Machines are usually designed to specifications for a particular purpose, so that there will be no great variation among them.	ref. 49

"... the addition of man to a spacecraft system will assure high reliability by his abilities to operate, manually override, maintain and repair vital spacecraft functions." ref. 1

In complex systems man makes the most significant contribution to output consistency; he can learn to adapt to changes in the system input. ref. 79

"Man can change his own operating characteristics so as to optimize system output in terms of some specified criterion." ref. 34

"Man can compensate for many sources of bias or constant error in systems." ref. 34

Discussion: —

Horst, 1962, ref. 49, pp. 233, 234.

> Individual Differences. Another important difference between men and machines is this: for any particular action to be accomplished, there are great individual differences with respect to how effectively a group of men can carry out a specified performance; whereas machines are usually designed to specifications for a particular purpose, so that there will be no great variation among them. For example, in the case of bomber planes such as B-52s, little variation in performance characteristics may be expected. However, one may expect considerable variation in a group of trainees with respect to their aptitudes for piloting B-52s.

Horst, 1962, ref. 49, p. 234.

> Upper Limits of Performance. Another important difference between men and machines is that for any particular function there is a definite limit to how well or how much of something a person can do, whereas these limitations are often greatly exceeded by machines. As a matter of fact, one of the primary roles of machines is to do better in, or more of, a particular activity than men can do. For example, with rare exceptions, men cannot lift 500-lb. weights, whereas machines can be developed to lift many tons ...

Modifiability. Another important difference between men and machines is that while both may be modified, the nature of this modifiability requires entirely different procedures. It is true that machines within systems are often modified so as to change or improve their functioning. It is also true that with training and experience the functioning of individuals or men can be modified. But it is much more difficult to predict how and to what extent men's functions can be modified than it is for those of machines. The difficulty in predicting the extent to which performance can be modified or improved for different individuals creates one of the most troublesome problems in personnel selection and classification. We can make machines to specification, given the raw materials. It is misleading however, to press the analogy and say that given raw recruits, we can also train or modify them precisely to specifications. This, of course, is the purpose of training programs ...

Horst, 1962, ref. 49, pp. 234-235.

Checking Specifications. Another important difference between men and machines has to do with their specifications. Presumably, in a man-machine system, just what the machines are to do has been spelled out in considerable detail. Presumably, also, there are reasonably straightforward procedures for determining how accurately the machines meet these specifications. This is true whether one wishes to find out how closely a ballistic missile will find its target ten thousand miles away or to check the washability of an army private's work fatigues.

The problem is far from being as simple in the case of the man component of the man-machine system. Although a task description and analysis for the various elements of a man subsystem may be provided in great detail, and although there may be a pretty good knowledge of human capacities and limitations in general, the problem of determining whether a particular individual satisfies a specification based on these various analyses is nevertheless not simple. Instruments may exist which may be assumed to measure these functions and so give an indication of the potential performance of the individual in a man-machine complex. But the problem of selecting and classifying individuals from a potential pool into the personnel subsystem of a man-machine system is one which, in the current state of our knowledge, requires in addition adequate models

for testing the validity of the hypotheses and instruments employed.

Checking whether individuals meet the specifications before being assigned to job activities is only one of two very important related problems. The second involves the determination of how well personnel assigned to job activities are actually meeting the specifications of those activities. Estimates of how well men are satisfying requirements of the job are called criterion measures. The logic of assessing human performance is considered ... [elsewhere]. As we develop the model of personnel selection and classification, however, we shall see that an essential part of this model consists of assessing human performance within the man-machine system. The problems of such assessment are comparable to those of checking specifications of individuals before they are placed in the man-machine system.

We may hypothesize that if individuals satisfy certain specifications, they will also satisfy corresponding job requirements. One of the great problems in verifying hypotheses is to get enough experience on the basis of which reliable conclusions can be drawn. We must have an adequate number of cases on the basis of which to validate our logical analyses, and this requirement must be incorporated in the personnel selection and classification model.

Edwards, 1962, ref. 26, pp. 95-96.

[The following three virtues of men in competition with computers] ... are crucial for most current man-versus-computer problems in man-machine systems.

The first of these is that in a very important sense men are far more reliable than computers. It has already been pointed out that computers make far fewer mistakes than men. But in general the mistakes computers make either remain unchecked or stop the computer completely. Man, on the other hand, can detect his own mistakes and spontaneously work out a plan to correct them or remedy their effects. Furthermore, once he has learned how to perform a task correctly, man does not repeat and repeat the same error, as will a computer with a broken part. In short, if a little allowance is made for the approximate nature of human reliability, man is far more reliable using any computer yet invented, or any likely to be invented in the near future. Of course, some computers are to a degree

self-correcting even now, and most large future computers will embody various kinds of self-correction features. But the versatility of human beings in dealing with error is an extremely remote goal indeed for computer technology. This human reliability characteristic is so important that major systems are likely to continue to include human components for a long time to come for this reason alone.

Perhaps the most practical advantages of men over computers, of course, are in cost and availability. Consider a system which has an expected life of ten years. Over that period, it might cost $120,000 in salary to employ one man to tend the system. The system for personnel support and other indirect personnel costs might over that time cost another $120,000. That puts the cost of one human brain, for many purposes the most effective computer now available, at something like $240,000 over a ten-year period. By contrast, an IBM 709, for many purposes much inferior to the man, costs something like $1,000,000 per year, or more than 40 times as much as the man over the ten-year period. Even if the system were to operate 168 hours per week, which requires at least five men for each operator position, the computer would be much more than 10 times as expensive (since the cost of supporting it would go up with round-the-clock usage). Of course, the 709 can do many things that men cannot do, and vice versa; which is preferable depends on the specific nature of the job to be performed. But the man has a powerful built-in economic advantage, which is not likely to change very much with time.

Availability is important also. There are many men, and at least a third of them can be trained to perform difficult intellectual tasks. There are few computers, and the number of really large ones is unlikely to become as large as, say, one millionth of the number of men. So men not only are cheaper, they are also easier to obtain.

Edwards, 1962, ref. 26, pp. 100-102.

Design Principles for Systems which Include Computers

Computers and men perform little-understood functions in competition with each other, and the system designer must, for each function included in his system, resolve the competition in favor of one or the

other. Unfortunately, the necessary scoring system is hard to find; these functions in human beings are not well understood, and in computers the score is constantly changing as technology advances. Still, some principles appear to be relatively valid and stable guides to good design practice.

The first question the designers of a new system must face is whether or not the system should include a computer. The sheer ecomonic considerations already discussed are important but not conclusive; social costs, such as technological unemployment and the cost of training system operators and technicians, must also be considered. Once the decision to put a computer into the system has been made, several general principles concerning the design of computerized systems can be used to guide design. [Principles applicable to core performance are covered in the appropriate section.]

1. Allocation of functions among men and computer should consider the best skills of each. It is seldom wise to allocate to the computer everything the designer knows how to mechanize, and to parcel out among the system operators whatever is left over.

2. If possible, the computer should be about 80 per cent used; if it has too much unused time or capacity, either a smaller computer should be used instead or tasks for which it is less than ideally suited (such as long-term memory) should be given to it. Computers do not profit from rest periods, other than the necessary halts for maintenance and repair; men do. On the other hand, tasks change, and a little flexibility is therefore desirable.

3. Provision of one sort or another must be made for system function during computer malfunction. This often implies either a second computer or a manual back-up system. In some cases, of course, no meaningful provision is possible or worthwhile.

4. Yet another important human function in computerized systems is censorship. Men monitor the output of computers, with responsibility to veto computer actions when it seems appropriate to do so. Unfortunately, as systems get more complicated and their tasks become more demanding, it will be more and more difficult for men to censor system output effectively. They cannot assimilate enough information to be sure whether the system is right

or wrong, except in the case of gross malfunction. More important, systems can seldom tolerate the response of doing nothing, and men often cannot accumulate the information or the time to supply alternatives to the computer's recommended course of action. So the veto function will become more and more symbolic, and the commander's telephone line will play a less and less important role in the system's functioning.

5. It will continue to be true that systems which include computers exist to serve human purposes, so system goal-setting will continue to be a human function, the most important human function in the system. However, that function will be performed mostly by the designers of the system and those who write the computer program; the nature of system design pretty completely determines the goals which it can effectively further.

The most serious problem which can arise as a result of using men as on-line components in a system which also includes a computer is caused by the severe mismatch in rate of performance between men and computers. Computers ordinarily perform their operations very fast indeed, while human beings are ridiculously slow by comparison. To make a computer wait while a man performs some function on line is extremely wasteful of computer time. It is worth doing only if the function cannot be satisfactorily performed in any other way. The assumption which underlies the preceding discussion is that cases in which that penalty is worth incurring are fairly frequent. Some psychologists and computer experts disagree, arguing instead that men should perform only off-line functions such as goal-setting, monitoring, and censorship. Some systems must function so quickly that human bottlenecks cannot be tolerated; it seems probable that antimissile missile systems would fall into this category. But for most slower systems, and in particular for most civilian systems, the advantages of exploiting human skills far outweigh the disadvantages of putting up with slow human reactions.

Steinbuch, 1965, ref. 95, p. 481.

A substantial difference between the human nervous system and automata is the following: if through damage or illness one part of the nervous system fails, correct functioning of the whole system will be restored by making use of other parts of the nervous system. Electronic systems at the present state of knowledge will malfunction even if only a single circuit element fails. In more sophisticated systems duplication of important parts of circuitry allows internal failures to be indicated, sometimes even corrected.

It is interesting that recently electronic systems have been designed in which the principle of self-correction is used, perhaps similar to that of the nervous system. This would be useful for space flights where regular checking and maintenance by service personnel is impossible. (Steinbuch and Zendah, 1963)

Steinbuch, 1965, ref. 95, pp. 481-482.

The fundamental theory for the design of self-checking and self-correcting codes is the following: For the transmission of messages from transmitter to receiver, signals must be used. If the messages are not encoded with the minimum number of elements, but some additional elements, the so-called "redundant elements", are added, then the human or mechanical receiver can recognize or even correct the messages perturbed by noise. The margin for noise can be made as large as necessary by adding more redundant elements.

Performance in punching cards seems to be a good measure for the relative reliability of man and automata. A man in the long-term average makes about one per cent of the errors in punching cards (to reduce these, checking by another person is provided). In automata, the error rate in punching cards is less by several powers of ten. Apparently the reliability of man at simple manual tasks is decreased when the outside environment proves to be distracting.

Amorelli, et al., 1964, ref. 1.

The concept of mission success and human safety are related but obviously are not the same. Spacecraft reliability and human safety requirements differ considerably. Abort provisions are made for conditions of spacecraft failure in order to insure human safety. Thus, this concept of safety is independent of mission success. Systems design, on the other hand, must consider the corollary, i.e., mission success must be dependent upon human performance. This is the area where the talents of man must be utilized. Obviously here one is not considering minor changes or degradations of function but inability or failure to perform critical operations. This implies, therefore, that the criteria for human performance is mission success and that failure to perform adequately may mean a catastrophic error. Human reliability considerations seldom reflect the attitude that human performance must be measured primarily in terms of mission success.

Wherever man is involved in a space system, human engineering techniques must be applied in order to establish the reliability requirements for a manned system. If the reliability program is to be most effective, it must consider the reliability of the personnel who will be engaged in design and construction, ground support, and operation of the spacecraft. It is possible, with present techniques, to establish human reliability values for some functions and should be possible for all important or vital human operations. Such human reliability values would be most valuable in planning space crew operations. Human reliability predictions are made from empirical test situations and, as such, are quite valid. These empirical values should only be used when system reliability is determined in the same fashion. In this way, human reliability is based on desirable but unobtainable values, as is frequently done in pre-design requirements, and not on analysis of actual past performance, it appears much better than human reliability values. Such a distortion frequently leads to statements about the poor reliability of the human subsystem. In truth the addition of man to a spacecraft system will assure high reliability by his abilities to operate, manually override, maintain, and repair vital spacecraft functions. This approach to reliability assurance is the major consideration of this paper. ...

In the limited Mercury series the reliability increase attributable to man varied from 0% to 100%. The X-15 series of flights is many times more extensive and therefore the data are more meaningful. There has been a sufficient number of flights with varying objectives and flight envelopes on which to base the preliminary curves shown in Figures 1 to 4 inclusive, and to indicate a rather conclusive trend. As of this writing peak altitudes have ranged from 42,640 to 351,000 feet; and the maximum velocity from M1.57 to M6.06.

Figure 1 indicates an inoperative ballistic control at the start of tests. Later, as improvements were made, the pilot was able to decrease progressively his work load in this area.

Figure 2 indicates the typical communications "bugs" in the early phases, with a rather consistent improvement.

Figure 3 illustrates the major role that a pilot can play in insuring mission success. First flights were very dependent upon the pilot for complete success.

Figure 4 illustrates a system that was unsatisfactory; it was redesigned to attain and hold a satisfactory performance level.

It will be noted that this paper suggests no firm percentage increase in reliability that should be expected due to the presence of man as a recognizable redundant or supplementary subsystem. This is due to the varying demands or requirements that may arise during a given mission.

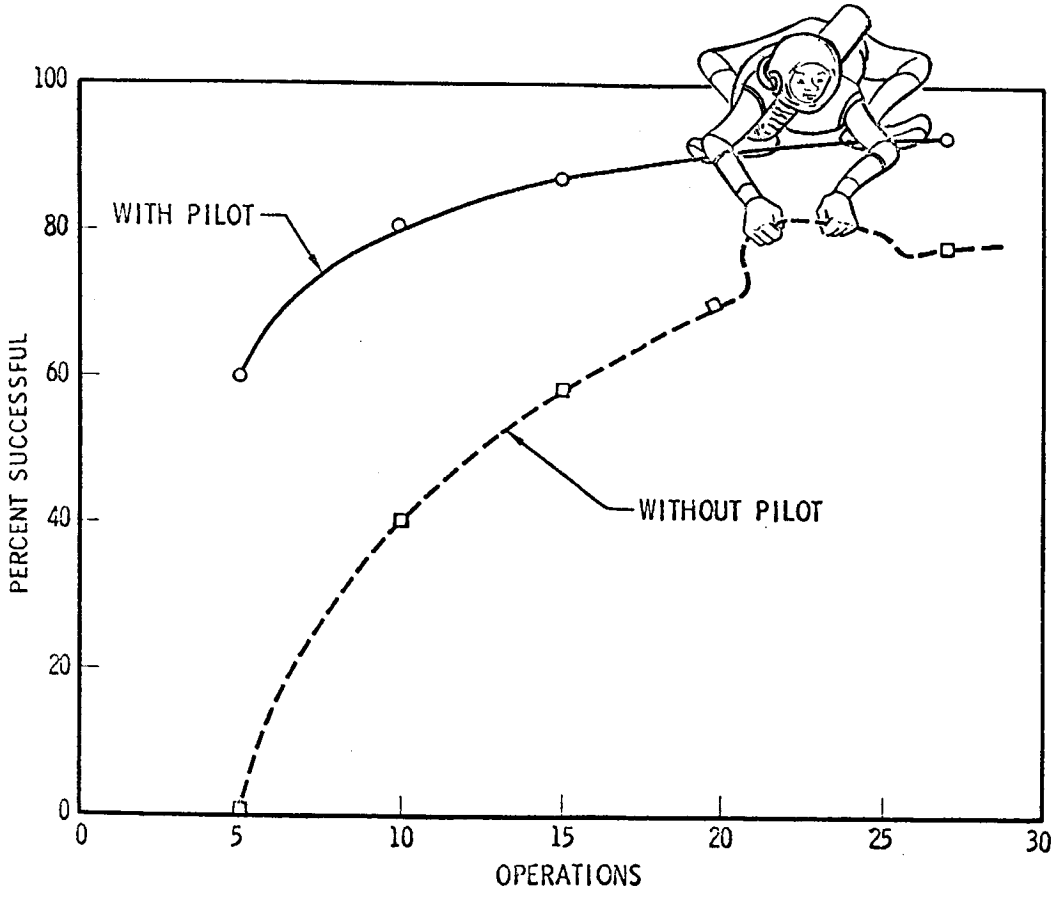


Figure 1. X-15 Ballistic Control Subsystem - Inoperative Ballistic Control

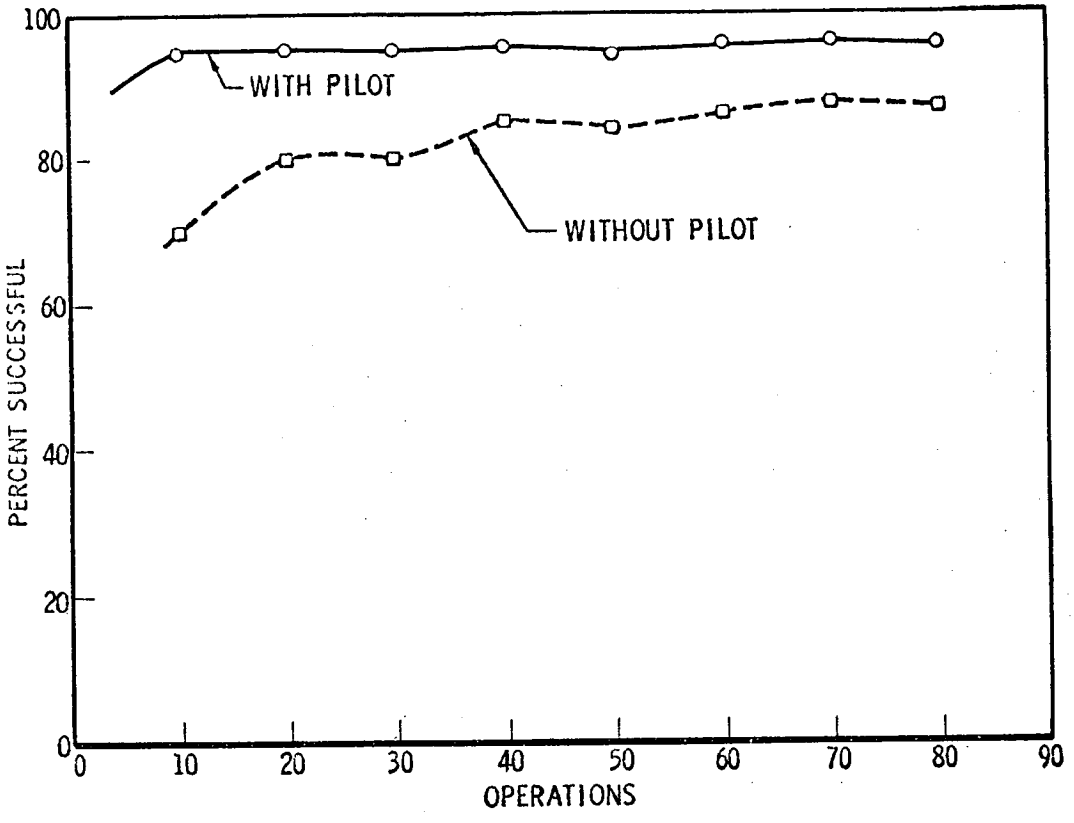


Figure 2. X-15 Communication Subsystems - "Bugs" in Early Phases

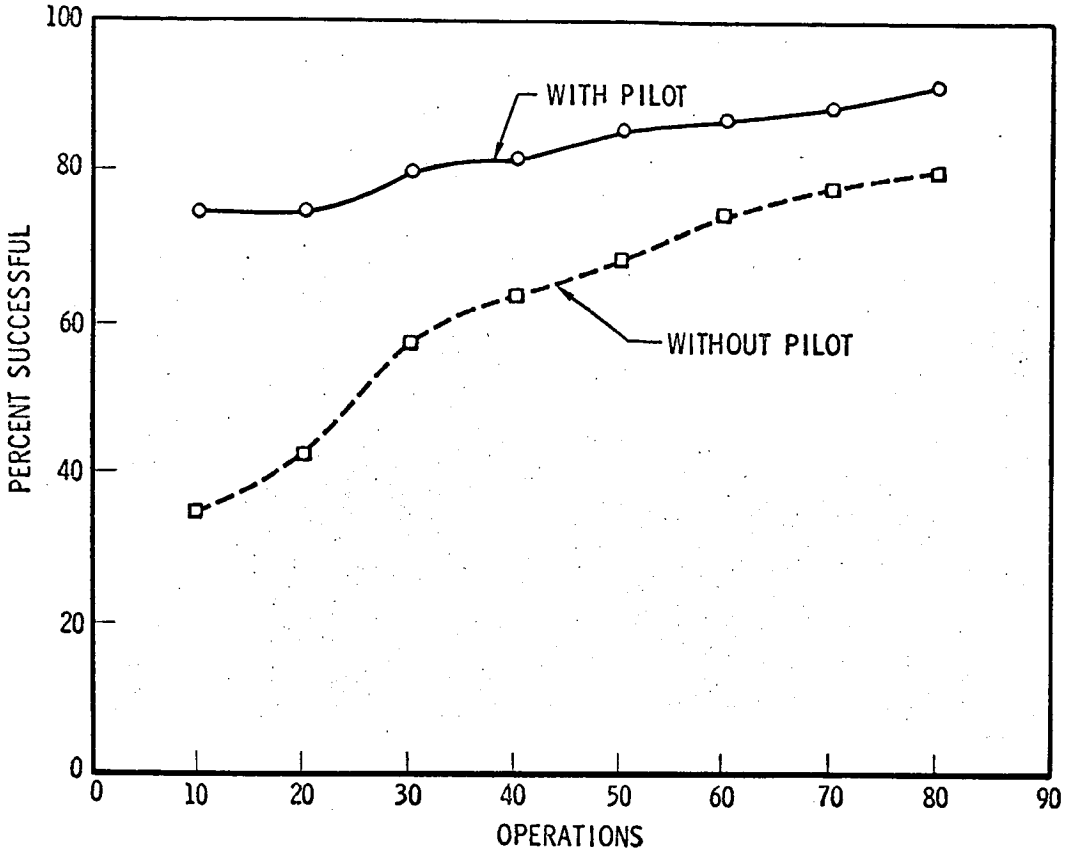


Figure 3. X-15 Propellant Subsystem

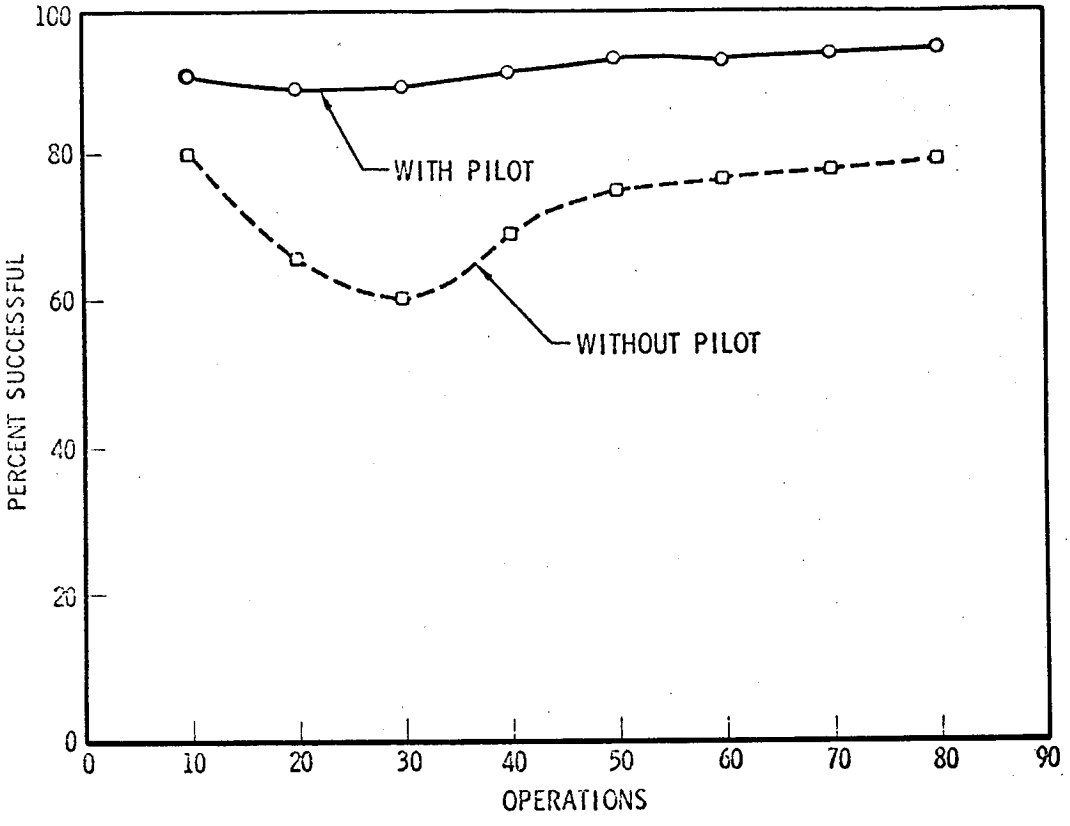


Figure 4. X-15 Stability Augmentation Subsystem

Amorelli, et al., 1964, ref. 1.

ASSETS AND PENALTIES OF MAN IN A SPACE VEHICLE

In theory, the effectiveness of man in space, compared with a machine, can be resolved in terms of which has the least weight and bulk and makes the most efficient use of power. In practice, however, there is no precise way to make this comparison. For the present, and possibly for a long time to come, there are many variable factors which require the use of man in successful space exploration.

Space crews will, of course, face intense stresses, but these need not be a great deterrent to successful space operations. An understanding of the effects of these stress phenomena and vigorous scientific research into their conditions and implications could result in a space program with a reasonable expectation of success. At present, the types of stresses involved in critical operations under unnatural environments are just beginning to be known. There is a distinct need for a mature, integrated and cooperative program which will attempt to simulate space conditions and select crew members and train them for all situations they may encounter.

A prerequisite for the most efficient use of men and machines in space is, that all environmental needs for human existence have been provided. These needs can be satisfied through research and through design and production of suitable equipment which protects man in a space environment within certain limits which are established here.

In general, the ultimate balance between man-performed and machine-performed functions cannot be predicted until both engineering development and biotechnical experiments have been carried out. Consequently, what follows is an emphasis on principles rather than a close specification of either engineering design or human task performance.

In space, man is needed to function as a strategist, to correlate low probability data and interpret these data intelligently, and to formulate effective plans of action. While a machine might be designed to perform some of these functions, it would be very large, complicated, and unreliable.

Man is needed as a scientific observer of space phenomena. He can control the instrumentation toward the most significant readings, make the unexpected observation, and gain basic insights into the pattern of results.

4.2 Human Acceptance and Reliability

Statements. —

"Man can often increase his reliability to meet the demands of the task." ref. 33

"Man can trade off time for accuracy." ref. 34

As a class, man is not very well standardized; not only in terms of specific factors, but in patterns or combinations of human characteristics. ref. 91

"Man has a great deal of built-in variability. It is difficult to predict with great accuracy exactly how a man will perform in any specific situation. Depending upon the particular task, and also upon many changing factors—motivation, state of health, experience—man's performance may be outstanding on one occasion and very poor on another." ref. 91

"If the functions required of individuals in a system turn out to be ones which men refuse to accept willingly, then a great many undesirable by-products may result." ref. 33

"Men are generally accepting of systems roles which give them an opportunity to exercise and, therefore, maintain skills which they feel are important to maintaining their position in the occupational and social status system in which they are immersed." ref. 79

"Men are more accepting of roles which permit them to learn." ref. 79

"Acceptance by human operators within the system will be greater toward the higher responsibility/authority (R/A) roles than toward the lower R/A roles. It is now known that acceptance is definitely negative if human beings are designed into the system at a lesser level of R/A than they are capable of accepting and performing. The result is to reduce system reliability." ref. 79

"The higher R/A roles in systems are apt to have more cognitive performance associated with them. These types of performance are where man does excel and where it is difficult and expensive to build equivalent machines." ref. 79

"Design decisions concerning the implementation by men or machines for the higher order of R/A roles will influence the requirements for the lesser order of R/A roles. Thus every conceivable means, including utilization of man, must be considered to approach the optimum design solution and reduce the negative consequences of poor design." ref. 79

The greater the experience, the greater the acceptance of automated equipment and the greater the use of it.

The greater the concern for an area of work and for its future, the more accepting of automated equipment providing it meets certain minimal criteria.

The greater the altitude at which a function is performed the greater the acceptance of automation of that function.

The greater the possibility for corrective action in the case of a malfunction of an automated function, the greater the acceptance of the automation of that function.

The less the function pertains to initial decisions, the greater the acceptance of automation of that function.

Discussion. —

Fitts, 1962, ref. 33.

Human Reliability

... Man's performance varies as a function of alertness, fatigue, and stress. Different people vary widely. In the present context, however, one point should be emphasized. Man can often increase his reliability to meet the demands of the task. In driving along a highway at 60 miles an hour, for example, it is obviously desirable to keep the automobile from straying into the opposite traffic lane. In this instance reliability is a life-or-death matter. Fortunately, it is a function which many individuals perform hundreds of times a day with small likelihood of a serious error within their lifetime. Elsewhere, the present author has estimated that, given any two cars which are closing with a speed of 120 miles an hour and must pass with a

clearance of 5 to 10 ft, the probability of a head-on collision is somewhere on the order of 10^{-9} or 10^{-10}. The generalizations about reliability hold, however, only if an individual realizes that reliable performance is required—as, for example, in the case of landing an airplane or passing another car....

Speed-Accuracy Trade-Off

Man has unique ability to interchange speed for accuracy. He can solve an arithmetic problem quickly in his head by using approximations, or he can find the answer to any required number of decimal places by using paper and pencil. A typist can produce a rough draft very quickly, or she can produce a perfect copy in a longer time, depending on which is requested. Thus, in spite of man's low information-handling rate, given sufficient time he can perform certain functions that require a great deal of precision. Man's capacity to trade off time for accuracy has very important implications for system design.

What Functions do Men Prefer to Perform in Systems?

A meaningful question, but one that often is not asked by the system designer, has to do with man's preferences for, and his acceptance of, different roles and functions in complex systems. From a humanistic point of view, it is of course desirable to maximize man's satisfactions, including those derived from the work in which he is engaged. If we accept this goal in system design, we are led to consider the effects of automation and other technological changes on the worker, and the degree to which the roles assigned to a man enable him to find satisfaction in his work. These are legitimate issues for engineers to consider in designing systems.

It is important to consider human preferences for another reason. If the functions required of individuals in a system turn out to be ones which men refuse to accept willingly, then a great many undesirable by-products may result. These by-products include absenteeism, labor turnover, low re-enlistment rates, strong demands for side benefits, and often poor job performance. Thus, except in unusual circumstances, it is desirable—for system designers to pay considerable attention to the degree to which a man will accept his proposed role in a new system.

Swain and Wohl, 1961, ref. 99, p. 27.

Ability to Perform When Overloaded

The human is capable of withstanding high conditions of loading that might cause a complete breakdown in a machine. That is, the human frequently can perform at a less optimum rate or at a lower level of proficiency under high load conditions, but he usually can continue to perform. This quality of "graceful degradation" is found in some machines, but to a lesser degree than in humans. However, this human ability is related to man's ability to generate his own inputs, and the negative side of this ability is the possibility that these inputs may be irrelevant to a solution. Thus, the human introduces internally generated "noise" to the man-machine system, and this can be part of the "overload."

Sinaiko and Buckley, 1957, ref. 91, pp. 13-14.

Differences Among Individuals

One of the most troublesome things about man as a system component is that fact that, as a class, he isn't very well standardized. In terms of . . . [many characteristics] . . . —physical size, data sensing, data processing, capability for learning, etc. —men differ widely from one another. Within limits, men differ in their sensory skill levels, their ability to utilize information, their motor skills, their ability to learn, their reaction to social and physical environmental factors, the strengths and types of their physical and psychological needs, their ability to coordinate their own activities and abilities, and their ability to keep their performance from being affected by their emotions, needs, and hardships.

Not only do people differ from each other in terms of specific factors, but there are wide differences in patterns or combinations of human characteristics. Two men of identical height and weight do not necessarily have similar perceptual or learning skills. And, because it is known that combinations of abilities are necessary for certain human tasks, psychologists use specific techniques in trying to select people for jobs. Men are chosen for flight training not on a single criterion, such as height or physical strength, but on a multiple criterion basis: tests of mental ability, physical examination, motor skill, size and weight, and so on.

It is important to note that most human characteristics are distributed in a "normal" or Gaussian fashion. While

there are extremes of all types in the population, the design engineer should keep in mind that there are far more people who are "average," in terms of most human abilities, than there are extreme cases.

Price, et al., 1964, ref. 79, pp. 64-70 (Chapter IV—ACCEPTANCE)

Man-machine system design has typically utilized data as to man's sensory, perceptual, cognitive and motor capabilities in allocating functions to man or machine, and in designing interfaces. However, man's motivational system (i.e., acceptance) has not been systematically included in man-machine system design. This is a serious error as a highly motivated man can compensate to a considerable extent for poorly designed equipment to maintain system output. Conversely, a man dissatisfied by a machine function, due to status, economic, or survival fears, or simply a desire to perform the function manually, because it is a function man enjoys, may not properly use equipment which has been designed to fit all other criteria. Consequently, the system output may suffer. Acceptance factors are most critical, and will have a maximum effect on system effectiveness, in the role area. As the design of man's role is a major output of System Design, ... it is important to include acceptance factors at this point. Acceptance factors should also be considered at the later design efforts, but they become less and less critical as Task Design, ... is approached.

Acceptance problems could be defined as any frustration of any human need. It is not necessary, however, to consider all unmet human needs. The purpose of the model being developed is to increase the efficiency of the man-machine system design process, not to make an academic contribution to the theory of motivation. Consequently, it is only necessary to add to system design some methods for delineating and preventing acceptance problems which are not resolved by current techniques. For example, sexual deprivation occurs in many manned systems, and is a need frustration which could be considered an acceptance problem. However, the possible effects of human need frustration due to the system environment, including sex frustration, are always considered in system design, and do not need to be pointed out again. The neglected acceptance problems, which need additional techniques to be resolved, are in the areas of role development and the means for obtaining and maintaining human capability. The acceptance problems with which the present approach is concerned are those man-machine interactions which do not satisfy human expectancies as regards mode of performance, social status, economic status or perceived survival probability....

Current Acceptance Problems in Man-Machine System Design

Automated functions. - Automated systems are man-machine systems in which some tasks are performed by machines. These systems all include manual tasks, although they may be performed at a remote time or place. Where man is a system component, he must be designed into the system in an optimum manner, like any other system component.

Current automatic methods for implementing tasks frequently do not solve the problems they are designed to solve, and, in fact, create new problems. For many years to come automated systems will be man-machine systems that, at a minimum, will require man to initiate the machine functions, monitor them, and decide when to disengage and override them. However, if all man-machine interfaces are not optimum, system effectiveness cannot be optimum, as the system will be under-used and/or used improperly, either covertly or overtly. Traditional human engineering, usually performed after the system has been designed and the breadboard equipment developed, has been applied as if man were rational and it were only necessary to consider such aspects of man as his perceptual and motor capabilities. In actual fact, however, it is equally important to consider man's fears, anxieties, aspirations, etc., as part of the design efforts.

Acceptance problems created by lack of confidence in the effective and reliable performance by hardware of automated functions must be considered independently of whether in fact the hardware is effective and reliable.

What is necessary is the utilization of data on human attitudes toward the automation of specific system functions and how they are automated. This information must be used when man or machine function allocation decisions are being made. This will permit the incorporation of acceptance factors as additional criteria in trade-off analyses, which already include a consideration of the performance capabilities, costs and reliabilities of man and machine components. It may be found, for example, that a decision to automate a particular system function based upon sound engineering considerations would produce a degree of negative acceptance that would clearly offset the anticipated advantages of the engineering solution. These cases should be systematically identified in a manner which would provide for a timely consideration of their importance, i.e., prior to the final specification of the system configuration. Where trade-off analyses which include acceptance criteria indicate a

machine allocation and means of implementing machine automation that will result in substantial nonacceptance, other methods for increasing acceptance need to be introduced. This is not as radical an innovation as it sounds. After all, we are using man as a system component. And we would not use a hardware component that would reduce the reliability of other hardware components without considering alternative designs, or taking steps to restore the reliability of the second component.

Skill maintenance and development. - The morale of man is frequently lowered if he is not functioning at what for him is a high skill level. Aristotle defined happiness as functioning at the highest level one was capable of. More recently, Nissen (1954) in his paper on motivation stated that "Capacity is its own motivation." Consequently, if a man's system role does not permit him to exercise his capabilities, or capacity, he will become frustrated and lose motivation for performing his assigned and expected system tasks. As Firstman and Jordan (1962) pointed out:

> The problem of maintaining skills has many psychological ramifications. A highly skilled person is "insulted" if he is given a task that does not call for his using these skills. He has invested much more time and energy in achieving his highest skilled performance and takes pride in it. People like to "show" others and see for themselves that which they take pride in. They expect to be able to do it in their job; being unable to do this is very frustrating. This frustration is aggravated by the awareness that the job does not permit them to keep the skills they acquired with so much difficulty.... So far as possible, equipment should be so designed that men of various proficiency levels can use it effectively. For example, both a novice and a highly skilled technician use meters; the difference being what they can do with meters. This "open-end" demand on the skill of a novice operator motivates him to increase his proficiency, and, as a by-product, makes him readier and more able to improvise and solve problems in times of emergencies.

The frustration of desires to exercise and maintain one's skills is a serious and common problem. An example is the very infrequent use on commercial airliners of the ILS-Autopilot Coupler, which was designed to make automatic landing approaches under low visibility conditions, and thereby permit the pilot more time at this critical point in landing for monitoring and scanning, by relieving him of the tedious servo task of staying on the radio beacons. In a study in which the non-use of this equipment was investigated, Smith and Price (1963), it was noted that a frequent explanation given by the pilot for not using this automatic equipment was that they needed to fly the plane themselves, during the low visibility conditions in which the ILS-Autopilot Coupler should be used, in order to maintain their proficiency.

This problem of not being permitted to maintain and improve a skilled capability can become compounded by an expectancy problem. Frequently, a man will be led to believe that he will function and learn at a higher level than in fact he will on the job. This false expectancy, often the result of overly zealous recruitment, will increase the frustration due to non-use of complex skills. We recently investigated an acute military morale problem. It was found to be due to the non-use, on the job, of the complex skills acquired before field assignment. The training which was received was designed to prepare men to devise procedures for solving problems as they occurred. However, the men found upon arrival in the field that they had to follow detailed written procedures in the performance of all their tasks. They were not allowed to deviate in any way from these procedures or to devise new procedures to deal with problems as they occurred. The false expectancies created by the recruitment and training program aggravated the frustrations produced by non-use of complex skills and the lack of opportunity to learn new skills, resulting in a severe morale problem.

It is apparent that the majority of people are motivated to use what are for them their highest level skills, and to develop new skills. High level skills are, for the individual, those that tax his abilities more than others, and those that place him in a higher relative status position compared to his associates than do his other skills (see Ewart, (1958) for a review of the research on morale, and the status factor). If this motivation to use and develop high level skills is frustrated morale drops, and in a man-machine system the man may attempt to circumvent, or refuse to perform his programmed functions, as has occurred with the ILS-Autopilot Coupler.

It may be noted, however, that there are some people in every situation who do not wish to perform at a more complex level. Furthermore, there are times and situations in which all of us wish to perform at a level of complexity or skill below our maximum, as in some forms of relaxation and play, in non-critical situations, when we are tired, etc. However, this model is being prepared for vulnerable systems, such as aerospace vehicles which will operate in unusual environments for extended periods of time far from sources of support. When man is assigned a local role in such a system, one of the primary reasons ... is so that he can solve unforeseen problems when they arise. This performance requirement will in turn require the kind of man who is frustrated by, and finds unaccepting, roles that do not maintain and even challenge his abilities. However, where the system requirements do not require man for solving unexpected problems, it will be possible (as discussed below) to consider the use of those who do not find routine, non-challenging jobs unacceptable.

Acceptance Principles and Data

The system designer seeking acceptance data... can utilize the following principles, data sources and methods.

Current knowledge. - Unfortunately, little work has been done on acceptance problems in system design. However, the previous work on this contract on acceptance of automated flight control techniques by pilots produced some principles that may be generalizable to other systems. However, it should be remembered that these were developed on this one specific system.

Acceptance of automated functions. - The work on acceptance factors in automating all-weather landing produced the following principles:

(1) The more system experience a man has, with this experience including exposure to automated equipment, the more accepting he is of the automated equipment and the more he will use it in the prescribed manner.

(2) Those with more status, responsibility and authority tend to be more accepting of and make more use of automated equipment than others.

(3) Where failure of the performance of its function by automated equipment can endanger the life of the man, he is less likely to accept and use it despite prescribed procedures.

(4) There is generally high acceptance, within the limits of the above three principles, of the automation of servo tasks, particularly those which must be performed over long periods of time.

(5) There is generally rather low acceptance of automation of decision-making functions.

Role of man. - The work performed on the automatic landing acceptance problem and the study of morale problems in a military unit revealed the following three principles regarding acceptance of the system role of man.

(1) Men are generally accepting of systems roles which give them an opportunity to exercise and, therefore, maintain skills which they feel are important to maintaining their position in the occupational and social status system in which they are immersed.

(2) Men are generally accepting of system roles which permit them to vary their procedures and the manner of accomplishing their tasks, on their own initiative. Roles that fail to permit man to vary his procedures on his own are generally labeled mechanical.

(3) Men are more accepting of roles which permit them to learn. In a recent study (unfortunately, utilizing a sample of only seventeen) a correlation of +. 61 (statistically significant at the .01 level of confidence) was found between how much the men felt they were learning on their job and their intentions to re-enlist.

Methods for Increasing Acceptance

Non-acceptance of automation. -

Re-allocation. - If a serious acceptance problem exists which will lower system effectiveness, a re-allocation can be made, with the subsystem or functions producing the acceptance problem changed to manual, providing this change will improve over-all efficiency.

Additional displays or controls. - Frequently non-acceptance of automation could be greatly reduced, if not eliminated, through the use of additional hardware, which hardware would not be necessary on grounds other than the acceptance problem. The feasibility of this type of solution was apparent in earlier research on this contract (see Smith and Price, 1963) on the resistance of pilots to automating certain landing functions. Pilots frequently would state that they would not accept

automation of some landing function, but when asked if they would accept such automation if they had a display for monitoring the function they stated that this would make the automation completely acceptable. Additional displays for monitoring and thus providing understanding of what is occurring while automatic functions are being performed is obviously the most likely additional hardware technique for reducing non-acceptance of automation. However, there may be cases in which additional controls could also improve acceptance.

Training on automated functions. - Man may often not have been given sufficient training to understand how many automatic functions are performed, because there was no requirement for such training. However, if an acceptance problem exists regarding such automated functions, it may be that training in how they are performed, the theory behind them, and their reliability will build confidence in them and, therefore, reduce the acceptance problem. The purpose of such training would only be to improve acceptance, and it should be designed accordingly.

Practice. - In earlier work on this contract, in a study of acceptance of the ILS-Autopilot Coupler (Smith and Price, 1963) it was found that the more system experience (i.e., flying hours) a pilot had the more accepting he was of the ILS-Autopilot Coupler and the more he used it. This suggests that the acceptance of automated functions might be increased by giving operators experience in the system in a controlled environment during their training, either through the use of simulators or real hardware. Consequently, when they became part of the system in its intended environment they would be more adapted to the automatic equipment and, therefore, less inclined to tamper with it or in other ways negate its effectiveness.

Attitude change techniques. - There are several powerful ways to change attitudes (see Smith, 1961) which, in some cases, could reduce the acceptance problem. The use of such techniques would probably not generally be desirable, because of the consequences of being seen as manipulative. However, where other data indicated that experience with the system would later reduce the acceptance problem to allowable levels it might be justifiable to use attitude change techniques to bridge the experience gap.

Selection. - The attitudes of men toward machines varies rather extensively, with some people quite anti-machine and others very pro-machine and pro-automation, with many gradations and individuals in between these

positions. These individual differences in attitudes toward machines could be utilized where there would be a general acceptance problem with machine automation to select individuals who would accept this allocation. Some work has already been done on developing a scale for measuring attidues toward computers (see Johnson and Kobler, 1962), which scale could undoubtedly be modified to include acceptance attitudes toward automation in general.

Non-acceptance of man's assignments. -

Selection. - Where it is necessary or more effective to utilize man in a manner which will create an acceptance problem with most men, it may be possible to utilize selection to avoid the acceptance problem. For example, a common problem is the necessity to use man in a mechanical, routine manner which frequently produces an acceptance problem. However, it is possible through careful selection of those who will not be offended by such tasks, and the control of job expectancies, to minimize or even completely avoid this problem, providing that all the tasks in the position will be consistent with this lower level selection requirement. A frequent mistake in designing man into systems is over-selection and over-training, which results in the system tasks being seen as dull and frustrating. If selection, training and job expectancies are more consistent with actual job requirements and realities, motivational problems of this type will not be produced.

Re-allocation. - In some systems it would greatly improve acceptance if the functions were re-allocated so that the manual roles would be more challenging. This follows from the study, mentioned above, in which a high correlation was found between a man's feeling that he was learning on the job and his intentions to remain in the military service.

Re-allocation of tasks. - In some cases acceptance problems could be removed through re-allocating tasks between man and machines to eliminate unacceptable manual roles. For example, systems sometimes have repetitious tedious tasks which for economic reasons have been assigned to man. However, it may sometimes be the case that if these tasks were automated it would improve morale and efficiency, and personnel retention, sufficiently to offset the cost of automation.

Additional tasks. - In some cases acceptance of the manual roles and tasks could be improved through the use of additional tasks, in a manner analogous to the discussion above in which additional hardware would be added to the

system in order to improve acceptance. For example, it would frequently, if not always be possible to add as tasks the learning of system theory, concepts and relationships. These learning tasks would be added to the subsystem only for purposes of improving acceptance and morale, not for providing necessary capability. Consequently, the learning tasks should be designed accordingly, i.e., they should be interesting and challenging, but within the aptitude levels of the men for mastery by them.

Serendipity Associates
Chatsworth, California, October 1966.

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TECHNICAL APPENDIX B
CREW SUPPORT REQUIREMENTS DATA

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INTRODUCTION

This appendix consists of a set of representative supporting data for accomplishment of Activity 3, Review Manned System Concept Feasibility, Activity 5, Analyze Personnel Support Requirements.

These data consist of figures, tables and explanatory notes, copied directly from several guides, handbooks and textbooks on bioastronautics and human engineering. This, of course, limits the data somewhat, both in terms of quantity and recentness. However, since the presentation of this data was not a major goal of the project, it was felt that these restrictions were necessary. The data organization allows expansion, both in terms of additional data within the original subject areas, and the addition of new subject areas.

All of the data for Activity 5 has been classified according to two sets of codes: (a) Human Variables (Table 1) and (b) System Parameters (Table 2). Activity 3 data are classified according to an abbreviated set of Human and System codes, described below. Multiple coding is used, so that a given item of data can be assigned several System (S#) and/or Human (H#) Codes. The lists of codes in no way represent a set of all possible subject areas. Codes were developed and modified on the basis of the data available in the above-mentioned sources, and designed to be expanded upon as new data become available.

The data set is designed for presentation in two ways: (1) in this appendix, with retrieval via three matrices; (2) and a set of 8" X 10-1/2" Royal McBee single-punched Keysort cards. System codes are punched along the 10-1/2" side of the card, and Human codes appear along the 8" side, to allow random retrieval of data. Use of the two opposing sides was not necessary for the original set of codes; however, these sides are available for additional codes. The capacity for codes is therefore about double the size now in use. Two code identification cards are printed, one for each set of variables (System and Human) to facilitate location of the appropriate code punches.

Data storage and retrieval within the format of the bound appendix cannot be quite so straightforward as with the card set. Organization of the data sequentially by item numbers is essentially random. It will be noted that

TABLE 1. HUMAN VARIABLES

H1 PHYSICAL
H2 Shape and Size
H3 Weight
H4 Age
H5 Sex
H6 Body Position
H7 PHYSIOLOGICAL
H8 Body Systems
H9 Cardiovascular
H10 Digestive
H11 Excretory
H12 Glandular
H13 Musculoskeletal
H14 Nervous
H15 Reproductive
H16 Respiratory
H17 Skin
H18 Thermoregulation
H19 Circadian Rhythm
H20 Metabolic
H21 Sexual Drive
H22 Exertion/Activity Level
H23 PSYCHOLOGICAL
H24 Performance Systems
H25 Sensory/Perceptive
H26 Perceptual Motor
H27 Cognitive
H28 Motor
H29 Individual Differences
H30 Social Sensitivities
H31 Recreation
H32 ECOLOGICAL
H33 Habitability
H34 Physiological Stress/Tolerance
H35 Psychological Stress
H36 THERAPEUTICS/PROPHYLAXIS
H37 Psychiatry
H38 Pharmacology
H39 PERSONNEL SUBSYSTEM DEVELOPMENT
H40 Crew Size
H41 Selection/Training
H42 Human Engineering
H43 Sustenance
H44 Protection
H45 Work/Rest Cycles
H46 Hygiene
H47 LIFE SUPPORT SYSTEM MEANS

TABLE 2. SYSTEM PARAMETERS

S1	ENVIRONMENT
S2	Atmosphere
S3	Toxins
S4	Temperature/Humidity/Ventilation
S5	Noise
S6	Illumination
S7	Radiation
S8	Magnetics/Electrostatics
S9	Biological
S10	Meteorites
S11	ACCELERATION
S12	Weightlessness
S13	Prolonged Linear Acceleration
S14	Vibrations
S15	Rotations
S16	Impact (Deceleration)
S17	Partial Gravity
S18	ALTITUDE/LOCATION
S19	PAYLOAD
S20	Volume
S21	Weight
S22	Power
S23	LOGISTICS
S24	On-board
S25	Resupply
S26	PERFORMANCE
S27	MISSION DURATION
S28	Hours
S29	Days
S30	Months
S31	Years
S32	EMERGENCY/ABORT/ESCAPE

there is some inherent organization of the data, particularly in terms of System codes. This is simply a function of the order in which those data were compiled, and dependence upon this ordering for data retrieval would be misleading. This is particularly true as the data become more and more randomized in the latter portion of the appendix. New data can be added onto the end of the appendix, coded and given the next item numbers in sequence.

Retrieval of data for Activity 5 within this appendix is achieved through three matrices: System by Human (S X H) (Table 3), Human by Human (H X H)

(Table 4) and System by System (S X S) (Table 5).[1] A ○ mark in any cell indicates that there exists at least one data item concerned with these two variables. When the cell is blank, it indicates that information or data were not available in the sources used. A series of lists following each matrix indicates the item number appropriate to each cell. The Accession Lists are organized by cell coordinates. The code for items along the left side of the matrix is presented first, followed by the code for items along the top of the matrix, e.g., S1 (left side) X H1 (top). The title of the principal code for each new group is printed at the top of each group, e.g., the word "Environment" is printed above the group S1 X H ___, indicating that each data item in that group is relevant to Environment versus human variable. Item numbers can appear several times, representing the different combinations of variables under which they have been coded. No attempt has been made to distinguish between a true interaction effect and a simple concurrent study of several variables, as this would require a more sophisticated data retrieval system. Order of data retrieval in either format (appendix or code cards) will probably be dependent on the particular aerospace system being studied. Data can be retrieved through System Parameters, Human Variables, or any combination. For each development system, then, a set of order-of-retrieval rules can be formulated to systematically investigate all of the subject areas of interest.

The supporting data for Activity 3 consists of a subset of the Activity 5 data. This is a 27-item set of data of a broader, more general nature to partially accomplish a Review of Manned System Concept Feasibility. Retrieval of Activity 3 data within the punch-card set is through an abbreviated set of codes. These include the major headings of the System codes of Table 2 (i.e., S1, S11, S18, S19, S23, S26, S27 and S32) and the first two orders of headings of the Human Codes of Table 1 (eliminating only the specific body systems, H-9 through H-17, and performance systems, H-25 through H-29). In addition, one particular punch code has been reserved to indicate that a data item is

[1] These matrices, with their accompanying lists, follow the narrative (pp. 6 to 20).

appropriate to Activity 3. Thus, the entire set of Activity 3 data can be separated out by this code, which is indicated on both identification cards.

Retrieval of Activity 3 data within this bound appendix is achieved through an abbreviated System by Human matrix (Table 6) with an accompanying list of items appropriate to filled cells. These items appear in a group as the first 27 data items in this appendix, and can be identified by an asterisk following the item number. In the accomplishment of Activity 3 for a given system, it is possible that this limited set of data will be insufficient. In such cases, the large set of Activity 3 data can be entered for the necessary subject areas.

This entire appendix can be easily converted into a random retrieval system simply by copying each item (via Xerox, for example, which will accept punch cards) onto blank 8 X 10-1/2 inch Royal McBee Keysort cards. Edges can be punched using Tables 1 and 2 as guides, and identification cards can be made by copying Tables 1 and 2 on blank punch cards.

This appendix is followed by an extensive reference list, as an attempt has been made to credit each data item to both primary and secondary sources. These sources appear in the lower right-hand corner of each data item sheet. The first reference number refers to the guide, handbook, or textbook from which the data actually were copied. Primary reference sources, where cited, are listed below this, preceded by such labels as "based on" or "adapted from." To facilitate use as a bibliography, these entries have been alphabetized as well as listed by reference numbers.

Table 3a. A KEY TO DATA RELEVANT TO ACTIVITY 5—"ANALYZE CREW SUPPORT REQUIREMENTS"
System Parameters by Human Variables Matrix

Human Variables \ System Parameters	S1 ENVIRONMENT	S2 Atmosphere	S3 Toxins	S4 Temperature/Humidity/Ventilation	S5 Noise	S6 Illumination	S7 Radiation	S8 Magnetics/Electrostatics	S9 Biological	S10 Meteorites	S11 ACCELERATION	S12 Weightlessness	S13 Prolonged Linear Acceleration	S14 Vibrations	S15 Rotations	S16 Impact (Deceleration)	S17 Partial Gravity	S18 ALTITUDE/LOCATION	S19 PAYLOAD	S20 Volume	S21 Weight	S22 Power	S23 LOGISTICS	S24 On-board	S25 Resupply	S26 PERFORMANCE	S27 MISSION DURATION	S28 Hours	S29 Days	S30 Months	S31 Years	S32 EMERGENCY/ABORT/ESCAPE
H1 PHYSICAL																				○	○											
H2 Shape and Size		○		○																○	○											
H3 Weight				○								○								○	○							○				
H4 Age		○													○						○											
H5 Sex																				○												
H6 Body Position		○									○		○	○		○																
H7 PHYSIOLOGICAL											○									○	○											
H8 Body Systems	○										○	○		○													○					
H9 Cardiovascular		○	○	○	○		○				○	○	○	○	○	○	○	○									○	○				
H10 Digestive																																
H11 Excretory		○	○	○								○									○							○				
H12 Glandular		○		○																								○	○			
H13 Musculoskeletal		○										○	○	○			○											○				
H14 Nervous		○		○		○	○					○	○	○		○	○	○										○				
H15 Reproductive							○							○																		
H16 Respiratory		○	○	○								○	○	○	○			○		○	○						○	○				
H17 Skin		○		○			○																					○				
H18 Thermoregulation		○	○	○		○						○	○		○			○					○					○	○			
H19 Circadian Rhythm																												○	○			
H20 Metabolic	○	○		○								○	○	○					○		○							○	○			
H21 Sexual Drive																																
H22 Exertion/Activity Level	○	○	○	○								○	○						○									○				
H23 PSYCHOLOGICAL																																
H24 Performance Systems	○	○		○	○							○	○		○			○										○	○			
H25 Sensory/Perceptive		○	○	○	○	○	○						○	○	○	○	○									○			○			
H26 Perceptual Motor		○											○	○	○											○		○				
H27 Cognitive		○		○										○		○												○				
H28 Motor		○		○										○	○											○						
H29 Individual Differences												○	○	○		○										○		○				
H30 Social Sensitivities																																
H31 Recreation																																
H32 ECOLOGICAL	○																															
H33 Habitability	○	○	○	○	○	○		○				○			○	○		○		○	○	○			○		○	○	○	○		○	○
H34 Physiological Stress/Tolerance	○	○	○	○	○	○		○				○	○	○	○	○	○	○			○					○	○	○	○			○
H35 Psychological Stress		○		○	○	○	○	○					○	○	○					○						○		○	○			
H36 THERAPEUTICS/PROPHYLAXIS																																
H37 Psychiatry																																
H38 Pharmacology		○		○		○	○					○	○	○	○		○									○			○			
H39 PERSONNEL SUBSYSTEM DEVELOPMENT	○																										○					
H40 Crew Size		○	○	○																○	○		○	○			○	○		○		
H41 Selection/Training		○		○								○			○					○	○											
H42 Human Engineering						○								○	○					○												
H43 Sustenance	○	○	○	○	○			○				○							○	○	○		○	○	○			○		○	○		
H44 Protection	○	○	○	○	○	○		○			○	○	○	○	○		○		○	○	○		○				○	○				○
H45 Work/Rest Cycles																										○		○	○			
H46 Hygiene	○											○								○	○											
H47 LIFE SUPPORT SYSTEM MEANS	○	○	○	○	○			○	○		○	○							○	○	○	○		○			○	○	○	○		

○ = information available in this appendix.

TABLE 3b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 3a

Cell Coordinate			Relevant Data Item Numbers
ENVIRONMENT			
S1 X	H8	-	3, 6, 13
	H20	-	6, 17
	H22	-	17
	H24	-	1, 3
	H32	-	13
	H33	-	2, 4, 5, 9, 11, 12
	H34	-	1, 6, 7, 8, 9
	H39	-	13
	H43	-	2, 9, 11
	H44	-	2, 9, 10, 14
	H46	-	2
	H47	-	2
ATMOSPHERE			
S2 X	H2	-	262, 263
	H4	-	45, 247
	H6	-	491
	H9	-	28, 39, 40, 41, 67, 241, 242, 244, 249, 250, 489, 490, 509
	H11	-	72
	H12	-	251, 509
	H13	-	68
	H14	-	69
	H16	-	30, 31, 32, 33, 34, 35, 36, 37, 39, 40, 41, 43, 45, 66, 67, 68, 70, 245, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 262, 263, 486, 489, 490, 492, 495, 496, 497, 501, 509, 510
	H17	-	29, 42
	H18	-	42, 45, 246, 249, 250, 251, 252, 260, 264, 485
	H20	-	41, 43, 66, 67, 68, 72, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 262, 263, 486, 487, 488, 500, 501
	H22	-	38, 41, 44, 67, 68, 71, 248, 256, 257, 258, 259, 260
	H24	-	75, 510
	H25	-	46, 69, 73, 74, 243, 491
	H26	-	47, 73, 74
	H27	-	73
	H28	-	68
	H33	-	483, 484, 487
	H34	-	48, 49, 50, 51, 52, 53, 54, 55, 56, 57, 69, 74, 75, 76, 77, 261, 264, 493, 494, 510, 522
	H35	-	69, 75
	H38	-	265
	H40	-	482
	H41	-	67
	H43	-	72, 483, 488, 500, 501, 504, 505, 506
	H44	-	75, 76, 77, 522, 536
	H47	-	58, 59, 60, 61, 62, 63, 64, 65, 66, 70, 71, 73, 482, 498, 499, 502, 503, 504, 505, 506, 507, 508, 536
TOXINS			
S3 X	H9	-	79, 241, 242, 525
	H11	-	78
	H16	-	79, 525
	H18	-	525
	H22	-	79
	H25	-	243
	H33	-	80, 81, 82, 483, 484, 512
	H34	-	79, 83, 84, 85, 86, 87, 88, 513
	H40	-	482
	H43	-	483
	H44	-	93
	H47	-	89, 90, 91, 92, 93, 482, 511
TEMPERATURE/HUMIDITY/VENTILATION			
S4 X	H2	-	262, 263
	H3	-	134, 135
	H9	-	103, 136, 244, 249, 250, 516, 524, 528
	H11	-	137, 514
	H12	-	104, 138, 251
	H14	-	516
	H16	-	106, 107, 108, 245, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 262, 263, 486, 524
	H17	-	94, 95, 96, 105, 139, 140, 141, 142, 524
	H18	-	97, 98, 99, 100, 101, 103, 105, 107, 109, 110, 111, 136, 143, 144, 145, 146, 147, 148, 149, 150, 151, 152, 234, 246, 249, 250, 251, 252, 260, 264, 485, 516, 517, 524, 529
	H20	-	104, 106, 107, 109, 111, 112, 113, 135, 149, 153, 247, 251, 252, 253, 254, 255, 256, 257,

TABLE 3b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 3a — Continued

Cell Coordinate		Relevant Data Item Numbers
	H20 -	258, 259, 260, 262, 263, 265, 486, 487, 488
	H22 -	102, 106, 108, 109, 110, 111, 112, 136, 143, 144, 145, 146, 147, 148, 153, 154, 155, 156, 157, 158, 159, 248, 256, 257, 258, 259, 260, 527
	H24 -	113, 160, 161, 517
	H25 -	117
	H27 -	114
	H28 -	115, 116, 117, 526
	H33 -	118, 119, 131, 154, 160, 161, 162, 163
	H34 -	120, 121, 122, 123, 131, 135, 138, 139, 141, 143, 144, 145, 150, 151, 154, 155, 156, 157, 159, 160, 161, 164, 165, 166, 167, 168, 261, 264, 515, 517, 520, 521, 527, 530
	H35 -	519
	H38 -	132, 265
	H40 -	482
	H41 -	136, 145, 146, 152
	H43 -	137, 487, 488, 530
	H44 -	133, 135, 140, 141, 142, 147, 148, 149, 152, 153, 154, 157, 158, 159, 162, 163, 164, 165, 166, 167, 168, 266, 517, 528, 536
	H47 -	124, 125, 126, 127, 128, 129, 130, 482, 518, 522, 536
NOISE		
S5 X	H9 -	169
	H24 -	170
	H25 -	171, 197, 267, 532
	H33 -	172, 173, 182, 198
	H34 -	174, 175, 176, 177, 178, 179, 182, 183, 184, 185, 186, 531
	H35 -	180, 181, 183, 184, 185, 186
	H44 -	187, 188, 189, 190, 191, 192, 193, 194, 195, 196, 197, 198, 531
ILLUMINATION		
S6 X	H14 -	203
	H18 -	485
	H25 -	199, 200, 201, 202, 203, 204, 205, 206, 207, 267, 533, 534, 535

Cell Coordinate		Relevant Data Item Numbers
	H35 -	204
	H38 -	203
	H42 -	205, 206, 207
RADIATION		
S7 X	H9 -	208, 209, 210
	H14 -	235
	H15 -	211, 212, 537
	H17 -	213, 233
	H25 -	233, 235
	H33 -	214, 215, 216, 234, 540, 543
	H34 -	217, 218, 219, 220, 221, 222, 223, 224, 227, 540, 541, 542, 544
	H35 -	225, 226
	H38 -	236, 237, 238, 239, 544
	H43 -	539
	H44 -	228, 229, 230, 231, 232, 234 236, 237, 238, 239, 266, 536, 538, 539
	H47 -	536
MAGNETICS/ELECTROSTATICS		
S8 X	H47 -	240
METEORITES		
S10 X	H44 -	545
ACCELERATION		
S11 X	H6 -	15
	H7 -	16
	H8 -	3,6
	H9 -	268
	H20 -	6, 17, 270
	H22 -	17, 270
	H24 -	3, 18, 271
	H29 -	270
	H33 -	4, 5, 9
	H34 -	6, 7, 8, 9, 19, 20, 21, 272
	H38 -	269
	H41 -	271
	H43 -	9
	H44 -	9, 22, 272, 536
	H47 -	536
WEIGHTLESSNESS		
S12 X	H3 -	548
	H8 -	286
	H9 -	273, 274, 275, 277, 285, 287, 409, 410, 414, 415, 416, 417, 546, 549

TABLE 3b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 3a — Continued

Cell Coordinate		Relevant Data Item Numbers
H11	-	288, 514, 549
H13	-	276, 287, 417, 548
H14	-	409, 417
H16	-	277, 410, 414, 415
H18	-	414, 415
H20	-	286, 287, 548, 549
H22	-	285
H24	-	287, 289
H25	-	278, 279, 406, 417
H26	-	280, 281, 282, 407, 408
H29	-	290, 411, 412, 413
H34	-	283, 286, 289, 290, 411, 412, 413
H35	-	283, 286, 289, 290, 409
H38	-	288, 416
H44	-	284
H46	-	547
H47	-	547
PROLONGED LINEAR ACCELERATION		
S13 X H6	-	318, 319, 320, 321, 324, 325, 326, 327, 328, 330, 423, 491
H9	-	291, 292, 294, 409, 410, 414, 415, 416, 489, 490
H13	-	294
H14	-	294, 409
H16	-	293, 295, 318, 410, 414, 415, 486, 489, 490
H18	-	414, 415
H20	-	295, 486
H25	-	296, 297, 298, 299, 300, 301, 302, 319, 320, 321, 322, 323, 329, 331, 334, 406, 423, 491, 533, 534
H26	-	303, 304, 305, 306, 307, 310, 332, 333, 407, 408
H27	-	310
H28	-	308, 309
H29	-	334, 411, 412, 413
H34	-	311, 312, 313, 314, 315, 316, 317, 323, 324, 325, 326, 327, 328, 329, 330, 331, 334, 335, 336, 337, 411, 412, 413, 419, 420, 422, 423, 515
H35	-	409
H38	-	416
H42	-	333, 418
H44	-	326, 327, 328, 330, 332, 335, 336, 337, 421, 422, 423

Cell Coordinate		Relevant Data Item Numbers
VIBRATIONS		
S14 X H6	-	366, 367, 368, 369, 370
H8-	-	340
H9	-	346
H13	-	338, 339, 366, 367, 368, 369, 371, 372, 373
H14	-	374
H15	-	537
H16	-	341, 346, 371, 492
H20	-	340, 341, 346
H24	-	342, 343
H25	-	344, 347, 375, 535
H26	-	345, 370
H28	-	347
H33	-	551
H34	-	348, 349, 350, 351, 352, 353, 354, 355, 356, 357, 358, 359, 360, 361, 362, 363, 364, 371, 372, 375, 493, 551
H35	-	357, 358, 359, 360, 361, 362, 363, 364
H38	-	374
H42	-	418
H44	-	365, 368, 369, 373
ROTATIONS		
S15 X H4	-	386
H9	-	414, 415
H16	-	414, 415
H18	-	414, 415
H25	-	376, 377, 378, 379, 380, 387, 388
H29	-	411, 412, 413
H33	-	387, 424, 425, 426, 552
H34	-	381, 382, 383, 384, 385, 386, 388, 411, 412, 413, 426
H41	-	386
IMPACT (DECELERATION)		
S16 X H6	-	423
H9	-	403, 416
H14	-	403
H25	-	423
H27	-	403
H34	-	389, 390, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 419 420, 422, 423, 494, 550
H38	-	416
H44	-	404, 405, 421, 422, 423

TABLE 3b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 3a — Continued

Cell Coordinate			Relevant Data Item Numbers
PARTIAL GRAVITY			
S17 X	H9	-	417, 546
	H13	-	417
	H14	-	417
	H25	-	417
	H33	-	424, 425, 426
	H34	-	426
ALTITUDE/LOCATION			
S18 X	H9	-	516, 546
	H14	-	516
	H16	-	495
	H18	-	516, 517
	H24	-	517
	H34	-	517
	H44	-	10, 517
PAYLOAD			
S19 X	H20	-	17
	H22	-	17
	H33	-	11
	H43	-	11, 23
	H47	-	23, 24, 25, 518
VOLUME			
S20 X	H1	-	444, 445
	H2	-	427, 428, 429, 432, 433, 434, 435, 436, 446, 447
	H3	-	446, 447
	H5	-	427, 428, 432
	H7	-	444
	H16	-	496, 497, 547
	H33	-	12, 430, 437, 554, 555
	H35	-	519
	H40	-	437
	H41	-	444, 445
	H42	-	429
	H43	-	553
	H44	-	431, 432, 433, 434, 435, 436, 447, 448
	H46	-	449
	H47	-	449, 498, 499, 547
WEIGHT			
S21 X	H1	-	444, 445
	H2	-	438, 446, 447
	H3	-	438, 446, 447, 558
	H4	-	439
	H7	-	444
	H11	-	443
	H16	-	501
	H20	-	487, 488, 500, 501
	H33	-	9, 483
	H34	-	9
	H40	-	26, 556, 557, 560, 561
	H41	-	444, 445
	H43	-	9, 26, 440, 441, 443, 483, 487, 488, 500, 501, 504, 505, 506, 539, 553, 556, 557, 558, 559, 560, 562
	H44	-	9, 439, 447, 448, 538, 539, 562
	H46	-	449
	H47	-	442, 449, 498, 499, 502, 503, 504, 505, 506, 507, 559, 560
POWER			
S22 X	H18	-	485
	H47	-	508
LOGISTICS			
S23 X	H40	-	26
	H43	-	26, 553, 562
	H44	-	562
ON-BOARD			
S24 X	H33	-	483
	H40	-	557
	H43	-	483, 557
	H47	-	450, 563
RESUPPLY			
S25 X	H43	-	451
PERFORMANCE			
S26 X	H25	-	452
	H26	-	453, 454, 455
	H28	-	452
	H29	-	456
	H34	-	27
	H35	-	27
	H38	-	453, 454, 455
	H45	-	456
MISSION DURATION			
S27 X	H8	-	13
	H32	-	13
	H33	-	11, 484, 540
	H34	-	520, 521, 522, 540
	H39	-	13
	H40	-	26, 482, 556, 557

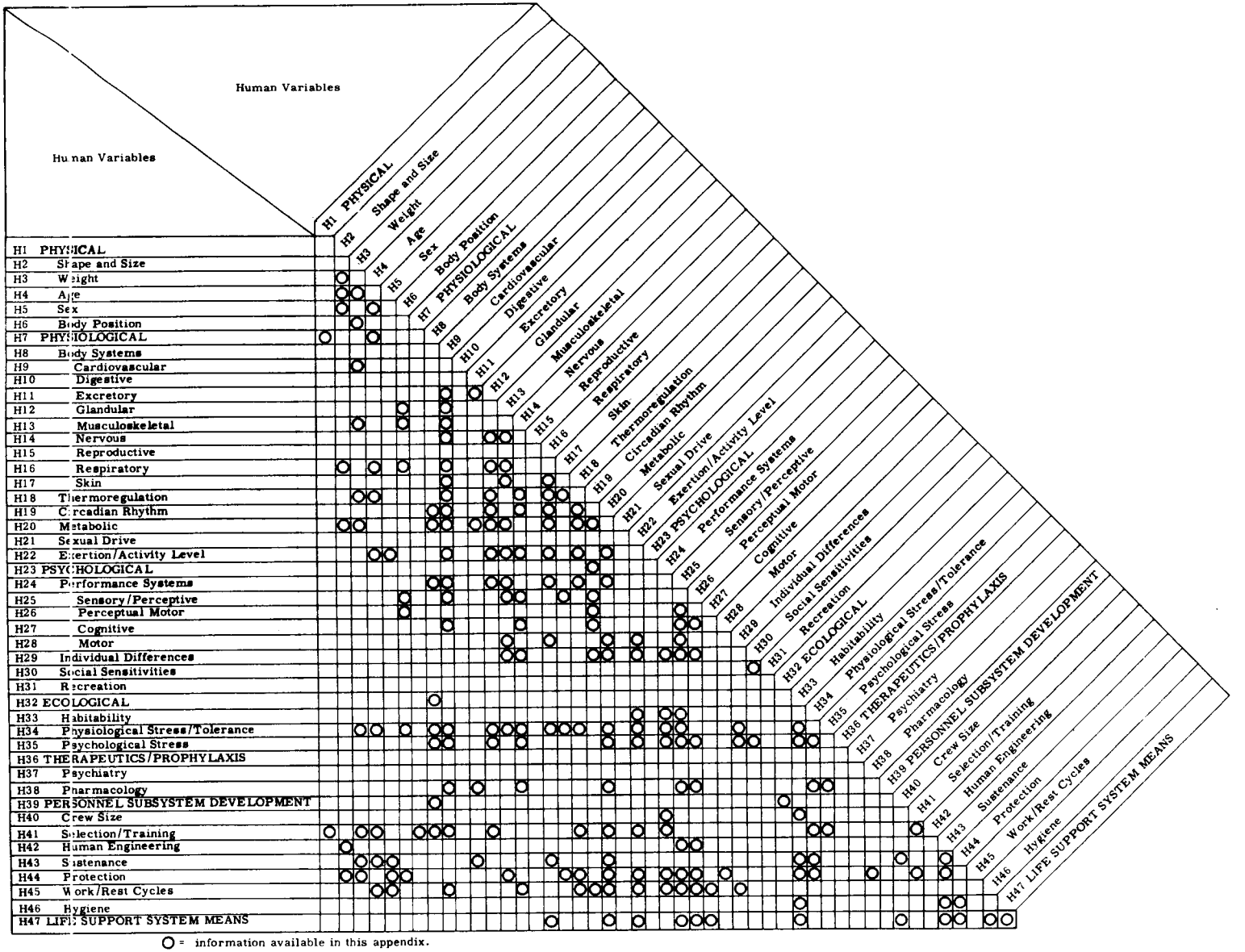
TABLE 3b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 3a —Continued

Cell Coordinate			Relevant Data Item Numbers
	H43	-	11, 26, 556, 557
	H44	-	522, 545
	H47	-	482, 523, 563
HOURS			
S28 X	H8	-	457
	H9	-	458, 524, 525
	H12	-	459, 460
	H16	-	458, 524, 525
	H17	-	524
	H18	-	524, 528
	H19	-	457, 458, 459, 460, 464, 465
	H20	-	457
	H22	-	527
	H24	-	461, 462, 463, 466, 467, 468, 469
	H26	-	464, 465, 470
	H27	-	471
	H29	-	462, 463, 464
	H33	-	466, 467, 468, 526, 551, 554
	H34	-	527, 531, 541, 551
	H35	-	467, 468
	H40	-	469
	H44	-	528, 531
	H45	-	470, 471
	H47	-	472, 499
DAYS			
S29 X	H3	-	548, 558
	H9	-	473, 474, 475, 509, 529, 549
	H11	-	549
	H12	-	509
	H13	-	548
	H14	-	473, 474
	H16	-	509, 510
	H18	-	476, 529

Cell Coordinate			Relevant Data Item Numbers
	H19	-	473, 474, 475, 476, 477, 478, 479, 480
	H20	-	548, 549
	H23	-	477
	H24	-	481, 510
	H25	-	478, 479
	H27	-	478, 479, 480
	H33	-	543, 552, 555
	H34	-	510, 530, 542, 544
	H35	-	481
	H38	-	544
	H43	-	530, 558, 559
	H45	-	473, 474, 475, 476, 478, 479, 480
	H47	-	499, 507, 511, 559
MONTHS			
S30 X	H33	-	512
	H40	-	560, 561
	H43	-	559, 560
	H47	-	559, 560
YEARS			
S31 X	H25	-	582
EMERGENCY/ABORT/ESCAPE			
S32 X	H33	-	513
	H34	-	550
	H44	-	14

TABLE 4a. A KEY TO DATA RELEVANT TO ACTIVITY 5-"ANALYZE CREW SUPPORT REQUIREMENTS"

Human Variables by Human Variables Matrix



○ = information available in this appendix.

TABLE 4b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 4a

Cell Coordinate			Relevant Data Item Numbers
PHYSICAL			
H1 X	H7	-	444
	H41	-	444, 445
SHAPE AND SIZE			
H2 X	H3	-	438, 446, 447
	H4	-	438
	H5	-	427, 428, 432
	H16	-	262, 263
	H20	-	262, 263
	H42	-	429
	H44	-	432, 433, 434, 435, 436, 447
WEIGHT			
H3 X	H4	-	438
	H6	-	565
	H9	-	564
	H13	-	548
	H18	-	134
	H20	-	135, 548
	H34	-	135
	H41	-	564
	H43	-	558
	H44	-	135, 447
AGE			
H4 X	H5	-	566, 567
	H7	-	568
	H16	-	45
	H18	-	45
	H22	-	566
	H34	-	386
	H41	-	386
	H43	-	567
	H45	-	566
SEX			
H5 X	H22	-	566
	H43	-	567
	H44	-	432
	H45	-	566
BODY POSITION			
H6 X	H12	-	569
	H13	-	366, 367, 368, 369
	H16	-	318
	H25	-	319, 320, 321, 322, 423, 491
	H26	-	370
	H34	-	324, 325, 326, 327, 328, 330, 423
	H44	-	326, 327, 328, 330, 368, 369, 423

Cell Coordinate			Relevant Data Item Numbers
PHYSIOLOGICAL			
H7 X	H41	-	444
BODY SYSTEMS			
H8 X	H19	-	457
	H20	-	6, 286, 340, 457, 570
	H24	-	3
	H32	-	13
	H34	-	6, 286
	H35	-	286
	H39	-	13
	H41	-	570
CARDIOVASCULAR			
H9 X	H11	-	549
	H12	-	509
	H13	-	287, 294, 417
	H14	-	294, 403, 409, 417, 473, 474, 516
	H16	-	39, 40, 41, 67, 79, 250, 277, 346, 410, 414, 415, 458, 489, 490, 509, 524, 525, 582
	H17	-	524
	H18	-	103, 136, 249, 250, 414, 415, 516, 524, 525, 529
	H19	-	458, 473, 474, 475, 582
	H20	-	41, 67, 287, 346, 549, 582
	H22	-	41, 67, 79, 136, 285
	H24	-	287
	H25	-	417
	H27	-	403
	H34	-	79, 403
	H35	-	409
	H38	-	416
	H41	-	67, 136, 564
	H45	-	473, 474, 475
EXECRETORY			
H11 X	H11	-	571
	H20	-	72, 549
	H38	-	288
	H43	-	72, 137, 443
GLANDULAR			
H12 X	H14	-	589
	H16	-	251, 509
	H18	-	251
	H19	-	459, 460
	H20	-	104, 251
	H22	-	572, 573
	H24	-	574

TABLE 4b ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 4a — Continued

Cell Coordinate			Relevant Data Item Numbers
	H34	-	138, 589
	H35	-	572, 573, 575, 589
	H41	-	573
MUSCULOSKELETAL			
H13 X	H14	-	294, 417, 578
	H16	-	68, 371
	H17	-	576
	H20	-	68, 287, 548
	H22	-	68, 577, 578
	H24	-	287
	H25	-	417
	H28	-	68
	H29	-	578
	H34	-	371, 372
	H44	-	368, 369, 373
NERVOUS			
H14 X	H18	-	516
	H19	-	473, 474
	H22	-	578, 579
	H25	-	69, 203, 235, 417
	H27	-	403
	H29	-	578
	H34	-	69, 403, 589
	H35	-	69, 409, 589
	H38	-	203, 374
	H45	-	473, 474
REPRODUCTIVE			
H15 X	H17	-	524
	H18	-	45, 107, 250, 251, 252, 260 414, 415, 524, 525
	H19	-	458, 582
	H20	-	41, 43, 66, 68, 106, 107, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 262, 295, 341, 346, 488, 501, 582
	H22	-	41, 44, 68, 79, 108, 256, 257, 258, 259, 260
	H24	-	510
	H28	-	68
	H34	-	79, 371, 501
	H43	-	501
	H47	-	66, 70
SKIN			
H17 X	H18	-	42, 105, 524
	H25	-	233
	H34	-	139, 141
	H44	-	140, 141, 142
THERMOREGULATION			
H18 X	H19	-	476, 580
	H20	-	107, 109, 111, 149, 252, 260,
	H22	-	109, 110, 111, 136, 143, 144, 145, 146, 147, 148, 251, 252, 260
	H24	-	517
	H34	-	143, 144, 145, 150, 151, 264, 517
	H41	-	136, 145, 146, 152
	H44	-	147, 148, 149, 152, 517
	H45	-	476, 580
CIRCADIAN RHYTHM			
H19 X	H20	-	457, 581, 582
	H23	-	477
	H25	-	478, 479
	H26	-	464, 465
	H27	-	478, 479, 480
	H29	-	464
	H45	-	473, 474, 475, 476, 478, 479, 480, 580, 581
METABOLIC			
H20 X	H22	-	17, 41, 68, 106, 109, 111, 112, 153, 256, 257, 258, 259, 260, 270
	H24	-	287
	H28	-	68
	H29	-	270
	H34	-	6, 135, 286
	H35	-	286
	H38	-	265
	H41	-	570
	H43	-	487, 488, 500, 501
	H44	-	135, 149, 153
	H45	-	581
	H47	-	66

TABLE 4b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 4a — Continued

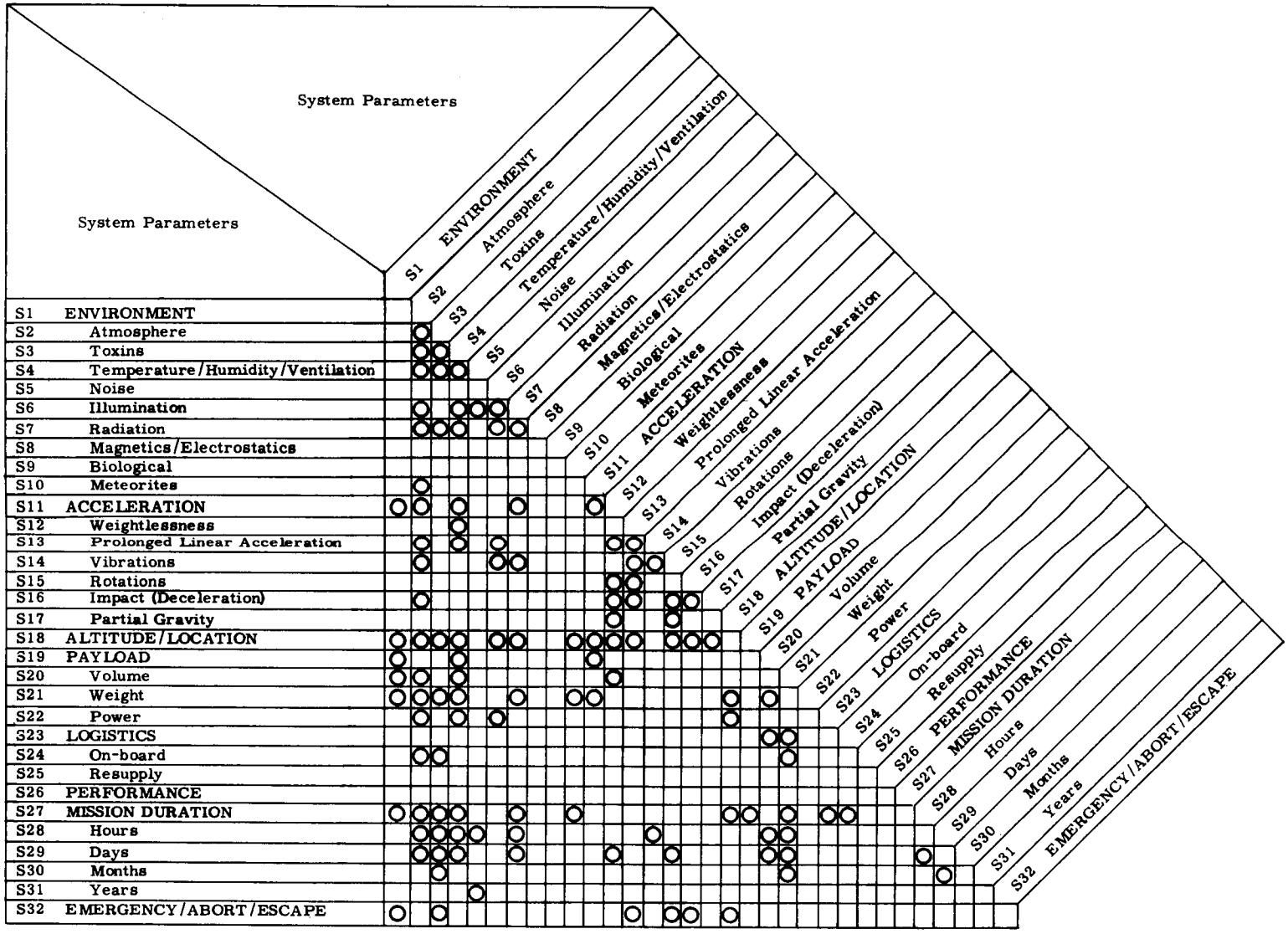
Cell Coordinate			Relevant Data Item Numbers
EXERTION/ACTIVITY LEVEL			
H22 X	H28	-	68
	H29	-	270, 578
	H33	-	154
	H34	-	79, 143, 144, 145, 154, 155, 156, 157, 159, 527
	H35	-	572, 573
	H41	-	136, 145, 146, 573
	H44	-	148, 153, 154, 157, 158, 159
	H45	-	566
	H47	-	71
PERFORMANCE SYSTEMS			
H24 X	H29	-	462, 463
	H33	-	160, 161, 466, 467, 468
	H34	-	1, 75, 160, 161, 289, 510, 517, 584
	H35	-	75, 289, 467, 468, 481
	H40	-	469
	H41	-	271
	H44	-	75, 517
	H45	-	585
SENSORY/PERCEPTIVE			
H25 X	H26	-	73, 74
	H27	-	73, 478, 479
	H28	-	117, 347, 479
	H29	-	334
	H33	-	387
	H34	-	69, 74, 323, 329, 331, 334, 375, 388, 423
	H35	-	69, 204
	H38	-	203
	H42	-	205, 206, 207
	H44	-	197, 423
	H45	-	478, 479
	H47	-	73
PERCEPTUAL MOTOR			
H26 X	H27	-	73, 310
	H29	-	464
	H35	-	583
	H38	-	453, 454, 455
	H42	-	333
	H44	-	332
	H45	-	470
	H47	-	73
COGNITIVE			
H27 X	H45	-	471, 478, 479, 480
	H47	-	73
MOTOR			
H28 X	H44	-	586
INDIVIDUAL DIFFERENCES			
H29 X	H34	-	290, 334, 411, 412, 413
	H35	-	290
	H45	-	456
SOCIAL SENSITIVITIES			
H30 X	H30	-	587
	H35	-	588
ECOLOGICAL			
H32 X	H39	-	13
HABITABILITY			
H33 X	H34	-	9, 131, 154, 160, 161, 182, 183, 184, 185, 186, 426, 540, 551
	H35	-	467, 468
	H40	-	487
	H43	-	2, 9, 11, 483
	H44	-	2, 9, 154, 162, 163, 164, 198
	H46	-	2
	H47	-	2
PHYSIOLOGICAL STRESS/TOLERANCE			
H34 X	H35	-	27, 69, 283, 286, 289, 357, 358 359, 360, 361, 362, 363, 364, 589
	H38	-	544
	H41	-	145, 386
	H43	-	9, 530, 591
	H44	-	9, 76, 77, 135, 141, 154, 157, 159, 165, 166, 167, 168, 234, 272, 326, 327, 328, 330, 335, 336, 337, 404, 405, 422, 423, 517, 522, 531
PHYSIOLOGICAL STRESS			
H35 X	H38	-	590
	H41	-	573
PHARMACOLOGY			
H38 X	H44	-	236, 237, 238, 239
CREW SIZE			
H40 X	H43	-	26, 556, 557, 560
	H47	-	482, 560

TABLE 4b. ACCESSION LIST TO RELEVANT DATA ITEMS FOR TABLE 4a

Cell Coordinate			Relevant Data Item Numbers
SELECTION/TRAINING			
H41 X	H41	-	592, 593, 594
	H44	-	152
SUSTENANCE			
H43 X	H43	-	595
	H44	-	2, 9, 539, 562
	H46	-	2
	H47	-	2, 23, 504, 505, 506, 559, 560, 596
PROTECTION			
H44 X	H46	-	2
	H47	-	2, 93, 536
HYGIENE			
H46 X	H47	-	2, 449, 547
LIFE SUPPORT SYSTEM MEANS			
H47 X	H47	-	597

TABLE 5a. A KEY TO DATA RELEVANT TO ACTIVITY 5—"ANALYZE CREW SUPPORT REQUIREMENTS"

System Parameters by System Parameters Matrix



○ = information available in this appendix.

TABLE 5b. ACCESSION LIST TO RELEVANT DATA ITEM FOR TABLE 5a

Cell Coordinate			Relevant Data Item Numbers
ENVIRONMENT			
S1 X	S11	-	3, 4, 5, 6, 7, 8, 9, 17
	S18	-	10, 598
	S19	-	11, 17
	S20	-	12
	S21	-	9
	S27	-	11, 13
	S32	-	14
ATMOSPHERE			
S2 X	S2	-	599, 600, 601, 603, 604
	S3	-	241, 242, 243, 482, 484, 602
	S4	-	244, 245, 246, 247, 248, 249, 250, 251, 252, 253, 254, 255, 256, 257, 258, 259, 260, 261, 262, 263, 264, 265, 482, 485, 486, 487, 488, 536
	S6	-	485
	S7	-	536
	S10	-	605, 606
	S11	-	536
	S13	-	486, 489, 490, 491
	S14	-	492, 493
	S16	-	494
	S18	-	495, 602, 607, 608
	S20	-	496, 497, 498, 499
	S21	-	483, 487, 488, 498, 499, 500, 501, 502, 503, 504, 505, 506, 507, 606
	S22	-	485, 508
	S24	-	583
	S27	-	482, 484, 608
	S28	-	499
	S29	-	499, 507, 509, 510
TOXINS			
S3 X	S3	- -	609, 610, 611
	S4	-	482
	S7	-	612, 613
	S18	-	602
	S21	-	483
	S24	-	483
	S27	-	482, 484
	S28	-	613, 614
	S29	-	511, 613, 614
	S30	-	512
	S32	-	513

Cell Coordinate			Relevant Data Item Numbers
TEMPERATURE/HUMIDITY/VENTILATION			
S4 X	S4	-	615, 616
	S6	-	485
	S7	-	266, 536, 617
	S11	-	536
	S12	-	514
	S13	-	486, 515
	S18	-	516, 517, 618, 619, 620
	S19	-	518
	S20	-	519
	S21	-	487, 488
	S22	-	485
	S27	-	482, 520, 521, 522, 523
	S28	-	524, 525, 526, 527, 528
	S29	-	529, 530
NOISE			
S5 X	S6	-	267
	S28	-	531
	S31	-	532
ILLUMINATION			
S6 X	S6	-	621
	S7	-	627, 628
	S13	-	533, 534
	S14	-	535
	S18	-	627, 628
	S22	-	485
ROTATION			
S7 X	S7	-	622, 623, 624
	S11	-	536
	S14	-	537
	S18	-	625, 626, 627, 628
	S21	-	538, 539
	S27	-	540
	S28	-	541
	S29	-	542, 543, 544, 629
METEORITES			
S10 X	S18	-	606
	S21	-	606
	S27	-	545
ACCELERATION			
S11 X	S11	-	630
	S18	-	631
	S19	-	17
	S21	-	9

TABLE 5b. ACCESSION LIST TO RELEVANT DATA ITEM FOR TABLE 5a — Continued

Cell Coordinate			Relevant Data Item Numbers
WEIGHTLESSNESS			
S12 X	S13	-	406, 407, 408, 409, 410, 411, 412, 413, 414, 415, 416, 632
	S15	-	411, 412, 413, 414, 415
	S16	-	416, 632
	S17	-	417, 546
	S18	-	546
	S20	-	547
	S29	-	548, 549
PROLONGED LINEAR ACCELERATION			
S13 X	S13	-	633
	S14	-	418
	S15	-	411, 412, 413, 414, 415
	S16	-	416, 419, 420, 421, 422, 423, 424, 632, 634, 635
	S18	-	636, 637
	S32	-	636, 637
VIBRATIONS			
S14 X	S14	-	638, 639, 640, 641
	S28	-	551
ROTATIONS			
S15 X	S16	-	643
	S17	-	424, 425, 426
	S18	-	643
	S29	-	552
	S32	-	643
IMPACT (DECELERATION)			
S16 X	S16	-	642
	S18	-	643
	S32	-	550, 643
PARTIAL GRAVITY			
S17 X	S18	-	546
ALTITUDE/LOCATION			
S18 X	S21	-	606
	S22	-	647
	S27	-	608, 648
	S32	-	636, 637, 643, 644, 645, 646
PAYLOAD			
S19 X	S27	-	11
VOLUME			
S20 X	S21	-	444, 445, 446, 447, 448, 449, 498, 499, 553
	S23	-	553
	S28	-	499, 554
	S29	-	499, 555
WEIGHT			
S21 X	S23	-	26, 553, 562
	S24	-	483, 557
	S27	-	26, 556, 557
	S28	-	499
	S29	-	499, 507, 558, 559
	S30	-	559, 560, 561
LOGISTICS			
S23 X	S27	-	26
ON-BOARD			
S24 X	S27	-	557, 563
HOURS			
S28 X	S29	-	499
DAYS			
S29 X	S30	-	559

TABLE 6a. A KEY TO DATA RELEVANT TO ACTIVITY 3

"REVIEW MANNED SYSTEM CONCEPT FEASIBILITY"

System Parameters by Human Variables Matrix

Human Variables \ System Parameters		S1 ENVIRONMENT	S11 ACCELERATION	S18 ALTITUDE/LOCATION	S19 PAYLOAD	S23 LOGISTICS	S26 PERFORMANCE	S27 MISSION DURATION	S32 EMERGENCY/ABORT/ESCAPE
H1	PHYSICAL								
H2	Shape and Size								
H3	Weight								
H4	Age								
H5	Sex								
H6	Body Position		O						
H7	PHYSIOLOGICAL		O						
H8	Body Systems	O	O					O	
H18	Thermoregulation								
H19	Circadian Rhythm								
H20	Metabolic	O	O		O				
H21	Sexual Drive								
H22	Exertion/Activity Level	O	O		O				
H23	PSYCHOLOGICAL								
H24	Performance Systems	O	O						
H29	Individual Differences								
H30	Social Sensitivities								
H31	Recreation								
H32	ECOLOGICAL	O						O	
H33	Habitability	O	O		O			O	
H34	Physiological Stress/Tolerance	O	O				O		
H35	Psychological Stress						O		
H36	THERAPEUTICS/PROPHYLAXIS								
H37	Psychiatry								
H38	Pharmacology								
H39	PERSONNEL SUBSYSTEM DEVELOPMENT	O						O	
H40	Crew Size					O		O	
H41	Selection/Training								
H42	Human Engineering								
H43	Sustenance	O	O		O	O		O	
H44	Protection	O	O	O					O
H45	Work/Rest Cycles								
H46	Hygiene	O							
H47	LIFE SUPPORT SYSTEM MEANS	O			O				

TABLE 6b. ACCESSION LIST TO RELEVANT DATA ITEM FOR TABLE 6a

Cell Coordinate			Relevant Data Item Numbers
ENVIRONMENT			
S1 X	H8	-	3, 6, 13
	H20	-	6, 17
	H22	-	17
	H24	-	1, 3
	H32	-	13
	H33	-	2, 4, 5, 9, 11, 12
	H34	-	1, 6, 7, 8, 9
	H39	-	13
	H43	-	2, 9, 11
	H44	-	2, 9, 10, 14
	H46	-	2
	H47	-	2
ACCELERATION			
S11 X	H6	-	15
	H7	-	16
	H8	-	3,6
	H20	-	6, 17
	H22	-	17
	H24	-	3, 18
	H33	-	4, 5, 9
	H34	-	6, 7, 8, 9, 19, 20, 21
	H43	-	9
	H44	-	9, 22
ALTITUDE/LOCATION			
S18 X	H44	-	10
PAYLOAD			
S19 X	H20	-	17
	H22	-	17
	H33	-	11
	H43	-	11, 23
	H47	-	23, 24, 25
LOGISTICS			
S23 X	H40	-	26
	H43	-	26
PERFORMANCE			
S26 X	H34	-	27
	H35	-	27
MISSION DURATION			
S27 X	H8	-	13
	H32	-	13
	H33	-	11
	H39	-	13
	H40	-	26
	H43	-	11, 26
EMERGENCY/ABORT/ESCAPE			
S32 X	H44	-	14

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DATA ITEMS

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THREE STRESSES AND VARIED EFFECTS

The data in the table below make the point that whether combinations of stresses produce additive or less than additive effects depends entirely on what effect is measured. Heat (105°F), noise (110 db white noise), and hypoxia (12,000 ft equivalent) were paired or used all together, while performance was measured with a continuous tracking task, and heart rate, respiration rate, and rectal temperature were monitored. In addition two secondary tasks were imposed--monitoring four meters for drift, and detecting brief flashes of light on an oscilloscope as a radar warning. Eight subjects were measured under all eight combinations, each serving also as his own control. The physiological measures all showed additive effects, the primary tracking task either additive or less than additive effects, and the secondary tasks additive or more than additive effects. Each stress individually was mild, and would not be expected to produce any particular effect alone.

Stresses	Effects		
	Primary task	Physiological measures	Secondary task
Hypoxia heat and noise	< additive	additive	additive
Hypoxia and noise	additive	additive	additive
Hypoxia and heat	additive	additive	> additive
Noise and heat	< additive	additive	additive

ITEM NO.*	SUBJECT AREAS:	SOURCE:
1	SYSTEM - S1 HUMAN - H24, H34	Reference 554, p. 165 Based on reference 160.

Ecological System: Some Possible Subsystems

ITEM	PHYSICAL	CHEMICAL	OTHER	REMARKS
O_2 Supply	Lox, High pressure—3000–7500 psi Steel, fiberglas Low pressure, 450 psi Steel, fiberglas, plastic	Superoxides KO_2, NaO_2, LiO_2, CaO_4 Peroxides H_2O_2, Na_2O_2, Li_2O_2 Others $NaClO_3$ KO_3	Electrolysis H_2O (direct) $CO_2 + H_2 \leftrightharpoons H_2O + C$ $CO_2 + H_2 \leftrightharpoons H_2O + CO$ $CO_2 + H_2 \leftrightharpoons 2H_2O + CH_4$ Photolysis $CO_2 \leftrightharpoons CO + \frac{1}{2}O_2$ $CO_2 \xleftrightarrow{cat} C + O_2$ Biological Algae, plants	High pressure and KO_2 systems can be used now. Other processes need research. Electrolysis of H_2O looks promising.
CO_2 Control	Freezeout Radiator panel Compressor Molecular sieve Linde 5a, 4A, 13X Membrane filter Activated charcoal	Hydroxides NaOH, KOH, LiOH $Ca(OH)_2$ Superoxides KO_2 MEA (Monoethanolamine) Baralyme	Hydrogenation $H_2 + CO_2 \leftrightharpoons C + H_2O$ $H_2 + CO_2 \leftrightharpoons CO + H_2O$ $H_2 + CO_2 \leftrightharpoons CH_4 + H_2O$ Biological Plants, algae	LiOH, KO_2 can be used now. Hydrogenation, molecular sieve and freezeout look promising but need research.
H_2O Humidity Potable	Condensation Freezeout Centrifuge Filtration Molecular sieve	LiCl KO_2 Silicagel $Mg(ClO_4)_2$ (anhydrone) $CaSO_4$ (drierite)	Biological purification Algae	Condensation via passive radiator panel appears to be the simplest and best at this time.
Temperature	Active control Compression Thermoelectric Passive control Radiator panels Stored cryogenics	H_2O		Heat loads—astronauts, sun, equipment
Nutrition (Food)	Food storage Dried, canned, irradiated, frozen Vacuum packed	Food supplements Vitamins Minerals	Food regeneration Algal, plants Chemical synthesis	Food preparation Cooking, electric, ir, microwave
Sanitation Feces Urine	Disposal Storage Decomposition (Heat) Purification Distillation Freezeout Filtration	Decomposition (Chemical) Urease Oxidation Ion exchange	Decomposition (Biological) Oxidation Protozoa Algal Bacteria	Garbage Storage Dump Incineration
Hygiene	Wash clothes Ultrasonics	Wash body and/or clothes H_2O + soap or detergent Alcohol Cleansing cream Cleaning agents	Disposable clothes and chemically-treated towels	Daily showers or baths may have to be extended to one a week
Auxiliary power	Solar turbo-electric Solar cells	Battery (chem.) Fuel cells	Nuclear (snap) (requires shielding or large separation distances)	Nuclear holds the greatest promise for high power requirements at low weight
Contaminants	Dust Hair Skin (debris) Tobacco particles	Odors and toxic substances (Cooking, food, wastes, body, garbage, smoking) NH_3, CH_4, CO, H_2, H_2S Indole, skatole, amines, volatile oils, phenol, nicotine	Bacteria Spores Viruses (Saprophytic bacteria) Decompose organic matter to H_2S, NH_4OH, CO_2, CH_4, lactic, butynic, and acetic acid, alcohols, mercaptons, etc.	Filters & absorbers Activated charcoal Electrostatic KO_2 Burners H_2 Flame P + electrode Hopcalite Chlorination of H_2O
Instrumentation and controls	Cabin pressure Temperature Fire detectors Cabin leaks	O_2, CO_2, N_2 control Humidity	Contaminants Alarm systems	Instrument panels Displays (T.V., Radar) Communications
Radiation shielding	U^{238}, Pb, cabin structure	Sustenance, fuel, H_2, O_2	Equipment	Use of useful payloads to double as shielding show promise
Safety and survival equip.	Escape capsule Repair facilities	Emergency O_2	Space suits	Better estimates required for additional study

ITEM NO.*	SUBJECT AREAS:	SOURCE:
2	SYSTEM - S1 HUMAN - H33, H43, H44, H46, H47	Reference 309, pp. 282-283.

STIMULUS-RECEPTOR-SENSATION RELATIONSHIP IN MAN

Stimulus	*Receptor*	*Sensation*	*Interpretation*
Electromagnetic waves (wavelength 10^{-5} cm)			
Electromagnetic waves (10^{-5} to 10^{-4} cm)	Photoreceptors	Light and color	All visual impressions
Electromagnetic waves (10^{-4} to 10^{-2} cm)	Thermoreceptors of the skin	Temperature hot to cold	Heat, fire, warmth, comfort, freezing
Mechanical oscillations 20 to 20,000 cps	Inner ear: cochlea	Noises, sounds (pitch and intensity)	Sounds, voices, music, tones
Pressure	Tangoreceptors of the skin and pressoreceptors within the body	Touch, weight, acceleration, deceleration	Objects, liquids, states of motion
Linear acceleration	Otoliths	Change of state of motion, equilibrium	Movements, voluntary and involuntary motion
Angular acceleration	Semi-circular canals	Rotation	Turning, voluntary and involuntary rotations
Chemicals in watery solution	Taste buds	Sweet, bitter, sour, salty	Food
Chemicals in the gaseous state	Olfactory cells	Smells	Odors of certain substances
Chemical and mechanical changes of inner milieu	Proprioceptors of the muscles and connecting tissue	Internal tension and pressure	Hunger, thirst, digestive processes
High-energy effects of all kinds	Free nerve endings of sense organs	Pain	Extreme stress, injury, illness

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
3	SYSTEM - S1, S11 HUMAN - H8, H24	Reference 219, p. 254.

GENERALIZED ENVIRONMENTAL VARIABLES

VARIABLE	UNITS	COMFORT ZONE	DISCOMFORT OR POSSIBLE DAMAGE
OXYGEN	---	15% - 60%	>60%, <?
VENTILATION	Cu Ft/Min	13 - 20	>50, < 5
HUMIDITY ↕ (Interrelated) TEMPERATURE	---	30% - 70%	>90%, < 10%
	Degree Fahrenheit	$65^{o}F$ - $75^{o}F$	$>100^{o}F$, $<30^{o}F$
HEAT LOSS	BTU/Hr.	1450 active, 330 rest	> 3000
ATMOSPHERIC PRESSURE	Pounds per Square Inch - Atmosphere	10 - 20 PSIA	>?, < 8 PSIA
ACCELERATION	lg=32 ft/sec/sec	0g - lg	> lg
ELECTRICITY 60 CYCLE	Milliamp	0 MA - 1 MA	10 MA
ATOMIC RADIATION	REM/Year	0 - 0.2	15
LIGHT	Foot Candles, Avoid Glare	20 FC - 100 FC	10,000 FC
NOISE	Decibels, Avoid Continued Silence	0 db - 85 db	> 94 db
MECHANICAL VIBRATION	Cycles/Second Inches Amplitude	0 - 1 CPS 0 - .005 in.	10 CPS .05 in.
SHOCK WAVES	Pounds/Sq. In.	0 - 2.5 PSIG	> 7 PSIG
CARBON MONOXIDE	Parts per Million Parts of Air	0 - 100 PPM	3000 PPM
CARBON DIOXIDE	Parts per Million Parts of Air	0 - 1700 PPM	40,000 PPM

ITEM NO.*	SUBJECT AREAS:	SOURCE:
4	SYSTEM - S1, S11 HUMAN - H33	Compiled from several primary sources.

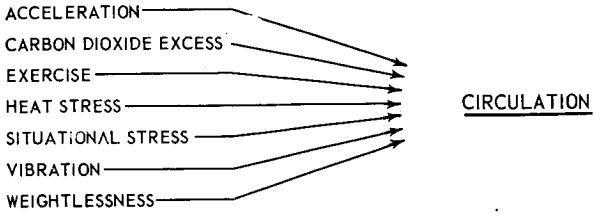
PARAMETERS FOR ENVIRONMENTAL MONITORING

Environmental Parameter	Range	Accuracy
3 axes acceleration	0–10 g	5%
Vibration	0–5 g	5%
Noise	140 db	5%
Radiation rate	0–12 rem	5%
Air temperature	0–250° F	3° F
Humidity	20–90%	5%
O_2 reserve	0–3,000 psia	1%
O_2 flow rate	2–12 cft/min	5%
CO_2 partial pressure	0–20 mm Hg	5%
CO_2 filter status	0–100%	10%
Cabin pressure	0–15 psia	1%
Suit pressure	0–15 psia	1%

Lawrence J. Fogel, BIOTECHNOLOGY: Concepts and Applications. (c) 1963. Reprinted by permission of Prentice-Hall, Inc.

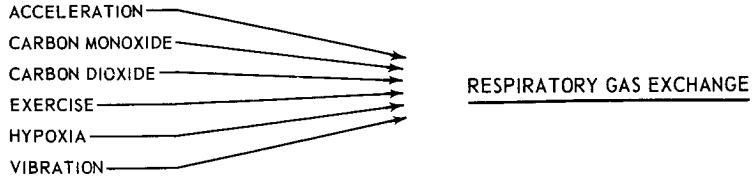
ITEM NO.*	SUBJECT AREAS:	SOURCE:
5	SYSTEM - S1, S11 HUMAN - H33	Reference 197, p. 452.

a.



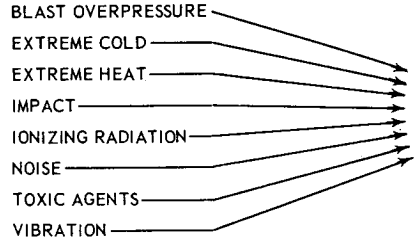
STRESSES WHICH AFFECT THE CIRCULATORY SYSTEM

b.



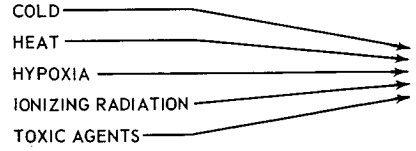
STRESSES WHICH AFFECT THE EXCHANGE OF O_2 AND CO_2 IN THE ALVEOLUS

c.



STRESSES WHICH CAN PRODUCE INJURY AND DEATH IN CELLS AND TISSUES

d.



STRESSES WHICH INTERFERE WITH CELL METABOLISM

ITEM NO.*	SUBJECT AREAS:	SOURCE:
6	SYSTEM - S1, S11 HUMAN - H8, H20, H34	Reference 554, p. 160.

ADDITIVE INTERACTIONS

Examples of Stresses with Additive Interactions

Stresses	Test animal	Effect	Source
Acceleration and heat	Man	Heat decreases tolerance to $+G_z$	Burgess
Acceleration and hypoxia	Man	Hypoxia decreases tolerance to $+G_z$.	Burgess
Acceleration and cold	Rats	Hypothermia decreases tolerance to $+G_z$ in rats at 20 G	Stiehm
Hypoxia and cold	Man	Cold with hypoxia increases shivering, heat production, heart rate, and respiratory ventilation	Bullard
Hypoxia and heat	Man	Increased heart rate in 63% of 19 subjects exposed to 120°F for 30 min and 18,000 ft the last 15 min	Hale
Hypoxia and vibration	Rats	Greater mortality in restrained rats	Megel et al.
Hypoxia and radiation	Rats	Radiation 30 days in advance decreases tolerance to hypoxia; probably there is suppression of red blood cells from radiation injury.	Newsom and Kimeldorf
Radiation and cold	Rats	Decreased cold tolerance following neutron and x-ray radiation.	Newsom and Kimeldorf
Vibration and heat	Rats	65% mortality (26 in 40 rats exposed) when sublethal heat was combined with random vibrations (5-800 cps, 17.5 G rms), which produces 7.5% mortality alone.	Megel et al.
Weightlessness and acceleration	Man	Endpoint reached at lower G levels following 18 hours submerged.	Benson et al.
Weightlessness, heat, and dehydration	Man	In one subject, bed rest plus heat plus dehydration of 3.8% of body weight produced a hypotensive response to 70° tilt.	Di Giovanni et al.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
7	SYSTEM - S1, S11 HUMAN - H34	Reference 554, p. 162 Based on several primary sources.

ANTAGONISM AND NONINTERACTION

a. Examples of Antagonistic Interaction Between Stresses

Stresses	Test animal	Effect	Source
Acceleration and cold	Rats	Hypothermia improves tolerance to $+G_z$ at levels of 30 and 40 G	Stiehm
Hypoxia and heat	Man	Slowing of heart rate in 27% of 19 subjects exposed to 120°F for 30 min and 18,000 ft for the last 15 min	Hale
Radiation and hypoxia	Rats	Prior irradiation with 600 r of x-ray improves tolerance for acute exposure to 25,000-30,000 ft altitude. Food deprivation in addition causes further improvement.	Newsom and Kimeldorf

b. Examples of Noninteraction Between Stresses

Stresses	Test animal	Effect	Source
Acceleration and radiation	Rats	γ irradiation before and following exposure to $+G_z$, $-G_z$, and G_x accelerations showed no change in lethal dose levels.	Zellmer et al.
	Rats	Acceleration during exposure to 100r of X-ray radiation did not aggravate the usual acute radiation illness.	Ivanov
Radiation and cold	Rats	The reduced longevity, retarded growth, cataracts, skin ulcers, etc. following exposure to 500 r x-radiation were not changed by a 3-hr daily exposure to 32°F (0°C)	Gambino et al.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
8	SYSTEM - S1, S11 HUMAN - H34	Reference 554, p. 164 Based on several primary sources.

BIOPHYSICAL AND LOGISTIC PARAMETERS OF SATELLITE VEHICLE ENVIRONMENT

Factors	*Characteristics*			*Weight*		*Remarks*
	Normal	*Tolerance Limits*	*Tolerable Stress (72 hours flight)*	*Per man per day*	*3 men 3 days*	
Cabin pressure	760 mm Hg	187 mm Hg	236 mm Hg	10 kg	30 kg	Weight of protective suit
Partial O_2 pressure	160 mm Hg	39 mm Hg	100 mm Hg			
pO_2 alveolar	107 mm Hg	30 mm Hg	100 mm Hg			At 100% O_2
O_2 consumption	603 l*	360 l*	500 l*	0.8 kg	7.2 kg	*Per day
CO_2 concentration	<1%	4.3%	<1%	2 kg	20 kg	Weight of CO_2 absorbent
Temperature	22° C	−40° C* +200° C	0–30° C			*Tolerance with protective clothing
Humidity	50% r. h.	<100% r. h.	<70% r. h.	2.5 kg*	22.5 kg*	*Anhydrone
Acceleration	1 g	>12 g	8 g			Depending upon duration
Deceleration		80 g/sec	80 g/sec			Re-entry t = <0.5 sec
Noise	30–40 db	150 db	<130 db			
Dry food	2,800 cal	80 cal	1,800 cal	0.5 kg	4.5 kg	
Water	2.1 l	0.2 l	2 l	2 kg	18 kg	
Lighting	30–300 NIT	0.1 NIT	>30 NIT			
Radiation	0.1 mrep/d	43 mrep/d	<43 mrep/d			
Personal equipment				5 kg	15 kg	Clothing, underwear, hygiene, etc.
Technical equipment (containers, blowers, ducts, etc.)				10 kg	20 kg	
Total				32.8 kg	137.2 kg	

ITEM NO.*	SUBJECT AREAS:	SOURCE:
9	SYSTEM- S1, S11, S21 HUMAN- H33, H 34, H43, H44	Reference 219, p. 413. Based on Reference 398.

BIOMEDICAL FUNCTIONS OF
THE TERRESTRIAL ATMOSPHERE

Normal physiologic and psychologic reactions during air breathing maintained up to	10,000 ft
Atmospheric oxygen contribution to respiration	50,000 ft
Air pressure sufficient to keep body fluids below boiling point	63,000 ft
Useful consciousness period of 10 to 12 seconds during hypoxia	65,000 ft
Air density sufficient high to permit ambient air pressurization in aircraft	80,000 ft
Protection against heavy primaries	120,000 ft
Protection against ultraviolet radiation (3000 to 2100 Å)	140,000 ft
Sufficient time to inflate pressure suit upon explosive decompression	150,000 ft
Scattering of visible light	400,000 ft
Propagation of sound waves	400,000 ft
Protection against macro-meteorites	400,000 ft

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS,(©) 1963. Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
10.	SYSTEM - S1, S18 HUMAN - H44	Reference 219, p. 18.

THERMAL AND ATMOSPHERIC SYSTEM REQUIREMENTS
AND VEHICLE FEATURES
(ASD TR 61-240 Pt I)

Item	*Vehicle 1A*	*Vehicle 1B*	*Vehicle 1C*
Crew size	5	2	2
Duration of mission	6 weeks	1 week	12 to 36 hours
Flight vehicle power for orbital phase	Nuclear or solar	Nuclear or solar or chemical	Chemical
Flight vehicle power for re-entry	Chemical	Chemical	Chemical
Approximate maximum power demand (orbital)	20 to 25 kw	20 to 25 kw	6 or 12 kw
Wing area available for radiator	1325 ft^2	915 ft^2	750 ft^2
Total pressurized volume	1500 ft^3	1200 ft^3	1080 ft^3
Total pressurized compartment wall area	1100 ft^2	800 ft^2	700 ft^2
Orbit altitude (nautical miles)	300	300	300
Pressurized level	15 psia	15 psia	10 psia
Maximum normal leakage rate	5 lbs/day	5 lbs/day	10 lbs/day
Maximum average emergency leakage rate	10 lbs/day	10 lbs/day	20 lbs/day
Number of pressurized compartments	2	2	1
Cabin temperature (nominal)	70° F	70° F	70° F
Re-entry maximum allowable cabin temperature	130° F	130° F	130° F
Cabin relative humidity (nominal)	50%	50%	50%
CO_2 concentration by volume (nominal)	0.5%	0.5%	0.5%
Cabin atmospheric O_2 and N_2 concentration	Sea level	Sea level	40% O_2 60% N_2
CO_2 production rate (average)*	2.25	2.25	2.25
Urine production rate (average)*	3.0	3.0	3.0
Perspiration & respiration water rate (average)*	2.2	2.2	2.2
Wash water required*	4.0	None	None
Solid waste (average)*	0.33	0.33	0.33
Drinking water (dehydrated food at 1.32 lbs/man/day)*	4.46	None	None
Drinking water (regular food at 3.32 lbs/man/day)*	2.46	2.46	2.46
Oxygen consumption*	2.0	2.0	2.0

* Lbs/man/day.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
11	SYSTEM - S1, S19, S27 HUMAN - H33, H43	Reference 219, p. 416 Based on Reference 398.

Ideal Environment for Man

1. Temperature: 68–72°F
2. Relative humidity: 40–50%
3. Ambient pressure: 14.7 psi
4. Oxygen partial pressure: 18–21%
5. Carbon dioxide partial pressure: 0.3 to 0.5%
6. Daily water requirements: 5 lb
7. Ozone and atmospheric pollution: 0
8. Nuclear radiation: less than 40 milliroentgens per day
9. Ambient illumination: 5 millilamberts
10. Ambient random noise: 20 db
11. Maximum noise level: 120 db – 0.0002 dynes/cm^2
12. Air movement: 100 cfm
13. Clothing: Shirt sleeves
14. Minimum operational space: 650 cu ft per man
15. Etc.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
12	SYSTEM – S1, S 20 HUMAN – H33	Reference 416, p. 78

Parameters of Biomedical Interest for Short-Duration Missions

Protection from

1. Acceleration and deceleration
2. Hypo-, zero-, and hypergravity states
3. Noise stresses—acoustic
4. Vibration stresses
5. Thermal stresses
6. Accidents: decompressions
7. Radiation: infrared-ultraviolet-electronic equipment
8. Meteoritic collision

Provision for

1. Potable water and means of ingestion
2. Nutrition and means of ingestion
3. Breathing gases: oxygen-nitrogen-carbon-dioxide-water balance
4. Ventilation
5. Temperature control
6. Emergency escape
7. Communications

Parameters of Biomedical Interest for Long-Duration Missions

Protection from

1. Radiation: alpha, beta, and gamma rays; X-rays (hard and soft); cosmic rays; solar flares; electromagnetic rays; magnetic field forces
2. Zero gravity
3. Thermal stresses
4. Accidents: decompressions; body trauma; surgical emergencies, etc.
5. Toxicological cumulative gases
6. Isolation and sensory deprivation
7. Disease
8. Deleterious ratio of negative ions to positive ions
9. Meteorites

Provision for

1. Nutrition and water
2. Breathing gases: oxygen-nitrogen-carbon-dioxide-water balance
3. Temperature control and ventilation
4. Waste disposal: urine, feces, sweat, flatus
5. Movement and exercise
6. Treatment for trauma and disease
7. Sanitation or body cleanliness
8. Light and darkness, or diurnal cycle
9. Maintenance of neurologic, emotional, and mental stability
10. Sleep-wake-work-recreation cycle
11. Detection of long-range aberrations in respiration, digestion, cardiovascular integrity, endocrines, dermatological changes, metabolism, genetics, reproduction
12. Emergency escape
13. Communications

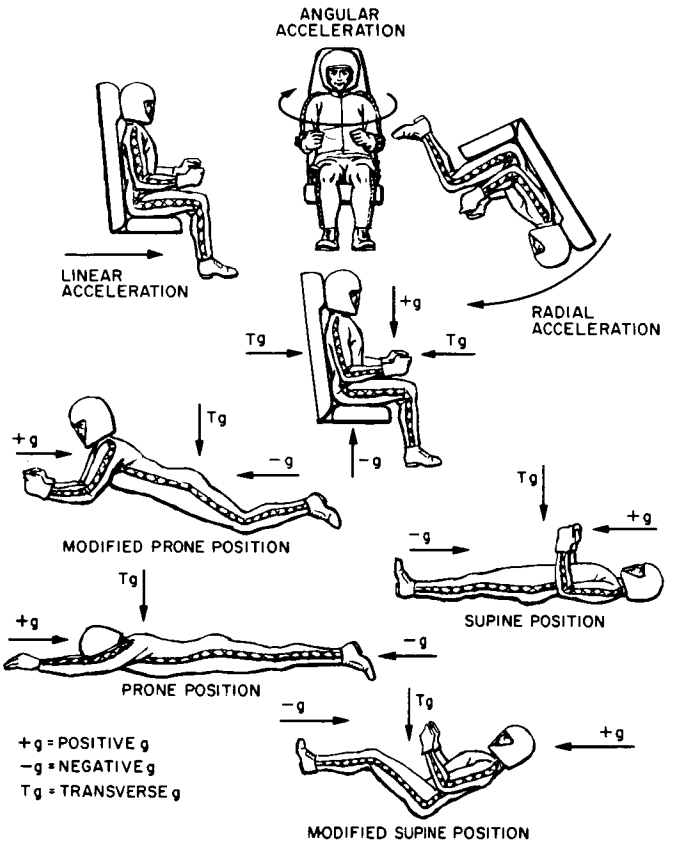
ITEM NO.*	SUBJECT AREAS:	SOURCE:
13	SYSTEM- S1, S27 HUMAN- H8, H32, H39	Reference 416, pp. 68-69.

EMERGENCIES AND CORRECTIVE ACTIONS

Hazard	I		II		III	
	Emergency	Corrective Action	Emergency	Corrective Action	Emergency	Corrective Action
1. Fire						
Small	Major	CO_2 extinguished	Minor	CO_2 extinguished	Minor	CO_2 extinguished
Large	Catastrophic	None	Catastrophic	None	Major	Decompress affected module
2. Explosion						
Small	Catastrophic	None	Major	1.Don pressure suit 2.Effect repair	Minor	1.Evacuate module 2.Decompress 3.Leisurely repair
Large	Catastrophic	None	Catastrophic	None	Major	1.Decompress module 2.Don pressure suits for rapid repair
					Catastrophic	None
3. Decompression						
Slow	No effect		Minor	1. O_2 masks or pressure suit 2. Effect repair	Minor	1, O_2 masks 2, Effect repair
Rapid	No effect		Major to Catastrophic	1. Don pressure suit 2. Rapid repair	Minor to Major	1. Pressure suits 2, Repair
Explosive	No effect		Catastrophic	None	Major	1, Evacuate module 2. Initiate rescue
4. Toxic Contamination	Major	1.Don pressure suit 2.Purge cabin	Major	1.Don pressure suit 2.Purge cabin	Minor	1. Evacuate module 2. Purge
5. Environmental Control System Failure	Minor to Major	1.Don pressure suit 2.Replace defective part	Minor	Replace defective part	Minor	Replace defective part
6. Radiation						
Solar Flare 3+	No effect		Major	Storm shelter or abort mission	No effect	
Dip down Anomaly	Minor	Remain within shielded area	No effect		Minor	Remain within shielded area
7. Aerial Nuclear Detonation	Major to catastrophic	Immediate abort	No effect		Catastrophic	None
8. Loss of Vehicle Control	Major to catastrophic	Attempt to repair	Major	Repair	Minor to Major	Attempt repair or evacuate station
9. Power Loss	Major	Replace module	Major	Attempt repair	Major	Attempt repair

ITEM NO.*	SUBJECT AREAS:	SOURCE:
14	SYSTEM - S1, S32 HUMAN - H44	Reference 378, p.64

ACCELERATION NOMENCLATURE FOR VARIOUS BODY POSITIONS

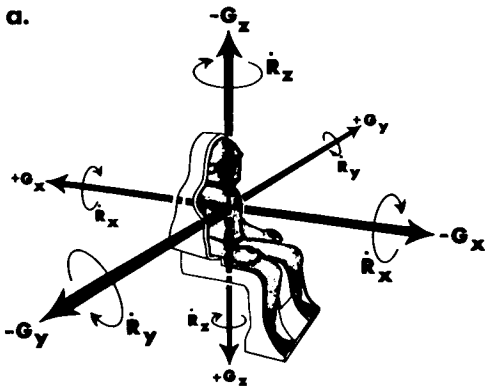


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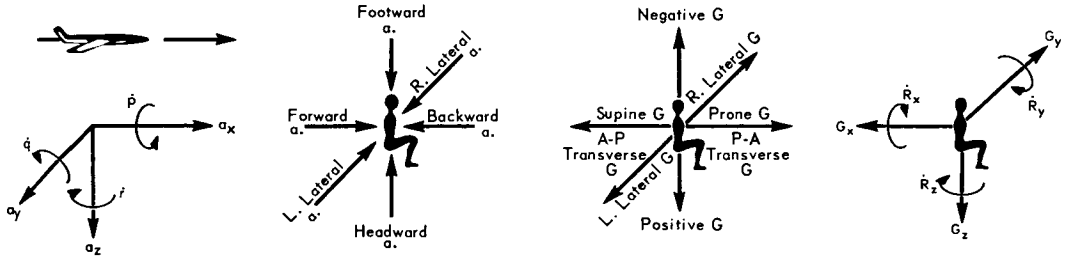
ITEM NO.*	SUBJECT AREAS:	SOURCE:
15	SYSTEM - S11 HUMAN - H6	Reference 380, p. 446

Symbols and vectors used in this book are based on the direction a body organ (e.g., the heart) would be displaced by acceleration. Table II below--and in particular System 4, which is based on displacement of body fluids--explains the most commonly employed terms.

a.



b.



SYSTEM 1 SYSTEM 2 SYSTEM 3 SYSTEM 4

c.

Table I
Direction of Acceleration

Linear Motion	Aircraft Vector (System 1)	Acceleration Descriptive (System 2)
Forward	$+a_x$	Forward accel.
Backward	$-a_x$	Backward accel.
Upward	$-a_z$	Headward accel.
Downward	$+a_z$	Footward accel. (tailward)
To right	$+a_y$	R. lateral accel. (rightward)
To left	$-a_y$	L. lateral accel. (leftward)
Angular Motion		
Roll right	$+\dot{p}$	cartwheel
Roll left	$-\dot{p}$	cartwheel
Pitch up	$+\dot{q}$	somersault
Pitch down	$-\dot{q}$	somersault
Yaw right	$+\dot{r}$	pirouette
Yaw left	$-\dot{r}$	pirouette

Table II
Inertial Resultant of Body Acceleration

Physiological Descriptive (System 3)	Physiological Displacement (System 4)	Vernacular Descriptive (System 5)
Transverse A-P G* Supine G Chest to back G	$+G_x$	Eyeballs in
Transverse P-A G Prone G Back to chest G	$-G_x$	Eyeballs out
Positive G	$+G_z$	Eyeballs down
Negative G	$-G_z$	Eyeballs up
Left lateral G	$+G_y$	Eyeballs left
Right lateral G	$-G_y$	Eyeballs right
Roll	$-\dot{R}_x$	
	$+\dot{R}_x$	
Pitch	$-\dot{R}_y$	
	$+\dot{R}_y$	
Yaw	$+\dot{R}_z$	
	$-\dot{R}_z$	

* A-P and P-A refer to Anterior-Posterior and Posterior-Anterior.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
16	SYSTEM - S11 HUMAN - H7	Reference 554, p. 32 Based on Reference 212.

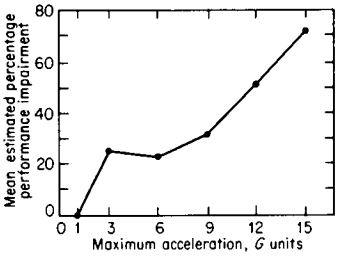
TOTAL DAILY OXYGEN COSTS IN DIFFERENT ENVIRONMENTS

FUNCTION	ENVIRONMENT AND GRAVITATION				NOTES
	Earth – 1 g	Capsule – 0 g	Free Space – 0 g	Moon Surface – 1/6 g	
Tissue Maintenance--Circulatory, Respiratory, and Other Functions	0.8-1.4 lb O_2 (250-450 liters)	-- -- same as Earth requirement -- --			No reduction expected in subgravity environments.
Temperature Regulation	Add 3% to tissue maintenance values for every 18° F of mean temperature below 50°, subtract 5% for every 18° above 50°		May be sharp changes due to temperature.	May be sharp changes due to low shade temperature and high radiation in open.	Energy costs raised in heat, but men more relaxed. Oxygen intake raised in cold.
Maintenance of Body Position Position	Sitting at rest involves 25% higher O_2 cost than lying. Standing requires further 10%.	In zero gravity, posture maintenance may cost more or less, according to restraint equipment.			In water at neutral temperature, O_2 costs drop toward cost lying horizontally.
Movement of Body Parts	In sitting and standing positions, movement of body parts can increase O_2 cost by up to 0.07 and 0.15 lb/hr respectively	In zero gravity, the inertial work of a given movement is unchanged, but the difficulties of moving and operating controls without traction or fixation may increase oxygen costs.			Training for zero gravity operations may be very important. Clumsy movements have high O_2 costs.
Movement of External Objects (levers, pushing, lifting)	Heavy engineering work raises O_2 cost by up to 0.12 lb/hr.	For controls unaffected by gravity, this increase is likely to hold. Use of powered tools and controls will naturally reduce the effect, assuming that controls are properly redesigned for use when gravity and traction are absent or reduced.			The O_2 cost of wearing a pressurized suit needs measuring, especially in respect to this type of operation.
Walking and Carrying	O_2 consumptions up to 1.5 liters per hr per lb total weight are commonly found.	Not applicable	Not applicable	O_2 consumptions up to and exceeding 0.015 liters/hr per lb total weight must be expected frequently if moon surface is rough and steep.	See also O_2 costs of movement in the snow.
TOTAL DAILY OXYGEN COST	2 lb of O_2 per man per day is common. On strenuous days, this may rise to 3-4 lb.	1-1.5 lb expected consumption.	Requires simulated or actual measurement		Highest recorded daily cost was in lumberjacks, and was about 5 lb.

This chart shows why the oxygen requirement in space and on the moon surface cannot be estimated more accurately than to say it will lie in the range 1 to 5 lb per day per man. Starting at the top and reading across each row, comparisons are made between the oxygen requirements for specific functions on earth, in the flight capsule, in free space, and on the moon surfact. At the end of each row is a note on some important aspect of the function under study--tissue maintenance, temperature regulation, body position, body movement, movement of controls, walking and carrying, or total daily oxygen cost.

Gaps in our knowledge are pointed out throughout the table, and it is suggested that simulated trials are needed before any precise estimates can be given. It is particularly important, because of person-to-person variation, to measure oxygen costs on individual astronauts before lengthy space flights are contemplated.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
17	SYSTEM- S1, S11, S19 HUMAN- H20, H22	Reference 554, p. 180



Average estimated performance impairment (across several aspects of performance)associated with acceleration forces.

Increasing levels (and/or durations) of acceleration have been found to be significantly related to reaction time, visual acuity, time estimation, tracking performance, time to activate control of an aircraft-ejection mechanism, and other aspects of human performance [Chambers and Brown, ; Brown,]. The general pattern of such performance degradation is fairly similar for different aspects of performance. This figure gives a generalized impression of such degradation, showing "average" estimated impairment for various aspects of performance.

ITEM NO:	SUBJECT AREAS:	SOURCE:
18	SYSTEM- S11 HUMAN- H24	Reference 362, p.552 Based on References 117 and 99.

VARIABLES INFLUENCING G TOLERANCE

a. The direction of the primary of resultant G force with respect to the axes of the human body.
b. The rate of onset and decline of G.
c. The magnitude of peak G.
d. The duration of peak G.
e. The total duration of acceleration from time of onset to termination.

Other conditions influence a human subject's tolerance. Some of them, in addition to the ones already presented earlier, are as follows:

a. The types of end points used in determining tolerance.
b. The types of G protection devices and body restraints.
c. The type of environment in which the subject is tested, such as temperature, ambient pressure, noise, and lighting.
d. Age.
e. Psychological factors, such as fear and anxiety, competitive attitude, willingness to tolerate discomfort and pain.
f. Previous acceleration training and accumulative effects.
g. The types of acceleration device used for exposing the subject to acceleration.
h. Muscular control, tensing, and effort.

Since physiological G tolerance is a function of many variables, it has not been possible to construct a single simple graph which adequately summarizes G tolerance. Also, there has been no systematic work in which the same subjects have been exposed to a sufficiently wide variety of conditions using reasonably comparable tolerance criteria. G tolerance may be expressed as a function of at least five primary acceleration variables, and a complex multidimensional graph would be required to show all of the relationships, even if the complete data were available. These major variables are described in(a) to (e) above.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
19	SYSTEM - S11 HUMAN - H34	Reference 116, pp. 208-209.

Some Maximum Acceleration Exposures Endured by Human Subjects

Type of G Field	Type of Maneuver	Peak G	Exposure Time (sec)	Type of Device
$+G_x$	Abrupt deceleration	$82.6G_x$	0.04	Deceleration sled
(Transverse G,	Abrupt deceleration	$55G_x$	0.01	Deceleration sled
sternumward)	Abrupt deceleration	$35G_x$	0.12	Deceleration sled
	High-G re-entry	$25G_x$	5	Centrifuge
	Re-entry simulation	$15G_x$	5	Centrifuge
	Tracking and endurance test	$14G_x$	127	Centrifuge
	Tracking and endurance test	$10G_x$	210	Centrifuge
	Tracking and endurance test	$6G_x$	555	Centrifuge
$-G_x$	Abrupt deceleration	$-60G_x$	0.01	Deceleration sled
(Transverse G,	Abrupt deceleration	$-38G_x$	0.12	Deceleration sled
spineward)	Endurance test in water capsule	$-31G_x$	5	Centrifuge
	Endurance test in water capsule	$-28G_x$	5	Centrifuge
	Re-entry simulation	$-15G_x$	5	Centrifuge
	Prolonged tracking and endurance test	$-10G_x$	71	Centrifuge
	Prolonged tracking and endurance test	$-6G_x$	350	Centrifuge
$+G_z$	Ejection escape	$+20G_z$	0.1	Ejection tower
(Positive G)	Endurance, tracking	$+9G_z$	6	Centrifuge
	Endurance, tracking	$+8G_z$	26	Centrifuge
	Endurance, tracking	$+7G_z$	90	Centrifuge
	Endurance test	$+5G_z$	240	Centrifuge
$-G_z$	Ejection escape (downward)	$-10G_z$	0.1	Ejection tower
(Negative G)	Push over	$-4.5G_z$	5	Airplane
	Endurance test	$-3G_z$	32	Centrifuge

ITEM NO.*	SUBJECT AREAS:	SOURCE:
20	SYSTEM - S11 HUMAN - H34	Reference 116, p. 213.

ACCELERATION

TYPE OF G	DIRECTION OF BODY MOVEMENT	AIRCRAFT MANEUVER	EXPERIMENTAL, HUMAN EXPOSURES (MAXIMUM)	PHYSIOLOGICAL LIMITS HUMAN	ACTIVITIES
POSITIVE	Head to Foot	Pull Out or Tight Turn	8 G for 15 Sec.	Blackout to Unconsciousness	All Centrifuges
			4.5 G for 5 Min. with G Suit	Pain in Legs and Blackout	
		Controlled Escape Deceleration	15 G for 1.75 Sec.	Unconsciousness	AMAL Centrifuge
		Ejection Escape (Upward)	20 G for 0.1 Sec. with Face Curtain - Arm Rest	Skeletal Damage (Spine)	AMEL and WADC Ejection Tower
NEGATIVE	Foot to Head	Push Over	4.5 G for 5 Sec.	Subjective Pain	Rod Jocelyn
			3 G for 32 Sec. with Special Helmet	Fullness of Neck and Head Bradycardia	WADC Centrifuge
		Ejection Escape (Downward)	10 G for 0.1 Sec. with Leg Support	Pain	WADC Ejection Tower
TRANSVERSE SUPINE	Chest to Back	Catapult Launching	5 G for 2 Sec.	No Damage	Carrier Takeoffs and AMAL Centrifuge
		Escape Deceleration or Higher Launching Stress	3 G for 9 Min. 31 Sec. Lying Flat	Monotony and Giddiness	WADC Centrifuge
			15 G for 5 Sec.	Surface Petechial Hemorrhage and Pain in Chest	AMAL Centrifuge
		Crash (Facing Aft)	55 G for 0.01 Sec. 35 G for 0.12 Sec.	Skeletal Damage	WADC Deceleration Track (Col. Stapp)
TRANSVERSE PRONE	Back to Chest	Arrested Landing	5 G for 2 Sec.	No Damage	Carrier Landings and AMAL Centrifuge
		Escape Deceleration or Higher Landing Stress	15 G for 5 Sec. Special Chest and Leg Support	Surface Petechial Hemorrhage and Pain in Chest	AMAL Centrifuge
		Crash (Facing Forward)	60 G for 0.01 Sec. with Special Harness 38 G for 0.12 Sec. with Special Harness	Skeletal Damage	WADC Deceleration Track (Col. Stapp)
FLUCTUATING POSITIVE	Alternating Positive and Transverse	Uncontrolled Aircraft "Jostle"	1.5 to 6.5 G for 20 Sec. Combined with 72° Pitch and Roll	Additional Support Required Other Than Conventional Lap Belt and Shoulder Harness	AMAL Centrifuge
CYCLIC	Alternating Positive Transverse Prone Negative Transverse Supine	Uncontrolled Escape Device "Tumbling"	No Human Experimentation Due to Severe Damage in Animal Exposures		AMAL Centrifuge

AMAL - Aviation Medical Acceleration Laboratory, Johnsville, Pennsylvania
AMEL - Aviation Medical Equipment Laboratory, Philadelphia, Pennsylvania
WADC - Wright Air Development Center, Dayton, Ohio

ITEM NO.*	SUBJECT AREAS:	SOURCE:
21	SYSTEM - S11 HUMAN - H34	Reference 557.

PROTECTION AGAINST HARMFUL EFFECTS OF G FORCES

The re-positioning of the operator has been attempted recently to combat the problems of g stresses. The supine position offers good g-force protection but makes visibility difficult. The prone position is also good; it improves visibility but makes control movements a problem.

A number of means exist for protection against or amelioration of the harmful effects of g forces.

SELF PROTECTION Muscle tension (i.e., shortening), voluntary. Eating meal before flight, full stomach helpful. Special breathing (forced) to produce alternately high and low intrathoracic pressures.	POSTURAL PROTECTION Prone or supine position. Crouch with step-up rudder bars. Tilting seat, to permit near-horizontal position when necessary.
PROTECTIVE CLOTHING Pneumatic belts and suits. Hydraulic suits. Net suits.	DRUGS

ITEM NO.*	SUBJECT AREAS:	SOURCE:
22-	SYSTEM-S11 HUMAN- H44	Reference 585, p.1-91.

FEEDING SYSTEMS FOR SPACECRAFT

WEIGHT, VOLUME AND POWER FOR SEVERAL TYPES OF FEEDING SYSTEMS

Feeding System	Food		Environmental Conditions	Equipment			
	Weight	Volume		Type	Weight	Volume	Power
	(lb)	(ft^3)			(lb)	(ft^3)	(kilowatt hrs/day)
Minimal Acceptability: Foods compressed, freeze dehydrated, and limited in variety; no food service equipment available; temperature of water for food reconstitution 80-90°F.	1.0	0.06	Weightlessness	Water Storage Unit	1.5	0.4	0.01
Moderate Acceptability: A moderate variety of pre-cooked dehydrated foods, instant beverages, and bite-size pieces; approximately half the water at 40°F ± 5°, the remaining half at 180°F ± 10°; food service equipment limited to a water cooler and heater.	1.7	0.13	Weightlessness	Water Heater	5.0	0.6	0.30
				Thermo-Electric Water Cooler	5.5	0.7	0.45
High Level of Acceptability: A moderate variety of pre-cooked dehydrated foods, instant beverages, bite-size solids, and one pre-cooked frozen meal per day; approximately 4/5 of the water requirement for food preparation, the remaining 1/5 contained in frozen foods.	2.5	0.15	Partial Gravity	Water Heater	5.0	0.6	0.30
				Thermo-Electric Water Cooler	5.5	0.7	0.45
				Thermo-Electric Freezer	158	12.0 capacity	15.00
				Oven	10.0	0.9	1.00

Food values cited are for one man for one day. A standard value has been assumed for the daily water supply: 2500 cc/man. It is assumed that the crew size will be two to four men and that mission durations will extend from two weeks to two months. Food weight and volume values include weight of food, dispensers, and packaging.

Equipment data are based on state of the art designs. Values for weight, power and volume of all equipment, except the freezer, will meet the needs of space missions of indefinite duration, provided only two crew members eat at one time. Freezer weight, volume, and power data are based on food supplies for a four man crew, 60 day mission.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
23	SYSTEM - S19 HUMAN - H43, H47	Reference 554, p. -194 Based on Reference 94.

SUMMARY OF DESIGN CONSIDERATIONS FOR WASTE DISPOSAL SYSTEMS

Basic Technique	Maximum Condenser Temp. (° F)	Minimum Power Required watts/man	Minimum Area of Radiation Panel ft²/man	Estimated Weight		Estimated Volume Required ft³/man	Reliability	Comment
				Fixed gm/man	Variable gm/man/day			
Freeze Distillation	−15	none	10.8	4,000	none	5.4	Very high	Materials handled in solid state
	20	none	7.93	4,000	none	7.9	Very high	
Vacuum Distillation	32	none	7.36	2,700	75	3.7	Very high	Small, simple system that requires no direct power. Sponges used to handle raw material, water, and residue.
	70	none	4.85	1,800	75	2.4	Very high	
Atmospheric	212	185	2.0	540	75	1.0	High	Small, but large power requirement.
Compression Distillation	212	6.2	none	20,000	75	2.0	High	Small, and low power requirements but heavy centrifuge and bladders utilized.

ITEM NO.*	SUBJECT AREAS:	SOURCE:
24	SYSTEM - S19 HUMAN - H47	Reference 197, p. 561 Based on Reference 596.

WEIGHT AND SPACE, AND ENERGY REQUIREMENTS FOR VARIOUS METHODS OF RECYCLING URINE

Method	*Additional Treatment Steps Needed*	*Volume Requirements—Cubic Feet*				*Weight Requirements—Pounds*				*Energy Requirement Per Day*	*Waste Water Storage Cu. Ft.*	*Fresh Water Storage Cu. Ft.*
		Water (4 Liters = .14 Cu. Ft.)	*Recycling System*	*Batteries (6 Volt Size = .3 Cu. Ft.)*	*Total*	*Water (4 Liters = 8.34 Lb.)*	*Recycling System*	*Batteries (6 Volt Size = 600 Watt)*	*Total*			
Distillation—All methods included. Differences are only slight	Metafilter anti-foaming still head; recondensation; aeration	0.14	1.0	(five) 1.5	2.6	8.34	10.0	(five) 250.0	268.3	2,480,000 cal. or 2.8 kw-h	0.5	0.5
Solar still	Metafilter aeration pumps	0.14	16.0	—	16.1	8.34	Not over 20.0	—	28.3	free	0.5	0.5
Ion exchange	Metafilter enzyme urease treatment aeration pumps	0.21	1.0	?	1.0 to 2.0	If water used for regeneration 12.52	10.0	?	22.5 to 100.0	Energy for pumps and regeneration if used—not established	0.5	0.5
Freezing	Metafilter screening aeration pumps	0.21	1.0	(two) 0.6	1.8	12.52	10.0	(two) 100.0	122.5	400,000 cal. or 0.46 kw-h	0.5	0.5
Electro-osmosis	Metafilter enzyme urease aeration pumps	0.14	<1.0	Estimated(two) 0.6	1.7	8.34	10.0	Estimated(two) 100.0	118.3	Not established but less than distillation	0.5	0.5

1 battery (6 volt) = 600 watts @ 100% efficiency; wt. 50 lbs., volume 0.3 cu. ft.
Specific heat (water) = 1.0 cal/g/1°C.
Heat of vaporization = 540.0 cal/g.
Heat of fusion = 80.0 cal/g.
1 B.t.u. = 252 cal.
1 kw-h = 3412 B.t.u.

ITEM NO.	SUBJECT AREAS:	SOURCE:
25	SYSTEM - S19 HUMAN - H47	Reference 219, p. 438. Based on Reference 265.

Approximate Pounds of Food, O_2, and H_2O Required for 1–80 Men for Excursions Up to 4 Years Long

Duration of Excursions		Number of Men				
Days	Years	1	10	20	40	80
1	0.0027	6.3	63	126	252	504
5	0.0137	31.5	315	630	1,260	2,500
10	0.027	63.0	630	1,260	2,520	5,000
182	0.5	1,150	11,500	23,000	46,000	92,000
365	1.0	2,300	23,000	46,000	92,000	184,000
730	2.0	4,540	45,400	90,800	180,000	360,000
1,095	3.0	6,840	68,400	136,800	274,000	550,000
1,460	4.0	9,100	91,000	182,000	364,000	730,000

ITEM NO.*	SUBJECT AREAS:	SOURCE:
26	SYSTEM - S21, S23, S27 HUMAN - H40, H43	Reference 101, p. 83 Based on Reference 97.

SUMMARY OF POSSIBLE EFFECTS RESULTING FROM MALFUNCTIONS

Vehicle Subsystems					
Subsystem	*Malfunction*			*Subject Affected*	*Probable Effects*
Internal environment	Temperature			Crew	Physical and mental impairment
				Equipment	Secondary malfunction
	Humidity			Crew	Physical and mental impairment
				Equipment	Secondary malfunction
	Atmosphere	Composition	Toxic gases odors	Crew	Discomfort, sickness, death
		Pressure		Crew	Physical and mental impairment
				Equipment	Secondary malfunction
	Illumination			Crew	Disorientation
	Radiation level			Crew	Physical impairment
				Equipment	Secondary malfunction of electronic components
Communications	Extra-vehicular			Crew	Loss of data, more extreme feeling of isolation, mission failure
	Intra-vehicular			Crew	Uncoordinated effort, more extreme feeling of isolation
Power	Main and emergency power				System becomes completely passive
	Transmission facilities				Effects depend on the portion lost

ITEM NO.* 27 a Page 1 of 2

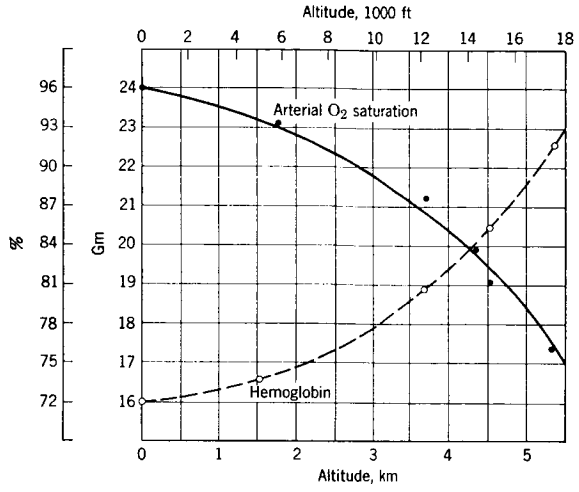
SUBJECT AREAS:
SYSTEM - S26
HUMAN - H34, H35

SOURCE:
Reference 219, p. 452.
Based on Reference 259.

SUMMARY OF POSSIBLE EFFECTS RESULTING FROM MALFUNCTIONS (continued)

Vehicle Characteristics				
Characteristics	*Malfunction*		*Subject Affected*	*Effect*
Surface properties	Optical systems (lenses, viewing ports, etc.)		Crew	Disorientation
			Vehicle	Mission failure, secondary malfunction
	Optical properties	Emissivity Absorptivity	Crew	Physical and mental impairment
			Equipment	Secondary malfunction
Puncture of pressure vessel		Decompression	Crew	Physical impairment, death
			Equipment	Secondary malfunction
		Excessive loss of atmosphere	Crew	Physical impairment
			Vehicle	Shorten mission
Degradation of structure	Material properties	Structural failure	Crew	Destruction, weakening of structure
	Members		Vehicle	
Navigation and control	Instrumentation	Erroneous data	Crew	Position in space not known
		No data		Mission failure
	Control actuators		Vehicle	No control of trajectory

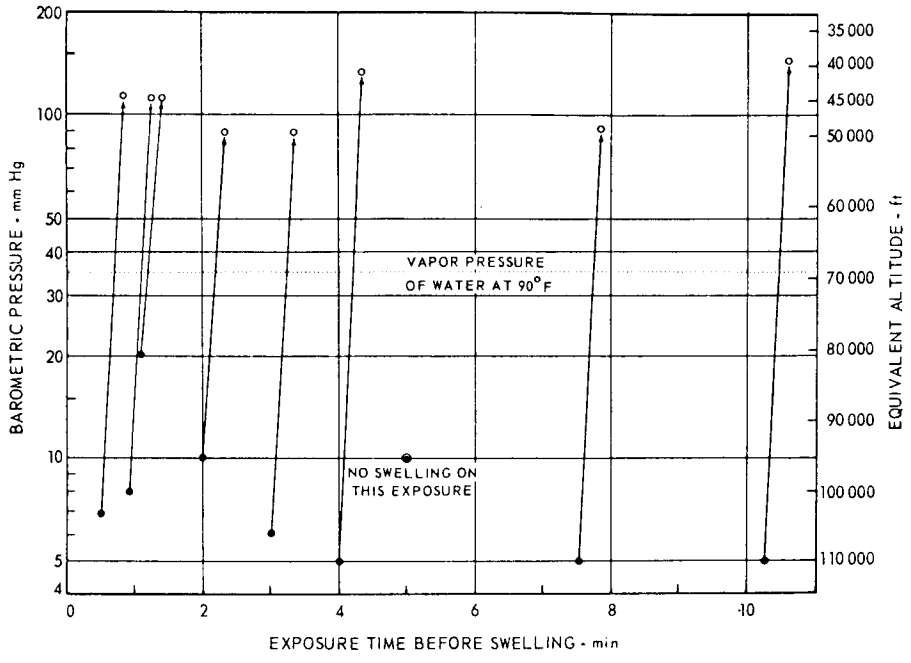
ITEM NO.*	SUBJECT AREAS:	SOURCE:
27 b Page 2 of 2	SYSTEM - S26 HUMAN - H34, H35	Reference 219, p. 453. Based on Reference 259.



Relationship between hemoglobin content, arterial oxygen saturation, and altitude.

An example of the long time element in adaptation to low atmospheric pressure or hypoxia is found in the study carried out on the natives living in the Andean regions of Peru at elevations of up to 16,500 ft. A most significant finding is the close relationship between the level of altitude and the degree of polycythemia (6,400,000 per cu mm), the hemoglobin concentration (20 gm per 100 cc blood), and the arterial oxygen saturation (80%), as shown in the above figure. The cell volume, expressed in cc per kg body weight, is about 60% greater in high-altitude natives than in sea level residents; the plasma volume is only 7% lower.

ITEM NO.	SUBJECT AREAS:	SOURCE:
28	SYSTEM - S2 HUMAN - H9	Reference 416, p. 124. Based on Reference 432.



Theoretically, water vapor should appear in human tissues if the barometric pressure is less than the vapor pressure of water at the temperature of the tissues. In experiments on the unprotected human hand, illustrated above, it was found that a pressure below that equal to water vapor pressure at skin temperature was required. The discrepancy may have been due to the forces exerted by connective tissues within the hand, and the elastic nature of the skin covering.

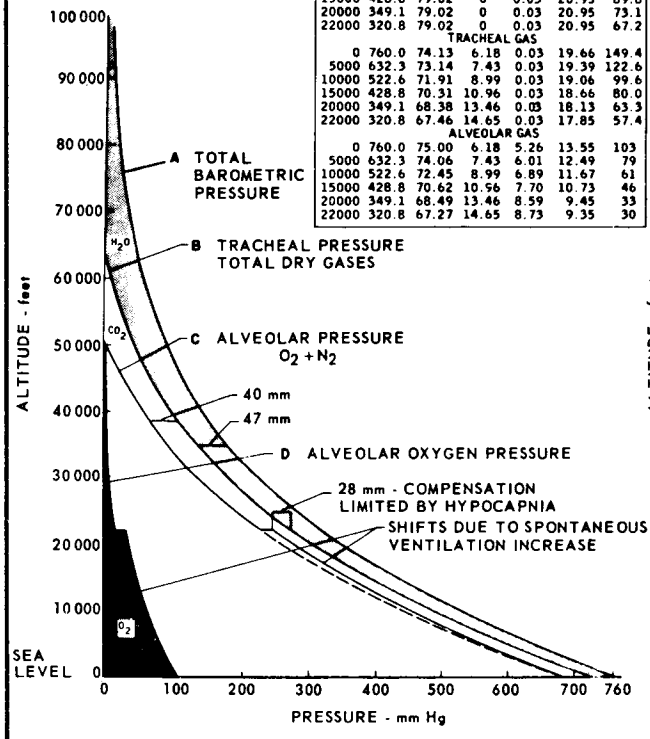
Appearance of water vapor occurred suddenly and manifested itself by marked swelling of the hand after a variable time at altitude. After appearance of swelling, the pressure in the altitude chamber was quickly raised; the hand was examined periodically. The upper point (O) represents the first point at which swelling was no longer visible to the eye. (X-ray photographs showed some residual vapor at somewhat higher pressures in a few experiments.)

If chamber pressure was again lowered slightly, swelling again appeared, indicating the continued presence of bubble nuclei in the hand tissues. This suggests that once water vapor bubbles appear, O_2 and CO_2 diffuse into the bubbles, which thus come to be made up of gas saturated with water vapor.

ITEM NO.	SUBJECT AREAS:	SOURCE:
29	SYSTEM - S2 HUMAN - H17	Reference 554, p. 100. Based on Reference 580.

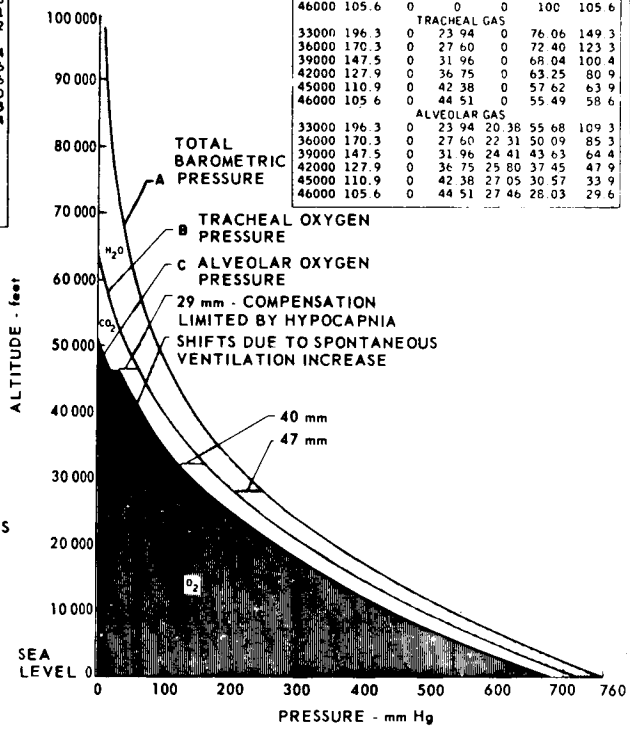
a. BREATHING AIR

Altitude (feet)	Total Pressure (mm Hg)	N_2 Percentage	H_2O Percentage	CO_2 Percentage	O_2 Percentage	O_2 Pressure (mm Hg)
AMBIENT DRY ATMOSPHERE						
0	760.0	79.02	0	0.03	20.95	159.2
5000	632.3	79.02	0	0.03	20.95	132.5
10000	522.6	79.02	0	0.03	20.95	109.5
15000	428.8	79.02	0	0.03	20.95	89.8
20000	349.1	79.02	0	0.03	20.95	73.1
22000	320.8	79.02	0	0.03	20.95	67.2
TRACHEAL GAS						
0	760.0	74.13	6.18	0.03	19.66	149.4
5000	632.3	73.14	7.43	0.03	19.39	122.6
10000	522.6	71.91	8.99	0.03	19.06	99.6
15000	428.8	70.31	10.96	0.03	18.66	80.0
20000	349.1	68.38	13.46	0.03	18.13	63.3
22000	320.8	67.46	14.65	0.03	17.85	57.4
ALVEOLAR GAS						
0	760.0	75.00	6.18	5.26	13.55	103
5000	632.3	74.06	7.43	6.01	12.49	79
10000	522.6	72.45	8.99	6.89	11.67	61
15000	428.8	70.62	10.96	7.70	10.73	46
20000	349.1	68.49	13.46	8.59	9.45	33
22000	320.8	67.27	14.65	8.73	9.35	30



b. BREATHING 100% O_2

Altitude (feet)	Total Pressure (mm Hg)	N_2 Percentage	H_2O Percentage	CO_2 Percentage	O_2 Percentage	O_2 Pressure (mm Hg)
AMBIENT DRY OXYGEN						
33000	196.3	0	0	0	100	196.3
36000	170.3	0	0	0	100	170.3
39000	147.5	0	0	0	100	145.5
42000	127.9	0	0	0	100	127.9
45000	110.9	0	0	0	100	110.9
46000	105.6	0	0	0	100	105.6
TRACHEAL GAS						
33000	196.3	0	23.94	0	76.06	149.3
36000	170.3	0	27.60	0	72.40	123.3
39000	147.5	0	31.96	0	68.04	100.4
42000	127.9	0	36.75	0	63.25	80.9
45000	110.9	0	42.38	0	57.62	63.9
46000	105.6	0	44.51	0	55.49	58.6
ALVEOLAR GAS						
33000	196.3	0	23.94	20.38	55.68	109.3
36000	170.3	0	27.60	22.31	50.09	85.3
39000	147.5	0	31.96	24.41	43.63	64.4
42000	127.9	0	36.75	25.80	37.45	47.9
45000	110.9	0	42.38	27.05	30.57	33.9
46000	105.6	0	44.51	27.46	28.03	29.6



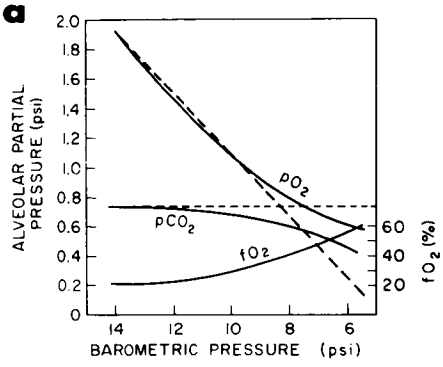
The two figures above summarize the key physiological interaction between the atmosphere and the lung-body system. The graphs, adapted from Hanff and Pegues, compare the composition (partial pressure) of tracheal and alveolar gases at different altitudes in subjects breathing (a) air, and (b) 100% oxygen. In both cases, inspired gases pick up water from the wet respiratory passages until the partial pressure of water vapor reaches saturation pressure of 47 mm Hg at body temperature (98.6°F or 37°C). Thus, the total pressure of dry gases in the trachea is always 47 mm less than the total barometric pressure (curves A and B), the tracheal oxygen and nitrogen pressures always being 9.9 mm Hg and 37.1 mm Hg respectively less than their dry air ambient pressures.

Comparison of the graphs shows that enriching the inspired air with supplementary oxygen will move curve D toward the right, as nitrogen is replaced with oxygen. The more oxygen is added, the farther to the right the curve shifts, until at 100% oxygen it becomes the same as curve C except for the portion shifted by the spontaneous increase in ventilation.

The term "equivalent altitudes" is used to describe the different altitudes at which, under different specific breathing conditions, alveolar (or tracheal) oxygen partial pressures are alike. In the tables of both figures it will be noted that the tracheal and alveolar oxygen pressures correspond closely.

ITEM NO.	SUBJECT AREAS:	SOURCE:
30	SYSTEM - S2 HUMAN - H16	Reference 554, p. 2. Adapted from Reference 252.

a

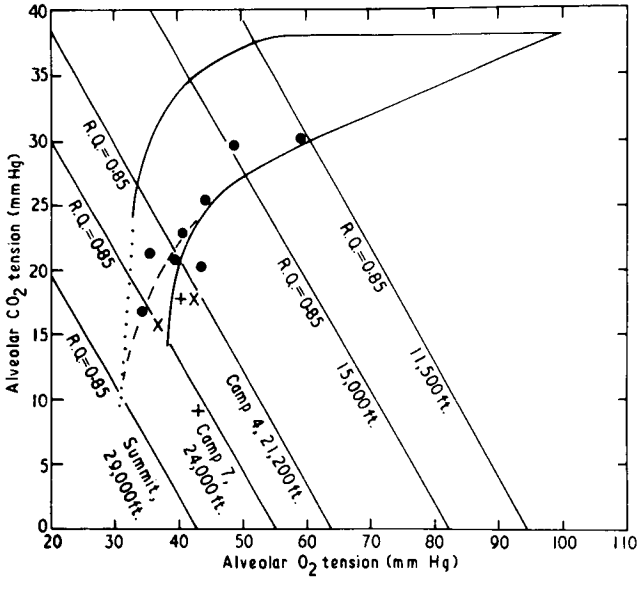


The partial pressure of alveolar oxygen is described by the following formula:

$$pO_2 = fO_2 (P - pH_2O) - pCO_2 (fO_2 + \frac{1 - fO_2}{RQ})$$

Figure a shows alveolar partial pressures. Dotted curves are theoretical; solid curves are from experimental data. The fO_2 is that calculated to preserve sea-level alveolar pO_2

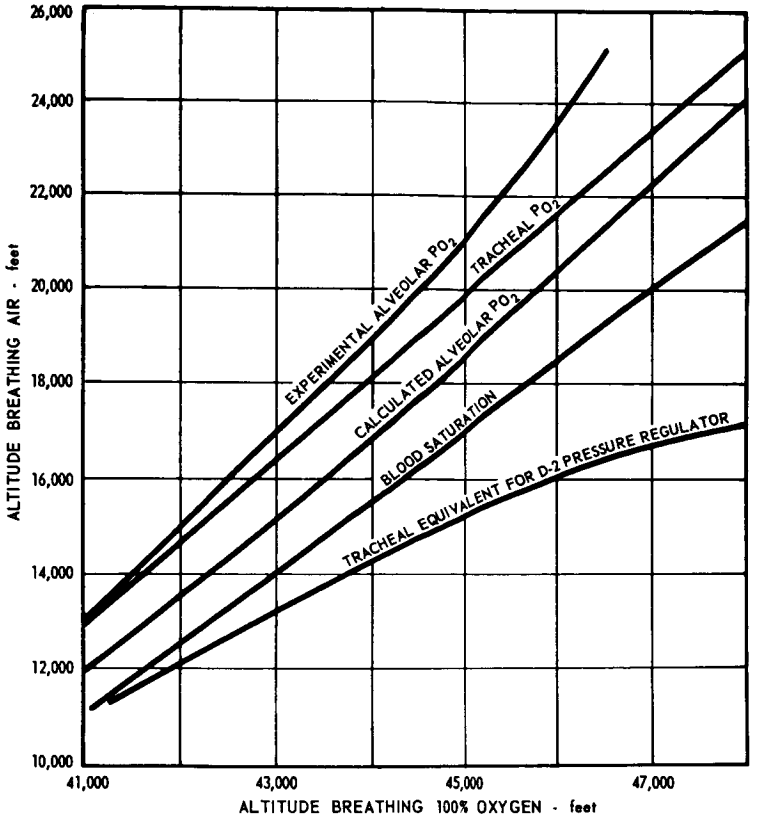
b



Alveolar oxygen and carbon dioxide tensions in man acutely exposed to altitude (upper curve) and in man acclimated to altitude (lower curve). Alveolar air samples were taken at various heights up to 24,000 feet on Mt. Everest.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
31	SYSTEM - S2 HUMAN - H16	a. Reference 380, p. 422. After Reference 112. b. Reference 465, p. 78. After Reference 420.



This graph compares several ways of expressing equivalence of altitudes when breathing air with altitude when breathing 100% oxygen. It elaborates the point that equivalent altitudes vary with the specific respiratory measurement in question.

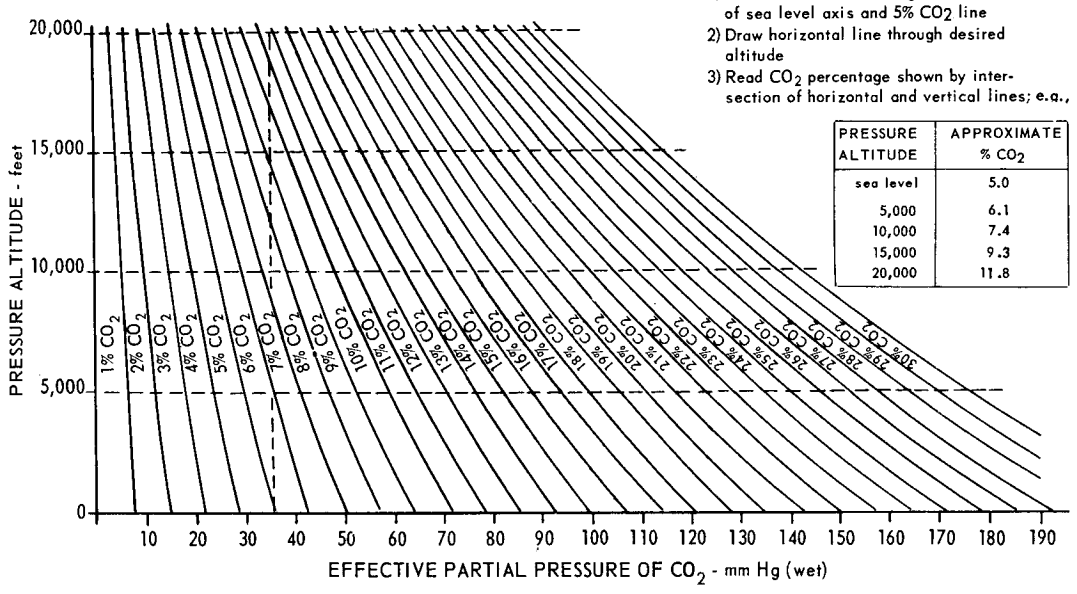
The physiological equivalence idea is useful only for first approximations and steady state conditions. It should not be used for transients, prediction of individual behavior, or other detailed computations.

ITEM NO.	SUBJECT AREAS:	SOURCE:
32	SYSTEM - S2 HUMAN - H16	Reference 554, p. 7. Compiled from References 78, 89, 391, 271.

EXAMPLE:
Problem: Find altitude equivalent of 5% CO_2 at sea level

Solution: 1) Draw vertical line through intersection of sea level axis and 5% CO_2 line
2) Draw horizontal line through desired altitude
3) Read CO_2 percentage shown by intersection of horizontal and vertical lines; e.g.,

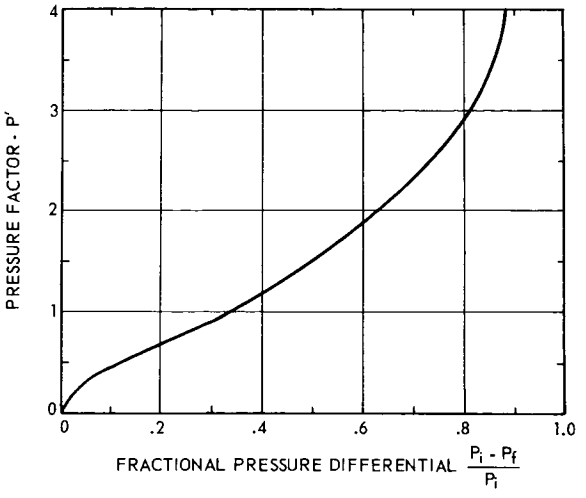
PRESSURE ALTITUDE	APPROXIMATE % CO_2
sea level	5.0
5,000	6.1
10,000	7.4
15,000	9.3
20,000	11.8



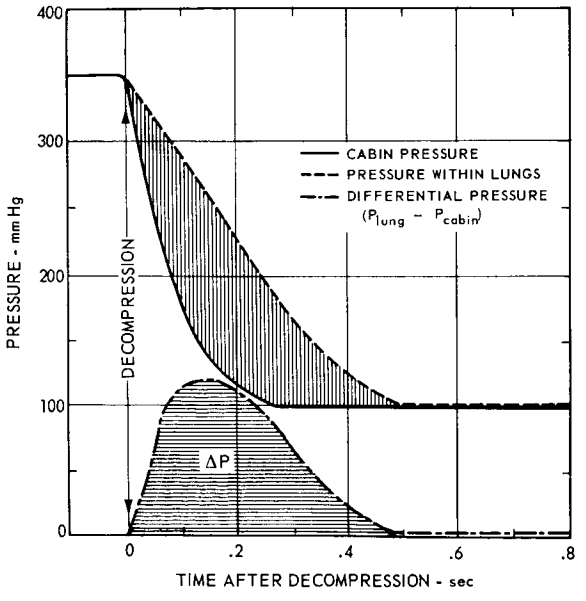
Toxic exposures to CO_2 as a result of failure of CO_2 absorption or use of CO_2 fire extinguishers may occur at altitude. Most data in CO_2 toxicity is for dry gas at sea level conditions. This graph allows one to determine quickly the dry per cent of CO_2 in a gas at altitude that will give the same partial pressure in the lung (calculated as the equivalent P_{CO_2} in the alveolar mixture of CO_2, N_2, O_2 and water) as does a given percentage of CO_2 in inspired air at sea level.

ITEM NO.	SUBJECT AREAS:	SOURCE:
33	SYSTEM - S2 HUMAN - H16	Reference 554, p. 10. Based on Reference 575.

a.



b.



The physical damage that may occur in the lungs is generally considered to be the critical limiting factor in human tolerance for very rapid decompressions.

Haber and Clamann have defined pressure transients during rapid decompression in terms of two principal parameters. The time characteristic, t_c, has the general form:

$$t_c = \frac{A}{A \cdot C}$$

where V is the volume of the container being decompressed, A is the effective area of the orifice (A is always somewhat smaller than the geometric orifice, for aerodynamic reasons), and C is the velocity of sound.

The pressure factor, P', is a function of the initial pressure, P_i, and the final pressure, P_f, in the container (figure a):

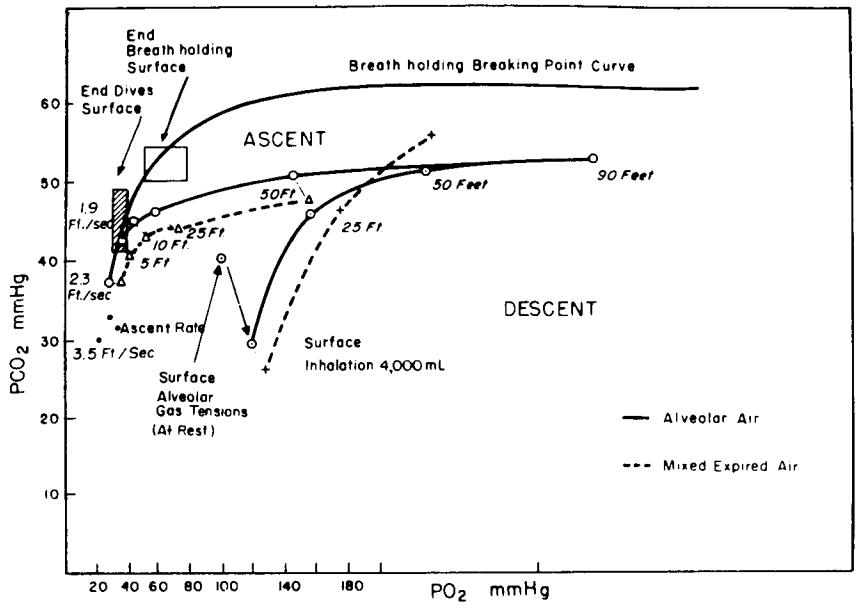
$$P' = f\frac{[P_i - P_f]}{P_i}$$

The total decompression time, or duration of the transient, t_d, is the product of the time characteristic of the system, t_c and the pressure factor, P':

$$t_d = t_c \cdot P'$$

If the time characteristic of the human lungs and airways is greater than the time characteristic of the pressure suit or cabin in which a subject is confined during a decompression, a transient differential pressure buildup must occur within the lungs. This is illustrated diagrammatically in figure b.

ITEM NO.	SUBJECT AREAS:	SOURCE:
34	SYSTEM - S2 HUMAN - H16	Reference 554, p. 90. Compiled from References 245 and 336.



Alveolar pathways during breathholding dives to 90 feet, showing reversed CO_2 gradient. At 50 feet pCO_2 mixed expired air is 6 mm Hg higher than pCO_2 "alveolar air." The surface breath-holding breaking point curve is drawn for comparison with diving breathholding curve. The end dive alveolar pCO_2 decreased with increasing rate of ascent, reaching 30 mm Hg at 3.5 ft/sec. The end dive alveolar pO_2 fell, also, to about 30 mm Hg.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
35	SYSTEM - S2 HUMAN - H16	Reference 465, p. 79. Based on Reference 463.

APPROXIMATE AMOUNT OF NITROGEN ELIMINATED FROM THE BODY OF A RESTING SUBJECT BREATHING PURE OXYGEN.

Time (min)	Nitrogen eliminated (cc)
15	250
30	350
45	480
60	550
75	650
90	700
120	850
150	950
180	1050
210	1150
240	1200

This table shows the approximate amount of nitrogen that is eliminated from the body while breathing pure oxygen. Complete elimination of nitrogen from the body is not necessary to achieve adequate protection from the "bends" and other evolved-gas syndromes. After 60 min, about 46% of the nitrogen is eliminated, and, for all practical purposes, this 1-hr "prebreathing" period has been found to provide adequate protection for personnel undergoing altitude-chamber flights at simulated altitudes of up to 75,000 ft while wearing pressure suits.

From HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN edited by Clifford T. Morgan, et al. Copyright 1963 by the McGraw-Hill Book Company, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
36	SYSTEM - S2 HUMAN - H16	Reference 380, p. 425.

PARTIAL PRESSURES AND PERCENTAGES OF TRACHEAL AND ALVEOLAR GASES WITH CHANGES IN ALTITUDE WHILE BREATHING AIR AT AMBIENT PRESSURE

Altitude feet	*Barometric Pressure*		*Atmospheric Pressure in mm Hg*		*Tracheal Gases Partial Pressures (mm Hg) and Percentage*						*Alveolar Gases*[a] *Mean Partial Pressures (mm Hg) and Percentages*								*Respiratory Exchange Ratio R*
	psi	*mm Hg*	pO_2	pN_2	pO_2	$\%O_2$	pN_2	$\%N_2$	pH_2O	$\%H_2O$	pO_2	$\%O_2$	pCO_2	$\%CO_2$	pN_2	$\%N_2$	pH_2O	$\%H_2O$	
Sea Level	14.7	760	159	601	149	19.6	564	74.2	47	6.2	109	14.3	37	4.9	567	74.6	47	6.2	0.92
1,000	14.2	733	154	579	144	19.6	542	74.0	47	6.4	102	13.9	37	5.0	547	74.6	47	6.4	0.86
3,000	13.2	687	144	543	134	19.5	506	73.7	47	6.8	89	13.0	36	5.2	515	75.0	47	6.8	0.80
5,000	12.2	632	132	500	122	19.3	463	73.3	47	7.4	82	13.0	36	5.7	467	73.9	47	7.4	0.87
6,000	11.8	609	128	481	118	19.3	444	73.0	47	7.7	74	12.2	36	5.9	452	74.2	47	7.7	0.80
8,000	10.9	564	118	446	108	19.2	409	72.5	47	8.3	70	12.4	36	6.4	411	72.9	47	8.3	0.80 *
9,000	10.5	543	114	429	104	19.1	392	72.2	47	8.7	61	11.2	35	6.4	400	73.7	47	8.7	0.80
10,000	10.1	523	110	413	100	19.1	376	71.9	47	9.0	61	11.7	35	6.7	380	72.6	47	9.0	0.91
12,000	9.4	483	101	382	91	18.8	345	71.5	47	9.7	51	10.6	35	7.2	350	72.5	47	9.7	0.83
15,000	8.3	429	90	339	80	18.6	302	70.4	47	11.0	44	10.3	33	7.7	305	71.0	47	11.0	0.90
18,000	7.3	379	79	300	70	18.4	262	69.2	47	12.4	38	10.0	32	8.4	262	69.2	47	12.4	1.01
20,000	6.8	349	73	276	63	18.1	239	68.4	47	13.5	35	10.0	29	8.3	238	68.2	47	13.5	1.07
22,000	6.2	321	67	254	57	17.8	217	67.6	47	14.6	30	9.3	28	8.7	216	67.4	47	14.6	1.06 *
25,000	5.5	282	59	223	49	17.4	186	66.0	47	16.6	30	10.6	24	8.5	181	64.3	47	16.6	1.26
30,000	4.4	226	47	176	37	16.4	142	62.8	47	20.8									
34,000	3.6	187	39	148	29	15.5	111	59.4	47	25.1									
38,000	3.0	155	32	123	23	14.8	85	54.9	47	30.3									
40,000	2.7	141	29	112	20	14.2	74	52.2	47	33.3									
45,000	2.1	111	23	88	13	11.7	51	46.0	47	43.3									
50,000	1.7	87	18	69	8	9.2	32	36.8	47	54.0									
60,000	9.1	47	10	37	0	0	0	0	47	100.0									

* Estimated

ITEM NO.	SUBJECT AREAS:	SOURCE:
37	SYSTEM - S2 HUMAN - H16	Reference 219, p. 426. Based on Reference 89.

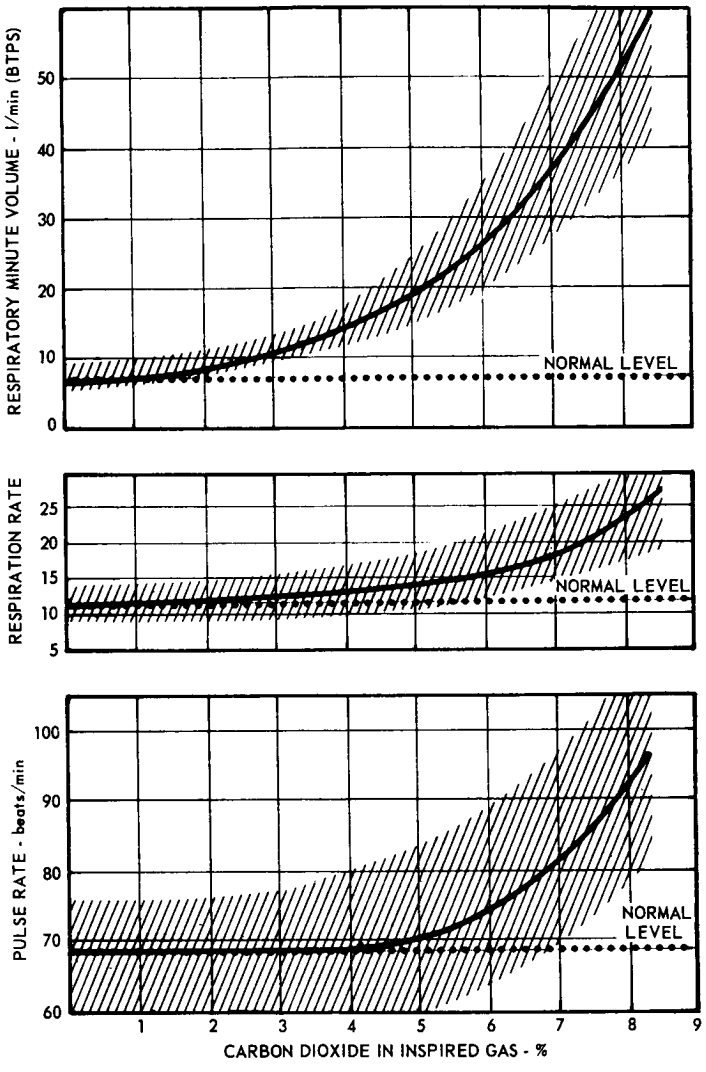
AIR REQUIREMENTS OF MAN

Work level	Air breathed, liters/min	Oxygen consumed, liters/min
Resting	6-15	0.2-0.4
Light work	20-25	0.6-1.0
Moderate work	30-40	1.2-1.6
Hard work	40-60	1.8-2.4
Severe work	40-60	2.5-3.0

The table above shows the amount of air, of which about 21 percent is oxygen, a man will inhale under various working conditions. In a closed environment, adequate flows of oxygen will be needed at all times. It is pointed out that a peak flow rate of 90 to 120 liters/min may be required, since peak requirements can be three to four times the regular flow rate.

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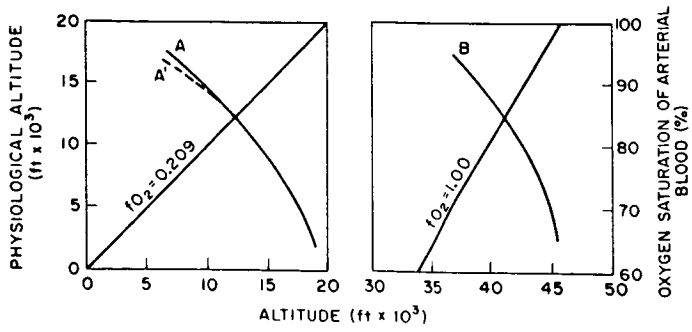
ITEM NO.	SUBJECT AREAS:	SOURCE:
38	SYSTEM - S2 HUMAN - H22	Reference 2, p. 249.



The immediate effects of increased CO_2 on pulse rate, respiration rate, and respiratory minute volume are shown for subjects at rest. The hatched areas represent one standard deviation on each side of the mean. To convert percentage of CO_2 to partial pressure, multiply per cent by 760 mm Hg.

ITEM NO.	SUBJECT AREAS:	SOURCE:
39	SYSTEM - S2 HUMAN - H9, H16	Reference 554, p. 9. Adapted from References 464 and 176.

a



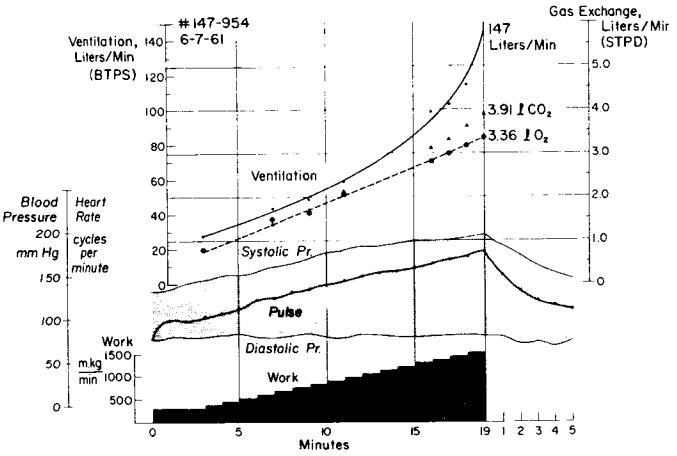
Relationship between alveolar composition and arterial oxygen saturation. Physiological altitude, based on alveolar pO_2 and pCO_2, is related to true altitude by two fO_2 parameters—air (fO_2 = 0.209) and 100% oxygen (fO_2 = 1.00) Curves A and B are means of oxygen saturation of arterial blood. Curve A' was obtained from oxyhemoglobin dissociation curve.

b Interrelationships among oxygen supply, alveolar conditions, and true and physiological altitudes.

True altitude (ft)	Atmospheric pressure (psi)	fO_2	Alveolar pressure (psi)			Arterial saturation (%)	Physiological altitude (ft)
			pO_2	pH_2O	pCO_2		
0	14.7	0.21	1.99	0.91	0.77	95	0
8,000	10.9	0.21	1.29	0.91	0.70	91	8,000
33,000	3.8	1.00	1.99	0.91	0.77	95	0
38,000	3.0	1.00	1.29	0.91	0.70	91	8,000

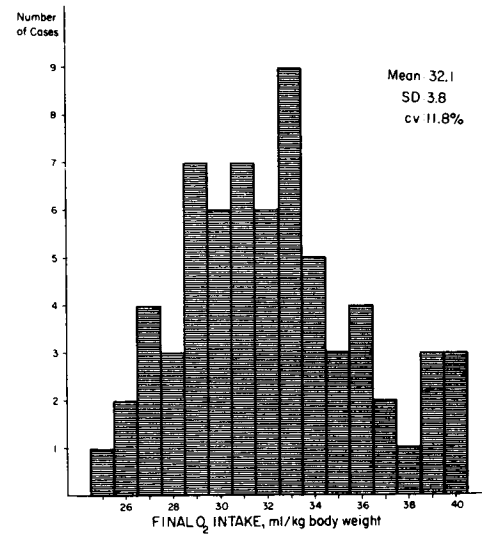
ITEM NO.	SUBJECT AREAS:	SOURCE:
40	SYSTEM - S2 HUMAN - H9, H16	Reference 380, p. 423. Based on Reference 508.

a



Physical competence test on bicycle ergometer

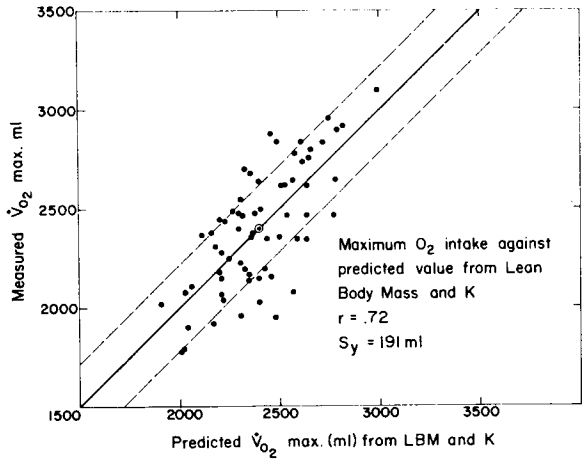
b



Distribution of the highest oxygen intake observed during the physical competence test on 65 pilots

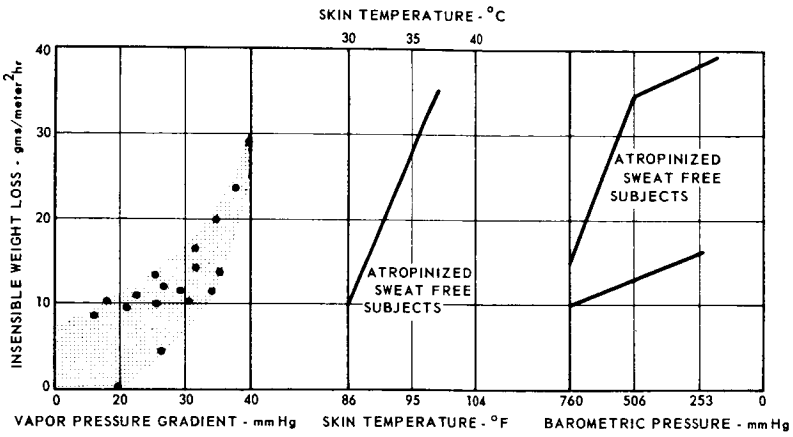
c

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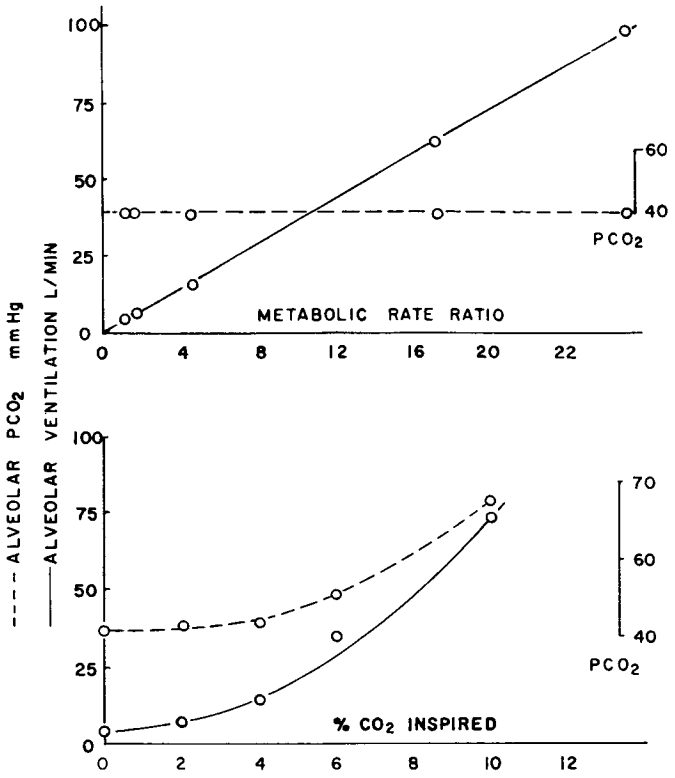
Highest oxygen intake measured in the physical competence test (ordinate) plotted against values predicted from lean body mass and total potassium (abscissa). By relating measured to predicted values an index of cardiorespiratory competence is obtained.

ITEM NO.	SUBJECT AREAS:	SOURCE:
41	SYSTEM - S2 HUMAN - H9, H16, H20, H22	Reference 333, pp. 54-55.



Loss of water through the skin by diffusion is influenced by the vapor pressure gradient, the skin temperature, and the barometric pressure. On the left, water loss in grams per square meter of body surface per hour is plotted against the difference in vapor pressure in the air and vapor pressure at the skin. In the center, a high skin temperature is seen to be related to high diffusion loss. Warm skin free of sweat was produced by high atropine dosage. On the right, the graph shows an increase in diffusion as the barometric pressure is lowered.

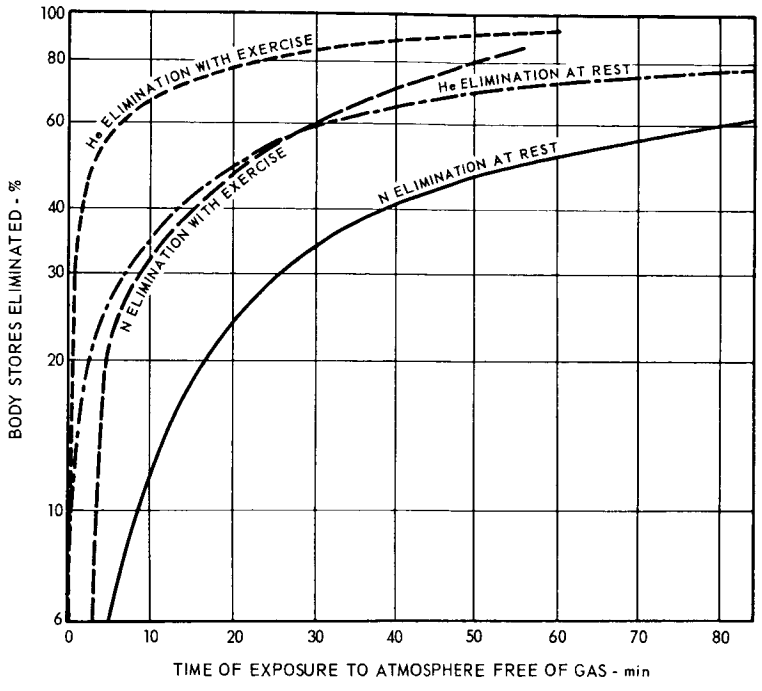
ITEM NO.	SUBJECT AREAS:	SOURCE:
42	SYSTEM - S2 HUMAN - H17, H18	Reference 554, p. 207. Compiled from References 93, 250, 556, 598.



Alveolar gas computations for internal CO_2 stress (upper curves) and external CO_2 stress (lower curves)

Yamamoto and Edwards perfused rats with variable quantities of CO_2-loaded blood via the interior vena cava using a heart-lung machine. The anesthetized CO_2-infused animal is thought to be equivalent to the exercising animal except that exercise cues other than the CO_2 load, such as neural inflow from the limbs, are absent. The data and their statistical analysis indicate a linear relation between CO_2 output and ventilation and the absence of a statistically significant relation between arterial PCO_2 and ventilation. The increased oxygen uptake associated with the hyperventilation seems to be related to the increased work of breathing. Over the range of CO_2 outputs and ventilatory rates studied, homeostasis of CO_2 is nearly perfect. The constant quantity is the mean (time average) arterial PCO_2. At extreme levels of CO_2, loading cardiovascular changes are observed suggesting that the regulation of PCO_2 involves both pulmonary and cardiovascular adjustments. Such arterial PCO_2 and pH are relatively unaltered, and no hyposia occurs; and, because evidence is lacking that perfusion per se produces hyperpnea, it seems reasonable that CO_2 is the adequate stimulus for the regulation of its own concentration.

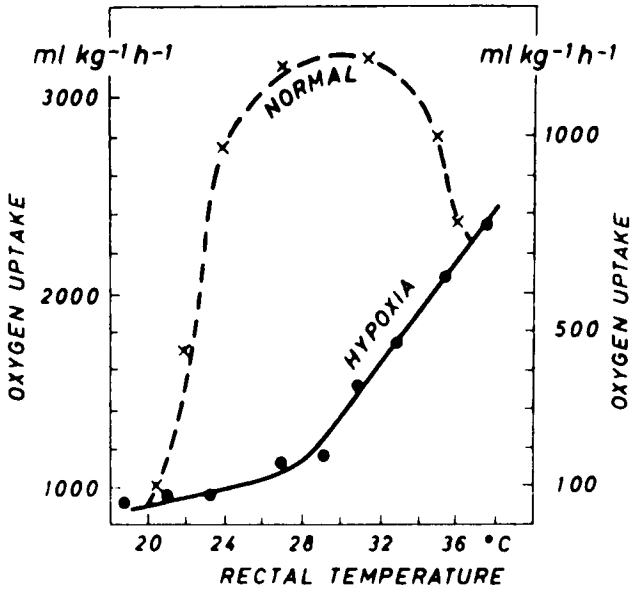
ITEM NO.	SUBJECT AREAS:	SOURCE:
43	SYSTEM - S2 HUMAN - H16, H20	Reference 318, p. 25. Based on Reference 591.



The quantity of inert gas in solution in the human body at equilibrium is a function of the partial pressure of that gas in the inspired air and the solubility of the gas in water and in fat. When the inert gas is removed from the inspired gas mixture, the gas will be cleared from the body ("washed out") at a rate which depends on a number of factors. Among these are the ventilation volume and the cardiac output, both of which are elevated during exercise. Inert gas in the lungs is diluted and washed out very quickly. Blood coming to the lungs is also cleared relatively rapidly. The clearance of gas from the various tissues of the body proceeds at a rate proportional to the blood flow through the tissues and the solubility of the gas in water versus that in oil.

Nitrogen is very soluble in fat, less soluble in water. In contrast, helium is only slightly soluble in body fluids. Nitrogen is cleared from the body rather slowly, helium much more rapidly. Elimination of either gas is facilitated by exercise.

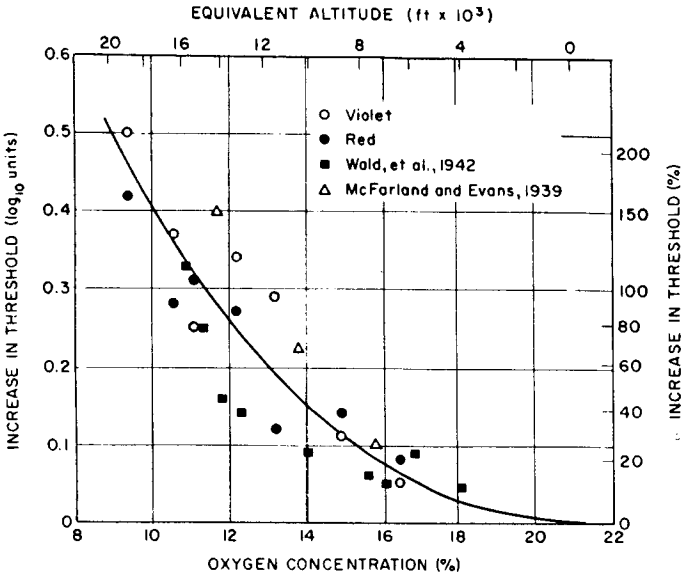
ITEM NO.	SUBJECT AREAS:	SOURCE:
44	SYSTEM - S2 HUMAN - H16, H22	Reference 554, p. 99. Compiled from References 55, 66, 444.



Oxygen uptake of the unanaesthetized rat as influenced by body temperature. Interrupted line and crosses, left vertical scale: breathing normal air (ambient temp. 20°C; oxygen uptake during spontaneous rewarming of the pre-cooled animal). Plain line and closed circles, right vertical scale: under severe hypoxic conditions (O_2 uptake during a 20 minute-period preceding death under "closed cabin" conditions). Experiments on 34 animals, each point being an average value from 2 to 10 experiments; ambient temp. equal in every case to body temp. at which premortal O_2 uptake was measured.

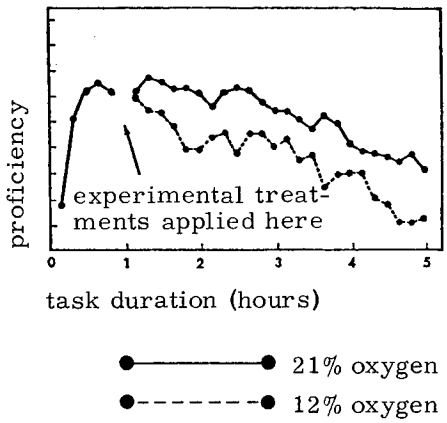
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ITEM NO.	SUBJECT AREAS:	SOURCE:
45	SYSTEM - S2 HUMAN - H18, H4, H16	Reference 18, p. 119.



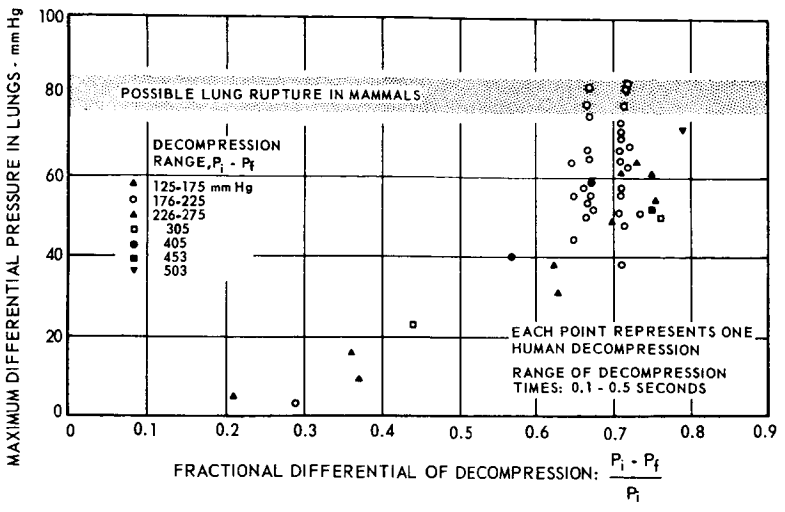
The most sensitive indicator of the effects of oxygen deficiency is loss of visual function. This is a general effect that manifests itself early as a loss in absolute sensitivity for light and in contrast sensitivity, both in central and peripheral vision. The figure shows how much the threshold of vision—the intensity of light just barely visible in total darkness—is increased as a function of increased altitude and decreased concentration of oxygen in the inspired air. Note that light sensitivity is impaired significantly at altitudes as low as about 5,000 ft, and, at 15,000 ft, more than twice as much light is required for minimum visibility.

ITEM NO.	SUBJECT AREAS:	SOURCE:
46	SYSTEM- S2 HUMAN- H25	Reference 380, p. 421. Based on Reference 266.



Two trained groups performed a complex 4-hour operator task, breathing different nitrogen-oxygen mixtures. One group got 21 percent oxygen, the other 12 percent. Low-grade hypoxia in the latter group increased the degradation of proficiency that normally is the result of fatigue.

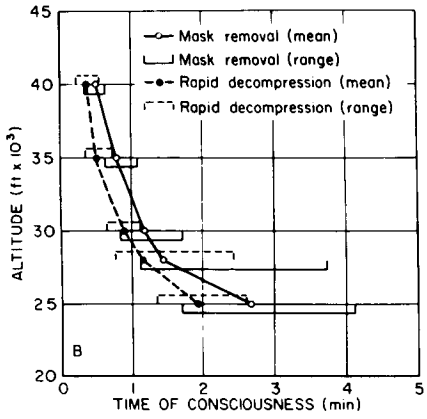
ITEM NO.	SUBJECT AREAS:	SOURCE:
47	SYSTEM - S2 HUMAN - H26	Reference 263, p. 94.



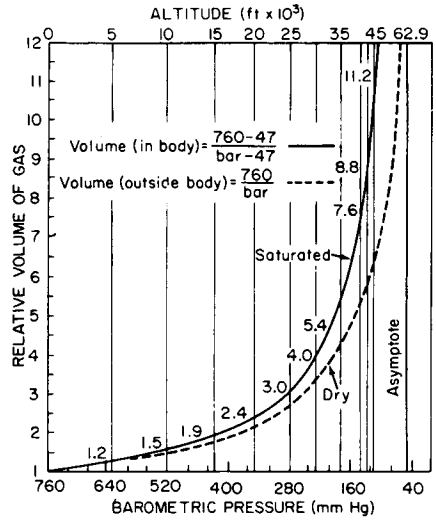
This figure shows experimental data demonstrating the differential pressures observed during various decompressions. Points have been derived from the data of Luft, Bancroft and Carter. It has been shown by Adams and Polak that the mammalian lung may rupture when distended by a differential pressure above about 80 mm Hg. The subjects whose data are shown were apparently uninjured.

ITEM NO.	SUBJECT AREAS:	SOURCE:
48	SYSTEM - S2 HUMAN - H34	Reference 554, p. 91. Compiled from References 338, 337, 1.

a



b

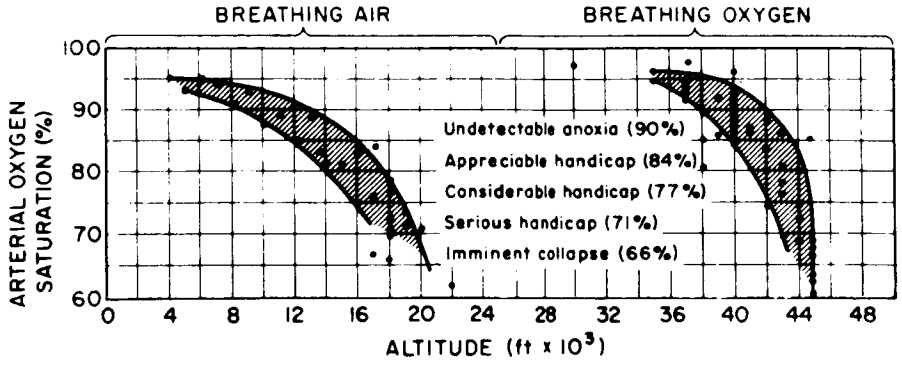


Hypoxia can be produced by gradual ascent or by sudden exposure, as might happen in the sudden loss of cabin pressure in a pressurized aircraft or the removal of an oxygen mask at high altitude. Figure a (Comfort and Wilson, 1950) shows the effect of sudden exposure on the duration of useful consciousness for an inactive person. With activity, the duration of consciousness decreases. Exercise sufficient to double pulmonary ventilation reduces consciousness time about 50%; tripling pulmonary ventilation reduces duration of consciousness about 67%.

Figure b (Lovelace and Hinshaw, 1942) illustrates the expansion of gases in body cavities at different altitudes. The most sensitive body areas that experience this effect are the middle ear, the sinuses, and the abdominal cavity. The pain from any of these areas can be very intense.

Abdominal pain results from a reduction in total pressure with altitude that permits expansion of abdominal gases. This effect rarely experienced below 25,000 ft, and can be relieved by the oral and anal emission of gases. Middle ear and sinus discomfort, on the other hand, occur during descent and are the result of gas escapes during ascent that cannot be recovered easily during descent. Thus, these pains are associated with external pressures rather than internal ones.

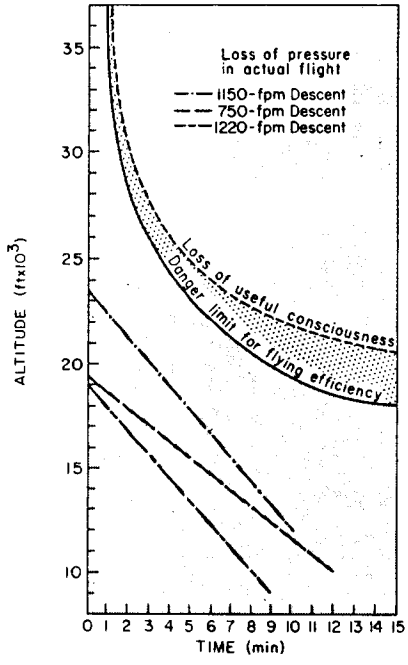
ITEM NO.	SUBJECT AREAS:	SOURCE:
49	SYSTEM - S2 HUMAN - H34	Reference 380, pp. 420, 424. Based on References 145 (fig. a) and 334 (fig. b).



Effect of lack of oxygen at various altitudes. Lack of oxygen is represented in terms of oxygen saturation of arterial blood. Indifferent stage of 90% or more saturation extends to 12,500 ft while breathing air, and to 42,000 ft while breathing 100% oxygen. Critical stage of 66% or less saturation, in which person collapses after short exposure, begins at about 20,000 ft while breathing air and about 44,000 ft while breathing 100% oxygen.

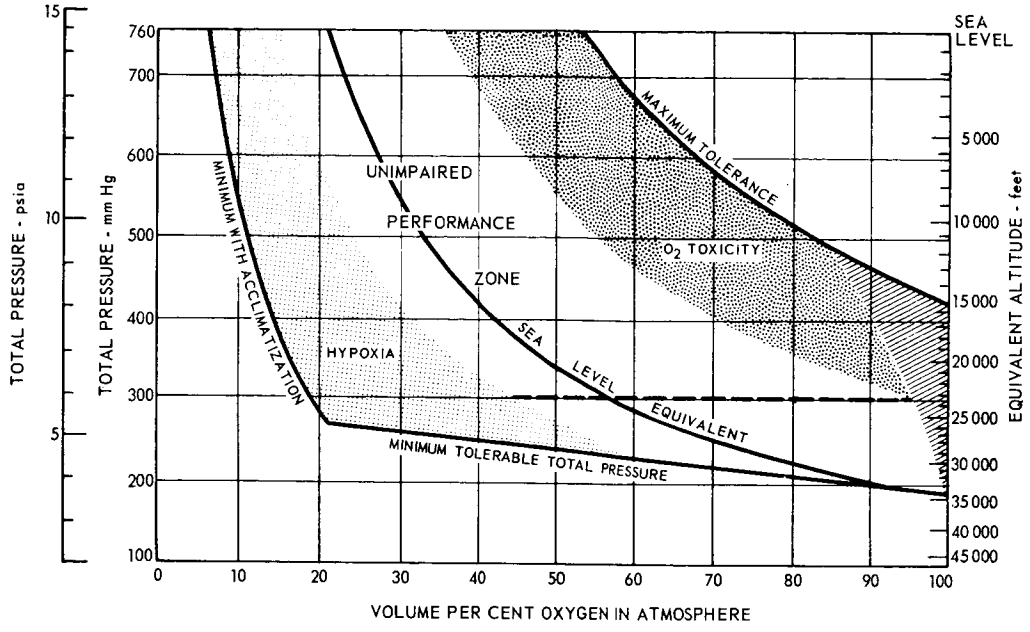
Most altitude design problems arise because people are adapted to sea-level atmospheric pressure. The effects of gradual increases in altitude on arterial-oxygen saturation for such persons are shown in the figure above. This graph shows the tremendous gain made in tolerance while breathing oxygen, but, as indicated, the absolute upper limit, even with supplemental oxygen, is under 44,800 ft.

ITEM NO.	SUBJECT AREAS:	SOURCE:
50	SYSTEM- S2 HUMAN- H34	Reference 380, p. 420. Based on Reference 529.



In high-altitude and space flight in small, pressurized cockpits or satellite capsules, pressure suits are worn to provide protection against the inadvertent loss of cabin pressure. The inadvertent loss of cabin pressure at high altitudes without pressure suits requires the immediate return to a safe physiological altitude because the time of useful consciousness is so short. This figure (McFarland, 1953) shows the actual flight paths taken by three commercial aircraft following accidents in which cabin pressure was lost during flight. If these same three accidents had occurred at altitudes above 30,000ft, and if the pilots had flown the same flight paths, it is apparent that the situation would have been very serious.

ITEM NO.	SUBJECT AREAS:	SOURCE:
51	SYSTEM - S2 HUMAN - H34	Reference 380, p. 425. Based on Reference 365.



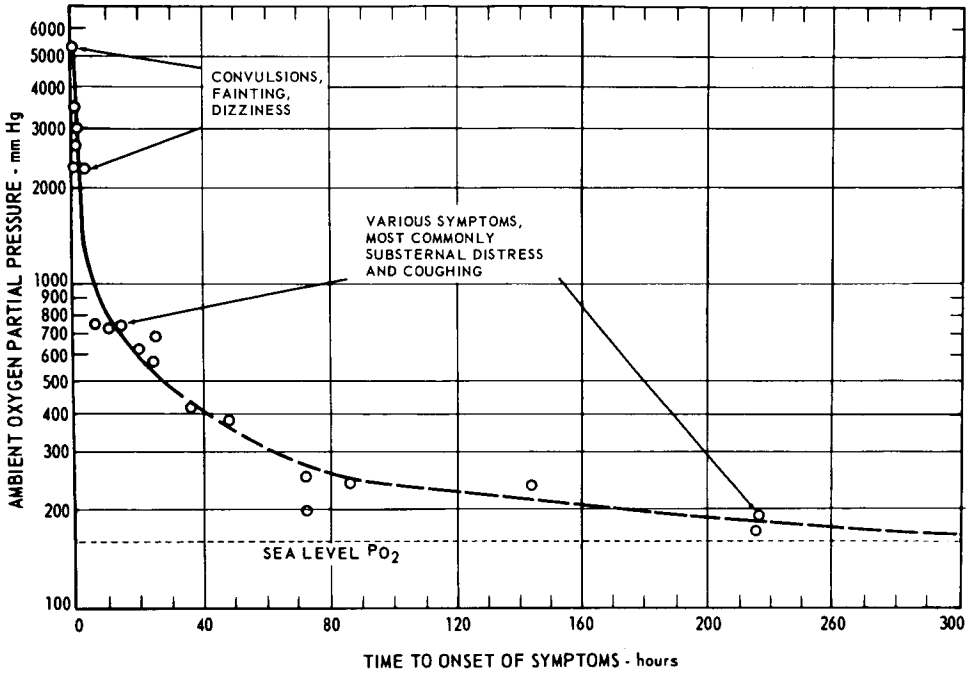
The physiological relations between the percentage of oxygen in the atmosphere of an aerospace vehicle and the total pressure of that atmosphere shown here are based on continuous exposure for one week or more. Atmospheric air contains 21% oxygen by volume. At sea level, this leads to a blood saturation of 95%. To maintain the same degree of oxygen in the blood at lower pressure, the percentage of oxygen in the atmosphere must increase as shown by the "sea level equivalent" curve. The Unimpaired Performance Zone, bounded by the heavy line, indicates the range of variation that can be tolerated without performance decrement.

The maximum oxygen tolerance (definite pathology) for long periods is currently under investigation. The role of nitrogen and trace contaminants on the symptoms of oxygen toxicity in the 90-100% oxygen range is still open to question, as shown by the hatched area.

Prolonged exposure to low oxygen levels lying to the left of the Unimpaired Performance Zone requires acclimatization. Acclimatization is accomplished by continuous exposure to successively lower pressures, with no intermediate return to higher pressures. Acclimatization to 25,000 feet required 4-6 weeks. As shown, performance is still impaired.

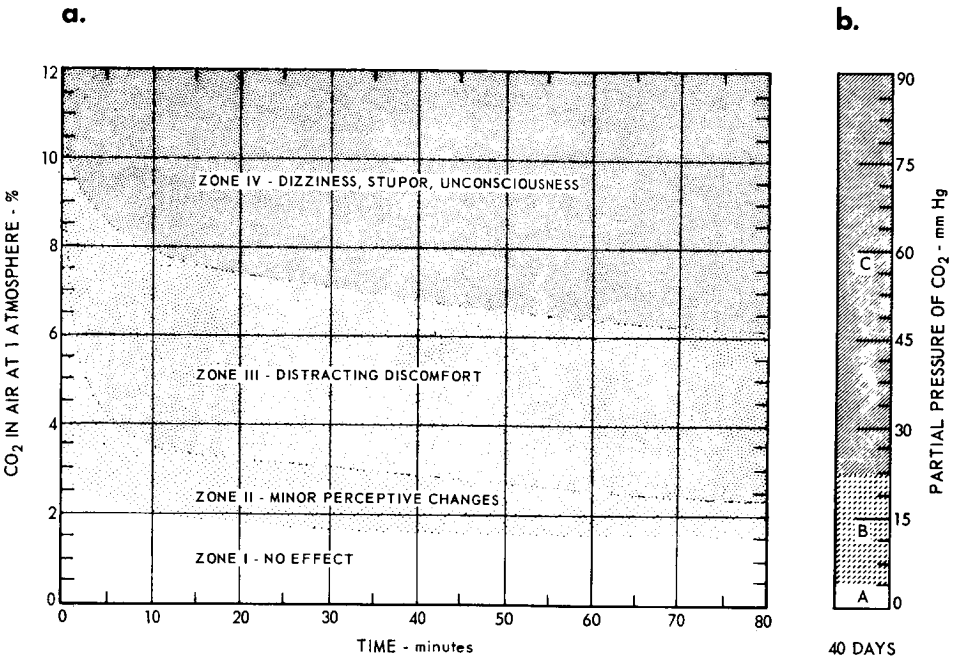
The minimum tolerable total pressure is based upon the effective partial pressure of oxygen, disregarding aeroembolism, which may occur below 300 mm Hg total pressure in the absence of adequate denitrogenation. This aeroembolism limitation is shown by the interrupted horizontal line.

ITEM NO.	SUBJECT AREAS:	SOURCE:
52	SYSTEM - S2 HUMAN - H34	Reference 554, p. 5. Based on Reference 335, graph by F. H. Green of the Garrett Corporation.



The curve represents the approximate time of appearance of toxic signs and symptoms. These vary with the partial pressures of O_2 ($^{P}O_2$) which cause them. Above 760 mm Hg, the central nervous system is the primary site of defect with symptoms such as nausea, dizziness, convulsions, and syncope. In the range of 400 to 760 mm Hg, respiratory and nervous system symptoms predominate. These are substernal distress (bronchitis and probably atelectasis), paresthesias, and nausea. In the range of 200-400 mm Hg, reported symptoms are respiratory and possibly hematological and renal: substernal distress, protein and cylindrical casts in the urine. Whether or not there is really "toxicity" in the low level, long time exposure is being debated. Studies in progress may clarify the exact cause of symptoms and laboratory findings in this lower range. The role of contaminating gases (N_2) and trace vapor contaminants in the oxygen is still unknown.

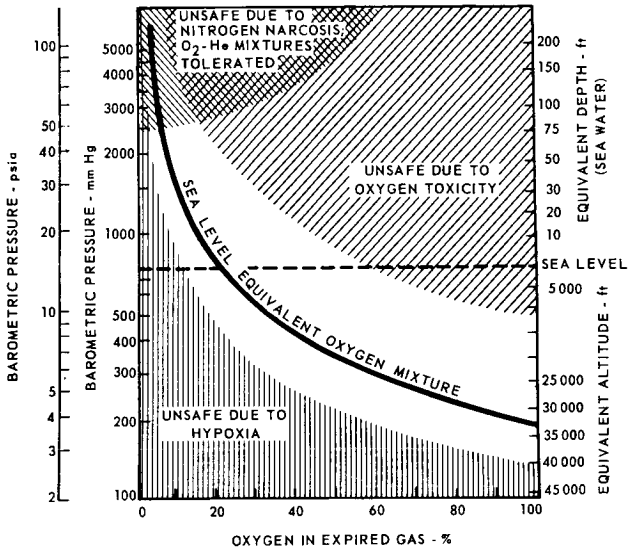
ITEM NO.	SUBJECT AREAS:	SOURCE:
53	SYSTEM - S2 HUMAN - H34	Reference 554, p. 6. Adapted from References 62, 443, and 567.



The chart shows the general symptoms common to most subjects when exposed for the times indicated to mixtures of carbon dioxide in air at a total pressure of 1 atmosphere. In Zone 1, no psychophysiological performance degradation, or any other consistent effect, is noted. In Zone II, small threshold hearing losses have been found and there is a perceptible doubling in depth of respiration. In Zone III, the zone of distracting discomfort, the symptoms are mental depression, headache, dizziness, nausea, "air hunger," and decrease in visual discrimination. Zone IV represents marked deterioration leading to dizziness and stupor, with inability to take steps for self-preservation. The final state is unconsciousness.

The bar graph at the right shows that for prolonged exposures of 40 days, concentrations of CO_2 in air of less than 0.5% (Zone A) cause no biochemical or other effects; concentrations between o.5 and 3.0% (Zone B) cause adaptive biochemical changes, which may be considered a mild physiological strain; and concentrations above 3.0% (Zone C) cause pathological changes in basic physiological functions.

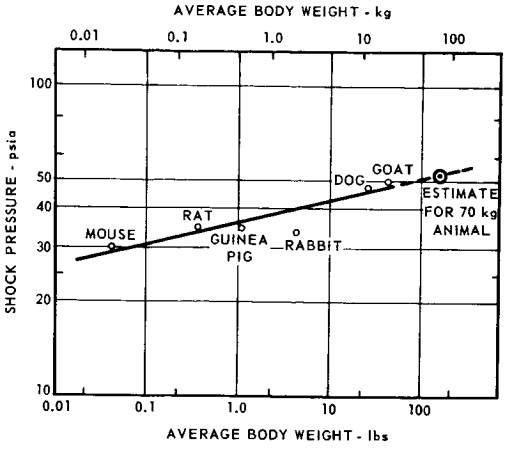
ITEM NO.	SUBJECT AREAS:	SOURCE:
54	SYSTEM - S2 HUMAN - H34	Reference 554, p. 8. Compiled from References 301, 393, and 460.



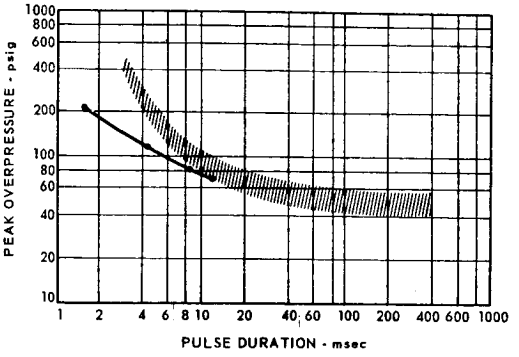
Shown here is the approximate range of barometric pressures above and below one atmosphere (mean sea level pressure: 14.7 psia or 760 mm Hg) that is tolerated by humans breathing gas mixtures containing the indicated proportions of oxygen. The heavy line indicates the gas mixture that will maintain a sea level equivalent oxygen partial pressure in the lungs at various barometric pressures.

ITEM NO.	SUBJECT AREAS:	SOURCE:
55	SYSTEM - S2 HUMAN - H34	Reference 554, p. 88. Adapted from Reference 40.

a.



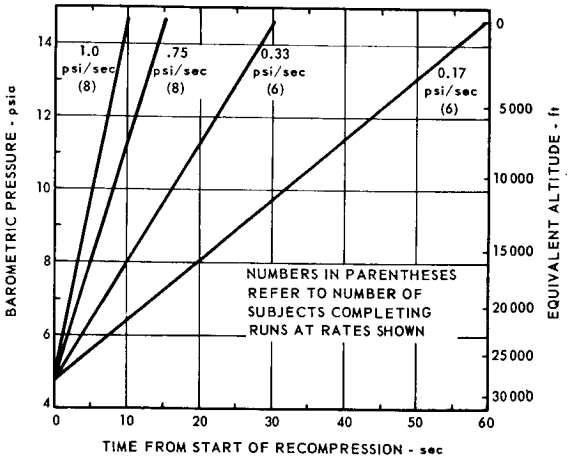
b.



No data are available on fatal pressure shock in man. These two charts show pertinent animal data and the estimates for man. The graph on the left, based on data of Richmond et al, shows overpressures necessary to kill 50% of animals of various species exposed in a shock tube to overpressures lasting 350-412 milliseconds. A regression line was extrapolated to provide an estimate of the mean lethal overpressure for a 70-kilogram (man sized) animal.

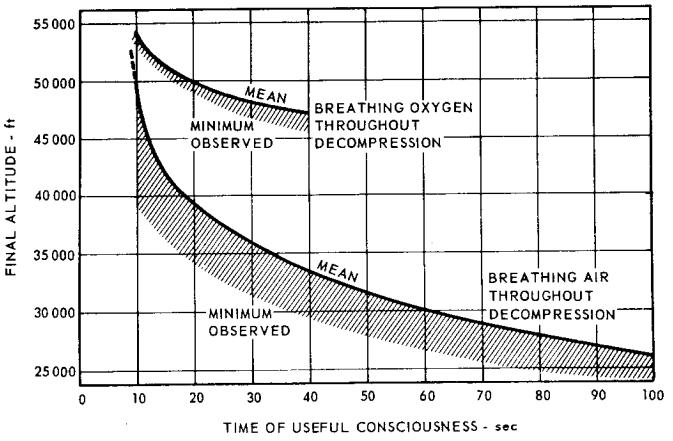
The graph on the right shows Desaga's threshold for lethality in dogs for incident pressure pulses in a free field. The shaded curve represents an estimated range of pressures and durations that would be lethal to 50% of adult humans. The estimates apply only to single, sharply rising overpressures of near-ideal wave forms.

c.



Rapid compressions from 28,000 feet to sea level (a pressure change of 10 psi) are shown for six subjects, none of whom had severe ear damage. In three of 28 tests, it was necessary to initiate re-ascent of the chamber to aid subjects in equalizing pressure across the eardrum. Ability to tolerate pressurization is limited primarily by the need to allow air to enter the middle ear, thus equalizing pressure across the eardrum. Air leaves the ear passages passively during ascent or decompression, but the characteristics of the mucous membrane lining the Eustachian tube or duct are such that air does not ordinarily re-enter the middle ear without voluntary muscular activity.

ITEM NO.	SUBJECT AREAS:	SOURCE:
56	SYSTEM - S2 HUMAN - H34	Reference 554, p. 92. Based on References 164, 429, 430 (figs. a and b) and 422 (fig. c).



This figure indicates minimum and average duration of effective consciousness in human subjects following rapid decompression breathing air (lower curve) and oxygen (upper curve). At altitudes above 20,000 to 23,000 feet, unacclimatized subjects breathing air will lose consciousness after a variable period of time. Individual susceptibility varies widely except at the highest altitudes.

ITEM NO.	SUBJECT AREAS:	SOURCE:
57	SYSTEM - S2 HUMAN - H34	Reference 554, p. 94. Based on Reference 78.

RESPIRATORY CHEMICALS

CHEMICAL	REACTIONS	LB O_2/LB CHEMICAL	LB CO_2/LB CHEMICAL	LB H_2O/LB CHEMICAL	HEAT OF REACTION	COMMENTS
Potassium superoxide (KO_2)	$2KO_2 + H_2O \rightarrow 2KOH + \frac{3}{2}O_2$ $2KO_2 + CO_2 \rightarrow K_2CO_3 + \frac{3}{2}O_2$ $KOH + CO_2 \rightarrow KHCO_3$ $KOH + H_2O \rightarrow KOH \cdot H_2O$ $2K_2CO_3 + H_2O \rightarrow 2(K_2CO_3 \cdot \frac{1}{2}H_2O)$	0.344	0.275	0.146	$\simeq$1620 Btu/lb O_2	Rate controlled by CO_2, H_2O, and cabin air flow/unit surface area.
Sodium peroxide (Na_2O_2)	$Na_2O_2 + H_2O \rightarrow 2NaOH + \frac{1}{2}O_2$ $Na_2O_2 + CO_2 \rightarrow Na_2CO_3 + \frac{1}{2}O_2$ $NaOH + CO_2 \rightarrow NaHCO_3$ $NaOH + H_2O \rightarrow NaOH \cdot H_2O$	0.205 (Theoretical)	$\simeq$0.564	$\simeq$0.230	1050 Btu/lb O_2	Similar to KO_2 but $\frac{1}{2}$ amount of O_2 generated.
Hydrogen peroxide (H_2O_2)	$H_2O_2 \xrightarrow{\text{Metal Cat}} H_2O + \frac{1}{2}O_2$	0.306 (for 65% sol.)	—	—	2820 Btu/lb O_2	Liquid, does not absorb H_2O or CO_2.
Sodium chlorate candles ($NaClO_3$)	$xNaCLO_3 + yFe \rightarrow xNaCL + yFeO + ZO_2$	0.320	—	—	1000 Btu/lb O_2	Does not absorb H_2O or CO_2. Rate only controlled by burning of surface area.
Lithium hydroxide (LiOH)	$LiOH + CO_2 \rightarrow LiHCO_3$ $LiOH + H_2O \rightarrow LiOH \cdot H_2O$	—	0.740	$\simeq$0.045	1260/lb CO_2	Dusting occurs (filter needed).

ITEM NO.	SUBJECT AREAS:	SOURCE:
58	SYSTEM - S2 HUMAN - H47	Reference 355, p. 248. Based on Reference 354.

VARIOUS CHEMICAL OXYGEN SYSTEMS

(1) *Hydrogen peroxide (90% H_2O_2).* This compound contains 0.80 lbs available oxygen for each pound of peroxide waste, not including equipment, which is much poorer than liquid oxygen. Exothermic, catalytic decomposition releases 2,820 BTU/lb O_2, the oxygen released is saturated and at a temperature of 300° F and required 100 lbs equipment to release 200 lbs of oxygen.

(2) *Chlorate candles.* Oxygen is released from sodium chlorate by thermal decomposition as follows:

$$x\ NaClO_3 + y\ Fe \longrightarrow x\ NaCl + z\ O_2 + y\ FeO$$

The particular formula varies with conditions of decomposition. BaO_2 is added to inhibit liberation of free Cl_2, and fiberglass is added for structural and reaction rate purposes. A fuse is provided for starting. Evolves 1,000 BTU/lb O_2 liberated, provides 0.5 lb O_2/lb nonavailable material plus equipment. Provides 27 lbs O_2/ft^3 of equipment. Particularly good for small-sized short-duration needs.

(3) *Potassium superoxide (KO_2 or K_2O_4).* On contact with water the following reaction occurs:

$$K_2O_4 + H_2O \longrightarrow 2\ KOH + 1.5\ O_2$$

The KOH will now absorb CO_2 with an assimilatory quotient of 0.7, as follows:

$$2\ KOH + CO_2 \longrightarrow K_2CO_3 + H_2O$$

or

$$2\ KOH + 2CO_2 \longrightarrow 2\ KHCO_3$$

Due to the necessity of using large particles, ultimate capacity is 80% of theoretical capacity. If water supplied by body loss, 0.409 lb O_2/lb nonavailable compound; if water must be carried, 0.344 lb O_2/lb nonavailable material. If allow for ducts, plates and filters, 1 lb O_2 is released for each 5.56 lbs of chemicals and equipment. This will also handle at no additional weight most of the CO_2 and H_2O.

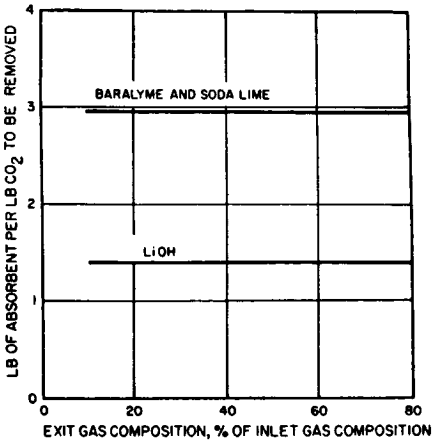
(4) *Sodium superoxide (NaO_2 or Na_2O_4).* Comparable to the K_2O_4, slightly lighter, but none currently available.

(5) *Other metallic superoxides.* Possibly calcium or lithium may show definite improvement in weight penalty, and they are worthy of serious consideration.

(6) *Sodium peroxide (Na_2O_2) and potassium peroxide (K_2O_2).* Similar to the superoxides, but liberate half as much oxygen.

(7) *Electrolysis of water.* Produce 0.002 lbs O_2 per hour per lb of equipment, excluding generators for power. If man uses 0.075 lbs O_2/hour, then 37.5 lbs equipment is needed, plus H_2O needed.

ITEM NO.	SUBJECT AREAS:	SOURCE:
59	SYSTEM - S2 HUMAN - H47	Reference 219, p. 421. Based on Reference 176.



Absorbent requirements for CO_2 removal.

MISCELLANEOUS DATA ON CO_2 REMOVAL SYSTEMS

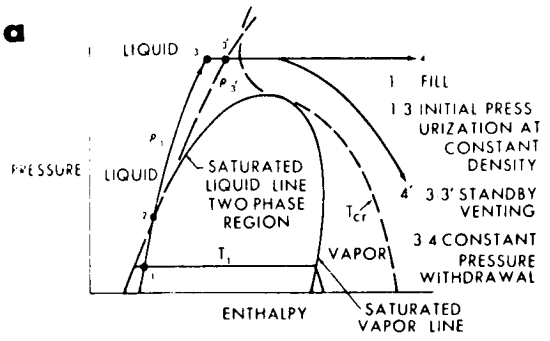
	Solid Absorbents
(a) NaOH and KOH	Theoretically quite good, but the formation of carbonate on the surface limits the rate of absorption performance.
(b) Potassium superoxide	Capacity is about 4 lbs K_2O_4/lb CO_2.
(c) Baralyme	A mixture of $Ca(OH)_2$ and $Ba(OH)_2 \cdot 8\ H_2O$. Bulk density, 58 lb/ft³. Actual capacity is 2.9 lbs/lb CO_2. Identical to soda lime except less alkaline and more uniform rate of absorption over useful life period.
(d) Soda lime	Mixture of hydrated lime, $Ca(OH)_2$, and caustic soda, NaOH, formed in highly porous granules. Bulk density, 50 lbs/ft³. Actual capacity, 2.9 lbs/lb CO_2.
(e) Lithium hydroxide	Presently under development. Best capacity of any, 1.35 lbs/lb CO_2. Bulk density, 28 lbs/ft³. Retains full reactivity at 35°F, does not deliquesce. Exothermic reaction with water, which impairs CO_2 absorption. Tends to dust.

Items (d), (c) and (e) have a theoretical capacity which is independent of CO_2 partial pressure within the range of 35-110°F.
No data could be found for systems using condensation methods in which radiation into space was used as a heat sink, and solar heating used for rewarming of gases.

ITEM NO.	SUBJECT AREAS:	SOURCE:
60	SYSTEM - S2 HUMAN - H47	Reference 219, pp. 422-423. Based on Reference 176.

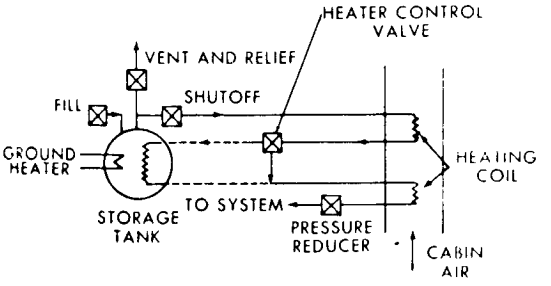
STORAGE OF GASES FOR SUPPLY
OF O_2, N_2 and H_e.

a



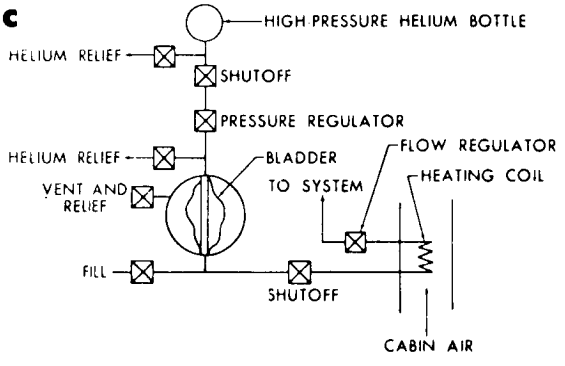
Pressure-enthalpy diagram for supercritical oxygen storage

b



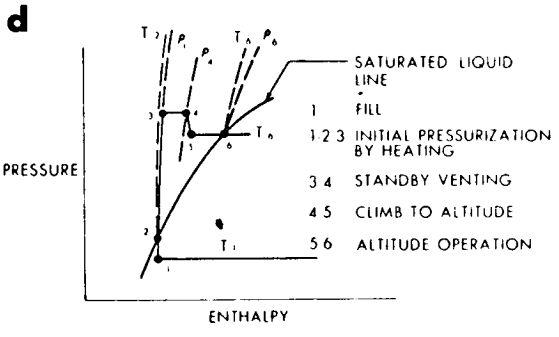
Thermally-pressurized supercritical storage

c



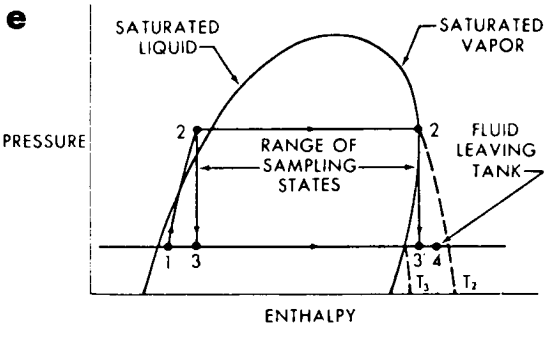
Liquid storage with positive expulsion

d



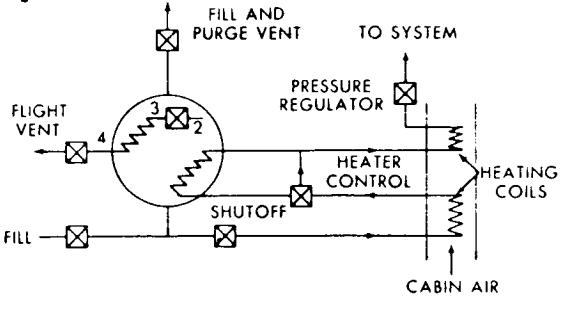
Pressure-enthalpy diagram for subcritical liquid storage

e



Pressure-enthalpy diagram for two-phase storage with vapor delivery

f



Two-phase storage with vapor delivery

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (©) 1964. Reprinted by permission of Fairchild Pub. Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
61	SYSTEM - S2 HUMAN - H47	Reference 483, pp. 139-140.

	KO_2	NaO_2	Li_2O_2	NaO_3	$LiNO_3$	$LiClO_4$	$NaClO_3$	H_2O_2
AVAILABLE O_2 LB/LB CHEMICAL	0.338	0.436	0.348	0.563	0.232	0.601	0.451	0.471
FINAL PRODUCT	K_2CO_3	Na_2CO_3	Li_2CO_3	Na_2CO_3	$LiNO_2$	LiCl	NaCl	H_2O
DENSITY, LB/CU IN	0.0237	—	0.0774	—	0.0861	0.0878	0.0815	0.0515
HEAT OF REACTION BTU/LB O_2	−1720(1)	−1968	−1680	—	+2100	+240	+1585	−2640

(1) – Indicates exothermic reaction; + indicates endothermic reaction

COMPARISON OF OXYGEN-PRODUCING CHEMICALS

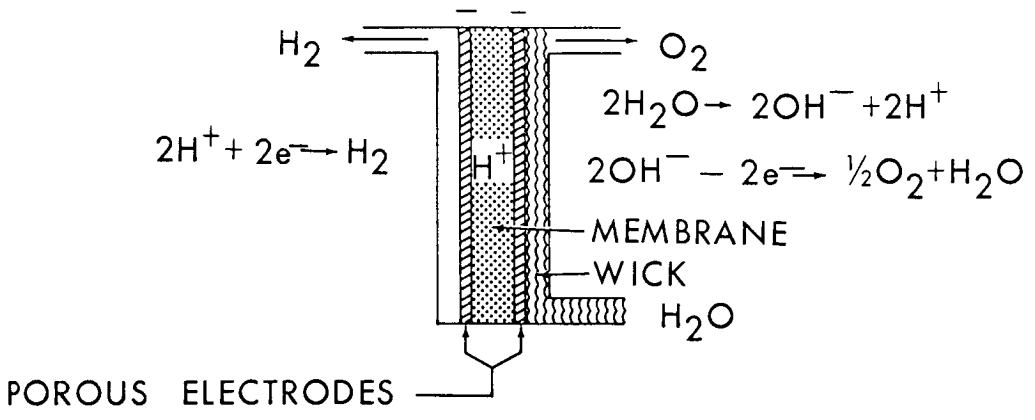
REACTION	ΔH KCAL	HEAT EVOLVED, BTU PER LB OF			WEIGHT RATIOS, LB OF REACTANT (KO_2, KOH, OR K_2CO_3) PER LB OF		
		O_2	H_2O	CO_2	O_2	H_2O	CO_2
$2KO_2 + H_2O = 2KOH + \frac{3}{2} O_2$	-11.8	442	1180	-	2.96	7.90	-
$2KO_2 + CO_2 = K_2CO_3 + \frac{3}{2} O_2$	-45.9	1722	-	1878	2.96	-	3.24
$2KOH + CO_2 = K_2CO_3 + H_2O$	-34.1	-	-	1395	-	-	2.56
$KOH + CO_2 = KHCO_3$	-33.5	-	-	1370	-	-	1.28
$\frac{4}{3}KOH + H_2O = \frac{4}{3}(KOH \cdot \frac{3}{4} H_2O)$	-22.1	-	2210	-	-	4.15	-
$KOH + H_2O = KOH \cdot H_2O$	-20.0	-	2000	-	-	3.12	-
$\frac{1}{2}KOH + H_2O = \frac{1}{2}(KOH \cdot 2H_2O)$	-16.9	-	1690	-	-	1.56	-
$K_2CO_3 + H_2O + CO_2 = 2KHCO_3$	-32.8	-	3280	1342	-	7.68	3.14

POTASSIUM SUPEROXIDE REACTIONS

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (©) 1964. Reprinted by permission of Fairchild Publications, Inc.

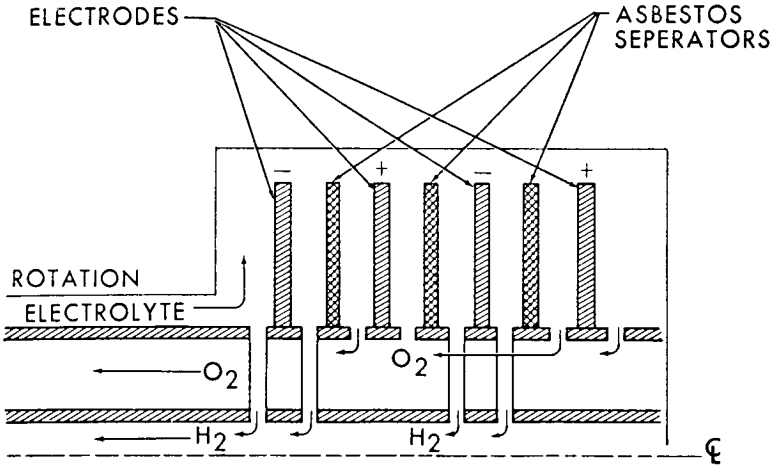
ITEM NO.	SUBJECT AREAS:	SOURCE:
62	SYSTEM - S2 HUMAN - H47	Reference 483, pp. 141-142.

a



Ion-exchange membrane electrolysis cell

b



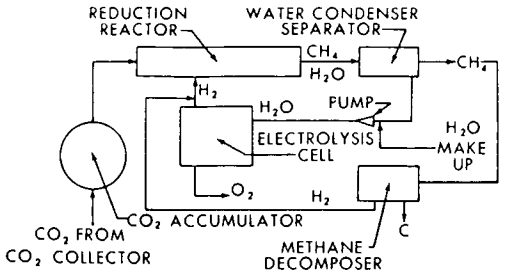
Rotating electrolysis cell

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
63	SYSTEM - S2 HUMAN - H47	Reference 483, pp. 142-143.

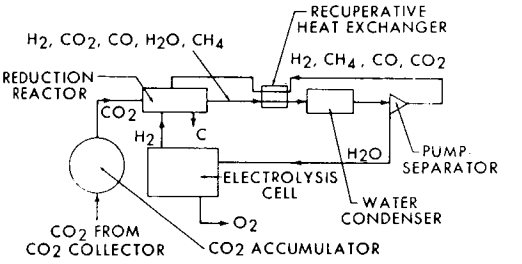
CO_2 REDUCTION SYSTEMS

a



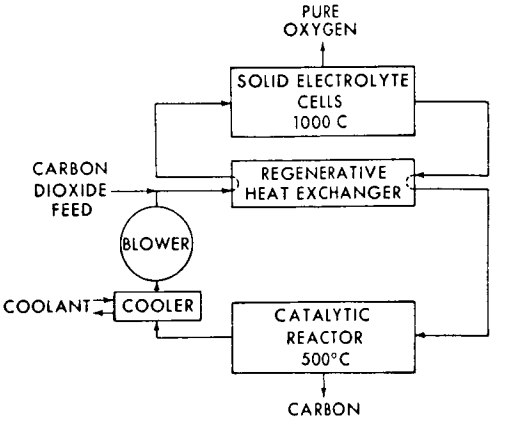
Sabatier reaction system with methane decomposition

b



Bosch-reaction system

c

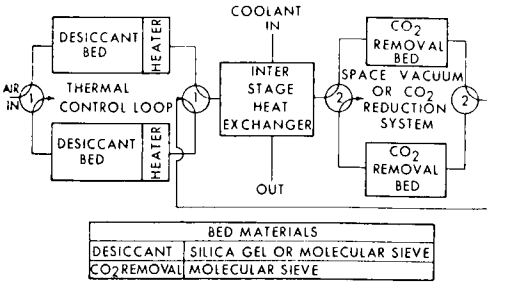


Solid-electrolyte CO_2 reduction system

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ITEM NO.	SUBJECT AREAS:	SOURCE:
64	SYSTEM - S2 HUMAN - H47	Reference 483, p. 144.

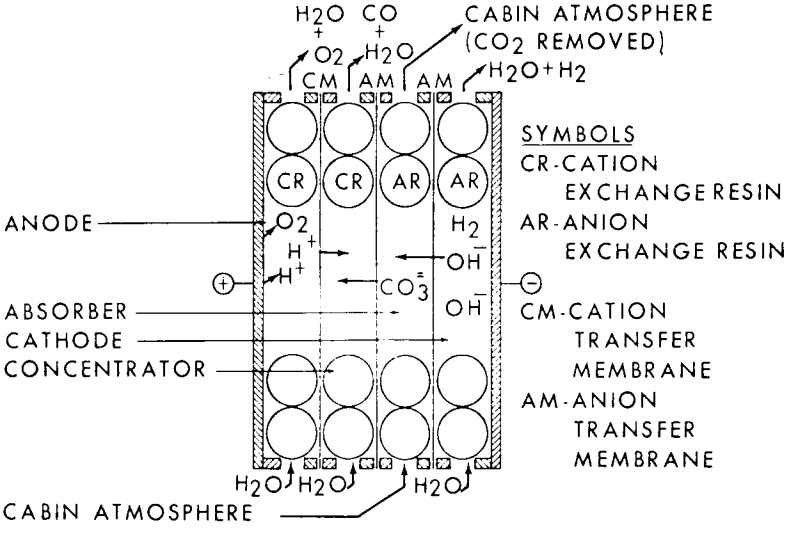
a



Schematic of typical molecular-sieve carbon-dioxide removal system

Schematic of typical molecular-sieve carbon-dioxide removal system

b



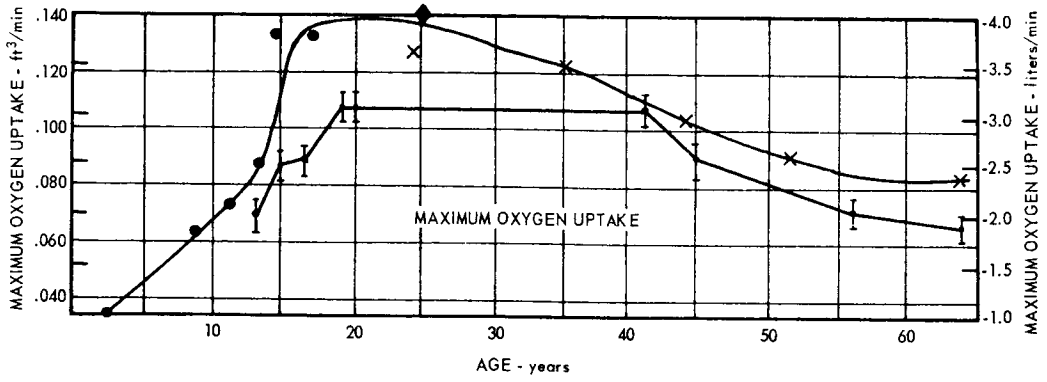
Ion-exchange electrodialysis carbon-dioxide absorber

Ion-exchange electrodialysis carbon-dioxide absorber

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

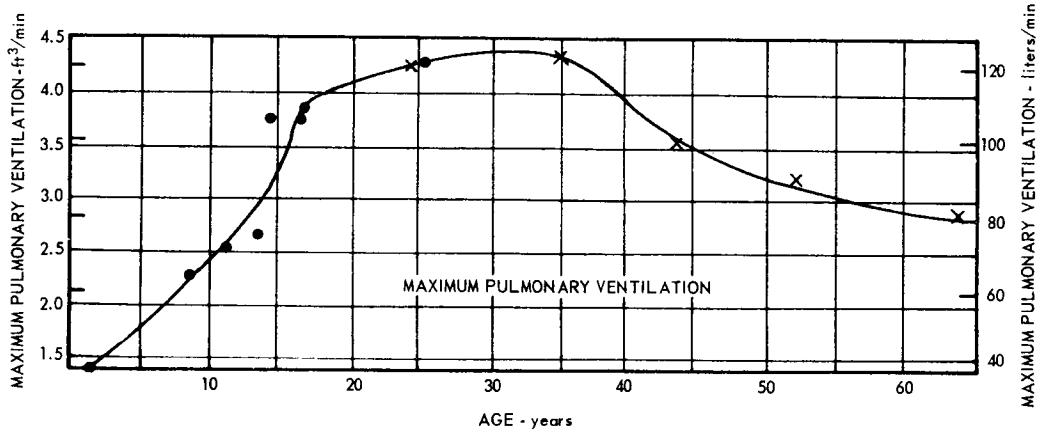
ITEM NO.	SUBJECT AREAS:	SOURCE:
65	SYSTEM - S2 HUMAN - H47	Reference 483, p. 151-152.

a.



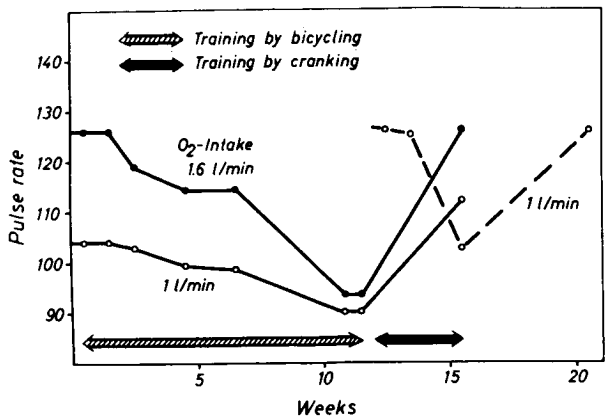
VALENTIN ET AL. (MEAN AND RANGE)
● ÅSTRAND - 73 MALE SCHOOLCHILDREN, NONE OBESE
× ROBINSON - 93 NONATHLETIC MALES
◆ ÅSTRAND - 42 MALE PHYSICAL EDUCATION STUDENTS

b.



These two charts show the greatest pulmonary ventilation and oxygen consumption of boys and men from 3 to 65 years old, while exercising strenuously for 5-minute periods. This measurement is an individual characteristic which varies with the subject's physical condition; it is often called the maximum aerobic capacity (MAC).

ITEM NO.	SUBJECT AREAS:	SOURCE:
66	SYSTEM - S2 HUMAN - H16, H20, H47	Reference 554, p. 183. Compiled from References 15, 49, 435, and 538.

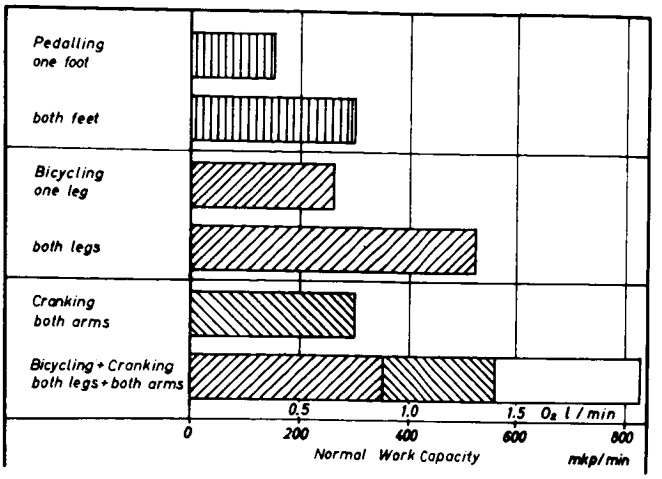


Changes in pulse rate for constant work per minute by different training

An important factor determining work capacity is the utilization of oxygen carried in the blood. During rest the tissues take up, on the average, only 1. 3 out of the available blood oxygen. (If this percentage is doubled, each beat of the heart can deliver double the amount of oxygen to a muscle and set free double the mechanical energy by oxidation.) Inactivity diminishes the capabity of a muscle to utilize blood oxygen. This is shown by experiments made in 1942. Note the fall in pulse rate for the same amount of work on the bicycle in the course of 11 weeks of training. This effect could be explained either by an increased stroke-volume, or by an increase in the oxygen uptake per beat. That the latter occurs can be concluded from the further course of the curve in the figure. In the 11th week exercise of the legs was stopped while arm exercise by cranking was begun. The metabolic rate remained the same (oxygen intake = 1 liter per minute). If the decrease in pulse rate during training on the bicycle was caused by an increase in stroke volume, it should have been possible for the heart to deliver 1 liter oxygen per minute at the same low heart rate to the arm muscles as to the leg muscles. It was observed, however, that when arm exercise was begun the heart rate was again high and this decresed only with training. At the same time the improvement seen earlier with the legs was lost; leg exercise was again accompanied by the high initial pulse rate. Thus the heart-sparing effect of increased oxygen utilization, which in this way increases physical work capacity, is lost when the muscles involved become inactive.

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer/Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
67	SYSTEM - S2 HUMAN - H9, H16, H20, H22, H41	Reference 383, p. 175.

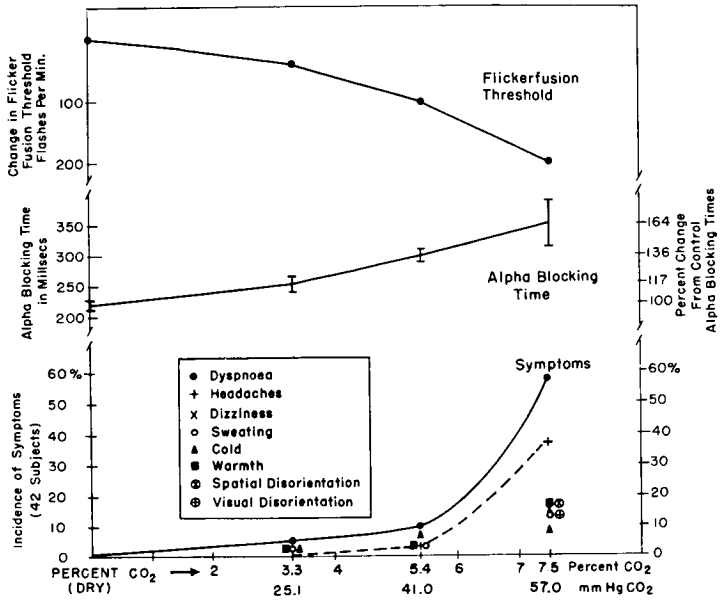


Normal aerobic work capacity for simultaneous work in different muscles

We have to consider that man is composed of many machines, many muscles of different work capacity, fed with energy by one single central pump, the heart. The size and the strength of the heart and the oxygen capacity of the blood provide physiological limits to the quantity of oxygen which may be supplied to the muscles (central limit). On the other hand the mass of the working muscles eventually limits their oxygen intake at a lower level than the central limit (peripheral limit). To determine the central limit, a sufficient mass of muscle must be set working such that the peripheral limit is as high or higher than the central one. This is demonstrated by the figure. It shows the limits of nonfatiguing work for six different activities in one normal man. One can see that pedalling with both feet doubles the work capacity possible with one foot. The same is true for bicycling with one and two legs. Up to an oxygen intake of about 1.3 liter per minute adding muscular mass to the task increases the work capacity, which means that below 1.3 liter per minute the central limit of his oxygen supply has not been reached. If the oxygen demands are further increased (e.g. cycling with both legs and cranking with both arms) an oxygen intake of slightly more than 2 liter per minute would be needed to meet the oxygen needs of all the muscle groups involved. Intake, however, was only 1.4 liter per minute: the demand in this case certainly surpassed the central limit.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
68	SYSTEM - S2 HUMAN - H13, H16, H20, H22, H28	Reference 383, p. 174.

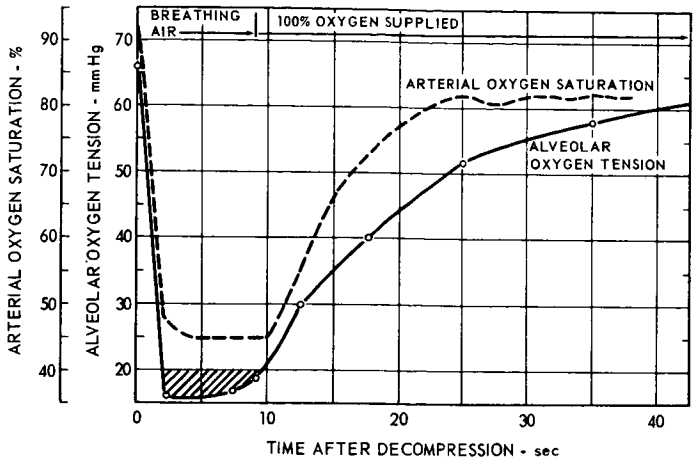


Effect of inhalation of increased carbon dioxide for periods of 15 minutes on flicker fusion threshold alpha blocking time and incidence of symptoms. Bars represent S. E. of Mean.

Schaefer, Karl E., BIOASTRONAUTICS, (c) 1964. Reprinted by permission of The Macmillian Company, New York, New York.

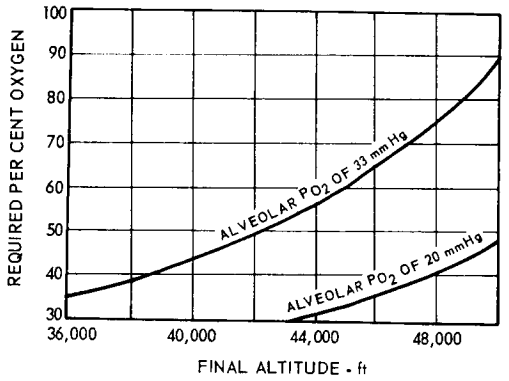
ITEM NO.	SUBJECT AREAS:	SOURCE:
69	SYSTEM- S2 HUMAN- H14, H25, H34, H35	Reference 465, p. 90. Based on Reference 462.

a.



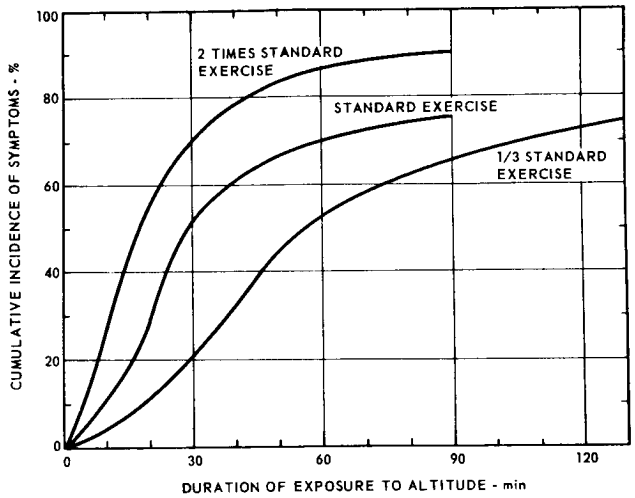
The changes in alveolar oxygen tension are shown, along with the consequent changes in arterial oxygen saturation, following 1.5 second decompressions from 8,000 to 40,000 feet. These are averages of four subjects who breathed air during the decompression; oxygen was supplied 8 seconds later. (Data of J. Ernstring.) The shaded area represents the "deoxygenation integral index." Impairment appears 10-15 seconds after the tension drops to 20 mm Hg, and the degree of impairment is roughly proportional to the integral of oxygen tension depression below 20 with respect to time.

b.



This chart shows an estimate of the oxygen enrichment of the breathing mixture in a cabin pressurized to 8,000 feet (565 mm Hg) needed to prevent a critical fall in alveolar oxygen during decompressions to various altitudes. The critical level on the upper curve is an alveolar PO_2 of 33 mm Hg, below which transient mental deterioration would occur. A critical value of 20 mm Hg is used for the lower curve. It is assumed that 100% oxygen (under positive pressure above 45,000 feet) would be supplied immediately.

ITEM NO.	SUBJECT AREAS:	SOURCE:
70	SYSTEM - S2 HUMAN - H16, H47	Reference 554, p. 95. Based on Reference 78.



The graph shows the effect of muscular exercise on appearance of symptoms of decompression sickness at 38,000 feet. Standard exercise was 10 step-ups onto a 9-inch stool in 30 seconds, repeated every 5 minutes. The number of subjects varied from 53 to 139 under three conditions of exercise.

ITEM NO.	SUBJECT AREAS:	SOURCE:
71	SYSTEM - S2 HUMAN - H22, H47	Reference 554, p. 97. Based on Reference 269.

a.

In this table are listed the components of water balance data from several sources--standard values for healthy adults in comfortable temperatures, data from studies made with the space cabin simulator at the USAF School of Aviation Medicine, and partial data calculated from three of the Project Mercury orbital flights. Evaporative losses (weight change data) do not differentiate between insensible loss and sweating. In the Mercury data, all three astronauts were subjectively hot, and sweated inside their pressure suits.

	Intake				Output				
	Liquid	Water (in food)	Metabolic Water	Total	Urine	Sweat	Insensible	Feces	Total
	-- all values in ml/man day --								
Standard values:									
Ruch & Fulton, eds.	1200	1000	300	2500	1400	0	900	200	2500
Goldberger	1500	800	300	2600	1500	0	1000	100	2600
Diem, ed.	1500	700	300	2500	1500	0	900	100	2500
Space cabin simulator (Welch et al average of 2 men for:									
14 days at 7.3 psia	1182	550	295	2027	832	-	-	50	-
17 days at 3.7 psia	1473	470	286	2229	1158	-	-	70	-
30 days at 7.3 psia	1053	545	245	1843	1042	-	-	62	-
30 days at 7.3 psia	1021	203	200	1424	756	-	-	48	-
Space cabin simulator; average of 4 men at 5 psia for 14 days (Morgan et al.)	1271	728	266	2265	1370	-	829	66	2265
Space cabin simulator; average of 2 men in ventilated pressure suits at 5 psia (Welch et al)	1867	732	241	2840	1210	---- 1561 ---- (from wt. loss)		69	2840
Orbital flights									
MA-6 (including pre- and post-flight data) (N. A. S. A.	724	-	-	-	1350	---- 1944---- (from wt. loss in 12-hr period including the flight)		0	-
MA-7 (including pre- and post flight data) (N. A. S. A.	3543	-	-	-	2515	---- 1623 ---- (for 14-hr period including the flight)		0	-
MA-9 (24-hr rates, estimated from N. A. S. A.	>1500		75 (est.)		850 (approx.)	---- 3905 ---- (24-hr rate calculated from data for 34 hrs flight)		0	

b.

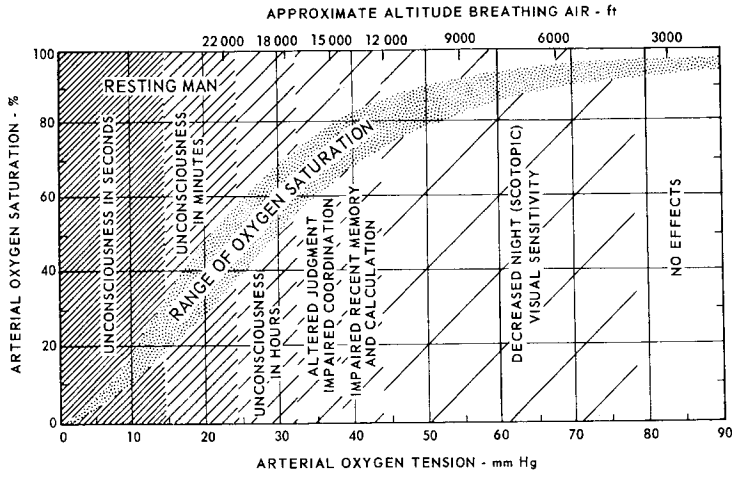
Summary of Water Data

The data in the table are averages from two men in a space cabin simulator during four separate experiments lasting 14 days, 17 days, 30 days, and 30 days. Values are recorded in ml/man day.

		14-day	17-day	30-day (1st)	30-day (2nd)
Liquid water required:	fluid intake	1182	1473	1053	1021
	food rehydration	550	470	545	203
Water in food and of oxidation		295	286	245	200
Liquid waste water produced	urine	832	1158	1042	756
	water in feces*	50	70	62	48

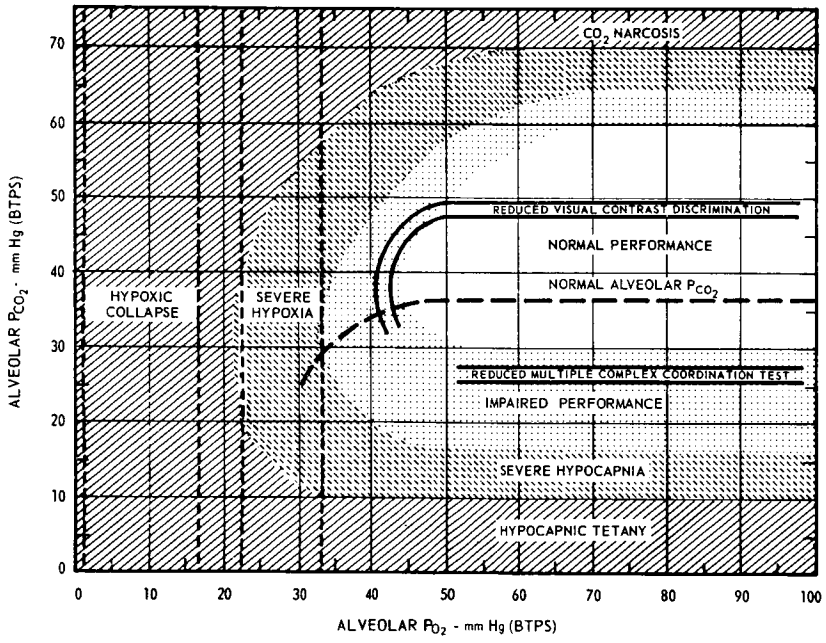
* Based on 80% of fecal weight.

ITEM NO.	SUBJECT AREAS:	SOURCE:
72	SYSTEM - S2 HUMAN - H11, H20, H43	Reference 554, p. 203. Compiled from References 168, 224, 381, 388, 389, 387, 446, 566, 570 (fig. a) and 569 (fig. b).



As arterial oxygen tension falls, progressive impairment occurs in the central nervous system, as indicated on the chart by zones of increasing density. These changes occur in resting men who are not fatigued or otherwise stressed. The oxygen saturation of arterial blood for resting men is also shown as a function of oxygen tension (the hemoglobin dissociation curve). A range of saturations for each value of tension is shown, because temperature and pH influence the saturation values also. Individual variability and time dependency are characteristic of these data.

ITEM NO.	SUBJECT AREAS:	SOURCE:
73	SYSTEM - S2 HUMAN - H25, H26, H27, H47	Reference 554, p. 94. Based on References 89, 365, and 527.



This graph shows the relationship of alveolar O_2 and CO_2 composition to performance. The scales are partial pressures of the two gases, at body temperature and pressure, saturated with water (BTPS). Above the dashed line labeled "normal alveolar CO_2" are zones of increasing hypercapnia, limited by the zone of CO_2 narcosis. Below the dashed line, marked as zones of increasing hypocapnia, are lower levels of alveolar CO_2, which are commonly the result of excessive respiratory ventilation. The left side of the graph shows low levels of alveolar P_{O_2}, labeled zones of "severe hypoxia" and "hypoxic collapse," and these hypoxic zones combine with hyper- or hypocapnia to affect performance as shown.

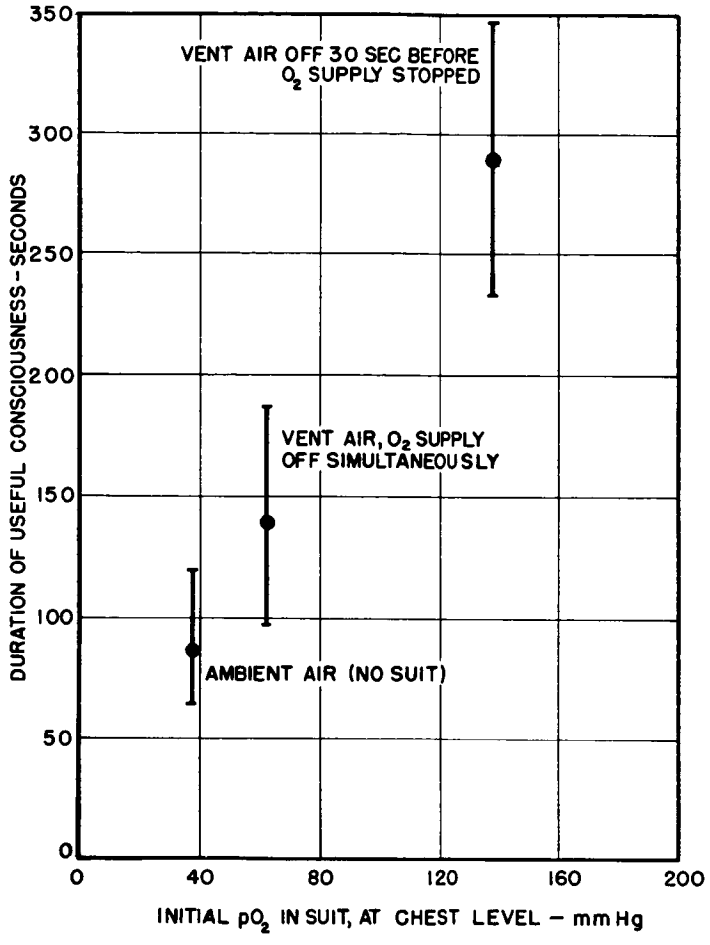
Normal performance is seen when the gas tensions fall in the clear area; impaired performance in a hand-steadiness test is shown by shading, and the results of two other performance tests are plotted also to indicate the variation to be expected when "performance" is variously measured.

ITEM NO.	SUBJECT AREAS:	SOURCE:
74	SYSTEM - S2 HUMAN - H25, H26, H34	Reference 554, p. 11. Based on References 54 and 403.

Major Effects of Altitude Without Supplemental Oxygen or Pressurization, Approximate Time of Consciousness, and Recommended Altitude Limits for Various Situations

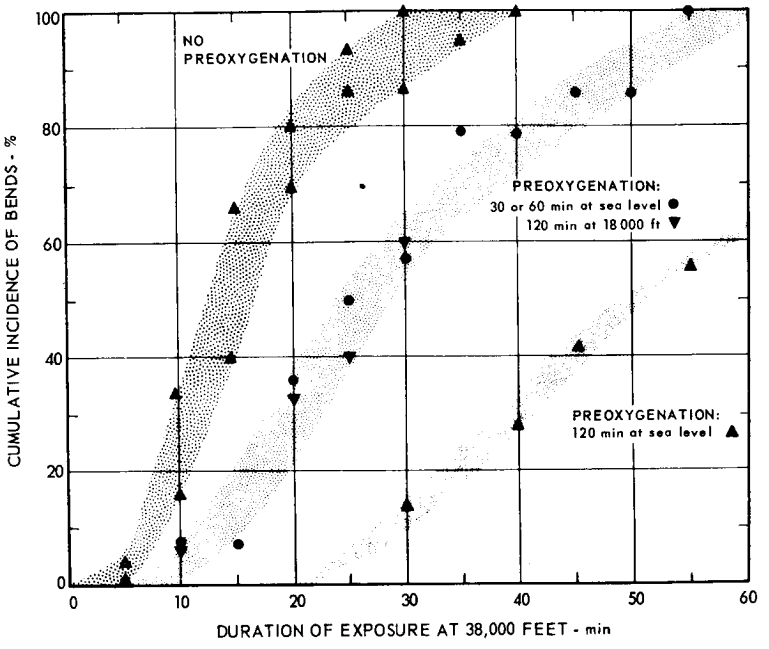
Altitude (ft)	*Major effects*	*Approx. time of consciousness (sec)*	*Recommended limits*
5,000	Loss of central night vision initiated	—	
8,000		—	Begin supplemental oxygen for routine flights
10,000	Loss of peripheral night vision, complex coordination, orientation, hearing, memory, and intellectual skills initiated	—	Maximum without supplemental oxygen in routine situation
15,000	Loss of tracking skills and reaction (decision) time initiated	—	
16,000	Loss of emotional control initiated	—	
17,000	Loss of simple coordination and vision initiated	—	
18,000		—	Maximum without supplemental oxygen in emergency
20,000		—	Begin cabin pressurization for routine flights
23,000	Decompression sickness initiated	—	
25,000		116	
28,000		69	Maximum without cabin pressurization
30,000		54	Begin positive-pressure breathing for routine flights
35,000		32	Maximum for demand oxygen in routine situation
40,000		23	
42,000			Maximum for positive-pressure breathing in routine situation Maximum for cabin pressurization
43,000			Maximum for demand oxygen in emergency
45,000			Maximum for positive-pressure breathing in emergency Begin use of pressure suit

ITEM NO.	SUBJECT AREAS:	SOURCE:
75	SYSTEM - S2 HUMAN - H24, H34, H35, H44	Reference 380, p. 426. Based on Reference 149.



Average values and ranges for useful consciousness times when the oxygen supply and ventilating air have been shut off in a Navy full pressure suit, at 35,000 feet in an altitude chamber. For comparison, control values are shown for subjects without suits, who removed their masks and breathed chamber air. Five experienced subjects were used, and their times of useful consciousness were determined with a device which tested manual dexterity and code comprehension. Notice the effectiveness of allowing oxygen to build up for 30 seconds by shutting off the ventilating air (the pO_2 went from 62 to 140 mm Hg). The values for pO_2 may not represent the general level of oxygen available, since only one sampling port was available, at some distance from the head. Part of the prolongation of time of useful consciousness rebreathing from the suit, as compared to the chamber air, may have been due to a buildup of CO_2 in the helmet area.

ITEM NO.	SUBJECT AREAS:	SOURCE:
76	SYSTEM- S2 HUMAN- H34, H44	Reference 555, p. 10. Based on Reference 372.



As noted on the preceding page, inert gas may be eliminated from the body by breathing air free of that gas. Most studies of decompression sickness have utilized 100% oxygen as the inspired gas during the nitrogen washout period. The effect of such pre-oxygenation (actually pre-exposure denitrogenation) is illustrated above. In all cases, after a control period at ground level, subjects were taken to 38,000 feet breathing oxygen, at which altitude they performed 5 knee bends every 3 minutes until the appearance of joint pains, presumably caused by extra-vascular bubble formation. The protective effect of nitrogen washout is in part a function of the duration of pre-oxygenation prior to exposure to altitude, but protection is not entirely proportional to the extent to which body nitrogen stores are depleted. Occasional cases of decompression sickness are seen even after many hours of pre-exposure denitrogenation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
77	SYSTEM - S2 HUMAN - H34, H44	Reference 554, p. 99. Based on References 55 and 350.

a. Flatus Generation*

Specimen	Volume		Source
	Mean ml/day	Range ml/day	
Estimated average volume of discharged gas	1000	-	Clemedson
Discharged gas; 47 normal individuals on ordinary (cabbage free) diet. Single emissions ranged between 25 and 100 ml.	825	100-2800	Kirk
Single discharge 50-500 ml.	1000	-	Fries
Normal average quantity passed daily; five subjects.	524	-	Beazell
Five male medical students unbothered by flatulence; quantities equally divided between day and night.		380-655	Davenport
From control volume of 17 ± 10cc per hr. to 203 ± 87cc per hr. for five men changing from control volume to a pork and beans or dried lima bean diet; (25-50% of calorie intake) for two weeks.		240-4872	Davenport
	2000	-	Mattoni

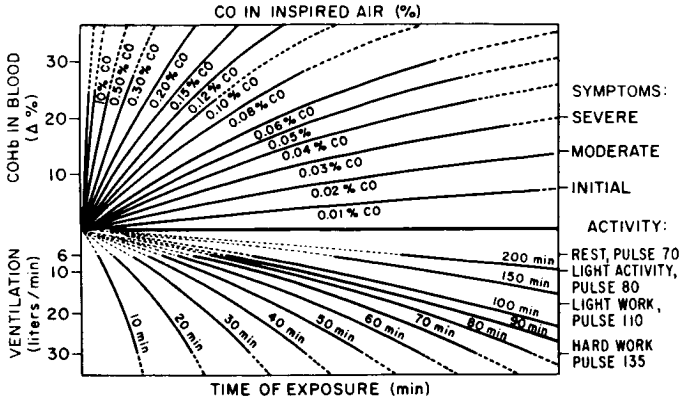
* Emitted flatus, not gas formed in stomach, small intestine, or colon; not eructed gas.

b. Chemical Composition of Flatus*

	Cabbage Free Diet, 1943-44 20 individuals		Cabbage & Milk Free Diet, 1945-46 25 individuals	
	Mean %	Range %	Mean %	Range %
Carbon dioxide	9.0	1.2-15.0	9.7	0.7-24.7
Oxygen	3.9	0.0-15.7	5.5	0.5-20.0
Methane	7.2	0.0-30.3	3.1	0.0-21.4
Hydrogen	20.9	3.1-34.0	12.0	0.4-36.5
Nitrogen	59.0	39.7-88.2	70.0	24.7-87.7
Hydrogen sulfide	.0003	0.0-.0017	.0002	0.0-.0003

*Samples obtained by rectal catheterization.

ITEM NO.	SUBJECT AREAS:	SOURCE:
78	SYSTEM - S3 HUMAN - H11	Reference 554, p. 223. Based on References 63, 137, 159, 204, 302 (fig. b), and 352.



The rate of uptake of CO depends on the time-concentration function, lung ventilation, and body-activity level. The figure above shows the inter-relationships among these variables in their effects on fCOHb. The upper half of the illustration shows the fCOHb as a function of fCO in the inspired air with exposure time; the lower half relates exposure time, activity, and ventilation.

To determine the fCOHb in a man whose ventilation rate is 25 liters/min after 80 min of exposure to an atmosphere whose fCO is 0.05%, for example, draw a horizontal line from 25 liters/min on the lower left-hand scale of the figure to the 80-min line, then go up vertically to the 0.05% line in the upper half of the figure, and then horizontally to the left on the %COHb scale. If this is done, it can be seen that, in this case, the saturation of blood by CO is approximately 28%.

In solving design problems, the engineer can calculate permissible time-concentration data by setting a given fCOHb for a given activity as constant and reading off the set of values that would produce it.

ITEM NO.	SUBJECT AREAS:	SOURCE:
79	SYSTEM - S3 HUMAN - H9, H16, H22, H34	Reference 380, p. 439. Based on Reference 198.

ITEM NO. 80 a
Page 1 of 3

SUBJECT AREAS: SYSTEM - S3
HUMAN - H33

SOURCE: Reference 378, p. 342.

Nonmetallic Materials for use in Habitable Areas

Material	Specification	Status*	Supplier	Commercial Designation
Sealing Compound		R	American Sealants	Grade D Loctite
Sealing Compound		R	American Sealants	Grade C Loctite
Silicone		R	Dow Corning	RTV 503
Silicone		R	Dow Corning	R 875 + Cat 24
Thermo Plastics				
Teflon Rod & Bar	AMS 3651	A	QSL	Teflon
Teflon Sheet		A	Carmer Ind.	Teflon
Teflon (FEP)	NAA RB-0130-007	A	QSL	Teflon (FEP)
Acrylic	MIL-P-5425	R	Rohm & Haas	Plex II - UVA
Miscellaneous				
Tape		R	3M	#466
Adhesives				
Synthetic Rubber		R	3M	EC 826
Synthetic Rubber	MIL-G-4003	R	3M	EC 827
Silicone	MIL-A-25457	R	Dow Corning	A-4000
Phenolic		R	Chrysler Corp.	Cycleweld
Glyptal		R	General Electric	Glyptal
Finishes, Coatings, & Marking Materials				
Epoxy Enamel		R	Glidden	36521
Coating		R	Hysol Corp.	Hysol 12007
Marking Ink		R	Bernhard-Meiners	209, 314
Lacquer		R	Lowe Brothers	C 18094
Lacquer		R	General Electric	GE 1557
Zinc Chromate Primer	MIL-P-8585	R	Glidden	RGL-19884

* Status: R = rejected
A = approved

NOTE: Materials tested for environmental conditions of 100% O_2 and 200°F maximum temperature.

ITEM NO. 80 b

Page 2 of 3

SUBJECT AREAS: SYSTEM - S3 HUMAN - H33

SOURCE: Reference 378, p. 343.

Nonemtallic Materials for use in Habitable Areas (Continued)

Material	Specification	Status*	Supplier	Commercial Designation
TEF Tubing Wrap		A	Hi Temp Wire and Cable Co. American Super Temp.	Teflon
Tape		R	3M	#466
Paper Tape		R	3M	#3
Tape		R	3M	#28
Glass Tape	MIL-I-5126	R	3M	#27
Elastomers				
Silicone		R	Dow Corning	R 875 + Cat 24
Silicone	MIL-R-5847	R	Union Carbide	K 1235
Silicone	MIL-R-5847	R	Dow Corning	#916
Silicone Sponge	AMS 3195	R	Nopco Chemical	B10470
Neoprene	MIL-R-3065	R	Robinson Rubber Co.	Type SC Class 415
Buna-N		R	DuPont	N 5580 HA
Enamel	MIL-E-5553	R	Glidden	GL-2-1284, GL-22980
Enamel		R	NAZ DAR	805 Red
Epoxy Enamel		R	Glidden	2B 7-B-505
Lacquer		R	Glidden	#207
Epoxy Enamel		R	Div. Peterson	AN-506 Yellow
Silicone		R	Andrew Brown	37038 (black)
Vinyl Primer		R	Amercoat Corp.	#33

* Status: R = rejected
A = approved

NOTE: Materials tested for environmental conditions of 100% O_2 and 200°F maximum temperature.

ITEM NO. 80 c
Page 3 of 3

SUBJECT AREAS:
SYSTEM - S3
HUMAN - H33

SOURCE:
Reference 378, p. 344.

Nonmetallic Materials for use in Habitable Areas (Concluded)

Material	Specification	Status*	Supplier	Commercial Designation
Electrical Insulation & Wiring				
Teflon Tubing	AMS-3654	A	Hi Temp Wire & Cable. Polymer Corp.	ES 4884
Teflon Insulated Wire	MIL-W-16878	A	Hi Temp Wire & Cable Co.	Type E
Teflon Insulated Wire	MIL-W-16878	A	Suprenant	Surok
Greases and Lubricants				
Silicone Grease	MIL-I-8660	R	Dow Corning	DC #4
Lubrication Oil	MIL-O-6068	R	F.E. Anderson Oil Co.	L-245 X
Molding Materials				
Diallylpthalate/glass	MIL-M-19833	R	Mesa Plastic	Diall FS-4
Phenolic		R	Durez	18001
Plastic Laminates				
Epoxy/glass	MIL-P-18177	R	General Electric	TexTo 11559
Epoxy/glass	MIL-P-18177	R	Continental Diamond Fiber Co.	GB-28-EFR
Epoxy/glass	MIL-P-18177	R	3-M	Lamicoid 6096
Potting & Sealing Compounds				
Sealing Compound	MIL-S-8516	R	Products Research	1201 Q
Sealing Compound	MIL-S-8516	R	Coast Pro Seal	Pro Seal 727
Sealing Compound		R	American Sealants	Grade A. Loctite

*Status: R = rejected
A = approved

Note: Materials tested for environmental conditions of 100% O_2 and 200°F maximum temperature.

One-hour Exposure to Atmospheric Contaminants

The Bureau of Medicine and Surgery recently recommended interim threshold limits for 1-hour exposures. It was emphasized that such limits represent the maximum allowable concentrations permissible under operational conditions and are not to be construed as permissible limits for repeated short-term exposures. It is envisioned that sufficient time between these peak exposures will have elapsed to allow complete recovery of the exposed individuals. In some cases, minor symptomatology may occur. The following recommendations represent 1-hour permissible limits for exposure for these compounds.

Ammonia	400 ppm
Monoethanolamine	100 ppm
Ozone	1 ppm
Oxides of nitrogen	10 ppm
Carbon dioxide	5 %
Carbon monoxide	200 ppm
Hydrogen chloride	50 ppm
Hydrogen fluoride	5 ppm
Phosgene	1 ppm
Sulfur dioxide	10 ppm

ITEM NO.	SUBJECT AREAS:	SOURCE:
81	SYSTEM - S3 HUMAN - H33	Reference 554, p. 27. Based on Reference 536.

Recommended Maximum Concentrations of Atmospheric Contaminants

COMPOUND	PPM	mg/M³ (APPROXIMATE)
ACETIC ACID	10	25
ACETONE	1000	2400
ACROLEIN	0.5	1.2
AMMONIA	100	70
AMYLACETATE	200	1050
AMYL ALCOHOL	100	360
BENZENE	25	80
BUTYL CELLOSOLVE	50	240
CARBON DISULFIDE	20	60
CARBON MONOXIDE	100	110
CARBON TETRACHLORIDE	25	160
CRESOL	5	22
CYCLOHEXANE	400	1400
DIOXANE	100	360
ETHYL ACETATE	400	1400
ETHYLENE DIAMINE	10	30
FLUORINE	0.1	0.2
FORMALDEHYDE	5	6
HYDRAZINE	1	1.3
HYDROGEN CHLORIDE	5	7
HYDROGEN FLUORIDE	3	2
HYDROGEN PEROXIDE, 90%	1	1.4
HYDROGEN SULFIDE	20	30
LITHIUM HYDRIDE		0.025
METHYL ALCOHOL	200	260
METHYL CELLOSOLVE	25	80
NITROGEN DIOXIDE	5	9
METHYL ETHYL KETONE	200	590
OZONE	0.1	0.2
PERCHLOROETHYLENE	100	670
PHENOL	5	19
PHOSGENE	1	4
PHOSPHINE	0.05	0.07
SODIUM HYDROXIDE	-	2
SULFUR DIOXIDE	5	13
SULFURIC ACID	-	1
TEFLON DECOMPOSITION PRODUCTS (AS FLUORINE)	-	0.05
TOLUENE	200	750
TRICHLOROETHYLENE	100	520
XYLENE	200	870

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

These tolerable limits for trace contaminants as set by the American Conference of Government Industrial Hygienists are based on a 40-hour work week with considerations of recovery by the workers during their off hours.

Since this off-duty recovery is not possible in a spacecraft, a new set of limits is being determined for spacecraft atmospheres which are based on continuous exposure. The primary sources of trace contaminants anticipated for spacecraft are:

(1) non-metallic materials used in the spacecraft,
(2) leakage of stored gases (H_2 etc.),
(3) leakage from material processing equipment (O_2 reclamation system, etc.),
(4) metabolic processes of the crew.

Note: Three overlapping lists are included for comprehensiveness.

ITEM NO.	SUBJECT AREAS:	SOURCE:
82 a	SYSTEM- S3	Reference 483, p. 153.
Page 1 of 3	HUMAN- H33	

Common Sources and Maximum Allowable Concentrations of Some Toxic Agents

Common source	Toxic agent	Maximum allowable concentration (ppm)
Fuels and propellants	Ammonia	100
	Aniline	5
	Ethyl alcohol	1,000
	Gasoline	250
	Kerosene	500
	Methyl alcohol	200
	Nitrogen tetroxide	5
Engine exhausts (including rocket engines)	Aldehydes:	
	Acetaldehyde	200
	Acrolein	0.5
	Formaldehyde	5
	Furfural	5
	Carbon dioxide	5,000
	Carbon monoxide	100
	Bromine	1
	Nitrogen dioxide	5
	Sulfur dioxide	5
Hydraulic fluids	Butyl cellosolve	50
	Diacetone	50
	Aryl phosphates	0.06
	Dioxane alcohol	100
Fire extinguishants	Carbon dioxide	5,000
	Carbon tetrachloride	25
	Chlorobromethane	400
	Methyl bromide	20
Oil sprays and fumes	Aldehydes: (see above)	
Refrigerants	Carbon dioxide	5,000
	Freon	1,000
	Methyl bromide	20
	Sulfur dioxide	5
Smoke	Phosgene (plus same as for engine exhausts)	1

Maximum allowable concentrations of common toxic agents as established by the American Conference of Industrial Hygienists in 1961. Note: Three overlapping lists are included for comprehensiveness.

From HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN edited by Clifford T. Morgan, et al. Copyright 1963 by the McGraw-Hill Book Company, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
82 b	SYSTEM - S3	Reference 380, p. 441.
Page 2 of 3	HUMAN - H33	

RESPIRATION SAFETY RECOMMENDATIONS

Maximum Allowable Concentration of Common Gases, Vapors, Dusts, and Fumes in the Breathing Atmosphere

Dusts:[a]	
Asbestos	5.0
Cement	15.0
Organic	50.0
Silica	
above 50% free SiO_2	5.0
5 to 50% free SiO_2	20.0
below 5% free SiO_2	50.0
Pottery	4.0
Silicon carbide	50.0
Mica	
below 5% free SiO_2	20.0
Soapstone	
below 5% free SiO_2	20.0
State	15.0
Portland cement	50.0
Talc	20.0
Nuisance dust	50.0

Gases and vapors:[b]	
Acetone	1000.0
Ammonia, anhydrous	100.0
Amyl acetate	200.0
Amyl alcohol	100.0
Analine	5.0
Arsine	1.0
Benzene (benzol)	25.0
Butenol	50.0
Butyl acetate	20.0
Carbon disulfide	20.0
Carbon dioxide	5000.0
Carbon monoxide	100.0
Carbon tetrachloride	25.0
Chlorine	1.0
Chlorine trifluoride	0.1
Chloroform	100.0
Dichlorobenzene	50.0
Dichlorethyl ether	15.0
Ether (ethyl)	400.0
Ethyl alcohol	1000.0
Ethyl bromide	1700.0
Ethyl chloride	70.0
Ethylene dichloride	100.0
Ethylene oxide	50.0
Fluorine	0.1
Formaldehyde	20.0
Gasoline	500.0
Hydrochloric acid	10.0
Hydrogen chloride	5.0
Hydorgen cyanide	20.0
Hydrogen fluoride	3.0
Hydrogen peroxide	1.0
Hydrogen sulfide	20.0
Methyl alcohol (methanol)	200.0
Methyl bromide	30.0
Methyl chloride	500.0
Monochlorbenzine	75.0
Naptha (coal tar)	200.0
Naptha (petroleum)	500.0
Nitric acid (fuming)	5.0
Nitrobenzene	5.0
Nitrogen dioxide	5.0
Ozone	0.1
Phosgene	1.0
Phosphine	0.05
Phosphorus trichloride	1.0
Propyl alcohol (isopropyl alcohol)	400.0
Sulfur dioxide	5.0
Tetrachlorethane	10.0
Tetrachlorethylene	200.0
Toluol	200.0
Trichlorethylene	200.0
Turpentine	100.0
Xylol (coal-tar naptha)	100.0

Metallic dusts and fumes:[c]	
Aluminum oxide	50.0
Cadmium	0.1
Chromic acid	0.1
Lead (or lead compounds)	0.15
Manganese	6.0
Mercury	0.1
Zinc oxide	15.0
Chlorodiphenyl	1.0

Smoke:	
40% density (i.e., 60% light visible through it)	

[a] Dusts: million parts per cubic foot. [b] Gases and vapors: parts per million. [c] Metallic dusts and fumes: milligrams per cubic meter.

Note: Three overlapping lists are included for comprehensiveness.

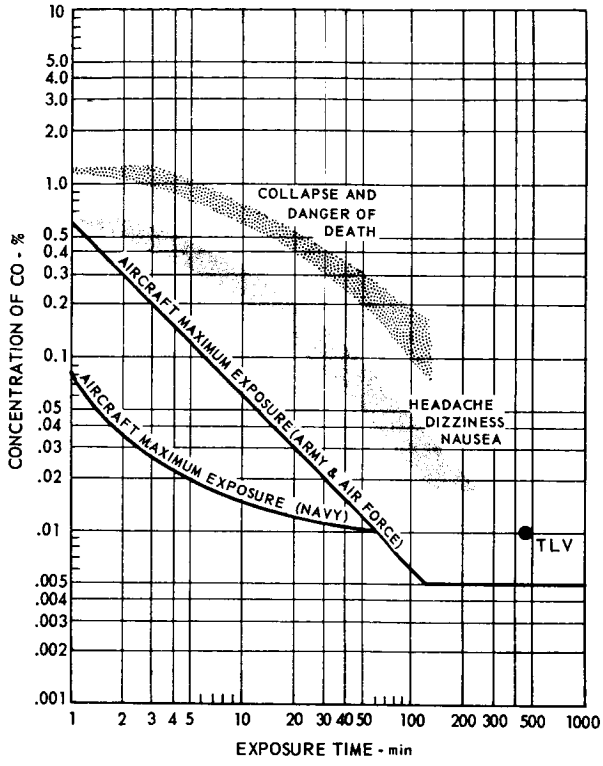
ITEM NO.	SUBJECT AREAS:	SOURCE:
82 c Page 3 of 3	SYSTEM- S3 HUMAN- H33	Reference 586, p. 2-263. Based on References 13 and 95.

Symptoms of Carbon Monoxide Poisoning

COHb in blood (%)	Resulting symptoms
0-10	None subjectively noticeable, but initial visual impairment is revealed in objective tests.
10-20	Tightness across forehead, slight headache, flushed complexion.
20-30	Headache with throbbing in temples, breathlessness from any exertion.
30-40	Severe headache, weakness, dizziness, dimness of vision, nausea, and vomiting with possibility of collapse.
40-50	All preceding symptoms with increased pulse rate and respiration and greater possibility of collapse.
50-60	Loss of consciousness, with increased or irregular respiration, rapid pulse, and possibility of coma with convulsions.
60-80	Coma, convulsions, depressed heart action, respiratory failure and possibility of death.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
83	SYSTEM - S3 HUMAN - H34	Reference 380, p. 439.



The graph shows the effects of carbon monoxide on man as functions of concentration and exposure time. Milder effects are shown as a lightly shaded band of exposure times and concentrations, while dangerous or lethal times and concentrations are grouped in the heavily shaded band. The solid lines are the exposure limits set by the military services for aircraft. The point marked at 0.01% CO (100 ppm) and 480 minutes is the current Threshold Limit Value (TLV) for 8-hours-a-day exposure in industry.

ITEM NO.	SUBJECT AREAS:	SOURCE:
84	SYSTEM - S3 HUMAN - H34	Reference 554, p. 23. Based on References 34, 249, 268, and 454.

a. Mortality from Propellants at Low (TLV) Concentrations

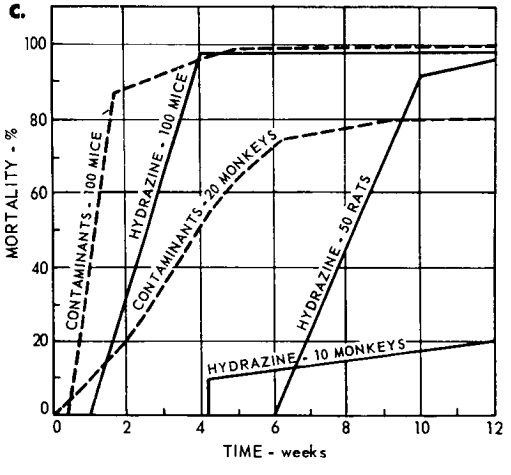
	concentration (TLV) ppm	Monkeys number dead	Monkeys number used	Monkeys mortality %	Rats number dead	Rats number used	Rats mortality %	Mice number dead	Mice number used	Mice mortality %
Hydrazine	1.0	2	10	20	48	50	96	98	100	98
Unsymmetrical dimethyl hydrazine	0.5	1	10	10	3	50	6	6	100	6
Nitrogen dioxide	5.0	0	10	0	9	50	18	13	100	13
Pentaborane	0.05	6	10	60	25	50	50	82	100	82
Controls		1	10	10	0	50	0	1	100	1

b. Mortality from Contaminants at Low (TLV) Concentrations

	concentration (TLV) ppm	Monkeys number dead	Monkeys number used	Monkeys mortality %	Rats number dead	Rats number used	Rats mortality %	Mice number dead	Mice number used	Mice mortality %
Carbon tetrachloride	25.0	1	10	10	0	50	0	0	100	0
Phenol	5.0	0	10	0	0	50	0	0	100	0
Indole	10.5	2	10	20	5	50	10	22	100	22
Hydrogen sulfide	20.0	0	10	0	12	50	24	26	100	26
Methyl mercaptan	50.0*	4	10	40	5	50	10	43	100	43
Mixture: indole, skatole, hydrogen sulfide, methyl mercaptan	10.5 3.5 20.0 50.0	16	20	80	32	50	64	99	100	99
Controls		0	19	0	2	50	4	38	200	19

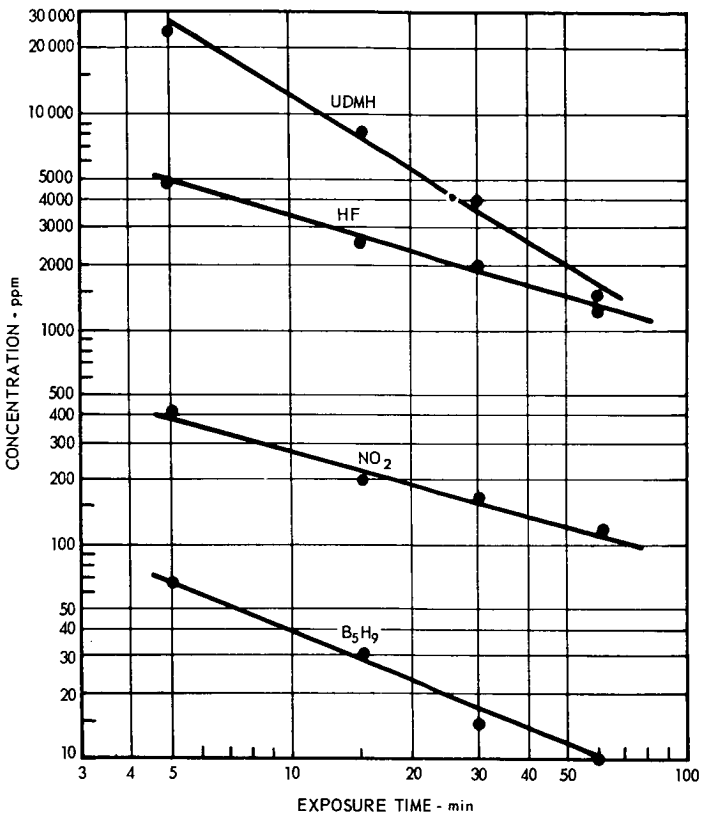
* Present TLV is 20 ppm.

c.



The data in the two tables and the graph were compiled from 90-day continuous exposure to the compounds at their TLV's (Threshold Limit Values). Note: the "contaminants" used to produce the curves in c are the same as those listed in the mixture in b. The work was performed to determine whether or not TLV's could be used as valid starting points for extrapolation to long term, continuous exposure. The data show conclusively that the majority of compounds tested are lethal under these conditions. Further, there are major differences in the susceptibility of various species, and there is wide variability in the rate at which animals are fatally affected.

ITEM NO.	SUBJECT AREAS:	SOURCE:
85	SYSTEM - S3 HUMAN - H34	Reference 554, p. 22. Based on Reference 518.



These data represent a compilation of comparative short-term inhalation toxicities of several fuels and oxidizers: unsymmetrical dimethyl hydrazine (UDMH); hydrofluoric acid (HF); nitrogen dioxide (NO_2); and pentaborane (B_5H_9). Note that the slopes of the curves are steep, which fact increases the validity of extrapolation to any point along the line for safe tolerance limits.

ITEM NO.	SUBJECT AREAS:	SOURCE:
86	SYSTEM - S3 HUMAN - H34	Reference 554, p. 20. Based on References 114, 113, 558, and 560.

Tolerance for Single Inhalations of Propellants

Propellant	TLV (8 hr)	Emergency tolerance limits; no effect in humans				No death in rats		No pathology in dogs	
	ppm	5 min	15 min	30 min	60 min	5 min	60 min	5 min	60 min
		ppm				ppm		ppm	
Unsymmetrical dimethyl hydrazine (UDMH)	0.5	50	35	20	10	19,800	813	600	50
Hydrazine	1.0	-	-	-	-	-	-	-	-
Pentaborane	0.005	-	-	-	-	62	7.5	-	-
Nitrogen tetroxide (N_2O_4)	5.0	35	25	20	10	190	72	104	28
Hydrofluoric acid (HF)	3.0	-	-	-	-	3,000	900	-	157

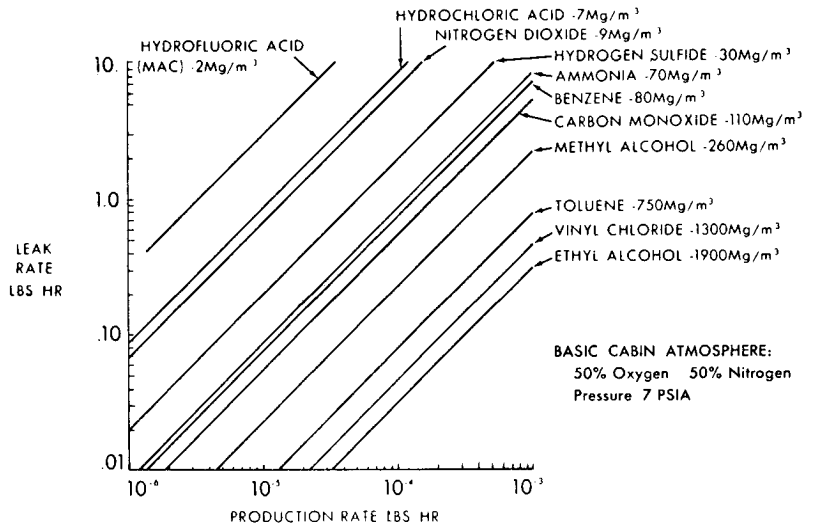
ITEM NO.	SUBJECT AREAS:	SOURCE:
87	SYSTEM - S3 HUMAN - H34	Reference 554, p. 21. Based on References 114, 113, 558, 560, 563, and 562.

Acute 24-hour Toxicity of Propellants

Compound	Intraperitoneal LD 50* in mg/kg (95% confidence limits)	
	Mouse	Rat
1, 1-Dimethylhydrazine	125 (117-134)	104 (95-114)
1-Methylhydrazine	30 (25-36)	32 ± 3.8 S.D.
1, 2-Dimethylhydrazine	47 (42-53) 940 (800-1110)	-
Hydrazine	76 (70-80)	68 (62-75)
Decaborane	33	18 (13-24)
Pentaborane		3.7 (2.8-4.6)

* LD 50 is the dose or quantity of a substance which causes death in 50% of animals treated.

ITEM NO.	SUBJECT AREAS:	SOURCE:
88	SYSTEM - S3 HUMAN - H34	Reference 554, p. 21. Based on References 50, 51, 174, 312, 531, and 561.



Control of trace contaminants at their maximum allowable concentration (MAC) by cabin leakage

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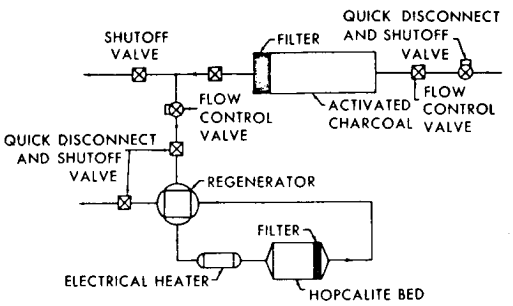
ITEM NO.	SUBJECT AREAS:	SOURCE:
89	SYSTEM - S3 HUMAN - H47	Reference 483, p. 154.

Adsorption of Materials by Carbon
(Percent Adsorbed by Weight)

30% or More	15%	8% or Less
Acetic Acid	Acetone	Low-Weight Amines
Butyric Acid	Acrolein	Ammonia
Dichloroethane	Bacteria	Formaldehyde
Essential Oils	Butyraldehyde	Hydrogen Chloride
Indole	Carbon Disulfide	Hydrogen Fluoride
Lubricating Oils	Chlorine	Sulfur Dioxide
Mercaptans	Ethylamine	Nitric Oxide
Nitromethane	Ethylene Oxide	
Putriscin	Formic Acid	
Skatole	Freons	
Sulfuric Acid	Hydrogen Sulfide	
Toluene	Nitric Acid	
Benzene	Phosgene	
Methanol	Sulfur Trioxide	
Ethanol		

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
90	SYSTEM - S3 HUMAN - H47	Reference 483, p. 154.

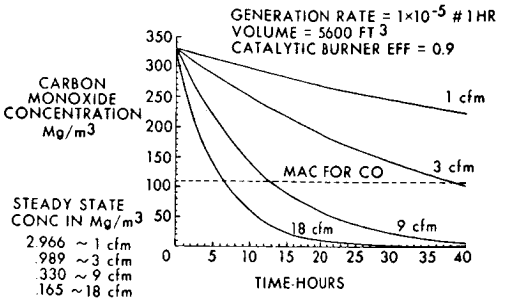


Trace contaminant removal subsystem.

The trace-contaminant control system considered most practical on the basis of present experience for spacecraft having a potential carbon-monoxide, methane, and/or hydrogen generation rate greater than can be handled by cabin leakage, consists of an activated charcoal canister and a hopcalite catalytic combustion bed with filters, valves, and piping. A sketch of the proposed system is presented.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
91	SYSTEM - S3 HUMAN - H47	Reference 483, p. 155.



Control of CO by catalytic combustion

The figure above shows the effect of the catalytic burner flow rate on the response of the system for the case where a mishap causes the level to rise suddenly to three times the MAC value. A system designed to handle a mishap of this severity should have a flow rate through the catalytic burner of at least 18 cfm.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
92	SYSTEM - S3 HUMAN - H47	Reference 483, p. 155.

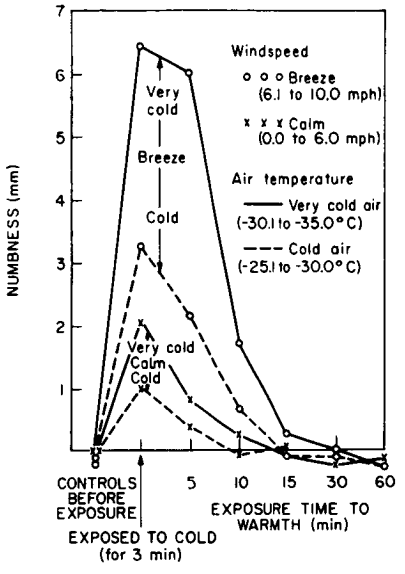
Purifying Materials for Canister Gas Masks

Contaminants	Filter Color	Filtering material
Acid gases and vapors	White	Soda lime (sodium hydroxide and calcium oxide)
Ammonia	Green	Silica gel
Ammonia and smoke	Brown	Copper sulfate, activated charcoal, and filter
Carbon monoxide	Gray	Hopcalite, calcium chloride, and caustic soda
Mixed gases, vapors, and fumes	Red	Charcoal, copper sulfate, calcium chloride, Hopcalite, and filter
Hydrocyanic acid	Blue	Caustic soda (sodium) hydroxide)
Mixture of organic vapor and acids	Yellow	Activated charcoal and soda lime
Mixture of organic vapor, acid, and smoke	Yellow (striped)	Activated charcoal, soda lime, and filter
Organic vapors and fumes	Black	Activated charcoal

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ITEM NO.	SUBJECT AREAS:	SOURCE:
93	SYSTEM - S3 HUMAN - H47, H44	Reference 380, p. 444.

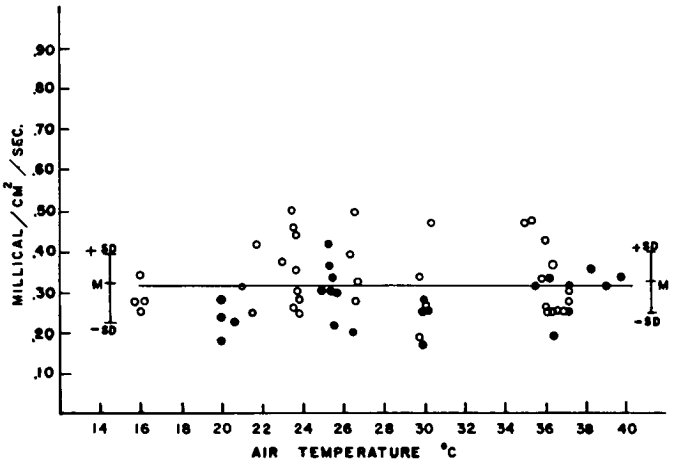
NUMBNESS WITH EXPOSURE TO COLD



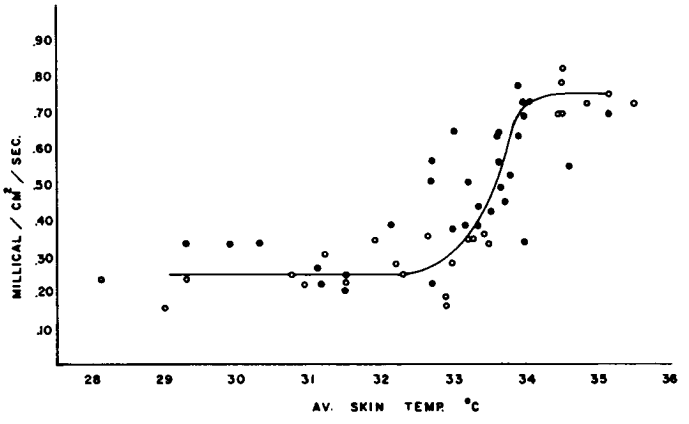
The Numbness Index is for 3-minute exposures of the skin to varying air temperatures and velocities. This graph shows the tremendous loss in sensitivity accompanying exposure and the slow recovery following it.

ITEM NO.	SUBJECT AREAS:	SOURCE:
94	SYSTEM - S4 HUMAN - H17	Reference 380, p. 436. Based on Reference 341.

a



b



(a) Warmth threshold as a function of environmental temperature

(b) Cold threshold as a function of average skin temperature

Experimental data were obtained for both warmth and cold thresholds over a range of room temperatures. It was shown that man is three times more sensitive to cold when the skin is cold. Notice that the warmth and cold sensitivity curves cross at the so-called "comfort zone."

ITEM NO.	SUBJECT AREAS:	SOURCE:
95	SYSTEM - S4 HUMAN - H17	Reference 318, p. 12. Based on Reference 256.

PROPERTIES OF THE SKIN

Approximate values of the physical dimensions of whole skin for the "average man": 154 lb, 5'7"

Weight	8.8 lb	4 kg
Surface area	20 sq ft	1.8 m^2
Volume	3.7 qt	3.6 liters
Water content	70 - 75%	
Specific gravity	1.1	
Thickness	0.02 - 0.2 in.	0.5 - 5.0 mm

Approximate values for thermal properties of skin:

Heat production	240 kcal/day
Conductance	9 to 30 kcal/m^2hr °C
Thermal conductivity (k)	$(1.5 \pm 0.3) \times 10^{-3}$ cal/cm sec °C, at 23 - 25° C ambient
Diffusivity ($k/\rho c$)	7×10^{-4} cm^2/sec (surface layer 0.26 mm thick)
Thermal inertia ($k\rho c$)	90 to 400 $\times 10^{-5}$ cal^2/cm^4 sec $(°C)^2$
Heat capacity	~0.8 cal/gm

Skin temperature and thermal sensation:

Pain threshold for any area of skin	113° F (45° C)

When mean weighted skin temperature is:

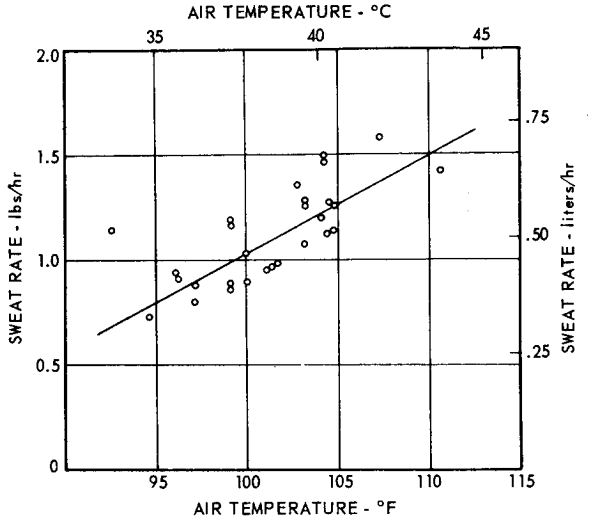
	The typical sensation is:
above 95° F (35° C)	unpleasantly warm
93° F (34° C)	comfortably warm
below 88° F (31° C)	uncomfortably cold
86° F (30° C)	shivering cold
84° F (29° C)	extremely cold

When the hands reach:	When the feet reach:	They feel:
68° F (20° C)	73.5° F (23° C)	uncomfortably cold
59° F (15° C)	64.5° F (18° C)	extremely cold
50° F (10° C)	55.5° F (13° C)	painful and numb

Approximate optical properties of skin:

Emissivity (infrared)	~0.99
Reflectance (wave-length dependent)	Maximum 0.6 to 1.1μ
	Minima <0.3 and >1.2μ
Transmittance (wave-length dependent)	Maxima 1.2, 1.7, 2.2, 6, 11μ
	Minima 0.5, 1.4, 1.9, 3, 7, 12μ
Solar reflectivity of surface	
Very white skin	42%
5 "white" subjects	28 - 40%, average 34%
6 "colored" subjects	19 - 24%, average 21%
Very black skin	10%
Solar penetration--very white skin	45.5% passes 0.1 mm depth
	39.6% passes 0.2 mm depth
	32.0% passes 0.4 mm depth
	19.0% passes 1.0 mm depth
	10.2% passes 2.0 mm depth
Solar penetration--very dark skin	75% passes 0.1 mm depth
	40% absorbed in the melanin layer
	35% passes 0.2 mm depth

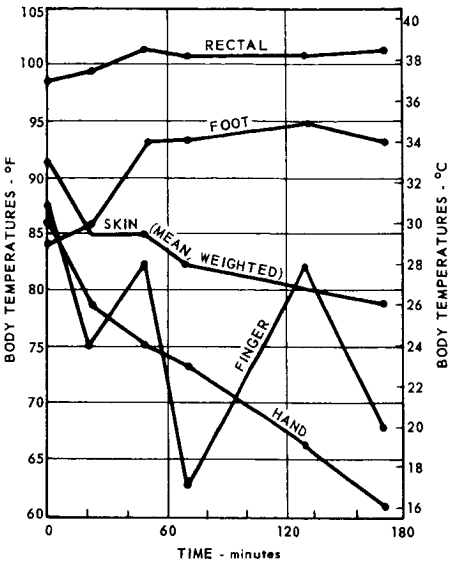
ITEM NO.	SUBJECT AREAS:	SOURCE:
96	SYSTEM - S4 HUMAN - H17	Reference 554, p. 122. Based on References 102, 537, and 497.



206.

Air temperature influences sweating in men sitting still (in the desert sun).

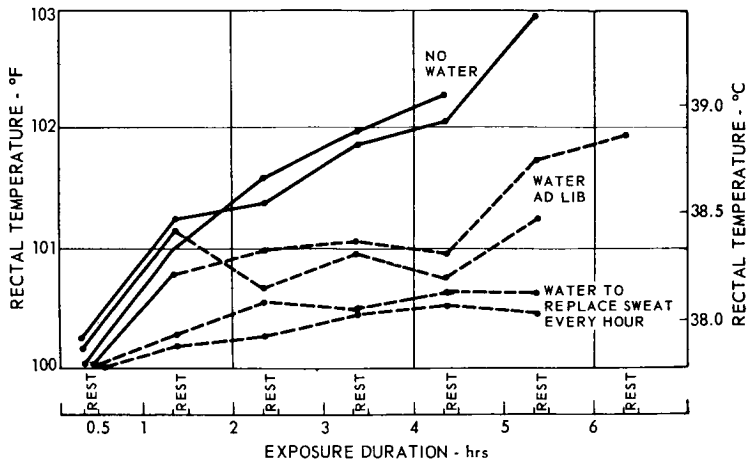
ITEM NO.	SUBJECT AREAS:	SOURCE:
97	SYSTEM - S4 HUMAN - H18	Reference 554, p. 206. Based on Reference 7.



This figure is a record of body temperatures while marching at $-38^{\circ}F$ ($-39^{\circ}C$) for one subject who was dressed in long underwear, wool shirt and sweater, army field jacket and trousers with liner, arctic felt boots, two pairs of socks, mittens and wool gloves. He walked six miles on hard-packed snow, with his metabolic rate averaging 220 kcal/m^2hr. The wind velocity was 8 mph, so that the windchill index was 1850 ("travel dangerous, flesh freezes 1 min").

These data illustrate the fact that rectal temperature can be maintained at its customary level during work in severe cold, provided sufficient clothing is worn. In such situations the constant dangers are of freezing of under-protected areas and sweating of over-protected parts of the body. As soon as the activity is reduced or stopped, excessive heat loss occurs from the area wetted by sweat during work, and a precipitous drop in body temperature may result.

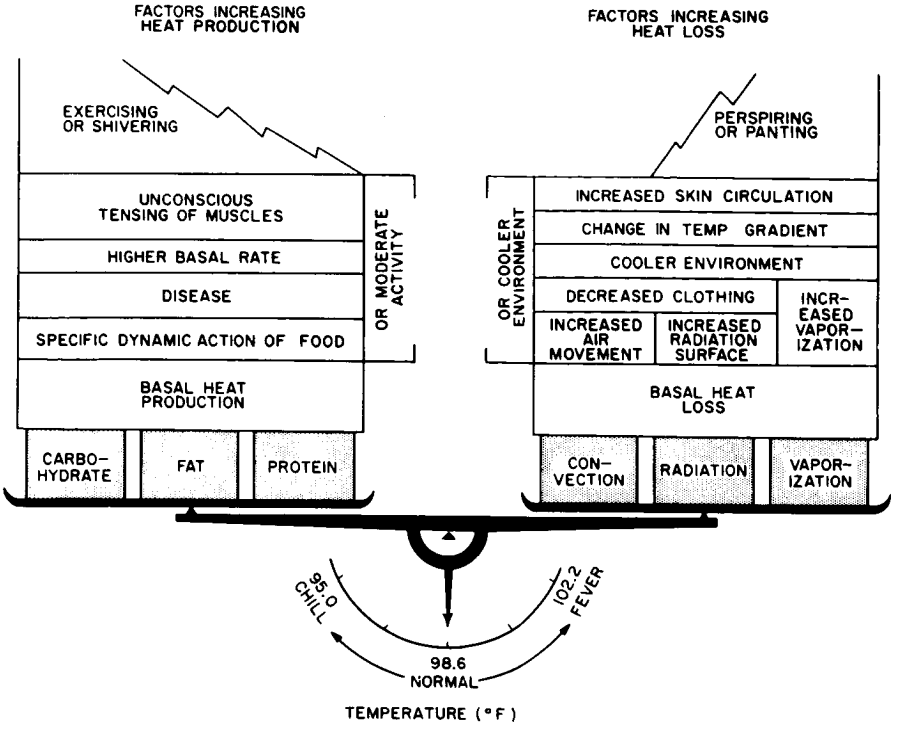
ITEM NO.	SUBJECT AREAS:	SOURCE:
98	SYSTEM - S4 HUMAN - H18	Reference 554, p. 127. Based on Reference 374.



Data are plotted here from six experiments on one subject, "fully acclimatized," of "better than average stamina," marching at 3.5 mph up a 2.5% grade, at 100°F and 20 mm Hg, with a 10-minute rest every hour. The more water drunk, the lower was the rectal temperature. Experiments with nude subjects resting at 110°F and vapor pressure of 25 mm Hg showed that they were able to maintain equilibrium only if they replaced water continuously. It may be concluded that failure to replace completely the water lost in sweat, hour by hour, leads to elevation of body temperature and excessive physiological strain. Thirst or the desire to drink is unreliable as an indication of the requirement for water intake to make up for heavy sweating.

Other work by the same authors has shown that replacement of salt at regular meal times is adequate, in contrast to the situation illustrated here for water.

ITEM NO.	SUBJECT AREAS:	SOURCE:
99	SYSTEM- S4 HUMAN- H18	Reference 554, p. 114. Based on Reference 415.



The internal temperature of the body is a summation of the external heat exchanges and internal heat production. A dual mechanism, triggered by the temperature sensors of the skin and controlled in the brain by the hypothalamus, regulates body temperatures. This dual mechanism is the regulation of internal heat-producing metabolic activities and the regulation of external heat loss through automatic variation in the rate of blood flow to the skin and operation of the sweat glands. The major elements in the process are shown in the figure above.

The summation of heat exchanges shown in the figure can be expressed in terms of a basic heat-balance equation as follows:

$$M + S = H_r + H_d + H_c + H_v,$$

where: M = energy metabolism or body heat production,

S = body-heat storage,

H_r = radiative heat exchange,

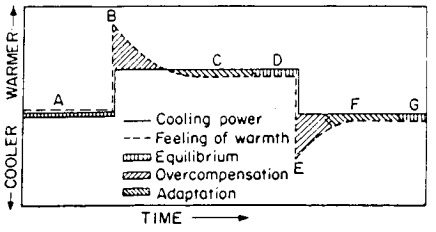
H_d = conductive heat exchange,

H_c = convective heat exchange, and

H_v = evaporative heat exchange.

Terms on the right are positive when heat flow is toward the environment and negative when it is away from the environment. The equation shows that thermal balance is obtained when the total heat production and storage of the body is equal to the total exchange of heat of the body with the environment.

ITEM NO.	SUBJECT AREAS:	SOURCE:
100	SYSTEM - S4 HUMAN - H18	Reference 380, p. 428. Based on Reference 177.



The self-regulating characteristics of the body's thermal control are similar to the general characteristics of any feedback control system. Changed inputs do not result in immediate, errorless, corrective actions. Instead, the thermal output of the body resembles an initially underdamped oscillation or "hunting reaction" followed by a second critically damped response. This is illustrated in the figure above, in terms of the feeling of warmth and cold of a person exposed to a changed environment following adaptation to a previous one.

Initially, in the figure, the person's body is in heat balance (A), and his thermal experience is slightly warmer than would be indicated by the ambient conditions. He then is exposed to a warmer environment, and there is an initial overreaction (B) during which he feels excessively warm. This feeling dissipates rapidly as the body cools in the direction of balance with the new conditions. This period is followed by one of adjustment (C) that ends in equilibrium (D), as a result of which he feels slightly cooler than the ambient temperature would indicate. If the air temperature is lowered, he overcompensates again (E) and feels excessively cool, and then, gradually, he comes into balance with the new condition (F and G).

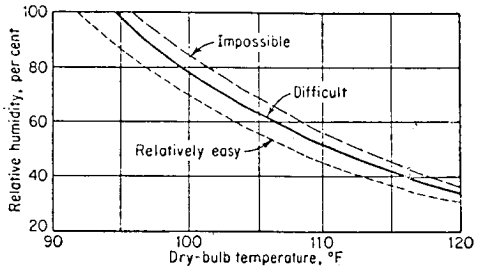
ITEM NO.	SUBJECT AREAS:	SOURCE:
101	SYSTEM - S4 HUMAN - H18	Reference 380, p. 430. Based on Reference 281.

a

NECESSARY AIR TEMPERATURE

	BTU EXPENDED PER HOUR	AIR TEMPERATURE NECESSARY (°F) (ASSUMING APPROPRIATE CLOTHING) FOR THERMAL BALANCE AT AIR MOVEMENT RATES OF		
		20 FPM (indoors)	100 FPM	20 MPH (outdoors)
At rest	400	70	75	78
Moderate activity	1000	58	60	63
Vigorous activity	4000	28	30	35

b

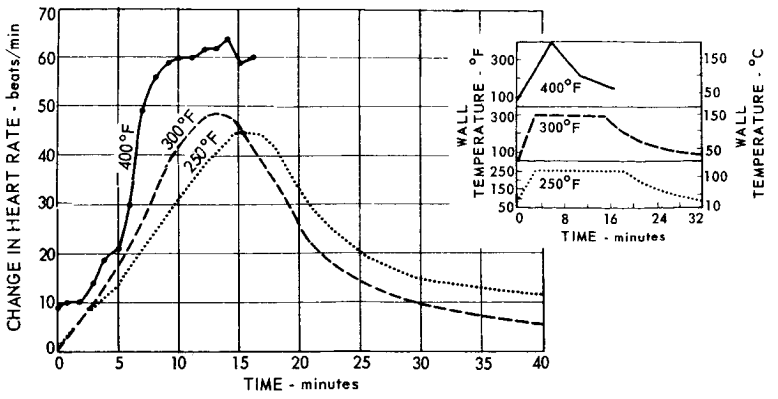


Relative difficulty of performing a marching task under various temperature and humidity conditions.

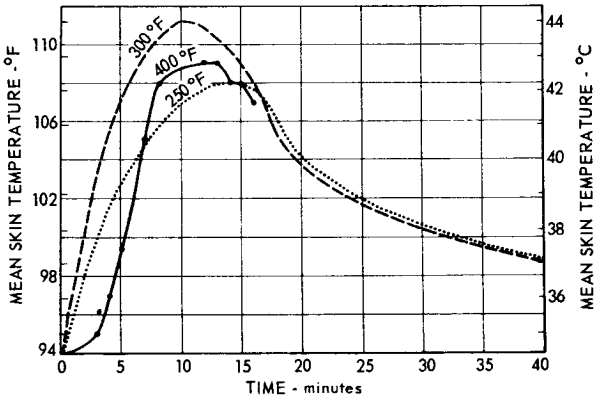
The effects of high levels of heat and humidity on physical activity were investigated with 16 Army enlisted men who performed a marching task in a controlled room on each of several days, marching at 3 mph for 4 hr with a 20-lb pack. Observation of these men made it possible to characterize their performance as (1) relatively easy, (2) difficult, and (3) impossible. The results, emphasize the importance of humidity in combination with temperature as a limiting factor relating to performance on such a task. For any given temperature, such as 100°F, the difference in ability to do the job versus not being able to do it is a matter of a small percentage of change in relative humidity.

ITEM NO.	SUBJECT AREAS:	SOURCE:
102	SYSTEM - S4 HUMAN - H22	a. Reference 586, p. 2-226. Based on Reference 583. b. Reference 362, p. 518. Based on Reference 182.

a.



b.



Charts a and b show the pulse responses and average skin temperatures of subjects exposed to three different severe heat exposure transients which come close to both the pain limit and the heat storage limit. Each curve represents the average data from five or six subjects. Clothing consisted of a standard flying coverall worn over long underwear with an insulation value of 1 clo.

ITEM NO.	SUBJECT AREAS:	SOURCE:
103	SYSTEM - S4 HUMAN - H9, H18	Reference 554, p. 119. Based on References 294, 303, and 552.

THERMAL RESPONSE OF HYPOPHYSECTOMIZED RATS

Animals	Metabolic rate		
	at thermal neutrality (BMR)	at 24.5°C	/ $MR^{24.5°}$ /
		total	compensatory
Control	100	128.3	28.3
Hypophysect-	46.1	79.0	32.7
omized	(-53.9 %)	(-38.4 %)	(+15.5 %)

NOTE: Rats were hypophysectomized at least 3 months previously. Control animals were of similar size (70 - 100g), but consequently younger. Average values from four measurements, expressed on the basis of BMR in the controls which is taken as 100 (actually 1637 $cm^3O_2/kg/h$).

The hypophysectomized animals, contrary to thyroid-fed ones, show at thermal neutrality a greatly reduced oxygen uptake in comparison to normal animals of the same size. While the rate of metabolism in the thyroid-fed animal is more than twice as high as that of its control, the metabolic rate of the hypophysectomized rat (3 months after hypophysectomy) represents only half of that recorded in the intact control of the same size. While in the cold the difference in metabolic rates between thyroid-fed and control animals may almost disappear, the difference between hypophysectomized animals and their controls is maintained in the cold: they both increase their metabolic rates on cold exposure, but the hypophysectomized animal starts from a level 50% lower and does not attain the metabolic level recorded in the cold-exposed control; in spite of the production of compensatory heat (and an almost normal metabolic quotient), total thermogenesis of the hypophysectomized rat remains low in the cold in comparison to the control animal exposed to the same thermal environment. As a matter of fact the hypophysectomized animals cannot tolerate severe cold, even in normal air: hypothermia is readily induced by ambient temperatures below 20°C in animals hypophysectomized several months previously.

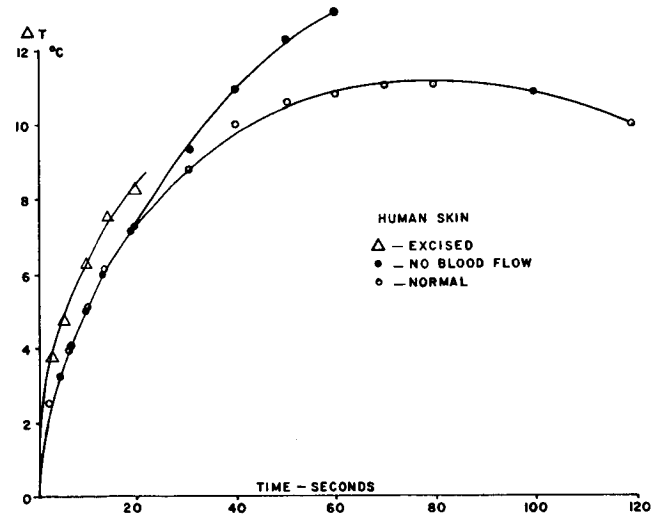
In spite of the great difference in overall metabolic rates, at an ambient temperature of 24.5°C, no such difference was found between the CTO (critical tension of oxygen) values of hypophysectomized and control animals. The difference, however, in total thermogenesis was not accompanied by a similar difference at the level of compensatory heat production, as shown in the table above.

In this case, therefore, the markedly lower rate of overall metabolism due to hypophysectomy did not result in a greater resistance to hypoxia (lower CTO), but it was not linked either to a reduced rate of compensatory thermogenesis.

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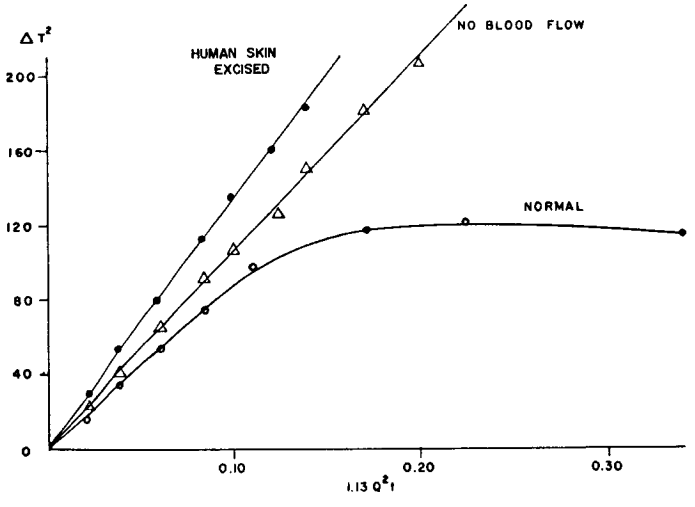
ITEM NO.	SUBJECT AREAS:	SOURCE:
104	SYSTEM - S4 HUMAN - H12, H20	Reference 18, p. 113.

a



Change in skin temperature with time during irradiation.

b



Thermal inertia parameter computed from figure a.

The role of the skin in the detection of changes in the environment, as well as of the more extreme stresses of pain and thermal burns, depends to a great extent on its physical characteristics. When the skin is irradiated, the skin temperature rises, and the temperature-time curve produced depends upon the product of the thermal conductivity (k), the density (p), and the thermal capacity (c) of the skin. The "inertia for surface heating," or the kpc value, is not constant for living skin but depends upon the thickness of the avascular stratum corneum, the amount of blood flow in the underlying tissue, and possibly on the state of tissue hydration.

In Figure a the skin temperature-time curves for excised, bloodless, and normal skin are compared. Irradiance was 0.055 cal/sec/cm^2. In the presence of normal blood flow the curve reaches a maximum at about 80 sec and begins to fall despite continued irradiation. The value of kpc is:

$$kpc = \frac{4a^2Q^2t}{\pi(\Delta T)^2}$$

where ΔT = rise in skin temperature, °C

a = absorptivity of India-inked skin (0.94)

Q = radiation intensity, cal/cm^2 — /sec

t = time in seconds

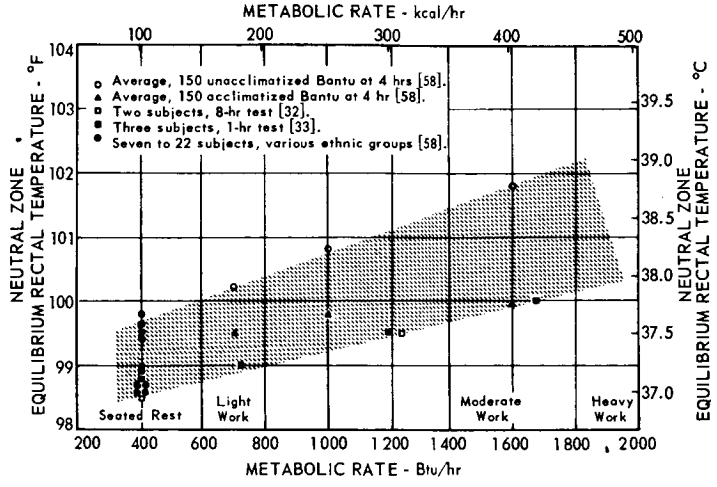
k = specific thermal conductivity, g-cal/cm/sec/°C

p = density, g/cm^3

c = thermal capacity, g cal/g/°C

$\frac{4a^2}{\pi}$ = 1.13

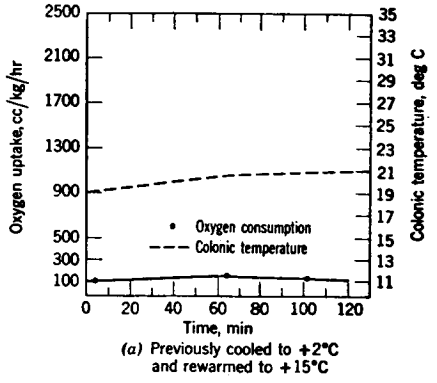
ITEM NO.	SUBJECT AREAS:	SOURCE:
105	SYSTEM - S4 HUMAN - H17, H18	Reference 318, pp. 13-15. Based on References 256 and 329.



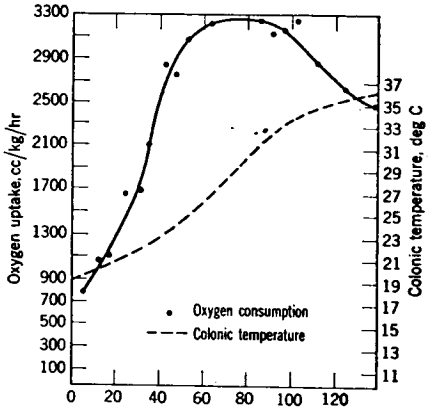
For each level of work, there appears to be a characteristic internal or core temperature at equilibrium which is unaffected by the environment so long as the neutral boundary condition is not exceeded. As shown here, the characteristic internal (i. e., rectal) temperature for a particular work load varies between groups; both physical training and training for work in the heat (acclimatization) produce lower values. Superficial differences between ethnic groups appear to be due to habit patterns and experience relative to working under hot conditions.

Note that persons completely untrained for a particular activity or exercise would probably show rectal temperatures considerably higher than those indicated in this chart for African natives recruited for mine labor.

ITEM NO.	SUBJECT AREAS:	SOURCE:
106	SYSTEM - S4 HUMAN - H16, H20, H22	Reference 554, p. 110. Based on References 253, 326, 327, 502, and 589.



(a) Previously cooled to +2°C and rewarmed to +15°C



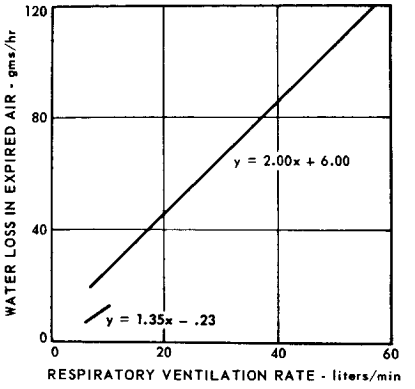
(b) Previously cooled to colonic temperature of +15°

The oxygen consumption and colonic temperature of two rats left at room temperature.

Research is now in progress, especially in England on deep-freezing the whole organism intact, but with only moderate success, since survival is dependent on the duration of the induced hypothermia. The figure above graphically demonstrates the decreased oxygen consumption in a rat previously cooled to +2°C, and compares it to that of a rat cooled to only +15°C.

ITEM NO.	SUBJECT AREAS:	SOURCE:
107	SYSTEM - S4 HUMAN - H16, H18, H20	Reference 416, p. 119. Based on Reference 17.

INSENSIBLE WATER LOSS



Activity	Respiratory Water Loss (grams/hour)
Resting outdoors in -29°C air	20
Walking (4 mph) over packed snow	73
Pulling loaded sled (2.27 mph), packed snow	100
Walking--snow above ankles (0.35 mph)	141
Running (6.5 mph) over packed snow	157
Walking--snow up to knees (0.28 mph)	208

The upper curve is for measurements of respiratory water loss in dry air for active men outdoors in temperatures from about 0° to -30°F, where measurements were taken during the activities listed in the table. The curve fits the equation $y = 2.00x + 6.00$. The lower curve is for measurements made in New Orleans at air temperatures of 20-21°C, at vapor pressures around 34 mm Hg. The curve fits the equation $y = 1.35x - .23$.

ITEM NO.	SUBJECT AREAS:	SOURCE:
108	SYSTEM - S4 HUMAN - H16, H22	Reference 554, p. 207. Based on References 92 and 105.

Human Heat Production

Metabolic heat production excluding latent heat of water vapor	300–500 Btu/man/hr
Skin temperature fluctuates, but this figure is normal for comfort	92°F
Body core temperature, oral constant	98.6°F
Water vapor elimination source of latent heat	0.6–0.13 lb/man/hr

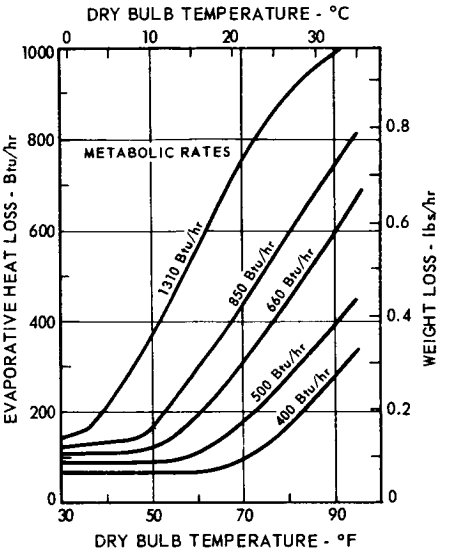
During intense activity the water elimination rate may increase by between 0.4 and 1.2 lb per man-hour.

ITEM NO.	SUBJECT AREAS:	SOURCE:
109	SYSTEM - S4 HUMAN - H18, H20, H22	Reference 416, p. 95. Based on Reference 297.

GENERATION OF SWEAT

Subject and Condition	Volume		Source
	Mean ml/hour	Range ml/hour	
Normal size adult	-	33-50	Sunderman & Boerner
70 kg man	20.8	-	Diem
Strenuous exercise for short (30 min) periods	3900	-	Clemedson
Several hours of strenuous exercise	-	500-2500	Clemedson
Maximum rate during exercise	1000		Best & Taylor
Hard-working laborers	700	-	McCord & Withiridge
Influence of heat and exercise	783	-	Dill
In tropics and deserts	-	208-500	Dill
Laboratory workers on hot summer days	-	125-137.2	Kuno

ITEM NO.	SUBJECT AREAS:	SOURCE:
110	SYSTEM- S4 HUMAN- H18, H22	Reference 554, p. 224. Based on References 137, 503, 70, 170, 360, 168, and 314.



The figure above shows sweating and evaporative heat loss varying with air temperature and activity level.

ITEM NO.	SUBJECT AREAS:	SOURCE:
111	SYSTEM - S4 HUMAN - H18, H20, H22	Reference 554, p. 206. Based on Reference 520.

ESTIMATED AVERAGE ENERGY EXPENDITURE OF A CREW MEMBER OF A TYPICAL SPACE VEHICLE

	K-CAL/HR	K-CAL/DAY	BTU/DAY
8 hours of sleep	65	520	2080
8 hours of light work	150	1200	4800
5 hours of rest, sitting	100	500	2000
1 hour of rest, lying down	80	80	320
1 hour of light exercise	200	200	800
1 hour of heavy exercise	500	500	2000
Total, 24 hours	2095	3000	12000

ITEM NO.	SUBJECT AREAS:	SOURCE:
112	SYSTEM - S4 HUMAN - H20, H22	Reference 586, pp. 6-17. Based on Reference 95.

The Critical Effective Temperatures at Which Impairment May Be Demonstrated, According to Various Sources

Name and type of test	Investigator	Temperature (°F)	
		Max. at which performance remains normal	Demonstrable impairment
Typewriter code (scrambled letters)	Viteles	80	87
Morse code reception	Mackworth	87.5	92[a]
Locations (spatial relations code)	Viteles	80	87
Block coding (problem solving)	Mackworth	83	87.5[a]
Mental multiplication (problems)	Viteles	80	87
Number checking (error detection)	Viteles	80	87[a]
Visual attention (clock test)	Mackworth	79	87.5[a]
Pursuit (visual maze)	Viteles	80	87
Reaction time (simple response)	Forlano	93[b,c]	—
Discrimeter (complex response)	Viteles	80	87
Lathe (hand coordination)	Viteles	80	87[a]
Pursuitmeter	Mackworth	87.5	92[a]
Motor coordination	Weiner	64.5[c]	91[a]
Ergograph (weight pulling)	Mackworth	81[d]	85.3[a,d]
Bicycle ergometer (heavy work)	Liberson	64.5[c]	91.5[c]
Weight lifting (heavy work)	N.Y. Ventil. Comm.	64.5[c]	70[c]

[a] Deterioration statistically significant.

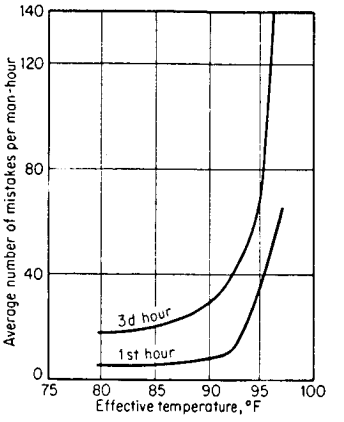
[b] Provided wet bulb does not exceed 86°F.

[c] Effective temperature estimated from data in report.

[d] Midpoint of a range of conditions.

Robert M. Gagne, (editor), Psychological Principles in System Development, (c) 1962. Reprinted by permission of Holt, Rinehart and Winston, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
113	SYSTEM- S4 HUMAN- H24	Reference 587, p. 150. Based on Reference 178.

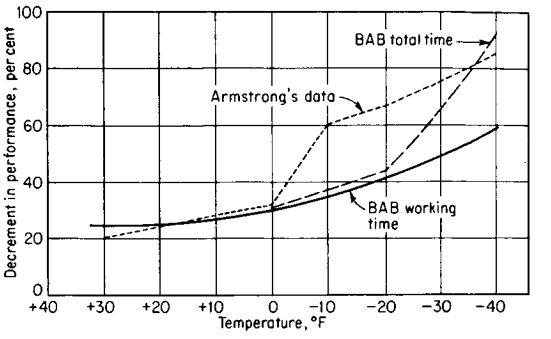


Average number of mistakes in Morse code receiving in relation to effective temperature.

The evidence regarding the effects of high temperatures on mental activities is less consistent and clear-cut than the activities of a more strictly physical nature. On the one hand, Mackworth reports serious performance decrements both on a coding test and in a wireless telegraphy task with increasing effective temperatures. In the telegraphy task, the subjects wrote down Morse code messages received over headphones in different atmospheric temperatures; these results are shown in the figure. The combination of high effective temperatures and of duration of work is particularly serious, as shown by the curve for the third hour of work on the task.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
114	SYSTEM - S4 HUMAN - H27	Reference 362, p. 520. Based on Reference 340.



Percentage of decrement in performance on two tasks under different temperature conditions. BAB (brush assembly breakdown) data are for working time and total time (including working and warming-up time). Armstrong's data relate to operational efficiency of flying personnel in open cockpit.

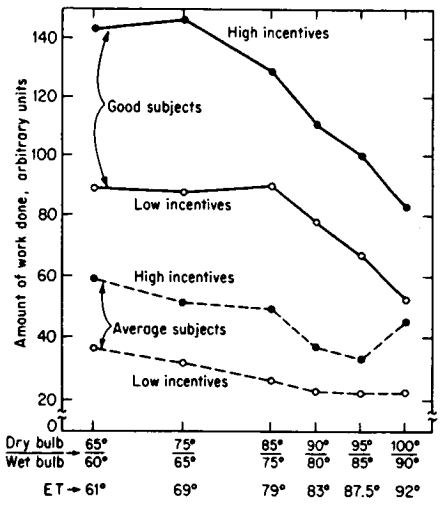
The effect of cold on performance of manual tasks is of particular concern. In this connection McCleary carried out an experiment under various conditions of cold in which the subjects disassembled and assembled an electric-brush assembly, using hand tools. The test, the Brush Assembly Breakdown (BAB), was somewhat similar to a line-maintenance job. The work was done while wearing wool-knit glove inserts, but the subjects could put on their large wool-lined leather gauntlets to warm their hands whenever they so desired.

The figure also shows the results of an earlier study by Armstrong in which he determined the loss in efficiency of flying personnel under operational conditions involving flight in an open cockpit. Because of the similarity between the two sets of data (discounting a discrepancy which can be explained), McCleary implies that there may be an effect of cold on efficiency of performance that is sufficiently basic to behavior in general that it manifests itself despite superficial differences in experimental conditions.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
115	SYSTEM- S4 HUMAN- H28	Reference 362, p. 522. Based on References 47 and 358.

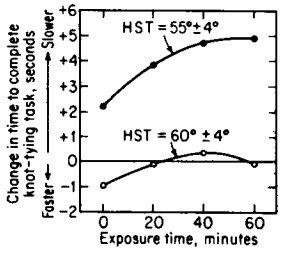
a



Relationship between effective temperature (ET) and performance on a weight-lifting test for "good" and "average" subjects under high and low incentives.

A number of studies of performance under high temperatures were carried out by Mackworth. Some of these involved physical activities, especially a "pull test" that required raising and lowering a 15-lb weight by bending and straightening the arm to a metronome that beat every second. The men continued this until they could not lift the weight again. The total distance the weight was raised was measured.

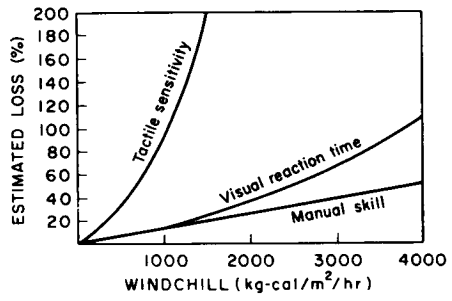
b



Changes in manual performance on knot-tying test as function of hand-skin temperature (HST) and duration of cold exposure. The differences for the 60°F hand-skin temperature are not significant. Those for the 55°F temperature are.

Whether the total body is cooled, or only the hands, apparently does not make any difference; manual performance presumably is rather specifically associated with hand-skin temperature.

ITEM NO.	SUBJECT AREAS:	SOURCE:
116	SYSTEM- S4 HUMAN- H28	Reference 362, p. 519 (fig. a) and 456 (fig. b). Based on References 342 (fig. a) and 133, 211 (fig. b).



The figure above shows tactile sensitivity, simple visual reaction time, and manual skill as they are affected by cold exposure for unadapted, unhabituated, but appropriately dressed men.

ITEM NO.	SUBJECT AREAS:	SOURCE:
117	SYSTEM- S4 HUMAN- H25, H28	Reference 380, p. 436. Based on Reference 516.

Temperature and Ventilation = Comfort Zone

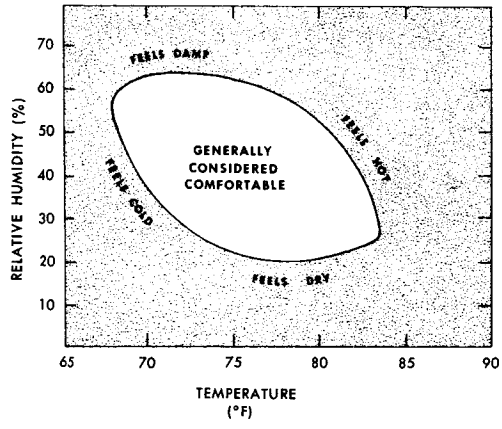
a

RELATION BETWEEN COMFORT AND MEAN SKIN TEMPERATURES (degrees F)

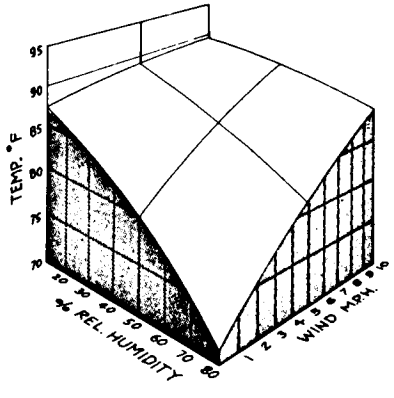
Very hot	98
Unpleasantly warm	96
Indifferently warm	94
Comfortable	93
Comfortably cool	91
Indifferently cool	88
Unpleasantly cool	86
Extremely cold	84

RELATION BETWEEN COMFORT AND TEMPERATURE OF THE EXTREMITIES (degrees F)

	Hands	Feet
Minimum	68	73
Tolerable	68–59	73–64
Intolerable pain	59–50	64–55
Numbness	50–	55–



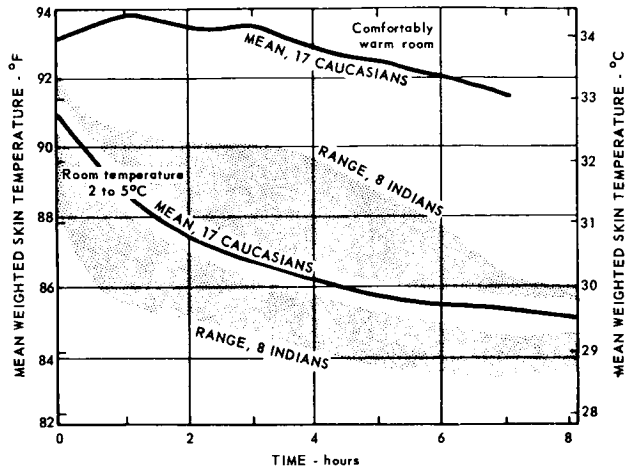
b



TEMPERATURE-HUMIDITY AND AIR FLOW

The curved surface on the chart at the left represents the "comfort" line. It illustrates how changes in any one of the parameters can maintain a comfort level. For example, with no air movement, comfort exists with temperature at 72° and humidity at 90 per cent. Temperature can rise to 75°, with humidity still at 90 per cent, if the air is caused to move at 2 mph, because the subject still "feels comfortable."

ITEM NO.	SUBJECT AREAS:	SOURCE:
118	SYSTEM - S4 HUMAN - H33	Reference 586, p. 2-227 and 2-228.



In this figure, skin temperatures are shown during sleep in a warm room and a cold one for two groups of subjects—17 Caucasians and 8 Peruvian Indians. The difference in relative comfort, for people habituated to civilization, between sleeping in a warm room and in one near freezing, is revealed by the time history of skin temperature. The sample of Indians whose data are shown for comparison is representative of some more primitive peoples whose special characteristics in this respect are that they accept the lower skin temperature (though they are not comfortable) as a normal condition, and are less likely to have their sleep disturbed by shivering, restlessness, etc.

While evidence in this and other studies is equivocal, it favors the hypothesis that the differences in tolerance for cold during sleep are due to life experience and conditioning, rather than to ethnic or genetic factors as such.

ITEM NO.	SUBJECT AREAS:	SOURCE:
119	SYSTEM - S4 HUMAN - H33	Reference 554, p. 127. Based on Reference 184.

a.

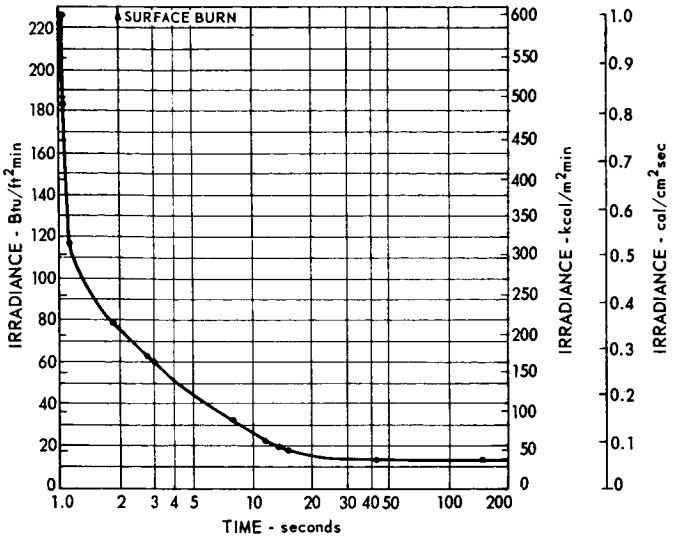
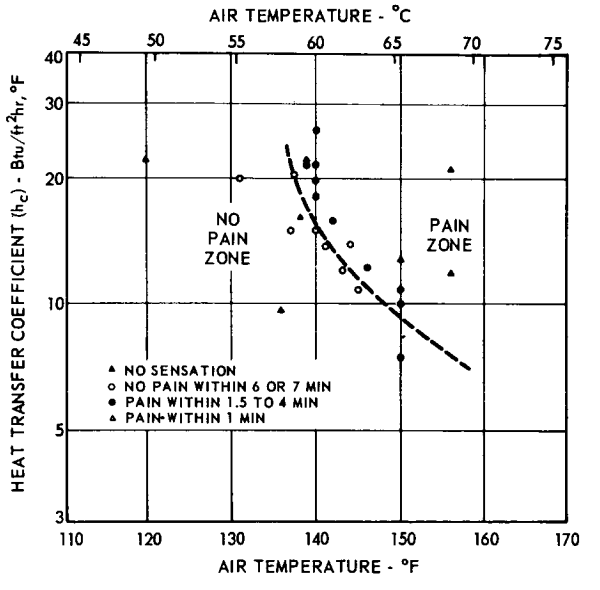


Figure a shows the time to reach strong skin pain from radiant heating, with radiation sources ranging from the simulated intense thermal flash of a nuclear weapon (approximately 100 Btu/ft^2 min) to the slow heat pulse associated with re-entry heating, where the heating is partly convective as well. The curve is derived from experiments involving heating of single small areas of forehead or forearm or exposed areas of skin of a subject in flight clothing, and of the whole body surface. The pain threshold is reached when the skin temperature comes to 45^{0}C, and a skin temperature of 46^{0}C is intolerably painful. For small skin areas the curve becomes asymptotic at about 18Btu/ft^2 min, which means that at this level and below, the blood supply to the skin is carrying off the heat as fast as it arrives, and heat is stored in the body; how long this can go on with the total body exposed is not established.

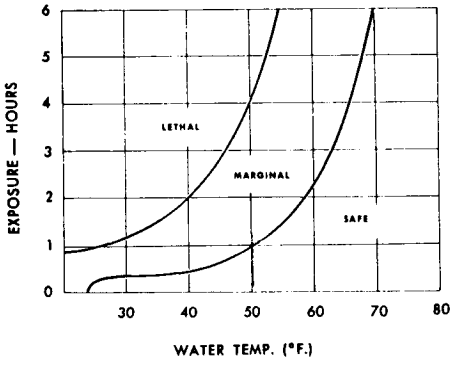
b.



These data indicate the dividing line between painful and non-painful heating for air at various temperatures, versus the heat transfer coefficient, which depends on air density, air velocity, and surface areas and shape. The data were obtained by exposing a small segment of the cheek to a flowing air stream through a padded hole in the wall of a cylindrical tube. h_c was computed from air velocity and duct geometry.

Based on unpublished data, North American Aviation, 1959.

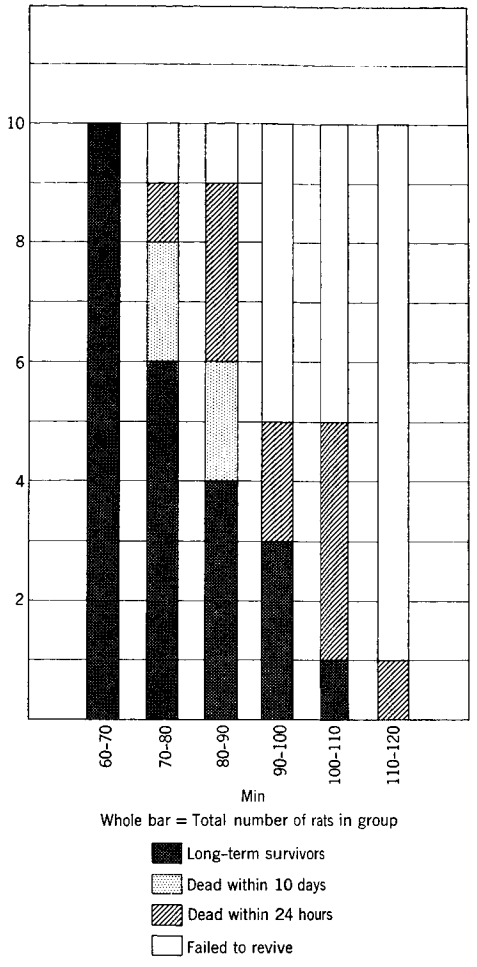
ITEM NO.	SUBJECT AREAS:	SOURCE:
120	SYSTEM - S4 HUMAN - H34	Reference 554, p. 120. Based on References 552, 102, 257, 295, and 496 (fig. a).



TOLERANCE OF COLD WATER EXPOSURE

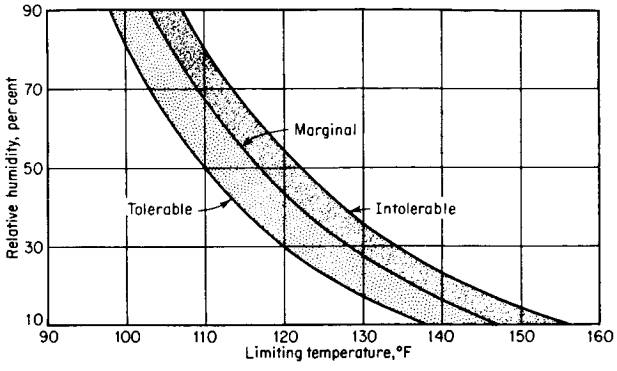
The chart at the left shows time of life-expectancy in cold water (no exposure suit). Under the category of "marginal," 50 per cent expectancy of unconsciousness would probably result in drowning.

ITEM NO.	SUBJECT AREAS:	SOURCE:
121	SYSTEM - S4 HUMAN - H34	Reference 586, p. 2-228.



Effect of the duration of suspended animation in rats maintained at 0° of body temperature on the rate of recovery.

ITEM NO.	SUBJECT AREAS:	SOURCE:
122	SYSTEM - S4 HUMAN - H34	Reference 416, p. 120. Based on Reference 17.



Judged tolerable and intolerable limits of high temperature and humidity conditions for a 60-minute exposure period. Subjects were clothed in thermocouple underwear, byrd-cloth flying overall, and socks.

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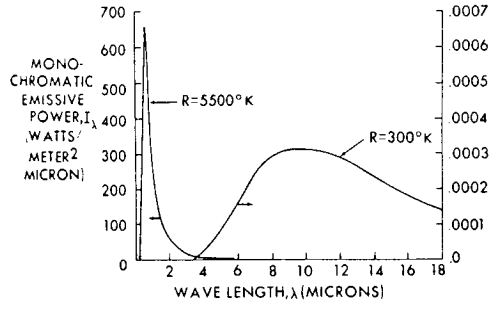
ITEM NO.	SUBJECT AREAS:	SOURCE:
123	SYSTEM- S4 HUMAN- H34	Reference 362, p. 525. Based on Reference 509.

MISCELLANEOUS DATA ON H_2O REMOVAL SYSTEMS

Insoluble Solid Desiccants	
Calcium oxide	Low capacity, over 10 lbs CaO/lb H_2O, due to formation of carbonates on surface.
Drierite	Calcium sulfate which forms a hemi-hydrate. Low capacity.
Barium oxide	High volume expansion when absorbing H_2O, non-regenerative, capacity of 10 lbs BaO/lb water.
Activated alumina	Low capacity for water below 30% RH.
Silica gel	Can be regenerated, but relatively poor capacity at low RH.
Linde molecular sieves	High capacity at low RH. Can be generated at 500°F. and 1 mm pressure.
Magnesium perchlorate (Anhydrone)	Best solid dessicant for high capacity at low RH, about 2-3 lbs/lb H_2O. Can be regenerated at 500°F. and 1 mm pressure. Explosive hazard if in contact with high concentration of organic vapors at high temperature.

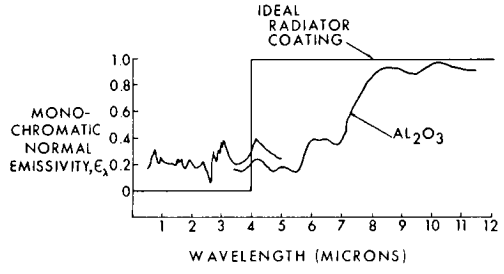
ITEM NO.	SUBJECT AREAS:	SOURCE:
124	SYSTEM- S4 HUMAN- H47	Reference 219, p. 424. Based on Reference 176.

a



Energy distribution of black body

b



Monochromatic normal emissivity versus wavelength

Surface coating properties play an important role in thermal control, since the amount of heat absorbed by or rejected from any surface is dependent on the surface properties. The two key parameters are solar absorptivity, a, and infrared emissivity, ϵ. It is well known that the surface absorptivity for a given wavelength equals the emissivity at the same wavelength, and surfaces exhibit absorptivity or emissivity which varies from 0 to 1 as a function of wavelength. Thus, the absorptivity at one wavelength may differ from the emissivity at another wavelength. Solar absorptivity, a_s, is defined as the mean value of absorptivity over the solar spectrum and, ϵ_i is defined as the mean value of emissivity over the infrared range. Surfaces with $a_s \neq \epsilon_i$ are quite common, and this fact can be used to advantage in thermal-control applications.

To minimize net inward heat leak, a surface coating can be chosen with a low value of a_s and a high value of ϵ_i. Such a coating will decrease the amount of solar radiation absorbed while increasing the quantity of heat radiated from the surface. From Figure a it can be seen that the solar and infrared spectra do not overlap very much, and they can be treated somewhat independently.

That is, a_s can be chosen to control the amount of solar radiation absorbed without affecting infrared radiation. A logical radiator coating would have the highest possible infrared emissivity for maximum heat radiated, and the lowest possible solar absorptivity to minimize the net heat absorbed. A typical radiator coating is shown in Figure b along with the ideal radiator coating properties.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
125	SYSTEM - S4 HUMAN - H47	Reference 483, p. 145.



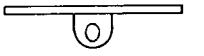
(A) TUBE-AND-FIN TYPE; SIMPLE RECTANGULAR FIN



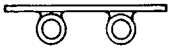
(B) TUBE-AND-FIN TYPE; OPTIMUM-WEIGHT TAPERED FIN



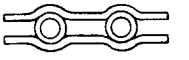
(D) TUBE-AND-FIN TYPE; FORMED SHEET FINS



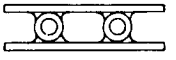
(G) TUBE-AND-FIN TYPE; SINGLE SHEET FINS WITH D-SHAPED ECCENTRIC TUBE USED WHERE METEOROID PROTECTION IS NOT NEEDED ON THE BACKSIDE, OF THE PANEL (E.G., CYLINDRICAL PANELS)



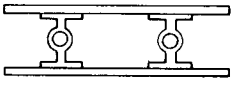
(C) TUBE-AND-FIN TYPE; SINGLE SHEET FINS



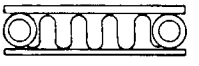
(F) TWO-SURFACE TUBE-AND-FIN TYPE, FORMED SHEET FINS



(E) TWO–SURFACE TUBE–AND–FIN TYPE; PLAIN SHEET FINS



(I) BUMPERED-AND-ARMORED TYPES USED WITH A TWO-SURFACE CONFIGURATION WHERE THE RADIATOR PANELS MUST SUPPORT THEMSELVES



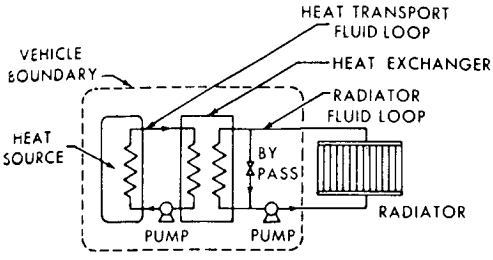
(H) TUBE-AND-FIN TYPE; SINGLE SHEET FINS WITH A HONEYCOMB STRUCTURE FOR ADDED SUPPORT

Radiator Configurations

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

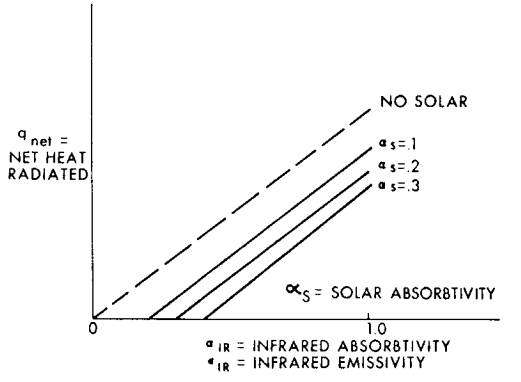
ITEM NO.	SUBJECT AREAS:	SOURCE:
126	SYSTEM - S4 HUMAN - H47	Reference 483, p. 146.

a



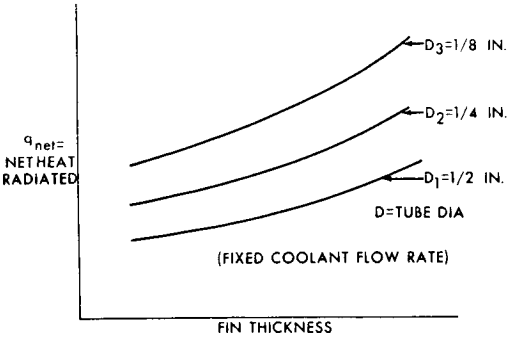
Space-vehicle heat-rejection system using a separate radiator heat-transport loop.

b



Radiator performance vs. surface coating thermal properties.

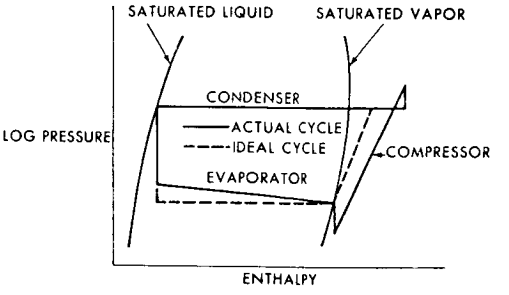
c



Radiator performance vs. radiator design parameters.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
127	SYSTEM - S4 HUMAN - H47	Reference 483, p. 147.



Vapor-compression cycle

VAPOR-COMPRESSION CYCLE

A radiator system cannot be employed to reject heat unless the coolant fluid temperature is higher than the environmental sink temperature. With minimum required radiator fluid temperatures established by ECS needs, such as water condensation, a space vehicle exposed to an environment with a high sink temperature cannot use a radiator system alone for thermal control. In such a situation, a more sophisticated heat-rejection system, such as the vapor-compression cycle, may be used.

In essence, the vapor-compression cycle is the same as that used in refrigeration and air-conditioning applications, (i.e., a low pressure vapor refrigerant is compressed to a higher pressure, condensed into a high-pressure liquid, expanded to a low-pressure liquid and evaporated into a low-pressure vapor). As can be seen by the above figure, the refrigerant collects heat in the evaporator (where the useful cooling effect is accomplished) and rejects heat in the condenser. At first glance, the most obvious heat rejection system would be one in which the condenser was replaced by a radiator. However, this system could cause serious complications due to the complexity of two-phase flow in the coolant tubes coupled with heat rejection to space. A more promising solution, which requires only a small power and weight penalty, is the addition of another coolant loop utilizing a different coolant, such as a glycol solution, for the radiator and condenser.

The vapor-compression cycle capitalizes on the fact that a radiator operating at high temperature levels is more efficient. For example, an ordinary liquid-transport system employing a radiator rejects a given amount of the vehicle heat load. However, if this system suddenly is exposed to extremely high external loads, the radiator may not deliver the desired outlet fluid temperature. The vapor-compression cycle, however, is not restricted in this manner. The addition of the compressor to the system allows the refrigerant to enter the radiator at higher temperatures. This system does not restrict the radiator to operation at temperatures dictated by environmental control needs within the vehicle living quarters.

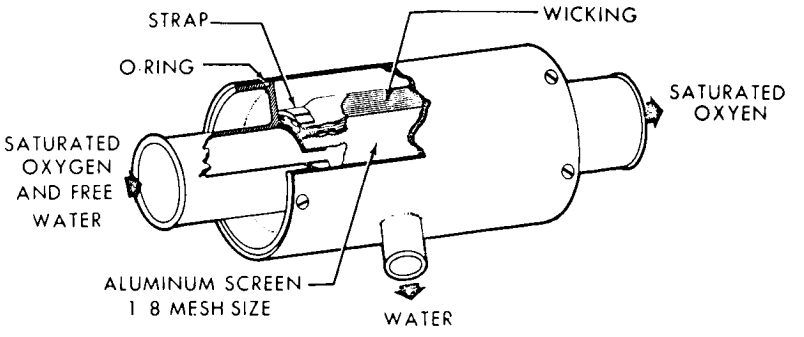
The primary disadvantages of the vapor-compression system are high power consumption, increased complexity, and system weight. Studies for space missions so far planned show that the vapor-compression system is not competitive with other methods of heat rejection. However, the system must be continuously re-evaluated as advances in technology will reduce both system weight and power penalties.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
128	SYSTEM- S4 HUMAN- H47	Reference 483, p. 148.

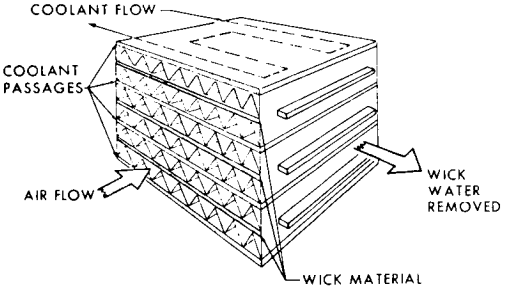
Water Separation and Humidity Control

a



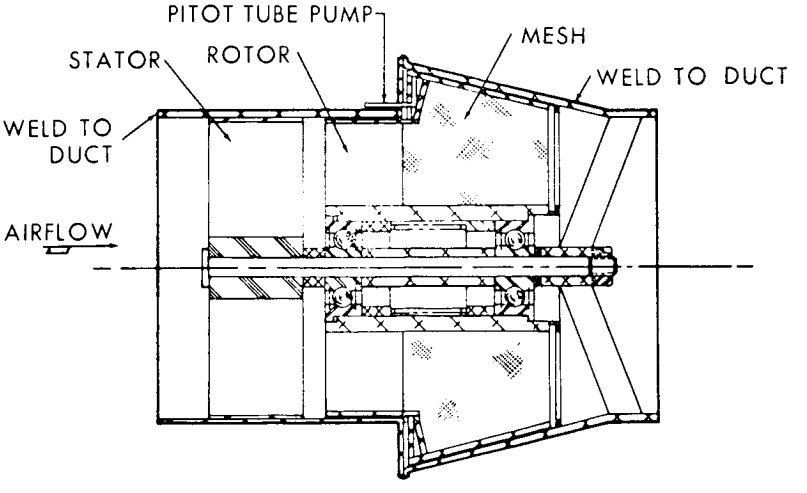
Project Mercury in-line water separator.

b



Wick type heat exchanger-water separator unit.

c

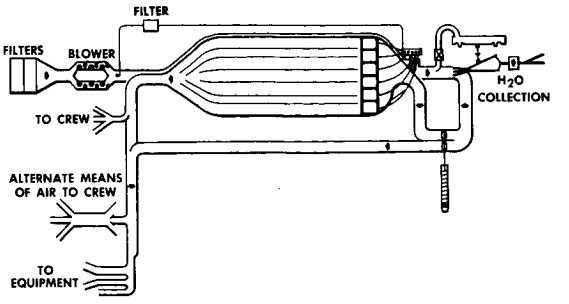


Centrifugal water separator.

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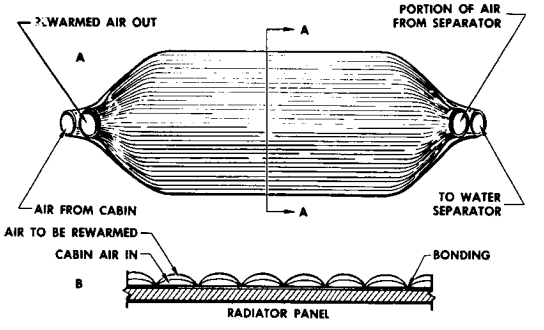
ITEM NO.	SUBJECT AREAS:	SOURCE:
129	SYSTEM - S4 HUMAN - H47	Reference 483, pp. 149 and 150.

a



Basic temperature and humidity control.

b



Basic heat exchanger ducting.

A typical design of a radiator type of temperature and humidity control is shown in figure a. This basic design can be easily modified. The ducting for the heat exchanger is Mylar or similar plastic sheets bonded in the manner shown in figure b. This ducting can be applied in any size or configuration like wallpaper.

ITEM NO.	SUBJECT AREAS:	SOURCE:
130	SYSTEM - S4 HUMAN - H47	Reference 309, p. 293.

For purposes of rough generalization, environments made up of a variety of combinations of the physical factors controlling heat exchange (temperature, air velocity, humidity, etc.) can be compared by expressing their net combined effect in terms of one or another index of heat stress. The most venerable of these is Effective Temperature (E. T.); the simplest, and handiest for estimation of time to collapse in the non-compensable zone, is the "Oxford" or Wet/Dry index; the most accurate in its reflection of physiological strain is "Predicted Four-Hour Sweat Rate"(P4SR). No single system is completely accurate, general, or reliable under all situations. Each is based on its own criteria and on interpretation of experimental data from a particular point of view.

a.

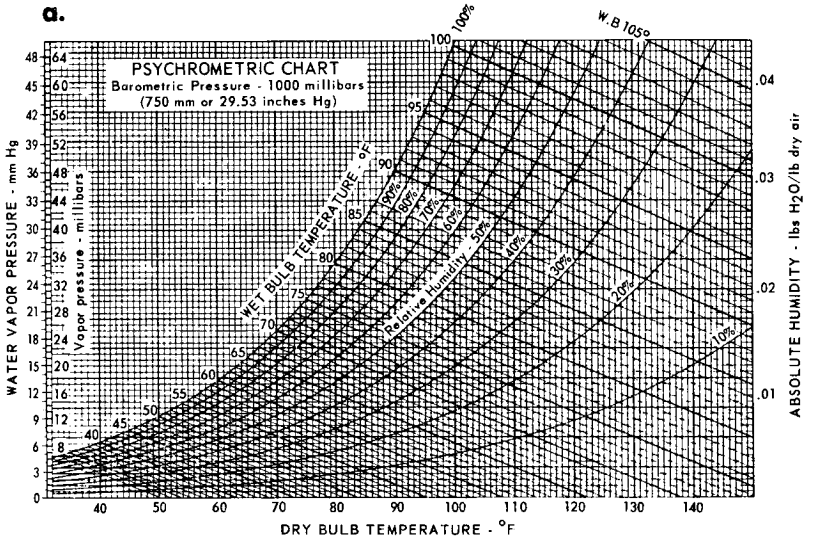


Figure a is a standard psychrometric chart for sea level conditions; on this background grid are drawn the three indices in charts b, c, and d.

b.

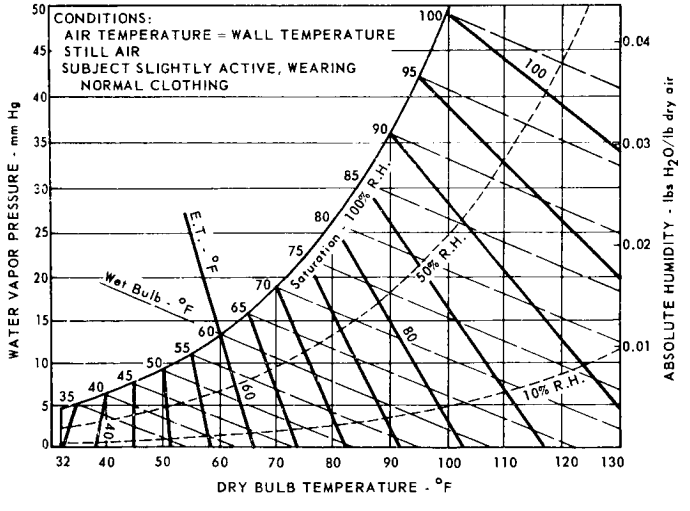


Figure b, the index of Effective Temperature, is based on immediate sensation upon passing from one environment to another. These sensations are complicated by the presence of clothing. The system has been criticized for misrepresenting the importance of humidity and air movement; equal E. T. does not mean equal physiological strain. Nevertheless, E. T. has been widely used, and therefore it carries a good deal of empirical meaning.

ITEM NO.	SUBJECT AREAS:	SOURCE:
131 a Page 1 of 2	SYSTEM - S4 HUMAN - H33, H34	Reference 554, p. 106. Based on References 16, 343, and 419.

Figure c, the "Oxford" or W/D Index, is a simple weighting of wet bulb temperature (85%) and dry bulb (air) temperature (15%); it is based on the observation that in non-compensable heat exposures the time to incipient collapse correlated well with this parameter. The presumption is that W/D value is directly related to rate of heat storage, or the imbalance of surface heat exchange. A related index for outdoor use is the wet bulb-globe temperature (WBGT) index.

c.

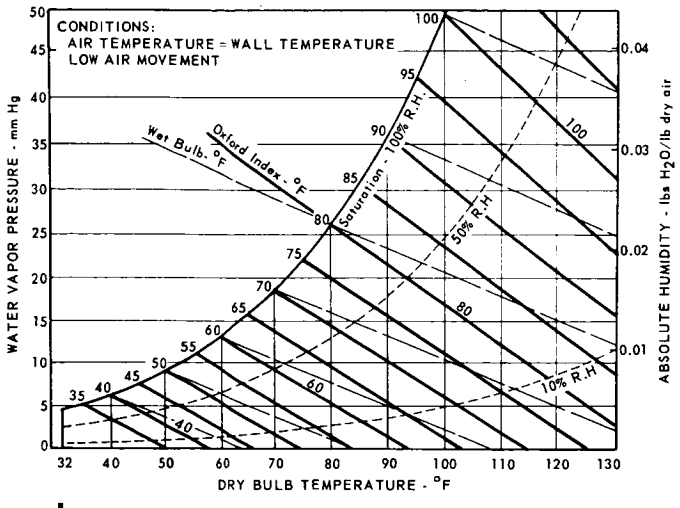
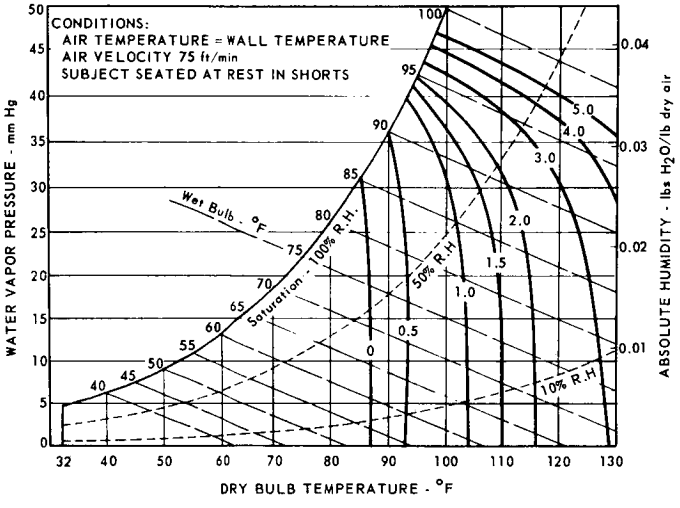


Figure d, Predicted Four-Hour Sweat Rate (P4SR), is based on the sweat production of acclimatized men during 4-hour exposures to heat. The curves shown are lines of equal P4SR, that is, loci of thermally equivalent combinations in terms of sweat output, for a specific combination of clothing, activity, and radiant surround; viz., seated at rest, wearing shorts, with air and wall temperatures equal and air velocity 75 ft/min.

d.



Note that only the P4SR system reflects the fact that change in humidity has little or no effect in extremely dry conditions. It is also the only index which attempts to accommodate on a common stress scale the effects of clothing, wind, solar or other excess radiation, and metabolic rate. Note also that for every change in metabolism, clothing, air movement or radiation, a new family of curves of P4SR would be produced using the nomogram and instructions in Macpherson [34], pages 296-300. As the conditions become more burdensome, the curves on the psychrometric chart begin to flatten as they move downward and to the left. Note also that the P4SR index is not intended to be a way of predicting sweat output for a given environment, but a means of expressing equivalence of heat stress.

ITEM NO.	SUBJECT AREAS:	SOURCE:
131 b Page 2 of 2	SYSTEM - S4 HUMAN - H33, H34	Reference 554, p. 107. Based on References 16, 343, and 419.

Survival: Prolonged Hypothermia

Group	Number	Survivors
Early controls	9	2 (22%)
5% CO_2 resp.	12	6 (50%)
Dibenzylene	7	3 (43%)
Vasoxyl	5	0
Cortisone	7	0
Reserpine	5	5 (100%)
Reserpine controls	7	5 (71%)

Although the possibility of suspending animation in man by freezing him for indefinite periods is remote from present-day knowledge and capability, long-range planning should not discount its possibilities as a technique allowing the spacemen to realize the more ambitious types of space flights. Lewis points out the convenience of such a technique in reducing the metabolic activity almost to nil; there would be minimal requirements for oxygen and food, and maximal protection from the psychological stresses of monotony as well as the physical stresses of radiation, acceleration, etc. Lewis further points out, as shown in Table 4.33, how pharmacological agents would be utilized to increase the percentage of survivors in animals exposed to deep-freezing.

ITEM NO.	SUBJECT AREAS:	SOURCE:
132	SYSTEM- S4 HUMAN- H38	Reference 416, p. 121. Based on Reference 321.

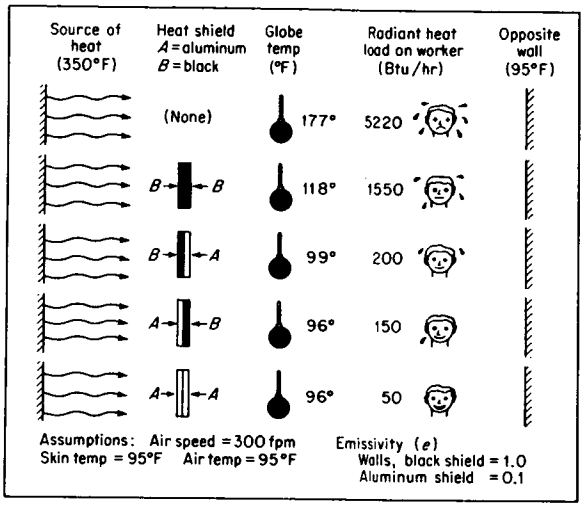
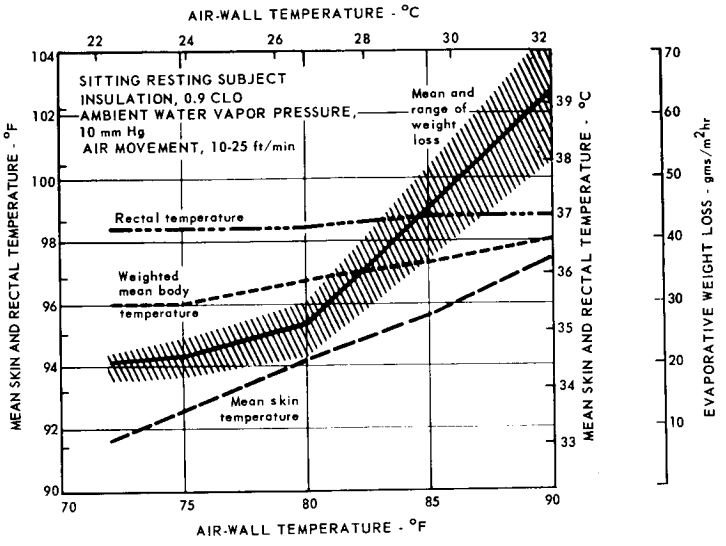


Illustration of use of shields as means of reducing radiant heat load from hot surfaces (such as furnaces).

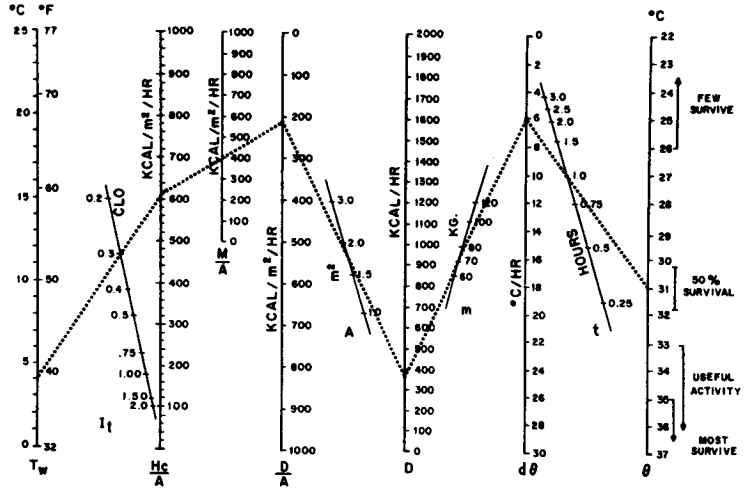
From HUMAN FACTORS ENGINEERING by Ernest J. McCormick. Copyright 1957, 1964 by McGraw-Hill, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
133	SYSTEM- S4 HUMAN- H44	Reference 362, p. 517. Adapted from Reference 272.



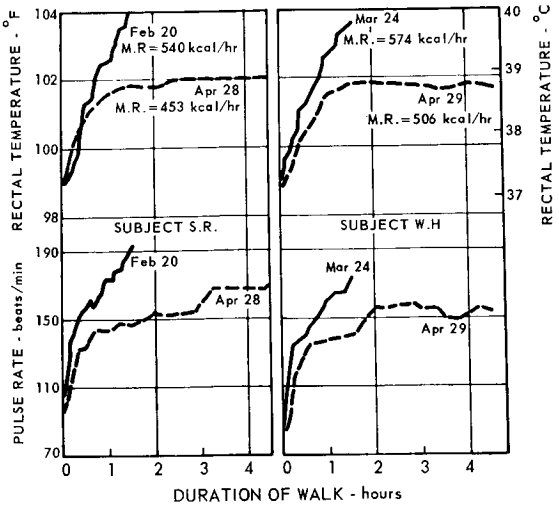
This figure shows the effect of environmental temperature (air equal to wall) on body temperatures and evaporative weight loss in ten subjects seated at rest in light clothing. Note the discontinuity in the relationship between weight loss and skin temperature in the vicinity of 94°F skin or 80°F air and wall temperature.

ITEM NO.	SUBJECT AREAS:	SOURCE:
134	SYSTEM - S4 HUMAN - H3, H18	Reference 554, p. 119. Based on Reference 254.



To relate the many factors involved in estimating tolerance in cold water, the nomogram below has been devised where one knows or can assume: water temperature (T_w); insulation of clothing and tissue (I_t); metabolic heat production per unit surface area (M/A); the immersed surface area (A); body mass (m); and exposure time (t). As shown by the dotted example line (for a nude man in water at 4°C, a metabolic rate of 400 kcal/m^2hr, an immersed surface area of 1.75 m^2, a body mass of 75 kg, and an exposure time of one hour) the nomogram predicts: heat loss to the environment H_c/A; heat debt per unit surface area (D/A); heat debt (D); change in mean body temperature ($d\theta$); and mean body temperature (θ).

ITEM NO.	SUBJECT AREAS:	SOURCE:
135	SYSTEM - S4 HUMAN - H3, H20, H34, H44	Reference 554, p. 128. Based on Reference 482.



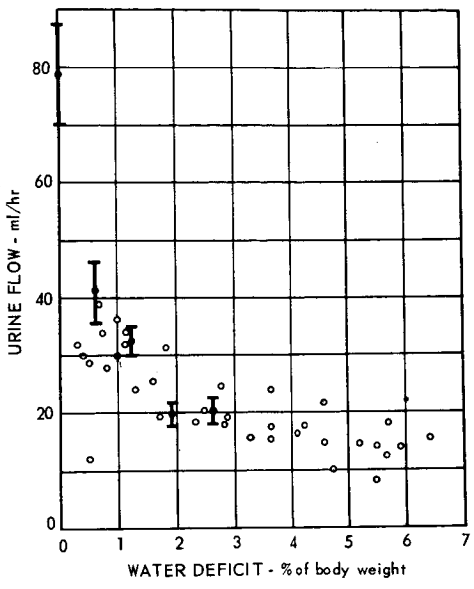
These data dramatically illustrate acclimatization to heat as shown by the lowering of body temperatures and heart rates of two men walking at 3.5 mph on a 5.6% grade in room temperature of 104°F, vapor pressure 13 mm Hg (E. T. 84°F).

(1) Subject S. R. was acclimatized by 23 exposures to these conditions between February 20 and March 20. After March 20 his only exposures were on April 16 and 28.

(2) Subject W. H. was acclimatized by 11 exposures between March 24 and April 8. After April 8 his only exposures were on April 22 and 29.

On the first exposure, the experiment was terminated by the collapse of the subjects at 90 minutes. After acclimatization; the men were still maintaining equilibrium with ease after 4.5 hours.

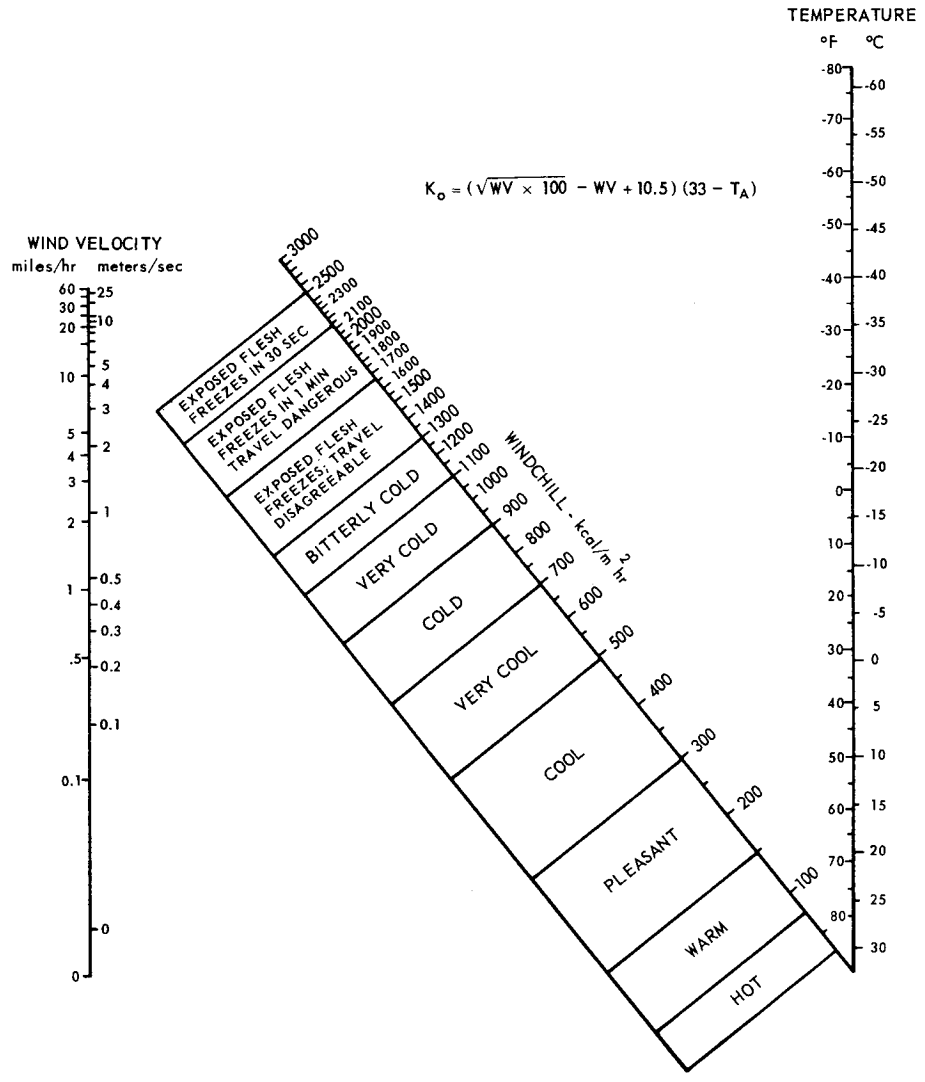
ITEM NO.	SUBJECT AREAS:	SOURCE:
136	SYSTEM - S4 HUMAN - H9, H18, H22, H41	Reference 554, p. 113. Based on Reference 436.



Urine flow decreases progressively during dehydration as shown here, but probably never goes to zero even in severe dehydration. The data points shown by open circles are from one subject dehydrated seven different times by exposure to an air temperature of 122°F for 8 to 10 hours without food or water. The closed circles with bars show the means and standard errors of the mean for 13 subjects exposed to 122°F without food or water.

ITEM NO.	SUBJECT AREAS:	SOURCE:
137	SYSTEM - S4 HUMAN - H11, H43	Reference 554, p. 205. Based on References 7 and 292.

WINDCHILL



In outdoor cold weather, the wind velocity has a profound, sometimes decisive, effect on the hazard to men who are exposed. The windchill concept dramatizes this well known fact by providing a means for quantitative comparison of various combinations of temperature and wind speed. Note for example that -50° F with an air movement of 0.1 mph has the same windchill value, and therefore is predicted to produce the same sensation on exposed skin, as -15° F with a wind of only 1 mph or +14° F with a wind of 5 mph. The windchill index does not account for physiological adaptations or adjustments and should not be used in a rigorous manner. It is based on field measurements by Paul Siple during World War II of the rate of cooling of a container of water.

ITEM NO.	SUBJECT AREAS:	SOURCE:
138	SYSTEM - S4 HUMAN - H12, H34	Reference 554, p. 123. Based on Reference 147.

a

Thermal Inertia *kpc* of Skin at Pain Threshold

Irradiance mc/cm²–sec	kpc (10^{-4}) cal²/cm⁴/°C/sec	
	Average	Range
100	96	75–117
150	110	89–142
200	127	95–158
300	139	115–168
400	159	144–181

b

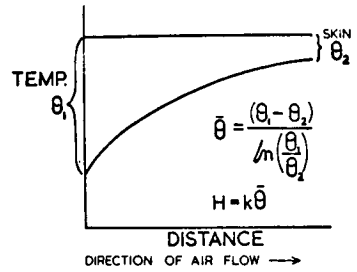
Irradiance, Time, and Temperature for Pain Threshold and Blister Production

Radiation Intensity, mcal/cm²–sec	PAIN THRESHOLD CONTROLS			PAIN THRESHOLD (During Burning)			THRESHOLD BLISTER			FULL BLISTER		
	No. of Observations	t, sec	Ts, °C	No. of Observations	t, sec	Ts, °C	No. of Observations	t, sec	Ts, °C	No. of Observations	t, sec	Ts, °C
100	49	13.5	45.1	6	12.4	45.8	2	33.8	52.9	1	37.2	53.4
125	31	10.1	45.3									
150	67	7.8	45.9	12	8.2	46.5	3	20.8	54.0	4	24.4	55.3
200	22	5.5	46.5	3	5.6	47.1	1	13.4				
300	36	2.9	47.1	10	2.6	46.5	2	7.8	56.7	1	8.6	57.9
400	13	2.2	48.3	8	2.2	49.7	5	5.6	59.1			

With sufficiently intense radiation, skin pain will be experienced in the irradiated area and tissue damage in the form of a skin burn or blister will occur. The kpc values at pain threshold vary depending on their irradiance.

ITEM NO.	SUBJECT AREAS:	SOURCE:
139	SYSTEM - S4 HUMAN - H17, H34	Reference 318, pp. 16, 18. Based on Reference 495.

a



Simplified scheme of heat exchange in an air ventilated garment. The skin temperature is assumed to be the same at all points. Air enters the microclimate at the air supply temperature and takes up heat as it passes over the skin to the exit point. The coefficient for heat exchange between the air and the skin is assumed to be the same at all points.

b

$$H = k\bar{\theta} \qquad \bar{\theta} = \frac{(\theta_1 - \theta_2)}{\ln\left(\frac{\theta_1}{\theta_2}\right)}$$

$$(\theta_1 - \theta_2) = \frac{H}{WC_p} \qquad \frac{k}{WC_p} = \ln\left(\frac{\theta_1}{\theta_1 - \frac{H}{WC_p}}\right)$$

Putting $\varepsilon = \frac{H}{\theta_1 WC_p}$ $\qquad \frac{k}{WC_p} = \ln\left(\frac{1}{(1-\varepsilon)}\right)$

Derivation of expressions for testing experimentally the validity of the simplified scheme. H, heat loss from skin; k, coefficient for heat exchange between skin and ventilating air; $\bar{\theta}$, logarithmic mean temperature difference between skin and air; θ_1, temperature difference between skin and air entry; θ_2, temperature difference between skin and air at air exit; w, mass flow of air; c_p specific heat of air; ε, effectiveness of the system as a heat exchanger.

c

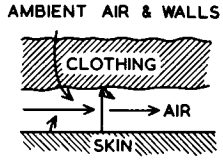


Diagram of heat exchange at a point on the skin surface. Heat is lost from the skin directly into the ventilating layer and after radiation to the inner clothing surface. It also passes from the outside through the clothing and into the ventilating air. The expressions derived in Fig. b can be used provided that the ambient temperature is equal to the mean skin temperature.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
140	SYSTEM - S4 HUMAN - H17, H44	Reference 300, pp. 155-157.

PAIN FROM CONDUCTIVE HEATING

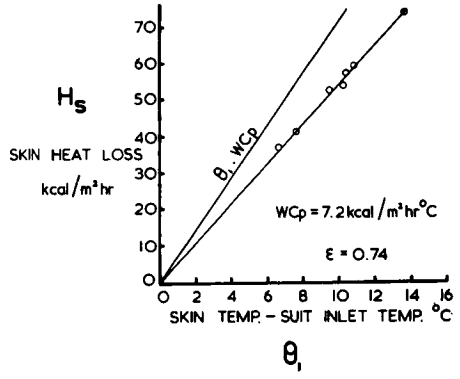
Body Area	Clothing Worn	Metal Surface Temperature	Average Tolerance Time
			seconds
Hand	Bare skin	120	10-15
Kneecap	Bare skin	117	34
	Bare skin	120	5
Fingertip	AF/B-3A leather gloves	150	12.6
	AF/B-3A leather gloves	160	7.3
Hand - palm	AF/B-3A leather gloves	150	25.2
	AF/B-3A leather gloves	175	9.7
	AF/B-3A leather gloves	185	8.0
Forearm	SAC alert suit	150	20.6
	SAC alert suit	175	8.0
Upper arm	K-2B light AF flight coverall	150	7.5
	SAC alert suit	150	31.3
	Alert suit plus Brynje net string underwear	300	7.2
	K-2B suit	150	18.1
	K-2B suit plus Brynje underwear	150	61.9
Buttocks	SAC alert suit	150	70.3
	Alert suit plus Brynje underwear	300	21.7
	K-2B suit	150	32.5
	K-2B suit plus Brynje underwear	150	+90
Mid-thigh	SAC alert suit	150	35.6
	Alert suit plus Brynje underwear	300	13.1
	K-2B suit	150	13.6
	K-2B suit plus Brynje underwear	150	+90
Kneecap flexed	SAC alert suit	150	14.4
	Alert suit plus Brynje underwear	175	9.5
	K-2B suit	150	7.3
Calf muscle	SAC alert suit	150	14.4
	Alert suit plus Brynje underwear	300	11.4
	K-2B suit	150	13.2
	K-2B suit plus Brynje underwear	150	66.1
Upper arm	MD-3A wool-nylon anti-exposure suit	300	12.0
	MD-3A wool-nylon anti-exposure suit	400	10.2
Forearm	MD-3A suit	250	15.9
Palm of hand	Aluminized asbestos glove	250	13.5
Back of hand	Aluminized asbestos glove	250	5.2
Palm of hand	Arctic mitten	300	18.7
	Arctic mitten plus B-3A glove	300	37.0
	Arctic mitten plus B-3A glove	400	27.6
	Pigskin '800°F' heat glove	300	30.7
	Pigskin '800°F' heat glove	400	21.0
	Pigskin '800°F' heat glove	500	18.5

Notes: Light touch pressure (less than 1 psi) applied to heated metal surface. The elbow and knee sometimes received second degree burns without pain.

Adapted from unpublished data by North American Aviation

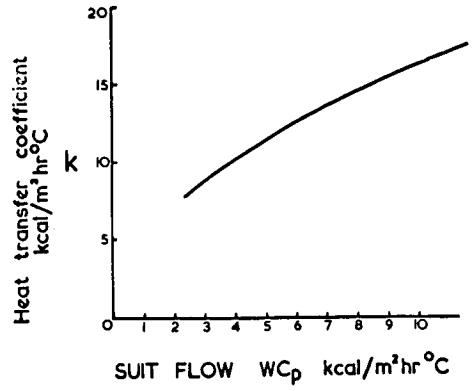
ITEM NO.	SUBJECT AREAS:	SOURCE:
141	SYSTEM - S4 HUMAN - H17, H34, H44	Reference 554, p. 121.

a



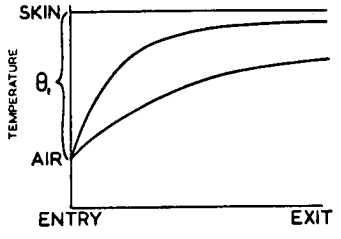
Results of a series of experiments made at the same mass flow. The effectiveness is independent of temperature difference. The line θ_1-WC_p shows the relation for an effectiveness of unity, i. e. if the ventilating air left the system at the mean skin temperature.

b



The relation between total heat transfer coefficient and air flow for the R.A.F. Mark II suit. This curve represents the situation when there is no heat transfer through the outer clothing.

c



Temperature changes in two suits of different effectiveness. To remove the same amount of heat the air flow must be greater in the suit of smaller effectiveness, but the heat transfer coefficient is smaller. The work required to drive the air through the ventilating layer depends on both these factors.

d

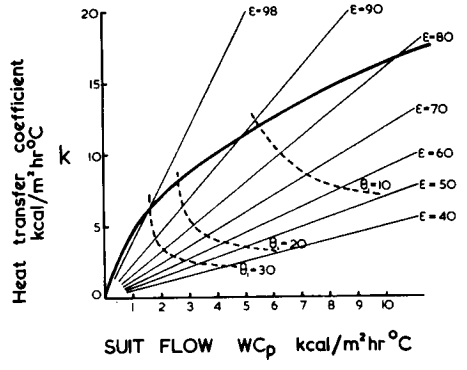


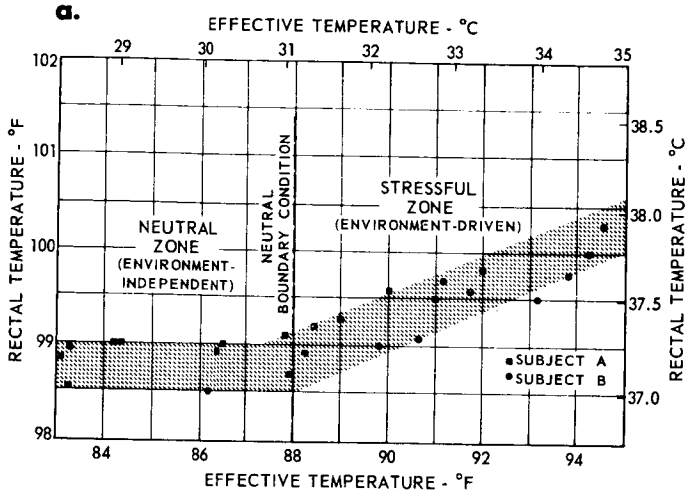
Diagram showing the relation between various factors in suit performance. The solid curve shows the behavior of the R. A. F. Mark II suit, assuming no heat exchange through the outer clothing. The broken lines show the requirements for heat balance at various values of temperature difference between skin and air supply. The working point of the suit would be at the intersection of the solid and broken curves.

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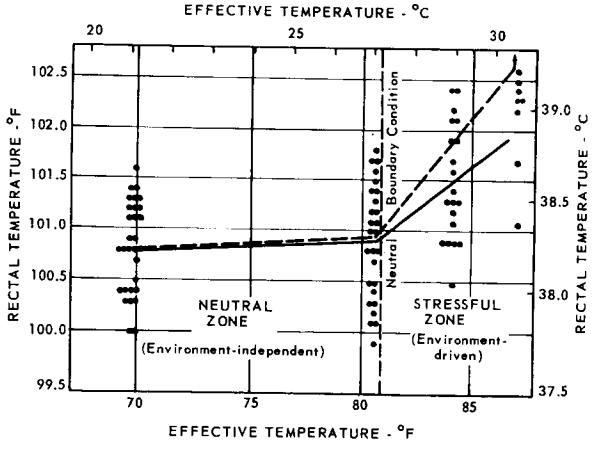
ITEM NO.	SUBJECT AREAS:	SOURCE:
142	SYSTEM - S4 HUMAN - H17, H44	Reference 300, pp. 157-159.

This graph relates the final rectal (core) temperature of resting men to a range of environmental heat stress. Each data point shows the level of rectal temperature observed in two men wearing coveralls and seated while exposed to dry bulb temperatures from 90 to 120°F and wet bulb temperatures from 83 to 88°F (E. T.'s from below 84 to above 94°F). In the region labeled "neutral zone," which extends well above the comfort zone, while other parameters such as skin temperature, heart rate, and sweat rate are increased with each successive increase in stress, core temperature remains independent of the environmental heat stress. Further increases in heat stress index beyond the "Neutral Boundary Condition" for the activity, clothing, and state of training concerned produce progressively higher core temperatures. This state of affairs characterizes the "stressful zone," where rectal temperature is environment-driven, and the probability of breakdown, or failure to compensate, becomes progressively higher, particularly for untrained or unacclimatized men.

a.

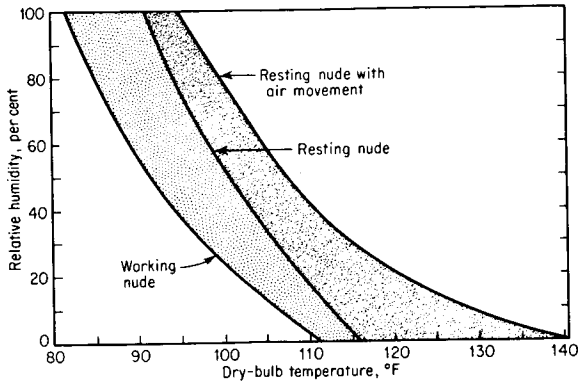


b.



Final rectal temperatures are shown as a function of environmental heat stress for working men. Each point represents a single exposure of a different man--approximately 30 men in each environment, or a total of 128 untrained subjects. The task was three hours of treadmill marching at 3.5 mph wearing shorts; the metabolic rate was 300 kcal/hr. Only in the two environments that lie in the Neutral Zone did all subjects complete the task. In the two hotter climates, 25% and 57% of the subjects had to be removed before the end of the period because of excessive heart rates or rectal temperature, to prevent collapse or damage. The dashed line on the graph connects the median values of final rectal temperature for all subjects, while the solid line connects the means for those subjects completing the full three hours.

ITEM NO.	SUBJECT AREAS:	SOURCE:
143	SYSTEM - S4 HUMAN - H18, H22, H34	Reference 554, pp. 110-111. Based on References 343 (fig. a) and 320 (fig. b).



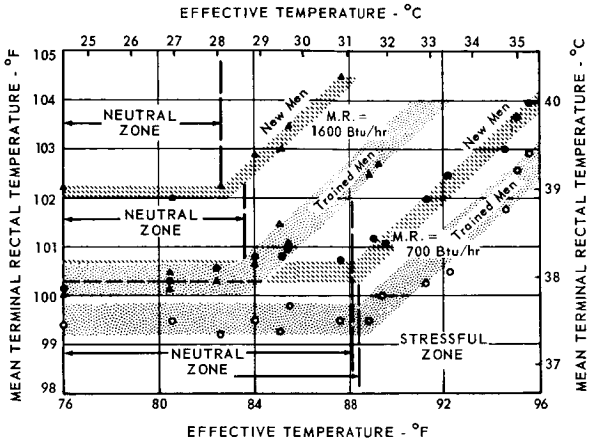
Approximate upper limits of tolerance for heat loss by evaporation. For any of the three conditions, temperature and humidity combinations to the right of the curve prevent evaporation.

To see the limiting effect of humidity on evaporation, let us look at the figure above. This shows the upper limits of tolerance in relation to temperature and relative humidity for working and for resting nude subjects. The upper limit of tolerance is the combination of atmospheric temperature and humidity beyond which the possible heat loss by evaporation does not equal the evaporative heat loss required for equilibrium. For any one of the three curves in the figure, combinations of temperature and humidity to the right of the curve represent conditions beyond the limit of tolerance. Such conditions impose a state of physiological imbalance upon people which, if accentuated enough and long enough, could result in some physiological consequences, ranging up to heartstroke or death.

In connection with this figure, it can be observed that resting people can tolerate higher temperatures and humidities than those at physical work (to this we can all testify personally, as well). A comparison of the two curves at the right shows that air movement usually helps to make conditions more tolerable by exposing the surface of the body to more air.

From HUMAN FACTORS ENGINEERING by Ernest J. McCormick. Copyright 1957, 1964 by McGraw-Hill, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
144	SYSTEM- S4 HUMAN- H18, H22, H34	Reference 362, pp. 512-513. Based on Reference 582.



Each point is the average of a group of ten men; the chart thus summarizes data from approximately 460 individuals, 2 work rates, and 15 different humid environments. The vertical lines delineate the boundary conditions separating the "Neutral" (environment-independent) and "Stressful" (environment-driven) zones before and after training.

Clearly illustrated is the effect of heat training (acclimatization) on the equilibrium rectal temperature, and the small, probably insignificant effect of training on the location of the Neutral Boundary. Note that in the "Neutral" zone, heat-trained men working at 1600 Btu/hr maintain body temperatures as low as or lower than novice workers working at 700 Btu/hr; however, when both groups are in the "Stress Zones" for their respective work levels, the difference between their mean body temperatures is 1.5°F. For comparison, new men working at 1600 Btu/hr have temperatures 1.5°F higher than similar men working at 700 Btu/hr, when both are in their neutral zone of environments.

ITEM NO.	SUBJECT AREAS:	SOURCE:
145	SYSTEM - S4 HUMAN - H18, H22, H34, H41	Reference 554, p. 111. Based on Reference 589.

ACCLIMATIZATION TO HEAT

a.

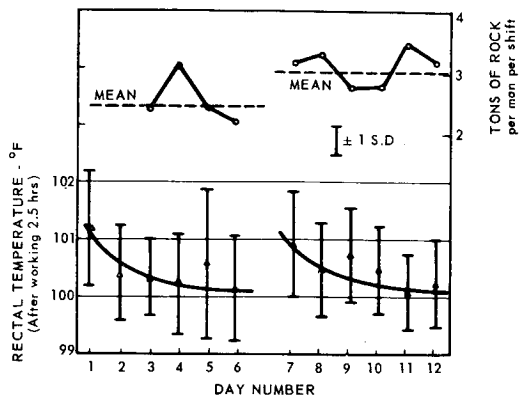
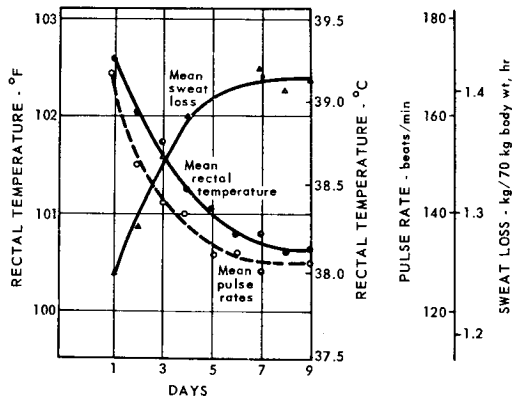


Figure a shows the results obtained with the standard acclimatization procedure used in South African gold mines to prepare laborers recruited from remote villages for work in saturated environments underground. The duration of the daily work period is five hours, and the work is shoveling rock under close supervision. For the first six days the Effective Temperature was 84°F; the next six days the E. T. was 89.5° F and the amount of rock shoveled was increased. Note the fall in rectal temperature--the curves are means for over 100 men, the bar shows ±1 S. D. --during each of the six-day work periods.

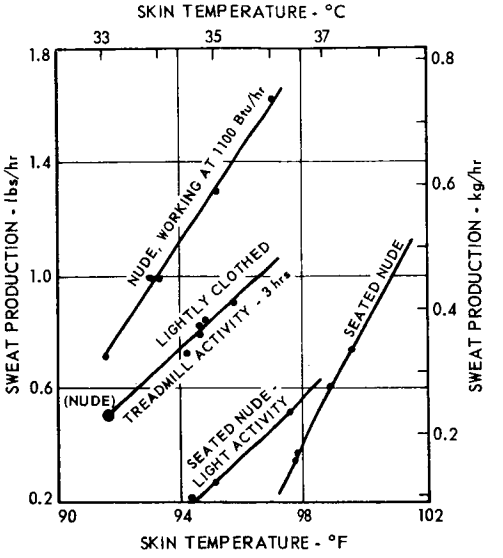
Figure b illustrates the results of a technique used at the U. S. Army laboratories at Natick, where men marched at 3.5 mph for 100 minutes each day in an environment of 120° F dry bulb, 80° F wet bulb, 200 ft/min air velocity (E. T. 89° F, vapor pressure 15 mm Hg). The value of the shorter exposure period technique in preparing men to work for long periods such as five hours or more in the heat is the subject of considerable controversy.

Newer techniques, pioneered by Fox in England, concentrate on raising core temperature to the same fixed level each day, so that thermal strain, rather than the stress, remains constant throughout the acclimatization process.

b.

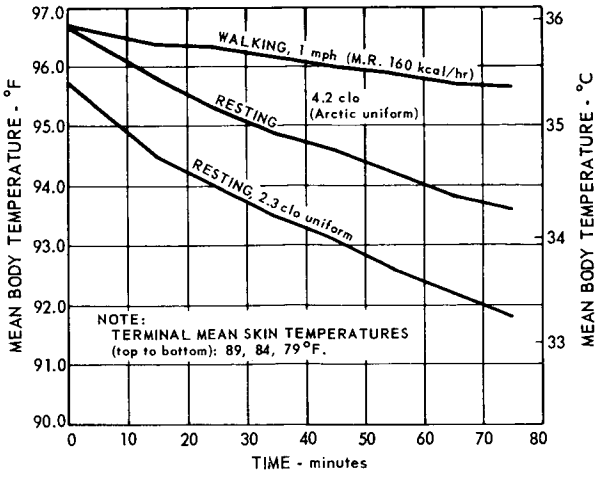


ITEM NO.	SUBJECT AREAS:	SOURCE:
146	SYSTEM - S4 HUMAN - H18, H22, H41	Reference 554, p. 112. Based on References 588 (fig. a) and 327 (fig. b).



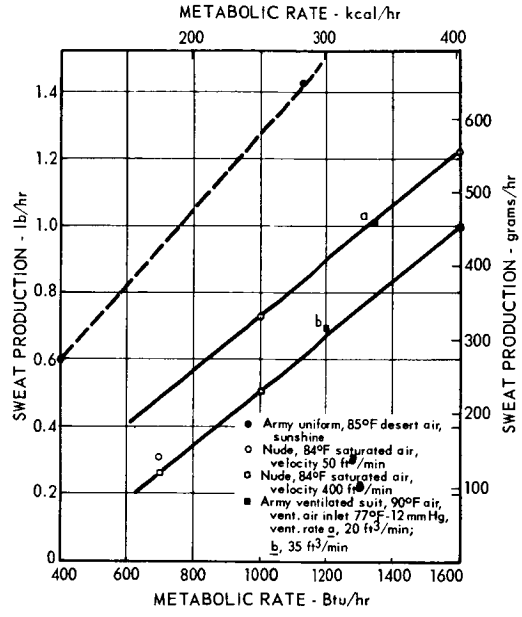
Various sweat rates during various laboratory procedures are plotted as a function of skin temperature, to show how variable this relationship is.

ITEM NO.	SUBJECT AREAS:	SOURCE:
147	SYSTEM - S4 HUMAN - H18, H22, H44	Reference 554, p. 206. Based on Reference 556.



Tolerance to cold wearing inadequate body insulation is shown in the figure which illustrates the principles underlying estimation of tolerance time in severe cold stress situations. The data are averages for four subjects studied outdoors in Alaska. Temperatures were all within a few degrees of the average, -32°C (-26°F), and wind velocity ranged from zero for the 2.3 clo tests to 65 ft/min for the resting experiments with the 4.2 clo uniform. The rate of fall of the body temperature (0.67 X rectal + 0.33 X skin) is a measure of the rate of negative storage, reflecting the imbalance between heat production and heat loss. It has been estimated that serious discomfort results from a total heat debt of 150 kcal. The survivable limit of heat debt is uncertain; it would in any case be heavily dependent on the procedures and facilities for re-warming. Most practical experiments are necessarily terminated at the point of incipient tissue damage--temperature of 4°C (39°F) or less at some local surface. It may be that death from hopelessness is a more frequent sequel of real exposures beyond this point than the incurring of an intolerable heat debt.

ITEM NO.	SUBJECT AREAS:	SOURCE:
148	SYSTEM - S4 HUMAN - H18, H22, H44	Reference 554, p. 124. Based on Reference 540.



Sweat production is a highly variable quantity, both within and between individuals. This chart is intended merely to indicate orders of magnitude and some of the sources of variability. Missing entirely from this picture is the question of the physiological cost of producing sweat, which is a function of the body temperatures and work rates at which a given sweat rate is achieved. Rates as high as 2 lbs/hr can be maintained for many hours if sufficient water is ingested, but rates between 3 and 4 lbs/hr cannot be sustained for 6 hours. When the skin is totally wet, the maximum achievable sweat rate is drastically reduced.

ITEM NO.	SUBJECT AREAS:	SOURCE:
149	SYSTEM- S4 HUMAN- H18, H20, H44	Reference 554, p. 114. Based on References 589, 7, 150, and 220.

COMPUTATION OF THE HEAT BALANCE

Characteristics of the environment which determine the level of heat stress are the following: air temperature, density, and rate of movement; wall temperature, emissivity, and geometry; radiation sources and sinks; water vapor concentration and diffusion resistance between the skin and the surrounding atmosphere. These determine respectively the convection (C), radiation (R), and evaporation (E) exchange of the body; together with the heat production of the body itself (metabolism, M), these quantities determine the heat balance of the body. This can be represented in simple notation as: M - (E + C + R) = S, where S is storage. The bracket encloses quantities which are normally heat losses from the body (i.e., when the surrounding environment is lower in temperature than the body). A sixth possible term, which may be significant in special situations, is conductive heat exchange. The following equations and charts permit determination of each term in the heat balance equation. All heat flows are expressed per unit body surface area.

CONVECTION (C) $= h_c (t_{surface} - t_{air})$ Btu/ft^2,hr

$$h_c = 0.57\left(\frac{t_{air} + 460}{536}\right)^{0.5} (V\rho)^{0.5} \quad \text{Btu/ft}^2\text{,hr,°F}$$

RADIATION (R) (exclusive of solar) $= h_r (t_{surface} - t_{mean\ radiant})$ Btu/ft^2,hr

$$h_r = \sigma F_{ae} f_r \left[\frac{(t_{surface} + 460)^4 - (t_{mean\ radiant} + 460)^4}{t_{surface} - t_{mean\ radiant}}\right]$$

where t = temperature in °F
$V\rho$ = mass velocity lb/ft^2 min
h_c = the convective conductance
h_r = radiant conductance
σ = Stefan-Boltzmann universal radiation constant; 0.173×10^{-8} Btu/ft^2, hr, °R^4
F_{ae} = shape and emissivity factor
f_r = ratio of radiation area to total body surface area (see 14-13, 14-14).

EVAPORATION. No general formula is possible due to dependence on sweat response and clothing characteristics (wicking, diffusion resistance, etc.). The following formula pertains only to the special case of the totally wet body. (Achievable for nude men only at severe levels of heat strain and in humid environments; feasibility unknown but unlikely for clothed men):

$$E = 3.6\, h_c (p_s - p_a) \quad \text{Btu/ft}^2\text{,hr}$$

where p_s and p_a are vapor pressures (in mm Hg) at the evaporating surface and in the air respectively. For cases where the surface (skin or garment) is not completely wet, a factor must be introduced to represent the "degree of wettedness" of the surface. In the case of a partially dry clothing layer, complex adjustments must be made to account for the resistance to vapor transfer of textiles and of still air. E may be obtained by experimental measurement of weight change in a given environment.

STORAGE (S) $= 0.83 \frac{W}{A} \frac{d}{dt} (t_{body})$ Btu/ft^2,hr

where $t_{body} = \frac{1}{3} t_{skin} + \frac{2}{3} t_{rectal}$
W = body mass in lbs
A = body surface area
0.83 = average heat capacity for body tissues

S is a rate, like the other terms in the heat balance, and is computed from the linear rate of change of the weighted mean body temperature (slope of the time history), not from a finite difference quantity.

METABOLISM (M) can be estimated from activity description or determined by measuring oxygen consumption

For equilibrium, S must equal zero. When M is changed substantially, 45 minutes or more may be required to reach a new equilibrium. Solving for E will permit an estimate of the magnitude of the sweat rate required. For most non-compensable heating conditions, a steady state of heat transfer can be assumed after about 10 minutes. Solving the equation for S permits prediction of "tolerance time" (time to collapse) from the following equation:

$$T_{tol} = \frac{1700}{S} \text{ minutes}$$

where T_{tol} = average tolerance time, and S is expressed in Btu/ft^2 hr;

Or: $$T_{tol} = \frac{4600}{S} \text{ minutes}$$

where S is expressed in kcal/m^2 hr.

The above equations are based on average experimental data taken on unacclimatized men. The corresponding constants for minimum predicted tolerance time are: 1200 and 3300 for English and metric respectively.

ITEM NO.	SUBJECT AREAS:	SOURCE:
150	SYSTEM - S4 HUMAN - H18, H34	Reference 554, p. 117. Based on Reference 81.

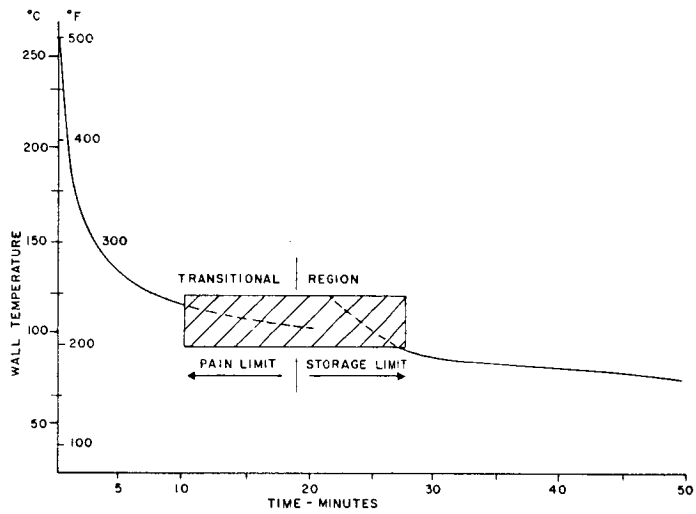
a

Thermal Inertia (kpc) for Whole-Body Heating at Pain Threshold

Wall, $T^{o}C$, T_w	Air, $T^{o}C$, T_a	q_r, cal/m^2hr	Q, $cal/m^2\,hr$	kpc (10^{-5}) $cal^2/m^4/sec^{o}/C$
149	121	399	988	83
204	177	745	1885	80
260	232	1262	2924	66

q_r = radiant heat transfer
Q = total heat transfer
T_w = wall temperature
T_a = air temperature

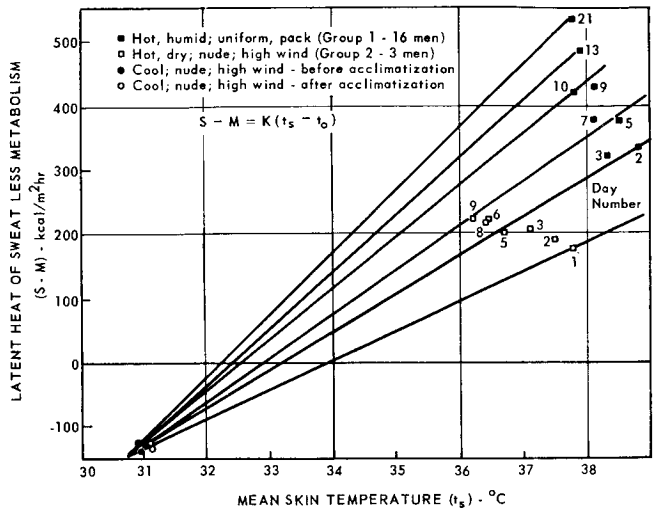
b



Pain-limited versus heat storage-limited heat tolerance.

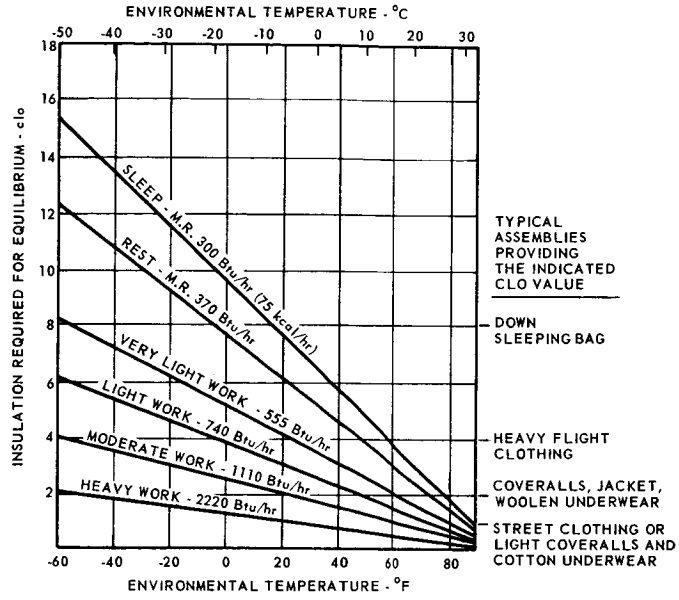
Webb has reported human exposures to operative temperatures between 115 and 260°C (240 to 500°F) and has demonstrated that such exposures are pain-limited. In these latter exposures careful attention was given to the control of the thermal environment. Exposures in some cases were abrupt. A preheated chamber, mounted on rails, was rolled to surround the subject in a period of 2 sec. Other exposures employed slow heat pulses and consisted of a linear increase in wall temperature at rates between 8 and 55°C per minute (15 to 100°F per minute) until pain occurred. The data on heat storage-limited and pain-limited tolerances are summarized in Figure b. A broad transitional zone between the two tolerance-limiting mechanisms is evident and reflects the present experimental uncertainty as to the exact limiting mechanism in individual cases.

ITEM NO.	SUBJECT AREAS:	SOURCE:
151	SYSTEM- S4 HUMAN- H18, H34	Reference 318, pp. 16-17. Based on Reference 551.



This is a diagrammatic presentation of mean results from two studies of the heat acclimatization phenomeon. Subjects in both groups were drawn from the same Army population at Fort Knox, Kentucky. The two studies are related by means of a parameter combining the sweat rate (expressed as its caloric value if evaporated) and metabolic rate. The slope of the straight lines in the diagram represents an estimate of the sensitivity of the sweat response to increases in temperature of the peripheral tissues or blood (expressed as a function of surface temperature and metabolic heat output). It can be seen that when men are unclothed and the air is dry, sweat rate changes but little, but the skin temperature needed to produce that amount of sweat becomes steadily lower in successive exposures; when the climate is humid, and evaporation is impeded by clothing, the skin temperature does not change much on successive days, but the quantity of sweat produced at that temperature is enormously increased as acclimatization progresses.

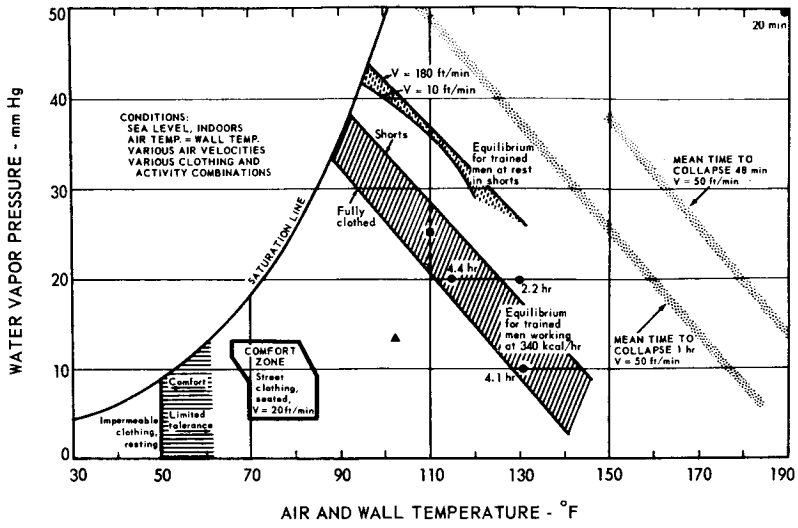
ITEM NO.	SUBJECT AREAS:	SOURCE:
152	SYSTEM - S4 HUMAN - H18, H41, H44	Reference 554, p. 113. Based on References 253, 280, and 183.



This chart illustrates the effect of metabolic rate on the insulation required for continuous exposure which requires maintaining heat balance indefinitely. The chart is slightly unrealistic because no activity, even sitting, is continued indefinitely. Note also that clothing insulation of more than 4.5 clo at one atmosphere becomes almost impossibly bulky, and even this amount of insulation is unattainable in ordinary footgear and handgear; thus the predictions of this diagram cannot be achieved in practice without taking special precautions to protect hands and feet (e.g., by electrical heating) or by using non-anthropomorphic protective enclosures.

ITEM NO.	SUBJECT AREAS:	SOURCE:
153	SYSTEM - S4 HUMAN - H20, H22, H44	Reference 554, p. 125. Based on References 110 and 511.

COMFORT AND VARIOUS THERMAL LIMITS



This chart locates a conventional comfort zone on the psychrometric chart, then proceeds to illustrate the effects of activity level or work rate, clothing, and training on the location of the boundary between zone 4 ("Equilibrium maintained for hours") and zone 5 ("non-compensable, storage-limited") heat stress.

The cross-hatched areas represent the upper limits for the maintenance of equilibrium for six hours by men thoroughly trained to work in the heat ("acclimatized"); the upper narrow zone pertains to seated rest, the lower larger zone to treadmill marching. The effect of clothing is shown at constant wind speed, and the effect of wind speed is shown in the absense of clothing.

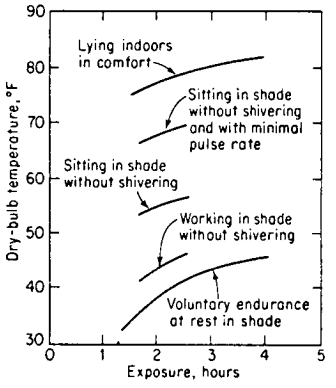
The square at 110°F, 25 mm, represents a demonstration by Hertzman and Ferguson that nude, reclining student subjects can maintain equilibrium for at least 32 hours if water lost in sweat is replaced hourly, but become restless and distressed after 10 hours if water is withheld, though sweat rates are the same in both cases.

The three black circles in the large cross-hatched area and just above it are identified as the average time for four military subjects exposed as a group to reach incipient collapse due to heat storage; they lie in the non-compensable zone (zone 5), for these particular subjects. Note that the identical environments, activity level, and clothing are in the next lower zone ("equilibrium maintenance, hours") for acclimatized subjects, even with the added burden of working.

The effect of training on particular individuals is illustrated by the triangular symbol. At this condition two men collapsed in heat exhaustion after 90 minutes of hard work on their first exposure. Some time later, after a lapse of weeks following an intensive period of training in the heat, they both were able to maintain perfect thermal equilibrium while performing the same work, and showed no sign of disturbance of this equilibrium at the end of 4.5 hours without a break.

On the extreme right of the chart are two tolerance limit lines--i.e., lines of predicted constant time to incipient collapse for untrained, resting men, lightly clothed. The point in the upper right corner indicates that the minimum predicted time to collapse (for these conditions) is 20 minutes. Note the large changes in environmental conditions associated with moderate reductions in tolerance time.

ITEM NO.	SUBJECT AREAS:	SOURCE:
154	SYSTEM - S4 HUMAN - H22, H33, H34, H44	Reference 554, p. 108. Based on References 81, 343, 294, 192, 275, and 437.

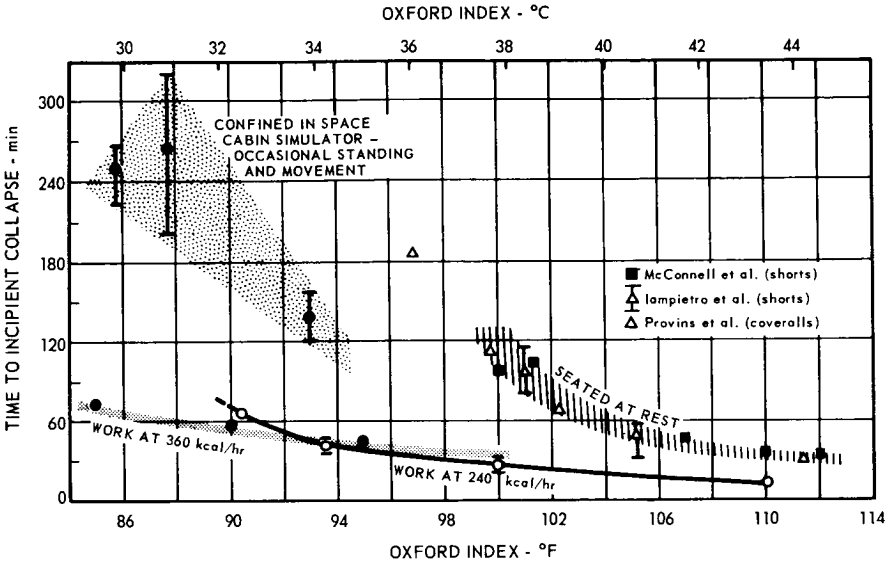


Lower bounds of tolerance limits (for indicated criteria) for seminude men under different conditions.

The lower bounds of subjective tolerance for men in a variety of atmospheric conditions are shown in this figure. The men, seminude, were exposed to various air temperatures, wind velocities, and solar intensities under such circumstances as siting, standing, working, and lying down. Their tolerances are expressed in terms of comfort and discomfort, voluntary endurance, and goose flesh and shivering.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
155	SYSTEM- S4 HUMAN- H22, H34	Reference 362, p. 524. Based on Reference 8.



The effect of activity on tolerance time for untrained men at sea level is shown for a wide range of heat stress conditions. Vertical bars indicate the range of times to incipient collapse.

The dramatic influence of metabolic rate on endurance time in hot environments is emphasized here. The use of the "Oxford Index" permits intercomparison of environments ranging from very hot and dry to very humid and warm (vapor pressures as low as 7 mm Hg and as high as 70 mm Hg).

Note the increase in variability at the milder conditions; it is in this same environment stress zone that the effects of training for work in the heat ("acclimatization") are most striking, endurance times for trained men being several times as high as those of the same men when they are unused to heat stress.

ITEM NO.	SUBJECT AREAS:	SOURCE:
156	SYSTEM - S4 HUMAN - H22, H34	Reference 554, p. 109. Based on References 419, 320, 294, 79, 284, and 359.

Estimates of Time for Maximum Safe Loss of Stored Body Heat in Cold Environments at Various Rates of Motion [1, 2]

Effective insulation (clo[3])	Air movement (ft/min)	Time for max. safe loss of stored body heat (hr)					
		Environment at 0°C			Environment at −40°C		
		Body at rest	Walking 3 mi/hr	Walking 4 mi/hr	Body at rest	Walking 3 mi/hr	Walking 4 mi/hr
1	4, 000	0.58	1.10	11.20	0.22	0.27	0.34
1	100	0.73	1.90	indef.	0.27	0.34	0.44
2	4, 000	1.15	indef. [4]	indef. [5]	0.48	0.78	1.60
2	100	1.17	indef.	indef.	0.53	0.90	2.10
3	4, 000	3.30	indef.	indef.	0.80	2.20	indef. [6]
3	100	3.80	indef.	indef.	0.85	2.50	indef.
4	4, 000	8.80	indef.	indef.	1.20	21.0	indef.
4	100	10.80	indef.	indef.	1.30	57.0	indef.

[1] Spector, 1956.

[2] Estimated safe loss of stored body heat by an adult is 80 cal/m^2 of body surface.

[3] See definition of this unit in text.

[4] Complete protection given by 1.2—1.7 clo of effective insulation.

[5] Complete protection given by 0.6—1.1 clo of effective insulation.

[6] Complete protection given by 2.6—2.7 clo of effective insulation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
157	SYSTEM - S4 HUMAN - H22, H34, H44	Reference 380, p. 434. Based on Reference 485.

Clo Units Required for Comfort
for Various Outdoor Activities

Temperature, °F	Resting, sitting	Level Walking		
		Slow	Normal	Fast
70	1.5	0.7	0.4	0.3
50	3.1	1.5	0.9	0.7
30	4.7	2.3	1.5	1.1
0	7.2	3.5	2.3	1.7

For the maintenance of optimal comfort, Gagge, Burton, and Bazett present the following relationships, expressed in formula terms:

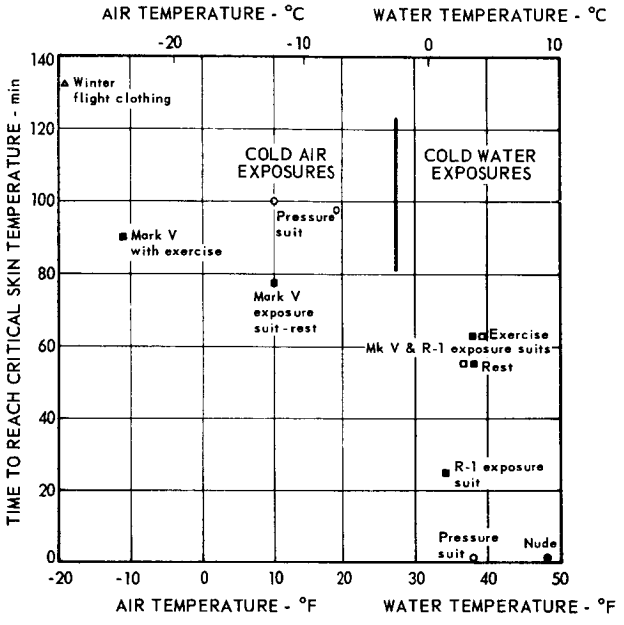
$$I_{cl} = \frac{92^{o} - Ta}{1.62(M - E)} - I_a$$

in which I_{cl} = Insulation of clothing in clo units
I_a = Insulation of ambient air in clo units
Ta = Temperature of air in °F
M = Heat production (metabolism)
E = Evaporative heat loss

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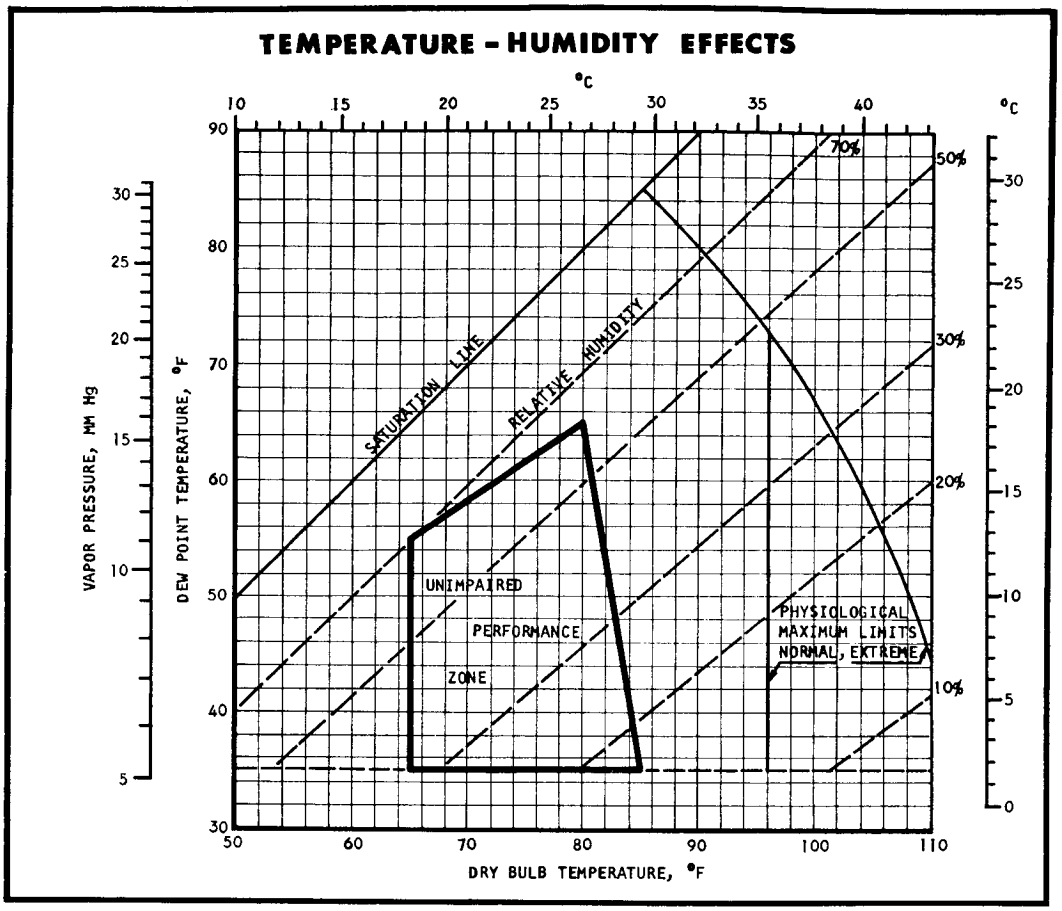
ITEM NO.	SUBJECT AREAS:	SOURCE:
158	SYSTEM- S4 HUMAN- H22, H44	Reference 362, p. 529. Based on Reference 207.

CLOTHING TESTS IN COLD AIR AND WATER



The relative protection of various types of aircrew clothing in water immersion and exposure to cold air is illustrated in this graph, which shows the time required to reach a critical mean skin temperature of 76°F in each assembly. The criterion of 76°F is based on the general observation of extreme discomfort when this point is passed; in most of the experiments summarized here, some subjects requested termination of the exposure at or near the time when the group average reached this point. The clothing assemblies were: winter flight clothing--the assembly specified by the Alaskan Air Command, USAF; the Navy anti-exposure suit assembly, Mark V; the (obsolete) Air Force anti-exposure suit assembly, R-1; and an Air Force pressure suit with bladders in torso, arms, and legs, designated CSU 4/P. Note for comparison the data point for nude exposure to water at 48°F. The value of exercising in cold air, and the lack of an advantage in cold water, is evident.

ITEM NO.	SUBJECT AREAS:	SOURCE:
159	SYSTEM - S4 HUMAN - H22, H34, H44	Reference 554, p. 126. Based on Reference 58.



This chart presents the physiological effects of the relation between the dry bulb temperature and the humidity of the atmosphere of a space vehicle or airplane. The humidity is expressed in terms of the dew point temperature, or vapor pressure, thus providing a chart which is valid for any of the pressures shown in the oxygen-pressure graph.

For a shirt-sleeve atmosphere, the conditions should be within the Unimpaired Performance Zone. The limits of this zone are (1) a dew point of 35°F, below which excessive drying of the respiratory passages takes place, (2) a relative humidity of about 70 percent, above which skin and clothes are uncomfortable, (3) a dry bulb temperature of 65°F, below which extra clothing is required, and (4) a dry bulb temperature of 80 to 85°F depending upon dew point.

At points to the right of the Unimpaired Performance Zone, appreciable perspiration will occur as the body seeks to maintain a heat balance. At the normal limit, the perspiration rate will be of the order of one pint per hour; at the extreme limit, to which many individuals are unable to adjust, the perspiration rate will reach one quart per hour.

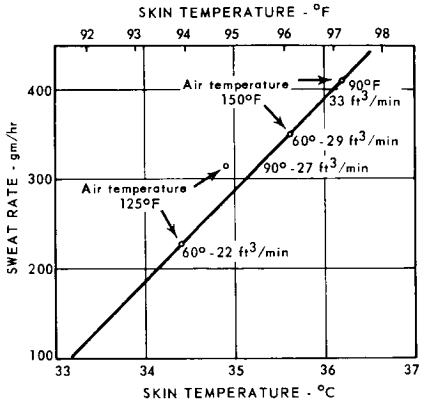
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ITEM NO.	SUBJECT AREAS:	SOURCE:
160	SYSTEM - S4 HUMAN - H24, H33, H34	Reference 36.

TOLERABLE LIMITS OF TEMPERATURE

Condition	Temp. in ° Fahrenheit
Comfort zone, summer	56°- 75°
Comfort zone, winter, light work	63°- 71°
Comfort zone, winter, heavy work	55°- 60°
Physiological limits, at rest, heat	156° for 30 min. at 10% humidity 107° for 30 min. at 90% humidity 500° for 2 min., air absolutely dry 200° for 35 min., air absolutely dry 122° for 120 min., air absolutely dry
Physiological limits, at rest, cold	38° for 5 hours at 3 miles per hour air velocity 44° for 4 hours at 9 miles per hour air velocity
Physical stiffness of extremities begins	50° and under
Physical fatigue begins	75° and over
Mental activities and complex performance begins to deteriorate	85° and over

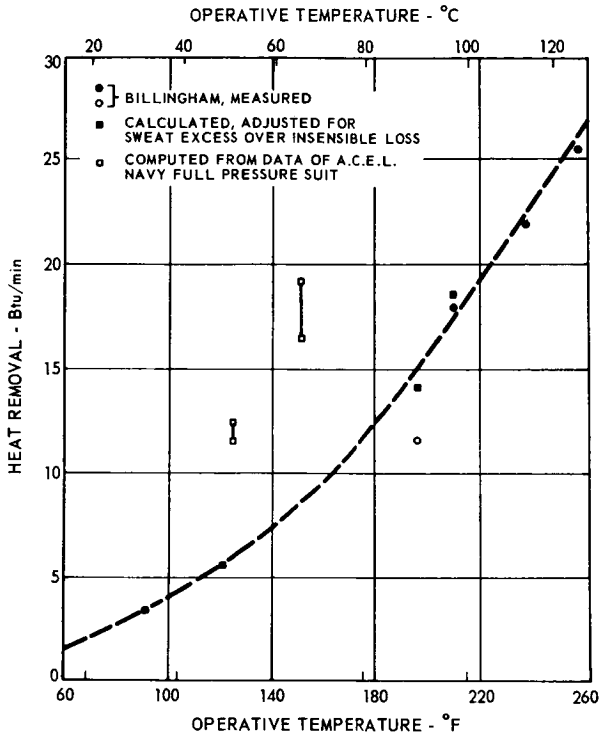
ITEM NO.	SUBJECT AREAS:	SOURCE:
161	SYSTEM- S4 HUMAN- H24, H33, H34	Reference 14, p. 150. Based on References 585, 361, and 28.



This figure presents mean data for three subjects exposed for two hours in an early model Goodrich pressure suit (model I-A) with the AMEL ventilation garment (no ventilation to the head). The subjects directed the adjustment of the ventilation air flow within limits in an attempt to attain a "comfortable" state. Average final flow rate for each combination of ventilation air inlet temperature and chamber environment temperature is shown for each point.

ITEM NO.	SUBJECT AREAS:	SOURCE:
162	SYSTEM - S4 HUMAN - H33, H44	Reference 554, p. 115. Based on References 254 and 452.

COOLING BY VENTILATED CLOTHING



The graph shows the rate of convective suit cooling which must be supplied a seated man at rest wearing typical aviation clothing to maintain a comfortable skin temperature of 90°F (32°C) for a range of hot conditions. Suit convective heat removal is computed from the mass flow of ventilating air and the difference between inlet air temperature and the desired surface temperature:

$$q_v = 0.24\,(90 - t_v)\,W_v$$

where q_v = suit convective heat removal in Btu/min,

t_v = temperature of ventilating air in °F, and

W_v = mass flow of ventilating air in lbs/min.

When air and wall temperature are equal, the operative temperature is the same; otherwise it lies between them; it is their average, weighted according to the convective and radiative conductance coefficients respectively.

The data points marked with hollow squares, which are farthest from the curve drawn through the other points, are from experiments where there was moderate sweating and some heat storage, although the subjects judged themselves to be comfortable. The adjustments and corrections for these cases could only be approximate.

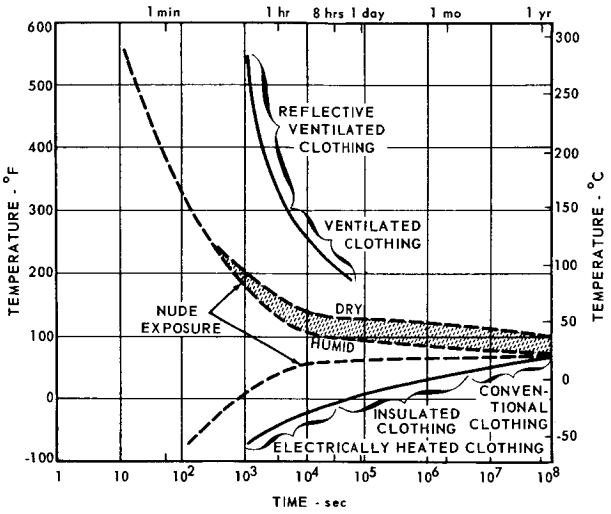
ITEM NO.	SUBJECT AREAS:	SOURCE:
163	SYSTEM - S4 HUMAN - H33, H44	Reference 554, p. 118. Based on References 73, 238, and 353.

Predicted Lowest Ambient Temperatures for 1-hr Exposure and for Prolonged Thermal Equilibrium in Various Stages of Attire [1, 2]

Activity	Environment: Wind (mph)	Environment: Sun or shade	Environment: Altitude (ft)	Predicted lowest ambient temperatures (° C): Exposure of 1 hr: Nude	Exposure of 1 hr: Normal attire [3]	Exposure of 1 hr: Heavy attire [4]	Thermal equilibrium: Nude	Thermal equilibrium: Normal attire [3]	Thermal equilibrium: Heavy attire [4]
Sitting [5]	0	Shade	0	17	−4	−67	27	21	0
Running [6]	5	Shade	0	10	−27	−138	14	−15	−104
Sitting [5]	5	Sun [7]	0	19	−1	−48	23	17	−7
Walking [8]	5	Shade	0	20	−3	−72	25	10	−34
Standing [9]	5	Shade	0	25	4	−56	29	20	−6
Sitting [5]	5	Shade	0	26	4	−55	30	24	4
Sitting [5]	25	Shade	0	28	12	−36	31	26	10
Sitting [5]	5	Sun [7]	20,000 [10]	8	−19	−111	13	4	−32

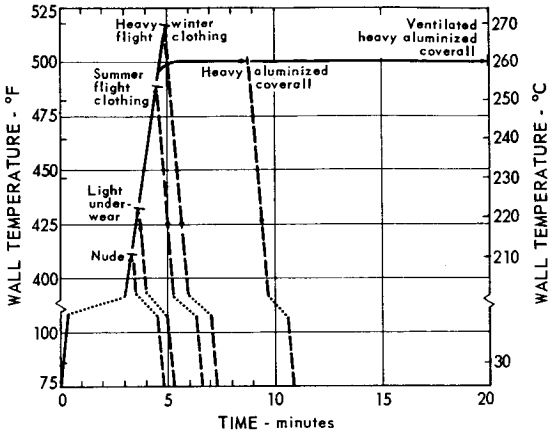
[1] Spector, 1956.
[2] Values are approximations for young, adult males.
[3] Business suit; effective insulation is 1 clo.
[4] Arctic clothing; effective insulation is 4 clo.
[5] Body at rest; M = 50.
[6] At 6.2 mph; M = 440.
[7] Absorbed solar heat (S) becomes part of H in basic formula; S = 130 for nude, S = 13.75 for normal attire, S = 16 for heavy attire.
[8] At 3.7 mph; M = 180.
[9] Performing light work; M = 80.
[10] Because of the greater intensity of solar radiation at the higher altitude, the value of S increases 70%.

ITEM NO.	SUBJECT AREAS:	SOURCE:
164	SYSTEM - S4 HUMAN - H34, H44	Reference 380, p. 434. Based on Reference 485.



The graph shows experimentally determined ranges of human thermal tolerance for resting men without protection, and also protected with the best clothing for each zone of heat or cold. The environments used in establishing the curves were all characterized by low air movement (less than 100 ft/min) and approximately equal air and wall temperatures. Tolerance limits for nude subjects are: surface pain above 250°F; body heat storage from 140° to 250°F; fatigue and dehydration from 100 to 140°F; fatigue, shivering and general body cooling, with increasing discomfort, from 65 to 0°F; and cold pain and increasing danger of frostbite below 0°F. The improvement in thermal tolerance times caused by properly chosen clothing is depicted by the two solid curves, one in the hot zone and one in the cold.

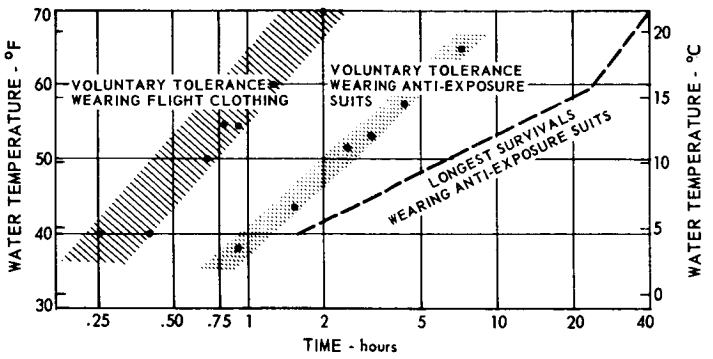
ITEM NO.	SUBJECT AREAS:	SOURCE:
165	SYSTEM - S4 HUMAN - H34, H44	Reference 554, p. 104.



This chart shows the increase in tolerance times (voluntary limit when surface pain becomes unbearable) for subjects exposed to a heat pulse where wall temperature was increased at 100°F/min, and the subjects wore clothing affording various degrees of protection. Each limit represents average data for from 3 to 10 subjects. When an aluminized surface was used with a heavy coverall, the protection increased again; exposures were changed in form --the increase in wall temperature was stopped at 500°F and that temperature held until tolerance was reached. Adding ventilation with air at about 85°F allowed these exposures to last beyond 20 minutes.

ITEM NO.	SUBJECT AREAS:	SOURCE:
166	SYSTEM - S4 HUMAN - H34, H44	Reference 554, p. 119. Based on References 294, 303, and 552.

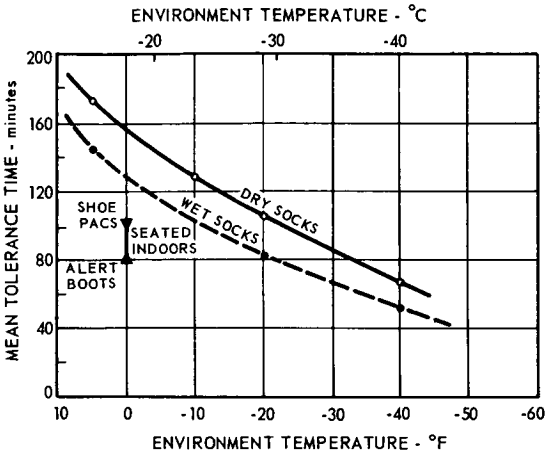
SURVIVAL IN COLD WATER



The "voluntary tolerance, flight clothing" zone in this figure shows the average results from numerous experimental studies, including a recent one using a diver's "wet suit" in conjunction with a flight suit and long underwear. Such experiments are typically terminated when the subject declines to accept the discomfort any longer, or reaches a skin temperature below 50°F. The second limit shown, pertaining to men protected by potentially waterproof garments, reflects the fact that hands and feet cannot be adequately insulated and remain functional. Nude men in 75°F water reach within 12 hours one or another tolerance limit (rectal temperature below 95°F, blood sugar below 60 mg/100 ml, or muscle cramps).

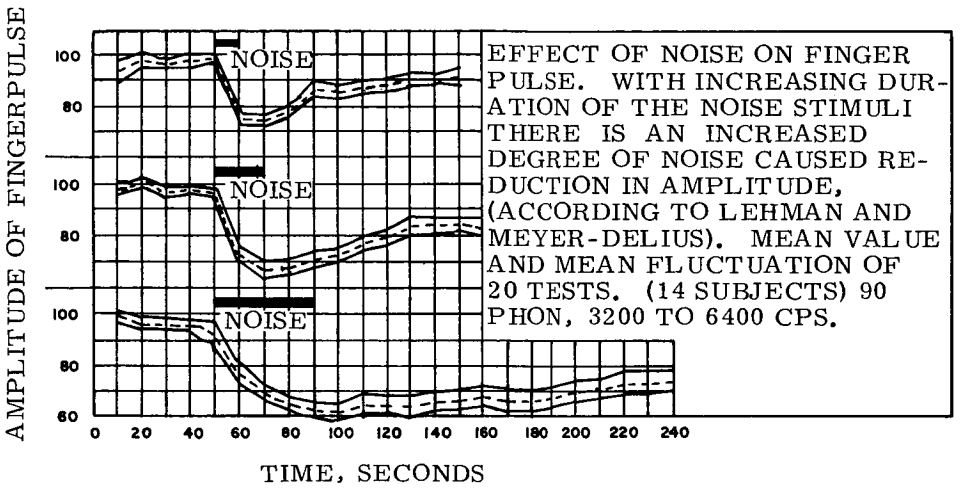
The extent to which real survival time would exceed this limit is difficult to predict, due to the importance of injury, equipment available, and such psychological factors as belief in the possibility of rescue. An analysis of over 25,000 personnel on ships lost at sea during 1940-44 showed that of those who reached life rafts, half died by the sixth day if the air temperature was below 41°F (5°C); survival time increased with increasing air temperature.

ITEM NO.	SUBJECT AREAS:	SOURCE:
167	SYSTEM- S4 HUMAN- H34, H44	Reference 554, p. 128. Based on References 64, 156, 255, 357, 377, and 535.



Cold tolerance at rest wearing adequate body insulation is shown in figure for increasingly cold environments. The prime limiting factor in voluntary tolerance of cold distress is the development of painfully cold feet. (The hands are more easily protected inside the clothing.) Even when the total body insulation is an impractical 5.9 clo (close to wearing a sleeping bag), ordinary footgear limits tolerance time at $0^{o}F$ (shown by the vertical bar) to 77-104 minutes, which are average times for five men. The chart shows that the improvement so far achieved with insulated boots is not impressive, particularly if the socks become wet. There is a distinct risk of tissue damage when any part of the skin reaches $39^{o}F$ ($4^{o}C$). Most men refuse to continue before this point is reached.

ITEM NO.	SUBJECT AREAS:	SOURCE:
168	SYSTEM - S4 HUMAN - H34, H44	Reference 554, p. 124. Based on References 111 and 481.



Effect of noise on peripheral circulation

The time for peripheral circulation to return to normal was, for exposure up to one hour, always longer than the exposure time. An example of such noise effects on the finger pulse and its recovery time is illustrated in the figure above. That continuous or too frequent activation of this normal primitive emergency reaction can lead to permanent changes and effects is only inferred in some studies.

ITEM NO.	SUBJECT AREAS:	SOURCE:
169	SYSTEM - S5 HUMAN - H9	Redrawn from Reference 547, p. 333. Based on Reference 319.

Some Effects of Exposure to Noise as Compared to Quiet on Human Performance and Other Processes

Type of performance	Noise level (db)	Noise duration	Quiet level (db)	Effect of noise
Addition problems	50	Continuous	Not given	No difference in number of correct solutions. Considerable increase in energy expenditure under noise as compared to quiet, especially during first few days.
Continuous tracking	120	Intermittent and random	" "	No effect
	120	12 × 2 min. in 4 hours	" "	Performance improved
	130	3 min. at middle and end of 4 hours	" "	Performance improved
Stereoscopic ranging	120	3 minutes	" "	No effect
Inserting pegs in pegboard	high	Intermittent clicks and complex noise	" "	Initial performance slowed but over-all performance showed no difference
Tracking requiring hand, foot, and eye coordination	115	continuous	90	Reactions in noise 5.4% slower
Card sorting	115	continuous	90	No effect
Marksmanship	115	continuous	90	No effect
Joystick pursuit tracking	115	continuous	90	No effect
Hand or foot key-pressing	115	continuous	90	No effect
Key pressing to translate letters to numbers	120	10 minutes	not given	Time required initially longer; greater tension in noise
Monitoring clock for erratic hand movements	114	last 1½ hours of 2-hour trial	83	Significantly poorer in last ½ hour
Conversation	0–60	continuous	—	Normal
	60–80	"	—	Raised voice
	80–100	"	—	Very difficult
	100–115	"	—	Shouting
	< 115	"	—	Impossible
Comfort level in aircraft	0–60	Continuous	—	Quiet and very comfortable
	60–80	"	—	Comfortable
	80–90	"	—	Acceptable
	90–100	"	—	Noisy
	100–115	"	—	Very noisy and disagreeable
	115–125	"	—	Uncomfortable
	< 125	"	—	Painful

Robert M Gagne, (editor), Psychological Principles in System Development. (c) 1962. Reprinted by permission of Holt, Rinehart and Winston, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
170	SYSTEM - S5 HUMAN - H24	Reference 587 p. 151-152 Based on Reference 178.

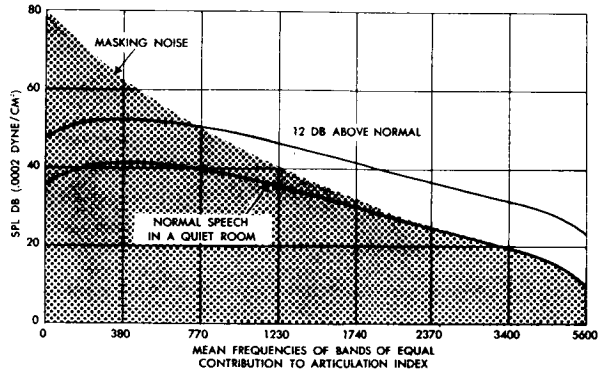
a

MAXIMUM PERMISSIBLE SPEECH-INTERFERENCE LEVELS

DISTANCE TO THE TALKER (feet)	ACOUSTIC ABSORPTION OF AREA (sabines)	SHOUT (db)	VERY LOUD (db)	RAISED VOICE (db)	NORMAL (db)
½	Any value	90	84	78	72
1	Any value	84	78	72	66
2	Any value	78	72	66	60
4	Below 100	78	72	66	60
	Above 100	72	66	60	54
8 or more	Below 100	78	72	66	60
	100 to 400	72	66	60	54
	400 to 1600	66	60	54	48

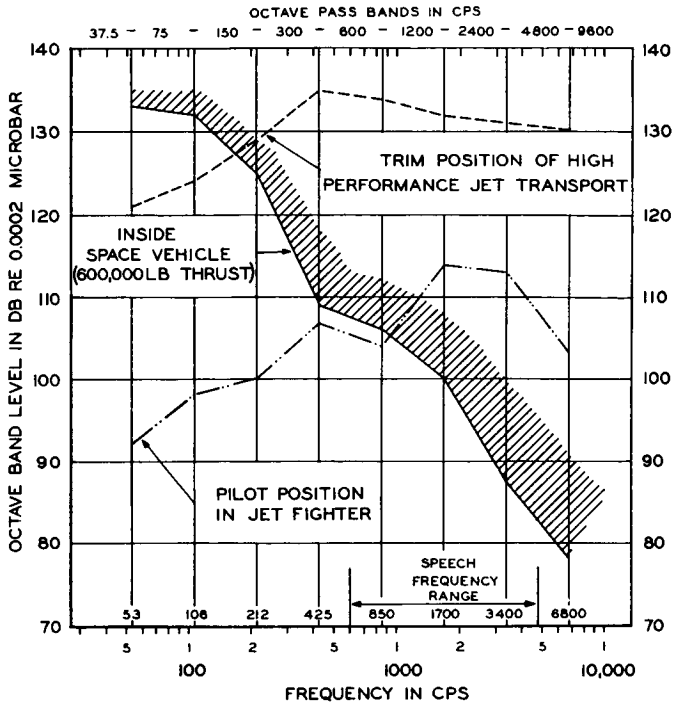
NOTE: A sabine is a unit of absorption equal to the absorption of 1 square foot of surface which is totally sound absorbent. As more absorption is present the less interference can be tolerated, because the speech energy is partially absorbed. The above Table is for the male voice — decrease 5 db for female voice. Speech energy below 200 cps or above 7000 cps contributes very little to speech intelligibility.

b



Speech within a noise background is intelligible when at least 40 per cent of the *average* speech level is above the spectrum level of the background noise. For this reason the normal voice level, which would be adequate in a quiet room 18 inches from a speaker, must be raised about 12 db in the presence of the masking noise of a DC-3 airplane for speech to be understood in the cockpit.

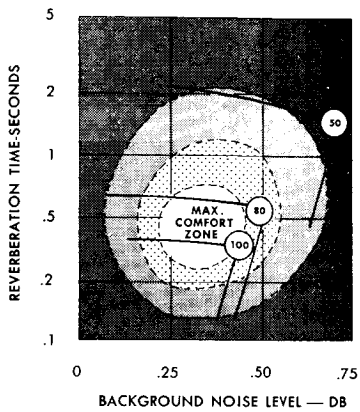
ITEM NO.	SUBJECT AREAS:	SOURCE:
171	SYSTEM - S5 HUMAN - H25	Reference 586 p. 2-225 Based on Reference 69. (figure b)



Maximum ambient noise field estimated inside space vehicle compared to two known noise fields.

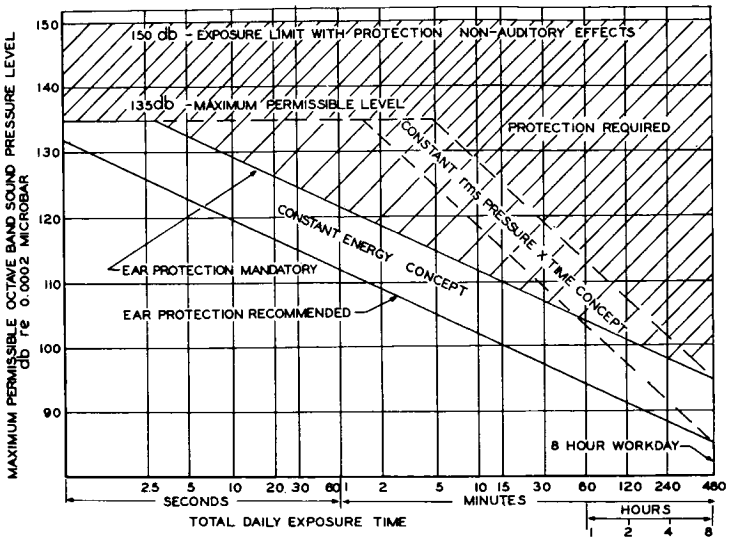
1. Estimated noise field inside space vehicle mounted on 600,000 lb. booster during static firing. Range shown to allow for transmission loss of various types of structures. For higher-thrust boosters, major increase is in very low frequency range (interior noise sources not included).
2. Measured noise field at engine trim position of high-performance jet transport during water injection. Wearing special headset and microphone worker can talk out of the noise clearly. Perception of hearing adequate for period up to 110 minutes daily.
3. Measured noise field at head of pilot in jet fighter aircraft at high speed, low altitude. Wearing protective helmet and mask pilot can talk out of noise clearly; perception of incoming speech is barely adequate. Protection of hearing adequate for period of 140 minutes daily. The graph shows that speech communication in the space vehicle, even under maximum noise conditions, poses no serious problem.

ITEM NO.	SUBJECT AREAS:	SOURCE:
172	SYSTEM - S5 HUMAN - H33	Reference 548, p. 64



The diagram at the right indicates qualitative zones of relative comfort in residential rooms. The outer zone is generally uncomfortable or annoying for normal living. The inner zone of maximum comfort also gives optimum conditions for ease and intelligibility of conversation. Contour numbers give per cent of speech sounds which will be heard correctly under average conversational conditions.

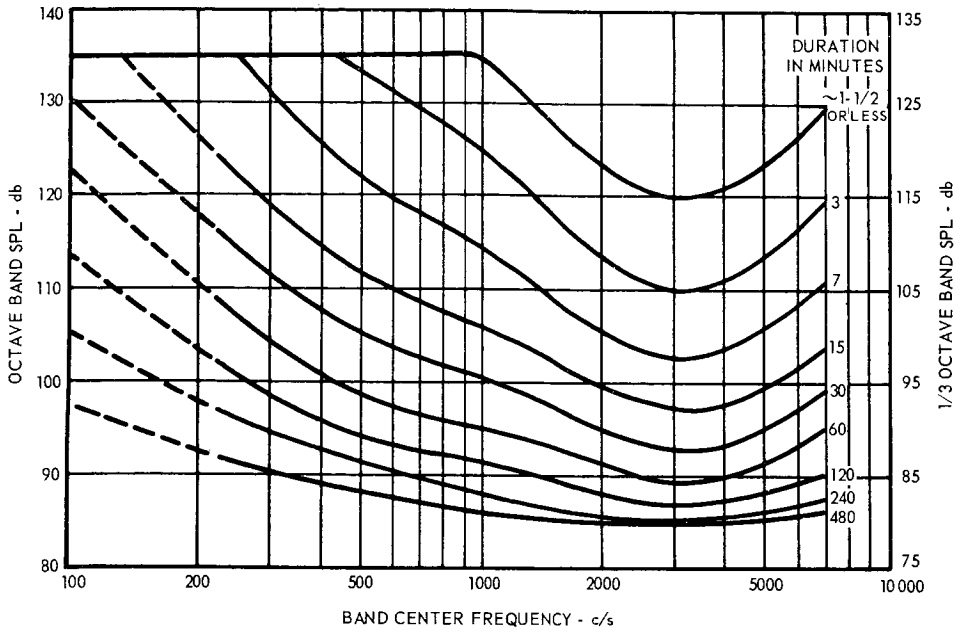
ITEM NO.	SUBJECT AREAS:	SOURCE:
173	SYSTEM - S5 HUMAN - H33	Reference 586 p. 2-223 Based on reference 313.



Damage risk criteria for short time exposure to broad-band noise. The curves based on the "constant energy concept" and the "constant pressure time concept" are shown. The curves designate the limits for safe daily exposure over a period of many years in terms of maximum permissible exposure time or sound pressure level in the octave bands 300-600, 600-1200, 1200-2400, and 2400-4800 cps. (For exposure to pure tone noise the curves should be lowered by 10 db; however, the maximum permissible level of 135 db stays the same.)

ITEM NO.	SUBJECT AREAS:	SOURCE:
174	SYSTEM - S5 HUMAN - H34	Reference 548 p. 62

TOLERANCE FOR NOISE

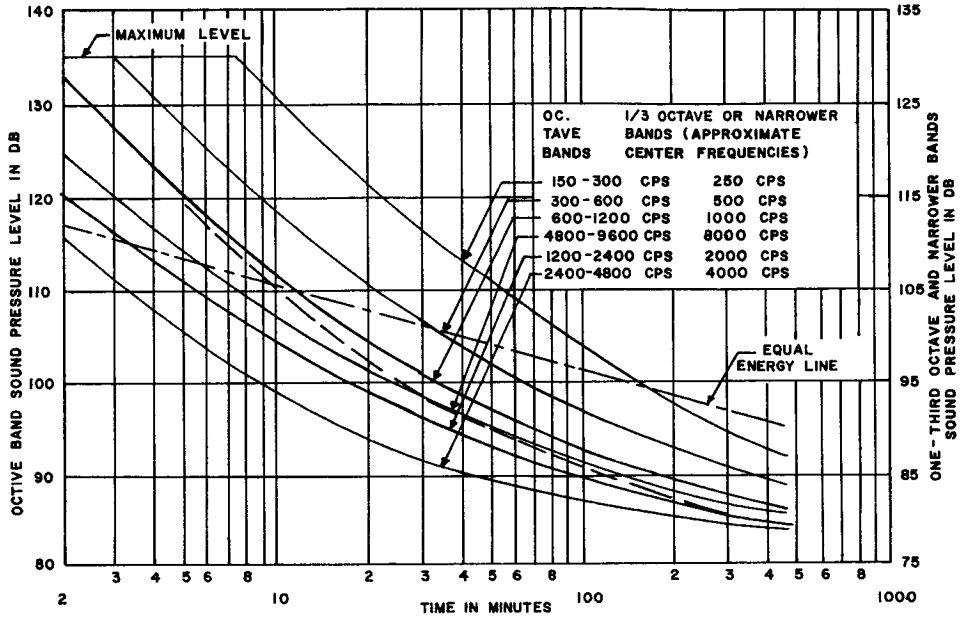


This chart shows Sound Pressure Levels required for octave bands (left-hand ordinate) and 1/3 octave or narrower bands (right-hand ordinate) of noise of different center frequencies to achieve a damage risk criterion. The parameter is the duration of daily exposure in minutes. The criterion level would produce hearing losses just sufficient to affect speech communication if the noise-exposure routine were continued five days a week for ten years.

The chart can be used directly to assess noise exposure for ground-support activities associated with space efforts, but should be applied conservatively if noise exposure is expected to occur on a 24-hours-per-day schedule. Space missions will have varied noise profiles, with the worst periods lasting no more than the few minutes of powered flight; but the noise of machinery associated with control of a capsule's internal environment and external guidance will be a constant feature of the environment throughout a mission. The 24-hour daily exposure for the few days, weeks, or months of a space mission might then be considered to be at least as severe as the eight-hours-per-day exposure for ten years (the bottom curve on the chart).

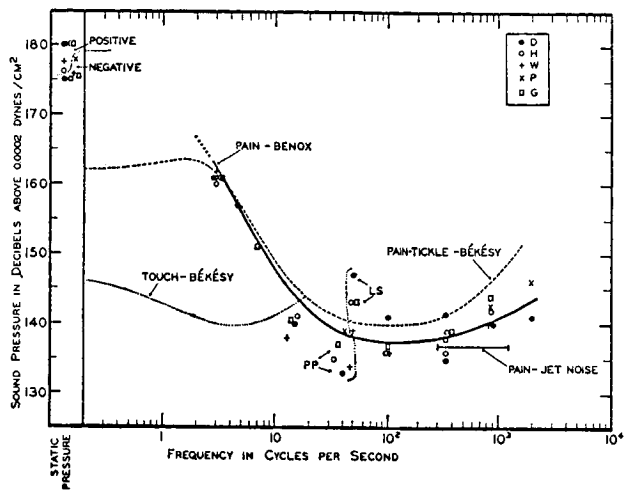
The problem of comfort is not treated in this chart, and present usage is to use the SIL as a measure of comfort. Note that the SIL for the lowest curve in this chart is about 85 db. If cabin noise is at this level, astronauts will probably prefer to communicate with intercoms rather than by shouting. The criteria in this chart are for SPL's at the ear. If ear defenders are used, their effect will be to attenuate noise selectively to produce a different spectral distribution of sound energy. For example, the noise of an F-100 fighter during warm-up will exceed the three-minute daily exposure curve of this chart. A mechanic servicing such aircraft will normally have to expose himself to the noise for, let us say, 60 minutes a day. He could do so if he wore ear defenders that would attenuate the sound from the jet to give an SPL at the ear drum that was below the 60-minute daily exposure level.

ITEM NO.	SUBJECT AREAS:	SOURCE:
175	SYSTEM - S5 HUMAN - H34	Reference 554 p. 304 Based on Reference 313.



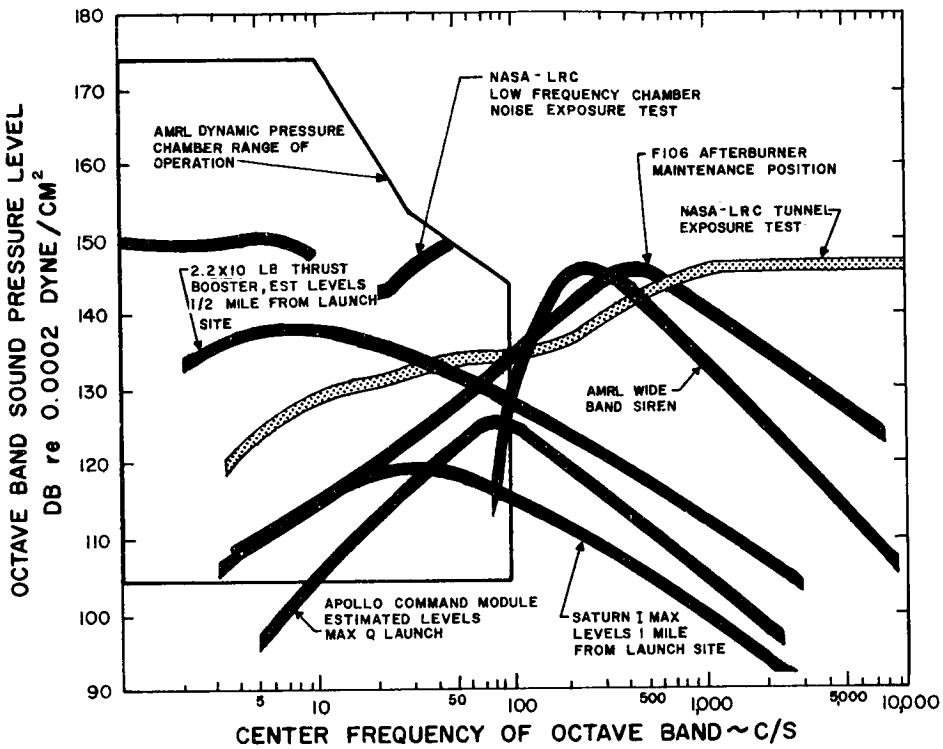
Damage risk contours for one exposure per day to certain octave (left hand ordinate) and certain 1/3 octave or narrower (right hand ordinate) bands of noise. This graph can be applied to the individual band levels present in broad band noise. Solid line: New contours proposed by CHABA Working Group 46; broken line (large) represents Glorig (A.A.O.O.), proposed by ISO; broken line (small) is proposed extension for revision of AFR 160-3 (exposure times in parenthesis apply).

ITEM NO.	SUBJECT AREAS:	SOURCE:
176	SYSTEM - S5 HUMAN - H34	Redrawn from Reference 547, p. 329 Based on References 29, 30, 213.



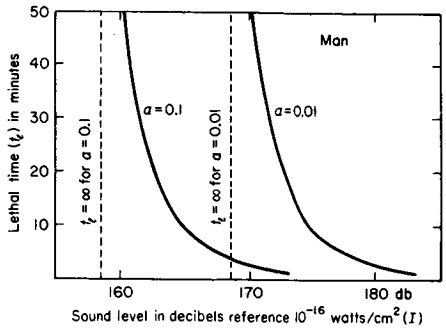
Thresholds for aural pain produced by pure tones and jet noise. Points represent means of 3-4 determinations. Duplicate points represent means taken on different days. Positive and negative static pressures in the external ear canal are referred to atmospheric pressure. Line representing jet noise threshold is placed at overall sound pressure level and extends to the frequencies of the octave bands (300-600 and 600-1200) carrying most of the sound energy. (Touch and Pain-Tickle thresholds after Békésy.) Solid line represents new contours proposed by CH-ABA Working Group 46, broken line Glorig (A. A. O. O.) proposed by ISO.

ITEM NO.	SUBJECT AREAS:	SOURCE:
177	SYSTEM - S5 HUMAN - H34	Reference 547, p. 329 Based on References 213 and 545.



Low frequency noise environments used in human exposure tests. In a series of tests a limited number of healthy human subjects safely tolerated without gross performance decrements the sound spectra indicated. The dots indicate the individual exposures to the NASA-Langley Research Center Low-Frequency Chamber. The measured spectrum for a Saturn booster and the estimated spectrum for a 2.2 · 170 lb. thrust booster are to indicate the shift of the noise spectrum to lower frequencies with increasing thrust.

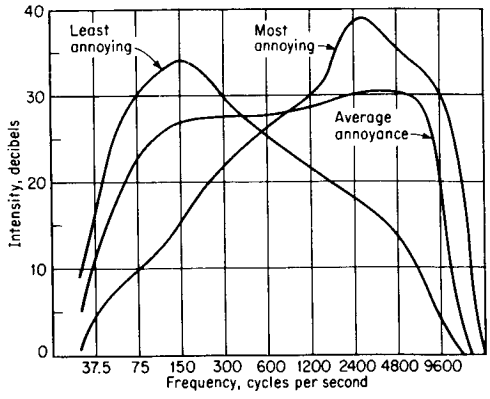
ITEM NO.	SUBJECT AREAS:	SOURCE:
178	SYSTEM - S5 HUMAN - H34	Redrawn from Reference 547, p. 330. Based on Reference 376.



Lethal time, t_l, as a function of sound intensity, I, for unclothed man (calculated).

Estimation of the specific sound intensity level which would cause dangerous overheating of man is extremely difficult. As a first approximation, however, let the maximum amount of heat which an unclothed human body may be able to dissipate, under room temperature and favorable conditions of humidity and air circulation, be about ten times the normal metabolism or 600 kilo calories per hour. According to H. E. von Gierke, H. O. Parrack, and D. H. Eldredge, the lethal time as a function of intensity is shown in the figure above for two values of the absorption coefficient. Measurements indicate that this coefficient is about 0.25 over small areas of human tissue. It is, therefore, reasonable to suspect that the whole body surface would have an average value of absorption coefficient somewhere between 0.01 and 0.1. Normal clothing may be expected to furnish some small amount of protection.

ITEM NO.	SUBJECT AREAS:	SOURCE:
179	SYSTEM - S5 HUMAN - H34	Reference 197, p. 571. Based on Reference 546.

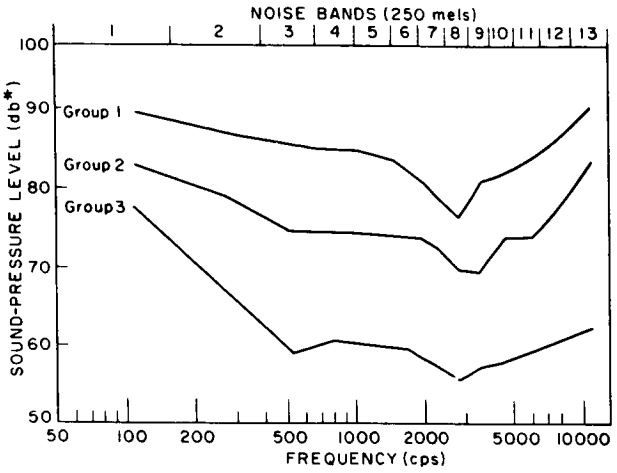


Generalized spectra of three sounds of equal (total) loudness vary in judged "annoyance." Note that the most annoying sound has greater relative intensity in the higher frequencies and the least annoying sound has greater relative intensity in the lower frequencies.

While the effects of noise upon human performance are not yet well established, both research and common everyday experience confirm the fact that noise can be subjectively annoying to people. While the specific characteristics that cause noise to be considered as annoying are not yet adequately known, in general terms it is fairly well established that annoyance is associated more with high frequencies, high intensity, intermittency, and reverberation. To illustrate the greater annoyance of high frequencies, a study by Fenwick will be summarized briefly. In that study, 32 different sound spectra were generated, varying in the relative intensity in each of eight octave bans. These were then equated for subjective loudness, and were presented in pairs to groups of subjects with instructions to indicate which sound (of each pair) was the more annoying. These judgments were then summarized and analyzed, and the 32 sounds were then ordered in terms of their annoyance. The figure above shows generalized spectra of three of the sounds, ranging the gamut of annoyance. It can be seen that, in general, the "most annoying" spectrum has greater relative intensity in the higher frequencies than in the lower frequencies.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
180	SYSTEM - S5 HUMAN - H35	Reference 362, p. 478. Based on Reference 191.



*Re 0.0002 μbar

NOISE BANDS NO.	RANGE (cps)
1	50 — 160
2	160 — 394
3	394 — 670
4	670 — 1000
5	1000 — 1420
6	1420 — 1900
7	1900 — 2450
8	2450 — 3120
9	3120 — 4000
10	4000 — 5100
11	5100 — 6600
12	6600 — 9000
13	9000 — 13000

Threshold of annoyance for bands of noise. Annoyance-threshold judgments of 20 observers on 13 noise bands. Observers were divided into three subgroups. Upper curve represents mean judgments of six observers who has once worked at noisy jobs and who imagined some definite work situation while making judgments. Middle curve represents mean judgments of seven observers who had only worked at quiet jobs and who imagined some definite work situation while making judgments. Lower curve represents mean judgments of seven observers who had only worked at quiet jobs and who attended to the noise as such, or otherwise did not imagine any definite work situation while making judgments.

ITEM NO.	SUBJECT AREAS:	SOURCE:
181	SYSTEM - S5 HUMAN - H35	Reference 380, p. 475. Based on Reference 488.

RECOMMENDED LIMITATIONS FOR AIRBORNE NOISE ABOARD SHIP

Maximum sound-pressure levels recommended for occasional exposure should be considered in all accessible areas.

Watch stations not requiring speech communication should follow levels tested under Repeated Exposure. (see table below).

Watch stations requiring minimum speech communication should observe the maximum permissible levels recommended under Repeated Exposure (below) and the speech-interference limits.

Spaces requiring close-up speech communications without strain and with other communication from loudspeakers possible to all parts of the area should maintain speech interference level below 70 db.

Small spaces (less than 5000 cubic feet) requiring speech communication to all parts of the area without strain should maintain a level below 60 db.

For noisy berthing spaces use values given under Noisy Comfort Criterion (below).

For social spaces, such as messing areas, use speech-interference level below 60 db.

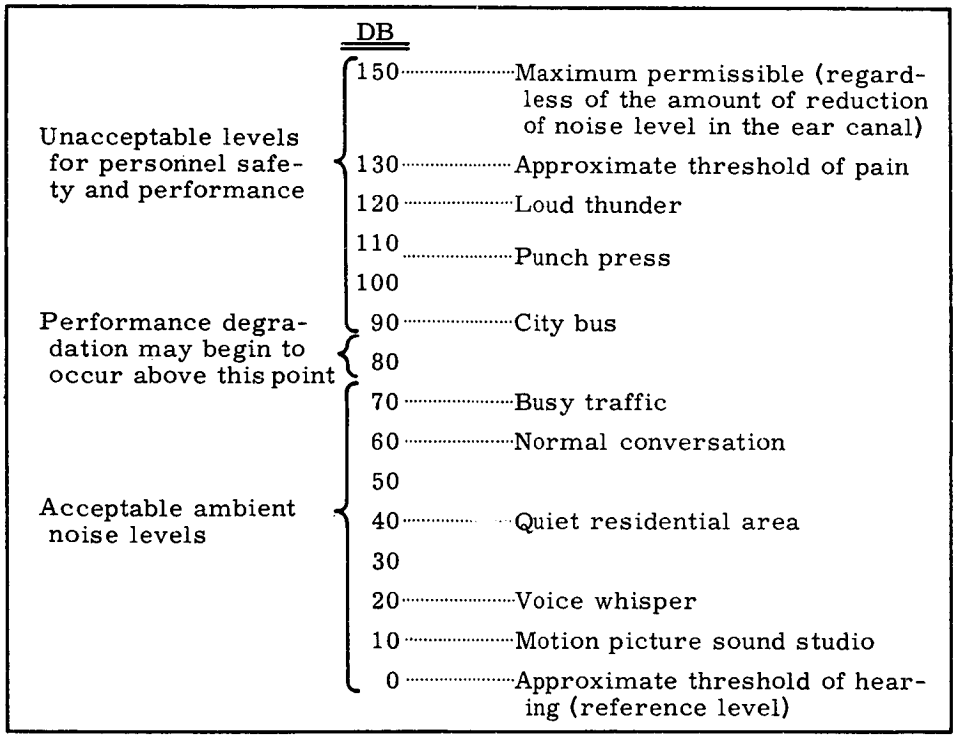
Special quiet ship spaces, such as sick bay, should maintain levels given under Quiet Comfort Criterion (below).

LIMITS FOR DEAFNESS-AVOIDANCE AND COMFORT

	MAXIMUM PERMISSIBLE SOUND PRESSURE LEVEL (db above 0.0002 microbar)			
	DEAFNESS-AVOIDANCE CRITERION		COMFORT CRITERION	
OCTAVE BAND	OCCASIONAL EXPOSURE (1 hour or less)	REPEATED EXPOSURE (period of months)	NOISY (people expect noise)	QUIET (people expect quiet)
38- 75	125	115	100	80
75- 150	120	110	95	70
150- 300	120	110	90	60
300- 600	120	105	85	55
600-1200	115	100	75	50
1200-2400	110	95	65	50
2400-4800	105	90	60	50
4800-9600	110	95	55	45

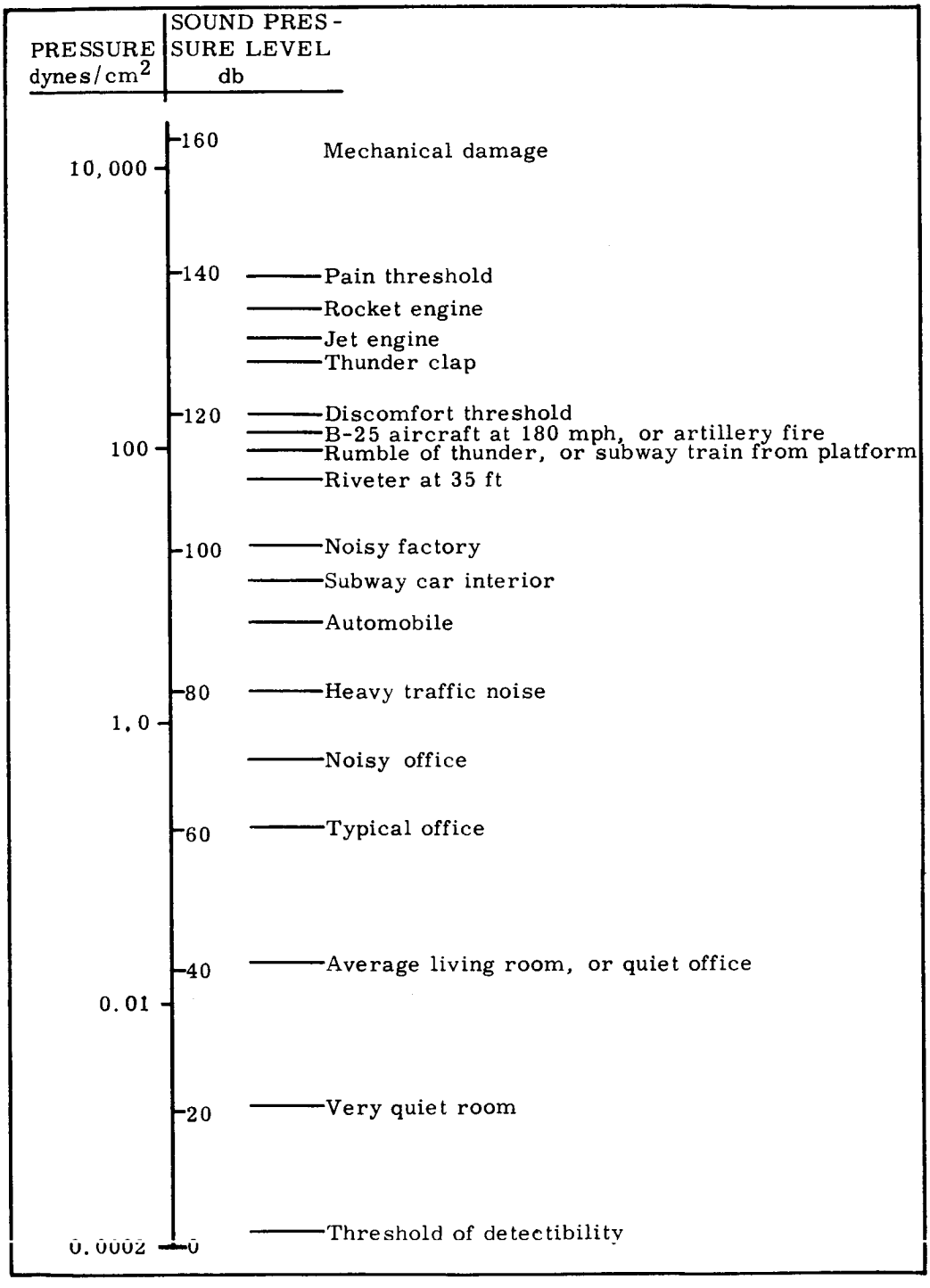
ITEM NO.	SUBJECT AREAS:	SOURCE:
182	SYSTEM - S5 HUMAN - H33, H34	Reference 586 p. 2-224. Based on Reference 499.

INTENSITY LEVELS OF SOME COMMONLY EXPERIENCED SOUNDS.



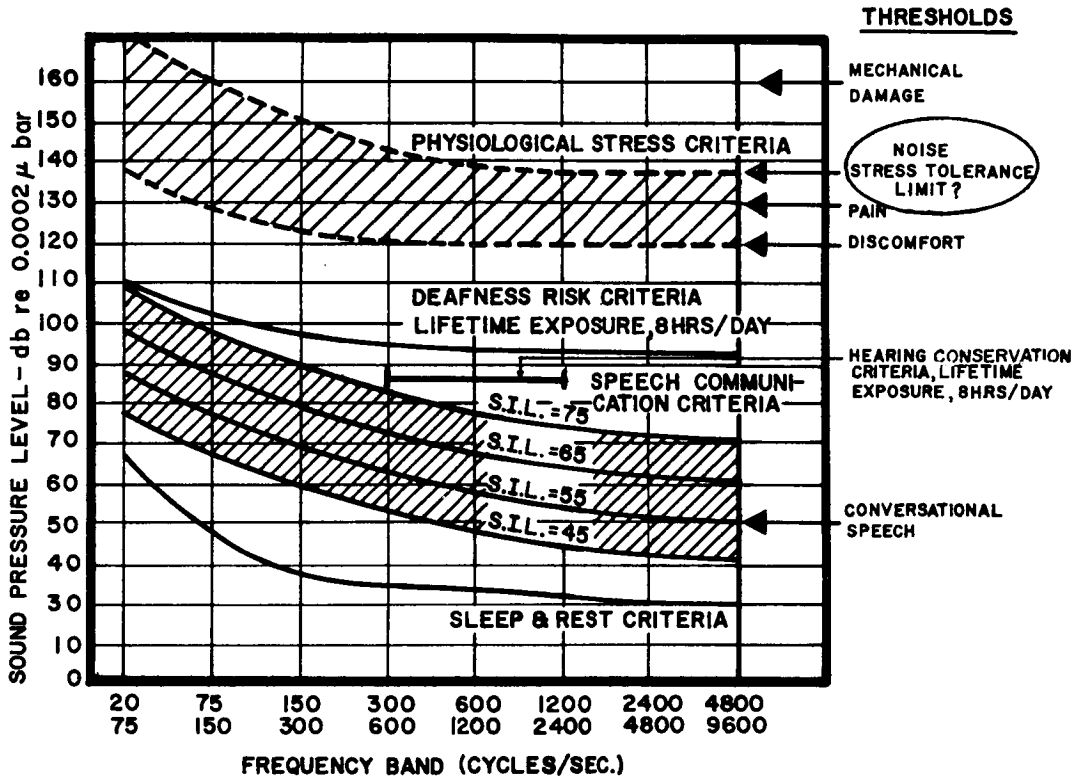
ITEM NO.	SUBJECT AREAS:	SOURCE:
183	SYSTEM -S5 HUMAN- H33, H34	Reference 31, p.10-20

INTENSITY OF COMMON SOUNDS



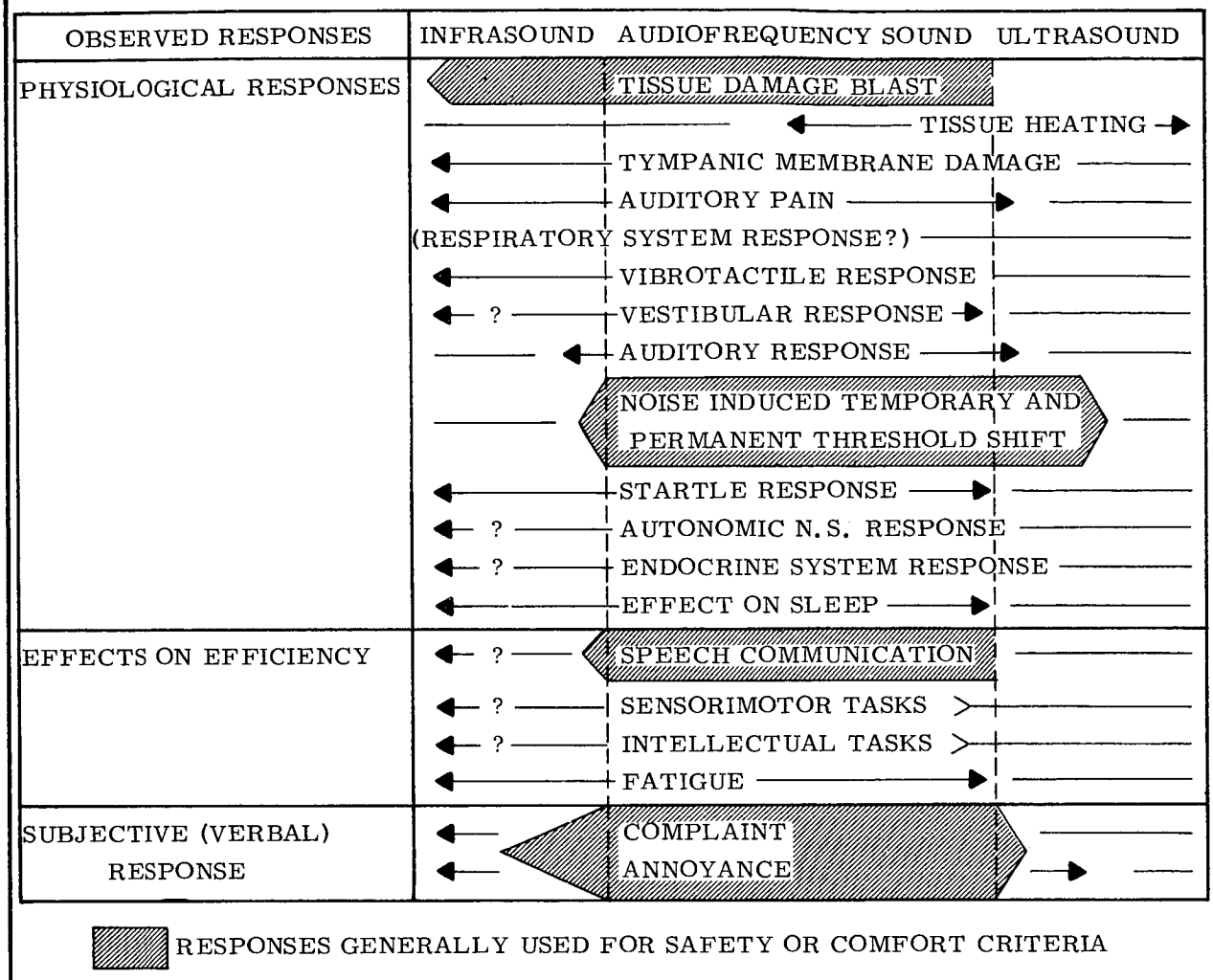
ITEM NO.	SUBJECT AREAS:	SOURCE:
184	SYSTEM - S5 HUMAN - H33, H34	Reference 555, p. 177. Adapted from Anthony & Ackerman, WADC TR 57-647.

TOLERANCE CRITERIA FOR NOISE



Criteria for evaluating tolerance limits for continuous exposure to wide-band noise in terms of sleep, speech interference level (S.I.L.), hearing conservation, and risk of deafness; and for immediate physiological stress reactions and mechanical damage to the ear. (Adapted from WADC TR 58-622, 1958, after Parrack and Glorig, 1952.)

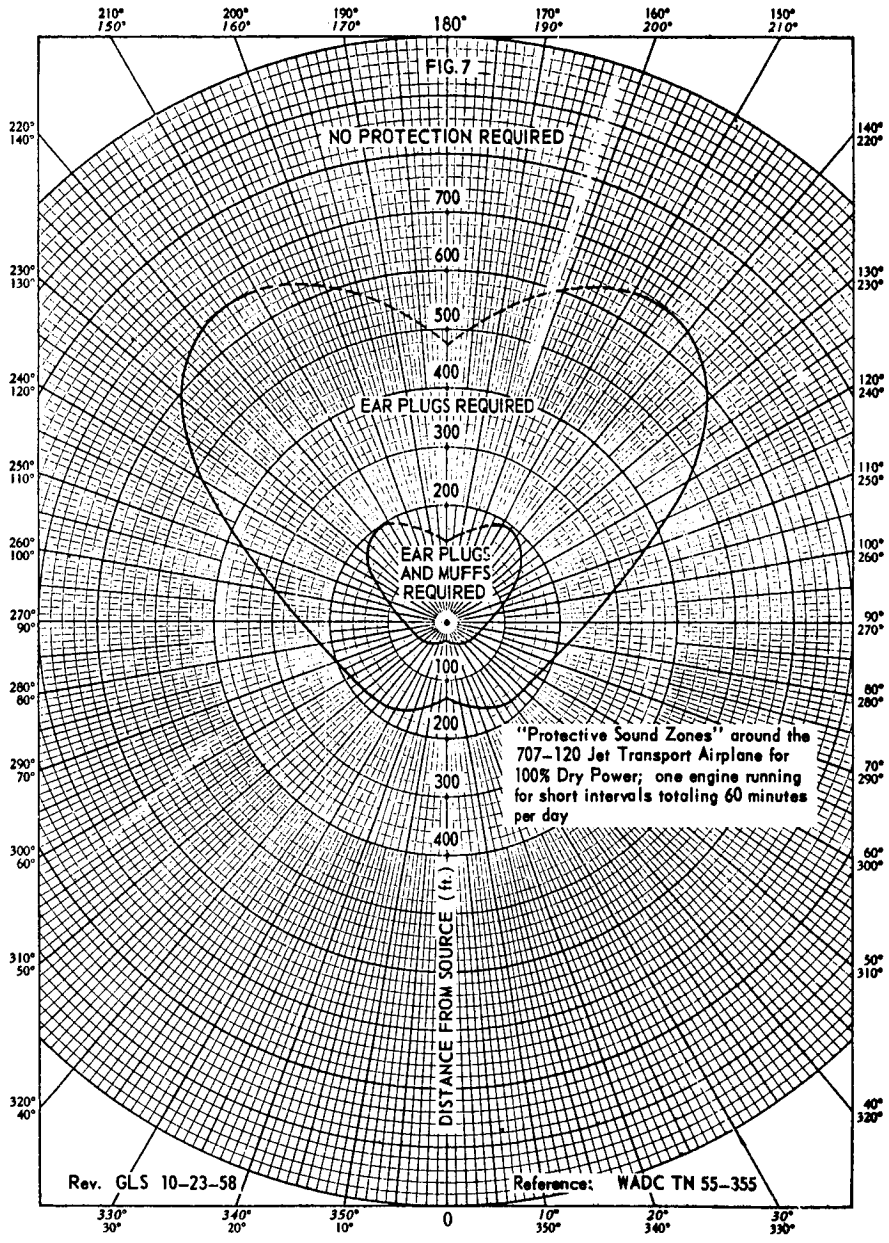
ITEM NO.	SUBJECT AREAS:	SOURCE:
185	SYSTEM - S5 HUMAN - H33, H34	Reference 555, p. 179.



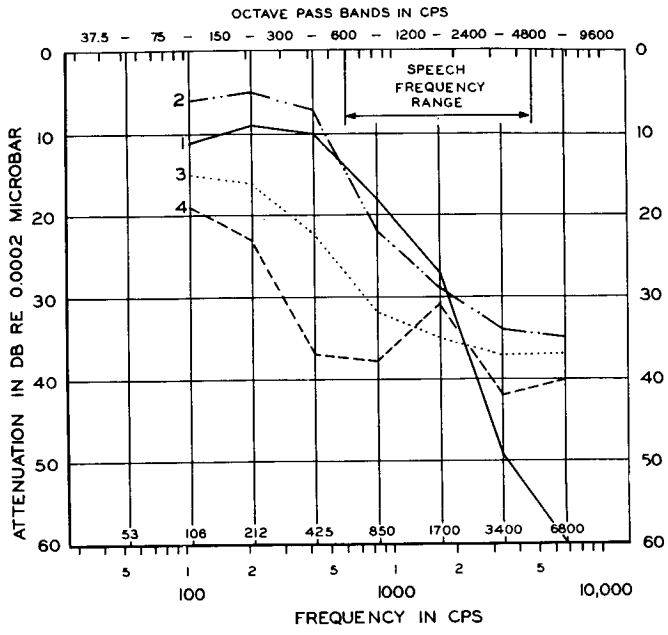
Human responses to airborne noise and impulses.

ITEM NO.	SUBJECT AREAS:	SOURCE:
186	SYSTEM - S5 HUMAN - H34, H35	Redrawn from Reference 547, p. 327.

JET ENGINE NOISE -- GROUND OPERATIONS



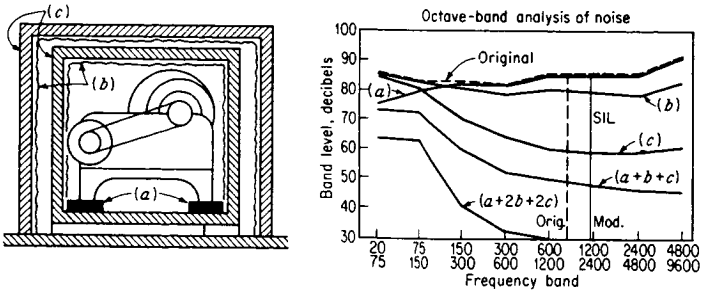
ITEM NO.	SUBJECT AREAS:	SOURCE:
187	SYSTEM - S5 HUMAN - H44	Reference 59.



Reduction of ambient noise reaching the ears provided by various types of helmets and earmuffs. 1. Full pressure helmet with earmuffs inside providing a poor seal around the ear (thin sponge rubber seal). 2. Protective flying helmet with earmuffs inside (thin sponge rubber cushion; poor seal). 3. Protective flying helmet with effective earmuffs (liquid filled cushion; good seal). 4. Effective earmuffs (liquid filled cushion; good seal) with headset inside for use by ground crews. This earmuff has a larger air volume under the muff than the earmuff used in the protective helmet above (3) and therefore it provides more attenuation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
188	SYSTEM - S5 HUMAN - H44	Reference 548, p. 63 Based partly on Reference 559.

a



Illustrations of the possible effects of some noise-control measures. The lines on the graph show the possible reductions in noise (from the original level) that might be expected by vibration insulation (a), an enclosure of acoustical absorbing material (b), a rigid, sealed enclosure (c), a single combined enclosure plus vibration insulation, (a + b + c), and a double combined enclosure plus vibration insulation (a + 2b + 2c).

b

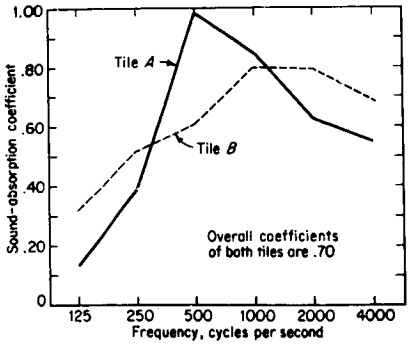
Transmission Loss for Various Wall Sections and for Various Porous Solids

Description	Average transmission loss, decibels
Wall sections:	
1/2-in. plaster on wood lath over 2- by 4-in. studs	42
Brick with plaster—both sides	42
3/8-in. plasterboard on wood frame	27
1 3/4-in. solid-oak door—normal cracks	20
Double-strength annealed window glass	27
Porous solids:	
Hollow-tile partition 4 in. thick	11
Hollow tile as above but plastered	35
Clinker-concrete slab, 3 in., unplastered	23
4-in.-thick rock wool—5-lb density	8

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ITEM NO.	SUBJECT AREAS:	SOURCE:
189	SYSTEM-S5 HUMAN-H44	Reference 362, p. 486. Based on references 410 (fig. a) and 33 (table 6).

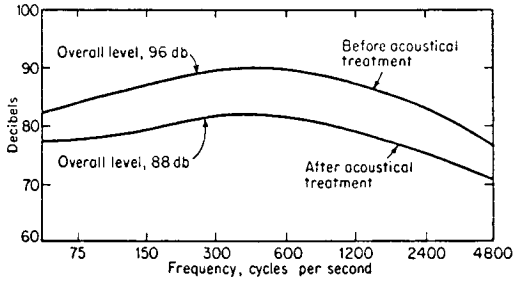
a



Comparison of sound-absorption coefficients by frequency for two different acoustical tiles having the same overall coefficients.

Acoustical materials vary in their total effectiveness and in the reduction of noises of different frequencies. The efficiency of acoustical materials is usually measured by a sound-absorption coefficient; this is the ratio of the energy absorbed to the total energy that strikes the surface. Because of differences in sound absorption of different frequencies, however, materials with similar overall coefficients can have different effects in noise reduction, as illustrated above. This shows for two acoustical tiles, A and B, with the same overall sound-absorption coefficient of .70, that the differences in coefficients for various frequencies are very noticeable. Tile A would then be more effective in reducing noise that had predominant components in the 500- to 1000-cps range, whereas tile B would be more effective in reducing noise that had predominant components in the higher frequencies of 2000 to 4000 cps.

b

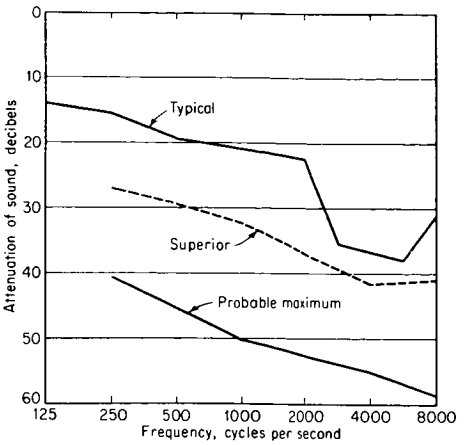


Spectrum of noise before and after acoustical treatment.

An example of the effect of acoustical treatment in a very noisy machinery room in a factory is shown in Figure b. The overall noise level was reduced from about 96 db to about 88 db.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
190	SYSTEM -S5 HUMAN- H44	Reference 362, p. 488-489. Based on References 413 and 88.



Attenuation of sounds resulting from the use of ear protectors as determined by laboratory tests. The "typical" line shows the usual degree of attenuation, and the "superior" line, the degree when the hearing device is well fitted.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
191	SYSTEM - S5 HUMAN - H44	Reference 362, p. 490. Based on Reference 574.

USE OF THE ACOUSTIC REFLEX FOR NOISE PROTECTION

The acoustic reflex is a reflex contraction of the two intra-aural (middle-ear) muscles that occurs spontaneously when certain tones above about 70 db occur. The contraction of these muscles serves to reduce the transmission of vibrations through the middle ear for a short time. The possibility of capitalizing on the acoustic reflex to provide protection against impulse noise would depend upon the feasibility of inducing the reflex just before the occurrence of the noise. In the case of such noises as from gunfire, drop hammers, dynamite blasts, etc., it presumably would be possible to cause a tone to be sounded at some predetermined brief interval before the impulse noise.

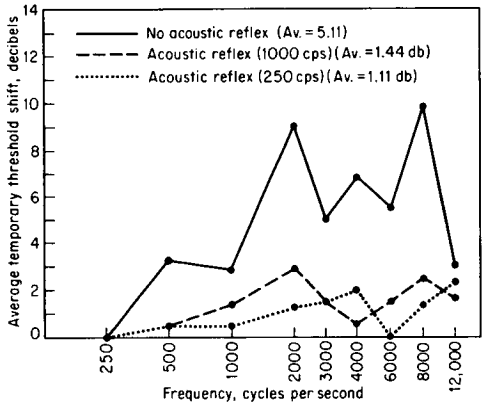
a

OVERALL THRESHOLD SHIFTS

No protection	19.23 db
Acoustic reflex	6.27 db
Earplugs	2.50 db

The table above presents the temporary threshold shifts with and without the acoustic reflex. The use of the acoustic reflex with machine gunfire was investigated with a 1000 cps tone of 98 db presented 200 milliseconds before each shot.

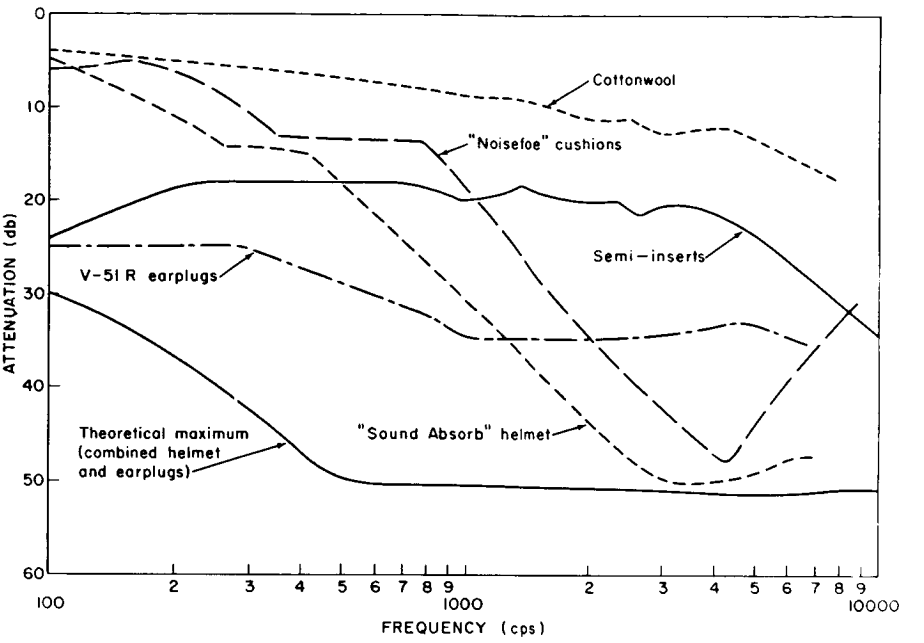
b



Average temporary threshold shift produced with and without acoustic reflex inducing tones.

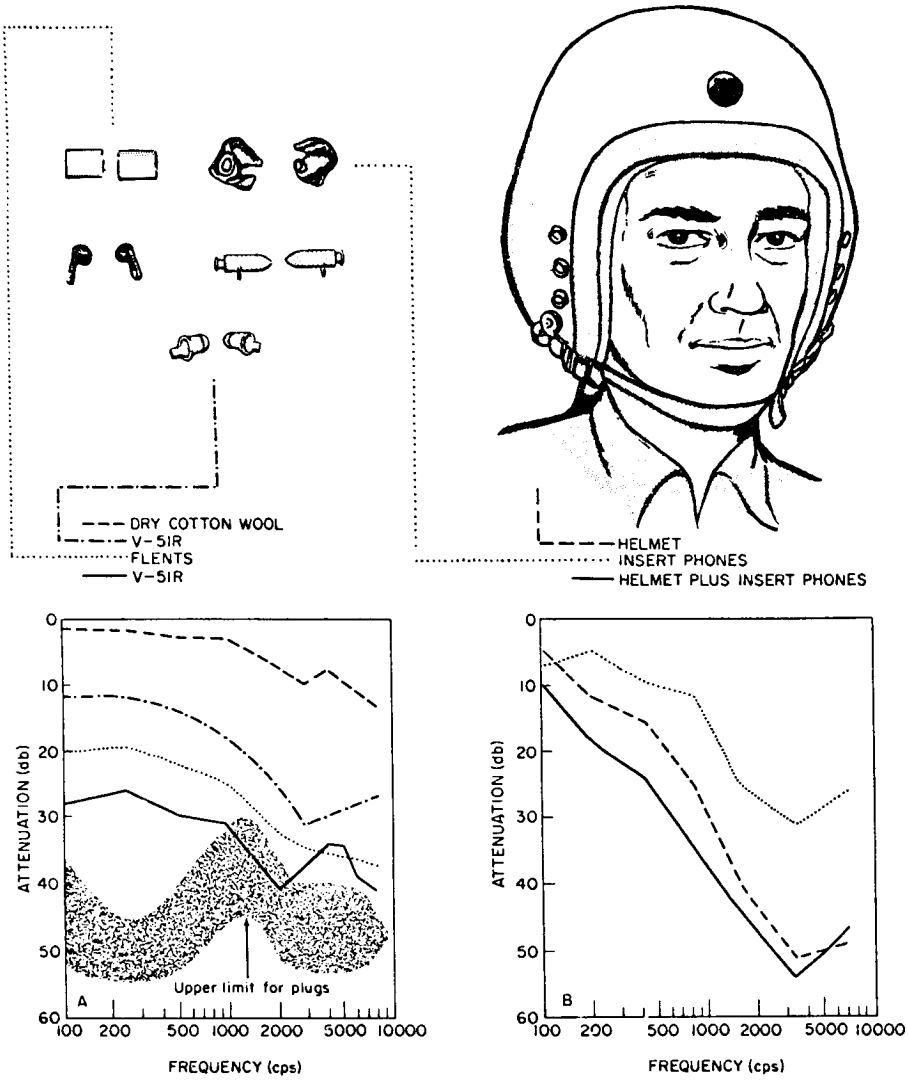
In the study above, a comparison was made of protection by the acoustic reflex against the (recorded) sound of a drop hammer. The acoustic reflex tone was increased from 70 to 100 db over 250 milliseconds (m sec), and was presented approximately 400 to 600 m sec before each impact. Tones of 250 and 1000 cps were used in different phases of the study.

ITEM NO.	SUBJECT AREAS:	SOURCE:
192	SYSTEM - S5 HUMAN - H44	Reference 362, pp. 491-492. Based on Reference 195(fig. a) and 124 (fig. b)



The figure above compares the attenuation characteristics of all types of ear-protective devices. Earplugs and ear muffs can be worn at the same time, however, to provide greater attenuation than either alone can provide, but the attenuation afforded by the combination is not the sum of the two separate attenuations; it is usually less than that sum. Another combination is a rigid helmet with earplugs that are worn under the helmet. This combination provides the theoretical maximum attenuation (50 db).

ITEM NO.	SUBJECT AREAS:	SOURCE:
193	SYSTEM- S5 HUMAN- H44	Reference 380 p. 478. Based on Reference 599.

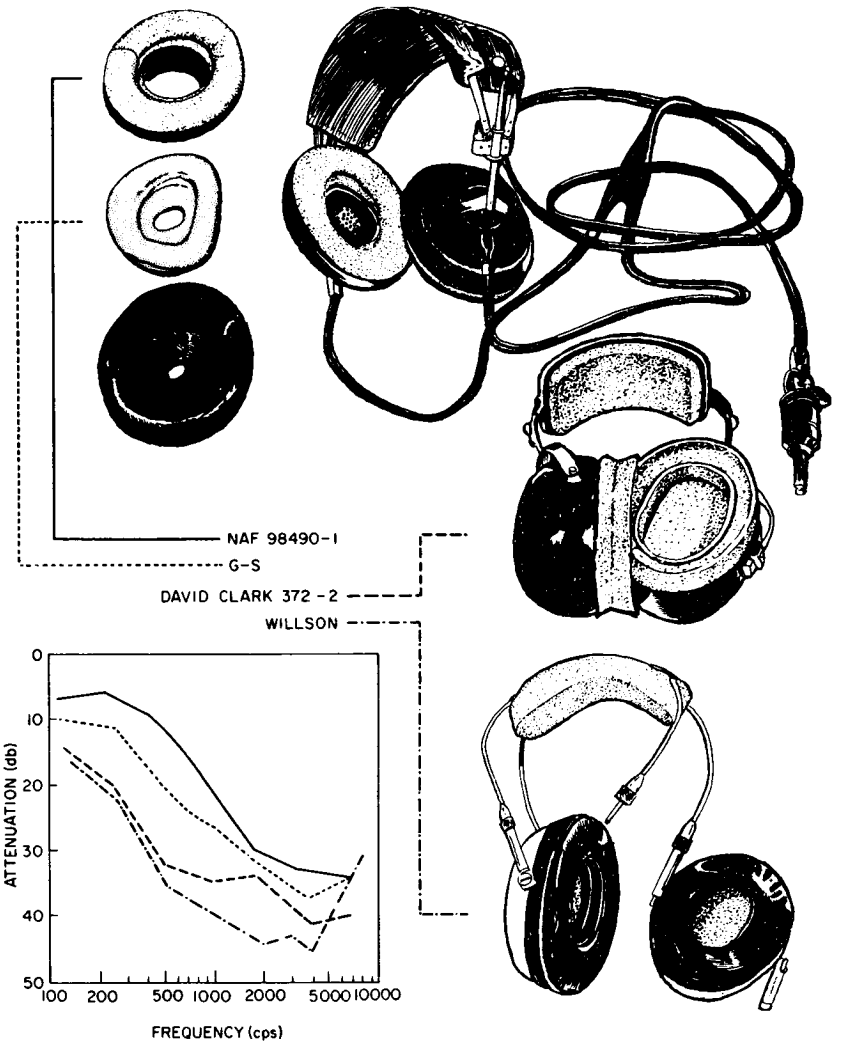


Attenuation provided by typical earplugs is shown in the figure above. Various earplugs are shown in the upper left, and their real-ear attenuation is plotted below. It can be seen that dry cotton is a very poor attenuator, but paraffin-impregnated cotton (FLENTS), when properly inserted in the ear canal, provides good attenuation. The V51-R is molded of soft rubber or neoprene in three sizes. The solid curve shows its attenuation with an optimum fit; the dash-dot curve shows an average for a group of 20 unselected persons in which it is expected that some have not obtained a very good fit.

The right-hand graph shows that the attenuation of individually molded insert earphones is no better than that of general-purpose plugs. The helmet shown in the upper right contains cups over the ears and seals to the head by means of an edge bead. The solid curve shows the attenuation of insert and helmet worn together.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
194	SYSTEM - S5 HUMAN - H44	Reference 380 p. 479.

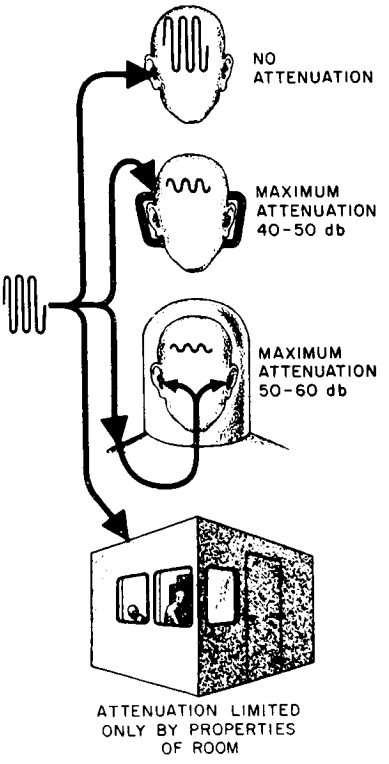


Acoustic attenuation of ear muffs and earphone sockets. Standard Navy headset with NAF 48490-1 sockets is shown at top right. At top left, reading down, are NAF 48490-1 (Kapok-filled chamois), Grason-Stadler (Mastic-filled plastic), and RCA (glass-fiber-filled rubber) ear muffs. Earphones in center and lower right are fitted with NAF 48490-1 and Grason-Stadler sockets. Willson ear muff has fluid-filled sac. David Clarke ear muff has foam rubber seal.

An ear muff of the highest attenuation is made of dense material. It encloses a large volume with a minimum opening at the ear or head. A properly designed muff has an attenuation as large or larger than an earplug at frequencies above 1,000 cps and approaches the attenuation of an earplug at lower frequencies. Attenuation of typical ear muffs and phone sockets is shown in the figure above.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
195	SYSTEM - S5 HUMAN - H44	Reference 380, p. 481.

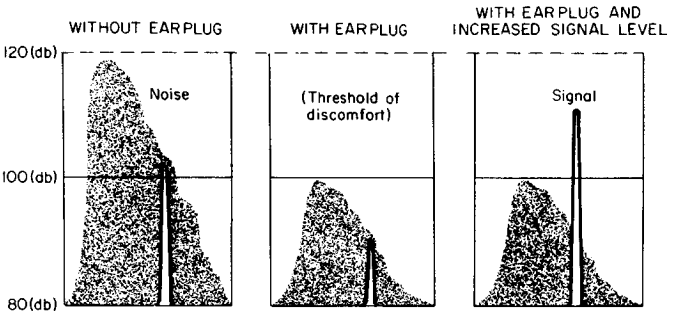


Maximum ear protection afforded by various devices. Protection that closes or covers ears only is limited to about 40 or 50 db before it becomes bypassed by bone conduction. Covering entire head allows another 10 db of attenuation before body-conducted sound bypasses helmet. Complete enclosure of entire body is required to get protection greater than about 60 db.

The head must be completely enclosed in a suitable helmet to obtain protection that appreciably exceeds the bone-conduction threshold. Even when the head is completely enclosed, attenuation is increased only about 10 db over the bone-conduction limit because sound is then transmitted to the head through the body.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
196	SYSTEM - S5 HUMAN - H44	Reference 380, p. 483.



Earplugs also can be used to increase the detection of signals in very intense noise. When noise levels are very high (110 db or above), the use of an earplug makes a signal more detectable. This is possible because the ear at high intensities acts like a peak clipper or compressor and fails to respond linearly to the signal. By reducing the overall level of the noise and the signal with earplugs, the sound-pressure level is brought within the range at which the ear responds more linearly, and signals are more easily detected.

Very-high-noise levels approach the threshold of discomfort and narrow the dynamic range of the ear. At such levels, an operator is unwilling to increase the gain (where it is possible to adjust the gain) because an increased signal becomes uncomfortable. Earplugs, however, reduce the level of both the noise and the signal, thereby enlarging the ear's usable dynamic range. By increasing the gain now, the signal-to-noise ratio (S/N) is increased, and the signal is more easily detected. Of course, this procedure does not work if the background noise is electrically amplified and comes through the same gain control as the signal.

When adequate signal power is available and earphones have good power-handling capacity, another method of improving the S/N ratio is feasible: earplugs worn under earphones equipped with ear muffs. The plugs attenuate both signal and noise by 20 db or so, but the signal is then restored by additional gain to the same level it would have been in the absence of the earplug. The net advantage in S/N ratio is then 20 db.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
197	SYSTEM - S5 HUMAN - H25, H44	Reference 380, p. 480.

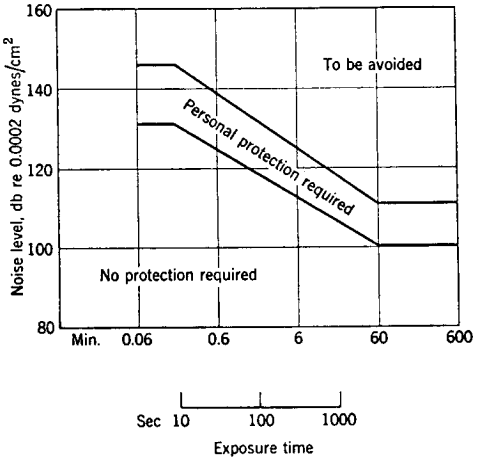
PROTECTION AGAINST NOISE

a

Permissible Values for Noise Intensity and Duration

Sound Level, db in 0.0002 dynes/cm^2	Maximum Allowable Exposure Time
With no ear protection	
108	1 hr
120	5 min
130	30 sec
135	10 sec or less
With ear plugs	
112	8 hr
120	1 hr
132	5 min
142	30 sec
147	10 sec

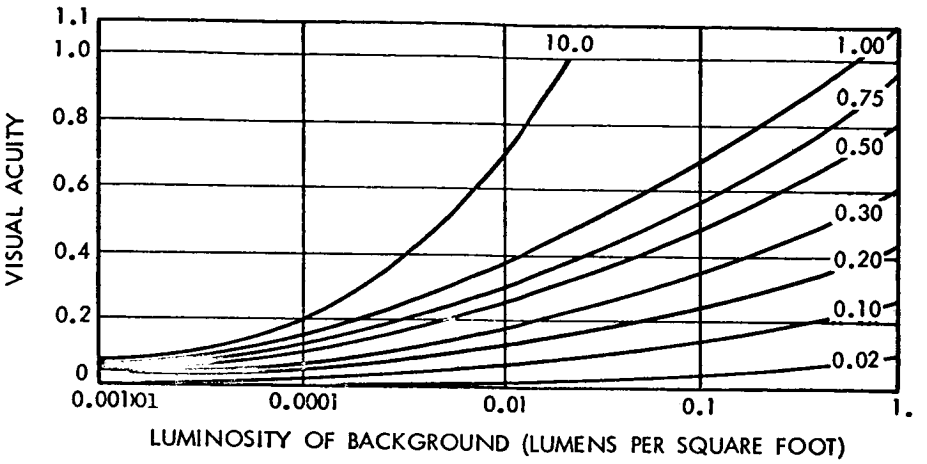
b



Allowable noise exposure per day (based on Air Force experience).

As can be observed in the table and figure above, noise levels of about 135 db are tolerable for 5 minutes to humans if they are wearing earplugs or other forms of noise defenders. This noise level is expected from our present boosters; if noise levels reach 150 db, human tolerance would be maximized at about 10 sec. Such high-energy acoustic noise can produce nausea, disorientation, deafness, injury to internal organs, and even death.

ITEM NO.	SUBJECT AREAS:	SOURCE:
198	SYSTEM- S5 HUMAN- H33, H44	Reference 416, p. 70-71. Based on References 348 (table a) and 41 (figure b).

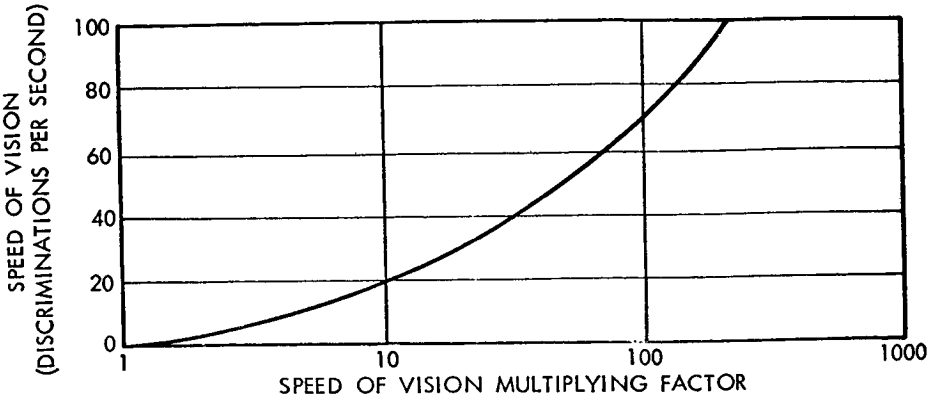


Illumination Required to See an Object as a

Function of Specific Contrast and Visual Acuity

The amount of illumination required to see an object as a function of specific contrast and visual acuity is presented in the figure above. Contrast for various tasks can be determined from the formula C = LD-LO/LA where C is contrast, LA is luminosity to which the eye is adapted, LB is luminosity of the target background, and LO is luminosity of the target.

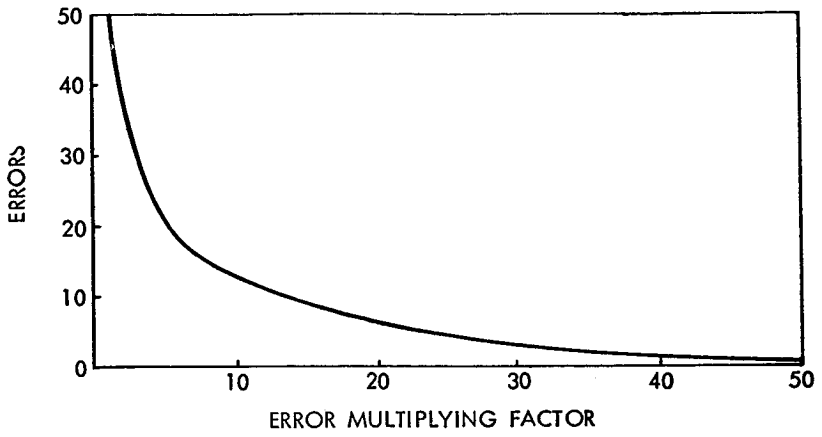
ITEM NO.	SUBJECT AREAS:	SOURCE:
199	SYSTEM - S6 HUMAN - H25	Reference 378, p. 199



Illumination Increase to Heighten Speed of Vision

The amount that illumination must be increased to obtain increased speed of vision is illustrated in the figure above. The speed of vision is expressed in discriminations per second with discrimination task being the identification of the opening in a Landolt ring (capital letter C). The determination of the number of discriminations per second involved in a given task would be based on a correlation between the time to do this task and the time to identify C openings with all conditions being identical.

ITEM NO.	SUBJECT AREAS:	SOURCE:
200	SYSTEM - S6 HUMAN - H25	Reference 378, p. 199 Based on reference 472.



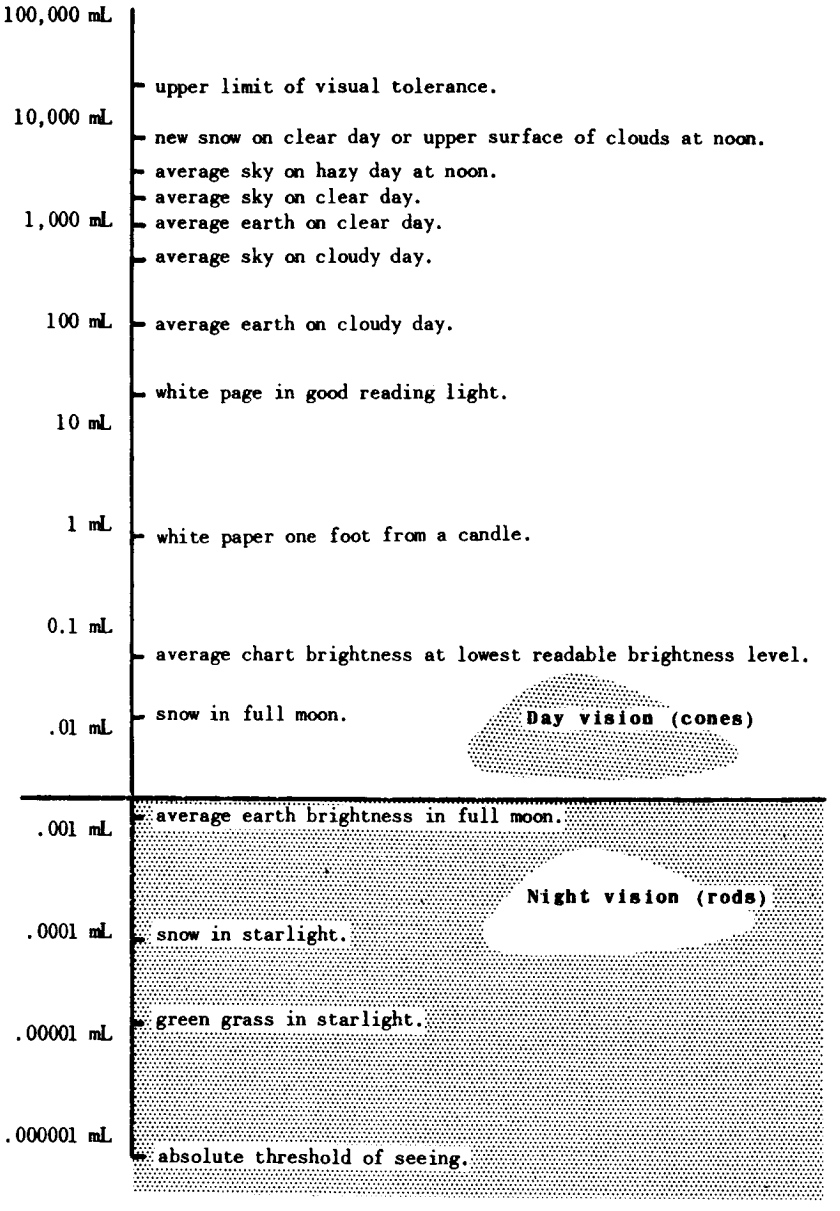
Illumination Increase Required to

Reduce Error in Vision

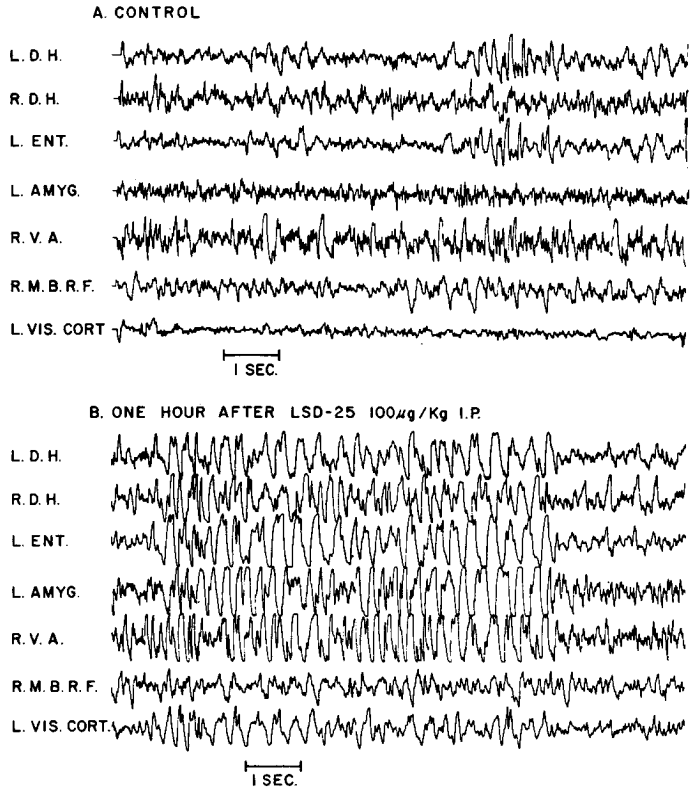
The amount that illumination must be increased to obtain increased accuracy of vision is illustrated in the figure above. Basic data on visual task performance as a function of other factors (speed, acceleration, etc.) has been based on 50% reading accuracy. The multiplying factor developed by Shearer and Downey was determined by evaluating data on reading instruments and on identifying the area occupied by a target. The shape of the curve is influenced by contrast, adaptation of the eye, acuity, speed of vision, and task difficulty.

ITEM NO.	SUBJECT AREAS:	SOURCE:
201	SYSTEM-S6 HUMAN- H25	Reference 378, p. 201 Based on reference 472.

TABLE OF APPROXIMATE BRIGHTNESSES



ITEM NO.	SUBJECT AREAS:	SOURCE:
202	SYSTEM - S6 HUMAN - H25	Reference 53, p. 74



Paroxysmal bursts of high amplitude slow waves induced by LSD-25 (100hg/Kg) under conditions of reduced auditory and visual stimulation. Channels from above down are left and right dorsal hippocampus, left entorhinal cortex, left amygdala, right nucleus ventralis anterior, right midbrain reticular formation, left visual cortex.

Studies have indicated that small doses of hallucinogenic drugs, including LSD, and LSD analogs, such as psilocybin and psilocin, regularly produce seizure-like discharges in the deep structures of the temporal lobe (dose 25 µg/kg LSD), particularly in the hippocampal system, but only under conditions of reduced sensory input, such as a darkened, quiet box. When these animals were exposed to a normally lit environment, the seizure discharges disappeared, and there was no disruption of learned performances. At higher dose levels (50-100 µg/kg LSD), these electrical seizure discharges persisted in well lit environments, and occurrence of these episodic discharges during attempted discrimination resulted in a failure of performance. Behavior during these episodes clearly indicated hallucinations, with pawing and clawing at unseen objects.

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
203	SYSTEM - S6 HUMAN - H 14, H 25, H 38	Reference 6, p. 419

REPORTS OF HALLUCINATIONS UNDER VARYING CONDITIONS OF MOTILITY AND VISION*

Experimenters	Motility	Visual Field	Hallucinations
Wexler et al.	Restricted	Monotonous, dim light	Yes
Heron et al.	Restricted	Homogeneous, diffuse	Yes
Goldberger and Holt	Restricted	Homogeneous, diffuse	Yes
Freedman et al.	i Restricted ii Restricted	Homogeneous, diffuse Blackout	Yes Yes
Cohen and Silverman	Restricted	Blackout	Yes
Vernon et al.	Free	Blackout	i None ii Minimal
Ruff and Levy	Free	Blackout	Minimal

* After Freedman and Greenblatt.

Purser, P. E.; Faget, M. A. and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
204	SYSTEM - S5 HUMAN - H25, H35	Reference 219, p. 306 Based on several sources, compiled on reference 203.

Illumination Required for Various Tasks on a Space Vehicle

Task	Visual Acuity	Percent Contrast	Threshold Background Luminosity (Footlambert)	Speed of Vision Required	Speed of Vision Factor	Acceleration	Acceleration Force Factor	Percent Accuracy Required	Accuracy Factor	Min. Luminosity Required (Footlambert)	Approximate Illumination Reqd. (Footcandles)
	A	B	C	D	E	F	G	H	I	J	K
Map and Chart Reading	0.25	90	0.004	30	20.0	4	3	1	50	12.0	20.0
Instrument Reading	0.25	150	0.003	50	50.0	4	3	1	50	22.5	30.0
Operate Radios	0.25	150	0.003	50	50.0	4	3	1	50	22.5	30.0
Operate Flight Controls	0.1	20	0.004	5	2.5	4	3	1	50	15.0	30.0
Perform Calculations	0.25	50	0.01	20	10.0	1	1	1	50	5.0	10.0
Prepare Reports	0.25	50	0.01	20	10.0	1	1	1	50	5.0	10.0
Clean Compartment	0.1	30	0.003	5	2.5	1	1	1	50	3.75	10.0
Scullery	0.25	20	0.1	20	10.0	1	1	1	50	50.0	60.0
Maneuver in Area	0.05	30	0.0001	5	2.5	1	1	1	50	0.0125	0.02
Enter & Leave Compartment	0.05	30	0.0001	5	2.5	1	1	1	50	0.0125	0.02
Reading for Pleasure	0.25	150	0.003	50	50.0	1	1	1	50	7.5	10.0
Playing Recreational Games	0.2	50	0.006	30	20.0	1	1	1	50	6.0	10.0
Preparing Food	0.25	90	0.004	30	20.0	1	1	1	50	4.0	5.0
Eating Food	0.25	30	0.035	5	2.5	1	1	1	50	4.375	10.0
Inventory Stores	0.25	90	0.004	20	10.0	1	1	1	50	2.0	5.0
Self Relief of Personal	0.1	30	0.003	5	2.5	1	1	1	50	0.375	1.0
First Aid	0.5	50	0.1	15	7.0	1	1	1	50	35.0	60.0
Personal Cleanliness	0.5	50	0.1	5	2.5	1	1	1	50	12.5	20.0
Emergency Repair	0.25	30	0.035	10	4.5	1	1	1	50	6.875	10.0

$J = (C)(E)(G)(I)$

$K = \frac{J}{\text{Reflection}}$

ITEM NO.	SUBJECT AREAS:	SOURCE:
205	SYSTEM - S6 HUMAN - H25, H42	Reference 378, p. 352 Based on reference 472.

LIGHTING REQUIREMENTS FOR OPTIMAL VISUAL EFFICIENCY

Visual Function	Luminance	Color	Notes
Interior observation	30-300 NIT	White	----
Rest area or periods	0.01 NIT	White	----
Exterior observation, light side	*	White	Sunglasses worn, 5-10% transmission
Exterior observation, dark side	0.3-10 NIT	Red	Red cutoff at 600 mu

* Must approach the luminance of the surface under observation, which is the product of the solar radiation received times the albedo. The Earth's albedo averages about 0.5, with a range of 0.3 (clear atmosphere, land mass) to 0.9 (complete cloud cover).

The lighting requirements for optimal visual efficiency under the four basic conditions of visual work are shown in the table above. Luminance is the preferable physiological method of measurement, for the total flux upon work surfaces is a sum of interior and exterior light sources. The interior surface generally should have over 35 per cent reflectance. The choice of colors should be in accord with the wishes of the crew.

White light illumination maintains the highest level of color sensitivity. Glare must be reduced to an extent that visual fatigue will not limit the functioning of the crew. The inside of the Man-high capsule was painted a flat white to minimize glare, but the use of differently colored surfaces may be desirable for large space stations.

ITEM NO.	SUBJECT AREAS:	SOURCE:
206	SYSTEM - S6 HUMAN - H25, H42	Reference 219, p. 447 Based on reference 513.

a

GENERAL ILLUMINATION LEVELS

TASK CONDITION	LEVEL (foot candles)	TYPE OF ILLUMINATION
Small detail, low contrast, prolonged periods, high speed, extreme accuracy	100	Supplementary type of lighting. Special fixture such as desk lamp.
Small detail, fair contrast, close work, speed not essential	50-100	Supplementary type of lighting.
Normal desk and office-type work	20-50	Local lighting. Ceiling fixture directly overhead.
Recreational tasks that are not prolonged	10-20	General lighting. Random room light, either natural or artificial.
Seeing not confined, contrast good, object fairly large	5-10	General lighting.
Visibility for moving about, handling large objects	2-5	General or supplementary lighting.

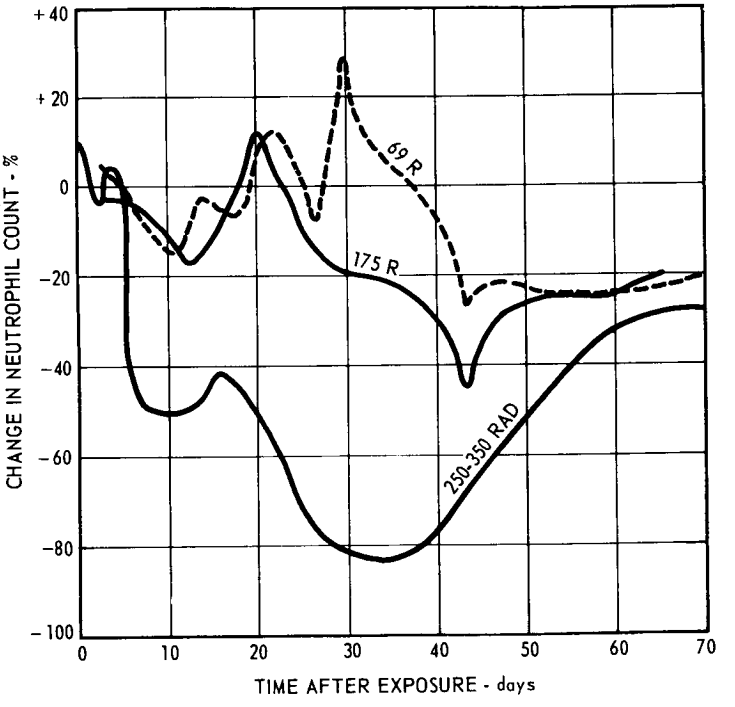
b

RED-LIGHTING LEVELS FOR DARK ADAPTATION.

AREA	LIGHT	LEVEL (foot candle)
Control Rooms	Illumination on working areas	0.01-0.4
	Illumination on black and white dials, figures, name plates	0.03-0.10
	Brightness of instrument faces (white portion)	0.02-0.08
	Brightness of indicator lights (not to exceed 1 square inch area)	0.10-1.00
Ready Areas; crew's mess, wardrooms	Illumination at table-top height	0.50-2.00
	Brightness of any area in the visual field not to exceed	2.00

ITEM NO.	SUBJECT AREAS:	SOURCE:
207	SYSTEM - S6 HUMAN - H25, H42	Reference 586, p. 2-181, 2-199 Based on reference 471 (table b)

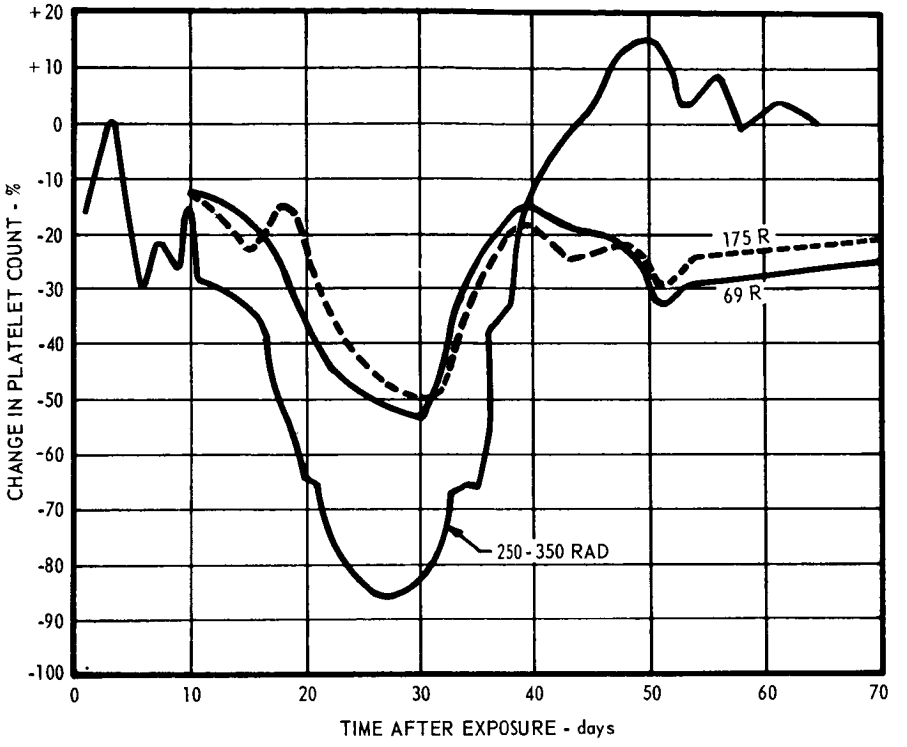
RADIATION EFFECTS ON WHITE BLOOD CELLS



The observed course of the neutrophil, or granulocyte, blood count in adults is shown following accidental exposure to 69 r and 175 r from gamma radiation in fallout (the Marshall Island cases), and to 250-350 rad from a mixture of fast neutrons and gamma rays (the Y-12 cases at Oak Ridge). The data have been replotted into percentage change from an estimated normal count, to make the curves comparable. Other white blood cells (lymphocytes and monocytes) are also depressed. Only the neutrophils are shown here; they are the predominant white cell, and the cell primarily involved in combating acute infections.

ITEM NO.	SUBJECT AREAS:	SOURCE:
208	SYSTEM -S7 HUMAN- H9	Reference 554, p. 147 Adapted from References 22 and 154

RADIATION EFFECTS ON PLATELETS

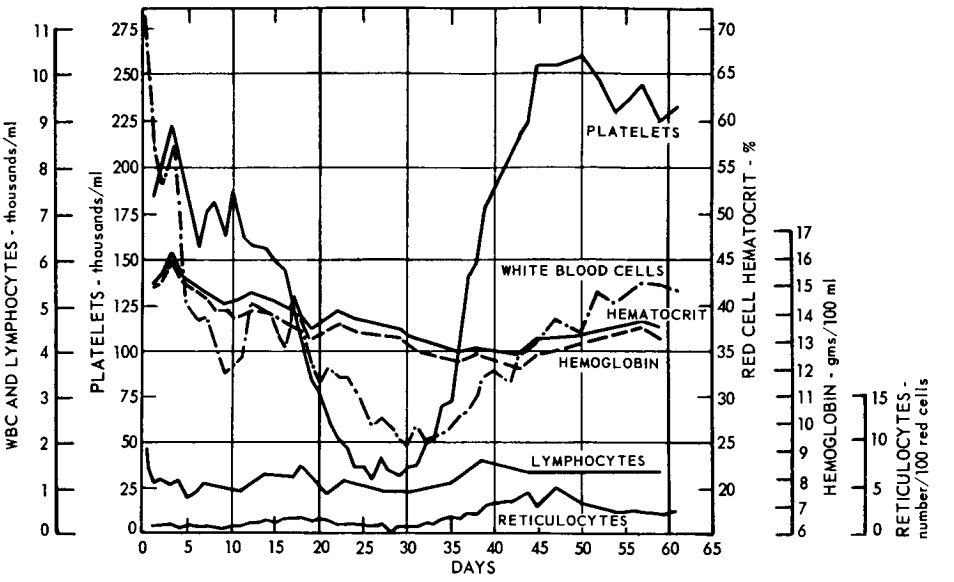


The observed course of platelet counts in adults is shown following accidental exposure to 69r and 175r from gamma radiation in fallout and to 250-350 rad from a mixture of fast neutrons and gamma rays. The data have been replotted into percentage change from an estimated normal count to make the curves comparable. Whenever the platelet count falls below 40 or 50% of normal, bleeding and oozing from minor wounds and scrapes is hard to stop, and hemorrhage is a serious problem from such radiation-damaged areas as the intestine.

ITEM NO.	SUBJECT AREAS:	SOURCE:
209	SYSTEM - S7 HUMAN - H9	Reference 554, p. 148 Based on References 22 and 154.

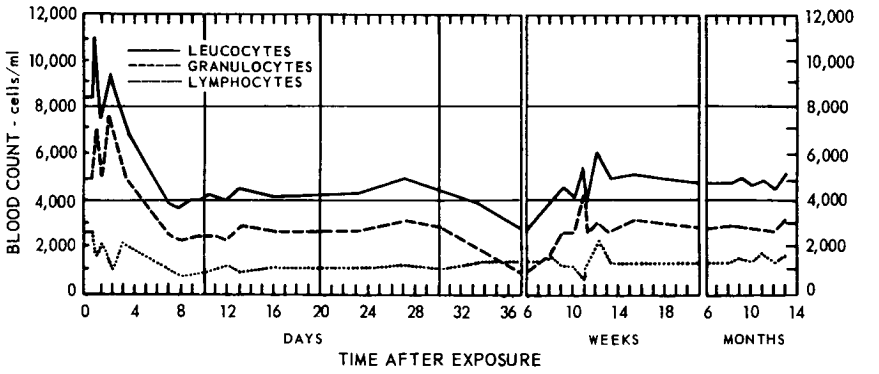
RADIATION EFFECTS ON BLOOD ELEMENTS

a.



These are average values of blood elements of five individuals exposed to estimated doses of 250 to 350 rad at the Oak Ridge criticality accident of June 16, 1958.

b.

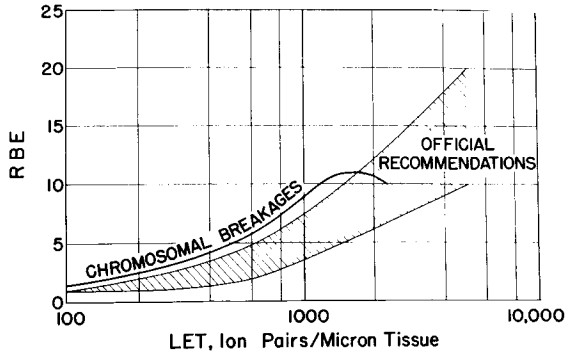


This illustration of one individual's response to a brief whole body exposure of about 130 rad of fission gamma radiation emphasizes the long persistence of radiation injury in man. The cellular elements of the blood show an early rapid decline in number, but do not reach a minimum for 4 - 5 weeks. The blood cell count remains at about 50% of normal for over a year, yet the affected individual, in this case, expressed no outward signs or symptoms of this injury. The individual was, undoubtedly, more susceptible to infection and his general response capability to any additional stress was probably depressed throughout the period of observation. No direct test was made; however, victims of other radiation accidents have complained of a persistent fatigue for many months after exposure.

ITEM NO.	SUBJECT AREAS:	SOURCE:
210	SYSTEM - S7 HUMAN - H9	Reference 554, p. 149 Based on References 451 (fig. a) and 315 (fig. b).

Radiation Damage to Male Gonads	
Dose	Response
< 100 rad	Reduced fertility; reduced sperm count and increased frequency of abnormal sperm
200-300 rad	Temporary sterility for approximately 12 - 15 months.
400-500 rad	Temporary sterility for 18-24 months.
500-600 rad	Permanent sterility probable, if individual survives.

ITEM NO.	SUBJECT AREAS:	SOURCE:
211	SYSTEM-S7 HUMAN-H15	Reference 554, p. 153 Adapted from Reference 98.



RBE (Relative Biological Effectiveness) as a function of LET (Linear Energy Transfer). Shaded area: values recommended by National Committee on Radiation Protection. Heavy curve: Production of chromosomal breakages by radiation. Note maximum RBE at about 1600 ion pairs/micron tissue.

The figure above shows, in addition to the data of the National Committee, a curve based on direct experimental determination of the RBE for the production of chromosomal damage carried out by Conger et al. It is seen that the RBE passes through a maximum at the relatively small LET of 1600 I.P./micron$_T$. This phenomenon of a maximum RBE for a finite LET is universal. It has been established by many experimenters for a wide variety of specimens and reactions. The curve shown in the figure is merely selected as a representative example.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
212	SYSTEM - S7 HUMAN - H15	Reference 459, p. 134 Based on Reference 146 and 390.

RADIATION EFFECTS ON SKIN

a

Radiation Damage to the Skin

Epilation - loss of hair	Erythema (first degree burns)	Wet dermatitis and blistering (second degree burns)	Ulceration (third degree burns)
Rare at less than 200 r			
Partial epilation at 350-450 r	Response is dependent on energy, dose rate, area exposed, & complexion of the individual. Full effect in 1 to 3 weeks after:		
Complete epilation in 16-18 days at > 450 r	200-400 r (<150 kev)		
	500-600 r (200-400 kev)		
Permanent epilation at > 700 r	800-1000 r (>400 kev)		
	Response in first hours at 1000 r	Effect in 1-2 weeks at >1000 r	
			Rapidly progressive effect at > 2000 r

Note: 1 r ≅ 1 rad since these statements are based on air doses.

b

Effect of Dose Rate on Skin Erythema in Man for X Rays

Dose Rate, R/Minute	Exposure Time, Minutes	Dose R
500	1	500
50	15.5	780
5	260	1300
0.5	4500	2250

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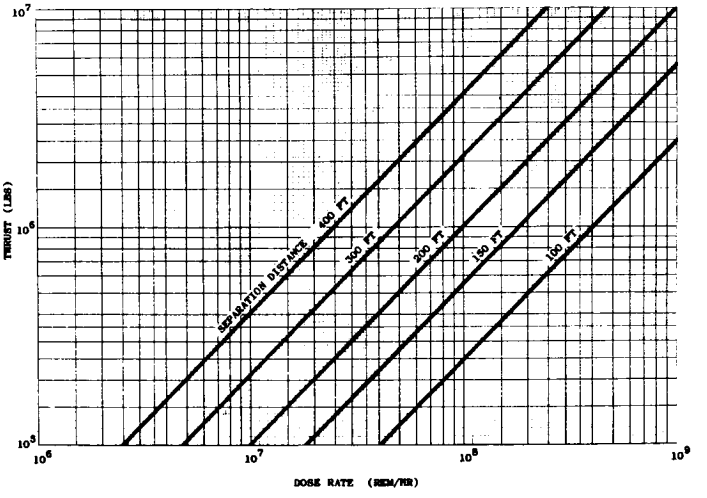
ITEM NO.	SUBJECT AREAS:	SOURCE:
213	SYSTEM - S7 HUMAN - H17	References 554, p. 153 (fig. a) and 459, p. 167 (table b) Based on References 154 and 451 (fig. a).

a

Maximum Permissible Radiation Dosages and Some Typical Exposure Levels (in Roentgens)

Item	*Amount*
PERMISSIBLE EXPOSURES	
Maximum permissible dosages	0.3 r/quarter 5.0 r/yr
Maximum permissible emergency exposure	25.0 r
TYPICAL EXPOSURES	
Normal radiation level (sea level)	0.001 r/day
Undisturbed interplanetary space (cosmic rays)	5–12 r/yr
Heart of inner belt (protons)	24 r/hr
Heart of outer belt (soft X-rays)	200 r/hr
Solar proton event (protons)	10–10^8 r/hr
Total exposure	2–400 r

b



Dose rate at crew compartment from unshielded direct radiation. Dose rate (REM/HR)

ITEM NO.	SUBJECT AREAS:	SOURCE:
214	SYSTEM - S7 HUMAN - H33	Reference 523, p. 401, 403 Based on Reference 525 (fugure b).

MAXIMUM IONIZATION RADIATION EXPOSURE LIMITS

IONIZING RADIATION OF ANY TYPE, OR COMBINATION OF TYPES	PERMISSIBLE REM[a] PER CALENDAR QUARTER (WITHOUT COMPLETE MEDICAL HISTORY)[b]
Whole body	1.25
Head, trunk, blood-forming organs, eye-lens, and gonads	1.25
Body extremities	18.75
Skin	7.50
Acute accidental single exposure (either internal or external to the body)	25.0 (or more in extreme cases)

[a]REM = Roentgen equivalent(s), man.

[b]If a medical record is available, a higher exposure, 80 per cent of the limit in effect, is permissible: 3/REM/quarter, provided no more than $5\ (n-18)$ REM total accumulated dosage has been met (where n is the age of the subject).

ITEM NO.	SUBJECT AREAS:	SOURCE:
215	SYSTEM - S7 HUMAN - H33	Reference 586, p. 2-241 Based on Reference 57.

LET-RBE RELATIONSHIP FOR PERMISSIBLE LEVELS OF HUMAN EXPOSURE TO RADIATION

LET keV per micron water	RBE
3.5 or less	1
3.5 to 7.0	1 to 2
7.0 to 23	2 to 5
23 to 53	5 to 10
53 to 175	10 to 20

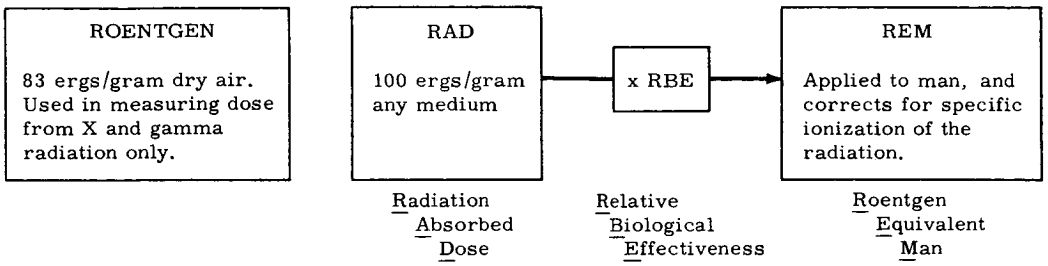
The doses in the International Commission of Radiobiological Protection (ICRP) Recommendations (1959) may be considered low in the table above showing Relative Biological Effectiveness (RBE) as a function of Linear Energy Transfer (LET) represents the best estimate of maximum RBE values for the most restrictive biological effects significant for human protection. The recommendations were obviously framed with avoidance of late effects principally in mind since early effects of small doses are less likely than late effects. It is not inconceivable that the RBE for some special effect of possible significance in space flight might be higher than the value in the table, but in the absence of knowledge of such possibilities there is no alternative to using the ICRP values of RBE when considering exposures within the permissible range, including emergency exposures up to 25 rems.

The rem is only applicable in the domain of permissible exposure levels for man, where it serves as a common unit of effectiveness for radiations of different LET. The effectiveness in rems of a given dose of radiation is expressed in terms of that dose of the standard radiation (hard X or gamma radiation) which would be equivalent and it is calculated by multiplying the absorbed dose in rads by the conventional RBE value specified in the table.

For doses appreciably above the permissible range which might be incurred in accidental exposure, the RBE for most known effects would be lower than the values in the table.

ITEM NO.	SUBJECT AREAS:	SOURCE:
216	SYSTEM - S7 HUMAN - H33	Reference 392, p. 276 Based on Reference 37.

RADIATION TERMS: RBE VALUES



RBE (relative biological effectiveness) expresses the effectiveness of a particular type of radiation in producing the same biological response as X or gamma radiation having a linear energy transfer (LET) equivalent to 3 kilovolts per micron of water and delivered at the rate of about 10 rads per minute.

Type of radiation	RBE
X-rays	1
Gamma rays	1
Beta particles, 1.0 mev	1
" " 0.1 mev	1
Neutrons, thermal energy	2.8
" 0.0001 mev	2.2
" 0.005 mev	2.4
" 0.02 mev	5
" 0.5 mev	10.2
" 1.0 mev	10.5
" 10.0 mev	6.4
Protons, greater than 100 mev	1 - 2
" 1.0 mev	8.5
" 0.1 mev	10
Alpha particles, 5 mev	15
" " 1 mev	20

The standard RBE values are based on the most detrimental chronic biological effect (for example, cataract induction by neutrons) for continuous low dose exposures that might be met in industrial situations. However, the RBE for many acute high dose rate exposures may be very much lower. The RBE for a large lethal dose of fast neutrons may be less than 1.0 for man, as against the values of 5 - 10 shown in the table above. Also, as a given particle degrades in tissue, the RBE will rise as its energy transfer per micron rises. At the same time, a heterogeneous beam of protons will have an average RBE that tends to drop with increasing depth in tissue as the lower energy component becomes fully absorbed and the higher energy component continues its traverse.

ITEM NO.	SUBJECT AREAS:	SOURCE:
217	SYSTEM - S7 HUMAN - H34	Reference 554, p. 141 Based on References 532, 451 and 57.

THE "EQUIVALENT RESIDUAL DOSE" CONCEPT

Equivalent Residual Dose (ERD) is a recent concept used in estimating what residual acute radiation injury persists for a period of weeks and months after an exposure to radiation. Thus a person exposed to radiation on Monday can be said to have a certain amount of that injury on the next Monday, something less on the next after that, and so forth. The ERD at any time, t days, after onset of exposure can be calculated on the basis of the following assumptions:

1. Ten per cent of the injury attributed to the dose is considered to be irreparable.
2. The body repairs the remaining 90% at the rate of 2.5% per day.
3. Recovery after a brief exposure (i.e., delivered over a period of a few seconds to four days) begins four days after the start of the exposure.
4. Recovery is continuous during protracted exposure.

These assumptions are all susceptible to challenge and none have been validated in man. Because of the uncertainties surrounding the concept, it is recommended that calculations not be made beyond 100 days; and even this may be risky, since (as shown in 8-14), severe hematopoietic depression has persisted in an irradiated man for more than twelve months.

If an individual is being continuously exposed to small doses of radiation, however, recovery will occur concurrently, and the ERD formulations provide a reasonable approach to the evaluation of the radiation "status." Arbitrarily, the use of the ERD calculations should be restricted to single or brief exposures of less than 50 r and daily exposures of less than 2 r/day. Within these limits, injury equilibration will probably occur, thus permitting some degree of freedom for an emergency situation. The whole question of time-intensity variation in the exposure parameters is so complex that each situation will undoubtedly require its own interpretation. In all instances, the ERD is only used to predict acute manifestations of radiation injury; late genetic effects, leukemia induction and life shortening are always based upon the exposure dose.

The ERD at t days may be expressed as:

$$ERD = D_0 [0.1 + 0.9\ (1.000-0.025)^{t-4}] + \dot{D} \int_4^t [0.1 + 0.9\ (1.000-0.025)^{t}]\, dt, \qquad (1)$$

where

D_0 = brief dose in r received during first 4 days,
$\dot{D}$ = protracted daily dose at a constant rate, r/day, received after the 4th day, and
t = time in days after onset of initial exposure.

Equation (1) may be expressed as

$$ERD = a D_0 + b \dot{D} \qquad (2)$$

where

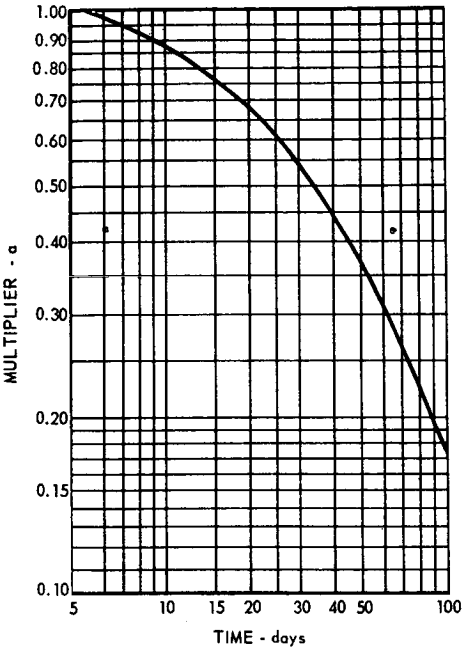
a = Multiplier for brief dose, for a given time, and
b = Multiplier for protracted dose rate, for a given time.

The values for a and b for anv time up to 100 days can be obtained from the two charts on the following page.

ITEM NO.	SUBJECT AREAS:	SOURCE:
218 a Page 1 of 2	SYSTEM - S7 HUMAN - H34	Reference 554, p. 150.

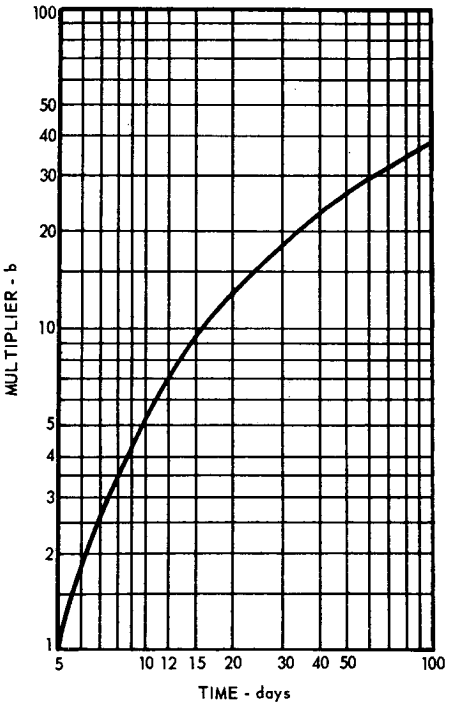
THE "EQUIVALENT RESIDUAL DOSE" CONCEPT, continued

a.



Multiplier "a" to be used with the formula on the previous page.

b.



Multiplier "b" to be used with the formula on the previous page.

Example:

100 r is received as a brief dose within the first 4 days. An exposure of 1 r/day is received from the 4th through the 40th days. What is the ERD at the end of 40 days?

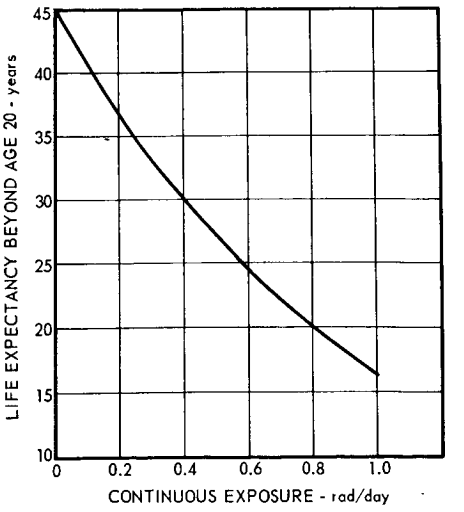
D_0 = 100 r; a = 0.45 (see left-hand graph)

$\dot{D}$ = 1 r/day; b = 23 (see right-hand graph)

ERD = (0.45 × 100) + (23 × 1) = approximately 68 r.

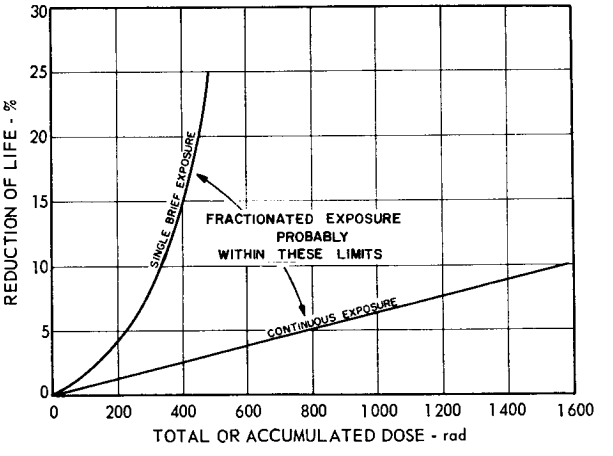
ITEM NO.	SUBJECT AREAS:	SOURCE:
218 b Page 2 of 2	SYSTEM-S7 HUMAN-H34	Reference 554, p. 151 Adapted from Reference 27.

a



This shows the estimated life expectancy of a 20-year-old population exposed to fixed daily doses of whole body radiation, continued until time of death. Deaths would be from natural causes. In fact, comparisons have been drawn between the effects of radiation and the normal process of aging.

b

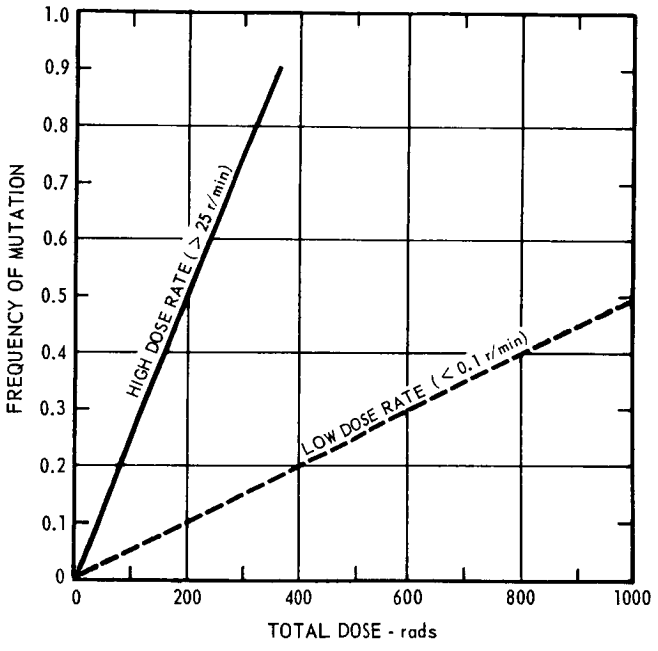


The effects on life expectancy of brief single doses of whole body radiation are compared in this graph with those of long term continuous exposure. Multiple brief exposures, separated by days or weeks, termed fractionated exposures, will be expected to have an effect somewhere between the limits shown for single and continuous exposure. (This chart and the upper one are based on animal work, since there are no human data.)

ITEM NO.	SUBJECT AREAS:	SOURCE:
219	SYSTEM - S7 HUMAN - H34	Reference 554, p. 154 Adapted from References 450 (fig a) and 229 (fig. b).

The probability of death from leukemia is about 10^{-6}/r/year for the first 15-20 years after brief exposure to whole body radiation. This probability is based on experience at rather high exposure dose-rates (>25 r/min). Animal data clearly indicate that the response is less at low dose-rates (<1 r/min), and presumably man would respond in a like manner.

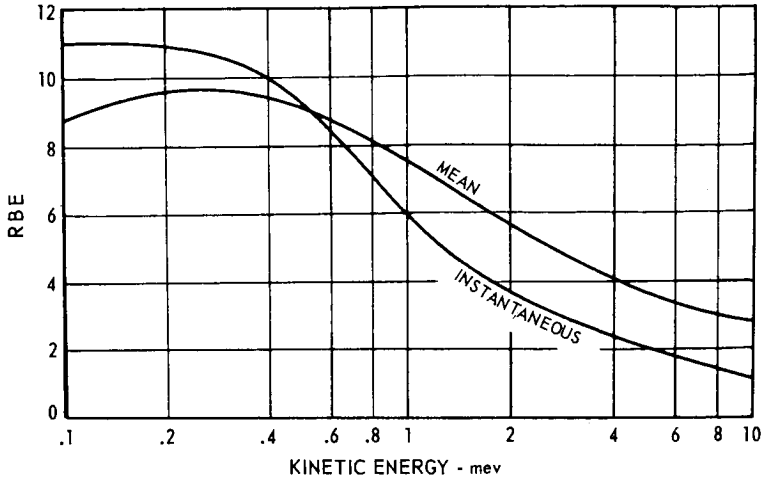
The genetic effect is expressed as the probability of induction of recessive mutations in the male germ cell. Two probabilities are given: (a), for high dose-rate exposure, 25×10^{-8}/r/gene; (b), for low dose-rate exposure, 5×10^{-8}/r/gene. Although these data were obtained from mice, man is expected to respond similarly. If he has 10^4 genes per germ cell, then the probability of occurrence of a new recessive mutation is that shown in the graph.



ITEM NO.	SUBJECT AREAS:	SOURCE:
220	SYSTEM - S7 HUMAN - H34	Reference 554, p. 155 Based on References 96 and 449.

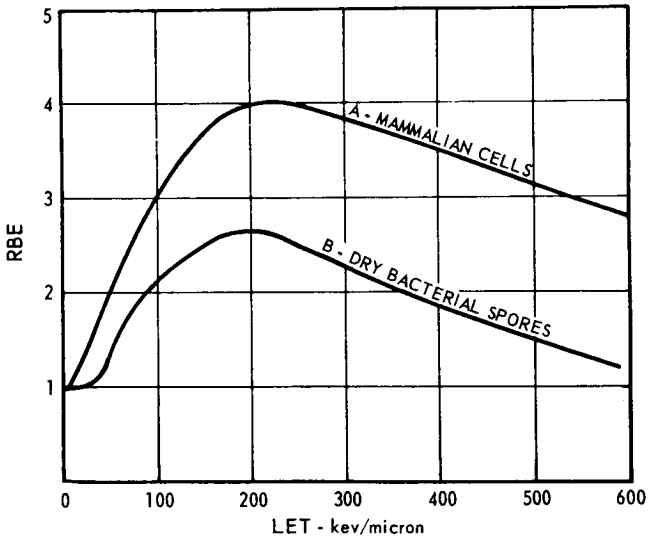
RBE AND LINEAR ENERGY TRANSFER

a.



Instantaneous and mean RBE's are shown for protons of different energies, corresponding to the instantaneous linear energy transfer at energy E, and the mean RBE for dissipation of the entire energy from E down to zero.

b.

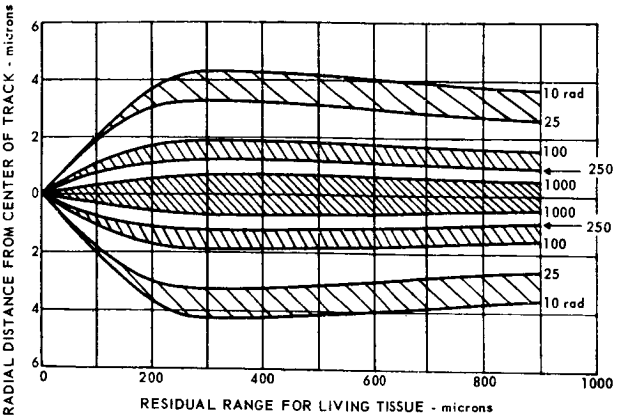


The relative biological effectiveness (RBE) is plotted as a function of linear energy transfer (LET) for survival of mammalian cells (curve A) and of dry bacterial spores (curve B) following exposure to charged particles at about 8.3 mev/nucleon.

ITEM NO.	SUBJECT AREAS:	SOURCE:
221	SYSTEM - S7 HUMAN - H34	Reference 554, p. 142 Based on References 456 (fig. a), 417 and 484 (fig. b).

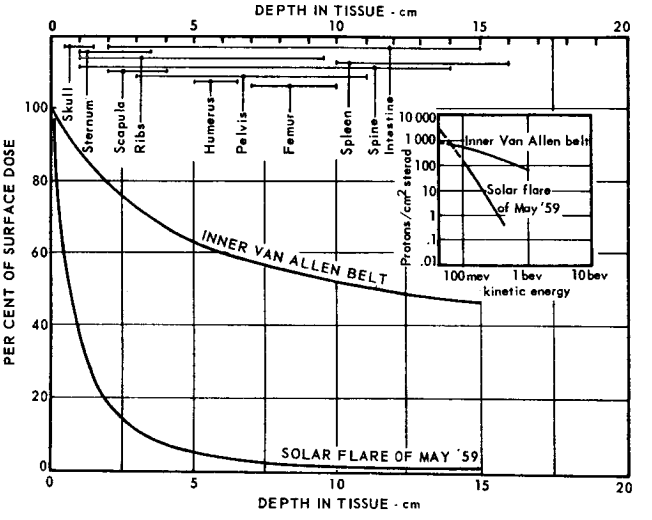
PARTICLE RADIATION IN DEPTH IN TISSUE

a.



A longitudinal section of the isodose line field in tissue is shown for the terminal section of a cosmic ray heavy nucleus of Z = 20(Ca). Section from 280 to zero micron residual range is "thindown" part.

b.

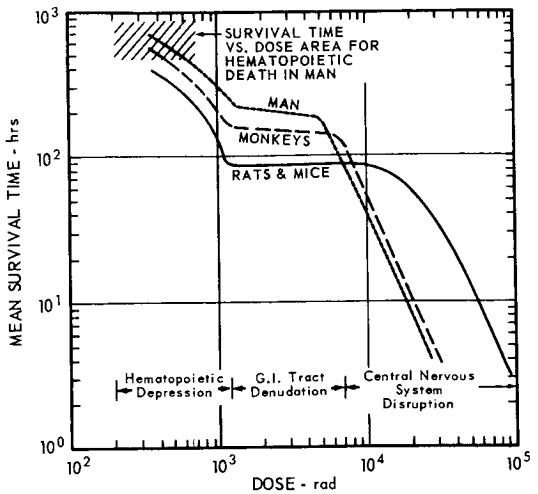


This chart shows the calculated dose from protons at various depths in tissue from Inner Van Allen Belt and the Solar Proton Event of May 12, 1959, assuming cabin provides only 2 gm/cm^2 of shielding. The greater drop of tissue depth-dose from flare protons as compared to Inner Belt protons is a function of the differences in the integral energy spectra (see inset); the greater frequency of higher energy protons in the Inner Belt increases the dose rate in deep tissues. Note the importance of knowing the integrated energy spectrum of the proton radiation when considering the critical targets--i.e., bone marrow, spleen, and intestinal locations beneath the surface.

ITEM NO.	SUBJECT AREAS:	SOURCE:
222	SYSTEM - S7 HUMAN - H34	Reference 554, p. 143 Based on References 458 (fig. a) and 457 (fig. b).

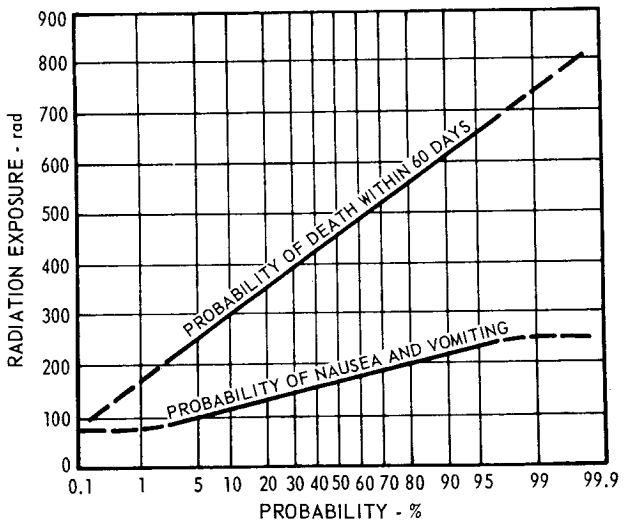
WHOLE BODY RADIATION EFFECTS

a.



The relationship between median survival time and acute radiation dose is shown for mice, rats, monkeys, and man.

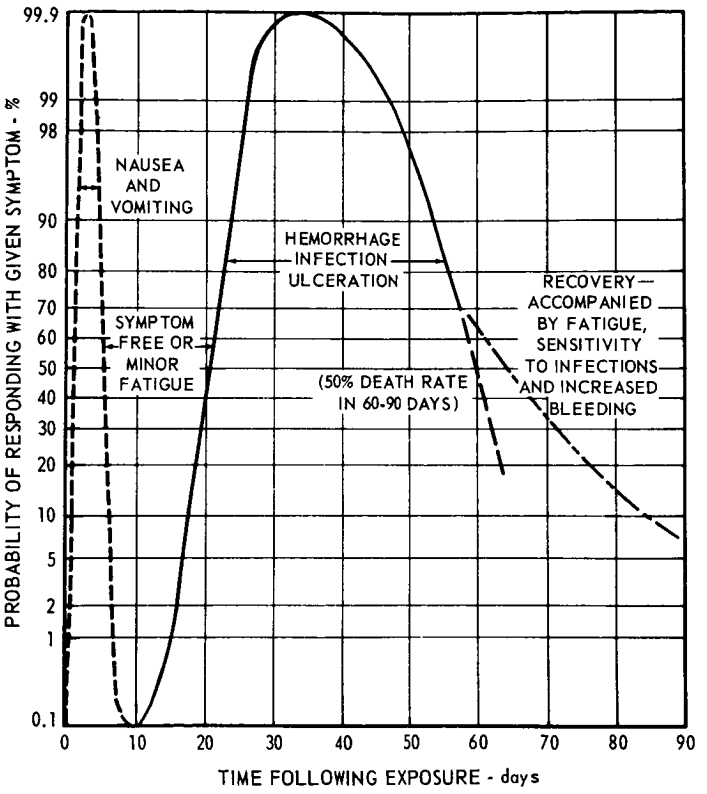
b.



The relationship is plotted for whole body radiation dosage and first symptoms of death. These probability plots are estimates based on accumulated experience from Japanese casualties, accidental exposure to fallout, and reactor incidents.

ITEM NO.	SUBJECT AREAS:	SOURCE:
223	SYSTEM - S7 HUMAN - H 34	Reference 554, p. 144 Based on References 315 (fig. a) and 223 (fig. b).

ACUTE RADIATION ILLNESS



This is an idealized description of the time course of symptoms of acute radiation illness following a mid-lethal acute exposure to whole body radiation of 250-500 rad.

ITEM NO.	SUBJECT AREAS:	SOURCE:
224	SYSTEM - S7 HUMAN - H 34	Reference 554, p. 146, Based on References 223, 451 and 154.

EXPECTED EFFECTS FROM ACUTE WHOLE-BODY RADIATION DOSES

Dose in Rems	*Probable Effect*
0 to 50	No obvious effect except, possibly, minor blood changes.
80 to 120	Vomiting and nausea for about one day in 5 to 10 per cent of exposed personnel. Fatigue, but no serious disability.
130 to 170	Vomiting and nausea for about one day, followed by other symptoms of radiation sickness in about 25 per cent of personnel. No deaths anticipated.
180 to 220	Vomiting and nausea for about one day, followed by other symptoms of radiation sickness in about 50 per cent of personnel. No deaths anticipated.
270 to 330	Vomiting and nausea in nearly all personnel on first day, followed by other symptoms of radiation sickness. About 20 per cent deaths within two to six weeks after exposure; survivors convalescent for about three months.
400 to 500	Vomiting and nausea in all personnel on first day, followed by other symptoms of radiation sickness. About 50 per cent deaths within one month; survivors convalescent for about six months.
550 to 750	Vomiting and nausea in all personnel within four hours from exposure, followed by other symptoms of radiation sickness. Up to 100 per cent deaths; few survivors convalescent for about six months.
1,000	Vomiting and nausea in all personnel within one to two hours. Probably no survivors from radiation sickness.
5,000	Incapacitation almost immediately. All personnel will be fatalities within one week.

Purser, P. E.; Faget, M. A. and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publication, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
225	SYSTEM - S7 HUMAN - H35	Reference 219, p. 239. Based on Reference 296.

ACUTE RADIATION SYNDROME

(A rough guide to its severity)

Approximate Dose in rads (X or Gamma Radiation).	
50-100	A few individuals will experience nausea. Laboratory investigations will detect damage.
200	Prodromal symptoms common but not all patients will vomit. Haematological changes present, may be an increased liability to bleeding. Erythema unlikely, conjunctivitis possible, may be some loss of hair. Sperm abnormal and reduced in numbers. Without treatment a very small number of patients may die.
400-600	Severe prodromal symptoms with transient reddening of skin possible. Latent period over during 3rd week. Severe haematological changes; increased liability to infection; haemorrhages, some severe. Widespread loss of hair, erythema likely. Intestinal symptoms, if present, will be relatively mild. 50% acute mortality if no treatment.
800-1200	Shorter latent period. Intestinal symptoms increasingly severe. Very severe haematological changes, serious haemorrhages likely. 100% mortality when untreated.
1500-5000	Short latent period before severe gastrointestinal symptoms develop. Watery diarrhoea. Severe haemorrhage. Radiation burns of skin and mucous membranes, probably with ulceration. Fatal outcome inevitable even with treatment.
over 10,000	Very severe prodromal symptoms including flushing of the skin; watery diarrhoea, disorientation, ataxia and loss of consciousness. Survival measured in hours rather than days. <u>Part-body irradiation</u> in this dose range can cause death, even radioresistant organs such as heart and brain can be severely damaged. If parts of limbs were exposed gangrene may necessitate amputation.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
226	SYSTEM - S7 HUMAN - H35	Reference 392, p. 272.

Estimated Recovery Half Times in Days

ANIMAL	RHT
Mouse	3-8
Rat	6-9
Dog	14-18
Burro	20-28
Man	25-35

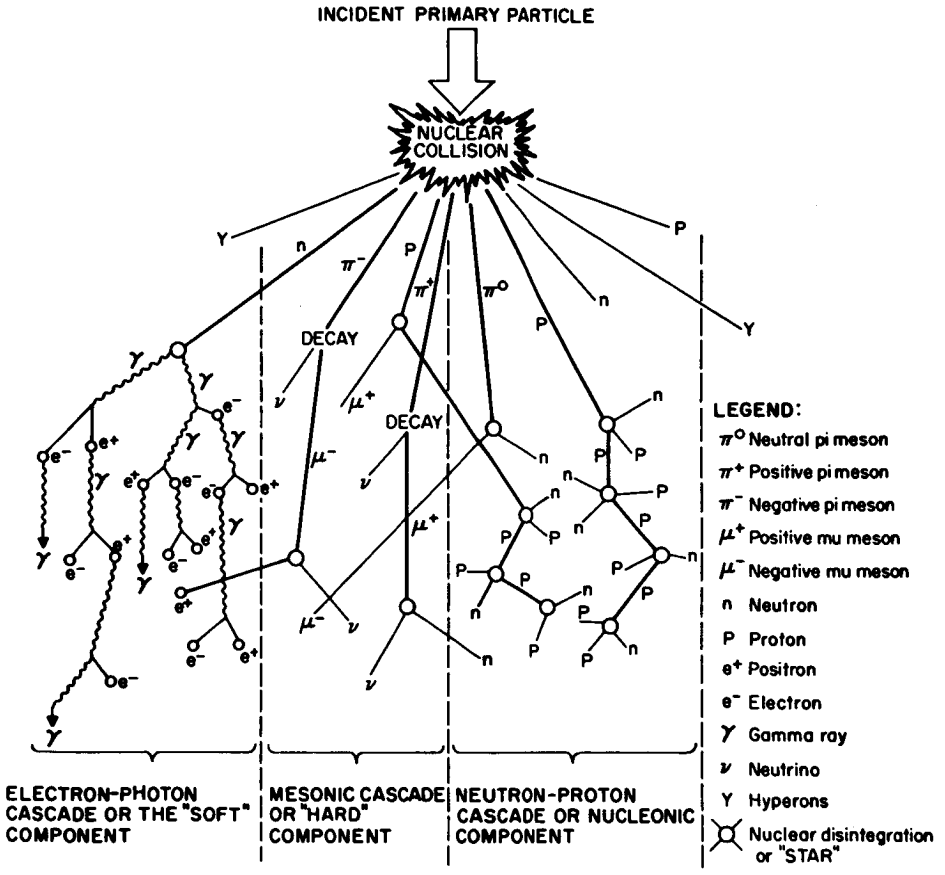
The recovery half time varies greatly for different species and seems to be correlated to the natural life span. The table above shows the ranges of the recovery half time for the four species mentioned above and the extrapolated value for man.

The recovery phenomenon has very obvious bearing on practical radiation safety procedures after nuclear catastrophies. For this reason the National Committee on Radiation Protection and Measurements has coined the official term ERD (Equivalent Residual Dose) proposing an equation for its computation which assumes, for injury from acute exposures, an irreparable fraction of 10 per cent and a recovery half time of one month for the remaining 90 per cent. This equation is a compromise reflecting the aforementioned experimental information. The ERD as conceived by the NCRPM is intended as a guideline for action during the "reconstruction phase after a nuclear attack," and is not a "reliable predictor of any of the late somatic effects of radiation or of the genetic effects." The NCRPM also expressly states that it is not recommended to extend the "calculation beyond one year." Emphasizing the just-mentioned restrictions, NASA has adopted the concept of the ERD and equation as proposed by the NCRPM for assessing the exposure status of astronauts as far as acute radiation sickness during a mission is concerned. This has, of course, no bearing on the problem of how to determine the accumulated ERD for repeated missions or for the entire career of an astronaut. Obviously for the latter determination, late damage such as life shortening should also be considered. In this respect, a more cautious attitude seems appropriate, since experimental evidence indicates that for late damage, exposure to high-LET radiation shows a smaller recovery factor than exposure to X or gamma rays. It seems advisable, therefore, that the high-LET fraction of a proton exposure be entered separately into the computation with an RBE of 10 and with no, or greatly reduced, recovery allowance.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
227	SYSTEM - S7 HUMAN - H34	Reference 459, p. 168. Based on Reference 77, 27 and 555.

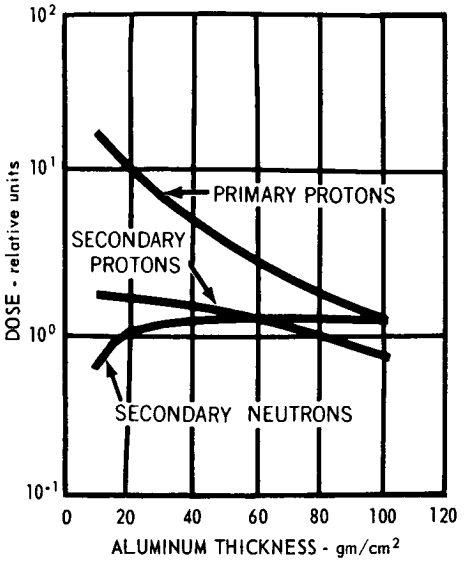
GENESIS OF SECONDARY RADIATIONS



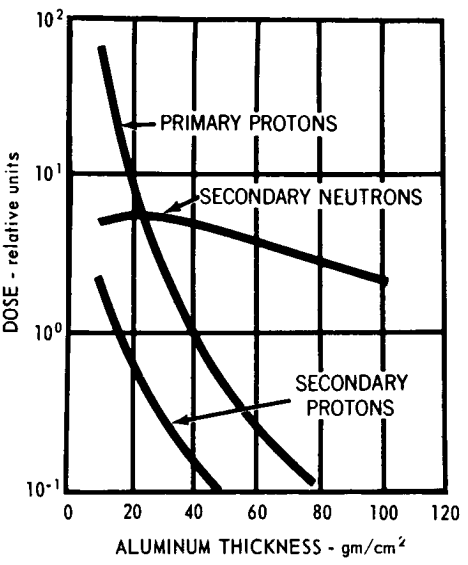
When a primary particle with an energy of 300 mev or greater hits a nucleus of target material, secondary particles and electromagnetic radiations are generated in great variety, as shown in this diagram.

ITEM NO.	SUBJECT AREAS:	SOURCE:
228 a Page 1 of 2	SYSTEM - H7 HUMAN - H44	Reference 554, p. 139. Based on Reference 455.

a. TRAPPED PROTONS



b. SOLAR PROTONS



The absorption of radiation in matter involves the transfer of all or some portion of the incident radiation energy to an electron or nucleus in the absorber mass. This may lead to the production of recoil protons, neutrons, electrons, X and γ radiation, or many other secondary particles as illustrated on the previous page. The space radiations are not qualitatively different from conventional radiations in this regard, but quantitatively the production of secondaries is somewhat unique. This is due to the presence of particles of unusually high energies that can generate a cascade of secondary photons and particles. The exact nature of the secondaries will be a function of the incident particle and its charge and energy, the density of the absorbing or shielding material and its thickness, and the proximity of masses of different composition or elemental form (i.e., laminated shielding, capsule wall, and black boxes).

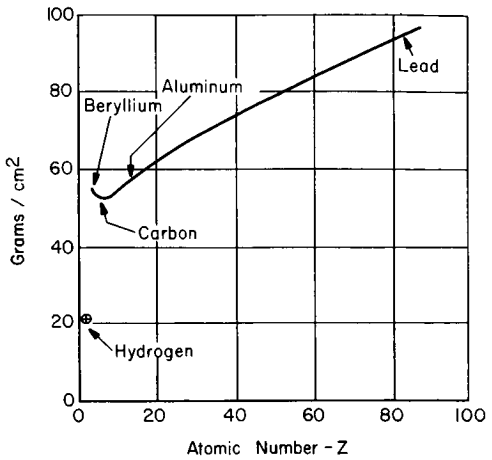
Several studies have been initiated on this general problem, and these can be reviewed in the Proceedings of the Symposium on the Protection Against Radiation Hazards in Space. The biological importance of the problem is indicated on the previous page, which demonstrates the buildup of secondary radiation dose in shielding material. In other words, while shielding is certainly an effective countermeasure, it does modify the quality of the radiation, which must then be the radiation of interest for biological consideration.

ITEM NO.	SUBJECT AREAS:	SOURCE:
282 b Page 2 of 2	SYSTEM - H7 HUMAN - H44	Reference 554, p. 140. Based on References 298, 532.

SHIELDING RECOMMENDATIONS FOR IONIZATION RADIATION PROTECTION

RADIATION TYPE	RANGE OF RAYS IN AIR	SHIELD MATERIAL	
		TYPE	THICKNESS
Alpha particles (4 million electron volts)	2.8 cm	Aluminum sheet Paper Ordinary clothing	1/64 inch 1/64 inch 1/64 inch
Beta particles (3 million electron volts)	13.0 meters	Lead Aluminum Pyrex Lucite Water	1.4 mm 5.3 mm 6.6 mm 12.4 mm 14.8 mm
Gamma rays (4 million electron volts)		Shielding is accomplished by reducing intensity of incident gamma radiation by scattering interactions within a shield (probability of completely absorbing the nuclei of atoms in a shield is slight). Thickness of material required to reduce radiation to one half is called the half-value layer. Half-value layers for typical materials are: Lead 0.3 inch Iron 0.5 inch Aluminum 2.7 inch Concrete 2.7 inch Water 8.3 inch	
Neutrons		Since gamma radiation is produced in the process of neutron attenuation, shielding against neutrons should also include shielding against gamma radiation. An effective material is cement mixed with iron shot. However, beryllium-lithium combinations are best for lightweight applications, such as in aircraft, space craft, or remote handling equipment.	

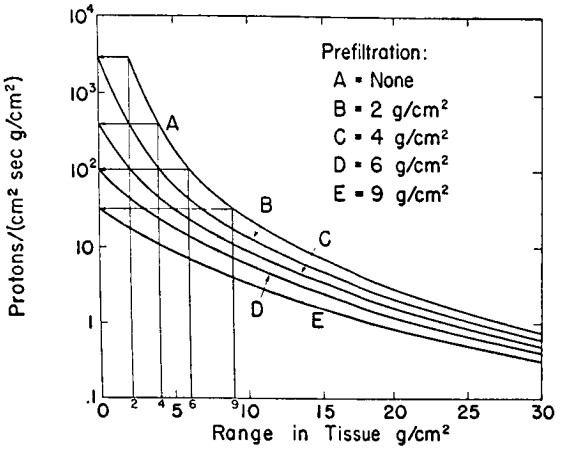
ITEM NO.	SUBJECT AREAS:	SOURCE:
229	SYSTEM - H7 HUMAN - H44	Reference 586, p. 2-242. Based on Reference 57.



A plot of range (g/cm^2) versus atomic number for various elements, based on 275 Mev protons.

Typical shield effectiveness for various material is shown in the figure above. Beryllium appears attractive structurally, but when bombarded by protons it is unfortunately a fine source of secondary neutrons against which shielding is impractical. The "storm cellar" concept is difficult to engineer, but might be employed in spite of the penalties involved. Even if this is done, however, the energy spectra of the solar flares is such that a substantial radiation dose might be received if multiple events were encountered. This is quite probable for the case of a manned Mars reconnaissance mission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
230	SYSTEM - S7 HUMAN - H44	Reference 355, p. 244. Based on Reference 434.



Differential range spectra of flare-produced proton radiation behind different shield thicknesses.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
231	SYSTEM - S7 HUMAN - H44	Reference 459, p. 151.

RELATIVE DOSAGE IN TYPICAL SOLAR BEAMS

Shielding (gm/cm^2)	Relative Dosage
2	2700
4	550
8	100
12	39
16	21
20	12

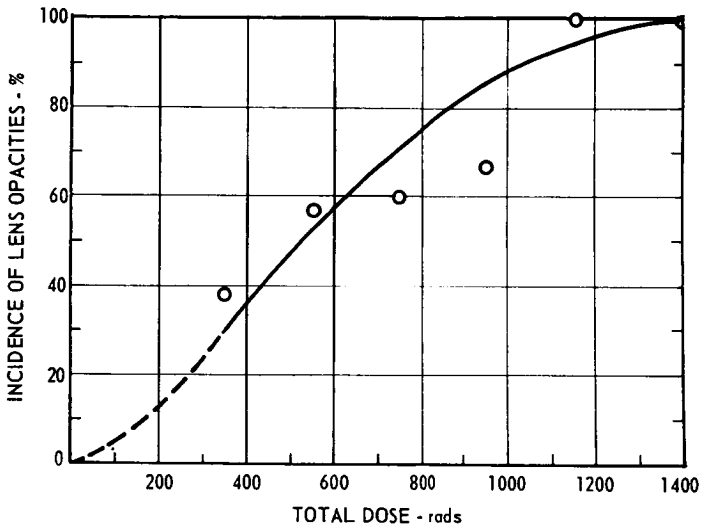
Flares occur in the so-called "active regions" of the Sun's atmosphere. These regions consist of a more or less complex group of sunspots with an overlying bright "plage." Flares frequently produce large and complex magnetic fields and strong bursts of radio noise. Often there is brightening of the Sun's outer atmosphere, or corona, over the active regions. There have been some preliminary studies of large plage and brightness areas, rate of flares, and age of active regions in relation to the production of proton beams. These studies indicate that the large flares which produce proton flux occur predominantly in active regions having lifetimes of at least one week and particularly in those containing fairly complex sunspot groups.

The particles emitted had energies ranging from about 2 to 3 mev to more than 500 mev. There were about thirty large flares which released and accelerated these particles during the period from 1957 to 1960. Some of these events were associated with such high intensity protons in the vicinity of the Earth that they were considered to be a major radiation hazard to manned space flight. The flux of protons with kinetic energies greater than 75 mev in these solar beams varies from about 20 to 350 times the normal cosmic ray intensity. Because the flux of solar beam particles increases steeply at lower energies, the dosage which a man would be exposed to rises rapidly as the thickness of shielding is decreased. With 8 gm/cm^2 of shielding by means of a suitable material, for example, the dosage would range from 2 to 200 rem. The shielding requirements for a typically large flare are shown in the table above.

Purser, P. E.; Faget, M. A. and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
232.	SYSTEM - S7 HUMAN - H44	Reference 219, p. 134.

RADIATION EFFECTS ON THE EYE



The incidence of lens opacities in man is shown as a function of dose for X and γ radiation delivered over a period of three weeks or less.

ITEM NO.	SUBJECT AREAS:	SOURCE:
233	SYSTEM - S7 HUMAN - H17, H25	Reference 554, p. 152. Based on Reference 371.

Grand Totals of Integral Tissue Ionization Doses in r at Zero, 1, 2, and 15 cm Depth in a 30 cm Diameter Tissue Sphere for Different Shielding

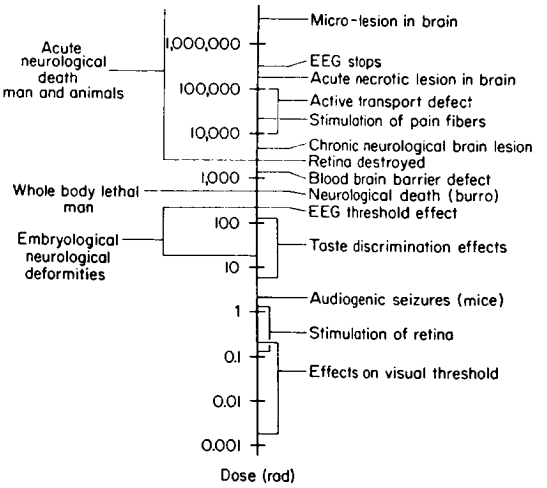
Depth in Target Sphere, CM	Shield Thickness 2 G/CM^2	4 G/CM^2	8 G/CM^2
Zero	200	69	19
1	110	49	16
2	70	36	14
15 (Midpoint)	12	10	6

The table above presents integral doses for a large flare event.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
234	SYSTEM - S7 HUMAN - H34, H44	Reference 459, p. 155.

NEUROLOGICAL EFFECTS OF RADIATION



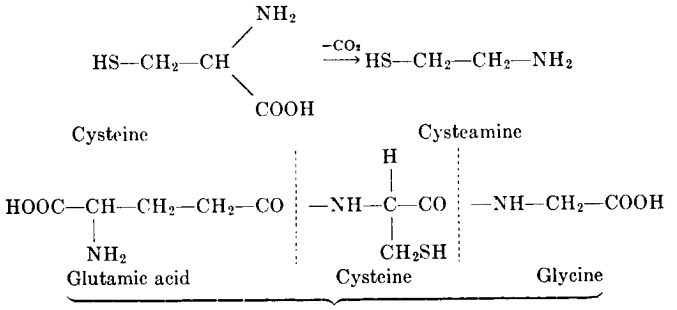
Purser, P. E.; Faget, M. A. and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
235	SYSTEM - S7 HUMAN - H14, H25	Reference 219, p. 242. Based on Reference 522.

Drugs for Increasing Tolerance to Radiation, Action by Lowering Tissue Oxygen Tension at Subtoxic Dosage Levels

Cyanide
Malononitrile
p-Aminopropiophenone
Sodium nitrite
Pitressin
Epinephrine
Carbon monoxide

Sulfhydryl Compounds



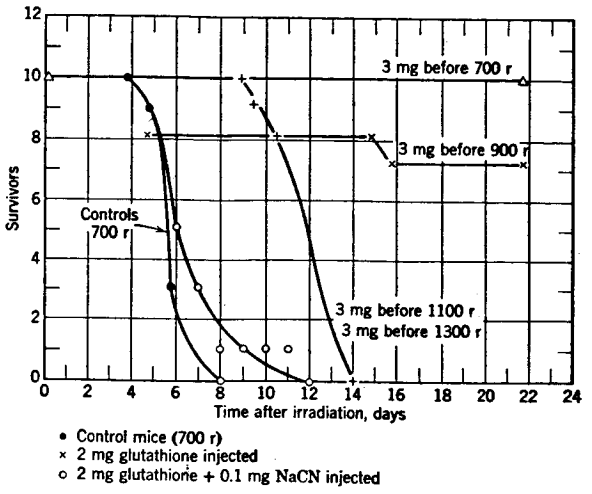
Glutathione

Aminoalkylisothioureas and Mercaptoalkylguanidines

S,2-Aminoethylisothiourea dihydrobromide (AET)
S,3-Aminopropylisothiourea (APT)

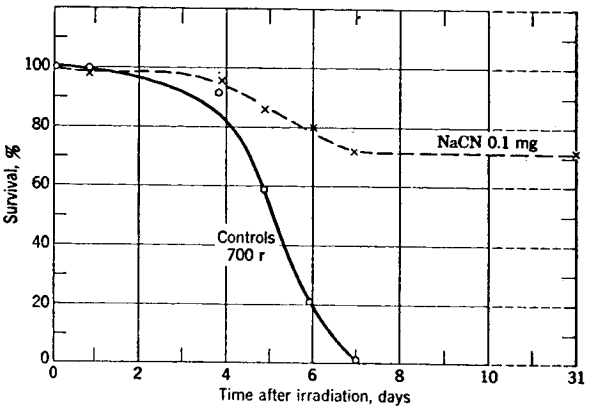
ITEM NO.	SUBJECT AREAS:	SOURCE:
236	SYSTEM - S7 HUMAN - H38, H44	Reference 416, p. 108. Compiled from several primary sources.

a



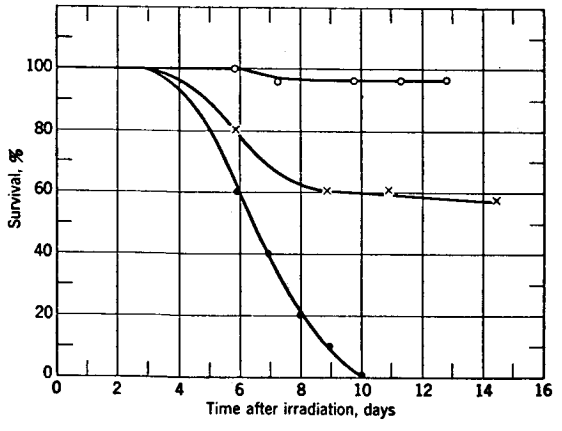
Radiobiological protective action of cysteamine in mice. Intraperitoneal injection of 3 mg cysteamine immediately before irradiation with various doses of X-rays.

b



Radiobiological protective action of cyanide in mice. Survival of control irradiated mice (700 r X-rays, 250 kev) and of cyanide-injected animals similarly irradiated. Intra-peritoneal injection immediately before irradiation.

c



Radiobiological protective action of glutathione and cyanide in mice.

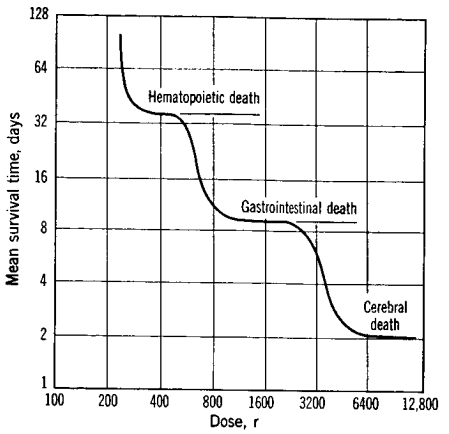
ITEM NO.	SUBJECT AREAS:	SOURCE:
237	SYSTEM - S7 HUMAN - H38, H44	Reference 416, pp. 109-110. Based on Reference 52.

TABLE 4.27
Drugs for Increasing Tolerance to Radiation, Miscellaneous Compounds

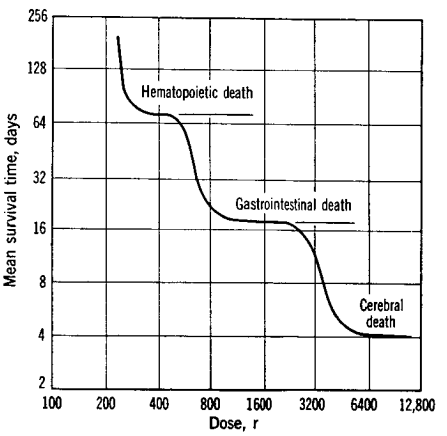
Cobalt	Somatotropic hormone
Magnesium	Glucose
Methyl linoleate	Colchicine
Chlorpromazine	Methimazole
Thiouracil	3-Aminotriazole
Cortisone with chlorpromazine	Bacterial endotoxins
Hexamethonium with cortisone	Homologous serum or plasma
Dibenamine	Infusion of living bone marrow suspension

The table above lists a variety of miscellaneous compounds which have been reported to exert radiation protective actions in varying degrees of activity.

ITEM NO.	SUBJECT AREAS:	SOURCE:
238	SYSTEM - S7 HUMAN - H38, H44	Reference 416, p. 110. Compiled from several primary sources.



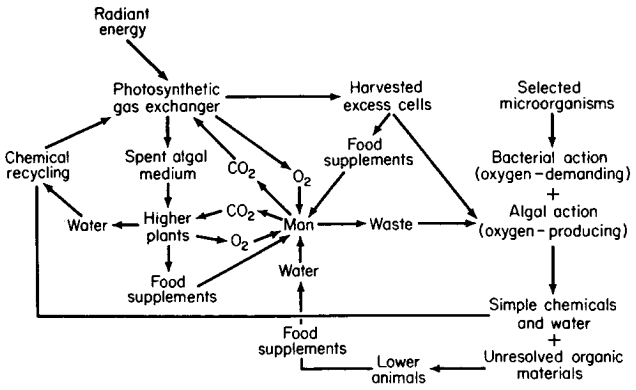
(a) Acute effects of gamma radiation in primates



(b) Shift in curve to show possible extent of radiation protection by drugs

Dose-survival time relationship predicted for man, with and without drugs.

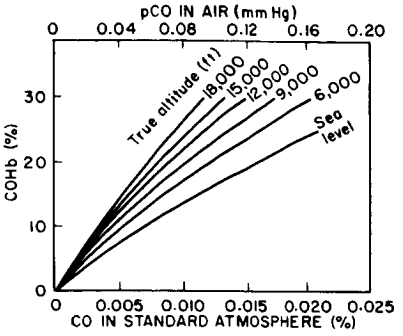
ITEM NO.	SUBJECT AREAS:	SOURCE:
239	SYSTEM - S7 HUMAN-H38, H44	Reference 416, p. 112. Based on Reference 221.



Interrelationships of biological systems in a closed ecological environment.

Purser, P. E.; Faget, M. A. and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

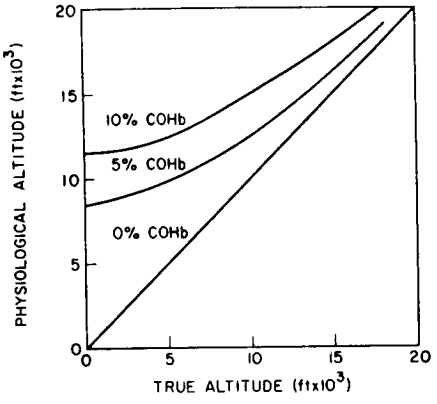
ITEM NO.	SUBJECT AREAS:	SOURCE:
240	SYSTEM-S9 HUMAN- H47	Reference 219, p. 440. Based on Reference 411.



Effect of altitude on uptake of carbon monoxide. Each curve is maximum amount of carbon monoxide taken up by blood on prolonged exposure. More carbon monoxide is taken up at high altitude because there is less oxygen to compete with it.

The figure above illustrates the intake of CO in hemoglobin (Hb) at different altitudes and at different values of fCO, assuming oxygen and CO combine with nearly all the hemoglobin in the blood. This graph is for equilibrium saturation resulting from prolonged exposure.

ITEM NO.	SUBJECT AREAS:	SOURCE:
241	SYSTEM- S2, S3 HUMAN- H9	Reference 380, p. 438. Based on Reference 364.

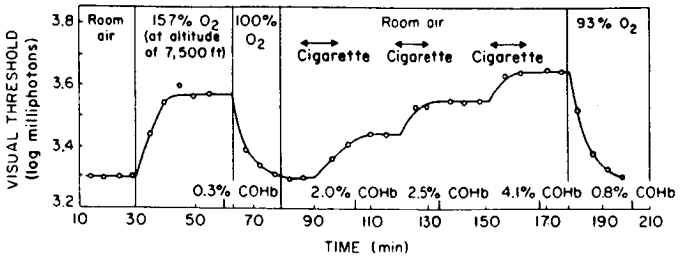


The figure above shows the relationship between physiological and true altitudes for 0, 5, and 10% COHb.

In establishing any CO time-concentration value, it is clear that the criterion is the oxygen requirement of the blood. Because noticeable effects of oxygen deficiency occur when the oxygen capacity of the blood is reduced about 10%, any CO concentration values or altitudes that would produce such a drop in a given period of exposure should be treated as dangerous. A standard of 12% COHb for long flights under noncombat conditions has been adopted as a critical level. This limit corresponds to blood in equilibrium for 1 hr before reaching the critical 12% value.

In general, it is recommended that 0.003% CO (30 ppm) be used as the standard permissible limit for long-term exposure. This standard provides a maximum COHb of 4% at sea level or a physiological altitude of approximately 8,000 ft. For shorter exposures where there is not enough time for equilibrium to be established between the blood and air, higher concentrations are permissible. For example, approximately the same blood concentration and physiological effect can be obtained from a 4-hr exposure to 0.005% CO as exposure for longer period to 0.003%.

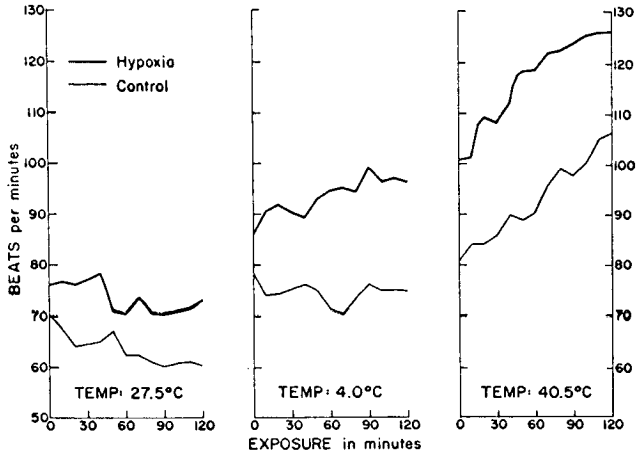
ITEM NO.	SUBJECT AREAS:	SOURCE:
242-	SYSTEM - S2, S3 HUMAN - H9	Reference 380, p. 440. Based on Reference 367.



The figure above shows the effects of time and CO (from cigarette smoking) on the visual threshold.

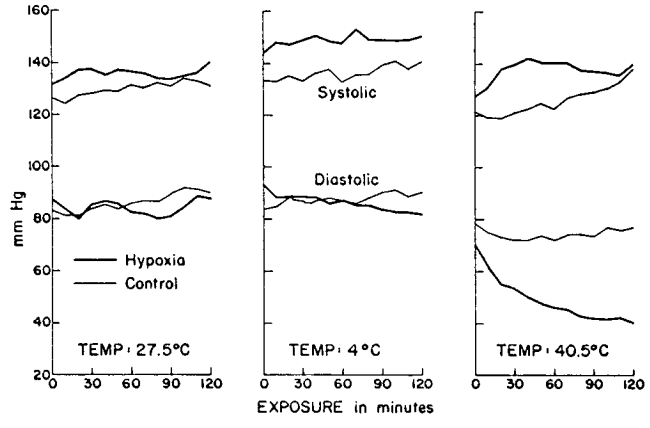
ITEM NO.	SUBJECT AREAS:	SOURCE:
243	SYSTEM - S2, S3 HUMAN - H25	Reference 380, p. 440. Based on Reference 367.

a



The effect of hypoxia on the resting heart rate at different environmental temperatures.

b

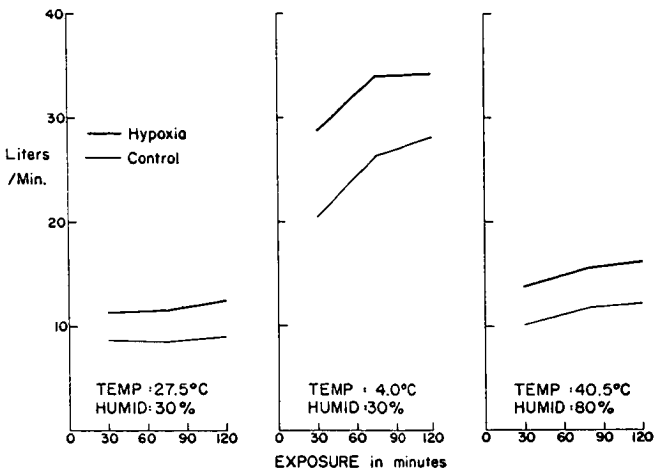


Blood pressure at rest in supine position during hypoxia and in control on air at different temperatures.

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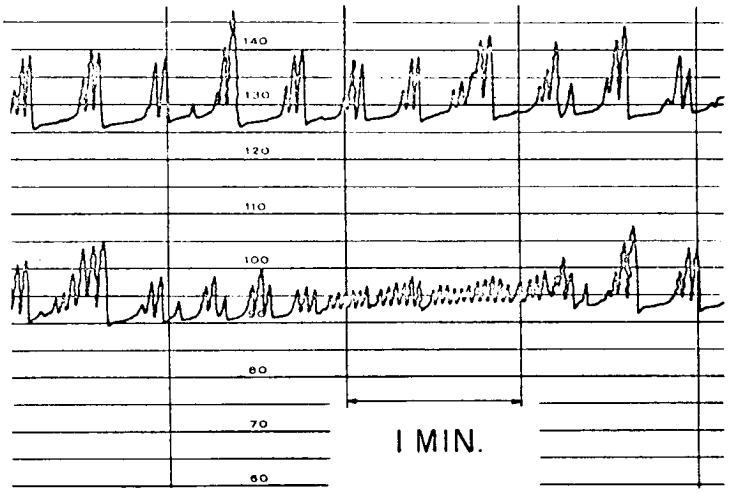
ITEM NO.	SUBJECT AREAS:	SOURCE:
244	SYSTEM - S2, S4 HUMAN - H9	Reference 325, pp. 141-142.

a



Pulmonary ventilation under three different thermal conditions, with and without hypoxia.

b

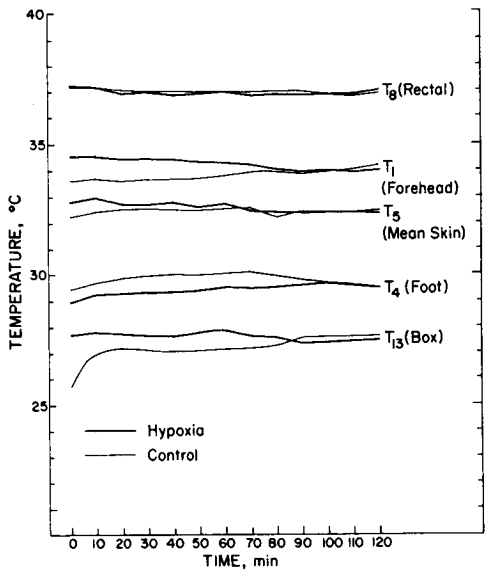


Typical Cheyne-Stokes (periodic) breathing observed most frequently in hypoxia combined with cold.

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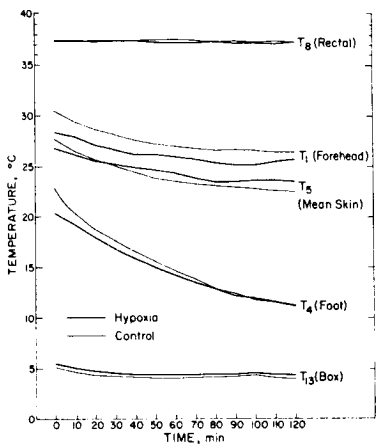
ITEM NO.	SUBJECT AREAS:	SOURCE:
245	SYSTEM - S2, S4 HUMAN - H16	Reference 325, pp. 140-141.

a



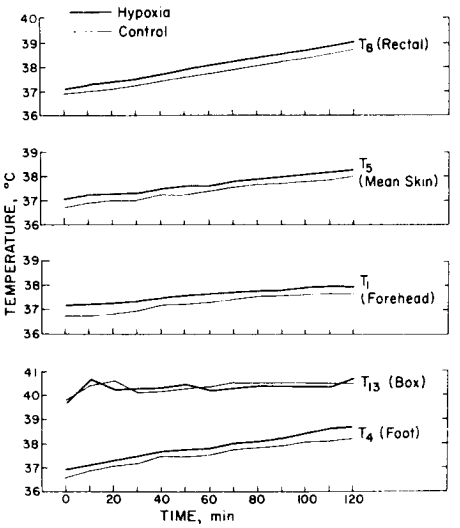
Course of rectal and peripheral temperature in neutral environment (27.5°C, RH = 30%, N = 5) with and without hypoxia (P_{IO_2} : 65 mm Hg)

b



Course of rectal and peripheral temperatures in a cold environment (40C, RH = 30%, N = 5) with and without hypoxia as in figure a.

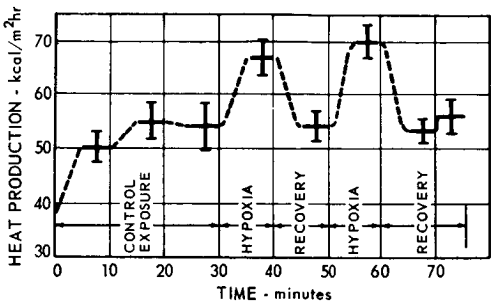
c



Course of rectal and peripheral temperature in a warm environment (40.5°C, RH = 80%, N = 5) with and without hypoxia as in figure a.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
246	SYSTEM - S2, S4 HUMAN - H18	Reference 325, pp. 138-139.



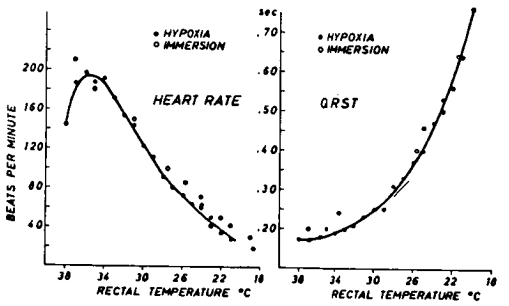
Mean values are shown for six subjects in ten exposures in a room at 41°F (5°C). The men wore only shorts and sat in a webbed chair. Hypoxia was produced by delivering 10% oxygen in the breathing mixture for two ten-minute periods. As oxygen consumption increased during each hypoxic period, so also did shivering, heart rate and respiratory ventilation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
247	SYSTEM - S2, S4 HUMAN - H20	Reference 554, p. 163. Based on Reference 104.

Required Ventilation in Relation to Carbon Dioxide Concentrations

	Level of Activity		
	At Rest	Moderate	Vigorous
Oxygen consumption at sea level in cu. ft./person/min.	.008	.028	.056
Ventilation rate required at sea level (cu.ft./person/min.)	1.2	3.9	8.7
Ventilation rate required at 5000 ft. (cu.ft./person/min.)	1.4	4.7	9.7
Ventilation rate required at 10,000 ft. (cu.ft./person/min.)	1.7	6.7	11.7

ITEM NO.	SUBJECT AREAS:	SOURCE:
248	SYSTEM- S2, S4 HUMAN- H22	Reference 14, p. 151. Based on Reference 585.

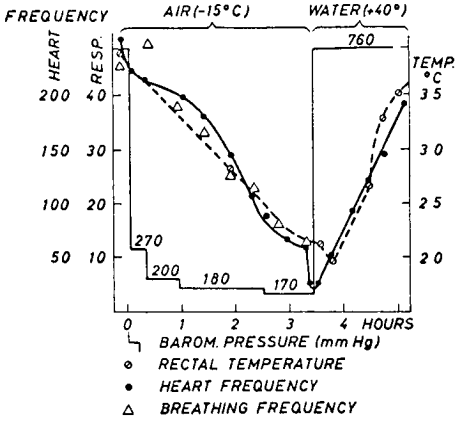


Heart rate and duration of the QRST* complex during body cooling induced by hypoxia in unanaesthetized dogs (closed circles) and by immersion in ice cold water under barbiturate anaesthesia (open circles). Means from experiments on 14 and 5 dogs respectively.

* QRST refers to a portion of the ECG tracing, and is a measure of the heart beat.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
249	SYSTEM- S2, S4 HUMAN- H9, H18	Reference 18, p. 124.

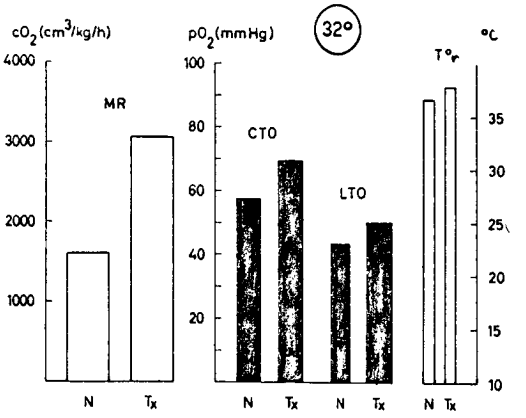


Deep hypothermia induced in an unanaesthetized adult dog by hypoxia (reduction of total air pressure) in a cold environment (-15°C in the barometric chamber). Rewarming in a warm bath (40°).

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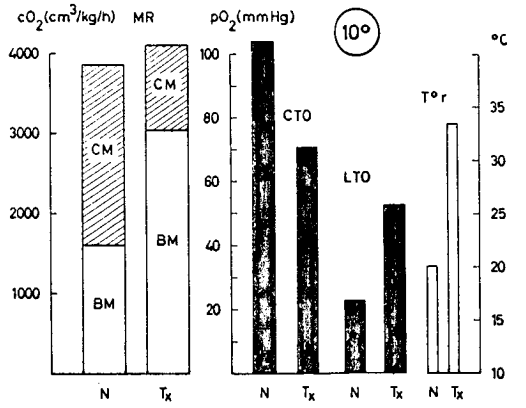
ITEM NO.	SUBJECT AREAS:	SOURCE:
250	SYSTEM- S2, S4 HUMAN- H9, H16, H18	Reference 18, p. 124. Based on Reference 21.

a



Influence of an excess of thyroid hormones on the metabolic rate and on the critical and lethal tensions of oxygen at 32° of environmental temperature. Experiments on thyroid-fed rats (desiccated pulverized bovine thyroid mixed with the standard pellet diet). Average values from 5 to 10 experiments. N - normal controls; Tx-thyroid-fed. MR = metabolic rate; CTO (first two black columns) - critical tension of oxygen; T°r - rectal temperature at the moment of death.

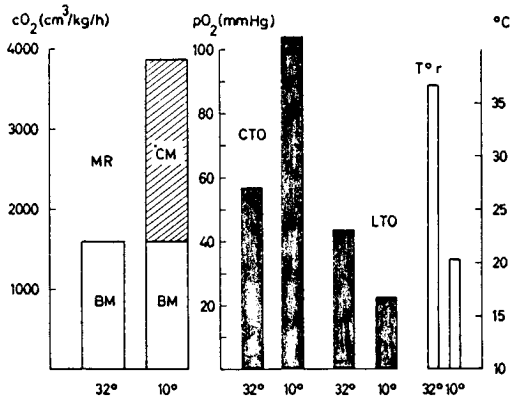
b



Influence of thyroid hormones on the metabolic rate, the critical and lethal tension of oxygen at 10°C environmental temperature. BM - basal metabolic rate; CM - compensatory mechanism. Other indications as in figure a, above.

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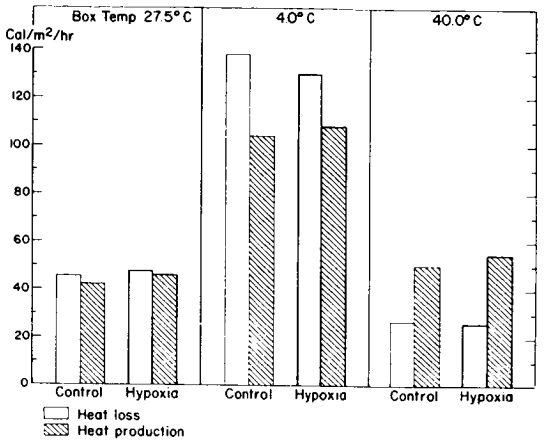
ITEM NO.	SUBJECT AREAS:	SOURCE:
251	SYSTEM - S2, S4 HUMAN - H12, H16, H18, H20	Reference 18, pp. 111-112.



Oxygen consumption rate and the critical and lethal tensions of oxygen (CTO and LTO), as influenced by the temperature of the environment (10° and 32°C). BM - basal metabolic rate; CM - compensatory metabolism. CTO (first two black columns) - critical tension of oxygen; $T^{o}r$ - rectal temperature at the moment of death. Average values from experiments on 4 - 12 normal adult rats ("closed cabin" exposure to decreasing oxygen tension).

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

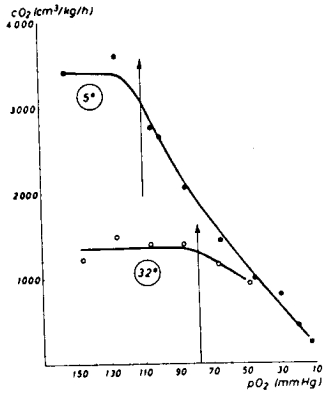
ITEM NO.	SUBJECT AREAS:	SOURCE:
252	SYSTEM - S2, S4 HUMAN - H16, H18, H20	Reference 18, p. 110.



Balance of heat production based on indirect calorimetry and heat loss calculated according to Hardy in a neutral, cold and warm enviornment with and without hypoxia.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
253	SYSTEM- S2, S4 HUMAN- H16, H20	Reference 325, p. 139. Based on Reference 258.



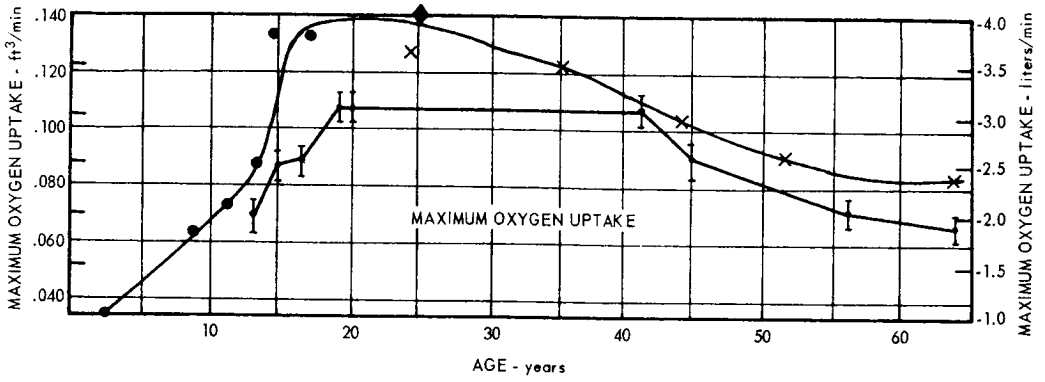
Oxygen consumption rate (cO_2) as a function of decreasing oxygen tension (pO_2) in the cold (5°C, closed circles) and at thermal neutrality (32°C, open circles). Experiments on individual rats under closed vessel conditions. Arrows, left and right, indicate the critical tension of oxygen (CTO) at 5° and 32°C respectively. Last right hand points in both curves indicate terminal values obtained at near-lethal O_2 tensions.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
254	SYSTEM - S2, S4 HUMAN - H16, H20	Reference 18, p. 109.

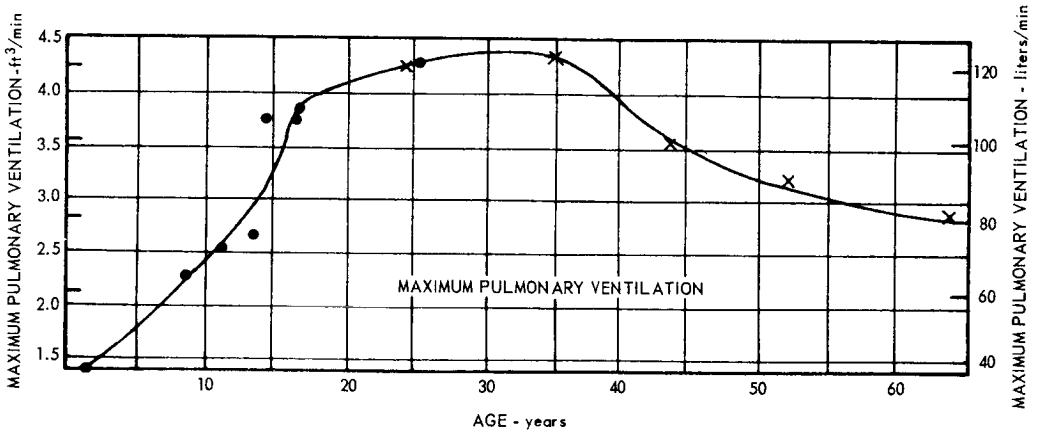
10-13. MAXIMUM OXYGEN UPTAKE AND AGE

a.



VALENTIN ET AL. (MEAN AND RANGE)
ÅSTRAND - 73 MALE SCHOOLCHILDREN, NONE OBESE
ROBINSON - 93 NONATHLETIC MALES
ÅSTRAND - 42 MALE PHYSICAL EDUCATION STUDENTS

b.

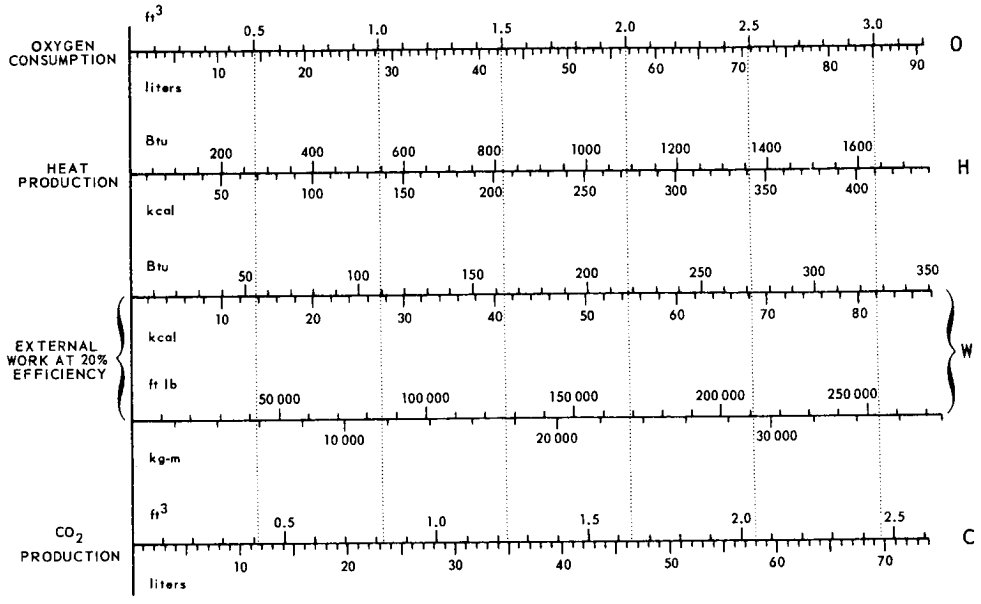


These two charts show the greatest pulmonary ventilation and oxygen consumption of boys and men from 3 to 65 years old, while exercising strenuously for 5-minute periods. This measurement is an individual characteristic which varies with the subject's physical condition; it is often called the maximum aerobic capacity (MAC).

Sources: Altman et al. [2], Åstrand [4], Robinson [44], and Valentin et al. [48].

ITEM NO.	SUBJECT AREAS:	SOURCE:
255 a Page 1 of 2	SYSTEM - S2, S4 HUMAN - H16, H20	Reference 554, p. 184.

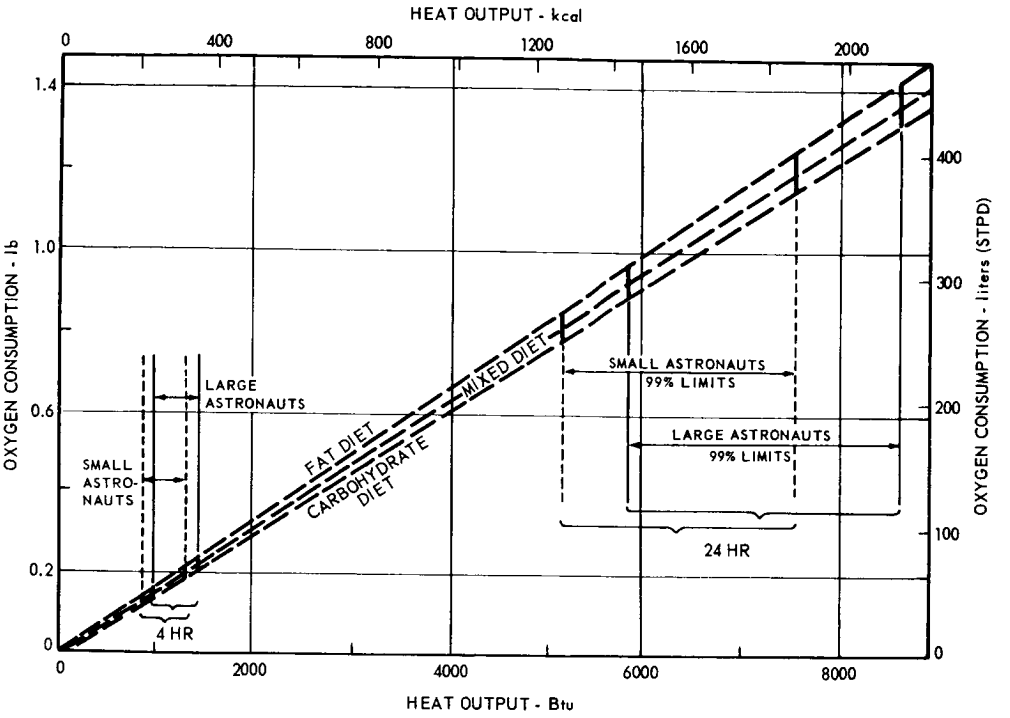
b.



Nomogram b uses the standard values: RQ = 0.82 and 1 liter of oxygen is equivalent to 4.825 kcal. This nomogram allows one to interrelate, by drawing straight vertical lines, the values for oxygen consumption (O), heat output (H), external work output (W), and carbon dioxide production (C), at typical conversion rates. Note that H may be as much as 3% lower or 5% higher than the quoted value at any specific oxygen consumption, depending on the RQ, which equals 0.7 for a pure fat diet and 1.00 for a pure carbohydrate diet. Values given in the third and fourth lines have to be modified if the efficiency changes. Typical ranges are 5 to 35%, average 20%, so that the listed work output may increase by three-quarters if the task is one that can be performed at high efficiency (e.g., bicycling). Conversely, the true value may be reduced by three-quarters if the function is inefficiently performed, e.g., high speed walking.

ITEM NO.	SUBJECT AREAS:	SOURCE:
255 b Page 2 of 2	SYSTEM- S2, S4 HUMAN- H16, H20	Reference 554, p. 185.

10-3. OXYGEN COSTS OF TISSUE MAINTENANCE



This chart gives the oxygen cost of tissue maintenance--that is, the irreducible quantity of energy needed for the work of breathing, circulation of blood, digestion, etc. The data are for men of the Mercury astronaut size range, for 4-hour and 24-hour periods at rest in a comfortable environment. The chart takes into account two factors that were not considered in 10-2: the difference between large and small astronauts, and subject-to-subject differences of biochemical origin.

Sources: Wilson [52] and Diem [15].

ITEM NO.	SUBJECT AREAS:	SOURCE:
256	SYSTEM - S2, S4 HUMAN - H16, H20, H22	Reference 554, p. 172. Compiled from several primary sources.

OXYGEN COSTS – EQUATIONS

a. Formulas for calculating the energy equivalent of any given oxygen consumption:

If breathing oxygen, $K = \theta \times O_{cons}$

where K is the energy expenditure,

θ is the energy equivalent per unit volume of oxygen consumed, and

O_{cons} is the volume of oxygen consumed, STPD (0°C, 760 mm Hg, dry).

If breathing gas mixtures, $K = \theta \times (O_{in} - O_{out})$

where O_{in} is the volume of oxygen (STPD) supplied to the mask, suit, or cabin, and

O_{out} is the volume of oxygen (STPD) leaving the mask, suit, or cabin.

If breathing air, $O_{in} = 20.93\%$, and $K = V(1.0429 - 0.0498\ O_{exp\%})$ with error less than 1%

where V is the volume of air (STPD) exhaled, and

$O_{exp\%}$ is the percentage of oxygen in the expired air.

Values for θ:

Pure fat diet; during extreme exhaustion:	θ = 525.3 Btu/ft^3, 4.686 kcal/liter
Mixed diet:	θ = 545.0 Btu/ft^3, 4.825 kcal/liter
Pure carbohydrate diet; heavy exertion:	θ = 565.8 Btu/ft^3, 5.047 kcal/liter

b. Formulas for calculating gross and net oxygen costs and efficiencies:

Gross values

--below maximum aerobic capacity*: $C_{gross} = \frac{O_{work}}{T_{work}}$ $\quad E_{gross} = \frac{W \times 100}{C_{gross}}$

--above maximum aerobic capacity: $C'_{gross} = \frac{O_{work} + O_{debt}}{T_{work}}$ $\quad E'_{gross} = \frac{W \times 100}{C'_{gross}}$

Net values

--below maximum aerobic capacity: $C_{net} = \frac{O_{work} - O_{rest}}{T_{work}}$ $\quad E_{net} = \frac{W \times 100}{C_{net}}$

--above maximum aerobic capacity: $C'_{net} = \frac{O_{work} + O_{debt} - O_{rest}}{T_{work}}$ $\quad E'_{net} = \frac{W \times 100}{C'_{net}}$

Oxygen debt: $O_{debt} = O_{recovery} - O_{rest}$

(measured over the same time interval, which must be adequate for the oxygen consumption to return to normal)

where C_{gross}, C'_{gross}, C_{net}, and C'_{net} are rates of oxygen consumption,

O_{work}, O_{rest}, O_{debt}, and $O_{recovery}$ are quantities of oxygen consumed,

E_{gross}, E'_{gross}, E_{net}, and E'_{net} are efficiencies (in percentage units),

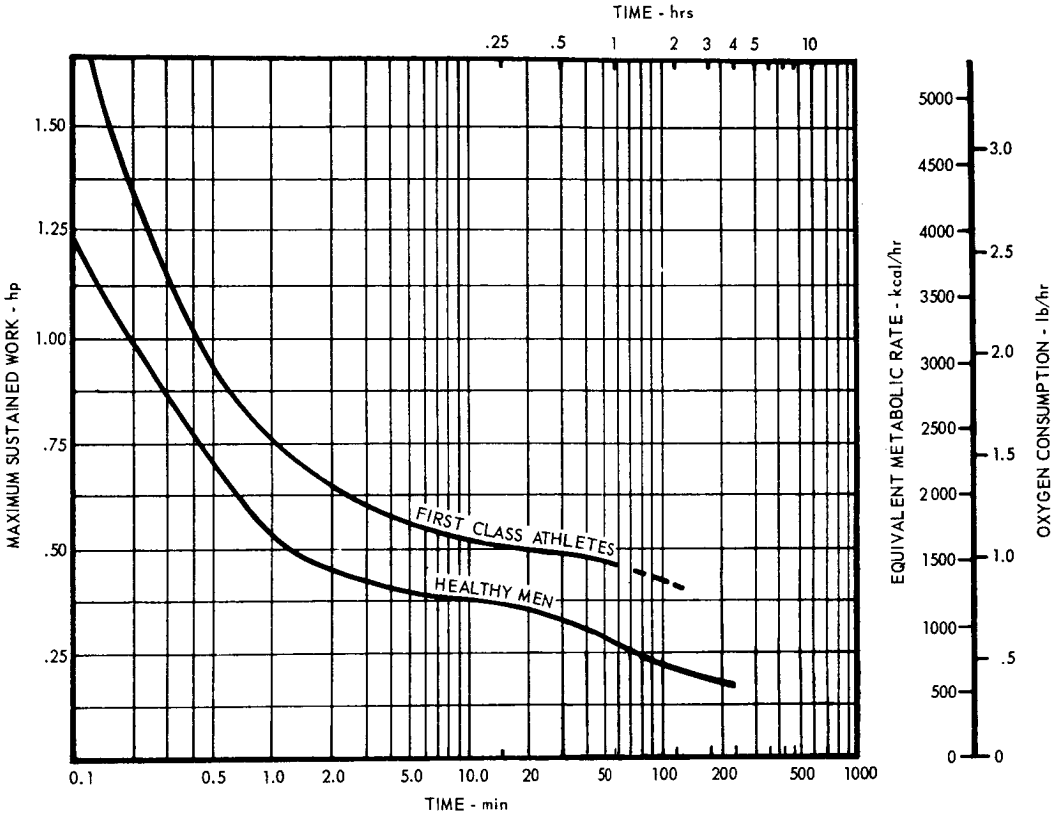
W is the quantity of external work produced, and

T_{work} is the time during which work is performed.

* The maximum aerobic capacity is a characteristic measurement for each individual, it is influenced by the individual's state of training, his age, and other factors.

ITEM NO.	SUBJECT AREAS:	SOURCE:
257	SYSTEM – S2, S4 HUMAN – H16, H20, H22	Reference 554, p. 186. Based on References 293, 324, 379, 428, and 564.

MAXIMAL WORK



This chart gives estimated endurance times for men at different rates of sustained work and oxygen consumption. The maximum measurable work which men can sustain is greatest for periods of less than one minute, when the oxygen demand can exceed the intake of oxygen, and an oxygen debt is incurred. These are rather special data in that the kind of work is chosen to yield highest power for a given metabolic rate, hence an efficiency of 20%. Running, rowing, cycling, and cranking are the favored methods, with cycling and cranking combined showing the best efficiency. Physical conditioning is of the greatest importance, as is evident from the difference in the two curves, where, incidentally, the healthy men are subjects who are young and physically active, and accustomed to the work used in the tests. Note the near plateau for the period from 5 minutes to 1 hour, showing that an athlete can sustain 0.5 horsepower for these times. However, efficiencies are usually 30% and higher for work at this level, which makes the oxygen consumption and metabolic rate values to the right about one-third too high. Data beyond 1 hour are sparse, and the maximum level one can sustain for 4-8 hours is not precisely known.

ITEM NO.	SUBJECT AREAS:	SOURCE:
258	SYSTEM - S2, S4 HUMAN - H16, H20, H22	Reference 554, p. 182. Based on several primary sources.

OXYGEN COSTS OF ACTIVITIES

These tables give typical values for the oxygen cost of everyday activities and of certain special activities, which may be useful in the bioastronautics program. The values were selected from the literature and adjusted for a man 69 inches tall and weighing 167 pounds (average values for the Mercury astronauts).

The first column of each table gives values for oxygen consumed, which can be regarded as the most direct estimate of energy expenditure generally available to us. Large men consume more oxygen than small men, and it is suggested that the values given be increased by 7.5% for large astronauts and reduced by 6% for small astronauts, based upon the size range of the men in current NASA programs.

Evidence is accumulating that important subject-to-subject differences exist even in men of the same size. These commonly give rise to variations as high as 60% when different men are performing the same task, as high as 30% when adjustments for body size are made, and as high as 10-15% when repeated measurements are taken on the same man.

The efficiency with which external work is produced also varies widely. It is lowest in the work of respiration (less than 5%), is 10-20% for common tasks, and highest in bicycling and walking on the inclined treadmill (up to 35% and occasionally 40% in trained men). Variations of these magnitudes must be allowed for in using the tables. To obtain closer estimates, measurements must be made on each astronaut.

The amount of energy that is produced when a given weight of oxygen is consumed depends on the fuel. On an average mixed diet, 0.1 lb of oxygen is used for every 613 Btu or 154 kcal. On a fat diet, however, this drops to 591 Btu. On a carbohydrate diet, and during prolonged physical work, the total energy produced is equivalent to 636 Btu per 0.1 lb.

Presented first is a useful table, derived from Christensen, given as an indication of the severity of physical work in terms of oxygen cost, energy expenditure, and heat output. The tables in 10-6 and 10-7 can be used to give an approximate value of the energy exchanges in a day by working out how many hours and minutes are spent on each activity. Thus, if 8 hours are spent asleep at 0.045 lb/hr, 4 hours are spent walking at 0.147 lb/hr, and 12 hours are spent in aircrew activities at 0.066 lb/hr, the total oxygen consumption in 24 hours is:

$$(8 \times 0.045) + (4 \times 0.147) + (12 \times 0.066) = 1.74 \text{ lb}$$

Several discrepancies in the tabulated values given in 10-6 and 10-7 are indicative of the imprecision of such data. This sort of variation is to be expected. For example, "shoveling sand" occurs twice; once under "Moderate activity--standing," and again under "Heavy activity--standing," with an appropriately higher level of energy cost. Both measurements shown have been reported in the literature, and both are probably valid for the subjects and activities measured. These disparities may be due to the wide range of subject-to-subject differences mentioned in the introductory paragraph above, to differences in the rate of work, or to some variation in experimental technique.

CLASSIFICATION OF PHYSICAL WORK BY ITS SEVERITY

	lb O_2/hr	kcal/min	Btu/hr
Very light work	below 0.10	below 2.5	below 595
Light work	0.10 - 0.19	2.5 - 5.0	595 - 1190
Moderate work	0.19 - 0.28	5.0 - 7.5	1190 - 1785
Heavy work	0.28 - 0.38	7.5 - 10.0	1785 - 2380
Very heavy work	0.38 - 0.47	10.0 - 12.5	2380 - 2975
Unduly heavy work	over 0.47	over 12.5	over 2975

ITEM NO.	SUBJECT AREAS:	SOURCE:
259 a Page 1 of 5	SYSTEM - S2, S4 HUMAN - H16, H20, H22	Reference 554, p. 173. Based on Reference 125.

10-6. OXYGEN COSTS OF ACTIVITIES

EVERYDAY ACTIVITIES

	Typical values for		
Asleep	lb O_2/hr	kcal/min	Btu/hr
Sleeping, men over 40	0.04	1.1	260
Sleeping, men aged 30-40	0.05	1.2	280
Sleeping, men aged 20-30	0.05	1.2	280
Sleeping, men aged 15-20	0.05	1.3	300
Resting			
Lying fully relaxed	0.05	1.2	290
Lying moderately relaxed	0.05	1.3	320
Lying awake--after meals	0.06	1.4	340
Sitting at rest	0.07	1.7	400
Very light activity--seated			
Writing	0.07	1.8	430
Riding in automobile	0.08	2.0	480
Typing	0.09	2.3	550
Polishing	0.09	2.4	570
Very Light activity--standing			
Relaxed	0.07	1.8	440
Drafting	0.07	1.9	460
Taking lecture notes	0.08	2.0	480
Peeling potatoes	0.08	2.1	510
Light activity--seated			
Playing musical instruments	0.11	2.9	690
Repairing boots and shoes	0.12	3.0	720
At lecture	0.12	3.0	730
Assembling weapons	0.14	3.6	860
Light activity--standing			
Entering ledgers	0.10	2.6	610
Washing clothes	0.15	3.7	890
Ironing	0.17	4.4	1040
Scrubbing	0.18	4.7	1130
Light activity--moving			
Slow movement about room	0.10	2.5	600
Vehicle repairs	0.13	3.4	820
Slow walking	0.15	3.8	900
Washing	0.16	4.2	1000
Moderate activity--lying			
Creeping, crawling, prone resting maneuvers	0.22	5.7	1360
Crawling	0.24	6.1	1450
Swimming breast stroke at 1 mph	0.26	6.8	1620
Swimming crawl at 1 mph	0.27	7.0	1670
Moderate activity--sitting			
Rowing for pleasure	0.20	5.0	1190
Cycling at 8-11 mph	0.22	5.7	1360
Cycling rapidly	0.27	6.9	1640
Trotting on horseback	0.28	7.1	1690

ITEM NO.	SUBJECT AREAS:	SOURCE:
259 b Page 2 of 5	SYSTEM- S2, S4 HUMAN- H16, H20, H22	Reference 554, p. 174. Compiled from several primary sources.

10-6. OXYGEN COSTS OF ACTIVITIES

EVERYDAY ACTIVITIES

	Typical values for		
Moderate activity--standing	lb O_2/hr	kcal/min	Btu/hr
Gardening	0.23	5.8	1380
Chopping wood	0.24	6.2	1480
Baseball pitching	0.25	6.5	1550
Shoveling sand	0.27	6.8	1620
Moderate activity--moving			
Golf	0.21	5.4	1290
Table tennis	0.23	5.8	1380
Tennis	0.25	6.3	1500
Army drill	0.28	7.1	1690
Heavy activity--lying			
Leg exercises, average	0.29	7.5	1790
Swimming breast stroke at 1.6 mph	0.32	8.2	1950
Swimming backstroke at 1.0 mph	0.32	8.3	1980
Lying on back, head raising	0.34	8.8	2100
Heavy activity--sitting			
Cycling rapidly--own pace	0.32	8.3	1980
Cycling at 10 mph--heavy bicycle	0.35	8.9	2120
Cycling in race (100 mi in 4 hr 22 min)	0.38	9.8	2340
Trotting on horseback	0.38	9.8	2340
Heavy activity--standing			
Chopping wood	0.29	7.5	1790
Shoveling sand	0.30	7.7	1830
Sawing wood by hand	0.31	8.0	1900
Digging	0.35	8.9	2120
Heavy activity--moving			
Skating at 9 mph	0.30	7.8	1860
Playing soccer	0.32	8.3	1980
Skiing at 3 mph on level	0.35	9.0	2140
Climbing stairs at 116 steps/min	0.38	9.8	2340
Very heavy activity--sitting			
Cycling at 13.2 mph	0.39	10.0	2380
Rowing with two oars at 3.5 mph	0.43	11.0	2620
Galloping on horseback	0.44	11.4	2720
Sculling (97 strokes/min)	0.49	12.6	3000
Very heavy activity--moving			
Fencing	0.41	10.5	2500
Playing squash	0.41	10.5	2500
Playing basketball	0.44	11.4	2720
Climbing stairs	0.47	12.0	2860
Extreme activity			
Wrestling	0.51	13.0	3100
Marching at double	0.52	13.3	3160
Endurance marching	0.56	14.6	3520
Harvard Step Test	0.63	16.1	3830

ITEM NO. 259 C
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SUBJECT AREAS:
SYSTEM- S2, S4
HUMAN- H16, H20, H22

SOURCE:
Reference 554, p. 175. Compiled from several primary sources.

10-7. OXYGEN COSTS OF ACTIVITIES

SPECIAL ACTIVITIES

		Typical values for		
Engineering tasks		lb O_2/hr	kcal/min	Btu/hr
Medium assembly work		0.11	2.9	680
Welding		0.12	3.0	720
Sheet metal work		0.12	3.1	760
Machining		0.13	3.3	800
Punching		0.14	3.5	840
Machine fitting		0.17	4.5	1060
Heavy assembly work--noncontinuous		0.20	5.1	1210
Driving vehicles and piloting aircraft				
Driving a car in light traffic		0.05	1.3	300
Night flying--DC-3		0.06	1.6	380
Piloting DC-3 in level flight		0.07	1.7	400
Instrument landing--DC-4		0.10	2.5	590
Piloting light aircraft in rough air		0.11	2.7	640
Taxi-ing--DC-3		0.11	2.9	680
Piloting bomber aircraft in combat		0.12	2.9	700
Driving car in heavy traffic		0.12	3.2	760
Driving truck		0.13	3.3	790
Driving motorcycle		0.14	3.5	840
Moving over rough terrain on foot				
Flat firm road	2.5 mph	0.11-0.19	2.8-4.9	660-1140
Grass path	2.5	0.12-0.20	3.2-5.1	760-1240
Stubble field	2.5	0.16-0.23	4.0-6.1	960-1440
Deeply plowed field	2.0	0.19-0.27	4.9-6.9	1160-1640
Steep 45° slope	1.5	0.19-0.27	4.9-6.9	1160-1640
Plowed field	3.3	0.30	7.8	1850
Soft snow, with 44 lb load	2.5	0.79	21.0	4850
Load carrying				
Walking on level with 58 lb load, trained men	2.1 mph	0.07	1.9	450
	2.7	0.11	2.9	690
	3.4	0.18	4.6	1100
	4.1	0.32	8.3	1980
Walking on level with 67 lb load, trained men	2.1	0.09	2.3	550
	2.7	0.11	2.9	690
	3.4	0.20	5.1	1210
	4.1	0.33	8.4	2000
Walking on level with 75 lb load, trained men	2.1	0.10	2.5	600
	2.7	0.13	3.4	810
	3.4	0.20	5.2	1240
	4.1	0.34	8.6	2100
Walking up 36% grade with 43 lb load, sedentary men	0.5	0.26	6.7	1590
	1.0	0.47	12.3	2910
	1.5	0.62	16.0	3800

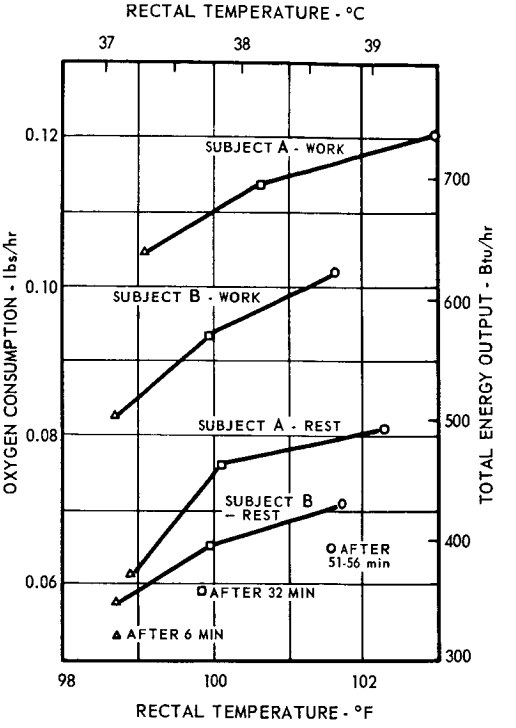
ITEM NO.	SUBJECT AREAS:	SOURCE:
259 d	SYSTEM- S2, S4	Reference 554, p. 176. Compiled from several primary sources.
Page 4of 5	HUMAN- H16, H20, H22	

10-7. OXYGEN COSTS OF ACTIVITIES

SPECIAL ACTIVITIES

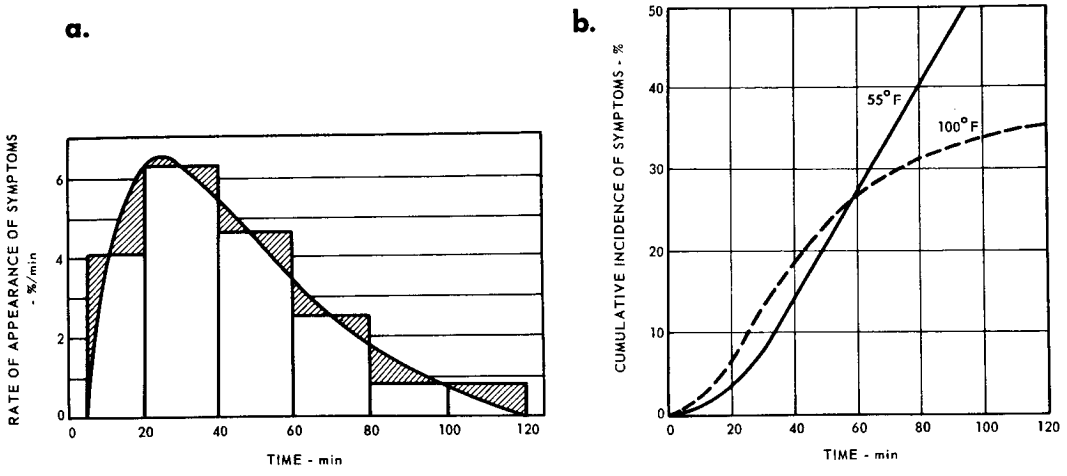
			Typical values for		
Swimming on surface			lb O_2/hr	kcal/min	Btu/hr
Breast stroke	1	mph	0.27	7.0	1650
	2		1.13	29.0	6900
	3		3.78	97.0	23100
Crawl	1		0.35	9.0	2150
	2		0.70	18.0	4200
	3		1.87	48.0	11400
Butterfly	1		0.47	12.0	2900
	2		1.13	29.0	6900
	3		2.92	75.0	17850
Walking under water					
Walking in tank	minimal rate		0.11	2.9	700
Walking on muddy bottom	minimal rate		0.21	5.5	1300
Walking in tank	maximal rate		0.28	7.2	1700
Walking on muddy bottom	maximal rate		0.33	8.4	2000
Movement in snow					
Skiing in loose snow	2.6	mph	0.32	8.1	1930
Sled pulling--low drag, hard snow	2.2		0.34	8.6	2020
Snowshoeing--bearpaw type	2.5		0.34	8.7	2070
Skiing on level	3.0		0.35	9.0	2140
Sled pulling--low drag, medium snow	2.0		0.38	9.7	2310
Snowshoeing--trail type	2.5		0.40	10.3	2460
Walking, 12-18"snow, breakable crust	2.5		0.50	12.7	3010
Skiing on loose snow	5.2		0.52	14.6	3800
Snowshoeing--trail type	3.5		0.59	14.8	4200
Skiing on loose snow	8.1		0.80	20.6	4900
Measured work at different altitudes					
Bicycle ergometer	430 kg-m/min	720 mm Hg	0.20	5.1	1230
	430	620	0.19	4.9	1170
	430	520	0.21	5.4	1290
Mountain climbing	880-1037 kg-m/min	610 mm Hg	0.36-0.43	9.2-11.0	2200-2640
	566- 786	425	0.30-0.37	7.7- 9.5	1840-2260
	393- 580	370	0.25-0.41	6.4-10.5	1530-2520

ITEM NO.	SUBJECT AREAS:	SOURCE:
259 e	SYSTEM- S2, S4	Reference 554, p. 177. Compiled from several primary sources.
Page 5 of 5	HUMAN- H16, H20, H22	



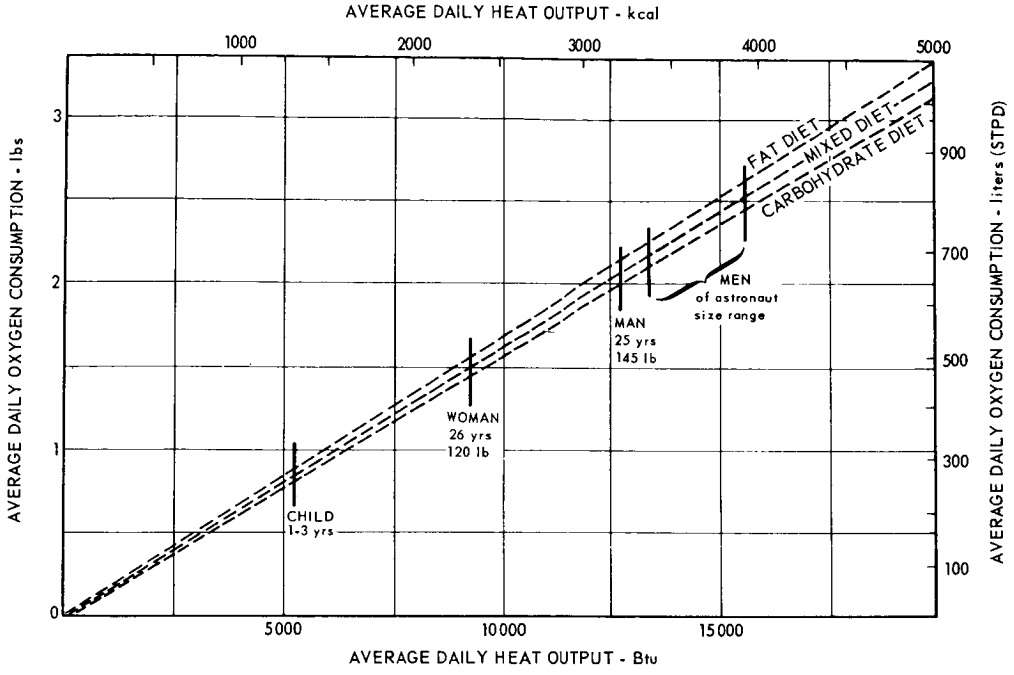
Average oxygen consumption and heat output as functions of rectal temperature for two men under heat stress, at rest and doing light work with a flight simulator. The percentage increase per °C rise in rectal temperature was 10 at work and 15 at rest, compared with a value of 11% cited by Robinson.

ITEM NO.	SUBJECT AREAS:	SOURCE:
260	SYSTEM- S2, S4 HUMAN- H16, H18, H20, H22	Reference 554, p. 181. Based on References 435 and 289.



Rate of appearance of symptoms of decompression sickness at altitude is shown here as a function of exposure time (left) and of exposure time and environmental temperature (right). Histogram at left represents observed data; the curve with it is derived from a formula for bubble formulation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
261	SYSTEM - S2, S4 HUMAN - H34	Reference 554, p. 97. Based on Reference 396.

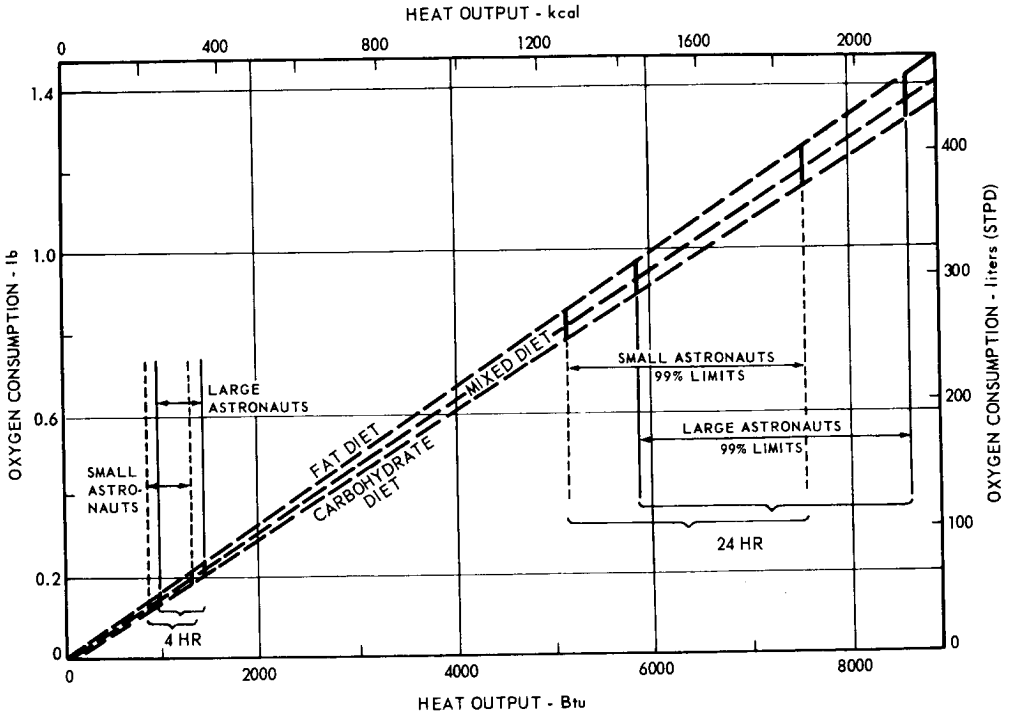


Body size is the most important determinant of average daily oxygen cost. This chart shows representative values for a child of 1-3 years, a woman of 25 years weighing 120 lb, and a man of 25 years weighing 145 lb. The values were calculated according to the method of the UN Food and Agriculture Organization, and assume that all three live at a mean annual temperature of 50° F and are neither sedentary nor very active. For comparison, the requirements of men of the size and age of the average of the Mercury astronauts are also given.

Modifications to the calculated values must be made for differences in environmental temperature. At 70° F the comparable daily expenditures, averaged over a year, would be reduced by 5%.

The three dashed lines show the values for oxygen consumption for different dietary mixtures.

ITEM NO.	SUBJECT AREAS:	SOURCE:
262	SYSTEM - S2, S4 HUMAN - H2, H16, H20	Reference 554, p. 170. Based on Reference 25.



This chart gives the oxygen cost of tissue maintenance--that is, the irreducible quantity of energy needed for the work of breathing, circulation of blood, digestion, etc. The data are for men of the Mercury astronaut size range, for 4-hour and 24-hour periods at rest in a comfortable environment. The chart takes into account the difference between large and small astronauts, and subject-to-subject differences of biochemical origin.

ITEM NO.	SUBJECT AREAS:	SOURCE:
263	SYSTEM - S2, S4 HUMAN - H2, H16, H20	Reference 554, p. 171. Based on References 168 and 581.

Effect of CO_2 Accumulation as Influenced by the Thermal Environment

	T°ext. (°C)	Time (min)	CO_2 accumulates	CO_2 removed	Final body temp.
Thermoneutral zone	32,5	70	dead	alive	Normal
	32,3	55	dead	alive	
	32,0	82	dead	alive	
	30,6	60	dead	alive	
Zone of chemical thermoregulation	22,5	86	alive	dead	Hypothermia
	22,5	117	alive	dead	
	17,2	90	alive	dead	
	17,0	113	alive	dead	
	14,0	115	alive	dead	
	8,7	107	alive	dead	

While severely detrimental at thermal neutrality, CO_2 accumulation may actually have survival value in the cold, when survival time is taken into consideration. This is shown by the following series of experiments on rats, enclosed separately in closed vessels of the same size (1.5 litres), and deprived of external oxygen supply. Each animal (150 - 180 g weight) served as its own control by being used in both of the two types of comparative experiments: exposure to hypoxia alone and to hypoxia combined with CO_2 accumulation.

At 30 - 33°C rats survived a given time (55 - 70 minutes) under closed cabin conditions when CO_2 was continuously absorbed on potassium hydroxide, but died at the end of the same time interval when the experiment was repeated without removing the expired carbon dioxide. At lower ambient temperature, however (from 23° down to 9°C), the opposite was observed: the animals have been kept alive by allowing expired CO_2 to accumulate for periods (1.5 to 2 hours) which were lethal if CO_2 was continuously removed.

However, under the conditions of these experiments which show the protective role of CO_2 accumulation, the lethal limits of CO_2 concentration were not approached. This protective effect can be expected to come into play only under special conditions in which the effect of CO_2 on the rate of cooling and the rate at which O_2 is removed from the enclosed atmosphere prevail over its toxic effects.

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
264	SYSTEM - S2, S4 HUMAN - H18, H34	Reference 18, p. 117. Based on Reference 20.

Use of Drugs Affecting Metabolism

Chlorpromazine	Glucose
Thiouracil	Chlorpromazine and cortisone
Methimazole	Hexamethonium and cortisone
Glutathione	Dibenamine
	Tris (hydroxymethyl)-Aminomethane, or THAM

Some of the drugs that might conceivably be of use to a space astronaut are listed above. These are compounds which exert their effect through the alteration of basic metabolic processes and are of such general use in clinical practice that their properties can be found in any complete textbook on pharmacology. Chlorpromazine has been known to lower body temperature and thereby decrease oxidative enzymatic metabolism. Such a pharmacologic tool would be useful if the oxygen supply within the sealed cabin were to be diminished, for any reason, or if the temperature in the internal environment were lowered to the point of uncomfortable constant shivering. The drug would then offer some degree of protection by decreasing the requirements of the body for oxygen through its body-temperature-lowering property. This drug apparently exerts a central action that abolishes the reflex impulses to the skeletal muscles in the same way as does any form of deep anaesthesia. This reflex blocking produces a lowered body temperature, since the skeletal muscles are a primary source of heat production, mediated by the hypothalmic centers. Thiouracil and methimazole are compounds that are specific in lowering basal metabolic rates should such needs arise, as on extended space voyages where biological or chemical systems for generating oxygen might have become unreliable or malfunctioning. Glutathione is known to provide a greater resistance to stress through enhancing hydrocortisone activity on carbohydrate metabolism. The addition of cortisone to compounds such as chlorpromazine or hexamethonium increases resistance to cold, as would the ingestion of glucose. Dibenamine is an adrenolytic which maintains a more homeostatic balance at the precapillary and capillary vascular level during exposure to stress. Nahas has suggested the possible use of THAM for the spaceman, working in his artificial atmosphere, as it tends to protect dogs from otherwise lethal levels of carbon dioxide in the blood. In general, compounds such as those mentioned would enhance the body's power of adjustment to a sudden or gradual change in environmental conditions.

ITEM NO.	SUBJECT AREAS:	SOURCE:
265	SYSTEM - S2, S4 HUMAN - H20, H38	Reference 416, p. 113. Based on References 108, 123, and 385.

Total Body Irradiation in Rats

	Survivors	Deaths
Normal Temperature	0	13
Hypothermia	11	2

ITEM NO.	SUBJECT AREAS:	SOURCE:
266	SYSTEM- S4, S7 HUMAN- H44	Reference 416, p. 121. Based on Reference 321.

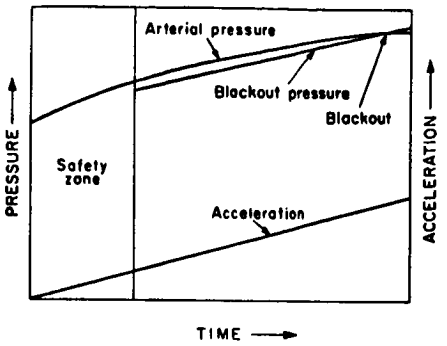
Effects of Reduced Environmental Stimulation on Perceptual Functions

Experimenters	Sensory Input	Visual Field	Effects
Hochberg et al.	Restricted	Homogeneous	Decolorization of Ganzfeld
Cohen and Cadwallader	Reduced or Increased	Uniform	"Blanking out" or "white-out"
Bexton et al.	Reduced	Unpatterned	Difficulty in focusing, color saturation
Freedman and Greenblatt	Reduced	Non-patterened	Perceptual distortions, increased time lag
Heron et al.	Reduced	Uniform	Perceptual lag
Ormiston	Reduced or Increased	Homogeneous	Increase or decrease in phi-phenomenon
Rosenbaum et al.	Reduced	Blackout or diffuse	No decrease of visual speed
Vernon et al.	Restricted	Blackout	Deterioration of various perceptual tasks

A survey about the effects of reduced environmental stimulation on visual functions is given above. By and large, the experimental situations are centered around two techniques: either the stimulus level is lowered or raised, or the stimulus structure (pattern) is changed. The auditory input may also be altered by masking noises or by reducing the absolute level of input below the auditory threshold. Similarly, the kinesthetic sensory input has been restricted in several ways. In many experiments the combined effects of the deprived sensory stimulation seem to have brought about the variability of the perceptual functions. The effects can best be characterized as a general loosening of the subject's ability to perceive reality and the weakening of stable internal norms against which perception is evaluated. The breakdown of internal norms is demonstrated in a number of accompanying factors but suggests one general parameter which makes isolation and sensory deprivation effective in (1) increasing the vulnerability of established frames of reference, (2) the generation of an active process which interferes with and degrades the existing schemata, and (3) susceptibility to new external environmental influences.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
267	SYSTEM- S5, S6 HUMAN- H25	Reference 219, p. 307. Based on References 277, 141, 71, 203, 172, 402, 442, and 541.



Arterial pressure and blackout pressure as function of time during gradual onset of acceleration. If rate of onset is slow enough, arterial pressure stays above blackout pressure. Therefore if the onset of acceleration is gradual, tolerance is considerably increased.

ITEM NO.	SUBJECT AREAS:	SOURCE:
268.	SYSTEM- S11 HUMAN- H9	Reference 380, p. 466. Based on Reference 179.

USE OF DRUGS FOR MOTION SICKNESS; ANTIHISTAMINICS

Diphenhydramine (benadryl)

Promethazine (phenergan)

Merezine

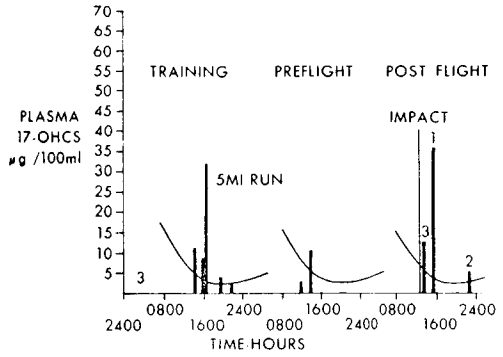
Dramamine

Hycosine

The compounds listed in the table are antihistaminics known to combat the effects of motion sickness. The need for such compounds might arise during the subgravity state, during exposure of the astronaut to low-cycle vibrations, and/or during spinning and tumbling, where disorientation, nausea, nystagamus, or the oculogravid illusion may be evident as psychophysiological stresses.

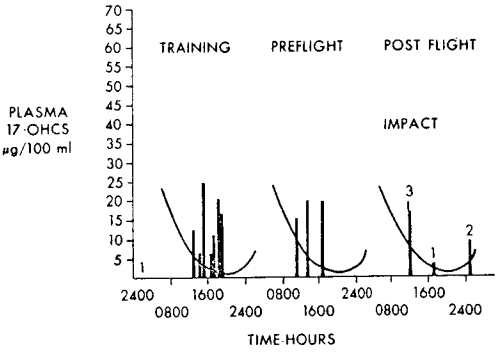
ITEM NO.	SUBJECT AREAS:	SOURCE:
269	SYSTEM - S11 HUMAN - H38	Reference 416, p. 114.

a



Plasma 17-hydroxycorticosteroid concentrations expressed as micrograms percent following astronaut training procedures, and during preflight and post-flight activities. Diurnal values are indicated by curved lines. Highest concentrations are seen following strenuous physical exertion (5-mile run) and immediately following impact. Responses generally characterize this subject as "hyporeactive."

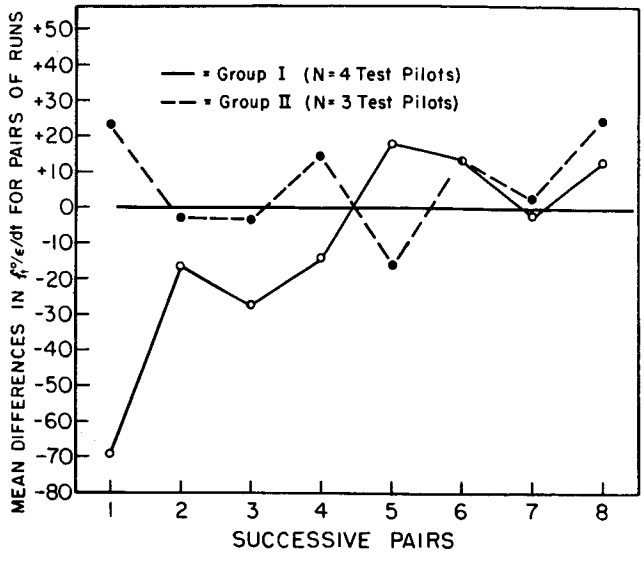
b



Plasma 17-hydroxycorticosteroid concentrations from a "hyperreactive" subject. Note the relatively high values following training procedures and during the preflight period. The diurnal curve also peaks at a relatively high level.

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

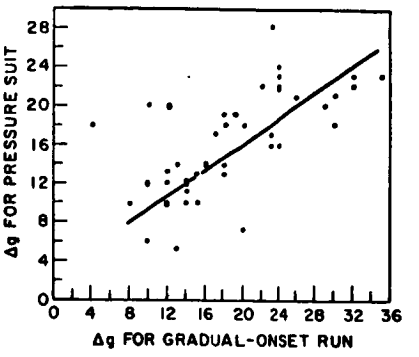
ITEM NO.	SUBJECT AREAS:	SOURCE:
270	SYSTEM - S11 HUMAN - H20, H22, H29	Reference 167, p. 131.



Comparison of performance curves for two groups of pilots who differed in terms of prior centrifuge experience. The scores are based on pairs of static and dynamic runs for each pilot tested under identical conditions, except for the presence or absence of acceleration stress.

Practice results in physiological adaptation and conditioning, as well as aiding the pilot in learning to make performance compensations for acceleration disturbances. The pilot improves his performance by: (1) accommodating to the sensations induced by G; (2) learning to resist the effects of G through the use of the proper straining and breathing techniques; (3) learning or relearning the task in the context of changed muscular and sensory capacities induced by the acceleration; and (4) learning to execute the physiological and performance aspects of the task simultaneously. As an example of such learning see the figure above. Group I had no prior centrifuge experience on the Johnsville centrifuge; Group II had prior centrifuge experience on other programs. Successive pairs indicate the first through eighth static-dynamic pair of runs which each pilot experienced. Each point is the mean difference between static and dynamic runs. Positive scores indicate that the pilot made more errors on the static runs; negative scores indicate that the pilot made more errors on the dynamic runs. The figure shows that it required several trials for Group I to do as well on its dynamic runs as on its static runs, while Group II performance shows no systematic change with practice. In higher G environments much greater increments in performance proficiency occur as a function of practice. The increment in proficiency is very rapid for subjects who have not had prior acceleration experience. However, even in the most experienced subjects, increments in performance proficiency may be expected in situations in which the task itself is difficult.

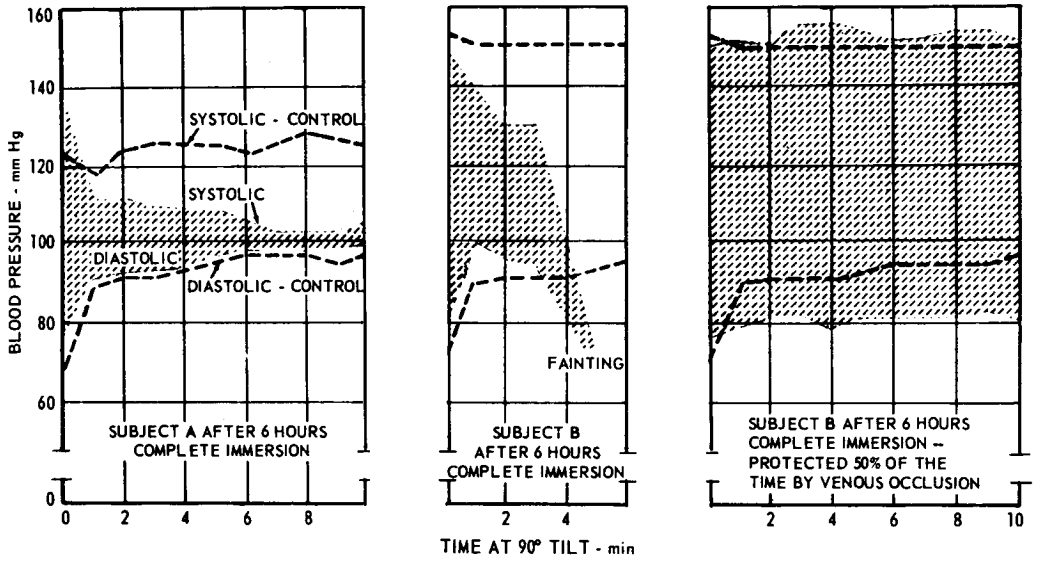
ITEM NO.	SUBJECT AREAS:	SOURCE:
271	SYSTEM - S11 HUMAN - H24, H41	Reference 116, p. 294.



Increment in tolerance produced by anti-g suit compared with that produced by making onset of acceleration more gradual. Criterion is relaxed blackout threshold for rapid onset.

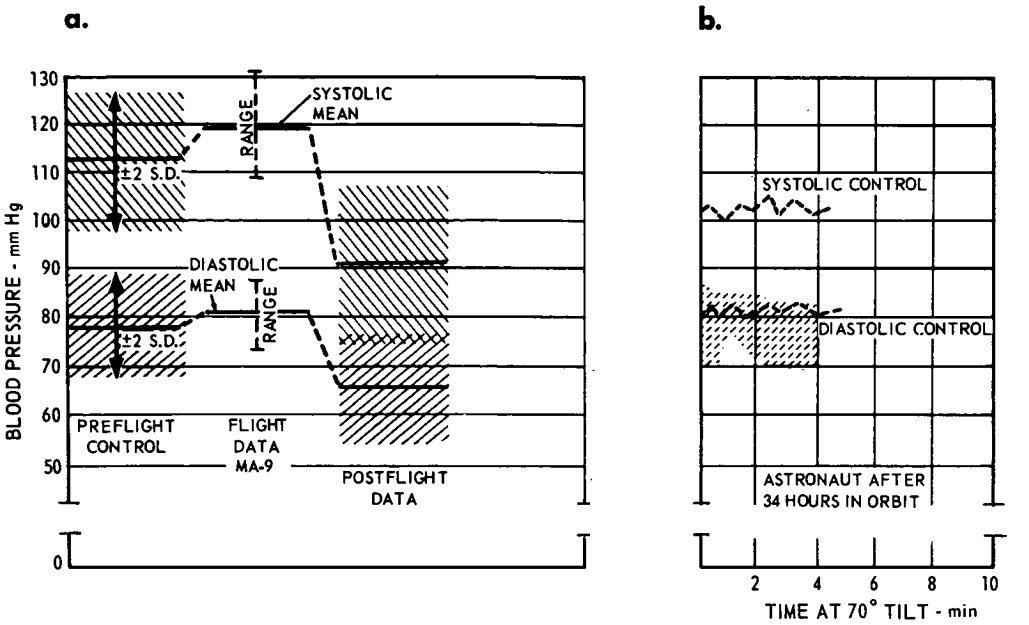
Although slow onset rates might not be achievable, the tolerance of the individual person under these hypothetical conditions may be used as a standard against which to compare the effectiveness of anti-g measures. Such a comparison is made in the figure above. The conditions represented in this graph are a constant rate of 0.07g/sec for the gradual-onset condition with no protection and 1g/sec to peak followed by 15 sec at plateau value for the rapid-onset condition with the protection of a standard pressure suit.

ITEM NO.	SUBJECT AREAS:	SOURCE:
272	SYSTEM- S11 HUMAN- H34, H44	Reference 380, p. 466. Based on Reference 179.



These graphs show the blood pressure responses of subjects being tilted from horizontal to vertical while held on a flat table. The normal response is to maintain both systolic and diastolic pressures about the same, or for either to rise slightly, as is evident in the control data shown with dashed lines for subject A, on the left, and subject B, in the center and to the right. The shaded areas show the range of systolic to diastolic blood pressure readings when the subjects were tilted following six hours of complete water immersion, during which they were free to move and stayed active. Subject A shows a rather typical narrowing of the pulse pressure (the pressure difference between systolic and diastolic pressures). Subject B (center graph) had a narrowing of the pulse pressure and then a rapid fall in pressure with fainting. When the same subject B was tested by tilting after another six hour period of immersion, during which blood was trapped in his arms and legs by inflating pressure cuffs to 60 mm Hg for one minute every two minutes (venous occlusion 50% of the time), he did not faint and in fact showed a perfectly normal response, as shown by the shaded area in the graph on the right. Similar improvements in response to tilt following immersion were observed when other subjects were protected by the venous occlusion procedure.

ITEM NO.	SUBJECT AREAS:	SOURCE:
273	SYSTEM - S12 HUMAN - H9	Reference 554, p. 59. Based on Reference 231.

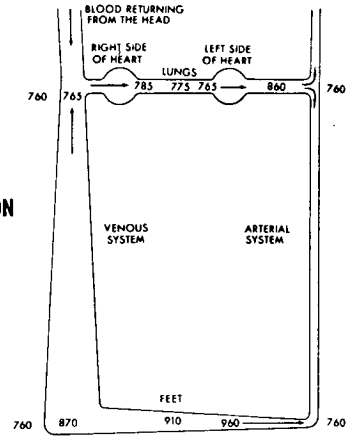


The blood pressure data shown here are from the final orbital flight of Project Mercury, the MA-9 flight of 34 hours with Astronaut Cooper. Three sets of averaged blood pressure data are shown on the left--the control data taken over the four years before the flight, the inflight readings, and the postflight data, which were taken during the first 6 1/2 hours after landing. The mean systolic pressure and the mean diastolic pressure are shown for all three periods. The variations around the means are shown as shaded areas representing twice the standard deviation (±2 S. D.) above and below the means for the preflight and postflight data, and shown by the range of readings taken in flight. Notice the distinct fall in both systolic and diastolic levels after the flight, compared to the essentially normal levels maintained in flight.

The graph on the right shows this astronaut's response to tilt in a procedure similar to the one described on the preceding page. His control data show a normal response to tilt, while just after the flight (1 hour, 20 minutes after landing) he shows a drop in systolic pressure and a narrowed pulse pressure. This postflight response is quite similar to the responses seen after water immersion.

ITEM NO.	SUBJECT AREAS:	SOURCE:
274	SYSTEM- S12 HUMAN- H9	Reference 554, p. 60. Based on Reference 387.

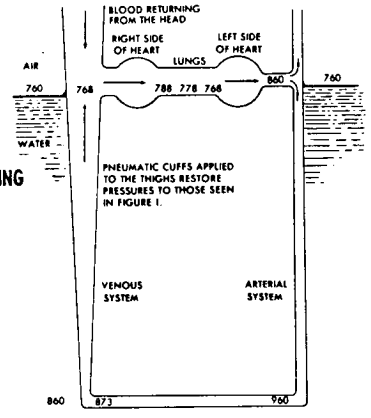
a



STANDING IN AIR BEFORE IMMERSION

Hypothetical diagramatic representation of pressure levels at various points in the cardiovascular system of a normal human subject standing in air in a 1g environment. Pressures are indicated in millimeters of mercury absolute.

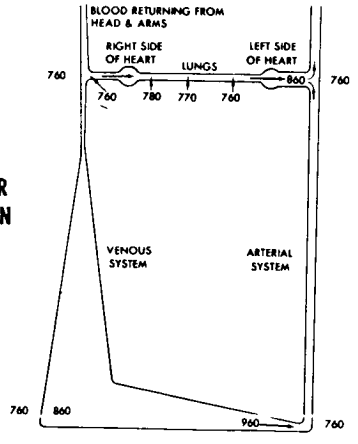
b



PRESSURES DURING IMMERSION

Hypothetical representation of the absolute pressures in the various parts of the vascular system of a human subject standing in water to neck level.

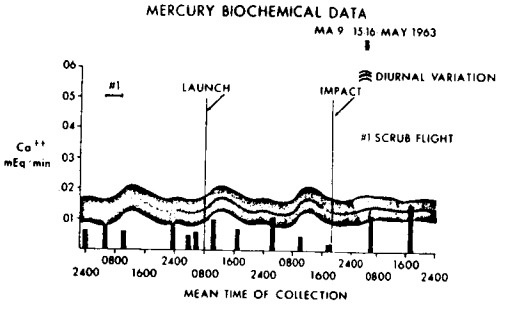
c



STANDING IN AIR AFTER IMMERSION

Changes in hypothetical pressure-volume relationships in the vascular system of a human subject standing in air following water immersion. Similar changes would be observed following prolonged bed rest of immobilization. Pressures indicated in millimeters of mercury absolute. Note the marked increase in volume of the venous reservoir as compared with that before and especially during immersion.

ITEM NO.	SUBJECT AREAS:	SOURCE:
275	SYSTEM - S12 HUMAN - H9	Reference 276, pp. 132-133. Based on Reference 72.



Urinary calcium data from Cooper's MA-9 flight. Bars indicate excretion rates of calcium in milliequivalents per minute for each timed urine specimen. Shaded wavy area represents diurnal range of a large number of random control specimens.

Because of the relatively short duration of the Mercury flights, no significant calcium mobilization, that is, demineralization of the bony structures was anticipated, and no serious attempt was made to perform precise metabolic balance studies. Appropriate samples of serum and urine were, however, analyzed for creatinine, calcium, and a number of other electrolytes for each of these flights. The figure above summarizes the urinary calcium data obtained before, during, and after Cooper's flight.

The shaded, wavy area represents the range of calcium excretion of some 40-50 random timed urine samples. The bars indicate the calcium content (expressed as milliequivalents per minute) of various timed urine specimens collected before, during, and after flight. In none of these samples was the excretion of calcium excessive or above Cooper's normal diurnal range. Hence, it would seem that at least for this 34-hour flight, no significant calcium mobilization occurred. More definitive calcium balance studies are planned for the longer flights of Gemini and Apollo, and it is hoped that these will shed more light on this potential problem area.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
276	SYSTEM - S12 HUMAN - H13	Reference 167, p. 130.

SUMMARY CARDIOPULMONARY DATA MA-8

EVENT	PULSE	BLOOD PRESSURE	RESPIRATION RATE
PRELAUNCH	72	117/89	20
LAUNCH	112	---	37
ORBITAL	76	126/69	19
REENTRY	104	---	43
POSTFLIGHT	56 (SUPINE)	120/84	--
	104 (ERECT)	94/70	--

FLIGHT TIME: 9 HRS 12 MIN
WEIGHT LOSS: 4½ ± ¼ LBS
POSTFLIGHT TEMPERATURE:
100. 1°F (RECTAL)
HEMATOCRIT: 44 TO 47
SUBJECTIVE SYMPTOMS: NONE

Mean values of biomedical data from Schirra's MA-8 flight and the postflight tilt table studies.

SUMMARY CARDIOPULMONARY DATA MA-9

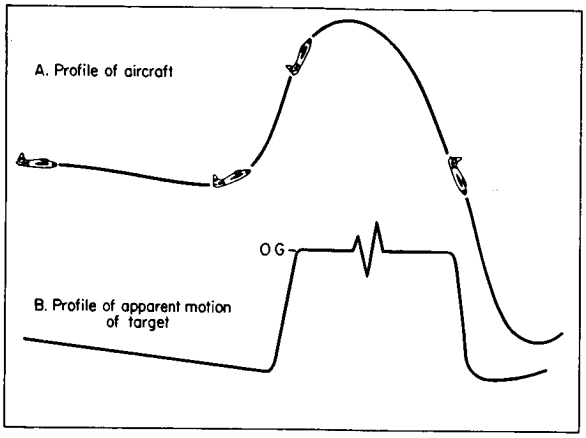
EVENT	PULSE	BLOOD PRESSURE	RESPIRATION RATE
PRELAUNCH	72	113/79	19
ORBITAL	89	119/81	15
POSTFLIGHT	83 (SUPINE)	89/64	--
(1-7 HRS) *	123 (ERECT)	90/73	--
(18 HRS)	58 (SUPINE)	98/61	--
	80 (ERECT)	94/68	--

FLIGHT TIME: 34 1/3 HRS
WEIGHT LOSS: 7¾ LBS
POSTFLIGHT TEMPERATURE: 99.4°F (ORAL)
HEMATOCRIT: 43 TO 49
SUBJECTIVE SYMPTOMS: DIZZINESS
* SUBJECT UNDER RESIDUAL EFFECTS OF 5 MGM D-AMPHETAMINE SULFATE

Mean values of biomedical data from Cooper's MA-9 flight and the postflight tilt table studies.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
277.	SYSTEM - S12 HUMAN - H9, H16	Reference 167, pp. 128-129.

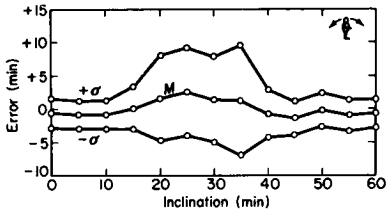


Apparent motion of a luminous target during a zero-G flight parabola. The upper line depicts the flight path, the lower line the apparent motion of the target, which was observed by the test subject in the cockpit of an F-94C aircraft.

Schock investigated the apparent displacement of a luminous target attached to the helmet at a distance of about 30 cm in front of the eyes of four test subjects during aerodynamic parabolas. The subjects reported that the target appeared to move upward or downward depending upon the changing acceleration vector. A schematic picture of the dynamic condition associated with these experiments is given above.

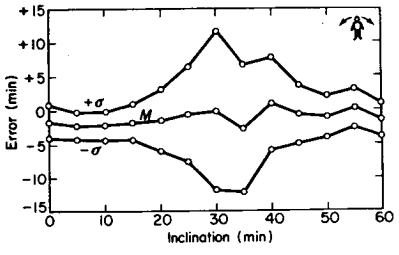
ITEM NO.	SUBJECT AREAS:	SOURCE:
278	SYSTEM - S12 HUMAN - H25	Reference 219, p. 280. Based on Reference 468.

a



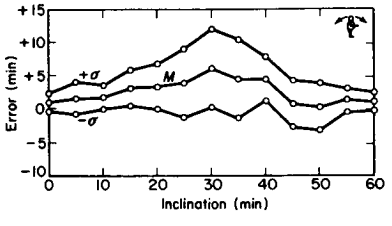
Errors in minutes by the subject floating in water as a function of the inclination of the axis of the body.

b



Lateral rotation of the body; otherwise same experiment as figure a, above.

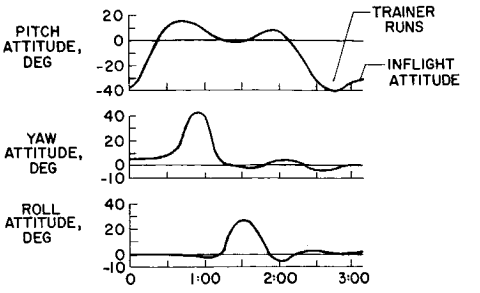
c



Same experiments as figure a, above, but carried out on a tilting table under normal conditions on the ground.

Blindfolded subjects were required to indicate the vertical by means of a pointer dial attached to their body, while underwater. The subjects were rather disoriented during the initial part of the test, and their errors frequently amounted to 180'. The orientation became more accurate after four or five trials.

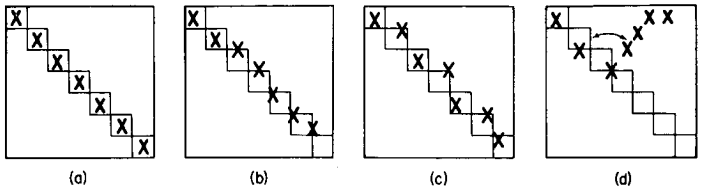
ITEM NO.	SUBJECT AREAS:	SOURCE:
279	SYSTEM - S12 HUMAN - H25	Reference 219, p. 283. Based on Reference 351.



Control Systems Check During the MA-6 Flight. Solid Line Contrasts Performance With Mean of Runs in the Trainer (shaded bands).

The figure above shows the performance of the astronaut during a period of manual control systems check of the orbiting vehicle. It is evident that he was performing within the standard attained in his previous experience with the simulator as represented by the shaded band. The detailed flight report gives much additional evidence of the astronaut's continued high level of performance and his clear introspection revealed no subjective disturbance such as nausea, vertigo, or spatial disorientation as a result of the weightless state.

ITEM NO.	SUBJECT AREAS:	SOURCE:
280	SYSTEM - S12 HUMAN - H26	Reference 270, p. 326. Based on Reference 386.

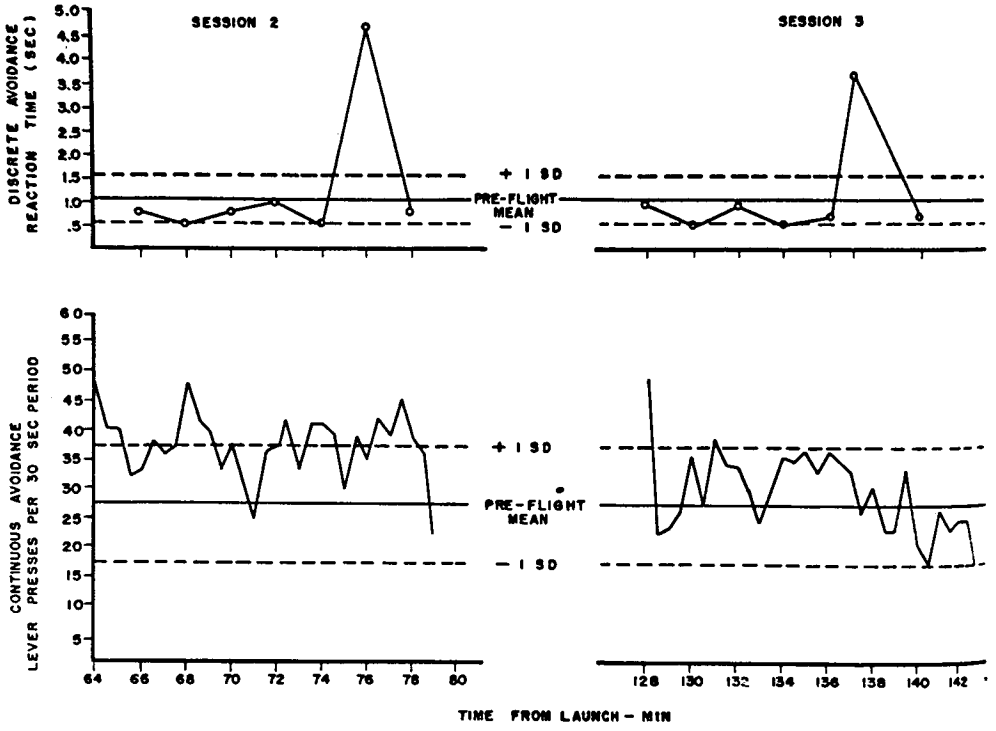


Cross-drawing test a and b were made during straight-and-level flight; b and c were made during the dive under subgravity conditions. (a) Eyes open: no deviations. (b) Eyes closed: some difficulties and irregularities. (c) Eyes open: even less accurate due to subgravity. (d) Eyes closed: the typical deviation of about 90° toward the upper right hand corner.

In order to study the effects of weightlessness on visual orientation and motor control, von Beckh performed a cross-drawing test in an aircraft. The subject had to place marks in seven squares arranged diagonally from the left top corner to the right bottom corner of a sheet of paper which was placed in front of him. The test was done in straight and level flight and during short periods of subgravity with eyes open and eyes closed.

The result is shown in the figure above. The pattern was irregular during subgravity. Without visual control it was impossible to place the marks in anything like a diagonal direction. After the third cross was drawn, a typical deviation toward the upper right-hand corner was observed in most cases. A great number of flights was necessary in order to obtain a regular pattern, and even then the results never were so accurate as those obtained under normal conditions.

ITEM NO.	SUBJECT AREAS:	SOURCE:
281	SYSTEM - S12 HUMAN - H26	Reference 219, p. 284. Based on Reference 544.



Shock Avoidance Performance of Chimpanzee Enos on Mercury MA-5 Flight, During Orbit

Enos was trained to perform several complex tasks, involving interpretation of panel lights and operation of levers. For the two tasks plotted above he was rewarded by avoidance of electric shock if he performed correctly. No failures to avoid shock occurred during these two periods.

ITEM NO.	SUBJECT AREAS:	SOURCE:
282	SYSTEM - S12 HUMAN - H26	Reference 239, p. 92.

EFFECTS OF EXPOSURE TO DIFFERENT TYPES OF WEIGHTLESSNESS

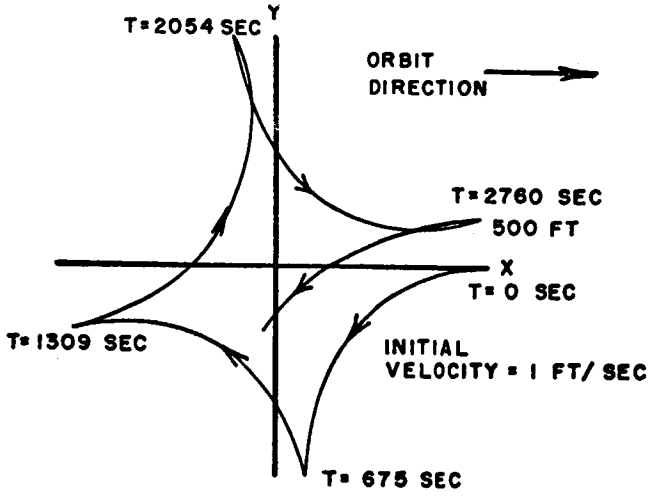
	Subgravity Tower	*Aerodynamic Flight Parabola*		*Immersion in Water*
Subject	At rest	Free-floating	Restraint	At rest
Duration	2 sec.	15 sec.	60 sec.	Several days
Dynamic Pattern	Fast sequence of acceleration (3 g) and very short periods of weightlessness	Moderate sequence of acceleration (3 g) and short periods of weightlessness	Pre- and post-weightlessness acceleration of moderate degree (2 g)	None
Mechanical Stress	None	None	None	None
Emotional stress	High	High	Moderate	None
Stimulation of Specific Gravireceptors	Very high	High	Low	Normal
Visceral Stimulation	High	Moderate	Low	None
Psychological Effects	Time dilation (subjective)	Disorientation	Pleasant-Unpleasant	None
Physiological Effects	High percentage of emesis	60% incidence of emesis	Less than 30% incidence of emesis	Sleeplessness, softening of muscles and bones

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ITEM NO.	SUBJECT AREAS:	SOURCE:
283	SYSTEM - S12 HUMAN - H34, H35	Reference 219, p. 235.

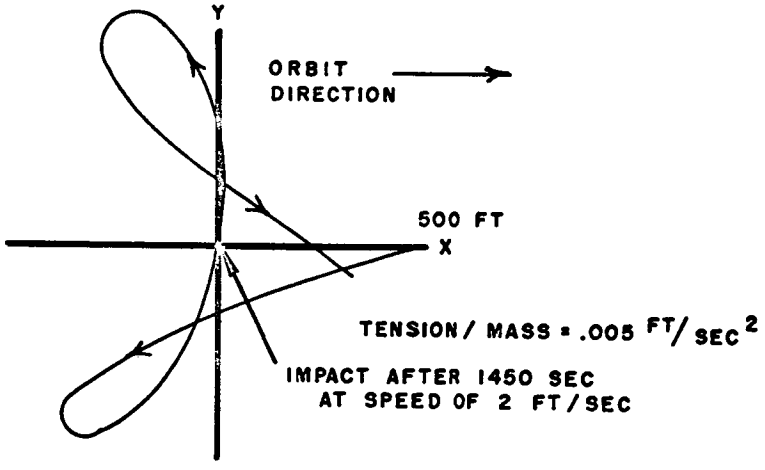
a

PATH OF MASS AT END OF TETHER AFTER INITIAL IMPUSE



b

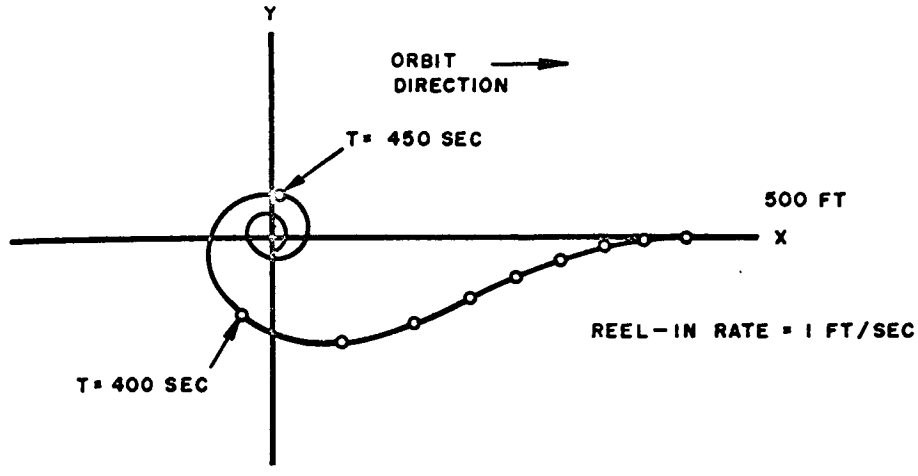
PATH OF MASS AT END OF TETHER WITH CONSTANT LINE TENSION



ITEM NO.	SUBJECT AREAS:	SOURCE:
284 a Page 1 of 2	SYSTEM- S12 HUMAN- H44	Reference 239, p. 94. Based on Reference 382.

c

PATH OF MASS AT END OF TETHER IF LINE IS REELED IN AT CONSTANT SPEED



Captain Donald Mueller has made a physical analysis of retrieving a man on a tether line. Suppose we jerk on the line to give the man a velocity vector toward the vehicle. An example of the possible consequences is shown in figure a for the situation where the man is ahead of the vehicle. This technique obviously will not return the man safely. If the tether is spring-loaded with a constant tension, the consequences could be as shown in figure b. Since this also is unacceptable, we might try a constant speed for retracting the tether, like reeling in a fish. The consequences of this are shown in figure c, with the man spiralling in to the vehicle at an increasingly high rotational velocity. There are some situations in which the tether line could succeed, but as a general solution it appears unworkable, except for rather short lengths. If we are to have astronauts operating outside of and free of their ship, there are serious problems still to be solved.

ITEM NO.	SUBJECT AREAS:	SOURCE:
284 b Page 2 of 2	SYSTEM - S12 HUMAN - H44	Reference 239, p. 95. Based on Reference 382.

IN-FLIGHT EXERCISE EXPERIMENT MA-9

(CALIBRATED WORKLOAD)

	PREFLIGHT (5 DETERMINATIONS)		FLIGHT (2 DETERMINATIONS)	
	MEAN HEART RATE	MEAN BLOOD PRESSURE	MEAN HEART RATE	MEAN BLOOD PRESSURE
PREWORK	74	104/81	89	117/77
WORK	115	---	131	---
POSTWORK	85	111/79	106	124/95

Table Summarizing the Preflight Control And In-Flight Data from Cooper's MA-9 Calibrated Workload Experiment

In an effort to obtain some information regarding the capacity of the astronaut to perform work during space flight, an inflight work or exercise-tolerance experiment was designed for Cooper's MA-9 flight. The exercise consisted of pulling on a nylon handle attached to a pair of rubber bungee cords, the other end of the cords being attached to the spacecraft near the astronaut's feet. A force of 60 pounds was required to stretch the exerciser through a maximum allowable distance of one foot. This rowing-type maneuver was performed once each second, thus providing a calibrated workload of 60 foot-pounds per second for a half-minute period. The results of this experiment are summarized in the table above.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
285	SYSTEM- S11 HUMAN- H9, H22	Reference 167, p. 128.

ANIMAL AND HUMAN RESPONSES DURING PERIODS OF WEIGHTLESSNESS OF DIFFERENT KINDS AND DURATIONS

Short Duration	*Moderate Duration*	*Long Duration*
Animal Experiments in Rockets and Aircraft No significant cardiovascular, pulmonary, and respiratory changes. No pathologic after-effects. Disorientation and panic during exposure, change of reflex pattern. Orientation through minimum otolith stimulation, visual and tactile clues, and learning.	*Animal Experiment in Sputnik II* No significant changes of physiologic functions during six days of weightlessness (Laika).	*Weightlessness Simulation by Means of Water Immersion* Pronounced functional deterioration ("weightlessness asthenia") during exposures up to about one week (Graveline); disturbance of cardiovascular reflexes, decreased muscle tone. Biochemical changes of blood and urine composition. Reduced need for sleep and metabolism. No or very little decrease of cardiovascular function, muscle strength and coordination during immersion (2 weeks); but marked postural hypotension on the tilt-table during and following immersion. Changes in blood and urine chemistry (Graybiel).
Human Experiments in Aircraft and Subgravity Devices Disorientation without visual reference. Disturbance of neuro-muscular coordination. Prolonged blackout and delayed motor responses during post-acceleration weightlessness. Motion sickness symptoms ("space sickness"). Mental set for falling. Oculo-agravic illusions in the dark. But: Majority of subjects feel elated, tolerate changing accelerations and subgravity, adapt and compensate during exposure, move easier than normal, and learn to perform as under 1-G conditions.	*Animal Experiments in Russian Spaceship Satellites* Dogs (Belka, Strelka, Pchelka, Mushka, Chernushka) exhibited "vegetative imbalance" after the fifth orbit (more than seven hours) and phases of "uncontrolled activity" which seemed to occur in cycles. These phases grew shorter with time, indicating a tendency to adapt to space flight conditions. *Human Experiments During Orbital Flights* Easy adjustment to weightlessness up to the third orbit (Gagarin, Grissom, Glenn, Carpenter, Schirra). Nausea after the fifth orbit and during the early reentry phase (cardiovascular and neuro-physiologic "imbalance") experienced by Titov. No such symptoms during three and four day flights of cosmonauts Nikolayev and Popovich, but higher calcium excretion.	

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ITEM NO.	SUBJECT AREAS:	SOURCE:
286	SYSTEM - S12 HUMAN - H8, H20, H34, H35	Reference 219, p. 399.

CHANGES WITH REAL AND SIMULATED WEIGHTLESSNESS

	Short-term Effects	Orbital Flight Data	Submersion Effects	Bed-rest Effects
	Free-fall, frictionless devices, Keplerian trajectory,* Mercury ballistic flights	Project Mercury primarily [Vostok flights V1 and V2]	Head-out submersion (HOS) Complete submersion (CS)	Normal subjects
General Metabolism				
Metabolic rate	--	Low-residue balanced diet pre-flight; low-caloric intake inflight.	Decreased	Decrease 6-9%
Body weight	--	Observed losses due to low-caloric intake and dehydration	Variable	Variable depending on caloric balance
Body temperature	--	Elevated due to thermal stress.	Depends on water temperature	No effect.
Water balance	--	Diuresis in one, low intake and low or normal urine volume in three Mercury astronauts.	Diuresis during both HOS and CS	Diuresis
Electrolyte balance	--	Post-flight Na^+ and Cl^- retention with rehydration.	Na^+ losses, HOS	Equilibrium
Musculoskeletal System				
Nitrogen balance	--	Not measured.	Equilibrium or negative	Equilibrium or negative, depending on method of calculation
Muscle girth and strength	--	No change.	Little or no change reported	Only slight wasting, little or no loss in strength
Calcium excretion	--	No increased excretion.	--	Sustained loss despite supine bicycle exercise
Cardiovascular System				
Resting responses				
Pulse	Abrupt decrease in heart rate on transition to weightlessness*	Normal values at rest, work, and sleep.	--	+0.5 beats/minute per day
Pressure	Influenced by prior G; resting value decreased while weightless*	Normal values at rest, work, and sleep.	Reduced pulse pressure	Increase
Stroke volume	--	--	--	Probable decrease
Cardiac output	--	--	--	No major change
Peripheral resistance	--	--	--	No marked change
Blood volume	--	Reduced in dehydration.	Plethora, elevated hematocrit	-9.3%
Tilt-table response	Abrupt decrease in heart rate on transition to weightlessness*	Transient faintness due to orthostasis on capsule egress with elevated heart rate--188; confirmed by tilt-table test post-flight.	Deterioration	Deterioration
Acceleration tolerance	No change	No apparent effect; good performance on reentry.	Decreased--small but significant	--
Exercise tolerance				
Work capacity	--	Maintained; work subjectively easier; pulse rate response slightly greater and slightly slower in return to normal.	Decreased	Decreased, but capacity can be maintained by supine exercise
Vasomotor activity	--	--	--	Response to supine exercise indicates effective arterial vasomotor activity but decreased venomotor tone

*In the body of the table, those data taken under the conditions of the Keplerian trajectory are marked with an asterisk.

ITEM NO.	SUBJECT AREAS:	SOURCE:
287 a	SYSTEM- S12	Reference 554, p. 56. Based on several primary sources.
Page 1 of 2	HUMAN- H9, H13, H20, H24	

CHANGES WITH REAL AND SIMULATED WEIGHTLESSNESS, continued

	Short-term Effects	Orbital Flight Data	Submersion Effects	Bed-rest Effects
	Free-fall, frictionless devices, Keplerian trajectory,* Mercury ballistic flights	Project Mercury--MA-9 Vostok flights V1 and V2	Head-out submersion (HOS) Complete submersion (CS)	Normal subjects
Mechanical Effects				
Swallowing	No problem with proper food containers and training*	No problem with proper food containers and training.	--	--
Urination	No problem	No problem; bladder sensation normal.	--	--
Free objects	Dust, droplet, and food crumb problem*	Dust, droplet, and food crumb problem.	--	--
Sensations				
Falling	Induced by prior G; absent when free-floating*	Not experienced.	--	--
Motion sickness	Related to G-transition*	One subject (Titov).	--	--
Orientation	Orientation unrestrained decays in dark, and tactile sensations become important; any surface can become floor for the individual*	Perceives earth or vehicle relative to self.	Otolithic sensitivity decreased in certain postures	--
Illusions	"Oculoagravic" illusion observed* ; no significant difference in semicircular canal sensitivity when weightless compared to 1G -- Oculogyral illusion*	Change in apparent position of objects in peripheral visual fields; head motion not disorienting.	Illusions related to sensory monotony	--
Vision	Small decrement in visual acuity*	Sightings indicate importance of pattern vision; no apparent decrement in acuity, color vision, or light sensitivity.	--	--
Performance				
Mass discrimination	Difference threshold twice as large for masses as compared to weights	--	--	--
Motor	Body restraint, hand-holds, tethers and adhesive footgear required for effective performance, closed force tools recommended; eye-hand coordination and object positioning shows overshooting, slight decrement in switch operation; rapid adaptation to altered motor requirements*	No operational decrement in restrained subject, as evidenced by reentry performance.	Vigilance, discriminative reaction time, and complex task performance show small decrements, HOS overshooting and applied force changes related to water displaced, CS	--
Sleep	Disorientation on sudden awakening*	Frequent dozing; oriented rapidly on awakening (one subject).	Diminished requirement	

*In the body of the table, those data taken under the conditions of the Keplerian trajectory are marked with an asterisk.

ITEM NO.	SUBJECT AREAS:	SOURCE:
287 b Page 2 of 2	SYSTEM - S12 HUMAN - H9, H13, H20, H24	Reference 554, p. 57. Based on several primary sources.

Use of Drugs for Excretory Problems

Stimulation of Intestine and/or Bladder Contractions

Physostigmine (eserine)

Neostigmine

Carbachol (carbaminoyl choline)

Diuretic Compounds	Antidiuretic Compounds
Caffeine	Prednisone
Theobromie	Amino acid mixtures
Acetozoleamide (diamox)	

The table indicates the drugs that might be considered for use in the presence of digestive malfunction or of problems concerning micturition. Such usage might be indicated during exposure to the prolonged subgravity state, wherein muscle atony or even atrophy may arise as space voyages become extensive. The compounds listed exert their effect primarily on the smooth musculature, so that drugs such as physostigmine, neostigmine, and carbachol may be used to stimulate contractions of the intestine; the last two enhance contractions of the bladder as well. Some space physiologists feel that the micturition reflex may be depressed under the influence of prolonged weightlessness, so that retention of urine may be a problem. Certain diuretic compounds may also be used to advantage; these include caffeine, which decreases fluid reabsorption in the kidney tubules; theobromine; and acetozoleamide, which inhibits carbonic anhydrase and prevents readsorption of the sodium ion. It might also be necessary to decrease urine production and, concomitantly, to reduce the need for normal quantities of drinking water by enhancing fluid retention. Drugs such as prednisone and certain amino acid mixtures could meet this requirement.

ITEM NO.	SUBJECT AREAS:	SOURCE:
288-	SYSTEM- S12 HUMAN- H11, H38	Reference 416, p. 115.

FACTORS DETECTED WHILE FREE-FLOATING

Subjective Sensations (subject's observations)	*Light Conditions*			*Weightless Conditions*			*Maneuver Conditions*				*Summary, Applications and Hazards*
	Light Cabin	*Dark Cabin and Moon*	*Dark Cabin*	*Low Friction*	*Free Body*	*G-Free Support and Stimulation*	*Rapid G Transition*	*Stress*	*Short Time Period*	*Aircraft Rotation*	
1. *Exhilaration* from surface freedom	×	×	×	×		×	×	×			Enjoyment increased in light cabin (knowledge of freedom), *G*-free support tends to induce an exciting and enjoyable environment. *G*-free training should be based on the advantages of such an environment.
2. *Comfort* of non-tactual support					×	×					Simpler bed and chair required, exercise required. Emphasis should be on man's position as focus, rather than cabin orientation within a vehicle.
3. Lack of *falling* sensation					×	×	×				Sudden vehicle accelerations induce falling sensations, while *G*-free training quickly dispels anticipated falling sensations. Slow *G* transitions reduce sensations during this phase.
4. Knowledge and control of *limb position* (orientation)	×				×	×	×		×		Positions were known during all conditions. Overshooting occurs in darkness but knowledge of results aids quick adjustment. Rapid motions perceived as weight.
5. Knowledge and control of *body position* in aircraft (orientation)	×				×	×	×		×		Posture orientation proposed as *basic reference plane*, for visual-gravitational conflict of subjective vertical is not a problem with posture identification. Man rather than vehicle should be design focus. The cockpit is 'floor oriented' whereas our space position may be 'man oriented.' Attitude and position information necessary to flight path knowledge can be related to basic reference plane. False rotation and loss of rotation knowledge noted.

ITEM NO.	SUBJECT AREAS:	SOURCE:
289. a Page 1 of 5	SYSTEM - S12 HUMAN - H24, H34, H35	Reference 219, p. 300. Based on data from Reference 480.

FACTORS DETECTED WHILE FREE-FLOATING

Subjective Sensations (subject's observations)	*Light Conditions*			*Weightless Conditions*			*Maneuver Conditions*				*Summary, Applications and Hazards*
	Light Cabin	*Dark Cabin and Moon*	*Dark Cabin*	*Low Friction*	*Free Body*	*G-Free Support and Stimulation*	*Rapid G Transition*	*Stress*	*Short Time Period*	*Aircraft Rotation*	
6. Knowledge of *vehicle attitude* (orientation)	×	×	×				×		×	×	Knowledge of surface location decreased in darkroom and apprehension and accidents increased because of inability to prepare for surface contact. Observers often unable to differentiate between subject motion and aircraft motion about subject without comparative *G*-free mass. *G*-free posture indoctrination (item 5) reduces need for vehicle information.
7. *Concern* over collisions	×	×	×	×	×	×		×			Difficulty in self rotation produces collision anxiety. Padding requirements are extensive, open machinery absolutely taboo. Training flights excellent for reducing overcontrol.
8. Illusions (target motion)		×				×	×	×		×	The apparent upward displacement of the visual target (oculo-agravic illusion) may not be a design problem with proper display information. Self propulsion units must have low thrust (low *G*) levels due to line of sight and deceleration program requirements. Autokinesis should be investigated with subjects moving in still visual field.
9. Sense of *zero, partial* and *excessive G's*	×	×	×	×	×	×	×				Lack of visual stimulation (dark cabin) increased sensitivity to *G*; *G*-free body systems tend to pick up strong sensations with minute stimulations (?) (Weber-Fechner law). Development of *G* cues may aid worker handling materials where small accelerations of mass and man are important factors.
10. Sense of *heaviness* after zero-*G* period					×	×	×		×	×	Variable control forces may aid psychomotor adjustment upon re-entry.

ITEM NO.	SUBJECT AREAS:	SOURCE:
289 b	SYSTEM- S12	Reference 219, p. 301. Based on data from Reference 480.
Page 2 of 5	HUMAN- H24, H34, H35	

FACTORS DETECTED WHILE FREE-FLOATING

Subjective Sensations (subject's observations)	*Light Conditions*			*Weightless Conditions*			*Maneuver Conditions*				*Summary, Applications and Hazards*
	Light Cabin	*Dark Cabin and Moon*	*Dark Cabin*	*Low Friction*	*Free Body*	*G-Free Support and Stimulation*	*Rapid G Transition*	*Stress*	*Short Time Period*	*Aircraft Rotation*	
11. Decrease in *clothing pressure*					×	×	×				Movies of loose clothing reveal that apparel tends to oscillate out of phase on moving limbs. Crews in shirt sleeve environments should wear form fitting, easily flexed clothing with elastic cuffs on limb extremities. The sensation could serve as a tactile perception of weightlessness.
12. Nausea and *motion sickness*	×			×	×	×	×	×	×	×	Rapid *G* transition and perceptual-sensation conflicts cause discomfort; may be valuable crew selection criterion.
13. Decrease in *span of attention*	×					×	×	×	×	×	During the excitement of the moment subjects forget their task. Criterion for crew selection might be their adaptation rate to unusual environment over short periods. Emergency tasks should be assigned to restrained workers. Task analyses should include a reorientation constant for free-floaters; omnidirectional displays should be developed.
14. Harness irritations					×	×					Harnesses tightened for 1-*G* behavior tend to limit *G*-free limb activity.
15. Change in *cabin pressure*										×	Changing cabin pressures were mistaken for weightless stimulations of the ear organs.
Performance Factors (Observable by subject or observer)											

ITEM NO.	SUBJECT AREAS:	SOURCE:
289 C	SYSTEM - S12	Reference 219, p. 302. Based on data from Reference 480.
Page 3 of 5	HUMAN - H24, H34, H35	

FACTORS DETECTED WHILE FREE-FLOATING

Subjective Sensations (subject's observations)	*Light Conditions*			*Weightless Conditions*			*Maneuver Conditions*				*Summary, Applications and Hazards*
	Light Cabin	*Dark Cabin and Moon*	*Dark Cabin*	*Low Friction*	*Free Body*	*G-Free Support and Stimulation*	*Rapid G Transition*	*Stress*	*Short Time Period*	*Aircraft Rotation*	
16. *Swimming* motions	×			×	×	×			×		These 'swimming in air' motions were unsuccessful attempts to translate, stabilize and turn; however, they tended to interfere with attitude control and disappeared after a few exposures (self rotation). Rotation training can be accomplished on simple swivel chairs.
17. *Body resilience* motions				×		×	×				Passive subjects tend to leave surfaces following sudden relaxation of excessive *G*-compressed tissues. Compressible objects should be tethered. Sleeping subjects should be restrained against their own accelerations.
18. *Cross-coupled* motion				×	×	×					3-d spinning subjects should extend limbs and thus reduce rpm. Any external force adds a linear component to the tumble. Stabilization gyros must be available for controlled rotation, before, during and after translation. Moments of inertia computed from segmented man models should include the transfer of energies between the muscular interactions of the various segments.
19. *Sloppy*, pendulous motion					×	×					Self induced accelerations tend to oscillate a *G*-free body causing unstable work performance, poor translation, and poor attitude and position control. Unharnessed operators should not be required to perform gross motions requiring discriminating movements. Open force systems must be avoided and man should work against himself.
20. Ease of *self propulsion*				×	×	×					Improper launches cause excessive motions, inadvertent tumbling, and rotating translations. Subjects can train for accomplishing straight and stable flight paths.
21. Difficulty in *walking*				×	×	×	×				Attempts at walking propel the worker from the surface. Handholds, rails, and foot devices are being developed.

ITEM NO.	SUBJECT AREAS:	SOURCE:
289 d	SYSTEM- S12	Reference 219, p. 303. Based on data from Reference 480.
Page 4 of 5	HUMAN- H24, H34, H35	

FACTORS DETECTED WHILE FREE-FLOATING

Subjective Sensations (subject's observations)	*Light Conditions*			*Weightless Conditions*			*Maneuver Conditions*				*Summary, Applications and Hazards*
	Light Cabin	*Dark Cabin and Moon*	*Dark Cabin*	*Low Friction*	*Free Body*	*G-Free Support and Stimulation*	*Rapid G Transition*	*Stress*	*Short Time Period*	*Aircraft Rotation*	
22. Change of *relaxed posture*					×	×	×				Subjects' limbs tend to contract toward the center of mass (fully relaxed subjects). Bed, chair, and control position designs should be affected.
23. Difficulty in *absorbing inertia* against a surface	×	×××	×××								The inability to self-rotate accurately and prepare for impact compels workers to absorb their previous launching forces haphazardly (lighted cabin). Exhilaration promotes overcontrol, which decreases with exposure. Cautious training, padded living areas, and attitude control aids are basic requirements.
24. Helplessness *between surfaces* (light cabin served as base line)		×	×	×	×	×					Suspended subjects are often incapable of surface return. Training methods should include proper methods of expending mass to achieve translation.
25. Rigidity of *powered tools*				×	×	×					Tools may be a source of stabilization, but are difficult to align and reposition. Motors impart forces to *G*-free capsules.
26. Suspension of dust and objects				×		×					Filters, screens, air circulation are required; smooth configuration of objects is a necessity.
27. Inadequacy of open containers, tethers		×	×	×		×	×				Covers, mounts, and tethers must be designed.

Note: × indicates conditions affecting factor.

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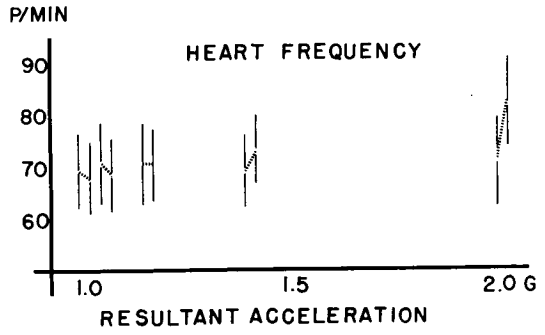
ITEM NO.	SUBJECT AREAS:	SOURCE:
289 e	SYSTEM - S12	Reference 219, p. 304. Based on data from Reference 480.
Page 5 of 5	HUMAN - H24, H34, H35	

HOW IT FEELS TO BE WEIGHTLESS. RESPONSES OF FORTY-SEVEN HUMAN SUBJECTS TO SHORT PERIODS OF VIRTUAL WEIGHTLESSNESS

Group	*No. of Subjects*	*Attitude Prior to Flight*	*Psychological Reactions*	*Physiological Symptoms*	*Autonomic Disturbances*
I	22	Normal, or slightly apprehensive.	Sensation of rest or slow floating; feeling of well being, comfort, pleasure, relaxation, enjoyment and exhilaration; same experience during repeated exposure; euphoric and/or enthusiastic responses.	Tingling and "light" sensation at abdomen; slight disorientation with eyes closed; slight giddiness; slight hyperventilation; slightly hyperactive Patellar reflex.	None
II	11	Normal, or slightly apprehensive.	Sensation of floating or tumbling forward and backward; sensation of falling or lift during transition; sensation of standing on head, or being suspended in an inverted position; mildly elated situation, neither unduly pleasant nor exactly comfortable.	Slightly disoriented with eyes open, enhanced with eyes closed; hyperventilation, mildly dizzy and slightly nauseated; hot or cold feeling, increased perspiration; tired and sleepy after flight.	None, or moderate degree of vertigo and nausea attributed to changes of acceleration and weight.
III	14	Normal or slightly apprehensive; occasionally fear and acute anxiety.	Sensation of floating, drifting and/or tumbling, sensation of falling forward or rolling over; "light" or "heavy" feeling in head or stomach; stomach seems to move upward; elated in the beginning with progressing discomfort.	Generalized motion sickness syndrome including sweating, dry throat, increased salivation; feeling of coldness or heat.	Vertigo and nausea; vomiting during flight.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
290	SYSTEM - S12 HUMAN - H29, H34, H35	Reference 219, p. 228.



Heart rate preceding and during acceleration, ±1 standard deviation indicated. 100 observations for each acceleration. Acceleration acting sideways. Data presented without respect to body and head position.

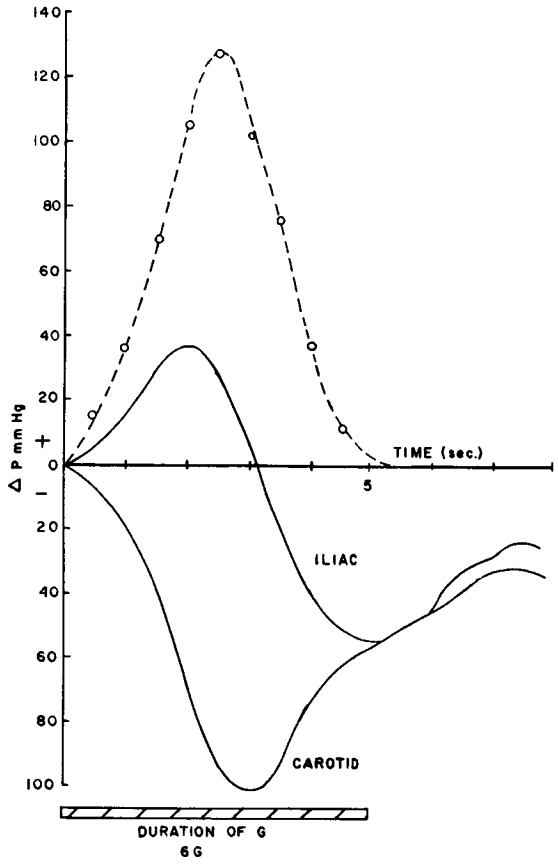
Heart rate preceding and during acceleration, ± 1 standard deviation indicated. 100 observations for each acceleration. Acceleration acting sideways. Data presented without respect to body and head position

Each pair of lines in the figure represents the control value immediately preceding centrifugation and the value during centrifugation with their respective standard deviations.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
291	SYSTEM - S13 HUMAN - H9	Reference 306, p. 389

a



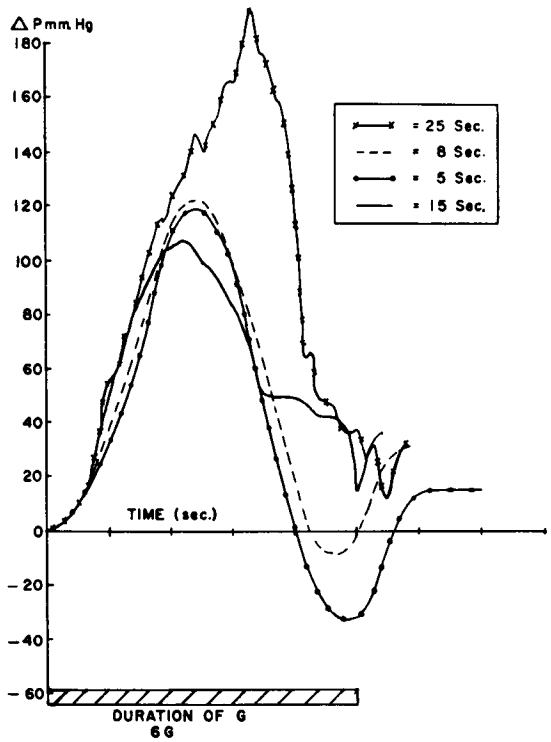
The pressure contribution of the fluid column (dotted line), the difference between iliac and carotid pressure curves, compared with the radial acceleration curve (open circles).

Modern computer-controlled centrifuges offer an opportunity to control the amplitude and temporal course of the acceleration transient so that the response can be analyzed. For a 5-sec 6-g peak exposure, having the form $A(1 - \cos \omega t)$, diastolic blood pressure as measured from catheters placed in the carotid and iliac arteries varied as shown in the figure above.

The pressure difference between these two curves is accounted for entirely by hydrostatic forces. Pressures measured in the carotid have little or no hydrostatic component. The pronounced decrease in pressure in this location is due to a generalized decrease in arterial blood volume occasioned by a pronounced decrease in cardiac output. In the central portion of the arterial tree the hydrostatic and volume effects are transiently in balance, so that little or no blood pressure change occurs for one or more of the 5 sec. Even in the extremes of the arterial system, however, where the hydrostatic forces are greatest, the blood pressure ultimately falls below pre-acceleration values.

ITEM NO.	SUBJECT AREAS:	SOURCE:
292 a Page 1 of 3	SYSTEM-S13 HUMAN-H9	Reference 318, p. 8. Based on Reference 316

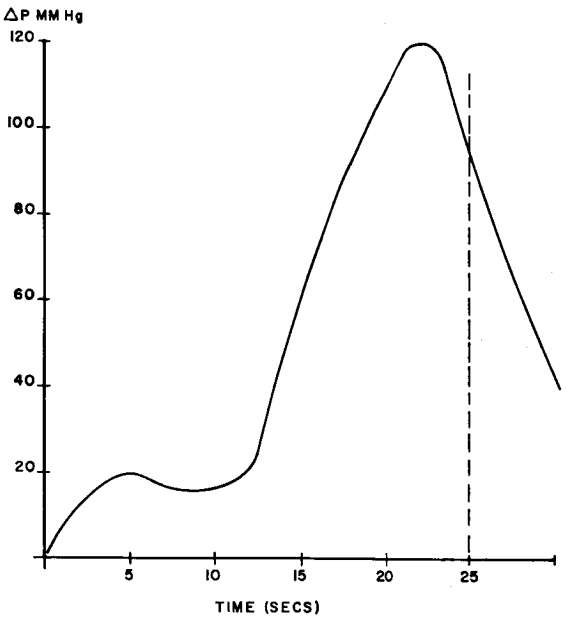
b



Effect of varying the period of acceleration on the blood pressure response (tibial artery). All records have been normalized to a common representation for the duration of the acceleration.

When exposure is prolonged, the blood pressure response is altered by cardiovascular reflexes. These take the form of cardiac acceleration and peripheral vasoconstriction. For accelerations of 6-g peak applied for periods varying between 5 and 25 sec diastolic blood pressure varies as shown in this figure.

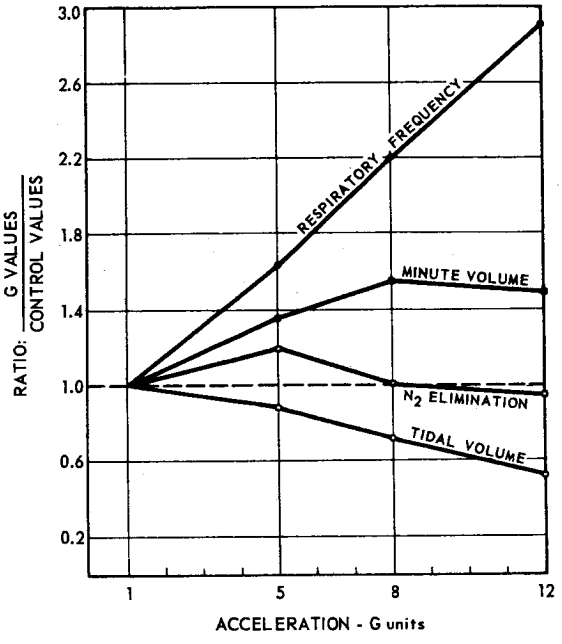
ITEM NO.	SUBJECT AREAS:	SOURCE:
292 b Page 2 of 3	SYSTEM - S13 HUMAN - H9	Reference 318, p. 9. Based on Reference 316.



Pressure difference due to reflex effects (26-sec curve minus 5-sec curve of Figure b.

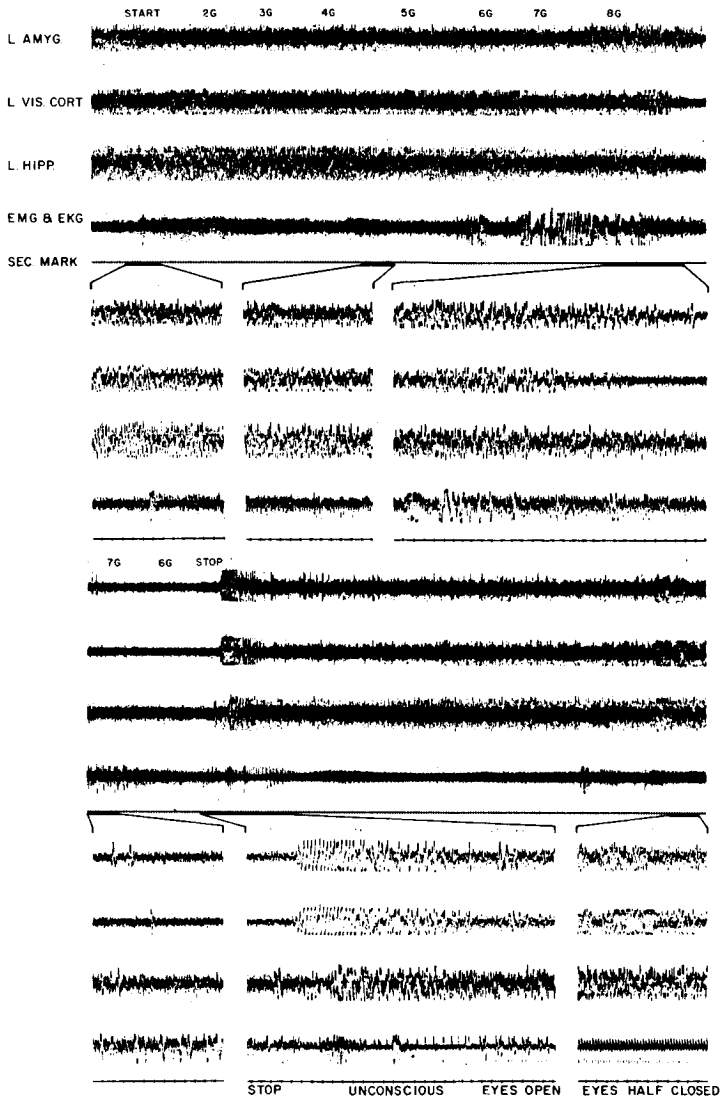
If we assume that the 5-sec blood pressure curve is equivalent to a 25-sec curve with no reflex effects, subtraction of the actual 25-sec curve from it yields the curve of Figure c. Although the difference blood pressure oscillates initially, fully developed reflex effects are not apparent in the blood pressure record until 10 sec or more have elapsed.

ITEM NO.	SUBJECT AREAS:	SOURCE:
292 c Page 3 of 3	SYSTEM - S13 HUMAN-H9	Reference 318, p. 10. Based on Reference 316



The figure above shows the effect of forward acceleration ($+G_x$) on respiratory frequency, tidal volume, minute volume, and nitrogen elimination (a rough index of alveolar ventialtion).

ITEM NO.	SUBJECT AREAS:	SOURCE:
293	SYSTEM - S13 HUMAN - H16	Reference 554, p. 42. Based on Reference 594.

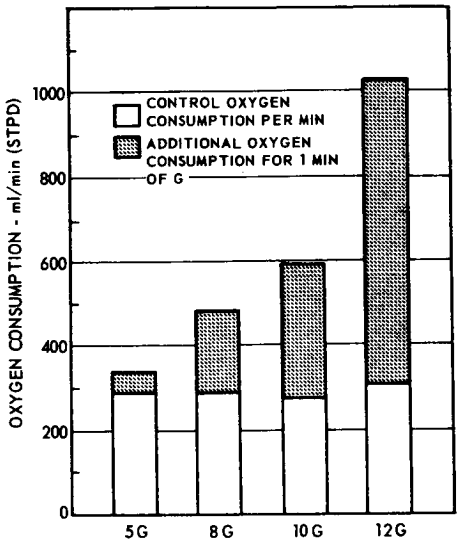


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Effects of longitudinal acceleration of monkey to unconsciousness on EEG, EMG and EKG. Panels 1 and 3 show a continuous low recording to these data, with unconsciousness appearing after reaching 8 G (right end of panel 1), and flattening of EEG records (panel 3). Return of cerebral circulation was associated with seizure-like discharges in many brain regions. Panels 2 and 4 show expanded portions of panels 1 and 3. Abbreviations: L. AMYG., left amygdala; L. VIS. CORT., left visual cortex; L. HIPP., left hippocampus; EMG & EKG, electromyogram and electrocardiogram.

The seizure-like discharges strongly resemble those in psychomotor epilepsy, and may be associated with similar disruptions of judgment and correct orientation to environmental stimuli, even in the absence of overt manifestations of an epileptic attack.

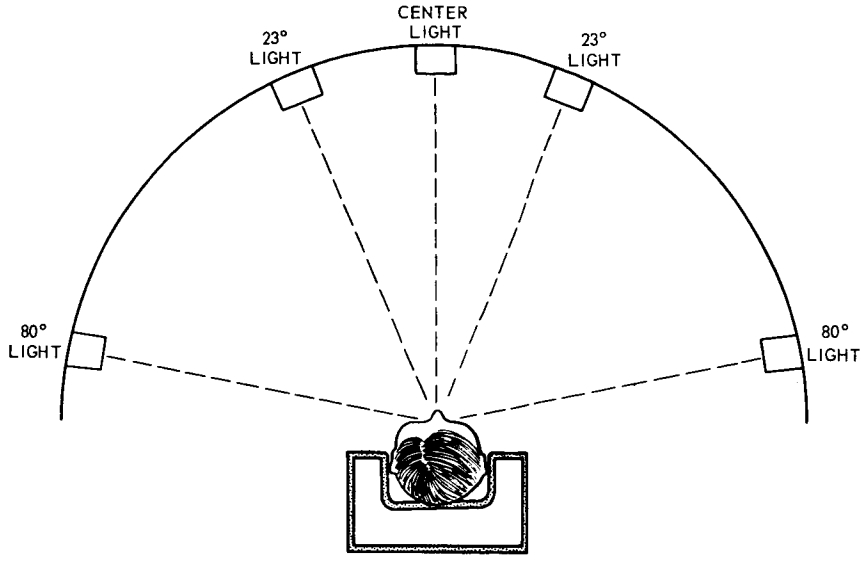
ITEM NO.	SUBJECT AREAS:	SOURCE:
294	SYSTEM - S13 HUMAN - H9, H13, H14	Reference 6, p. 413. Based on Reference 584.



The figure above shows the effect of forward acceleration ($+G_x$) on oxygen consumption.

ITEM NO.	SUBJECT AREAS:	SOURCE:
295	SYSTEM - S13 HUMAN - H16, H20	Reference 554, p. 42. Based on Refernce 594.

GRAYOUT THRESHOLDS DURING $+G_z$



One hundred fifteen subjects exposed to positive acceleration ($+G_z$) with a light array as shown in the diagram almost invariably lost the 80° light before loss of the light of 23° (23° LL). After completing the experiment it was decided to quantitate this in 30 subjects, and it was found that the 80° light loss (80° LL) occurred at a mean of 4.2 G_z, standard deviation ± 0.7 G; and in the same subjects, the 23° LL occurred at a mean of 4.5 G_z, S. D. ± 0.8 G. Central light loss (CLL) occurred at 5.3 G_z, ± 0.8 G.

This demonstrates also the reliability of the method used, since the original 115 subjects and the 30 subjects lost their 80° light at 4.24 G and 4.20 G respectively.

Comparison of 80° Light Loss, 23° Light Loss, and 0° Light Loss

	Symptoms			
	Clear	80° LL	23° LL	CLL
Mean (G_z level)	3.8	4.2	4.5	5.3
Range (G_z level)	2.3-5.1	2.7-5.7	2.9-6.4	3.6-7.0
Standard Deviation	0.7	0.7	0.8	0.8
Duration of symptom-Mean (sec)		5.4	5.1	6.8
Duration of symptom-Range (sec)		1.9-17.0	1.9-11.9	2.1-23.4

ITEM NO.	SUBJECT AREAS:	SOURCE:
296	SYSTEM - S13 HUMAN - H25	Reference 554, p. 43. Based on Reference 593.

BRIGHTNESS DISCRIMINATION DURING $+G_z$ and $+G_x$

a.

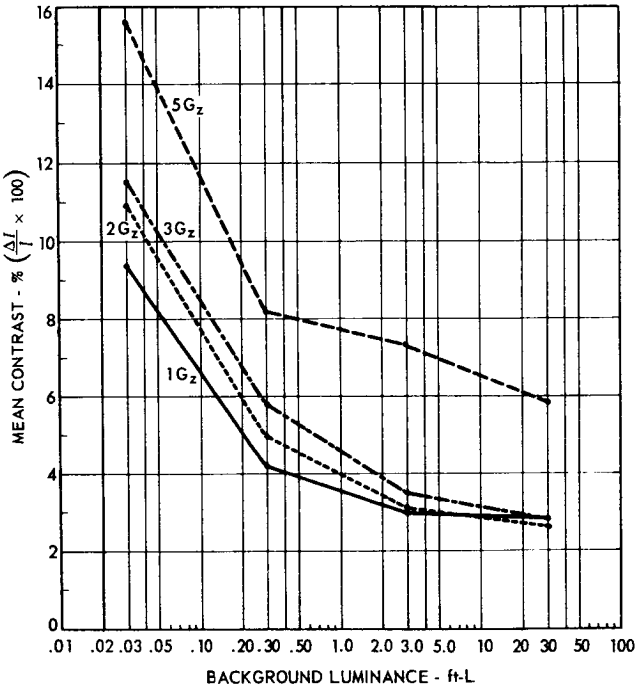


Figure a shows the relationship between brightness discrimination and background luminance at four levels of positive acceleration ($+G_z$).

The minimal detectable difference in intensity between a test patch and its lighted surround has long served as a test of visual sensitivity. The threshold difference has been found to be a function of basic energy level as well as contrast between the patch and its reference illumination; thus, the greater the background intensity, the smaller the ratio between the patch and the background required for detection. The data compiled in these graphs also illustrate an interaction between acceleration and the minimal discernible differential intensity (ΔI). The stimulus display used to collect these data consisted of a background subtending 8° 4' visual angle positioned 28 inches from the eye and viewed monocularly through a circular aperture 17.5 inches from the eye. The test patch, projected upon the background, subtended a 1° 28' visual angle.

b.

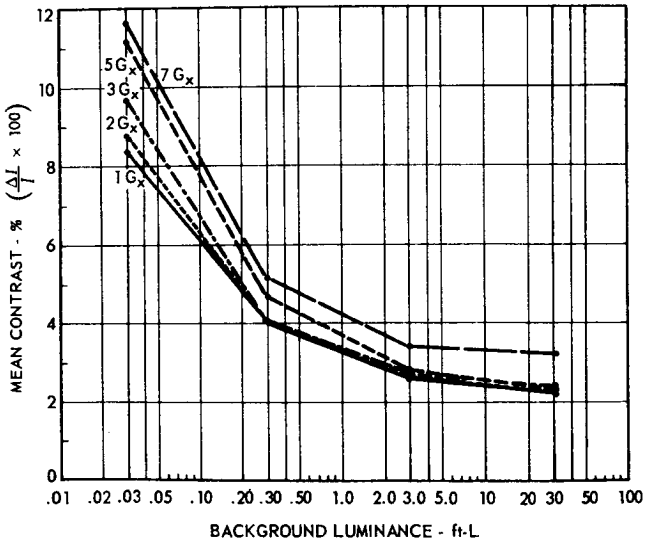
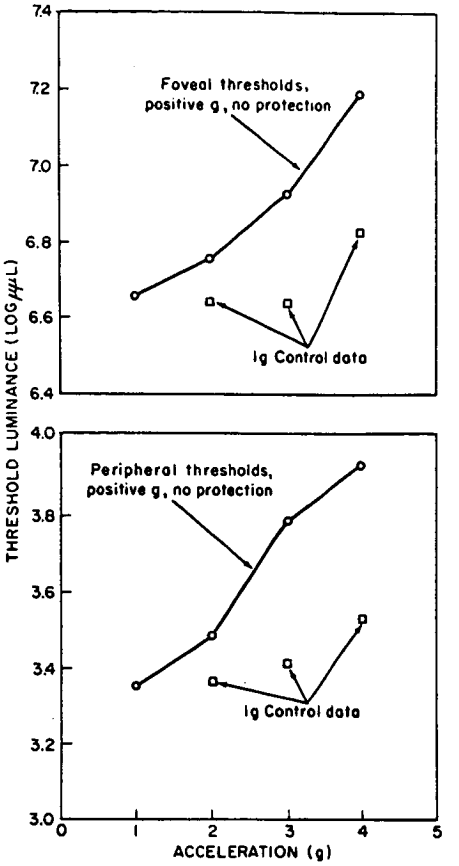


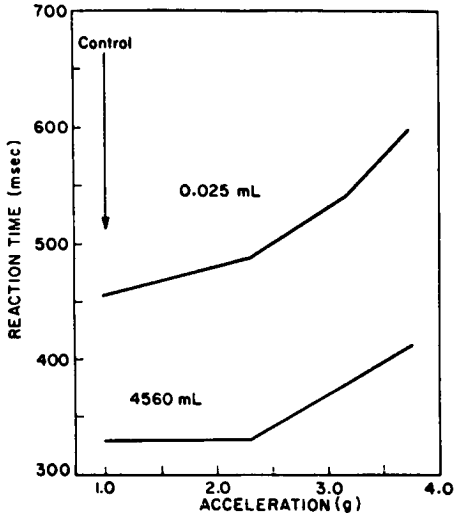
Figure b illustrates the relationship between brightness discrimination and background luminance at each of five levels of transverse acceleration ($+G_x$).

ITEM NO.	SUBJECT AREAS:	SOURCE:
297	SYSTEM - S13 HUMAN - H25	Reference 554, p. 44. Based on Reference 119.



At levels less than grayout, important losses in both central and peripheral visual functions are observed. These effects are shown in the figures above in terms of the brightness just detectable by the human eye at various accelerations. Compared with the control data shown in this graph, it can be seen that the loss in peripheral brightness sensitivity is slightly greater than the loss in central brightness sensitivity and that, in both cases, the loss is appreciable by 2g and becomes relatively greater with increased acceleration.

ITEM NO.	SUBJECT AREAS:	SOURCE:
298	SYSTEM -S13 HUMAN- H25	Reference 380, p. 458. Based on Reference 576.

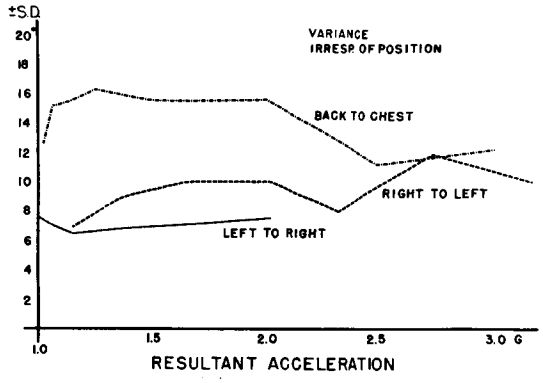


To some degree, visual loss during acceleration can be counteracted by increasing the brightness of the signal light. This fact is illustrated in the figure above which also illustrates the effects of g forces on visual reaction time. This graph shows that the normal increase in speed of reaction that is associated with increased signal intensity is not reduced even though the sensitivity of the eye is reduced.

The figure also shows the reduction in visual reaction time with acceleration. The same kind of reduction also has been observed for auditory signals. A word of caution, however, regarding reaction times in the use of both kinds of signals: the loss in speed of response in both cases presumably depends partly on the impairments in motor performance associated with reacting. In the case of the visual reaction time, loss of visual function also would seem to be involved; whether the loss in response to acoustic signals involves a loss in hearing acuity is not known.

ITEM NO.	SUBJECT AREAS:	SOURCE:
299	SYSTEM - S13 HUMAN - H25	Reference 380, p. 459. Based on Reference 100.

Orientation in Space Under Increased Acceleration



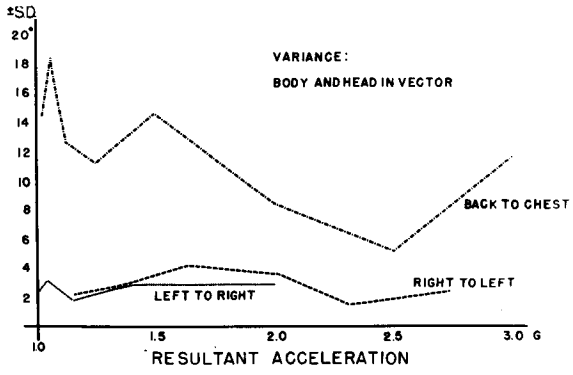
Standard deviation of all individual settings of the apparent vertical in three series of experiments depending on acceleration, but without regard to the position of body and head.

The accuracy of the setting of the apparent vertical depends on the direction of acceleration between 1 and 3 G. When the acceleration acts in the direction back-to-chest the variance, plotted as standard deviation, exceeds by a factor of 2 the variance of the setting with lateral acceleration. This graph includes all data obtained at different accelerations, irrespective of the position of body and head. The dotted line represents a completely randomized series of experiments, in which five body and head positions and five accelerations (125 conditions) were presented to five subjects, three times each. The variance of the apparent vertical is least for this series.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
300	SYSTEM - S13 HUMAN - H25	Reference 306, p. 389.

Orientation in Space Under Increased Acceleration



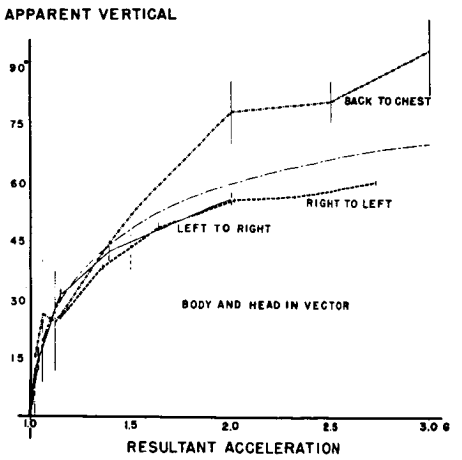
Standard deviation of all individual settings of the apparent vertical in three series of experiments depending on acceleration, but with body and head in the direction of acceleration. The apparent vertical was monitored after exposure to the resultant acceleration for at least 20 seconds. The exposure did not exceed 60 seconds.

The variance of the apparent vertical is shown in the figure when body and head are in the direction of the resultant acceleration. All gravity receptors are acted upon in "normal" direction. The setting of the apparent vertical should be optimal for all conditions without visual cues. Changes can be appreciated in the variances following progression of the vector of forces through the frontal or sagittal plane to a direction parallel to the longitudinal axes of body and head. The variances decrease for accelerations up to 2.5 G with a vector shift through the sagittal plane. For accelerations with a vector shift through the frontal plane the variances do not change systematically.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
301	SYSTEM - S13 HUMAN - H25	Reference 306, p. 391.

Orientation in Space Under Increased Acceleration

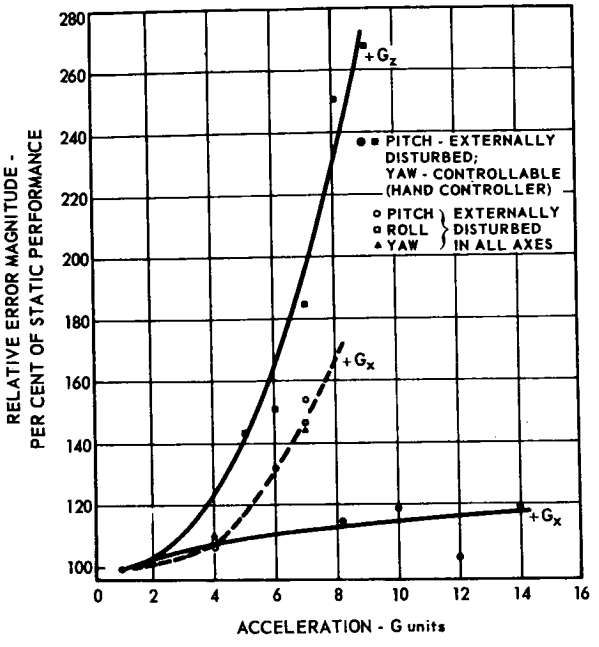


The apparent vertical depending on acceleration, with body and head in the direction of the resultant acceleration. For the experiments "back-to-chest" the vector of forces moved through a sagittal plane to its final position during the starting phase of centrifugation. For experiments "right-to-left" and "left-to-right" the vector of forces moved through a frontal plane to its final position.

The settings of the apparent vertical and their variance with body and head in the direction of acceleration are finally shown in the figure. The apparent vertical is set very close to the direction of the resultant acceleration up to approximately 1.2 G regardless of the plane through which the vector of forces moved transiently. Above 1.2 G there is an increasing underestimation in experiments where the vector of forces moved transiently through a frontal plane (left-to-right or right-to-left). In the randomized experiment, designated as "left-to right," the apparent vertical is set closer to the direction of acceleration, but the difference is small when compared with the less well controlled experiment "right-to-left." Transition of the vector of forces through a sagittal plane (back-to-chest) leads to an overestimation of the direction of the resultant acceleration.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
302	SYSTEM - S13 HUMAN - H25	Reference 306, p. 391.



Performance of two separate piloting tasks is shown, plotted as functions of the magnitude and vector of acceleration exposure. The solid points represent a replotting of data from experiments by Creer et al. in which experienced pilots used a two-axis hand controller and performed a task in which programmed disturbances were introduced into the pitch axis only, but in which yaw error introduced by the pilot also contributed to the overall piloting task. The open points represent unpublished data from experiments at the USN Aviation Medical Acceleration Laboratory in which disturbances were introduced into all three axes by the computer, and compensatory control was effected by the pilots through a three-axis fingertip controller. It is apparent from this graph that changing the piloting task has an effect almost as great as that accompanying a change in acceleration vector.

ITEM NO.	SUBJECT AREAS:	SOURCE:
303	SYSTEM - S13 HUMAN - H26	Reference 554, p. 48. Based on References 152 and 534.

TRACKING DURING TRANSVERSE ACCELERATION

a.

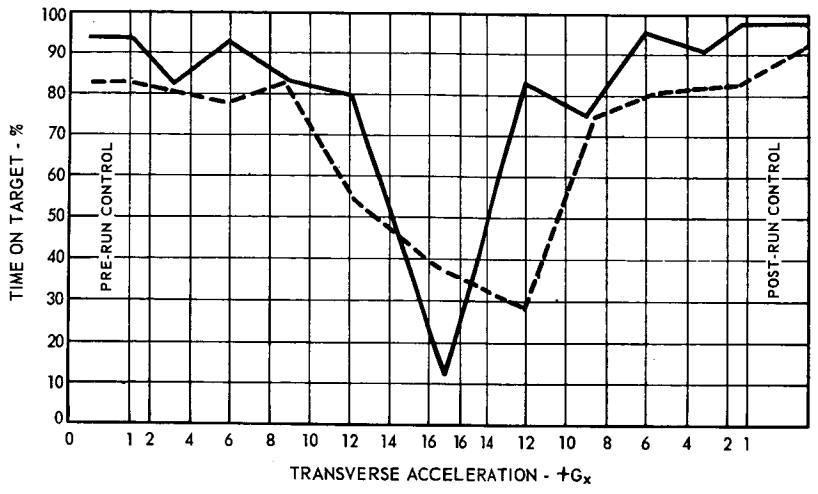
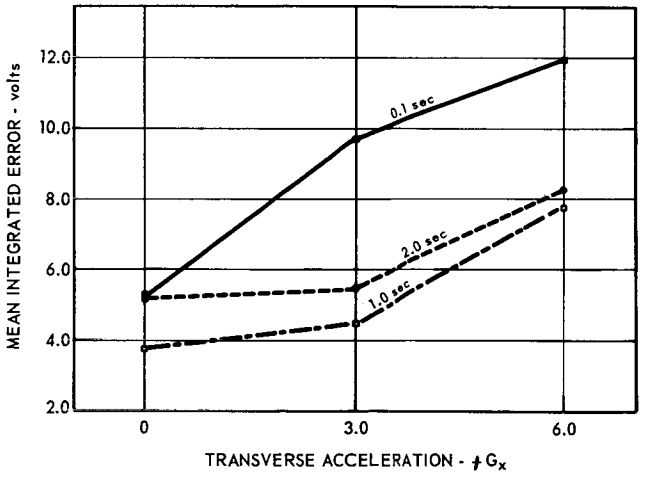


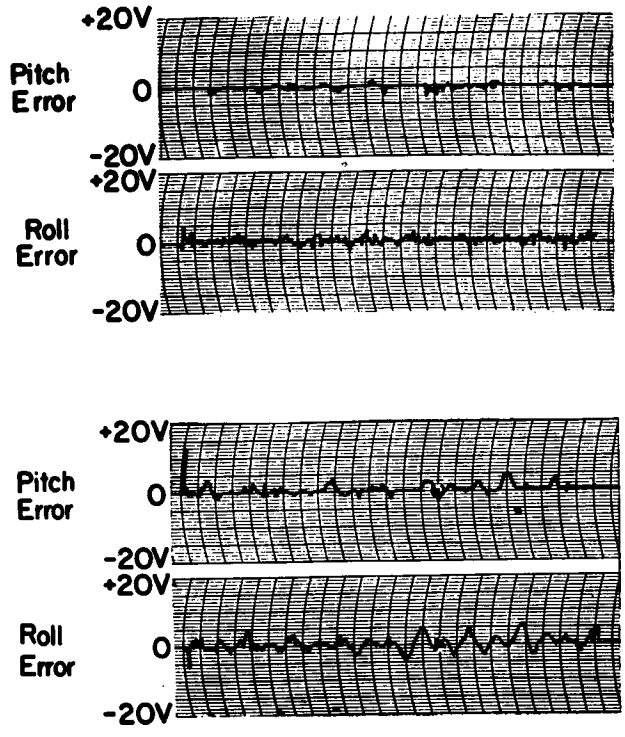
Figure a shows the decrement in tracking performance, using a 3.5 mm target in a dual pursuit task, for two subjects through a ±16 G_x acceleration profile simulating re-entry.

b.



Mean integrated error for tracking a display varying in the x-axis is shown as a function of increased acceleration and various time-lag constants. Notice that error is caused by both changing time-lag constants and acceleration.

ITEM NO.	SUBJECT AREAS:	SOURCE:
304	SYSTEM-S13 HUMAN-H26	Reference 554, p. 49. Based on References 135 and 291.



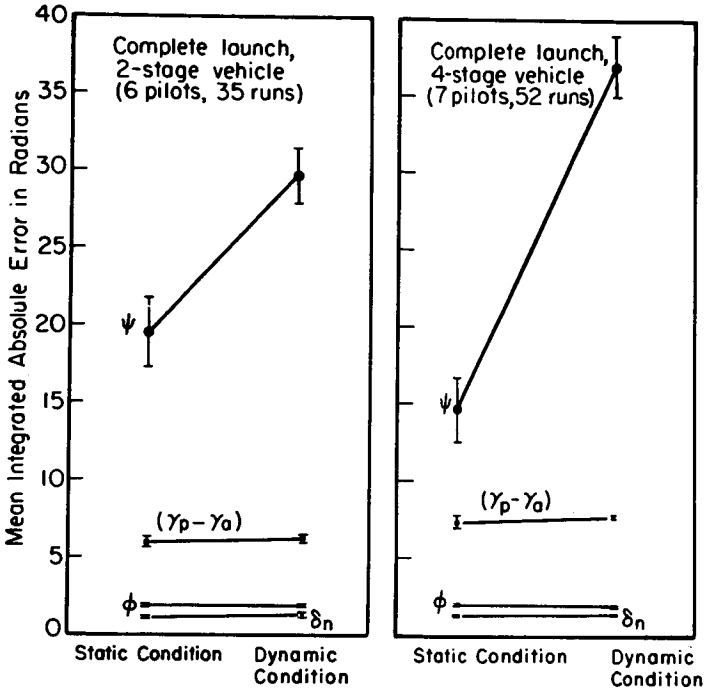
Example of performance errors in pitch and roll during exposure to $+6G_x$.

Presented here are records of errors made in a compensatory tracking task while under accelerative stresses. This particular problem was presented by randomly varying the position of a target on the face of an oscilloscope by means of analog computer control. The subject's task was similar to that used in the current Mercury capsule, in the two axes of pitch and roll to overcome scope disturbances in the vertical and horizontal axes.

In the upper chart, the most noticeable performance impairment is that the roll axis is allowed to degrade and primary attention is focused on the elimination of errors in pitch. In this respect, we also have an example of the previously listed reduction in performance output on one of the task components. Lapses and irregularity in performing the task in the preferred pitch mode may be observed. This particular subject functions at a very high level with almost perfect tracking for a period of time and then lapses into relatively large errors. Following this brief lapse, performance again returns to normal, only to be followed by another lapse.

The lower portion of the figure illustrates one other type of error commonly found in performance records. A phasing or cyclical type of error is shown very clearly in roll error, and to some extent also in pitch error. Here the small random errors in tracking seem to be superimposed on a relatively low frequency sinusoidal type of error.

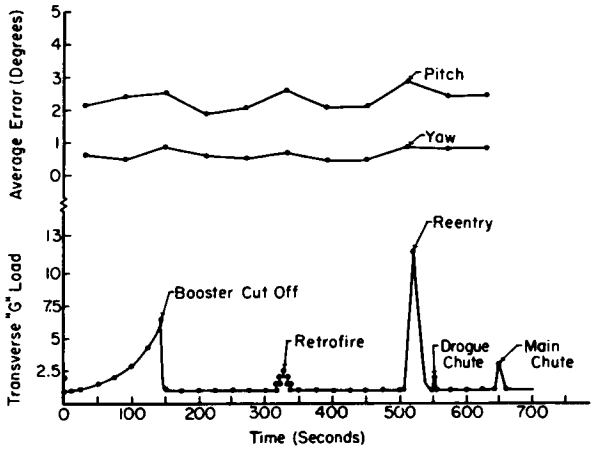
ITEM NO.	SUBJECT AREAS:	SOURCE:
305	SYSTEM - S13 HUMAN - H26	Reference 116, p. 274.



Examples of inadvertent control inputs which occurred during dynamic simulations but not during static simulations of the Mercury Redstone vehicle on the human centrifuge.

A partial decrease in performance proficiency may be an indication that the subject is reaching his performance limits, or that he is unable to cope with the problem during the stress. The figure above presents an example of this kind of situation. This study of the ability of 7 pilots to fly complete launch simulations of 2-stage vehicles and of 4-stage vehicles demonstrated that in both cases one aspect of the task (yaw) suffered major impairment under the acceleration stress, whereas other aspects (angle of attack, roll and nozzle angle) did not. This illustration indicates that in studying performance, all components of the task must be examined. This same principle also holds for the simultaneous performance of different tasks during acceleration.

ITEM NO.	SUBJECT AREAS:	SOURCE:
306	SYSTEM - S13 HUMAN - H26	Reference 116, p. 277.



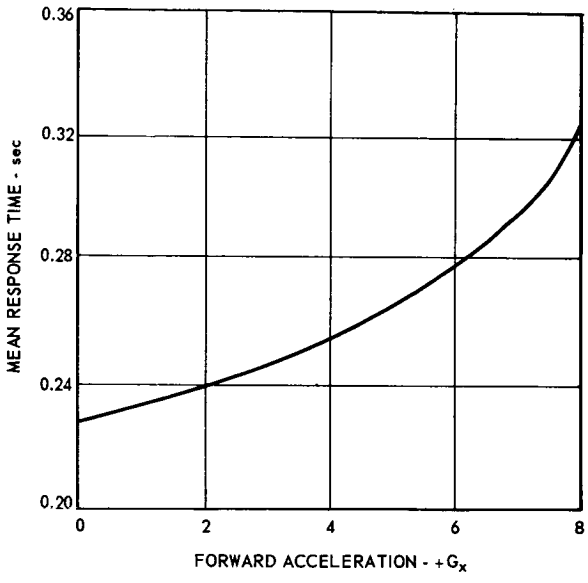
Mean performance scores for three astronauts who performed a tracking task before, during, and after a centrifuge simulated Redstone sub-orbital flight.

The mean error of performance for these astronauts is plotted as a function of integrated error during successive minutes throughout launch and re-entry, part of which took the astronauts through a 11.4 G_x. No significant effects on their performance were found at the times these records were taken. The performance shown here had been preceded by extensive practice.

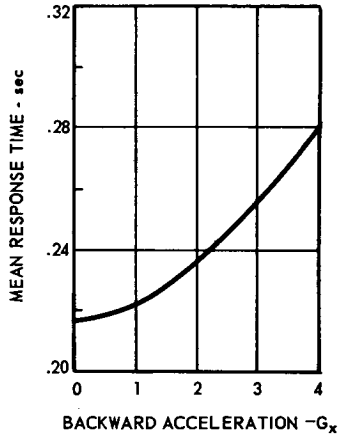
ITEM NO.	SUBJECT AREAS:	SOURCE:
307	SYSTEM - S13 HUMAN - H26	Reference 116, p. 295.

RESPONSE TIME DURING TRANSVERSE ACCELERATION

a.

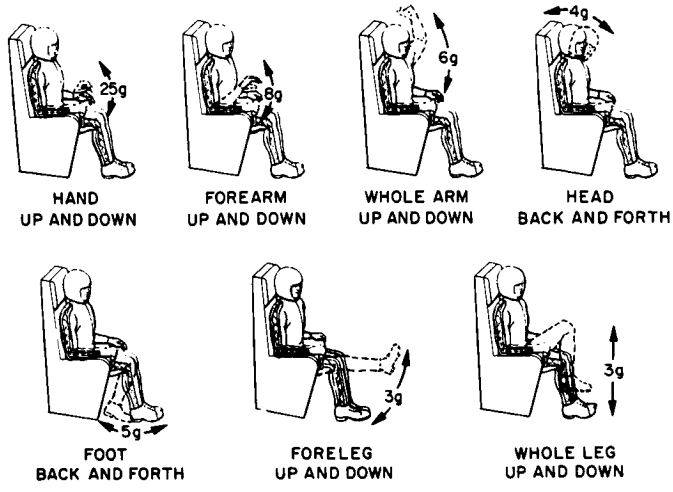


b.



The two graphs show mean response times (the time from appearance of a red signal light to the movement of the subject's hand from his lap) for five male college students, 20-25 years old, exposed to transverse accelerations. Graph a shows the combined response times for both right and left hand operation in more than 900 forward ($+G_x$) acceleration exposures up to 8 G_x. Graph b shows the combined response times for both right and left hand operation in more than 500 backwards acceleration ($-G_x$) exposures up to 4 $-G_x$. The times required to reach and operate a horizontal lever, a toggle switch and a push button were longer as the accelerations increased, and variable times were recorded for left and right hand operation. Still longer times were needed for adjusting a rotating knob and a vertical "trim" wheel.

ITEM NO.	SUBJECT AREAS:	SOURCE:
308	SYSTEM - S13 HUMAN - H28	Reference 554, p. 47. Based on Reference 290.



Vehicle accelerations at which movement of various parts of the body is barely possible.

Normal body weight is defined as weight at 1g. As the accelerative force exceeds this value, weight is increased; as 0g is approached, weight decreases. As body weight increases with increased g force, the power demands on the muscle system become greater. The result is a loss in speed of limb displacement and applied force. The effect varies, however, according to whether the acceleration is directed along the longitudinal axis of the body or perpendicular to it.

This figure shows the vehicle accelerations (rather than those of the body) at which movement of various body parts is barely possible. It can be seen that, although transverse g has much less effect on circulatory, visual, and other similar functions, it has a much greater effect on movements; a man under high transverse g might retain vision and consciousness but might not be able to move his body.

ITEM NO.	SUBJECT AREAS:	SOURCE:
309	SYSTEM - S13 HUMAN - H28	Reference 380, p. 461. Based on Reference 117.

Tracking and Coordination Errors with Acceleration

Task	Average error score	
	No acceleration	With acceleration
Horizontal tracking	50	53
Vertical tracking	39	45
Flight coordination	52	37

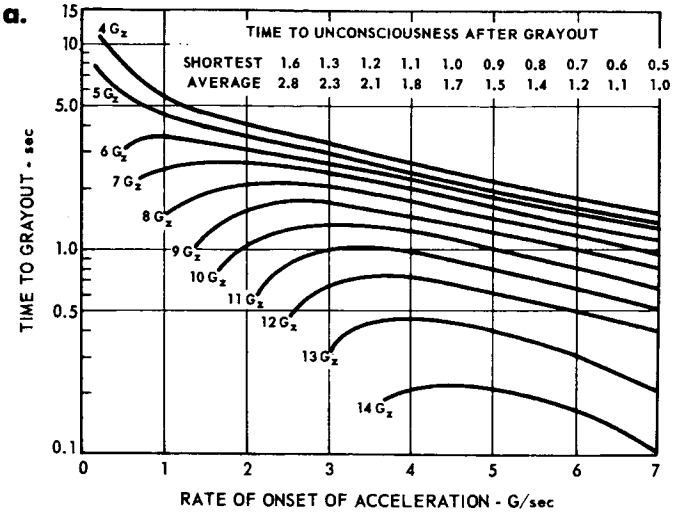
Subjects performed on a tracking task in a centrifuge during exposure to accelerations which they could control. While their average error scores on horizontal and vertical tracking deteriorated under acceleration conditions, their "flight coordination" actually improved as indicated in the table. It seems apparent, however, that the requirement under acceleration for additional attention to flight coordination (imposed by the fluctuating acceleration pattern) would appear to be met at the expense of some other aspect of performance (in this case, tracking performances).

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ITEM NO.	SUBJECT AREAS:	SOURCE:
310-	SYSTEM - S13 HUMAN - H26, H27	Reference 362, p. 553.

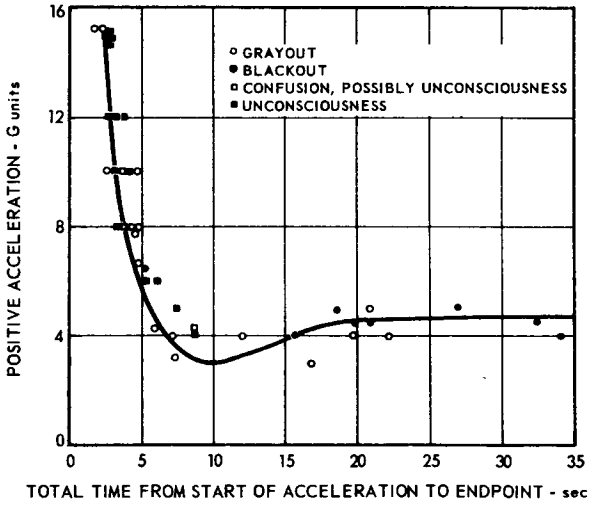
This graph relates the onset rate of acceleration to time-to-endpoint. It shows that for any given positive acceleration (G_z) from 4 to 14 G, the time to grayout depends on how rapidly the acceleration level was reached. Further, the table inset in the graph shows the shortest times and the average times for unconsciousness to develop following grayout, each pair of values being related to an onset rate. For example, at onset rate of 4 G/sec, the shortest time to unconsciousness was 1.1 sec, and the average 1.8 sec.

a.

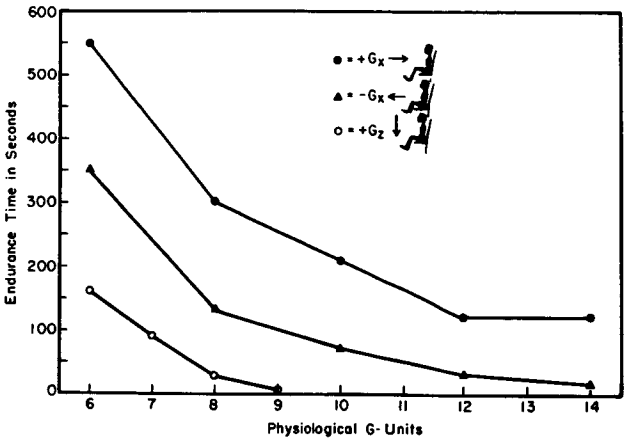


This graph shows human tolerance to positive G_z for varying rates of onset, G amplitudes, and exposure times.

b.

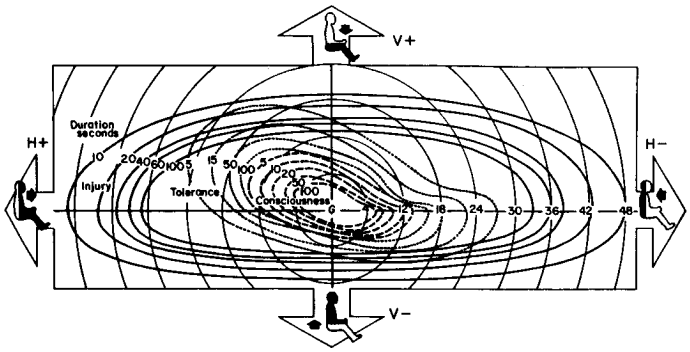


ITEM NO.	SUBJECT AREAS:	SOURCE:
311	SYSTEM - S13 HUMAN - H34	Reference 554, p. 35. Based on Reference 498.



Summary of time-tolerance centrifuge endurance tests in which pilots were exposed to high prolonged $+G_x$, and $-G_x$, and $+G_z$ steady-state accelerations. The pilots wore special G-protection equipment and were all experienced centrifuge riders. They were required to maintain satisfactory tracking performance continuously during exposures to the physiological G-stress.

ITEM NO.	SUBJECT AREAS:	SOURCE:
312	SYSTEM - S13 HUMAN - H34	Reference 116, p. 217.



Steady acceleration-tolerance limit curves.

The figure above summarizes diverse empirical data. The magnitude of the imposed force is measured radially and the time duration in seconds is shown for three limits, designated as "injury," "tolerance," and consciousness." More specifically, "injury" implies permanent injury and is defined as a threshold of trauma, irreversible by surgery or therapy. The physiological limits which establish this threshold vary from hemorrhage to shock, anoxia, and mechanical injury. The limit of voluntary "tolerance" defines the area of human capacity within which applied acceleration can be expected to produce no worse than short periods of extreme discomfort or unconsciousness. The specific limits include petechiae, pain, difficulty of respiration, black-out to unconsciousness, and threshold of shock and mechanical injury. The limit of useful "consciousness" is the boundary of awareness sufficient for proper response to stimuli which normally generate familiar and indoctrinated reactions. Experimental studies have shown that within this domain the psychomotor performance is not usually degraded. At levels of steady acceleration up to and including the psychological tolerance limits, only the onset of physiological change acts to materially deteriorate the control capability of the human operator.

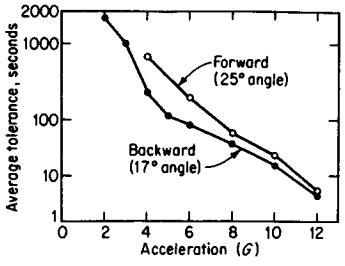
ITEM NO.	SUBJECT AREAS:	SOURCE:
313	SYSTEM - S13 HUMAN - H34	Reference 197, p. 544. Based on Reference 247.

TOLERANCE LIMITS FOR THE SECURED SEATED SUBJECT

	Forward Facing Seated Position	Backward Facing Seated Position	Upward Ejection Position	Downward Ejection Position
Voluntary Tolerance	40 g at 1,500 g/sec.– 0.15 sec.	Over 40 g at 1,000 g/sec.	33 g at 500 g/sec. optimum position	1 g at 200 g/sec.
	50 g at 600 g/sec.– 0.25 sec.	0.25 sec.	Less than 10 g at 200 g/sec. Back hyperflexed	
	25 g at 1,000 g/sec.– 1.0 sec.			
Injury	60 g at 5,000 g/sec. 0.1–0.5 sec.	90 g at 5,000 g/sec. 0.1–0.5 sec.	Over 10 g at 200 g/sec. poor position Over 35 g at 500 g/sec. optimum position	
Lethal	Over 200 g at 5,000 g/sec. 0.1–0.5 sec.	Over 200 g at 500 g/sec.		

For the data represented above, protection consisted of straps, a lap belt of 3 inch wide nylon webbing, with a pair of tie down straps, known as the inverted V, to hold the belt and shoulder straps down against the bottom of the seat.

ITEM NO.	SUBJECT AREAS:	SOURCE:
314	SYSTEM - S13 HUMAN - H34	Reference 197, p. 548. Based on Reference 589.

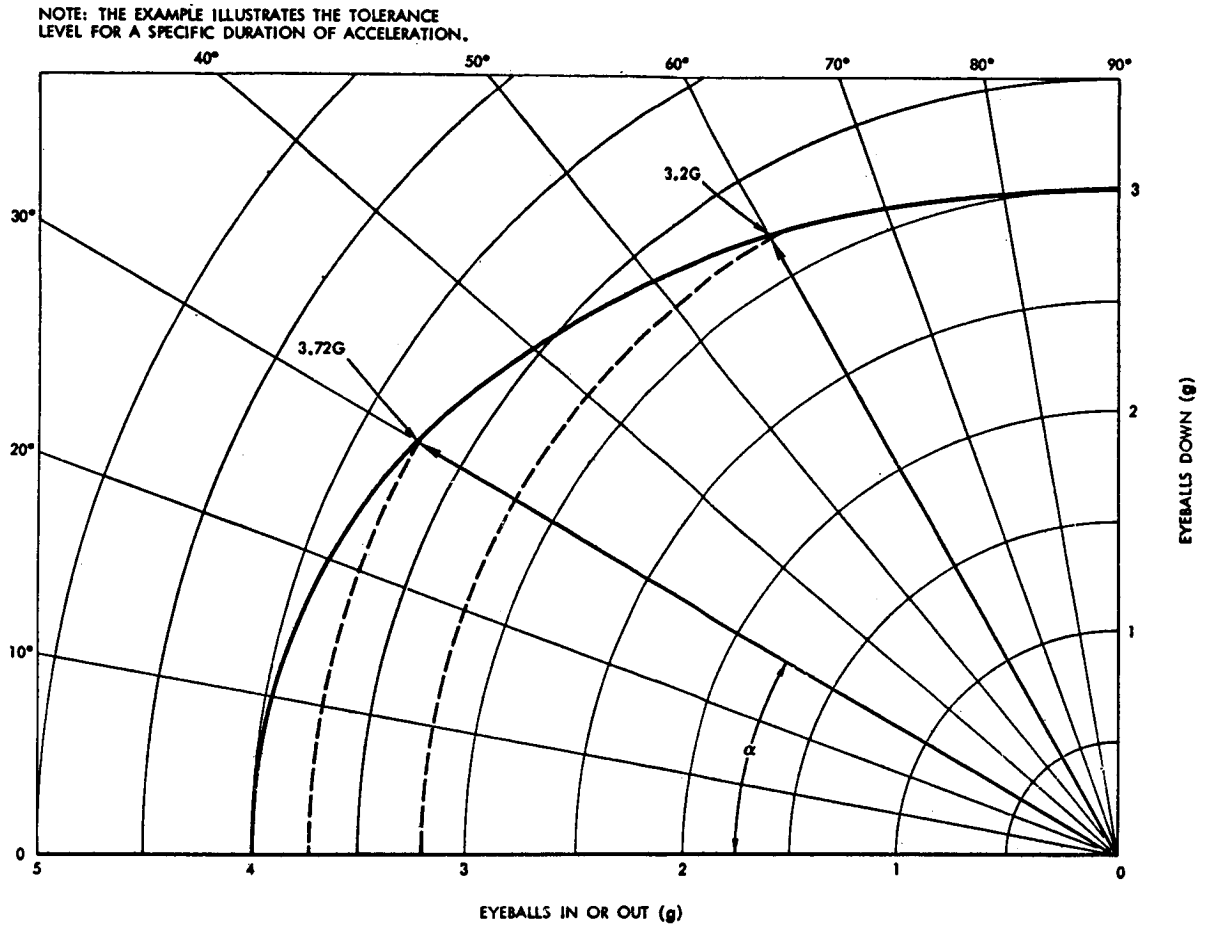


Relationship between acceleration and tolerance to forward and backward acceleration.

The investigation represented above, and carried out with eight subjects for the specific purpose of comparing forward and backward acceleration, indicated a moderate, but significant, difference in favor of forward acceleration. The results of this comparison are shown in the figure, indicating a consistently greater time tolerance for the various levels of acceleration in forward acceleration.

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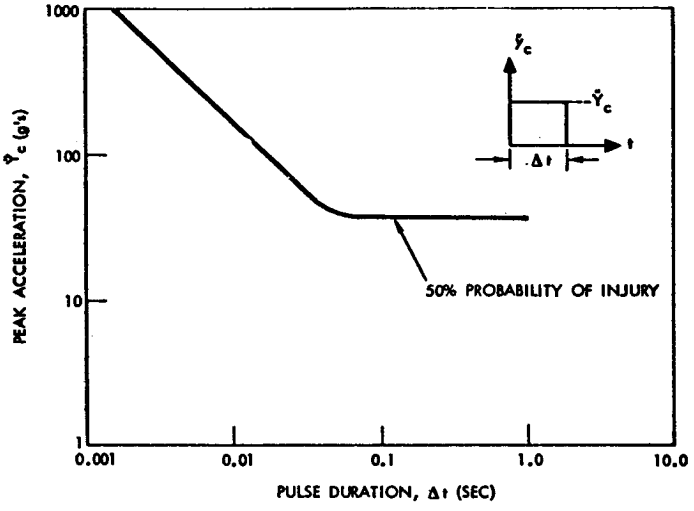
ITEM NO.	SUBJECT AREAS:	SOURCE:
315	SYSTEM - S13 HUMAN-H34	Reference 362, p. 551. Based on Reference 134.



Determination of Tolerance to Combined Accelerations by Use of the Elliptical g Function Method

In the example shown above the tolerance at an angle α to the eyeballs in acceleration is equal to the vector radius of an ellipse, the semi-minor and semi-major axes of which represent respectively the tolerance values of the eyeballs in and eyeballs down accelerations for a specific duration of time.

ITEM NO.	SUBJECT AREAS:	SOURCE:
316	SYSTEM -S13 HUMAN- H34	Reference 378, p. 12. Based on Reference 409.



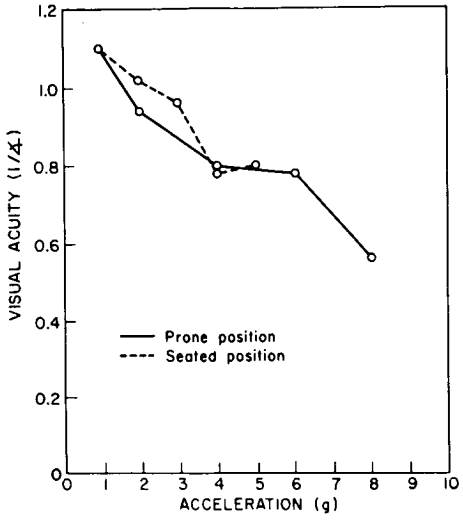
Tolerance to Transverse Accelerations
(Rectangular Pulse)

ITEM NO.	SUBJECT AREAS:	SOURCE:
317	SYSTEM - S13 HUMAN - H34	Reference 378, p. 8. Based on Reference 408.

Respiratory Responses of 31 Pilots to $+G_z$ and $+G_x$

		$+G_z$	$+G_x$				
			0° Back Angle		12° Back Angle		
		5G	5G	8G	5G	8G	12G
Control vital capacity (liters)	mean	4.00	3.75	3.75	3.70	3.70	3.70
	S. D.	.48	0.45	0.45	0.48	0.48	0.48
Experimental vital capacity (liters)	mean	2.20	1.68	0.48	1.60	0.55	0.20
	S. D.	0.41	0.43	0.37	0.53	0.43	0.22
Control forced expiratory capacity (0. 5 sec, percent)	mean	59%	59%	59%	55%	55%	55%
	S. D.	13%	11%	11%	12%	12%	12%
Experimental forced expiratory capacity (0.5 sec, per cent)	mean	63%	80%	86%	77%	91%	94%
	S. D.	19%	18%	26%	20%	13%	13%

ITEM NO.	SUBJECT AREAS:	SOURCE:
318	SYSTEM - S13 HUMAN - H6, H16	Reference 554, p. 42. Based on Reference 283.



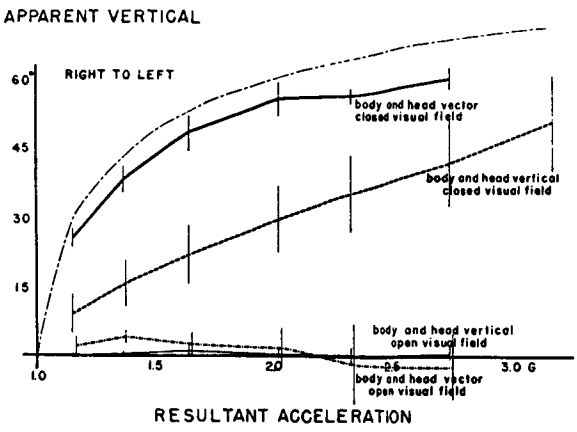
Visual acuity under increased acceleration.

Visual acuity, i.e., the ability of the eyes to resolve detail, is affected by moderate g forces, as is shown above. The loss in visual acuity can be seen to be essentially linear and not importantly affected by the two body positions shown. The graph shows that, at 7g, target size must be twice that at 1g to be seen.

ITEM NO.	SUBJECT AREAS:	SOURCE:
319.	SYSTEM - S13 HUMAN - H6, H25	Reference 380, p. 460. Based on Reference 577.

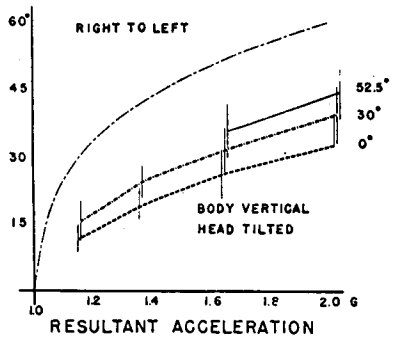
Orientation in Space Under Increased Acceleration

a



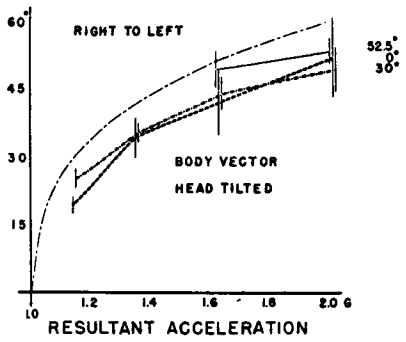
Dependence of the apparent vertical on resultant acceleration for different positions of body and head in unrestricted and restricted visual fields. The vertical bars indicate ±1 standard deviation. The thin dash-dotted line represents the direction of the resultant acceleration. "Vector" means the direction of the resultant acceleration.

b



The apparent vertical with head tilt in the direction of acceleration, while the body remains vertical. Acceleration acting sideways.

c



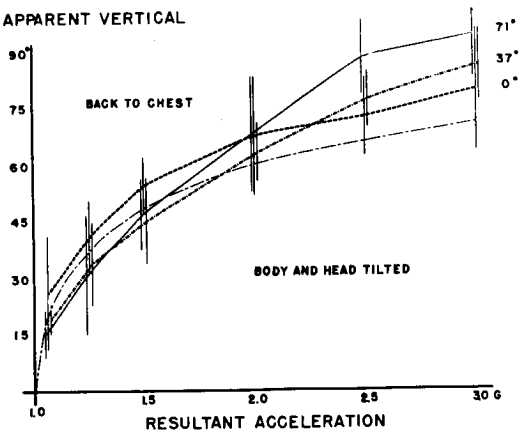
The apparent vertical head tilt and body in the direction of acceleration. Acceleration acting sideways.

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
320	SYSTEM -S13 HUMAN- H6, H25	Reference 306. pp. 381-382.

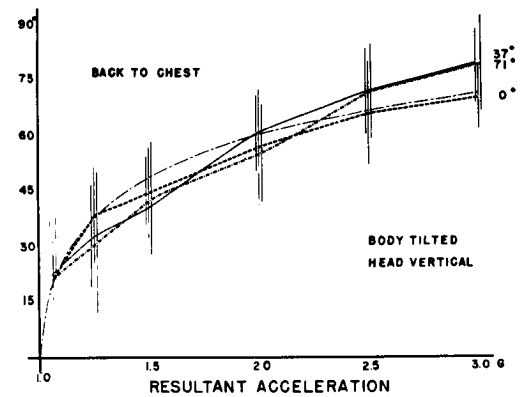
Orientation in Space Under Increased Acceleration

a



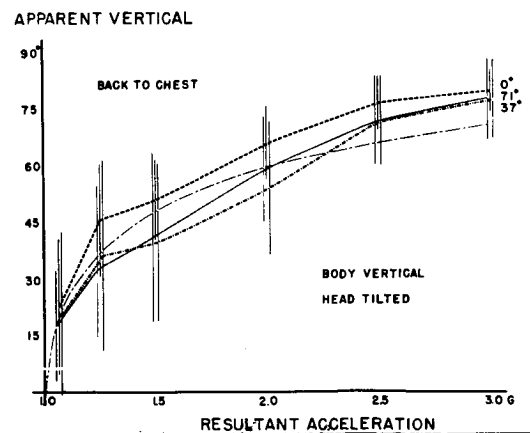
The apparent vertical with simultaneous tilt of body and head acceleration acting backwards.

b



The apparent vertical with body tilt, the head remaining vertical. Acceleration acting backwards.

c

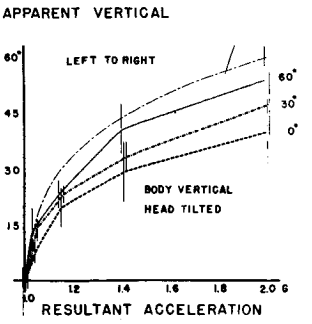


The apparent vertical with head tilt while the body remains vertical. Acceleration acting backwards.

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

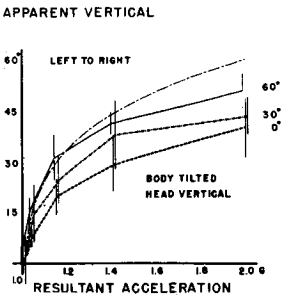
ITEM NO.	SUBJECT AREAS:	SOURCE:
321	SYSTEM - S13 HUMAN - H6, H25	Reference 306, pp. 384-385.

a



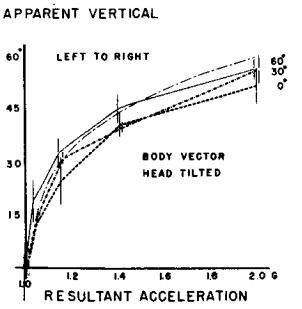
The apparent vertical with head tilt, while the body remains vertical. Acceleration acting sideways.

c



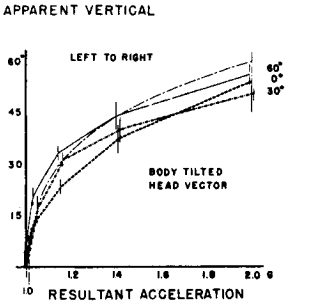
The apparent vertical with body tilt, while the head remains vertical. Acceleration acting sideways.

b



The apparent vertical with head tilt, while the body remains in the direction of acceleration. Acceleration acting sideways.

d



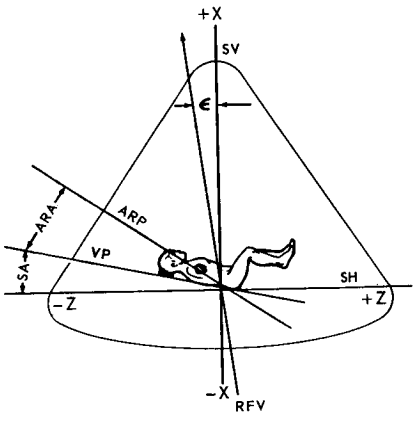
The apparent vertical with body tilt, while the head remains in the direction of acceleration. Acceleration acting sideways.

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
322	SYSTEM - S13 HUMAN - H6, H25	Reference 306, p. 388.

G TOLERANCE AND BACK ANGLE

a.



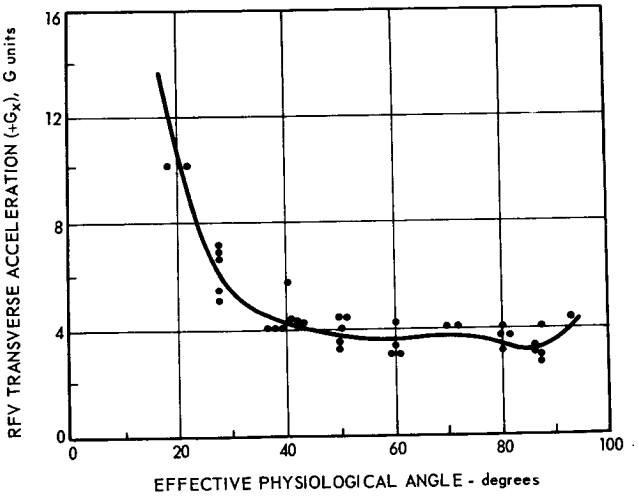
ARA – AORTIC RETINAL ANGLE
ARP – AORTIC RETINAL PLANE
€ – ANGLE INSCRIBED BY RFV WITH SV
RFV – RESULTANT FORCE VECTOR
SH – SPACECRAFT HORIZONTAL
SV – SPACECRAFT VERTICAL
VP – VERTEBRAL PLANE
SA – SEAT ANGLE
EPA – EFFECTIVE PHYSIOLOGICAL ANGLE
= SA + ARA + €

The pilot orientation and grayout terminology proposed by the NASA Manned Spacecraft Center is diagrammed above. The figure shows the relationship between the primary vector direction and pilot orientation employed to calculate the magnitude of sustained forward acceleration force applied along the axis of the column of blood above the heart. The relationship is expressed as follows:

$$\text{Sin (EPA) (X)} = \text{(Z)}$$

where X= magnitude of primary forward accelerative force applied along ARP in $+G_X$ units, and
Z = magnitude of resultant accelerative force applied along ARP in $+G_Z$ units.

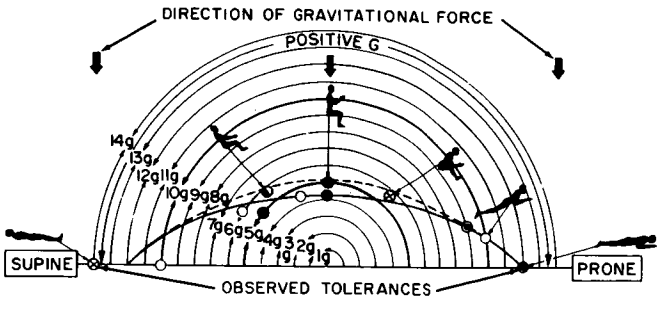
b.



Susceptibility to grayout is shown as a function of pilot orientation with respect to the primary resultant vector of a transverse acceleration ($+G_X$).

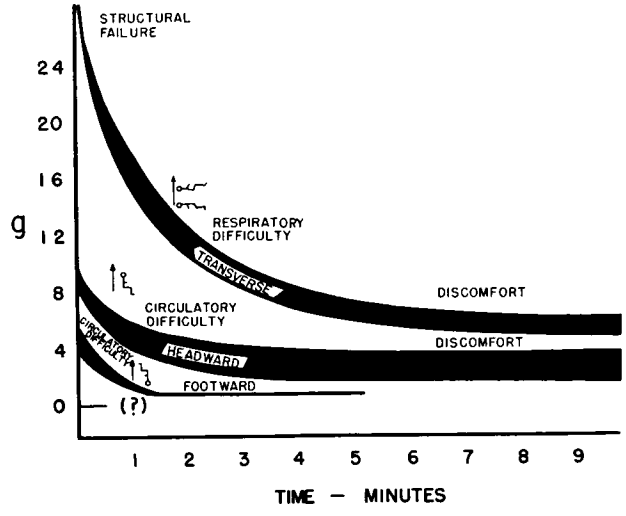
ITEM NO.	SUBJECT AREAS:	SOURCE:
323	SYSTEM - S13 HUMAN - H25, H34	Reference 554, p. 39. Based on Reference 9.

Acceleration Tolerance and Body Position



By combining the crouching-hunching effect with total body position so as to permit the resultant force to act in the transverse direction, maximum tolerance by variation of posture and position can be achieved. The figure illustrates this fact with the results of several studies of the effects of body position. It can be seen that as body position varies from supine, through seated upright, to prone, tolerance is varied in the manner expected.

ITEM NO.	SUBJECT AREAS:	SOURCE:
324	SYSTEM-S13 HUMAN-H6, H34	Reference 380, p. 465. Based on Reference 206.

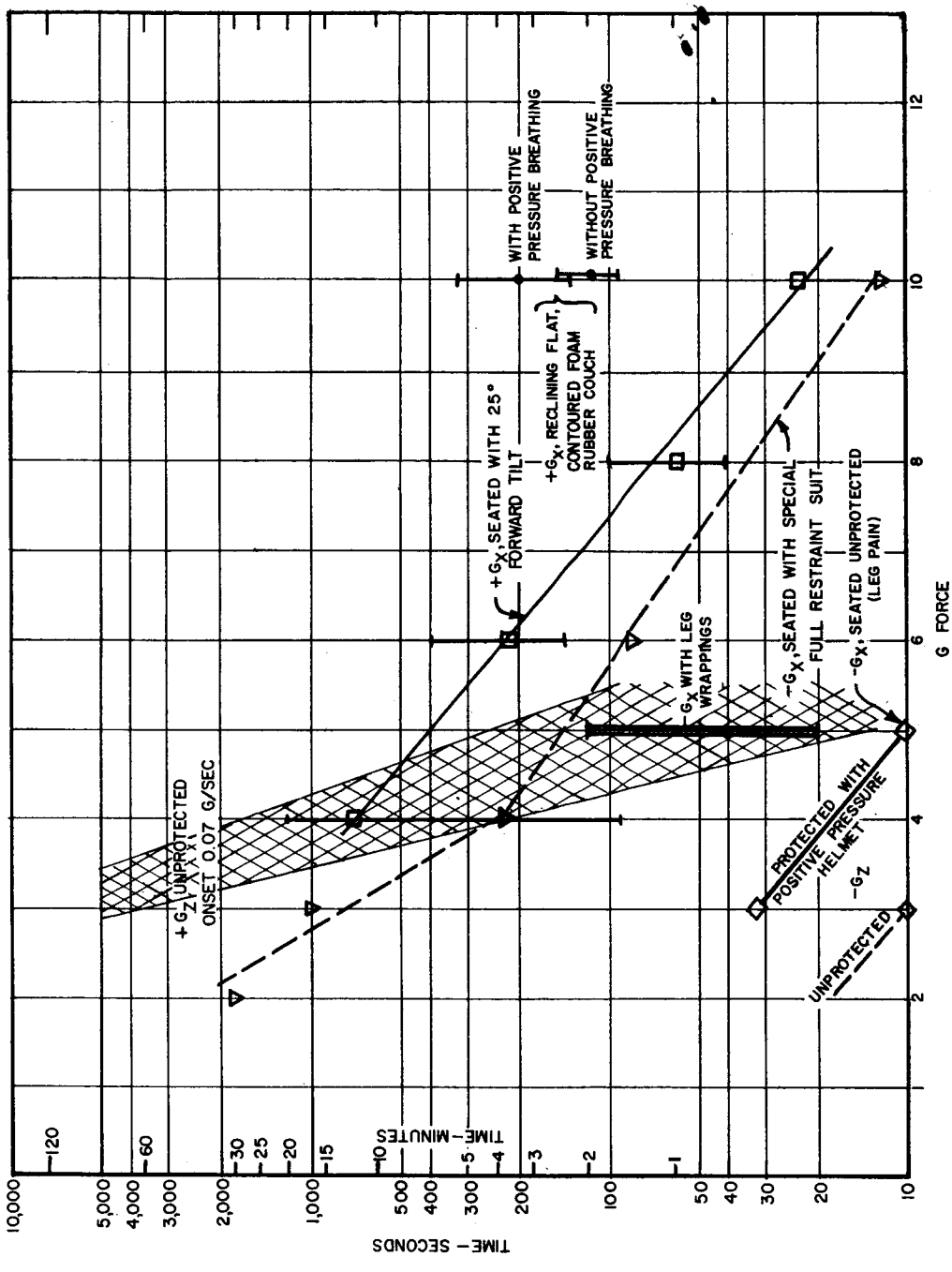


Voluntary Human Tolerance to Acceleration in Different Body Positions (May 1960)

The figure above shows that tolerance for transverse acceleration is much higher than that for headward acceleration and that the tolerance for footward acceleration is very low. The lines in this graph are purposely drawn as wide bands to indicate variation in the subjects of these tests even though they are highly selected. There is a factor of safety built into these curves because they represent voluntary exposures which did not produce injury.

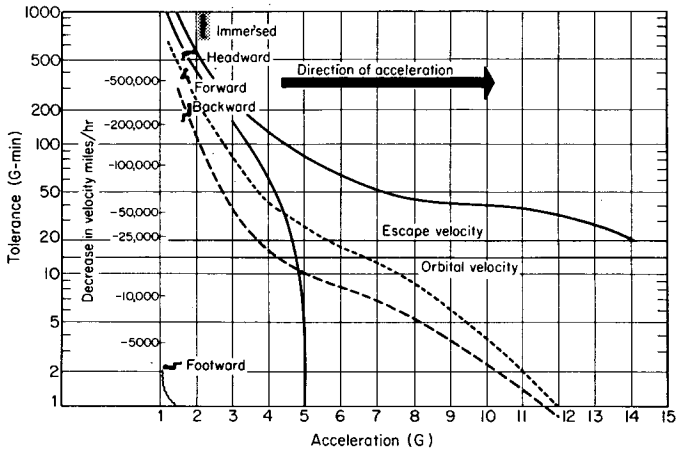
From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
325	SYSTEM - S13 HUMAN - H6, H34	Reference 276, p. 190.



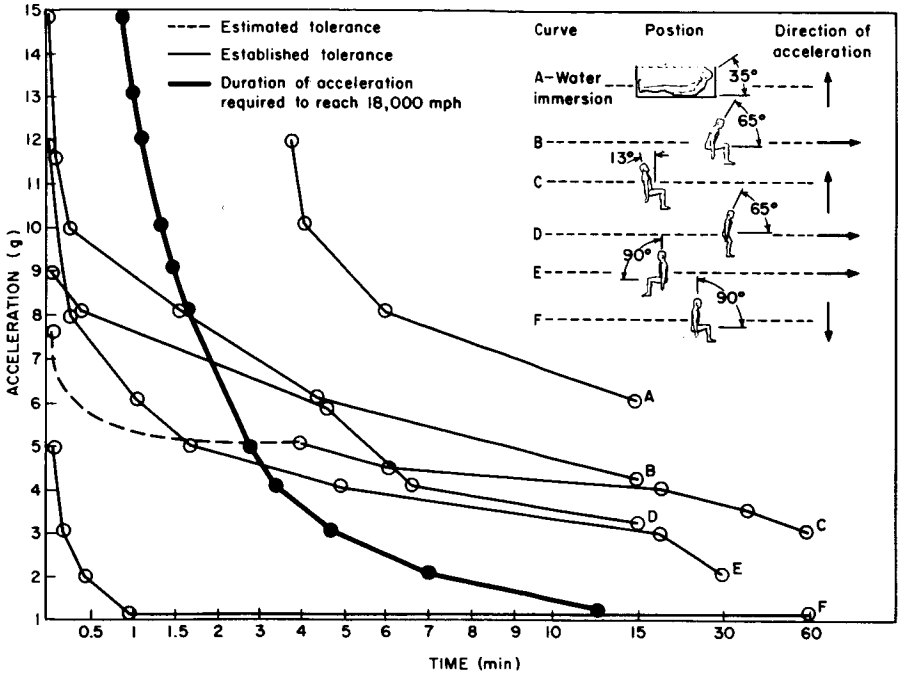
Experimental tolerance data from many sources showing the wide range of forces and times defining "tolerance" as the directions of force and other conditions are changed. Notice also the spread of tolerance data for single conditions, shown with vertical bars and crosshatching.

ITEM NO.	SUBJECT AREAS:	SOURCE:
326	SYSTEM - S13 HUMAN - H6, H34, H44	Reference 555, p. 15.



Relation Between Magnitude of Acceleration And Tolerance Expressed in G Minutes for Man in Various Body Orientations.

ITEM NO.	SUBJECT AREAS:	SOURCE:
327	SYSTEM - S13 HUMAN - H6, H34, H44	Reference 219, p. 394. From ARS



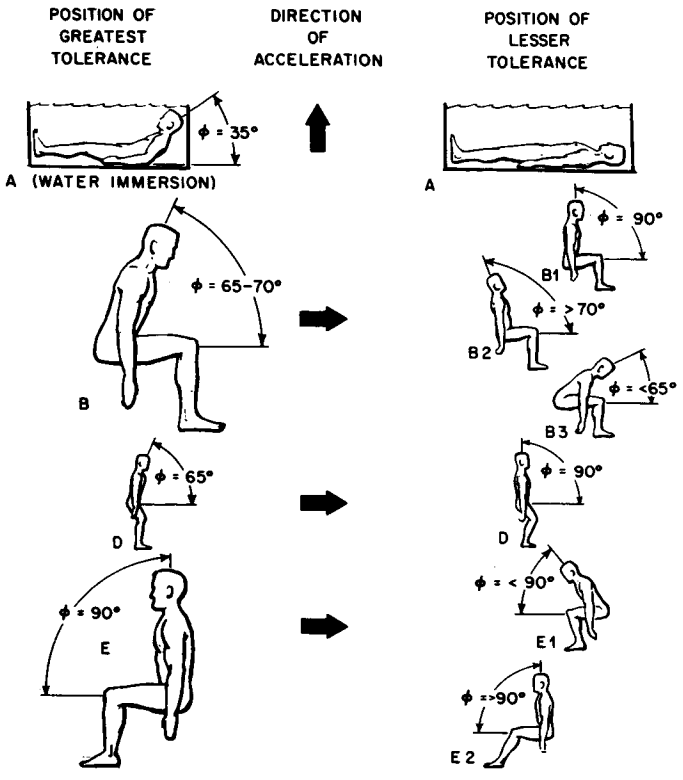
Acceleration Tolerance with Varying Body Positions

ITEM NO.	SUBJECT AREAS:	SOURCE:
328	SYSTEM - S13 HUMAN - H6, H34, H44	Reference 380, p. 454. Based on Reference 85.

Human Tolerance to Positive Acceleration (N = 1000)

CRITERION	MEAN G THRESHOLD	STANDARD DEVIATION	RANGE
Loss of peripheral vision	4.1	±0.7	2.2-7.1
Blackout	4.7	±0.8	2.7-7.8
Unconsciousness	5.4	±0.9	3.0-8.4

ITEM NO.	SUBJECT AREAS:	SOURCE:
329	SYSTEM - S13 HUMAN - H25, H34	Reference 368, p. 8. Based on Reference 210.



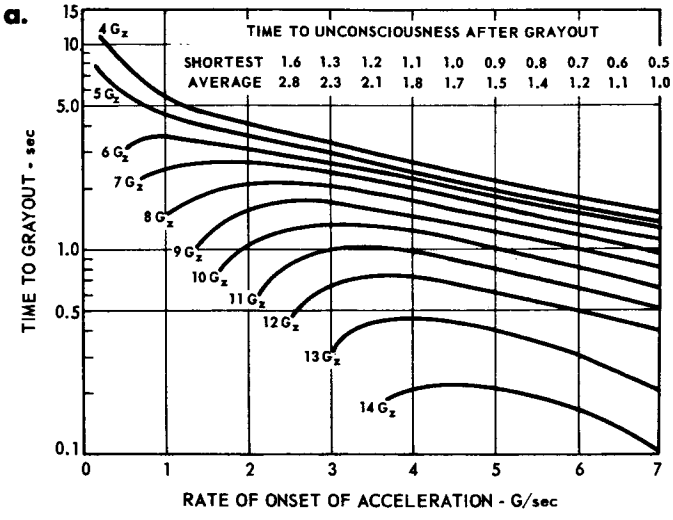
Acceleration Tolerance and Body Position

ITEM NO.	SUBJECT AREAS:	SOURCE:
330	SYSTEM - S13 HUMAN - H6, H34, H44	Reference 380, p. 455. Based on Reference 85.

GRAYOUT AND RATE OF ONSET OF $+G_z$

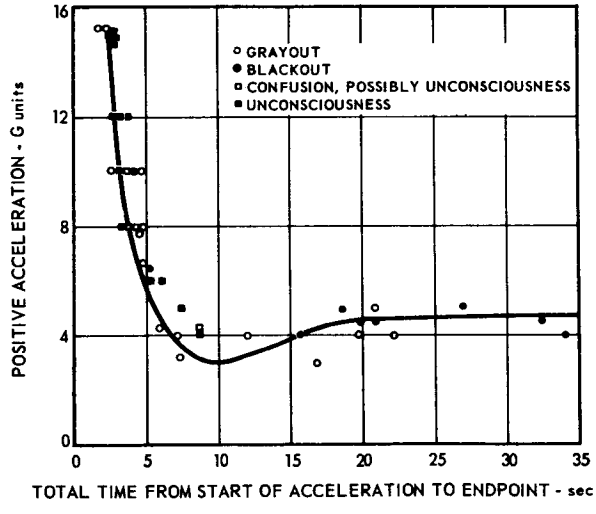
This graph relates the onset rate of acceleration to time-to-end-point. It shows that for any given positive acceleration (G_z) from 4 to 14 G, the time to grayout depends on how rapidly the acceleration level was reached. Further, the table inset in the graph shows the shortest times and the average times for unconsciousness to develop following grayout, each pair of values being related to an onset rate. For example, at onset rate of 4 G/sec, the shortest time to unconsciousness was 1.1 sec, and the average 1.8 sec.

a.

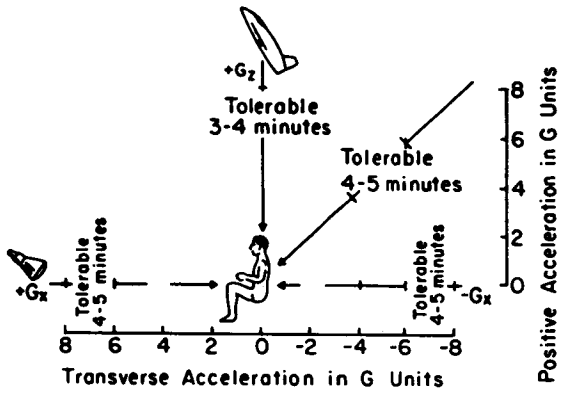


This graph shows human tolerance to positive G_z for varying rates of onset, G amplitudes, and exposure times.

b.



ITEM NO.	SUBJECT AREAS:	SOURCE:
331	SYSTEM - S13 HUMAN - H25, H34	Reference 554, p. 35. Based on Reference 498.

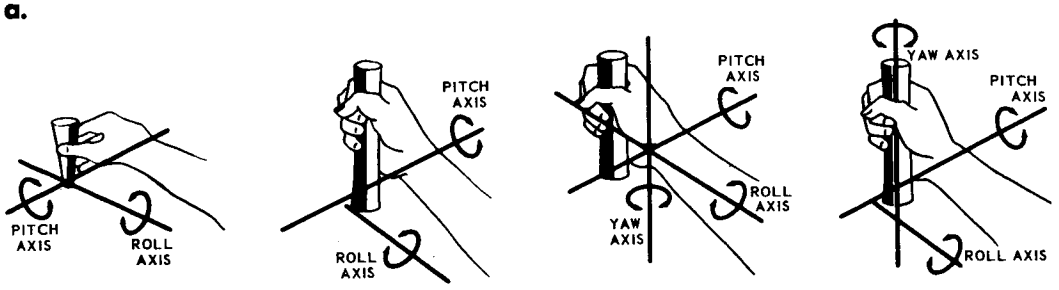


Approximate performance time-tolerances for pilots in advanced restraint system including individually fitted contour couches and associated chest, leg, arm, and head restraints. The figure shows approximate limits beyond which performance of piloting tasks would be unsatisfactory. These approximations are based on data obtained at AMAL during centrifuge simulations of proposed space vehicles.

ITEM NO.	SUBJECT AREAS:	SOURCE:
332	SYSTEM-S13 HUMAN-H26, H44	Reference 116, p. 262.

TRACKING, CONTROLLER CHARACTERISTICS, AND G VECTORS

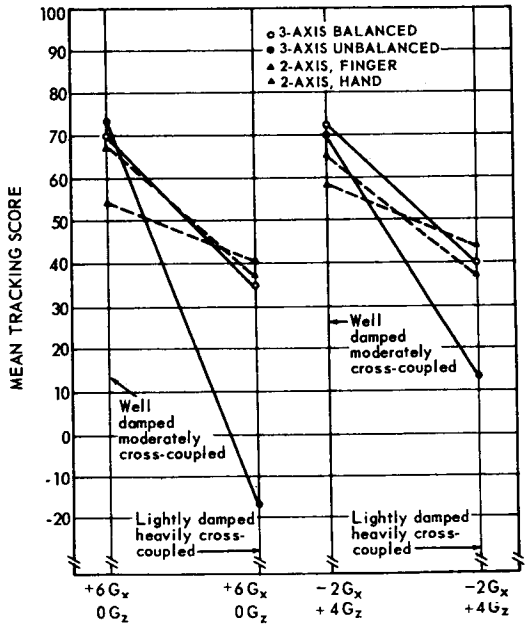
a.



2-AXIS, FINGER TIP CONTROLLER | 2-AXIS, HAND CONTROLLER | 3-AXIS, BALANCED CONTROLLER | 3AXIS, UNBALANCED CONTROLLER

Shown in figure a are four types of right-hand side-arm controllers used in sustained acceleration studies on the human centrifuge. Under acceleration, each controller responds differently, and piloting performance is consequently influenced by both the type of control stick and the type of acceleration forces that are applied. Figure b illustrates that the mean tracking efficiency scores obtained by pilots using these controllers were influenced by the type of controller, the amount of damping and cross coupling, and the acceleration vector.

b.



ITEM NO.	SUBJECT AREAS:	SOURCE:
333	SYSTEM - S13 HUMAN - H26, H42	Reference 554, p. 50. Based on References 118 and 115.

Examples of Variation in Human Tolerance to Headward Acceleration for 10 sec *

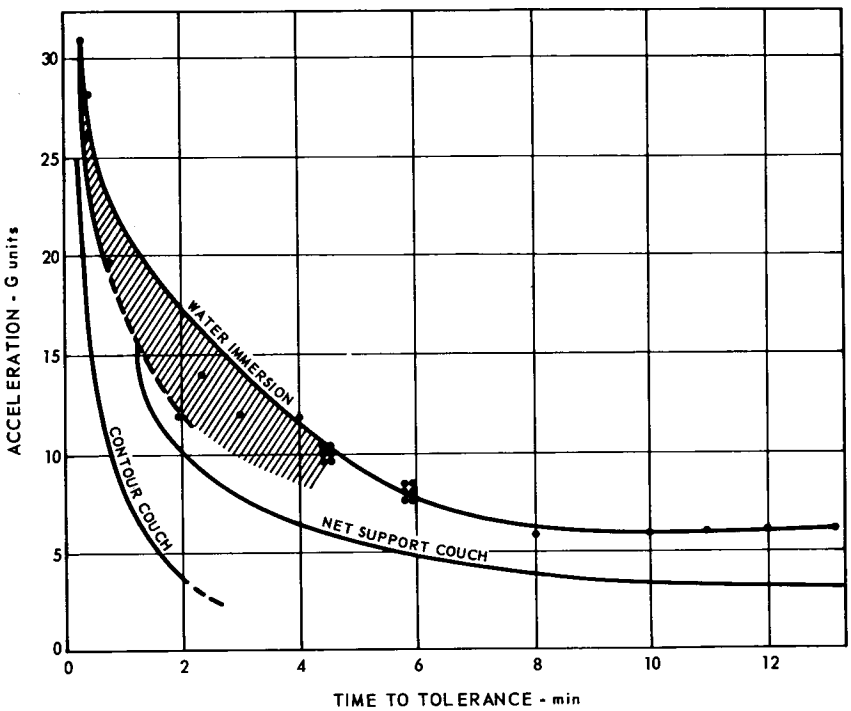
Symptom	Acceleration at which symptom occurred (g)			Range at which symptoms occurred in different subjects (g)		
	Min.	Avg.	Max.	Able	Baker	Charlie
None	2.5	3.5	5.0	—	—	—
Early grayout (peripheral lights dim)	2.6	3.8	7.0	3.0–4.3	2.8–3.8	2.1–6.7
Late grayout (peripheral lights lost)	3.3	4.7	7.7	4.9–6.0	3.7–4.7	5.4–7.2
Blackout (central lights lost)	3.3	5.2	7.8	4.9–6.0	4.6–6.5	5.5–7.6
Confusion	3.6	5.4	8.3	6.0–6.2	4.9–6.9	5.6–7.7
Unconsciousness	3.5	5.6	8.6	6.1–6.5	5.2–7.5	5.6–7.9

* Stauffer, 1953.

As do all biological data, the limits of human tolerance to acceleration vary widely from one person to another and from time to time with the same person. This error introduced by human variation is likely to be a factor close to two or three as shown in the table above.

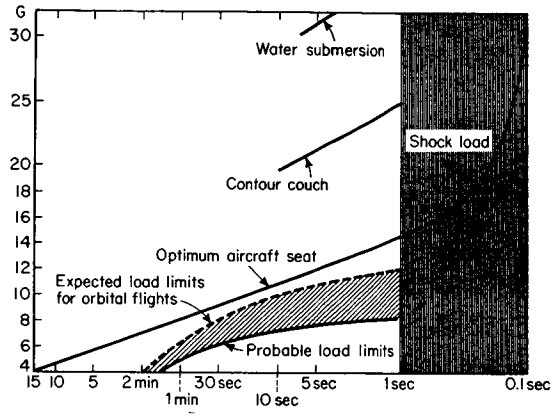
ITEM NO.	SUBJECT AREAS:	SOURCE:
334	SYSTEM - S13 HUMAN - H25, H29, H34	Reference 380, p. 461. Based on Reference 493.

PROTECTION AGAINST G_x



The data points show the protection given against the effects of transverse acceleration (G_x), as indicated by increased tolerance times and higher tolerable G levels, when the subject is immersed in a small tank of water. G tolerance curves are also shown for subjects protected by optimal support and positioning.

ITEM NO.	SUBJECT AREAS:	SOURCE:
335	SYSTEM - S13 HUMAN - H34, H44	Reference 554, p. 38. Based on References 84, 143, 144, 233.



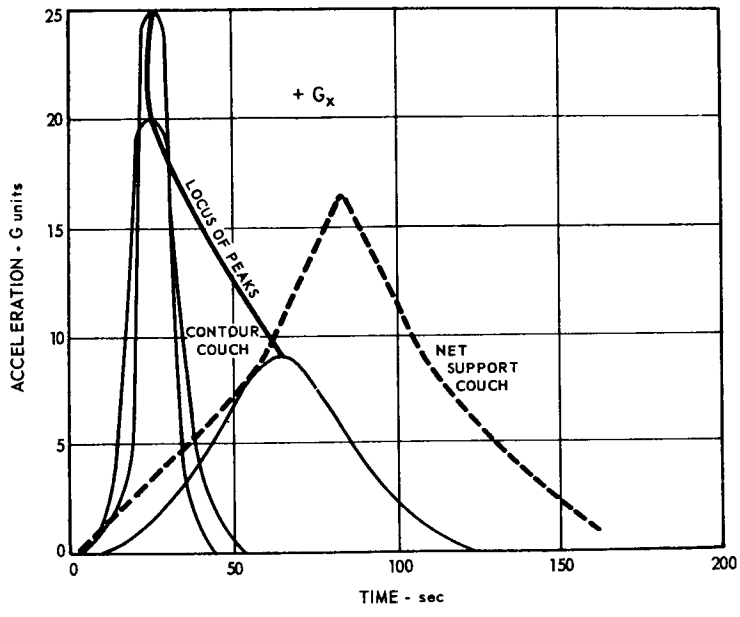
Human tolerance to prolonged forward acceleration

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963. Reprinted by permission of Prentice-Hall Inc., Englewood Cliffs, New Jersey.

ITEM NO.	SUBJECT AREAS:	SOURCE:
336	SYSTEM-S13 HUMAN- H34, H44	Reference 219, p. 397.

MAXIMUM TOLERABLE ACCELERATION PROFILES

a.



b.

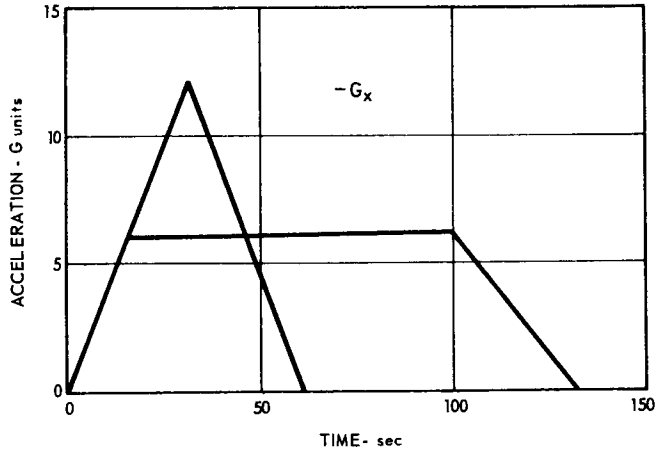
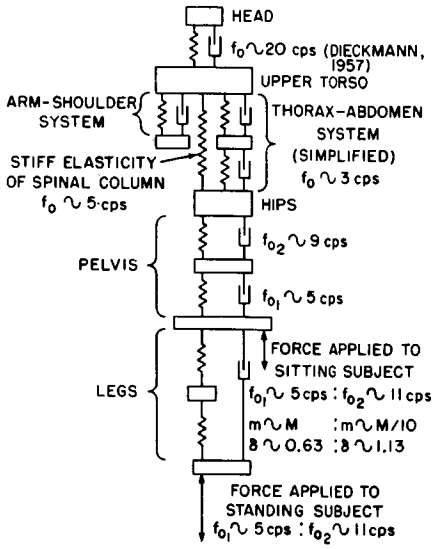


Figure a shows the greatest acceleration-time histories that have been tolerated on centrifuges when special support structures and positioning are used. Solid lines show three curves which define about the same area of $+G_x$ times time. A heavy line connects the peaks of these three curves and locates the peaks of other curves enclosing the same area. The dashed line encloses a number of possible acceleration profiles related to space flight, all of which are tolerable, since the border of the envelope has been tolerated experimentally. Figure b depicts two tolerable G_x accelerations (eyeballs out) when the subject is restrained in a special harness.

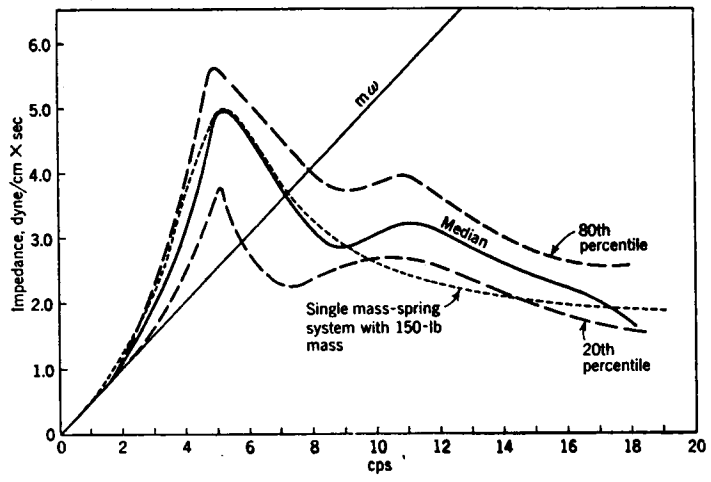
ITEM NO.	SUBJECT AREAS:	SOURCE:
337	SYSTEM - S13 HUMAN - H34, H44	Reference 554, p. 37. Based on References 135, 143, 144, 85, 317



Although a general model covering the body's response to a wide range of frequencies is available, a simplified, lumped-parameter model has been found satisfactory within the range of 1-70 cps. It is in this range that the energies of vibrations from vehicle sources are likely to be most important to man. A simplified mechanical circuit analogue of a man standing or sitting on a vertically vibrating platform is shown above. This analogue, which is applicable to low-frequency vibration, describes transmission along the longitudinal axis in terms of the series impedances offered by various parts of the body.

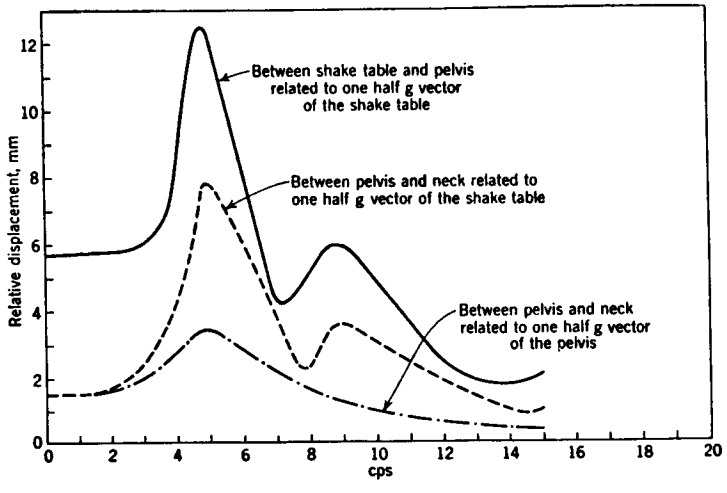
ITEM NO.	SUBJECT AREAS:	SOURCE:
338	SYSTEM - S14 HUMAN - H13	Reference 380, p. 468. Based on Reference 139.

a



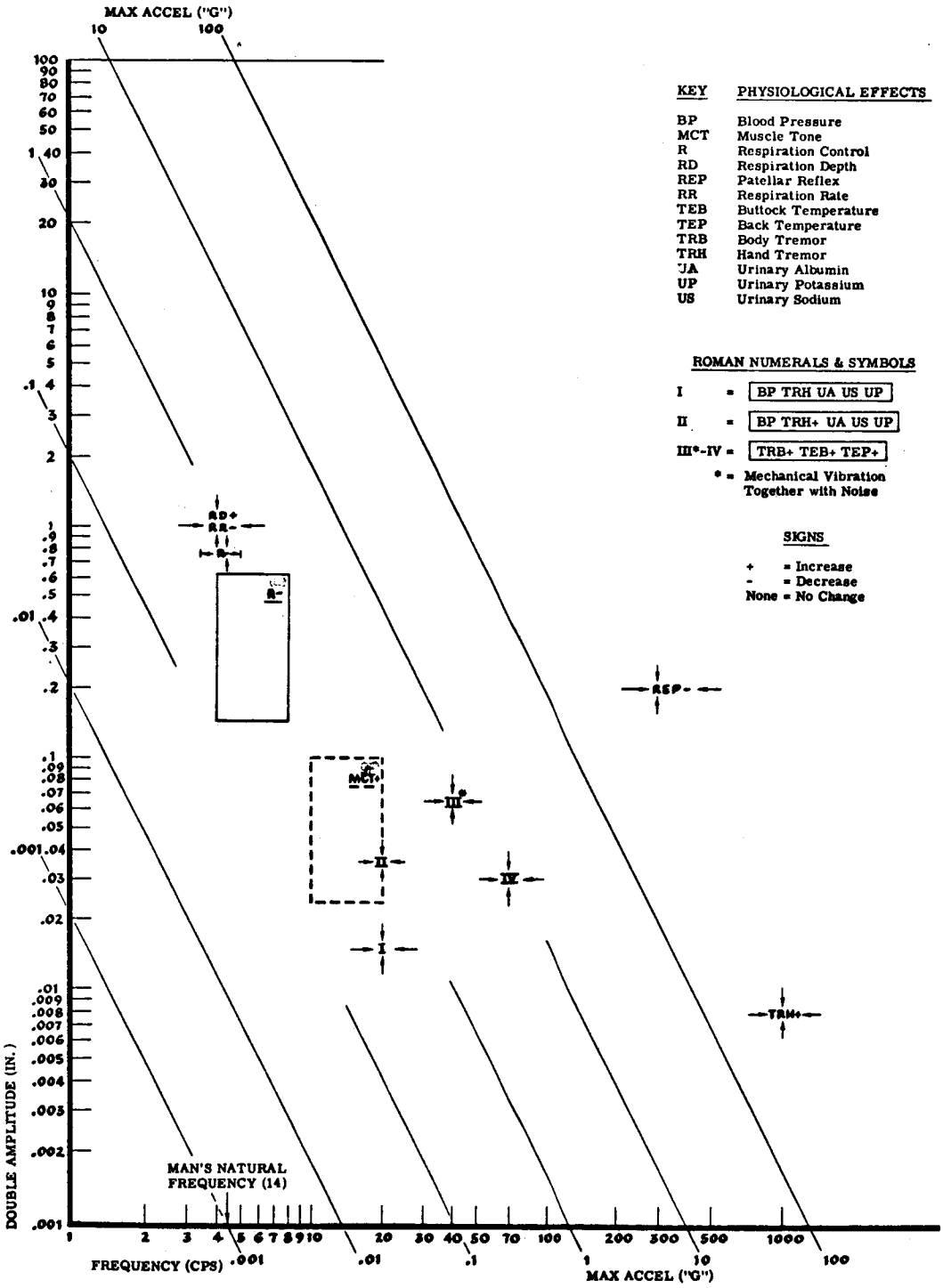
The median and the twentieth and eightieth percentiles of the impedance of five different subjects as compared with the impedance of a single mass-spring system and a pure mass system (mω).

b



Relative body displacements of one subject sitting erect during vertical vibration.

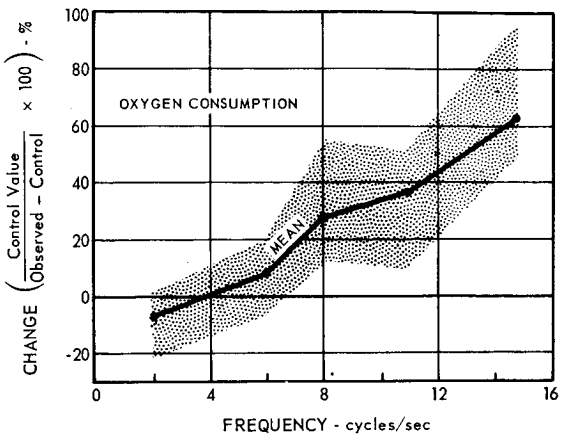
ITEM NO.	SUBJECT AREAS:	SOURCE:
339	SYSTEM - S14 HUMAN - H13	Reference 346, pp. 90, 92. Based on References 140 (fig. a) and 344 (fig. b).



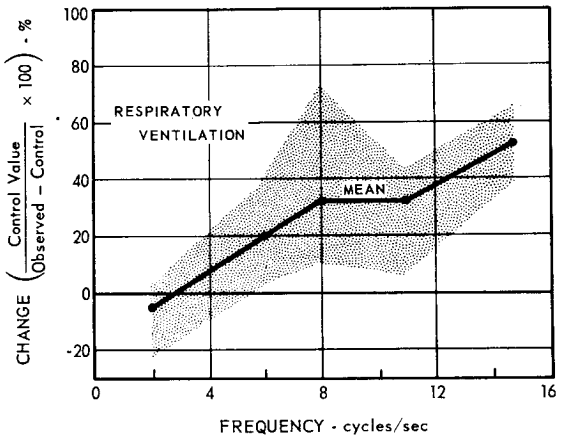
Vibration: Physiological Effects

ITEM NO.	SUBJECT AREAS:	SOURCE:
340	SYSTEM - S14 HUMAN - H8, H20	Reference 555, p. 29. Based on Reference 328.

a.

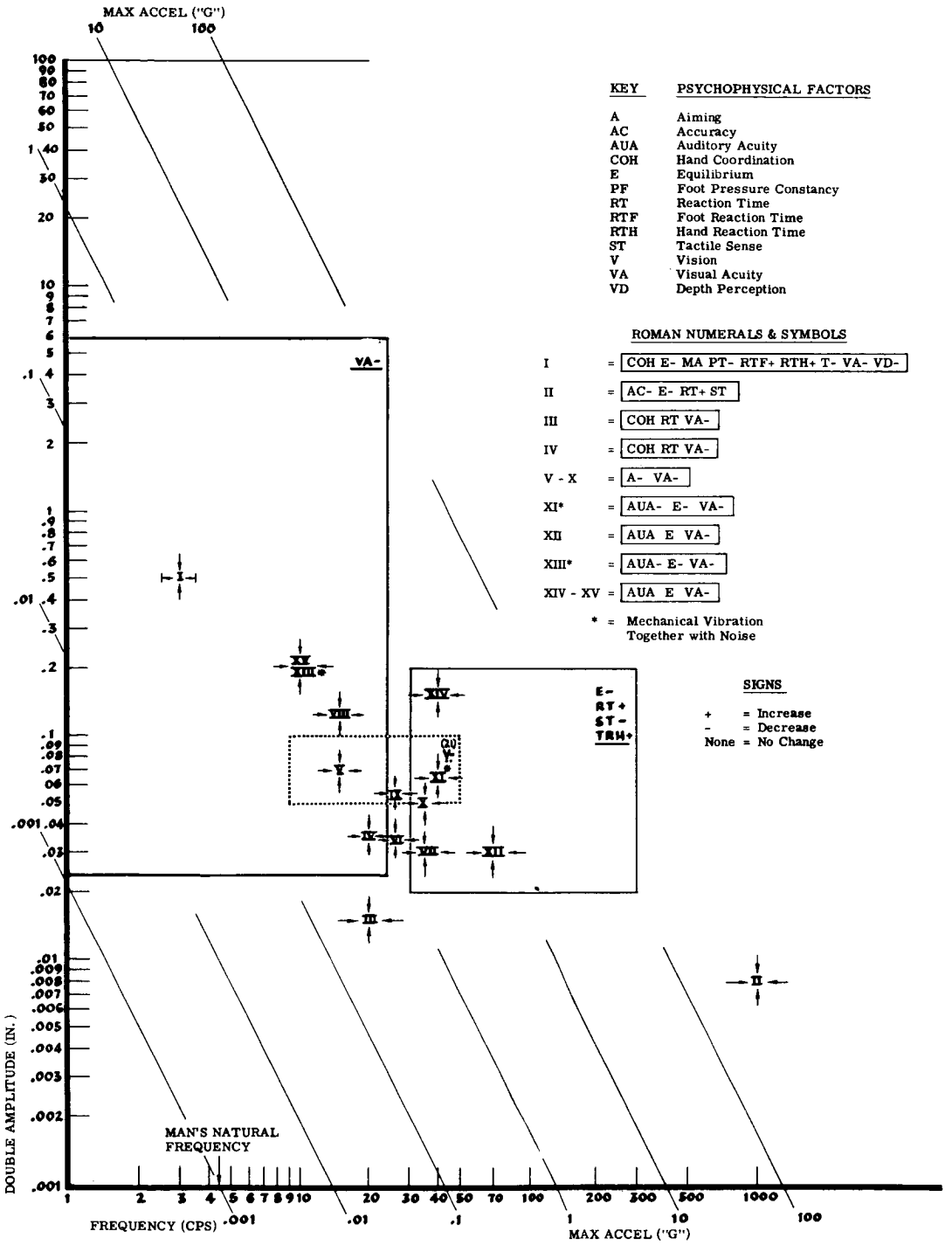


b.



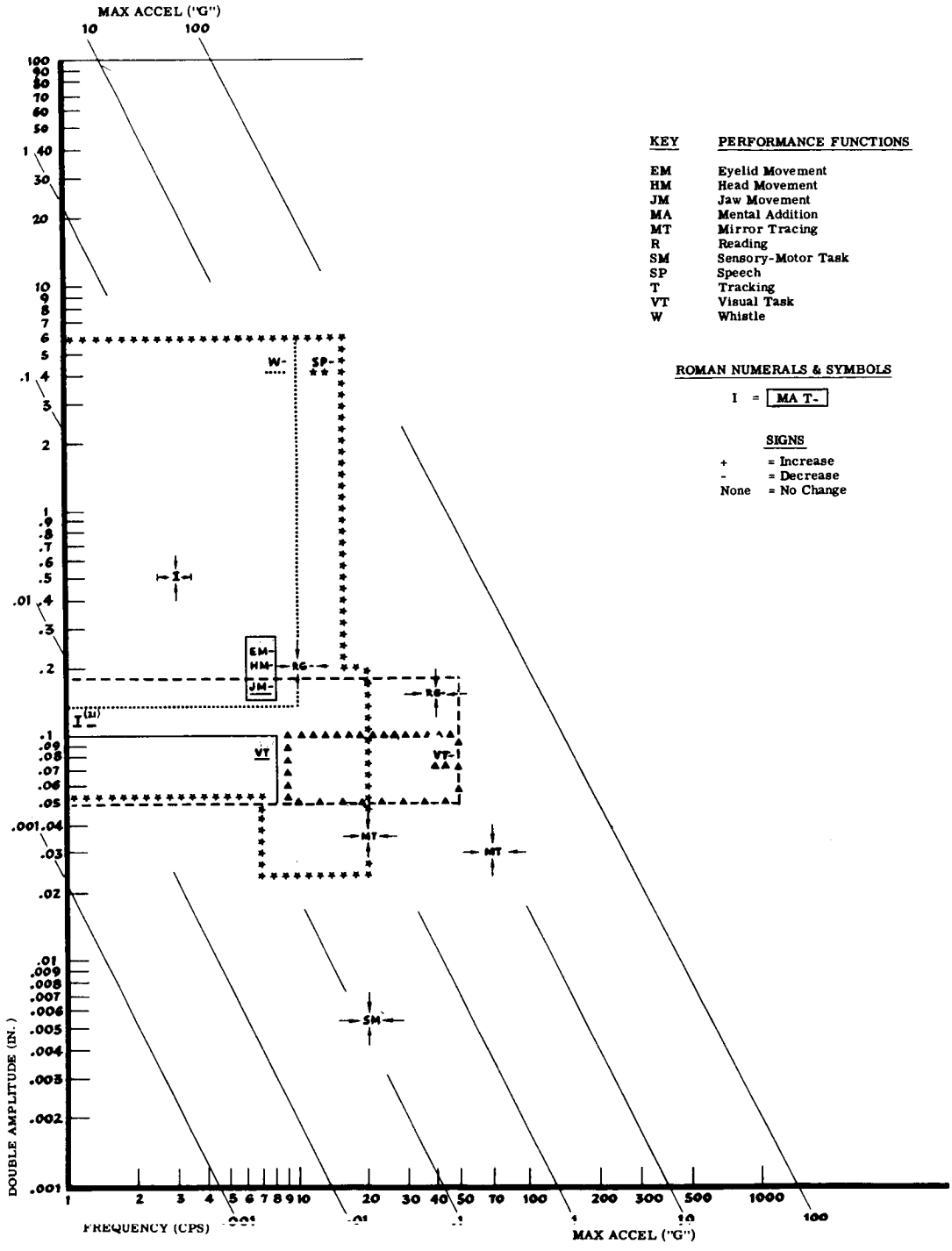
The change in oxygen consumption for four male subjects during vibration is shown in a as a percentage change from the control value, with the mean values being connected by a line and the range shown with shading. Similar data are shown in b, where respiratory ventilation is also shown to increase as a function of frequency, when amplitude is held constant. The subjects were exposed to 20 minutes of vibration at an amplitude of 0.132 inch while seated on a chair and entirely unrestrained.

ITEM NO.	SUBJECT AREAS:	SOURCE:
341	SYSTEM - S14 HUMAN - H16, H20	Reference 554, p. 79. Based on Reference 205.

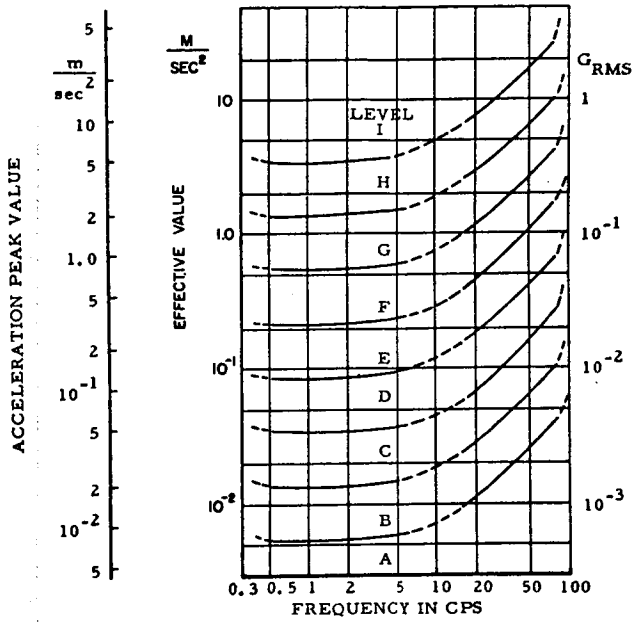


Vibration: Psychophysical Factors

ITEM NO.	SUBJECT AREAS:	SOURCE:
342	SYSTEM - S14 HUMAN - H24	Reference 555, p. 30. Based on Reference 328.



ITEM NO.	SUBJECT AREAS:	SOURCE:
343	SYSTEM - S14 HUMAN - H24	Reference 555, p. 31. Based on Reference 328.

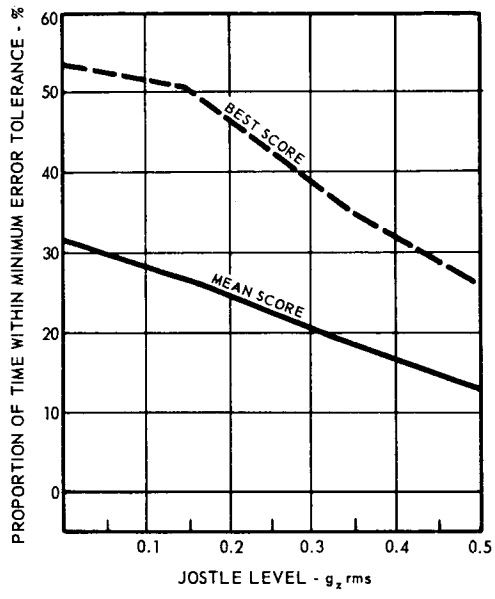


German Standard for the classification of vibration exposures (VDI 2057, 1961). The curves of equal perceived intensity (K-value) classify ranges (levels A to I) of equal perception and tolerability.

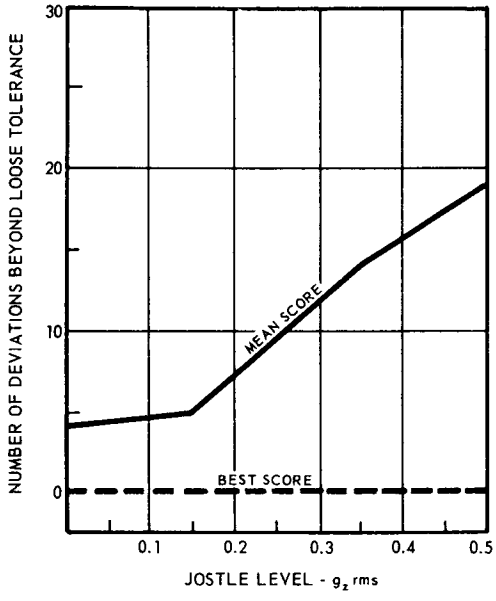
ITEM NO.	SUBJECT AREAS:	SOURCE:
344	SYSTEM - S14 HUMAN - H25	Reference 547, p. 336 Based on Reference 539

TRACKING PERFORMANCE DURING JOSTLE

a.



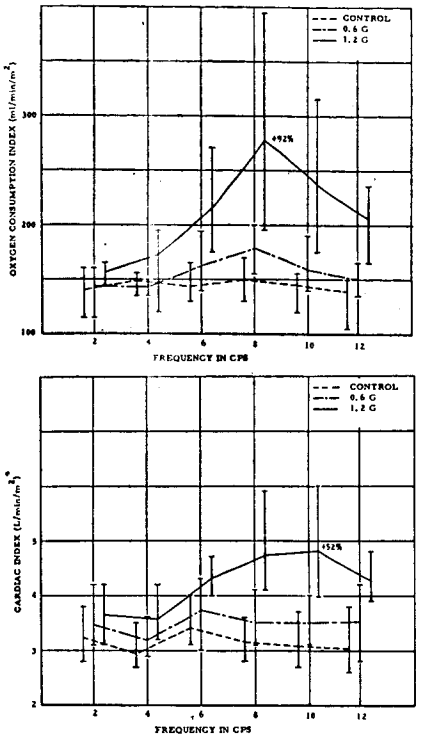
b.



These two figures illustrate the increasing difficulty of performing a demanding control task as random vertical vibrations ("jostle") increased in magnitude. Pilots were held by a Navy torso restraint device in the North American Aviation "G-seat", which was then programmed to move in the $\pm G_z$ direction with an electrical white noise input, and jostle levels of: 0.15 g_z rms (root mean square) described by the pilots as similar to flying through mild turbulence; 0.35 g_z rms, described as severe turbulence; and 0.50 g_z rms, in which the largest jolts were classed as one-of-a-kind in a real flight. Power density spectra peaked near 1 cps. A panel-mounted accelerometer showed maximum and minimum accelerations of 0 to 2.5 G_z for 0.15 g_z rms; -1.2 to 4.0 G_z for 0.35 g_z rms; and -2.5 to 5.0 G_z for 0.5 g_z rms. The demanding control task was to track in pitch, shown on a 5-inch oscilloscope screen, and hold roll to 0. Fourteen highly motivated and skilled Navy pilots made 70 runs; they tolerated the random vibrations well, although they had to brace themselves against the larger seat movements to avoid slapping of the head or body against the structure. Longer runs – 15 to 30 minutes at 0.35 g_z rms – produced muscular fatigue.

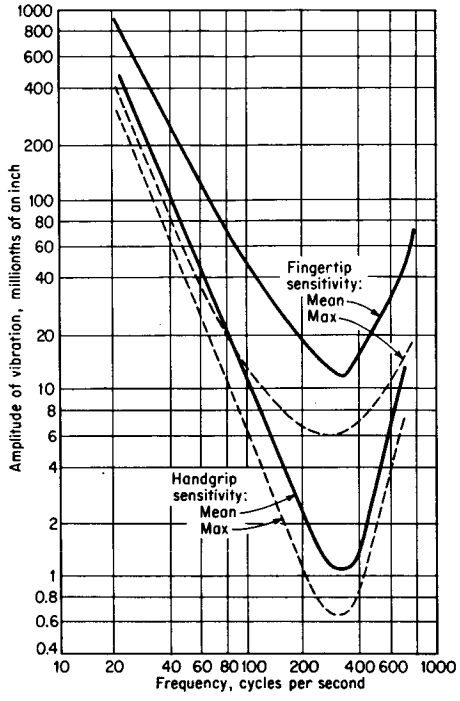
Chart a shows what tracking error occurred as the jostle levels increased; the minimum tolerance for error was set to be 1/12 of the task amplitude. Chart b shows that as jostle increased, more and more tracking deviations appeared beyond the loose tolerance level of 5/6 of the task amplitude.

ITEM NO.	SUBJECT AREAS:	SOURCE:
345	SYSTEM - S14 HUMAN - H26	Reference 554, p. 82 Based on Reference 131



Average oxygen consumption and cardiac output of 4 human subjects vibrated in the X (front to back) direction. The subjects were in the semi-supine position and vibrated for 6 minutes at two vibration intensities (.6G and 1.2G). (The bars indicate the range of the data.)

ITEM NO.	SUBJECT AREAS:	SOURCE:
346	SYSTEM- S14 HUMAN- H9, H16, H20	Reference 547, p. 335 Based on Reference 132



Mean and maximum sensitivity level of vibration when object is touched with finger tips and when gripped by hand, by frequency.

There is little data available regarding the tolerance to, or effects of, vibration that is localized, but there are some data on sensitivity thresholds to touch. Some of these data are given in the figure above. In particular this figure shows the average and maximum sensation level (the minimum intensity) that can be detected by people for vibrations of varying frequencies for the fingertips and for a full handgrip (such as when gripping portable hand tools). The "maximum" is the lowest intensity that was detected by any individual in the group of 25 subjects. The general patterns in both cases are fairly similar in that sensitivity is greatest (meaning that smaller amplitudes can be perceived) in the range of frequencies around 300 cps. While there were marked individual differences, the pattern of the greatest sensitivity (finger or hand) follows generally the same pattern as that of the respective mean. While these data do not reflect tolerance amplitudes, it is probable that they would follow similar patterns.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
347	SYSTEM- S14 HUMAN- H25, H28	Reference 362, p. 499 Based on Reference 193

VIBRATION THRESHOLDS

Threshold	Cycles per Second	Amplitude in Inches
Absolute Threshold	above 1000 and below 400	.00015
Perceptible vibration	100	.0002
	20	.001
	8	.01
	1	.2
Threshold of pain and discomfort	200	.002
	100	.005
	20	.05
	10	.2
	5	.5

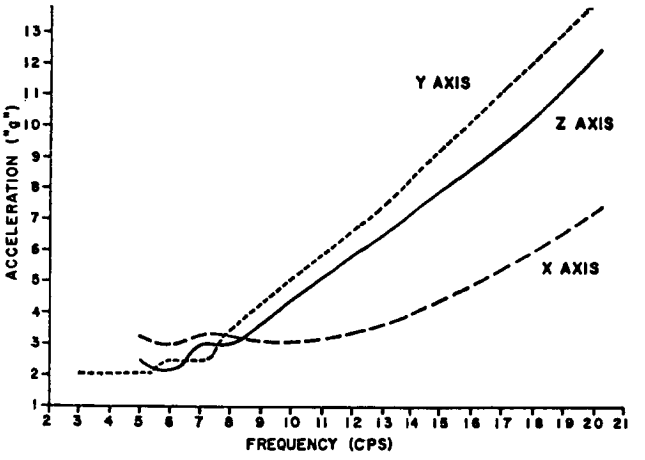
ITEM NO.	SUBJECT AREAS:	SOURCE:
348	SYSTEM- S14 HUMAN- H34	Reference 14, p. 153

HUMAN BODY VIBRATION STRESS RESPONSE

Frequency	Amplitude	Effective g	Response	Critical Time
10 cps	1/3 in.	2 g	Intense precardial pain	3 min
25 cps	1/3 in.	4-6 g	Bowel and bladder damage	8 min
40 cps	1/3 in.	4 g	Eyeball and brain damage	5 min

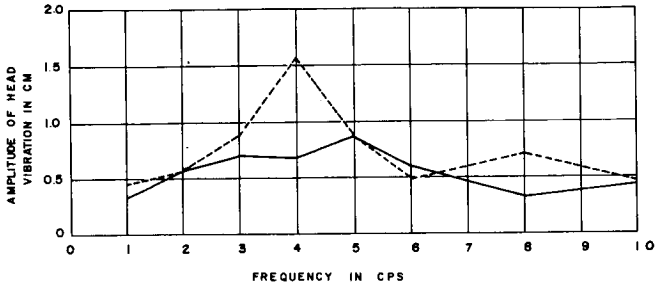
Above 8 cps, tolerance to vibration increases sharply, probably because of natural dampening or attenuation of vibrations. The table above presents the data compiled by Schwichtenberg on the damages occurring in these critical vibration ranges.

ITEM NO.	SUBJECT AREAS:	SOURCE:
349	SYSTEM - S14 HUMAN - H34	Reference 416, p. 73 Based on Reference 469



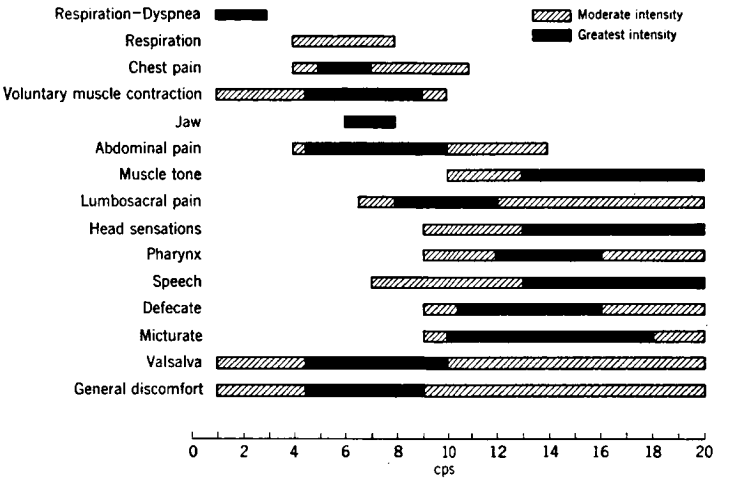
Short-time tolerance curves for young, healthy, male subjects exposed to sinusoidal vibrations in three different directions. (Z axis = longitudinal body axis; X axis = front to back; Y axis = side to side.) The subjects are restrained in contoured couches.

ITEM NO.	SUBJECT AREAS:	SOURCE:
350-	SYSTEM - S14 HUMAN - H34	Reference 547, p. 334 Based on Reference 517



Amplitude of vertical vibration of head of two different subjects sitting on a shake-table (no cushion). Shake-table vibrates at an amplitude of 0.4 cm.

ITEM NO.	SUBJECT AREAS:	SOURCE:
351	SYSTEM- S14 HUMAN- H34	Reference 384, p. 391 Based on Reference 148



Range of perceptible sensations.

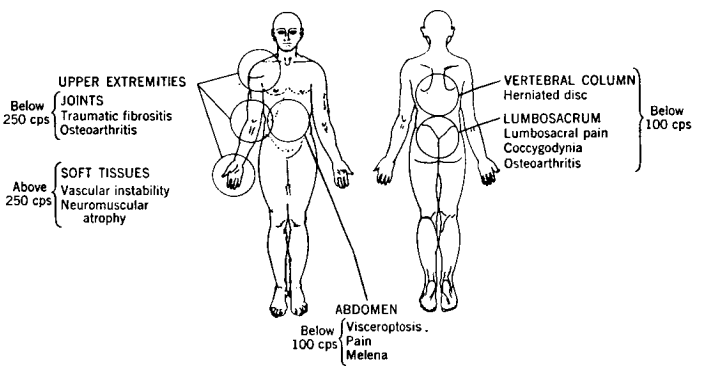
ITEM NO.	SUBJECT AREAS:	SOURCE:
352	SYSTEM - S14 HUMAN - H34	Reference 346, p. 108 Based on Reference 344

AVERAGE SUBJECTIVE RATINGS ON 0 TO 4 SCALE OF SENSATIONS EXPERIENCED DURING WHOLE BODY VIBRATIONS

Body-region symptomatology	Average subjective rating per frequency										
	1 cps	2 cps	2.5 cps	3 cps	3.5 cps	4 cps	4.5 cps	5 cps	5.5 cps	6 cps	7 cps
Head-neck area:											
Head sensations—vibration or "tight sensation" of facial skin	0	0.1	1.0	1.3	1.1	1.7	1.3	2.7	3.6	3.4	3.7
Pharynx—pharyngeal tug or "lump in throat" (occurs only above 10 cps)											
Jaw—sensation of vibration (occurs only above 10 cps)											
Speech—lower frequencies secondarily affected because of reactions of thorax and abdomen; high frequencies affected because of superimposed transmitted vibrations to laryngeal tissues and possibly main-stem bronchi	0	0.4	0.3	0.7	1.0	2.2	1.5	2.4	2.8	3.6	3.7
Thorax:											
Respiration—decreased ability to perform physiological respiratory movements of the thoracic cage because of superimposed forces from oscillating platform	0.2	0.7	1.0	1.2	1.7	1.9	2.7	3.1	2.9	3.7	3.9
Dyspnea—air hunger	0	0.5	0.6	0.1	0.6	1.2	1.2	2.7	3.5	3.4	3.8
Valsalva—partial or complete closure of glottis, resulting in increased intrathoracic and intra-abdominal pressure	0	0.4	0.7	0.5	0.7	1.6	1.4	2.8	3.3	3.3	3.8
Substernal and/or precordial pain—dull to severe pain of the precordium, occasionally radiating to the sternum but with no other radiations; pain subsides immediately upon cessation of vibration	0	0	0	0	0	0	0	1.8	2.0	3.2	3.4
Abdomen:											
Voluntary abdominal musculature contraction—degree of contraction or "bearing down"	0	0	0	0.3	0.8	1.3	2.9	3.2	2.8	3.3	3.5
Abdominal pain—usually periumbilical with tendency to radiate to right lower quadrant	0	0	0	0	0	0	0.6	2.0	1.3	2.5	1.9
Skeletal musculature:											
Skeletal musculature—sensation of "muscle tightness" or possibly increased muscle tone primarily of the lower extremities, dorsum, and neck (occurs only above 10 cps)											
Voluntary muscle contraction of extremities—muscular contraction in an effort to counteract severe movements of oscillating platform	0	0	1.0	0.3	1.8	1.8	1.6	3.0	3.4	3.6	4.0
Lumbosacral pain—dull to severe pain at midline with bilateral radiation; pain subsides immediately upon cessation of vibration	0	0	0	0	0	0	0.4	0.8	0	0.4	0.4
Pelvic-perineal complex:											
Micturate (urge)—mechanical stimulation of bladder neck and proximal portion of urethra (occurs only above 10 cps)											
Defecate (urge)—mechanical stimulation of distal portion of sigmoid colon and rectum (occurs only above 10 cps)											
General discomfort	0	0	1.0	0.5	0.6	1.7	1.1	2.8	3.4	3.7	3.9
Total (overall)	0.2	2.1	5.6	4.9	8.3	13.4	14.7	27.3	29.0	34.1	36.0
Total (minus pain)	0.2	2.1	5.6	4.9	8.3	13.4	13.7	22.7	25.7	28.0	30.3

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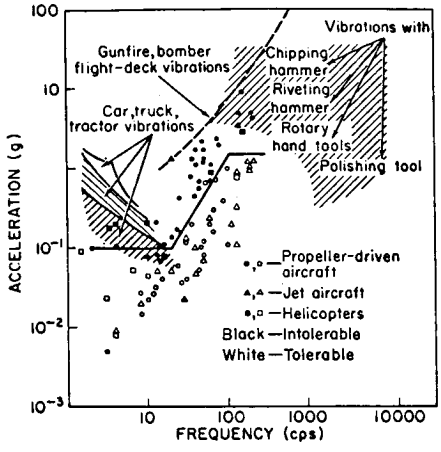
ITEM NO.	SUBJECT AREAS:	SOURCE:
353	SYSTEM - S14 HUMAN - H34	Reference 346, pp. 105-106



Common regional pathology resulting from occupational vibratory environments.

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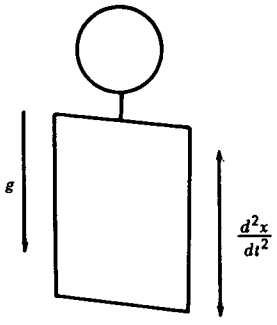
ITEM NO.	SUBJECT AREAS:	SOURCE:
354	SYSTEM - S14 HUMAN - H34	Reference 346, p. 87

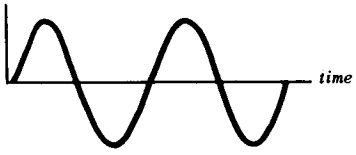


The figure above (Goldman and von Gierke, 1960) describes the vibration levels associated with various types of ground and air vehicles. This figure also indicates vibrations that, for long-term exposure, are intolerable and those that are tolerable. Areas indicated for ground vehicles are maxima rather than spectra. In general, rubber-tired farm tractors and trucks have maximum vertical vibrations of 2-6 cps; for earth-moving equipment the range of maximum vibration is 1.5-3.5 cps; for crawler-type tractors it is about 5 cps. The figure also shows the effects of various powered hand tools; most of these are within the range at which chronic hand injuries can be expected. Tool design and operation, therefore, are critical for these devices.

ITEM NO.	SUBJECT AREAS:	SOURCE:
355	SYSTEM- S14 HUMAN- H34	Reference 380, p. 472 Based on Reference 226

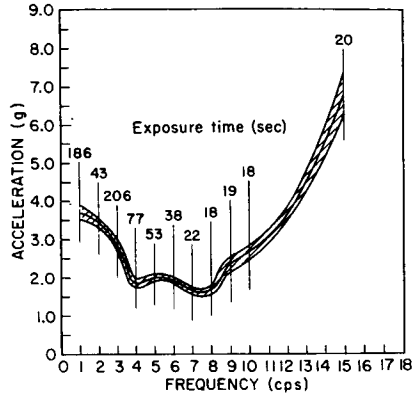
MOTION SICKNESS WITH VIBRATION





Vertical linear oscillation (7-foot peak-to-peak wave at 22 cycles per minute) produced sickness in 53% of a group of naval officers in 20 minutes.

ITEM NO.	SUBJECT AREAS:	SOURCE:
356	SYSTEM- S14 HUMAN- H34	Reference 554, p. 376 Based on Reference 571



Human vibration tolerance. Average peak acceleration at various frequencies at which subjects (restrained with standard USAF lap and shoulder straps) refused to tolerate further short exposure to vertical vibration. Shaded area is about one standard deviation on either side of mean.

ITEM NO.	SUBJECT AREAS:	SOURCE:
357	SYSTEM - S14 HUMAN - H34, H35	Reference 380, p. 471 Based on Reference 597

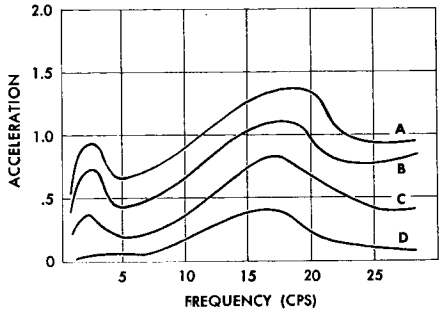
Reaction to sinusoidal, whole body vibration in the vertical axis (taken on a hard seat with subject restrained by seat belt) is shown in the graph at right

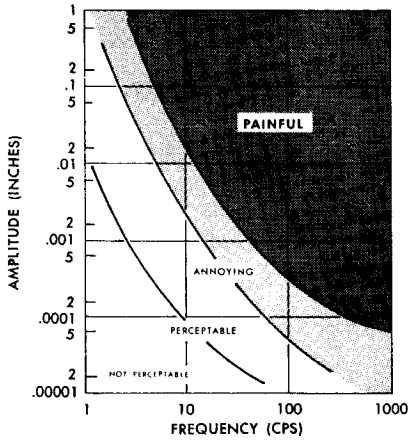
A = alarming

B = extremely annoying

C = mildly annoying

D = definitely perceptible





The human body reacts to vibration and resonating stimuli much the same as does a mechanical system of masses and springs. When the resonant stimulus approximates the natural human — body resonance of about 5 cycles per second, the person concerned finds this quite disagreeable.

Resonant frequency of the human body should be considered in the design of vehicles and vehicle seating: i.e., avoid amplifying the effect on the body through damping.

Pelvic region, 4–6 cps

Abdominal mass, 4–8 cps

Head (relative to shoulders), 30 cps

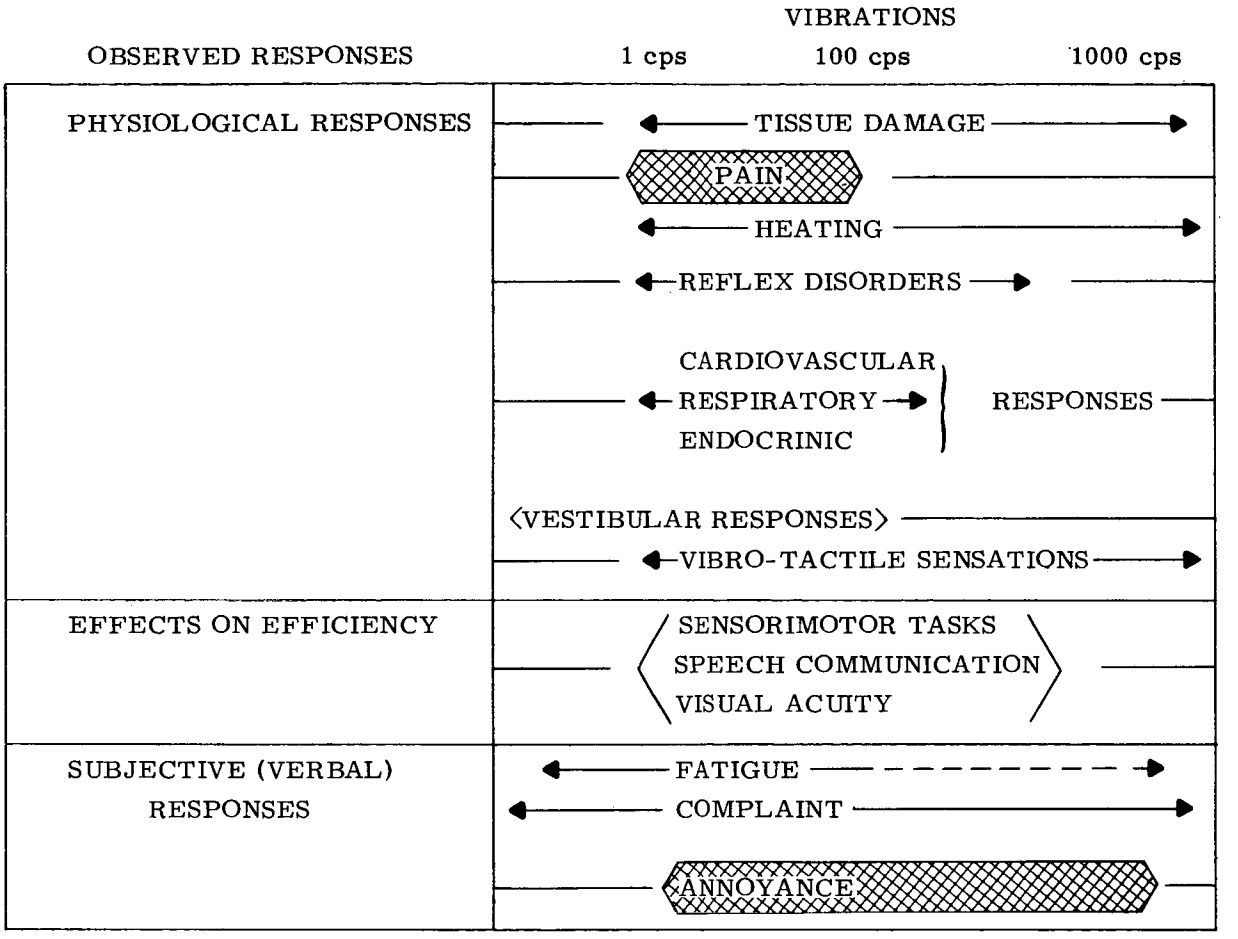
ITEM NO.	SUBJECT AREAS:	SOURCE:
358	SYSTEM - S14 HUMAN - H34, H35	Reference 586, pp. 2-234 and 2-235. Figure b based on Reference 405

CRITERIA OF VIBRATION TOLERANCE

Cps	Sensations						
	Abdominal pain	Chest pain	Testicular pain	Head symptoms	Dyspnea	Anxiety	General discomfort
1	...	...	...	...	8	...	3
2	...	...	...	...	8	...	4
3	2	2	...	...	5	1	5
4	2	2	...	2	3	2	5
5	...	4	...	...	...	1	6
6	3	4	...	1	...	...	4
7	2	5	1	1	...	...	1
8	1	4	...	1	...	2	3
9	2	4	...	...	1	...	5
10	1	1	3	2	...	1	10
15	...	...	...	...	...	...	8

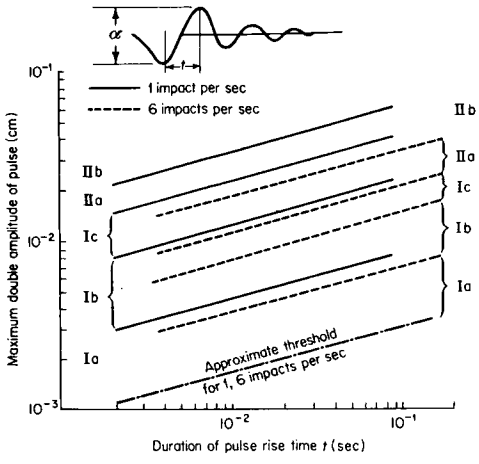
The table above lists the reasons given by subjects for stopping a run consisting of sinusoidal acceleration. The frequency was preset and, starting from zero, the peak-to-peak amplitude was increased at 0.75 mm/sec until the subject stopped the run.

ITEM NO.	SUBJECT AREAS:	SOURCE:
359	SYSTEM - S14 HUMAN - H34, H35	Reference 346, p. 99 Based on Reference 345



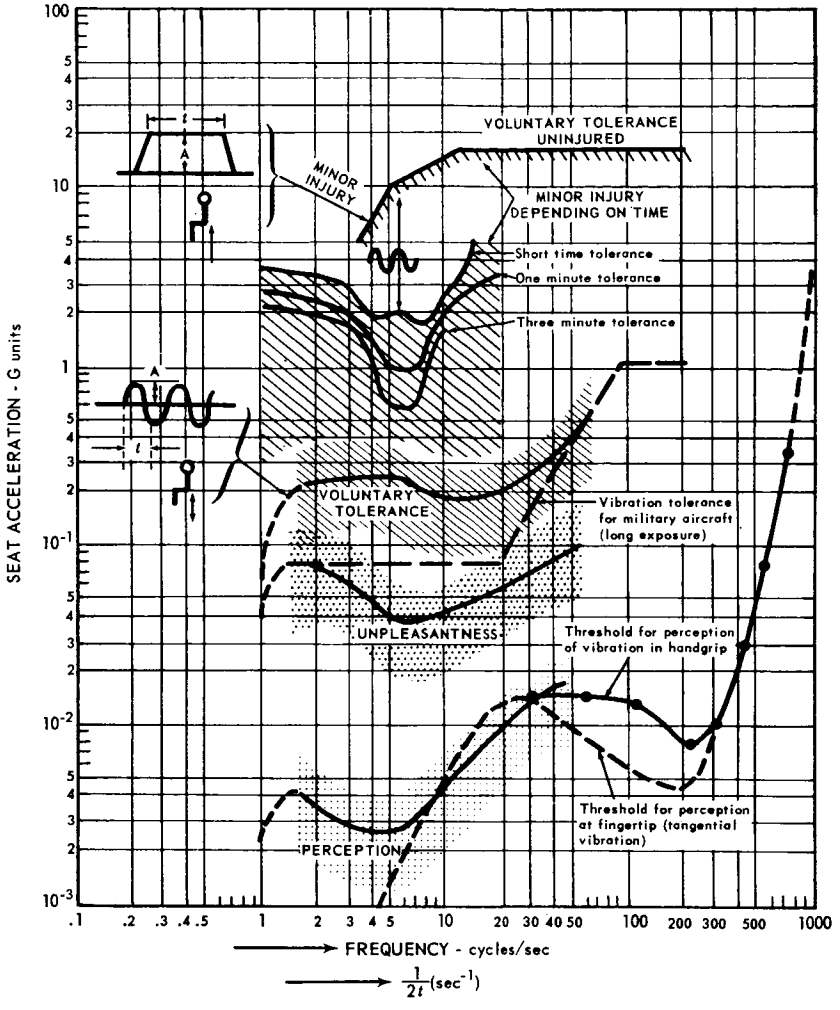
Human reactions to vibration.

ITEM NO.	SUBJECT AREAS:	SOURCE:
360	SYSTEM - S14 HUMAN - H34, H35	Reference 547, p. 328



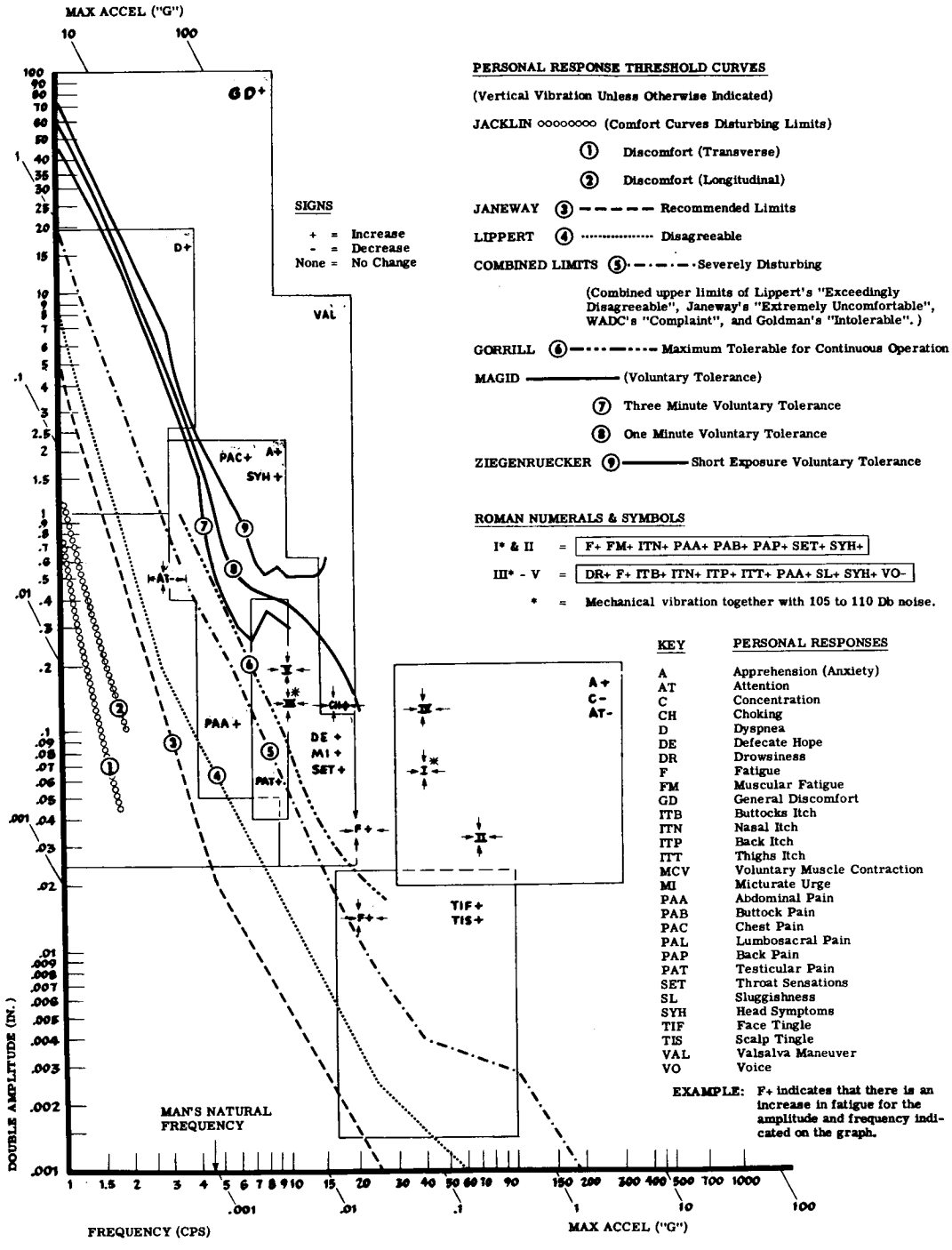
Tolerance of human subjects in the standing or supine position to repetitive vertical impact pulses representative of impacts from pile drivers, heavy tools, heavy traffic, and so on. Subjective reaction is plotted as a function of the maximum displacement of the initial pulse and its rise time. The numbers indicate the following reactions for the areas between lines: Ia, threshold of perception; Ib, of easy perception; Ic, of strong perception, annoying; IIa, very unpleasant, potential danger for long exposures; IIb, extremely unpleasant, definitely dangerous. The decay process of the impact pulses was found to be of little practical significance. (After H. Reiher and F.J. Meister)

ITEM NO.	SUBJECT AREAS:	SOURCE:
361	SYSTEM- S14 HUMAN- H34, H35	Reference 197, p. 557



This illustrates schematically a number of tolerance criteria for vibration. The four shaded zones represent: threshold for perception; the unpleasant area of vibration; the limits of voluntary exposure, unprotected, for 5-20 minutes; and the voluntary tolerance limits for subjects with lap belt and shoulder harness for three minutes, one minute, and less than one minute. Above this, minor injuries occur, depending on time. At the top of the chart is plotted the voluntary tolerance curve for impact, which may be considered to be half-cycle vibration of large magnitude. The conventional way of measuring durations (t) and amplitudes (A) is shown in the small diagrams at the left.

ITEM NO.	SUBJECT AREAS:	SOURCE:
362	SYSTEM- S14 HUMAN- H34, H35	Reference 554, p. 76 Based on Reference 549

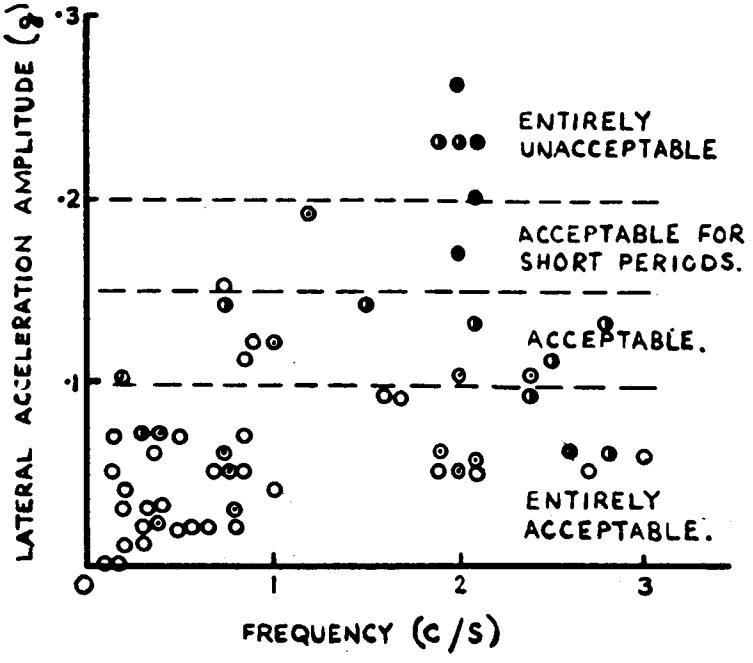


Vibration: Subjective response and tolerances.

ITEM NO.	SUBJECT AREAS:	SOURCE:
363	SYSTEM- S14 HUMAN- H34, H35	Reference 555, p. 27 Based on Reference 328

OSCILLATIONS IN FLIGHT

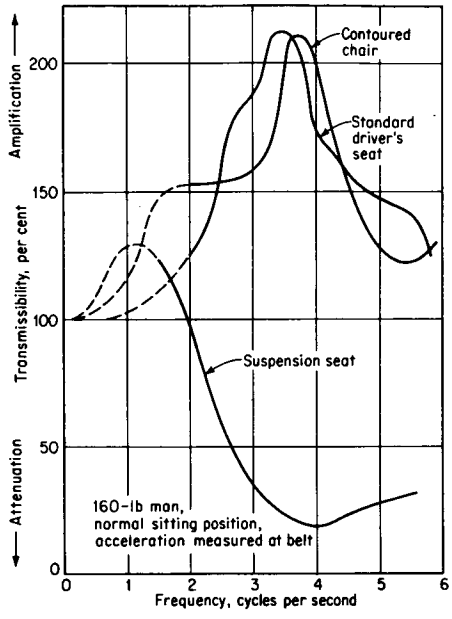
● ENTIRELY UNACCEPTABLE.
◐ ACCEPTABLE ONLY FOR SHORT PERIODS.
◎ ACCEPTABLE.
○ ENTIRELY ACCEPTABLE.



Subjective tolerance of 5 flight officers for induced roll oscillations in actual flight.

Pitch oscillations in flight from 0.25 to 1 per second with angular velocities of from approximately 2 to 9 °/sec (vertical linear accelerations of 0.1 to 1G) produced severe and persistent nausea. Higher frequencies could not be obtained in the aircraft, a two-seater Javelin Mark 8.

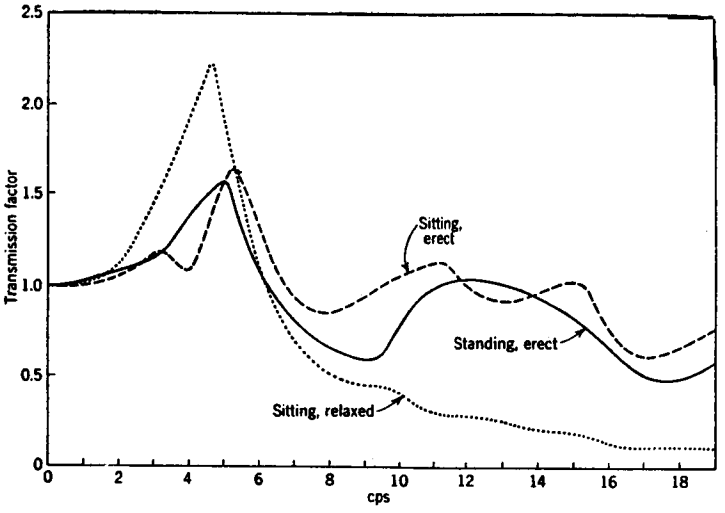
ITEM NO.	SUBJECT AREAS:	SOURCE:
364	SYSTEM - S14 HUMAN - H34, H35	Reference 555, p. 37 Based on Reference 334



Mechanical response of a man's body to vibrations, when seated in different seats.

Damping can be controlled to some degree by appropriate seat design, spring design, cushioning, etc. The figure above illustrates the amplification and attenuation effects of various seats. It can be seen that, in this particular comparison, the suspension seat resulted in substantial attenuation over the critical frequencies of 3 to 6 cps.

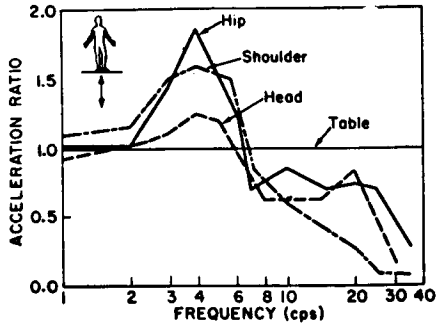
ITEM NO.	SUBJECT AREAS:	SOURCE:
365	SYSTEM - S14 HUMAN - H44	Reference 362, p. 498 Based on Reference 477



The transmission of vibrations from the shake table to the head of one subject with varied postures.

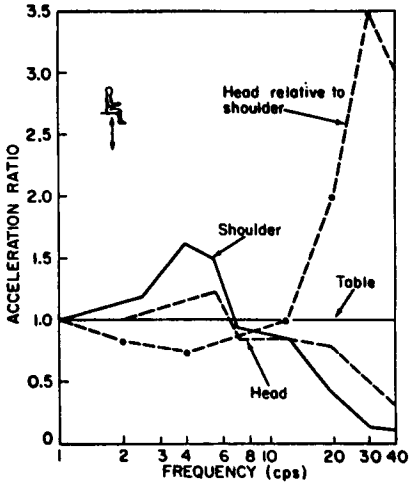
ITEM NO.	SUBJECT AREAS:	SOURCE:
366	SYSTEM- S14 HUMAN- H6, H13	Reference 346, p. 92 Based on Reference 344

a



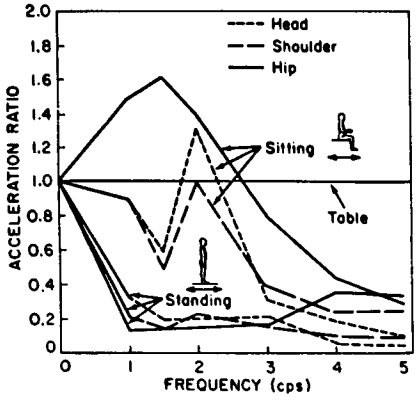
Relative amplitude of vibration of different parts of the body for the standing man.

b



Relative amplitude of vibration of different parts of the body for the sitting man.

c

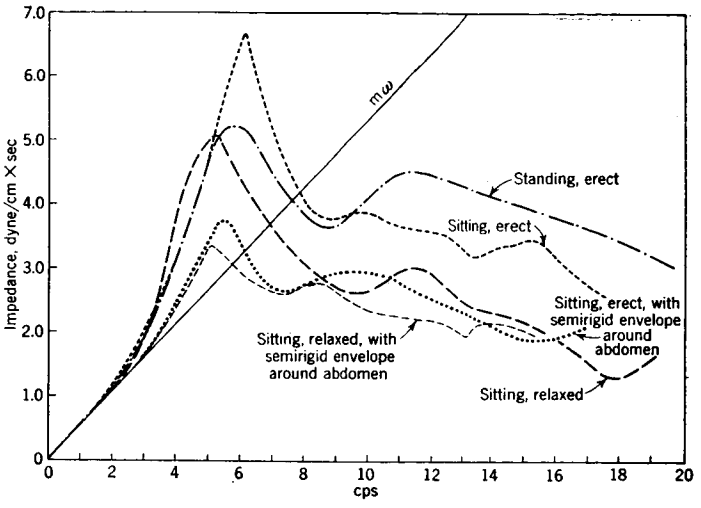


Transverse forces depend importantly for their effect on the distribution of body masses rather than on the line of gravitational force. These effects for the standing and sitting man are presented in figure c.

The measure used for the figures above is the ratio of acceleration of the body member to that of the vibrating table.

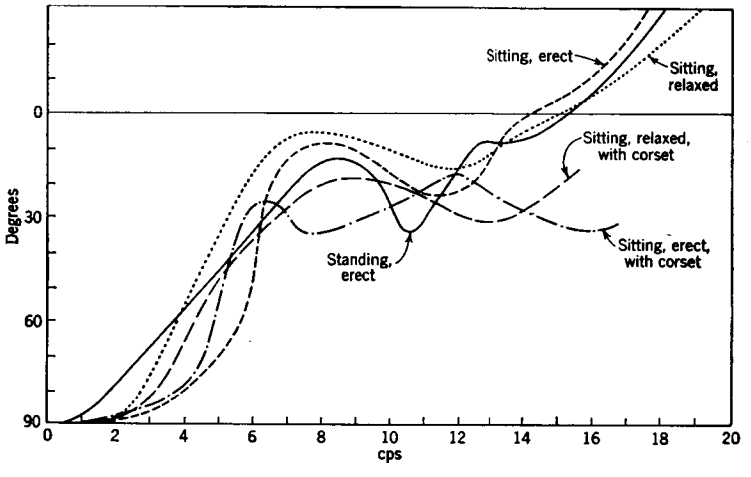
ITEM NO.	SUBJECT AREAS:	SOURCE: Reference 380, pp. 469-470. Based on References 165 (Figs. a and b) and 166 (Fig. c).
367	SYSTEM - S14 HUMAN - H6, H13	

a



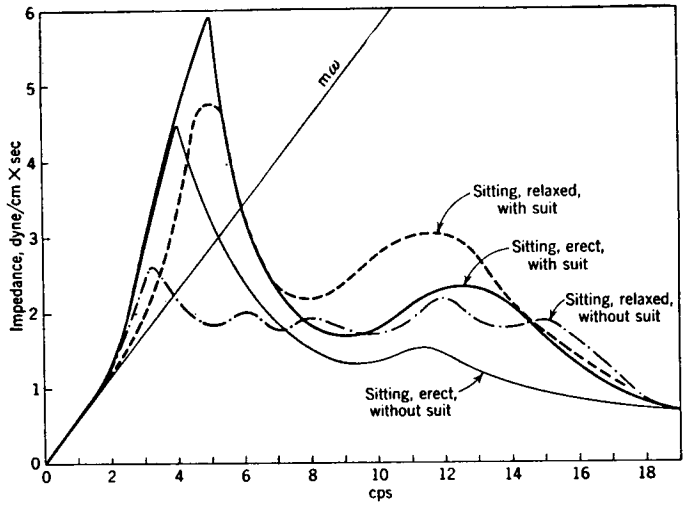
The mechanical impedance of one subject sitting and standing in varied postures and with varied supports.

b



Phase shift of force vs. velocity as measured on one subject in varied postures.

ITEM NO.	SUBJECT AREAS:	SOURCE:
368	SYSTEM - S14 HUMAN - H6, H13, H44	Reference 346, p. 91 Based on Reference 140 (Fig. a) and 344 (Fig. b)

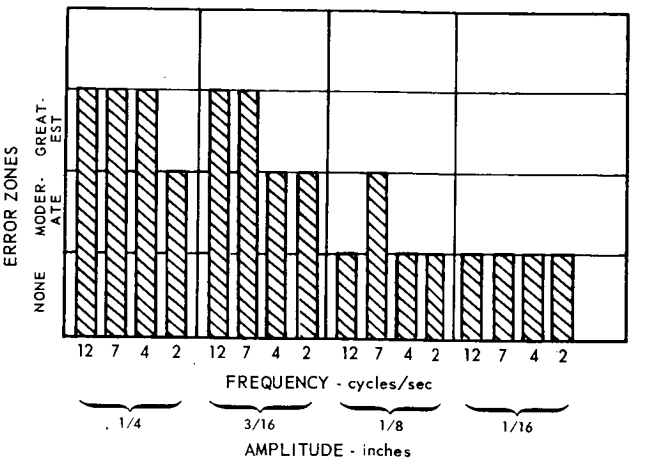


Effect of partial pressure suit on mechanical impedance of one subject with change in posture.

ITEM NO.	SUBJECT AREAS:	SOURCE:
369	SYSTEM- S14 HUMAN- H6, H13, H44	Reference 346, p. 96 Based on Reference 344

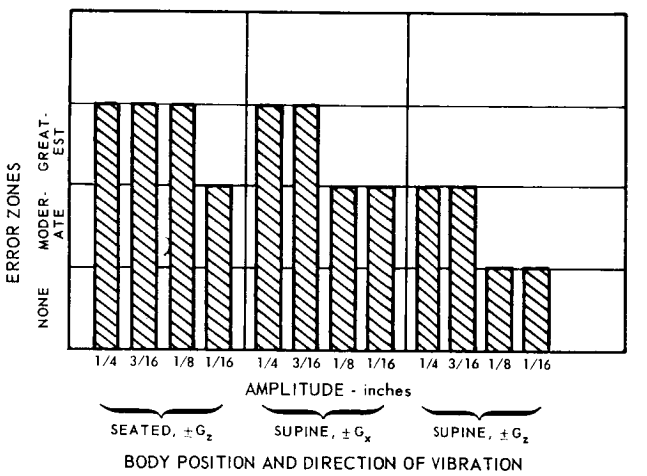
TRACKING PERFORMANCE DURING VIBRATION UNRESTRAINED

a.



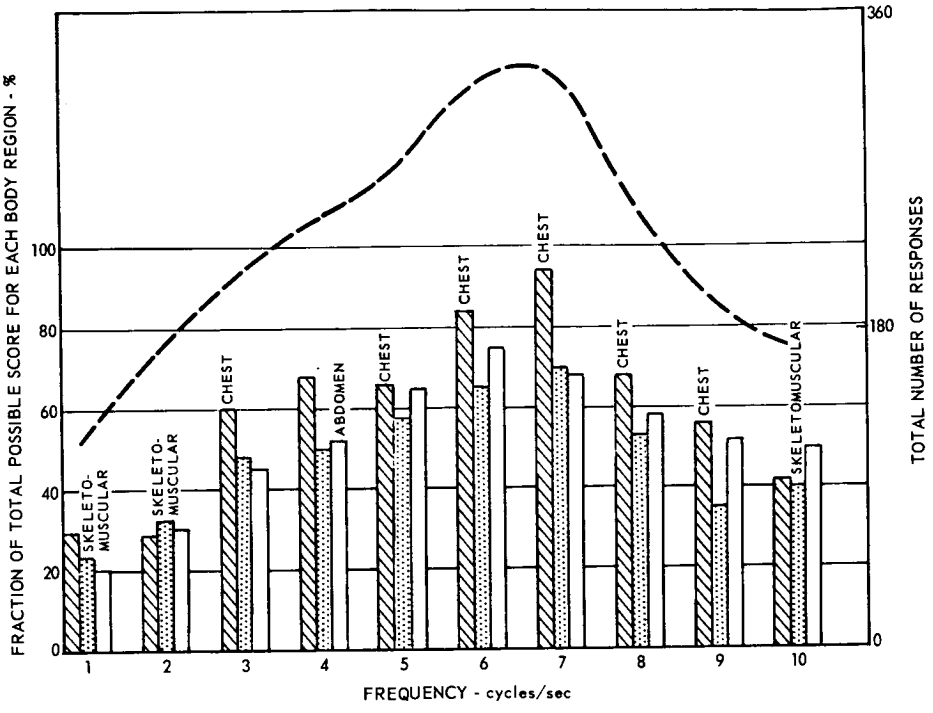
The averaged effects of both amplitude and frequency of sinusoidal vibrations on error in a tracking task are shown for four subjects who were entirely unrestrained. Maximum accelerations were 3.63 G.

b.



The effects of the direction of vibration and of amplitude are shown for the same experimental situation as in a.

ITEM NO.	SUBJECT AREAS:	SOURCE:
370	SYSTEM - S14 HUMAN - H6, H26	Reference 554, p. 81 Based on Reference 202



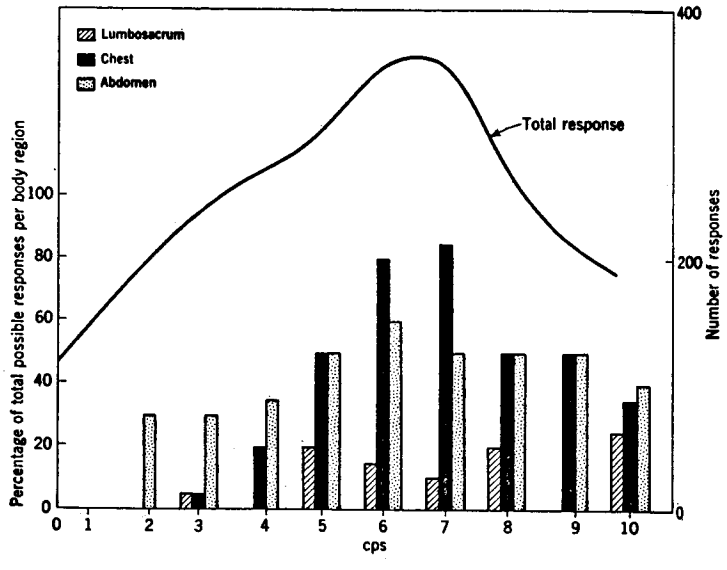
This chart summarizes the subjective responses of ten experienced subjects exposed to vertical sinusoidal vibrations ranging from 35 inches double amplitude at 1 cps to about 1/4" double amplitude at 6-10 cps, which produced accelerations of 1.2 ± 0.6 G. They were seated on a hard surfaced aircraft seat and were restrained by a lap belt and shoulder harness. The total number of subjective responses for each frequency was summed; they reached a peak at 6 and 7 cps, as shown by the upper dashed curve and the right hand vertical scale. The vertical bars show the approximate magnitude of the following groups of symptoms:

Chest (cross-hatched bars) – Respiratory difficulty, pain, and breath holding (Valsalva maneuver).
Skeletomuscular (stippled bars) – Muscle pain, back pain, general discomfort.
Abdomen (open bars) – Contraction, pain.

The words above each set of bars state what symptom set the limit for voluntary tolerance for that particular frequency.

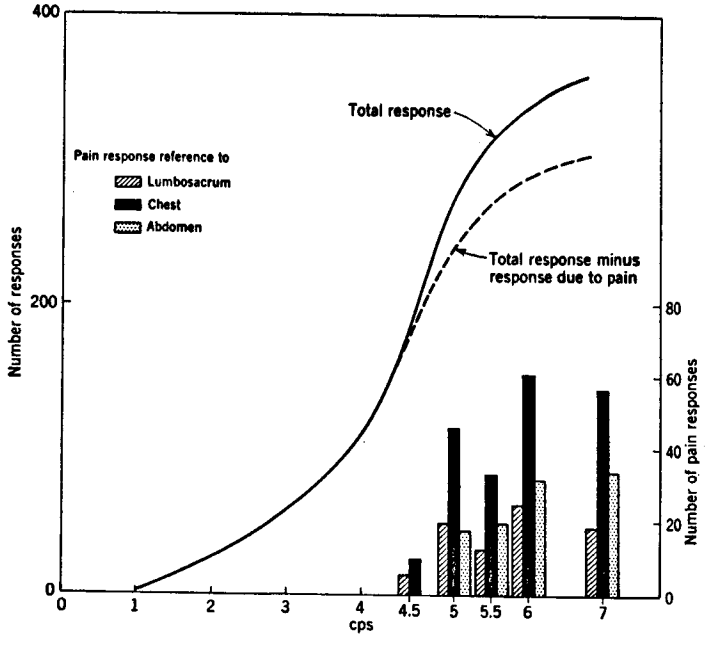
ITEM NO.	SUBJECT AREAS:	SOURCE:
371 a Page 1 of 2	SYSTEM - S14 HUMAN - H13, H16, H34	Reference 554, p. 77 Based on Reference 347

a



Subjective response due to pain, results of 10 subjects

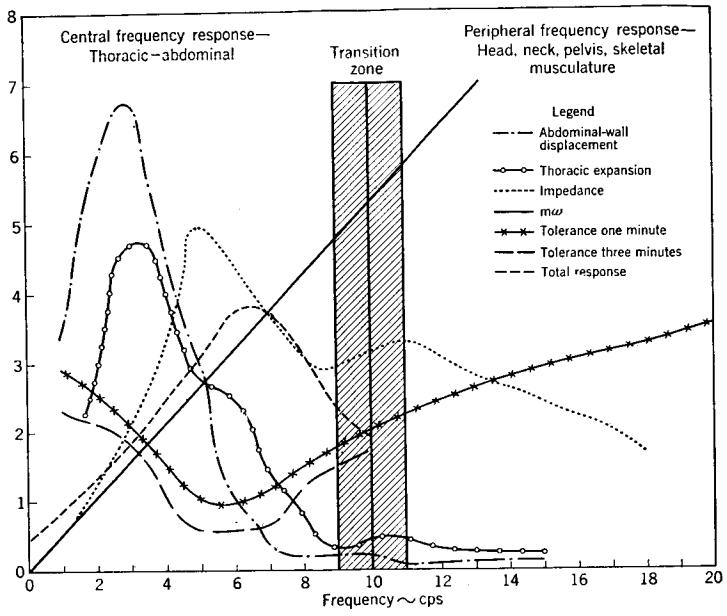
b



Subjective response to whole-body vibrations at constant acceleration of 1/2 g vector during a three minute vibratory period for each frequency.

Except as noted above, experimental conditions were the same as for the previous page.

ITEM NO. 371 b Page 2 of 2	SUBJECT AREAS: SYSTEM - S14 HUMAN - H13, H16, H34	SOURCE: Reference 346, pp. 103-104 Based on Reference 344



Comparison of mechanical and subjective responses to vibration.

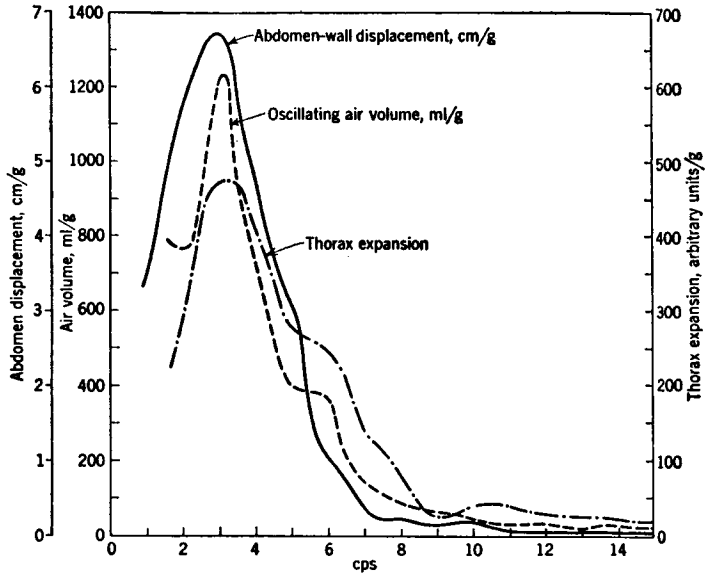
A comparison of mechanical and subjective response is presented above. The greatest total subjective response and the least tolerance to vibrations occur within the frequency range of 1 to 10 cps. In this range, the greatest mechanical response for the thoracic and abdominal compartments correlates with the greatest physiological response of these areas and thus with the greatest subjective responses. The frequencies of greatest thoracocabdominal response to vibration may therefore be referred to as the central frequency range.

The symptoms referable to the head-neck, pelvic-perineal, and skeletal-muscular systems occur primarily in the frequency range of 10 to 20 cps (within the scope of the present studies). Rigid skeletal structures are inherent to each of these systems. Resonances of these structures would be expected to occur within the higher frequency range. Indeed, the symptom spectrum demonstrates that these structures are mechanically excited, perhaps because of resonance above 10 cps. The frequencies having the greatest mechanical and therefore the greatest physiological effect upon these body regions are referred to as the peripheral frequency range.

From HUMAN FACTORS IN TECHNOLOGY edited by Edward Bennett, James Degan and Joseph Spiegel. Copyright 1963 by the McGraw-Hill Book Company, Inc. Used by permission.

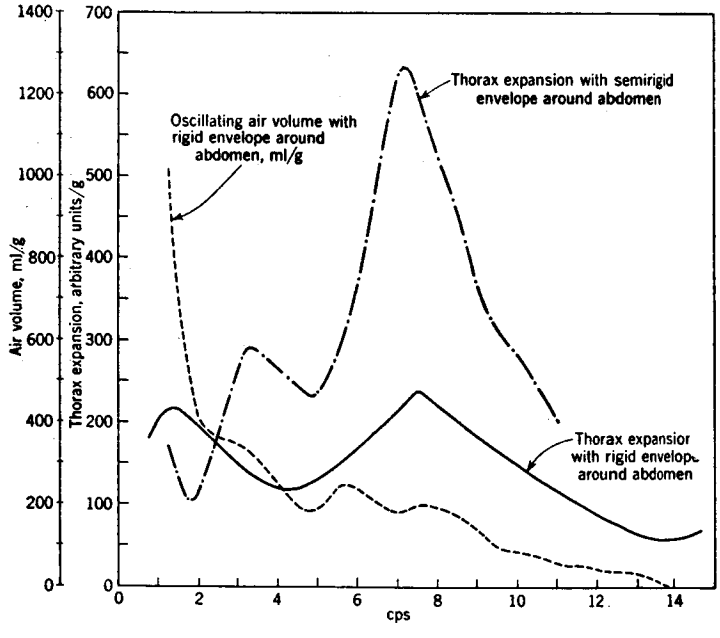
ITEM NO.	SUBJECT AREAS:	SOURCE:
372.	SYSTEM- S14 HUMAN- H13, H34	Reference 346, p. 113

a



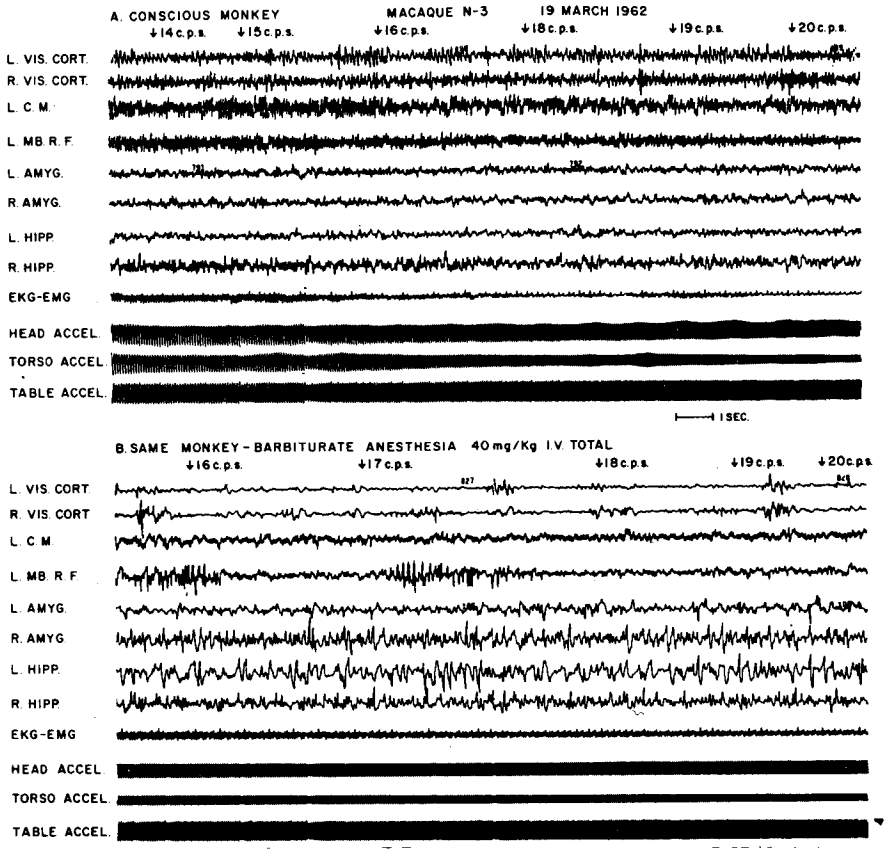
Abdominal-wall displacement, thorax expansion, and oscillatory air volume of a human subject (supine position, shaker horizontally).

b



Thorax expansion and oscillating air volume of a human subject with envelope around abdomen (supine position, shaker horizontally).

ITEM NO.	SUBJECT AREAS:	SOURCE:
373	SYSTEM- S14 HUMAN- H13, H44	Reference 346, pp. 93-94 Based on Reference 140

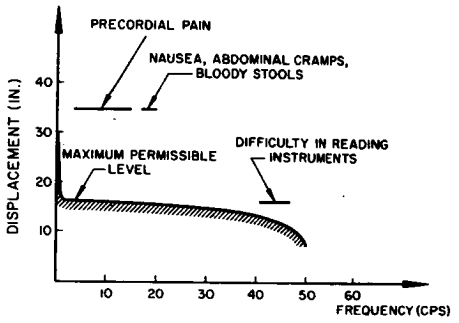


Spectral sweep from 14 to 20 c/sec. Driving of EEG rhythms fell progressively at shaking frequencies higher in conscious animal (A). With 16 c/sec shaking, rhythmic activity in left visual cortex occurred at half the shaking frequency. In the same animal (B) under pentobarbital anesthesia, no appreciable driving was present in cortical or subcortical leads.

NOTE: Abbreviations indicate following channels from above down: left and right visual cortex, right midbrain reticular formation, head accelerometer, right nucleus centrum medianum, left amygdala, right amygdala, left and right hippocampi, electrocar diographitrunk electromyograph lead, and torso accelerometer.

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
374	SYSTEM - S14 HUMAN - H14, H38	Reference 6, p. 416 Based on Reference 5



Low frequency vibration limits on humans in manned vehicles. (After McClain, Shook and Wyatt, 1959)

ITEM NO.	SUBJECT AREAS:	SOURCE:
375	SYSTEM - S14 HUMAN - H25, H34	Reference 219, p. 446

ILLUSIONS ASSOCIATED WITH MOTION

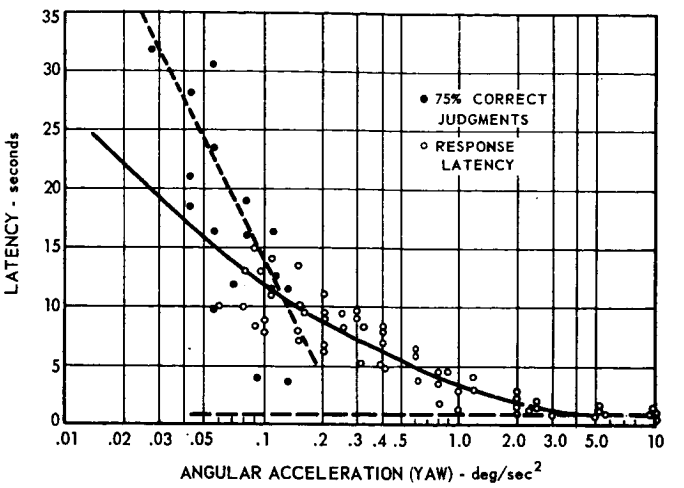
CONDITION OF OBSERVER	CONDITION OF VISUAL STIMULUS OBJECT(S)	NATURE OF ILLUSION
Starts motion	Stationary	Observer sees visual stimulus moving in opposite direction, feels himself stationary
Stationary	Starts motion	Observer sees object stationary, feels self moving in direction opposite to object's motion
Accelerating rotation to 15 rpm; dark room with only target illuminated	Slow revolution around observer's head, in same direction as his acceleration	* Object loses motion, is displaced in direction opposite to its direction of movement
Above rotation continued at 15 rpm	As above	* Observer loses own sensation of motion; object appears to move in opposite direction with greater velocity than before
Strong rotation suddenly stops	Fixed	* At first, object and subjects both seem to rotate. Then observer may feel self fixed while visual stimuli rotate about him in a direction opposite to that of his previous motion. This illusion is called the oculo-gyral illusion. After all apparent motion stops, subject still feels vaguely unpleasant sensations.

* When experiments are conducted in a lighted room the last three illusions do not occur.

ITEM NO.	SUBJECT AREAS:	SOURCE:
376	SYSTEM - S15 HUMAN - H25	Reference 586, p. 6-46.

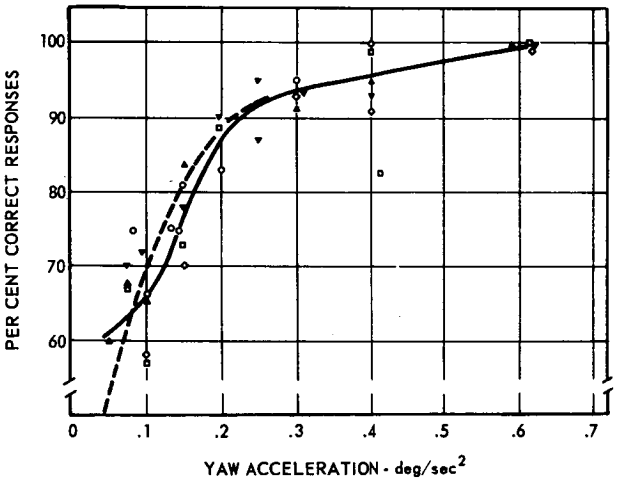
PERCEPTION OF ANGULAR ACCELERATION

a.



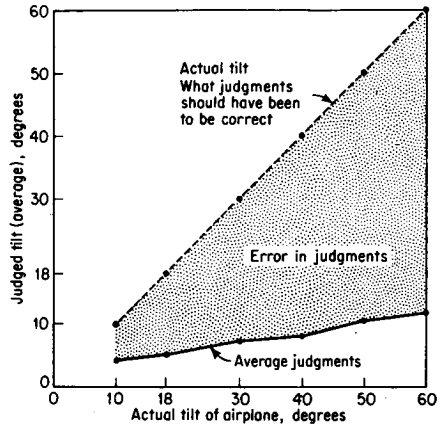
The times required to make judments of the direction of rotation about the yaw axis are plotted as a function of the angular acceleration. The solid points indicate the time required to make judgments that are correct 75% of the time, as determined by Mann and Ray. The open points represent the time required to make judgments, whether the judgments are correct or not, and are redrawn from the data of Clark and Stewart.

b.



The per cent of direction-of-rotation judgments that are correct is plotted as a function of the level of angular acceleration. The 75% point is considered to be the threshold point. Also included are the 75% points from the data of Mann and Ray.

ITEM NO.	SUBJECT AREAS:	SOURCE:
377	SYSTEM - S15 HUMAN - H25	Reference 554, p. 46. Based on References 129 and 349.



Averages of judgments of tilt of blindfolded observers in comparison with actual tilt of airplane.

In a study by MacCorquodale, blindfolded pilots were flown in an airplane that followed predetermined flight patterns; these patterns included six different angles of bank (10, 18, 30, 40, 50, and 60°). The subjects reported their sensations of turning, tilting, and direction and their estimates of acceleration forces.

It was found that pilots made reasonably good judgments of the amount of acceleration. Their judgments of the amount of bank, however, were grossly underestimated and inconsistent. The figure above shows a comparison between the actual and the judged tilt. The tilts of the banks were from 10 to 60°, but the average judgments were only from 4.11 to 11.9°. Some of the 60° banks were not even identified as banks. As mentioned earlier the sensation of the vertical is felt more in relation to the plane than to the earth, because of the influence of acceleration forces, which act on the otolith organs. This feeling apparently is so strong that tilt is grossly underestimated.

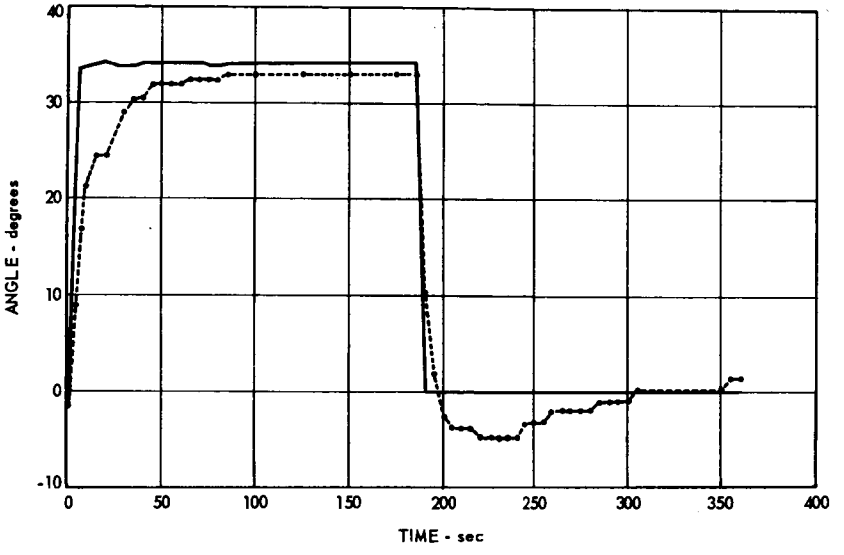
It was also found that the perception of any tilt lagged behind the actual turn by an average of over 9 sec and that the turns were judged to be much shorter in time than they really were. In some cases the recovery from turn was accompanied by an impression of turning in the opposite direction, although the plane had straightened out. Thus, a pilot without any visual landmarks might think of himself as turning to the right (and "correct" by turning a bit to the left) when actually he is on a straight course.

The tendency to underestimate the amount of bank misleads the pilot into "perceiving" the plane as being oriented more vertically than it really is in such situations. In this connection, in case there is no external visual frame of reference (because of fog, darkness, clouds, etc.), the pilot also tends to perceive the ceiling of the plane as being vertical.

From HUMAN FACTORS ENGINEERING by Ernest J. McCormick. Copyright 1957, 1964 by McGraw-Hill, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
378.	SYSTEM - S15 HUMAN - H25	Reference 362, p. 563. Based on Reference 339.

PERCEPTION OF THE VERTICAL

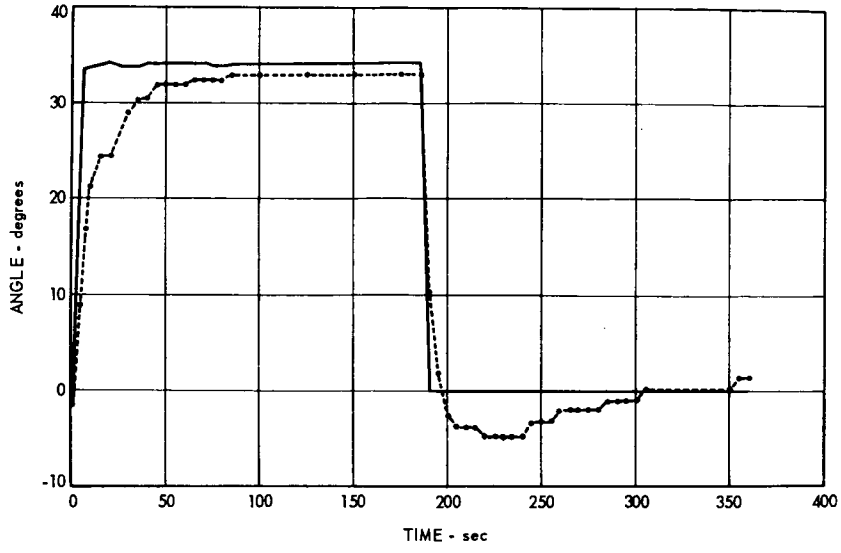


When a subject is tilted from vertical through an angle relative to gravity, the vertical semi-circular canals are stimulated, and he immediately perceives the misalignment between his axis and gravity.

If an equal misalignment is achieved without stimulation of the vertical canals by creating a centrifugal acceleration, during which the only angular acceleration is in a horizontal plane, then the perceived tilt follows a slower time course. In the figure above, the solid line shows that the centrifuge reached constant angular velocity within 6 seconds, yet the subject's perception of tilt, as indicated by a manual alignment of a line of light with the apparent horizontal, required over 40 seconds to reach 95% of final value.

ITEM NO.	SUBJECT AREAS:	SOURCE:
379.	SYSTEM- S15 HUMAN- H25	Reference 554, p. 372. Based on Reference 236.

PERCEPTION OF THE VERTICAL



When a subject is rotating at a constant angular velocity (figure a), a tilt of his head in a direction which changes the radius vector to the center of rotation will cause him to experience a sensation of tilt in a plane perpendicular to that of the original tilt. The sensation is due to movement of fluid in the canals caused by purely mechanical forces.

If an enlarged model of one of the canals, consisting of a liquid-filled transparent torus (figure b), is moved through an arc as shown, circulation of the liquid will be observed. The necessary conditions for circulation are that the torus must be rotating and that the radius of its center from the axis of rotation must be changing.

The liquid is circulated by the resultant of Coriolis accelerations $2(\Omega X \dot{r})$ due to the individual velocity $\dot{r}$ of each element of the fluid. If the torus translates only, so that r is constant, then the resultant will be zero. Similarly if it rotates only, so that the radius of its center is constant, accelerations in the half of the torus moving away from the axis will be equal and opposite to those in the half moving toward the axis.

When the subject is seated at the axis of rotation, tilt of his head in any direction will fulfill the conditions for Coriolis circulation in at least two of the canals. The magnitude of the response is a function of the rate of head tilt (ω), the total angle of tilt, and of the speed of rotation (Ω).

Figure c shows the control stick movement by the subject used to indicate apparent angular displacement of a target light following head tilt. Average values of the peak stick displacement were a function of angular velocity. Each point is the average of 8 runs on 6 subjects (total of 48 runs) during which the subject tilted his head 30° to the right in 0.5 sec while being rotated clockwise. After the illusion had decayed, he returned his head to the upright position producing an illusion in the opposite direction.

ITEM NO.	SUBJECT AREAS:	SOURCE:
380	SYSTEM - S15 HUMAN - H25	Reference 554, p. 371. Based on Reference 244.

Effect of Tumbling Rate on Humans

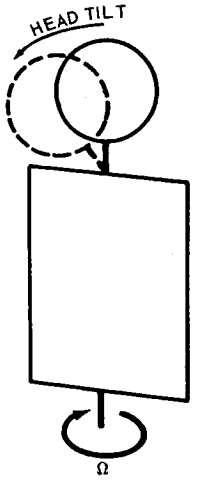
Axis	Spin Rate (rpm)	Time To Vertigo (sec)	Deceleration Vertigo (sec)	Results
Heart	60	None to 300-350	8-14	
	80	100	9-15	Eye hem. 120-150 sec
	90			Eye hem. 60-70 sec Feet numb
	100	60	9-17	Eye hem. 10-15 sec 4-5 Neg. G at forehead
	120	Very few		6-9 Neg. G at forehead
	125	Very few		
	140	3-10		Predicted 9-10 Neg. G at forehead
	160	3-10		
Hips	50	120-150		Eye hem. 120 sec
	60	60-70		
	70	10-15		Head pressure, uncomfortable
	80	4-5		
	85-90	3		Head pressure, near intolerable

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963.
Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

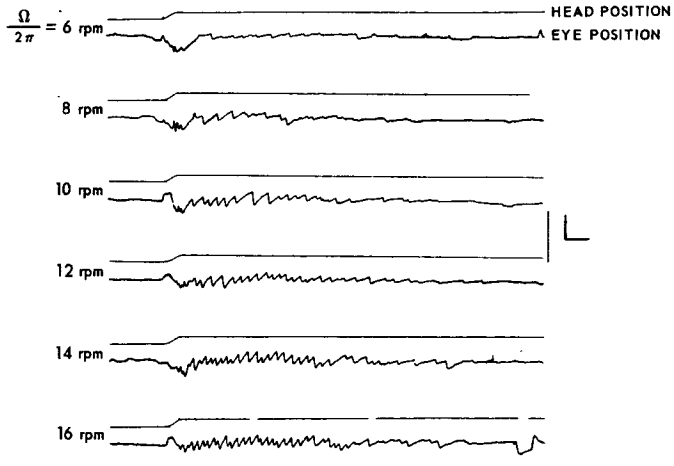
ITEM NO.	SUBJECT AREAS:	SOURCE:
381	SYSTEM - S15 HUMAN - H34	Reference 219, p. 408.

MOTION SICKNESS FROM HEAD TILT

a.



b.

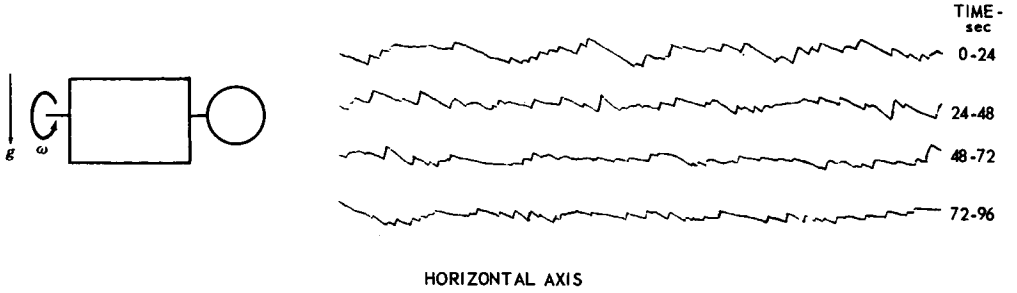


While the body is rotating at constant angular velocity, tilting the head to one side produces a sensation of pitching forward, if the head tilt is to the left during clockwise rotation. This sensation is accompanied by corresponding vertical movements of the eyeballs (nystagmus). For a given head movement (75° to the right in one second), the intensity and duration of effect, exemplified by the nystagmus records in Figure b, is a function of the angular velocity of the platform. The calibration marker shows 1 second and 40° vertical eye movement.

ITEM NO.	SUBJECT AREAS:	SOURCE:
382	SYSTEM - S15 HUMAN - H34	Reference 554, p. 374. Based on Reference 244.

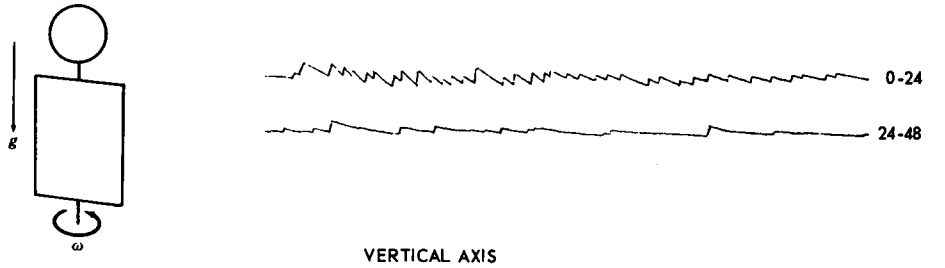
MOTION SICKNESS FROM ROTATION

a.



HORIZONTAL AXIS

b.



VERTICAL AXIS

Rotation at constant velocity about a horizontal axis, with gravitational acceleration perpendicular to the axis of rotation, produces a nystagmus response sustained long after the sensory response of the semicircular canals has decayed. The continual reorientation of the otoliths relative to gravity may be the reason for the sustained nystagmus.

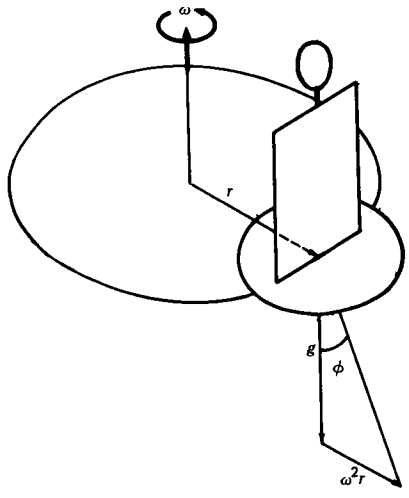
Evidence for that inference comes from the companion case of rotation about a vertical axis. Strong nystagmus begins with the acceleration to constant angular velocity, and then decays along the theoretical time course of semicircular canal response.

Rotation about a vertical axis is not a potent cause of motion sickness so long as the subject's eyes are closed. Prolonged rotation about a horizontal axis carries with it the self-contradictory vestibular input which can cause motion sickness independent of the visual input.

ITEM NO.	SUBJECT AREAS:	SOURCE:
383	SYSTEM - S15 HUMAN - H34	Reference 554, p. 375. Based on Reference 241.

MOTION SICKNESS FROM COUNTER-ROTATION

a.



b.

SYMPTOMATOLOGY OF MOTION SICKNESS IN NORMAL SUBJECTS, SEQUENTIAL EXPERIMENTS IN COUNTER ROTATING ROOM

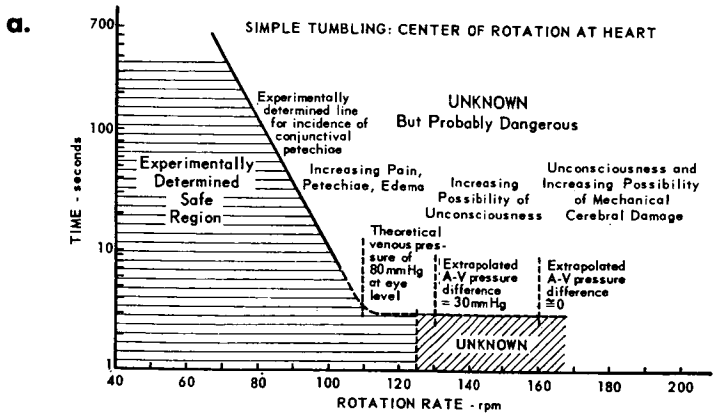
EXPERIMENTAL CONDITIONS		I 20 RPM 2 min ϕ 15° 15' Head fixed Eyes closed	II 12 RPM 2 min ϕ 5° 36' Head fixed Fixate Vertical Line	III 30 RPM 10 min. ϕ 31° 31' Head fixed Eyes closed	IV 30 RPM 10 min ϕ 31° 31' Head fixed Eyes open	V 10-30 RPM 10 min ϕ 3 °54'-31° 31' Head moving Eyes open
"MOTION-SICK" SUBJECTS	JO	NONE	NONE	DISCOMFORT S-A† I PALLOR II SWEAT II	VOMITED PALLOR III SWEAT III DISORIENT. II DISCONT. 7 min.	NAUSEA III PALLOR III SWEAT II DISCONT 4 min
	MO	DISCOMFORT I S-A I PALLOR I	NAUSEA I INC. SALIVA I PALLOR I SWEAT I	DISORIENT * S-A	NAUSEA III DESIRE 8 M PALLOR III SWEAT III	
	GR	NAUSEA I SWEAT I	NONE	NAUSEA I PALLOR II SWEAT I DISCONT 2 min	NAUSEA II PALLOR II SWEAT II DISCONT 2 min.	NAUSEA II PALLOR II SWEAT II DISCONT 2 min
REGULAR SUBJECTS	BA	S-A	NONE	S-A	S-A	
	FO	NONE	NONE	NONE	NONE	
	GI	NONE	NONE	NONE	NONE	
	KR	DIZZY I SWEAT II	SWEAT II	SWEAT II	DISCOMFORT I DIZZY I SWEAT I	
	ME	NONE	NONE	NONE	NAUSEA III PALLOR II SWEAT I	
	NI	NONE	NONE	NONE	NONE	
	MU	NONE	NONE	NONE	NONE	
	TO	PALLOR I	NONE	NONE	NONE	
	WO	NONE	NONE	NONE	NONE	

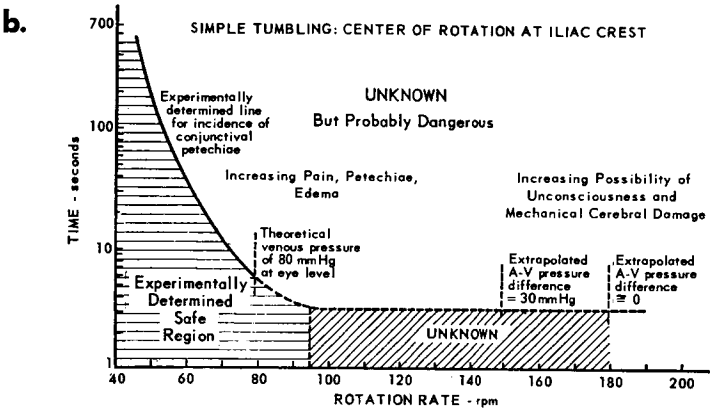
†STOMACH AWARENESS * BEFORE ROTATION BEGAN

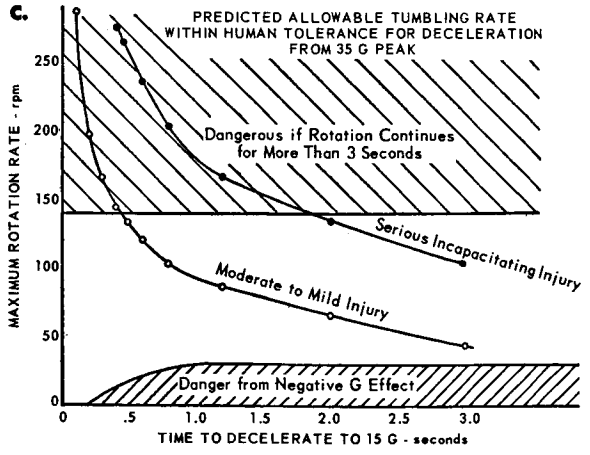
In the apparatus used, the platform carrying the subject rotated counter to the main centrifuge at a radius (r) of 2 feet, so that the subject faced the same direction throughout each revolution. For this reason, the direction centrifugal acceleration ($\omega^2 r$) varied relative to his body. Since the subject had no net angular velocity, the semicircular canals received no stimulus. Subjects selected for motion sickness susceptibility reacted to all levels of the contradictory stimuli. The group of unselected normal subjects included one who reacted with nausea to strong stimulation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
384	SYSTEM - S15 HUMAN - H34	Reference 554, p. 376. Based on Reference 237.

TOLERANCE TO TUMBLING







These three charts show theoretical limits for human tolerance to tumbling, based on animal work and limited human experience.

Figures a and b describe safe and unsafe regions and damages likely to be incurred in simple tumbling about two axes of the body. Figure c estimates tumbling tolerances for the specific case of tumbling combined with deceleration from 35 to 15 G.

ITEM NO.	SUBJECT AREAS:	SOURCE:
385	SYSTEM - S15 HUMAN - H34	Reference 554, p. 83. Based on Reference 180.

COMPARISON BETWEEN THREE GROUPS OF NAVY FLYERS IN RESPONSE TO STANDARD SCREENING TEST IN SLOW ROTATION ROOM

	Incoming Flight Students	Aviators in Proficiency Billets	Graduates Test Pilot School
No. Subjects	100	40	22
Mean Age	22.3	29.6	32.7
Failure (Group) to Complete [1]	37.6	21.8	2.8
% of Sick	67	30	5
% Vomiting	10	0	0

[1] In % prescribed exposure to stress.

The findings in this table summarize the results in three selected groups of U.S. Navy flyers when exposed to a standardized screening test in the SRR. The principal task was to set a series of five dials, requiring different head motions, while the SRR was rotating at 7.5 RPM. The test was ended either on the subject's request or when 20 such sequences had been completed. Inasmuch as few flight students are dropped because of airsickness, the better performance of the flyers in proficiency billets must represent adaptation. The still better performance of the test pilots represents either further adaptation or a natural selection process. At all events, the differences in the three groups were readily brought out in the SRR.

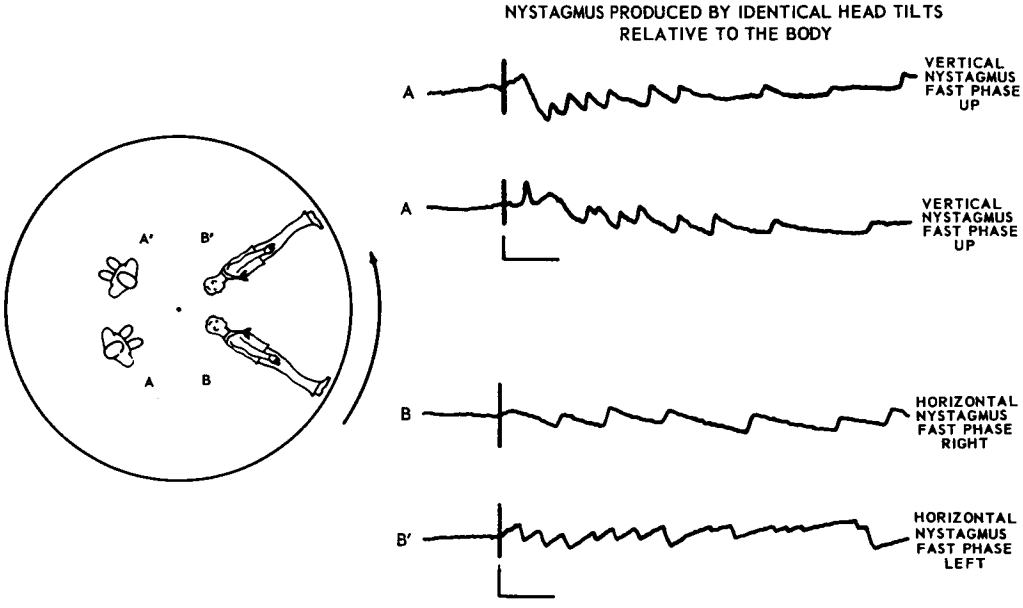
From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
386-	SYSTEM - S15 HUMAN - H4, H34, H41	Reference 234, p. 337. Based on Reference 299.

ROTATION EFFECTS ON SPACE VEHICLE DESIGN

Maximum angular velocity was set at 4 rpm on the basis of the results of rotating room experiments, which can be summarized as follows. At 3 rpm, selection of the crew need be no more stringent than to exclude persons who are unusually susceptible to motion sickness. At 5.4 rpm, crew selection would become more important. At 10 rpm, careful selection and pre-adaptation of crew members would be essential, although adaptation might not be complete.

Transfer effects, which become evident upon leaving the rotating station and are due to a pattern of conditioned reactions, are manageable at 3 rpm, and become increasingly serious at 5.4 and 10 rpm. Habituation conditioning and a readjustment period in a counter rotating chair at the center of the space station are techniques which may reduce transfer effects on sensory-motor coordination.



Conditions in the rotating room experiments differed from those at the rim of a rotating space station in two important ways, namely 1) that the body was oriented axially rather than radially, and 2) that gravity was present.

Axial orientation is the easier condition for habituation, since head tilt and illusion of pitching are consistently related (A, A' above). In contrast, when a radially oriented subject tilts his head, the direction taken by the illusion of pitching depends upon the direction he is facing at the time. If he is oriented with his feet toward the rim and facing the direction of rotation, the illusion and nystagmus following a head tilt to the left (B) will be opposite to that when he is facing the opposite direction (B').

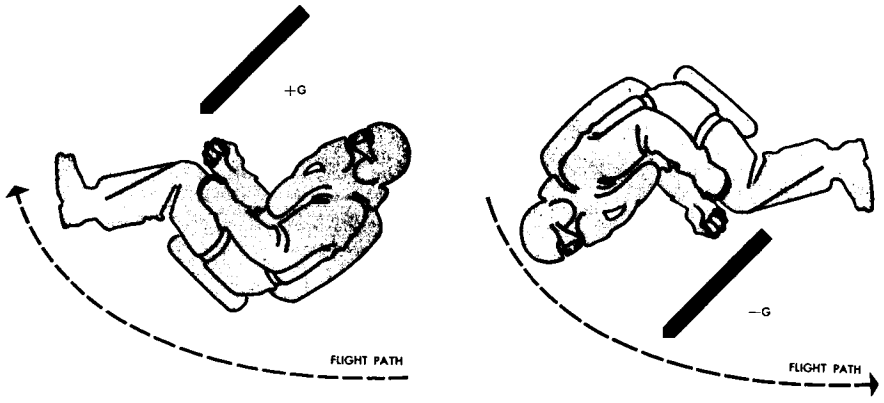
This inconsistency may be less confusing on earth, where the direction of gravity is a cue to the direction in which the illusion will occur. In a space station, providing a visual cue, such as wall colors or lighting, might resolve the ambiguity and speed habituation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
387	SYSTEM - S15 HUMAN - H25, H33	Reference 554, p. 379. Based on Reference 242.

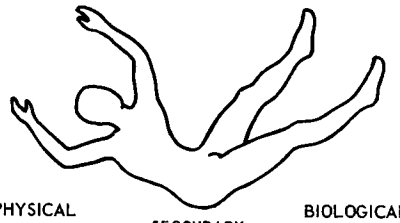
EFFECTS OF ANGULAR CHANGES IN VELOCITY

G	
+3	vision begins to dim.
+4	visual perimeter narrows and movement is slightly limited.
+5	visual blackout occurs, with almost complete loss of body control.
—2	throbbing of the temples and severe head pains occur.
—3	visual red-out and mental confusion develop.
—4	Possible retinal bleeding and cerebral hemorrhage may occur, with loss of vision and complete mental confusion.

NOTE: Above figures apply to prolonged exposures. Brief exposures of 30-40 g's have been withstood.



ITEM NO.	SUBJECT AREAS:	SOURCE:
388	SYSTEM - S15 HUMAN - H25, H34	Reference 585, p. 180.



PHYSICAL

DURATION OF IMPACT
MAGNITUDE OF FORCE
(Protective clothing - distance
Velocity - air drag)
IMPACTED MATERIAL
(Deformation characteristics
and contour)
DIRECTION OF FORCE
(Orientation of body)
DISTRIBUTION OF FORCE

SECONDARY IMPACTS

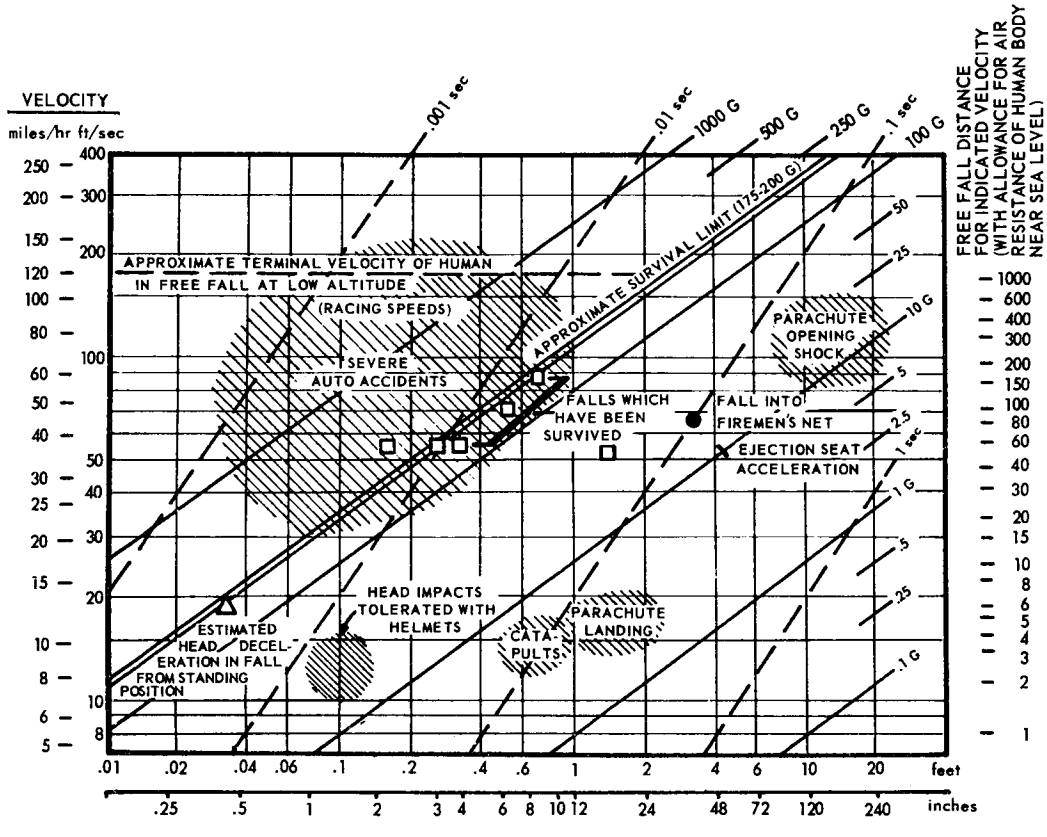
BIOLOGICAL

AGE
SEX
PHYSICAL CONDITION
MENTAL CONDITION
TISSUE PROPERTIES

The biophysical factors which influence the degree of injury in free falls are listed in this diagram.

ITEM NO.	SUBJECT AREAS:	SOURCE:
389	SYSTEM - S16 HUMAN - H34	Reference 554, p. 64. Based on Reference 507.

IMPACT EXPERIENCE



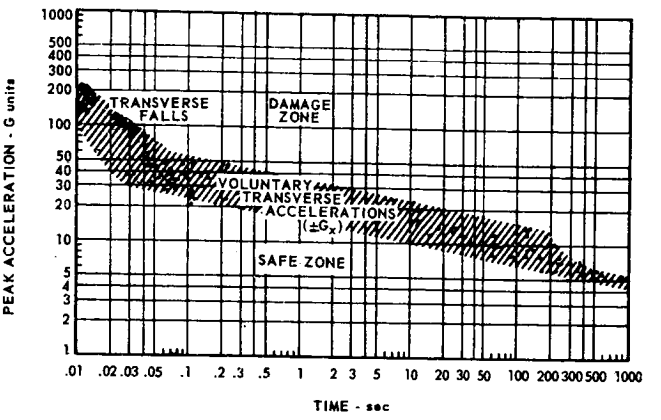
DECELERATION - DISTANCE

This chart brings together a variety of impact and deceleration experiences by plotting the data from a number of sources on the common axes of deceleration distance and velocity. Stopping time and impact force in G units are shown as secondary scales. The data points with hollow squares are for free falls of 50-150 ft with survival. There are many other cases of more extreme and less extreme impacts with survival, for free falls from 5 to 275 ft (Snyder), but deceleration distance is not always available. The line labeled "approximate survival limit" must be used with caution, since many biophysical factors influence the injury due to deceleration.

ITEM NO.	SUBJECT AREAS:	SOURCE:
-390	SYSTEM - S16 HUMAN - H34	Reference 554, p. 67. Based on References 507 and 445.

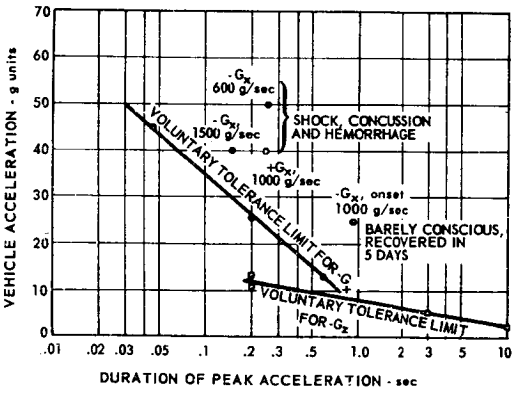
PEAK ACCELERATIONS

a.



This shows peak transverse accelerations which have been survived without permanent injury in a variety of situations, including data from falls (below 0.03 sec), short track impact facilities (0.03 to 0.1 sec), high speed sled runs (0.1 to 1.0 sec), and centrifuge studies (2-1000 sec). Peak accelerations lying below the band of data would be assumed to be non-injurious, while those above the plotted data would be presumed to produce severe injury or death.

b.

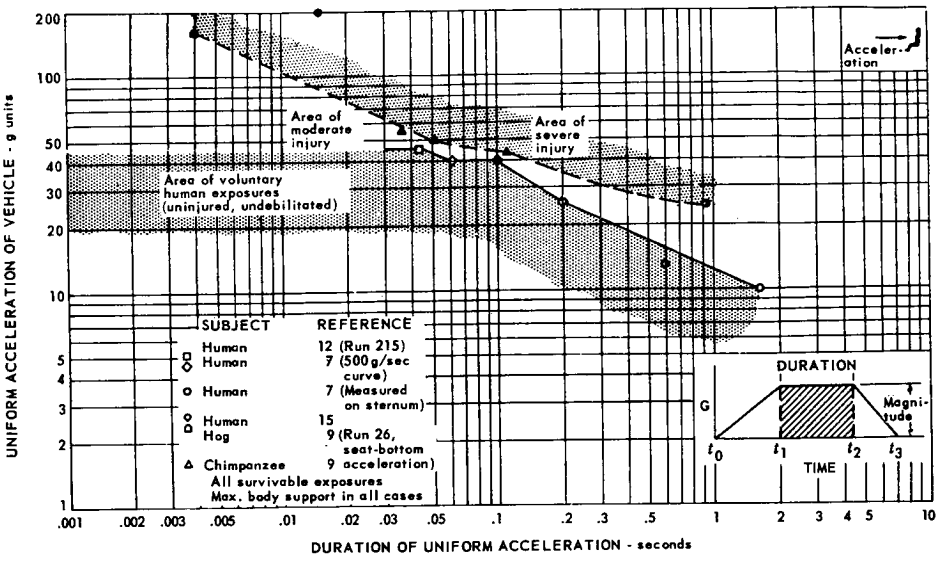


The two lines connect data points for the highest peak accelerations – transverse, $-G_X$ and negative, $-G_Z$ – which carefully restrained subjects have voluntarily endured without injury on high speed rocket sleds which are decelerated to give the vehicle accelerations and times shown. The four points above the lines show accelerations which produced reversible but none-the-less serious injury in transverse acceleration ($\pm G_X$); these points were established by J. P. Stapp on rocket sled runs.

ITEM NO.	SUBJECT AREAS:	SOURCE:
391-	SYSTEM- S16 HUMAN- H34	Reference 554, p. 69. Based on References 80 (fig. a) and 519 (fig. b).

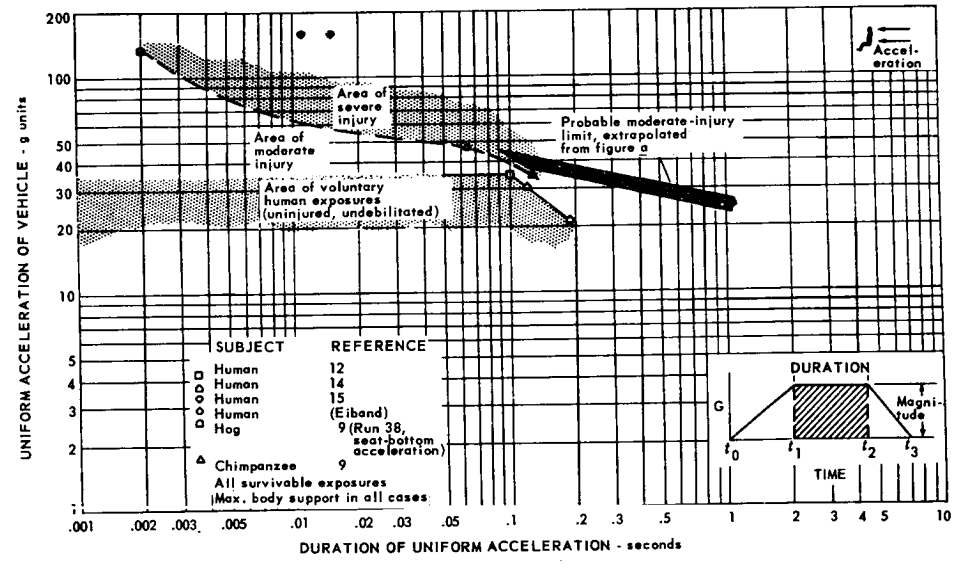
ABRUPT TRANSVERSE DECELERATIONS

a.



These two graphs show the durations and magnitudes of abrupt transverse decelerations which have been endured by various animals and man, showing areas of: voluntary endurance without injury; moderate injury; and severe injury. Graph a summarizes $-G_x$ data (back to chest acceleration) and b shows $+G_x$ data (chest to back acceleration). Reference numbers on the graphs are those in the original reports.

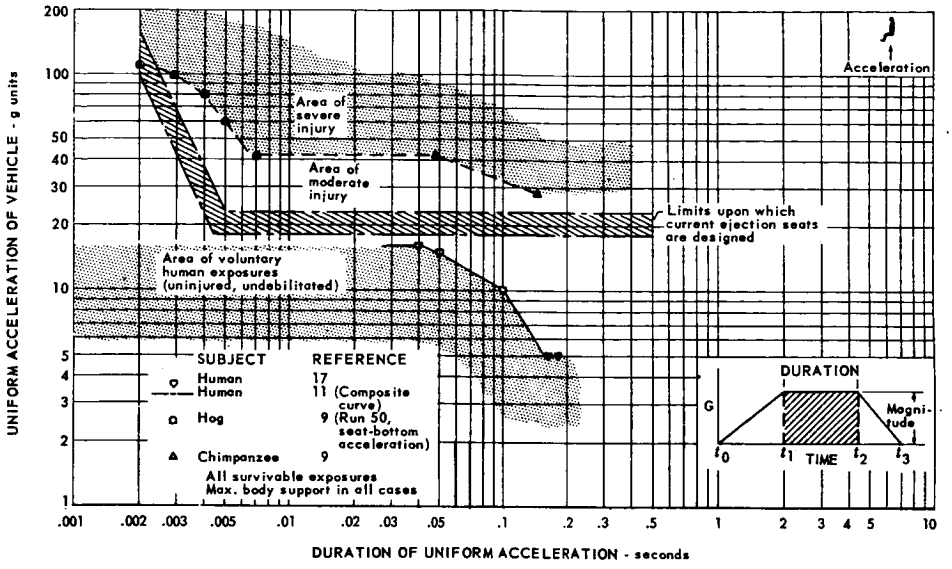
b.



ITEM NO.	SUBJECT AREAS:	SOURCE:
392	SYSTEM-S16 HUMAN- H34	Reference 554, p. 70. Based on Reference 181.

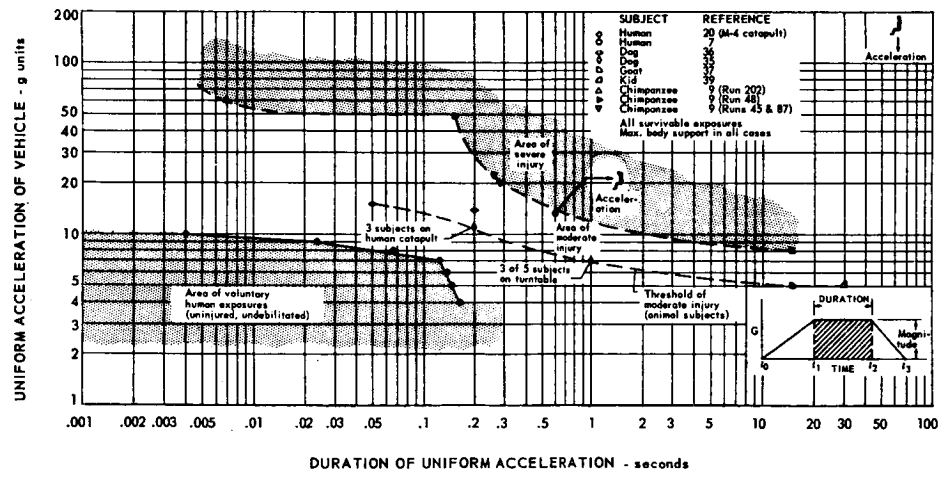
ABRUPT LONGITUDINAL DECELERATIONS

a.



These two graphs show the durations and magnitudes of abrupt deceleration in the G_z (longitudinal) directions which have been endured by various animals and man, showing areas of voluntary endurance without injury, moderate injury, and severe injury marked by shading. Graph a shows data of $+G_z$ acceleration (headward), and b shows data for $-G_z$ acceleration (tailward). Reference numbers on the graphs are those in the original reports.

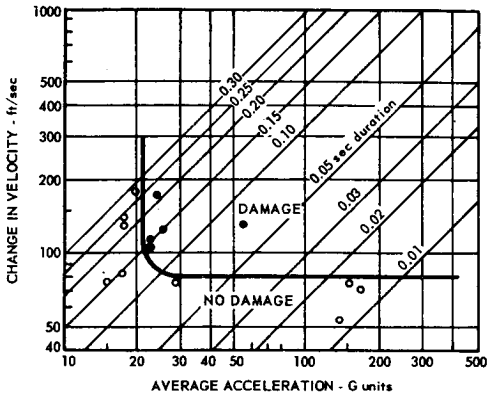
b.



ITEM NO.	SUBJECT AREAS:	SOURCE:
393	SYSTEM - S16 HUMAN - H34	Reference 554, p. 71. Based on Reference 181.

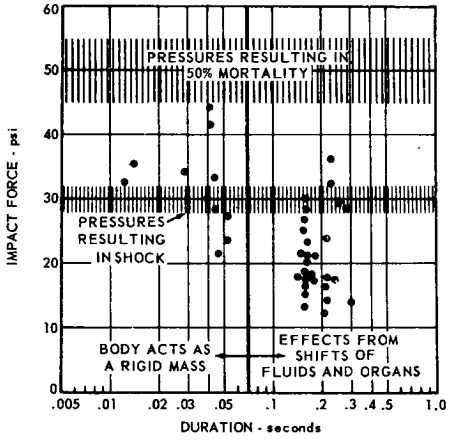
IMPACT SENSITIVITY DIAGRAMS

a.



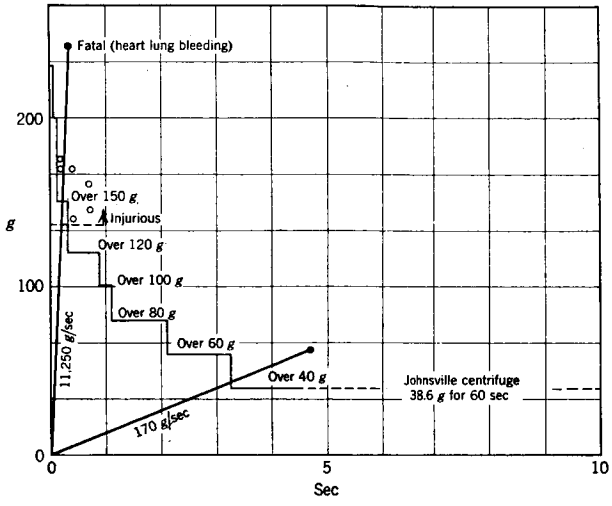
This is a curve calculated to define the dividing line between mild injury (no damage) and severe injury such as shock and retinal hemorrhage in humans, in terms of velocity change and average acceleration force. The data points shown are from human experiments in several laboratories. Animal data (not shown) support the shape and approximate location of the curve.

b.



This is another way of defining impact sensitivity, in terms of impact force per unit area and duration. For the shorter times on the left half of the chart, the body is thought to act as a rigid mass; for the longer times to the right, effects are caused by shifts in body fluids and tissues. The data points are taken from human experiments in drop towers, falls, and rocket sleds, with various restraint devices. The two shaded areas define approximate areas of effect in terms of impact pressure for any duration. Body position affects these results.

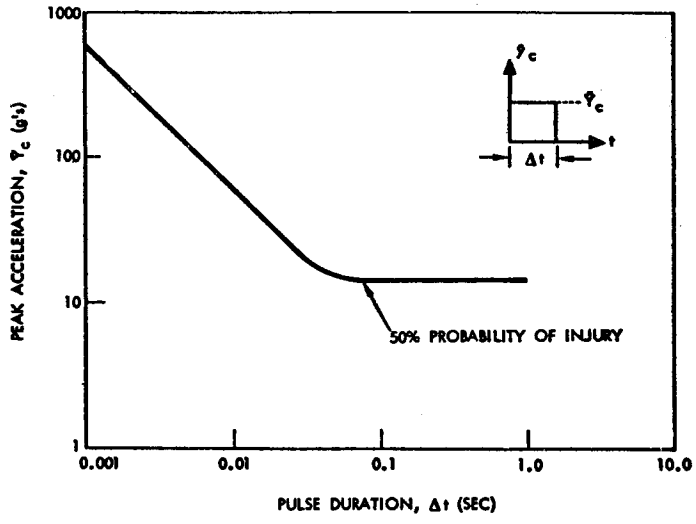
ITEM NO.	SUBJECT AREAS:	SOURCE:
394	SYSTEM - S16 HUMAN - H34	Reference 554, p. 75. Based on References 311 (fig. a) and 80 (fig. b).



Rate of change and duration and magnitude of deceleration. The figures are for a chimpanzee seated forward and facing maximum restraint, and were obtained from thirty-two experiments.

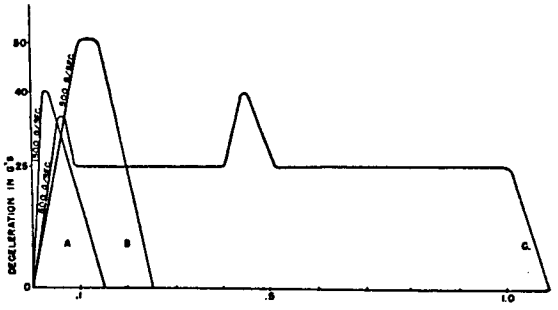
Stapp has investigated the chimpanzee and human tolerance to these abrupt linear forces by using the rocket-powered rail-mounted sled, which can be accelerated to sonic velocities in 5 sec and decelerated to a standstill within 0.4 sec by water inertia. The figure above indicates that injuries and death result from pulmonary and cardiovascular trauma. Stapp concludes that decelerations of less than 40 g at a rate of onset lower than 600 g per sec, with total exposure of less than 0.2 sec, can be readily tolerated, if there are protective restraints.

ITEM NO.	SUBJECT AREAS:	SOURCE:
395	SYSTEM- S16 HUMAN- H34	Reference 101, p. 76. Based on References 491 and 490.



Tolerance to +Gz Impact Acceleration
(Rectangular Pulse)

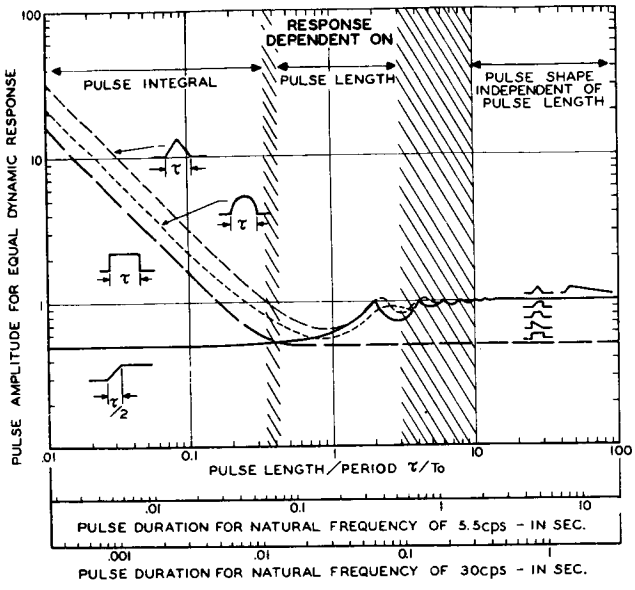
ITEM NO.	SUBJECT AREAS:	SOURCE:
396	SYSTEM - S16 HUMAN - H34	Reference 378, p. 8. Based on Reference 408.



Human tolerance to linear deceleration limit for reversible incapacitation to: (A) rate of onset, (B) magnitude, (C) duration of decelerative force in the forward-facing seated position.

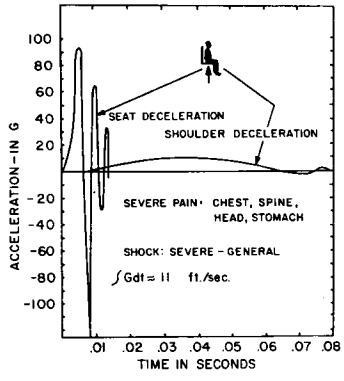
ITEM NO.	SUBJECT AREAS:	SOURCE:
397	SYSTEM-S16 HUMAN- H34	Reference 490.

a



Theoretical impact tolerance curves of a one-degree-freedom system. The curves show for various types of pulses the pulse height (as a function of the ratio pulse length to natural period of the system) which is necessary to achieve the same maximum displacement of the system. (T=natural period of the system, τ = pulse duration.) The additional pulse duration scales on the abscissa are for a system having its resonance at 5.5 cps (main body resonance) and for a system with its resonance at 30 cps (head resonance).

b

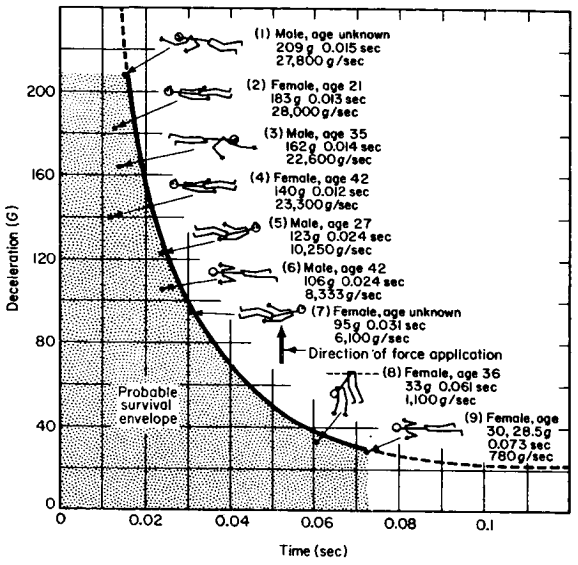


Response of a subject seated in a rigid chair to short-duration vertical impact. Since the pulse is short compared to the natural period of the body, the impulse of the impact ($\int$Gdt) is the significant input to the body system. The body (shoulder accelerometer) responds with its natural period and with a low acceleration peak compared to the high input acceleration. The impulse of both functions is approximately the same, 11 ft./sec.

From the dynamic response factor for the transient response of linear structures to shock excitation follows a pattern as illustrated in figure a, which shows curves of equal physical displacement of organs (tolerance curve) as a function of maximum acceleration and pulse duration. It is important to note that if the pulse duration is much shorter than the natural period of a system, the response is only dependent on the acceleration-time integral, i.e., "impulse;" which is equal to the difference in velocity of the system before and after impact. The response ceases to be a direct function of the peak acceleration. This has been demonstrated by Swearingen et al., as shown in figure b.

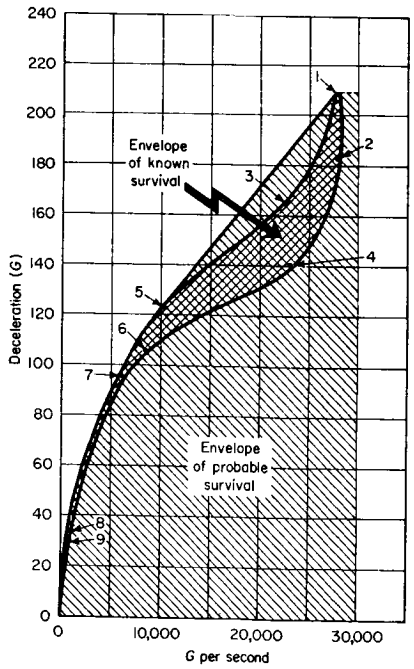
ITEM NO.	SUBJECT AREAS:	SOURCE:
398	SYSTEM- S16 HUMAN- H34	Reference 548, p. 46. Based on Reference 506 (fig. b).

a



Magnitude, duration and rate of onset of mean decelerations sustained by nine survivors of free falls from heights of 55 to 185 feet.

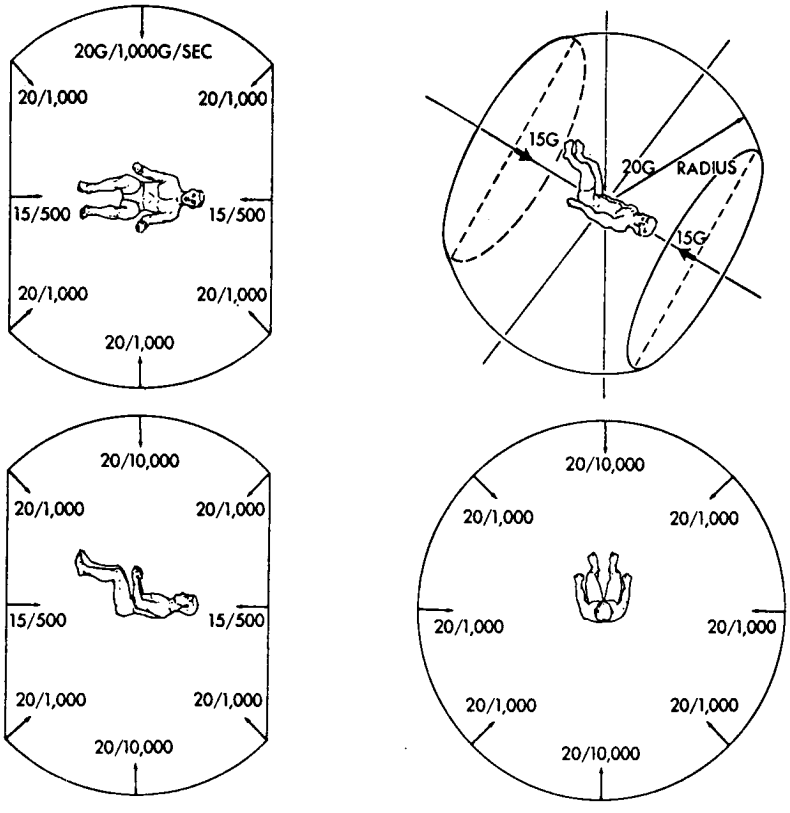
b



Numbers refer to case histories

Magnitude and rate of onset of mean decelerations sustained by nine survivors of falls from heights of 55 to 185 feet.

ITEM NO.	SUBJECT AREAS:	SOURCE:
399	SYSTEM - S16 HUMAN - H34	Reference 197, pp. 552-553. Based on Reference 161.



Impact-tolerance envelopes

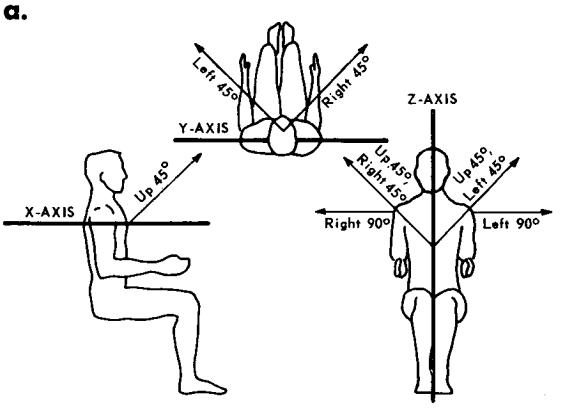
Injury occurs when the tensile, compression, or shear strength of the tissue is exceeded. Impact forces can be applied to the body in almost any direction. This is especially true if the spacecraft impacts on land rather than water. Tolerance limits have been set which provide a margin of safety for conditions of emergency such as might occur during a single parachute failure where terminal velocity is greater. Present limits are shown in the above figure.

Purser, P. E.; Faget, M. A. and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

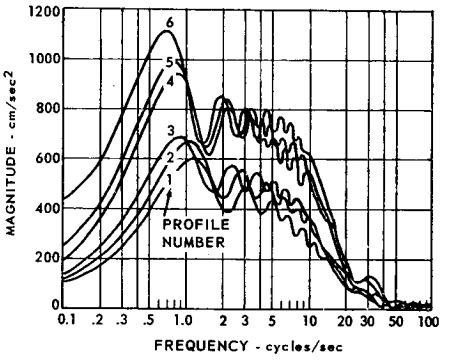
ITEM NO.	SUBJECT AREAS:	SOURCE:
-400	SYSTEM - S16 HUMAN - H34	Reference 74, p. 113.

IMPACTS OFF AXIS

a.



b.



Early data are illustrated here on the tolerability of impacts laterally applied and applied off the major X, Y, and Z body axes. The directions of impact for five body positions 45° off axis, and for left and right lateral positions (on the Y-axis) are shown in a. Using a vertical drop tower device which decelerates the falling vehicle when a shaped plunger enters water, the experimenters exposed some 20 subjects to six different acceleration profiles while in each of the seven body positions. The subjects were carefully restrained and supported on a form-fitting couch, and wore the helmet used in Project Mercury. Peak accelerations ranged from 13.4 to 26.6 g, and onsets from 426 to 1770 g/sec; the power density spectra of the six acceleration profiles are shown in b. There were no injuries produced. Some transient changes were seen in the electrocardiograms, such as premature ventricular beats. The subjects said they would be willing to endure the impacts again. Their subjective comments are summarized in the table below.

c. SUBJECT RESPONSES

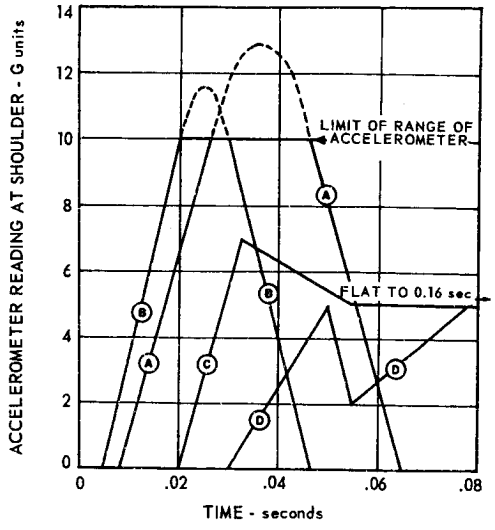
Orientation	Acceleration Profile Number					
	1	2	3	4	5	6
Right 45°	None	None	"Slight pain" in center of forehead lasting 5 minutes.	"Slight pain" above left ear in skull.	Complained bitterly but diffusely – EKG shows abrupt rhythm changes and four premature ventricular contractions.	Complained bitterly but diffusely.
Up 45°	None	Transient pain in occiput.	Transient pain in occiput – developed severe pain in neck four hours post-test, gone in a. m.	None	Slight head pain – pain about T_2 or T_3;* transient – developed severe muscle pain at point of left scapula – gone 24 hours.	None
Left 45°	Transient pain in occiput moving to temples.	None	None	None	None	Mild pain radiating from right midaxillary line at level of 11th rib to left iliac crest, transient.
Left 45°, up 45°	None	None	None	Fleeting pressure under chest belt.	Mild pain beneath chest strap – mild pain about C8 or T1* in midline posterior.	None
Right 45°, up 45°	None	None	None	None	"Wind knocked out."	"Wind knocked out."
Right 90°	None	None	Skinned right elbow.	Pain in right calf.	Pain in right calf.	"Knocked wind out."
Left 90°	None	None	Pain in right trapezius.	None	"Wind knocked out."	One premature ventricular contraction 2 minutes post-test and one 11 sec pre-test.

*T1, T2, T3 – first, second and third thoracic vertebrae; C8 – eighth cervical vertebra.

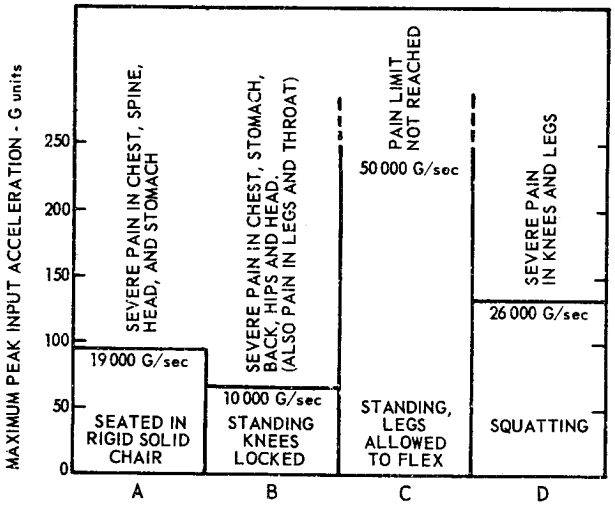
ITEM NO.	SUBJECT AREAS:	SOURCE:
401	SYSTEM – S16 HUMAN – H34	Reference 554, p. 73. Based on Reference 565.

VERTICAL IMPACT

a.



b.



The greatest impact which subjects would voluntarily endure during test drops in several positions is shown. In chart a the time histories of impact are drawn from readings of accelerometers located on the subjects' shoulders, while in b the symptoms for the four different drop positions are related to the maximum peak accelerations. There were 13 subjects and a total of some 500 test drops.

ITEM NO.	SUBJECT AREAS:	SOURCE:
402	SYSTEM - S16 HUMAN - H34	Reference 554, p. 72. Based on Reference 506.

BIOLOGICAL EFFECTS OF IMPACT

A review of experimental experiences with impacts produced by short track deceleration devices has shown that there are numerous physiological changes following impacts in the transverse ($\pm G_x$) direction when the peak forces range from 15 to 25 G, and onsets range from 400 to 1000 G/sec. These are transient changes, and occur in subjects who are entirely uninjured in the mechanical sense of bone fracture or detectable tearing of tissues and organs.

Effect	Notes
Shock	Blood pressure 90/60 mm Hg routinely seen 15-30 sec after impacts producing 15-20 $\pm G_x$ peaks, where onset rate was 500 G/sec. Lower pressures observed after greater impacts.
Bradycardia	Slight slowing of heart rate (bradycardia) following 15 G peak impacts facing forward ($-G_x$), and greater slowing in backward facing impacts ($+G_x$). The effect was related to activity of the vagus nerve, since atropine blocked the bradycardia. At greater peak accelerations, greater slowing occurred.
Transient neurological changes	Subjects appeared to be stunned for 10-15 seconds at 20 G peak accelerations (onset at 400 and 800 G/sec), and abnormal slow wave patterns were seen on the electroencephalogram for several minutes following peak impacts at 25 $+G_x$, 1000 G/sec onset. Other changes included increased muscle tone, euphoria, loquacity, hand tremor, decreased coordination, and gross involuntary movements in head, arms, and trunk. Increased deep tendon reflexes were commonly present after ± 15 G_x, and after a peak impact of 25 G reflexes were absent for several seconds, then hyperactive for about a minute.
Changes in blood platelets	One hour after impacts with +20 G_x peaks and onsets of 400 or 800 G/sec, blood platelets were found to be reduced. A week later the platelet count was higher than the control value.
Psychological changes	Psychological evaluation with the Kahn symbol arrangement test showed changes which increased with $+G_x$ impacts from 10 to 25 G peak accelerations.
General stress reactions	Changes were seen in the indicators of adrenal gland activity, and various changes occurred in chemical constituents of the blood.

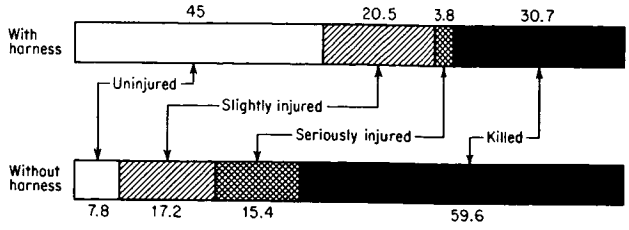
ITEM NO.	SUBJECT AREAS:	SOURCE:
403	SYSTEM - S16 HUMAN - H9, H14, H27, H34	Reference 554, p. 74. Based on Reference 514.

Effects of Negative g on Protected [1] and Unprotected Subjects Seated Upright

	Percent of subjects experiencing symptoms							
	Without protection			*With protection*				
Symptoms	*1g*	*2g*	*3g*	*1g*	*2g*	*3g*	*4g*	*5g*
Uncomfortable fullness and pressure in head and neck	40	90	100	0	10	40	50	80
Abnormally slow heartbeat	30	90	100	60	50	50	40	30
Headache	0	0	50	0	0	0	0	30
Ear pain	0	0	20	0	10	30	50	50
Cardiac insufficiency and dilation	0	0	50	0	0	0	0	0
Conjunctival hemorrhage	0	0	40	0	0	0	0	0
Difficulty in breathing	0	0	40	0	0	0	0	30
Diminished vision	0	0	40	0	0	10	20	30
Sinus pain	0	0	30	0	0	0	0	0

[1] Pressure helmet only.

ITEM NO.	SUBJECT AREAS:	SOURCE:
404	SYSTEM - S16 HUMAN - H34, H44	Reference 380, p. 465. Based on Reference 476.



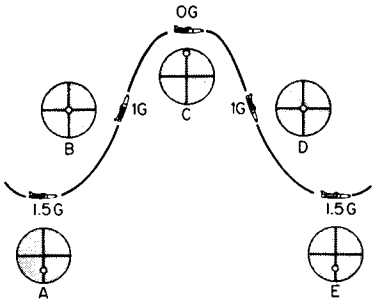
Percentage of pilots uninjured, injured and killed, with and without harness.

While the garden variety of seat belt that holds at the waist has saved many lives, two types of injuries can occur with it: abdominal injuries and, more importantly, head injuries due to the body flopping forward from the middle and the head hitting a seat or obstruction in front. Harnesses of various designs, on the other hand, typically restrain the shoulders under such circumstances and reduce head injuries. The effectiveness of harnesses in reducing injuries and fatalities in the case of aircraft pilots during crashes is shown above.

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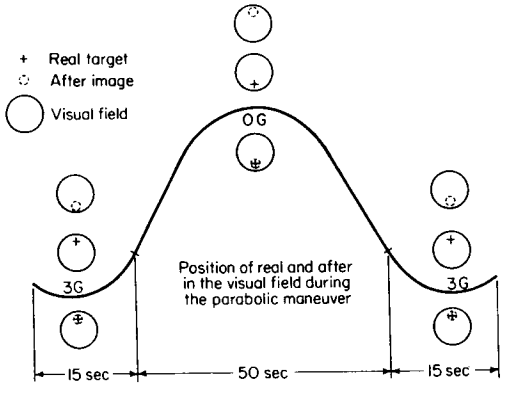
ITEM NO.	SUBJECT AREAS:	SOURCE:
405	SYSTEM- S16 HUMAN- H34, H44	Reference 362, p.556.

a



Apparent displacement of the visual after-image during the aerodynamic parabola in an F-94C type aircraft. The visual after-image is displaced upward during the short period of weightlessness.

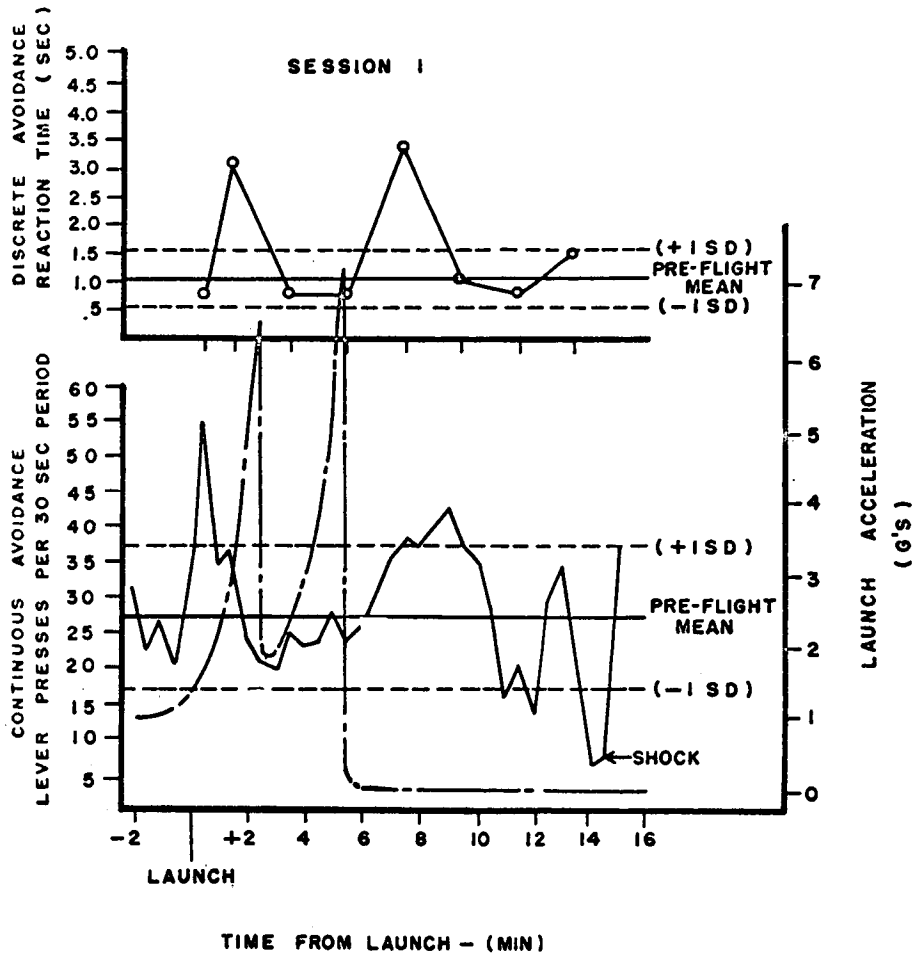
b



Summary of result of ocular illusion studies in SAM F 100 aircraft.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
406-	SYSTEM - S12, S13 HUMAN - H25	Reference 219, pp. 281-282 Based on References 215 (fig. a) and 441 (fig. b).

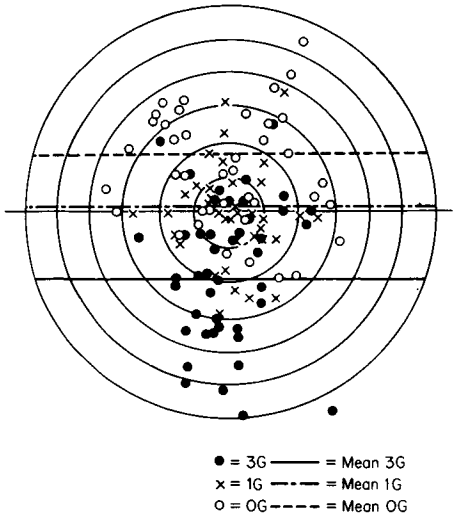


Shock Avoidance Performance of Chimpanzee Enos on Mercury MA-5 Flight, During Launch

This period includes two periods of high g force and about ten minutes of weightlessness. Results are plotted against preflight performance as a base. Only once during this period did Enos fail to avoid the threat of shock.

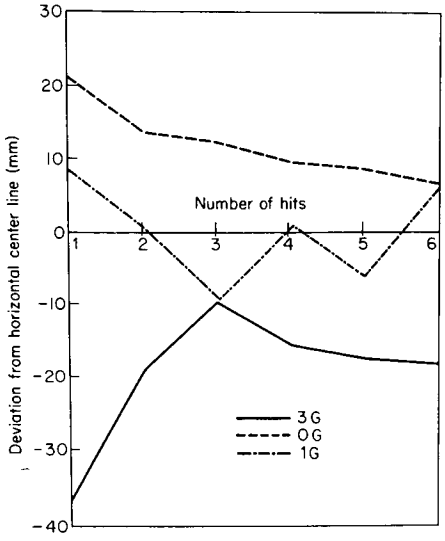
ITEM NO.	SUBJECT AREAS:	SOURCE:
407	SYSTEM - S12, S13 HUMAN - H26	Reference 239, p. 91

a



Accuracy in striking at a target with a stylus under different conditions of gravity.

b

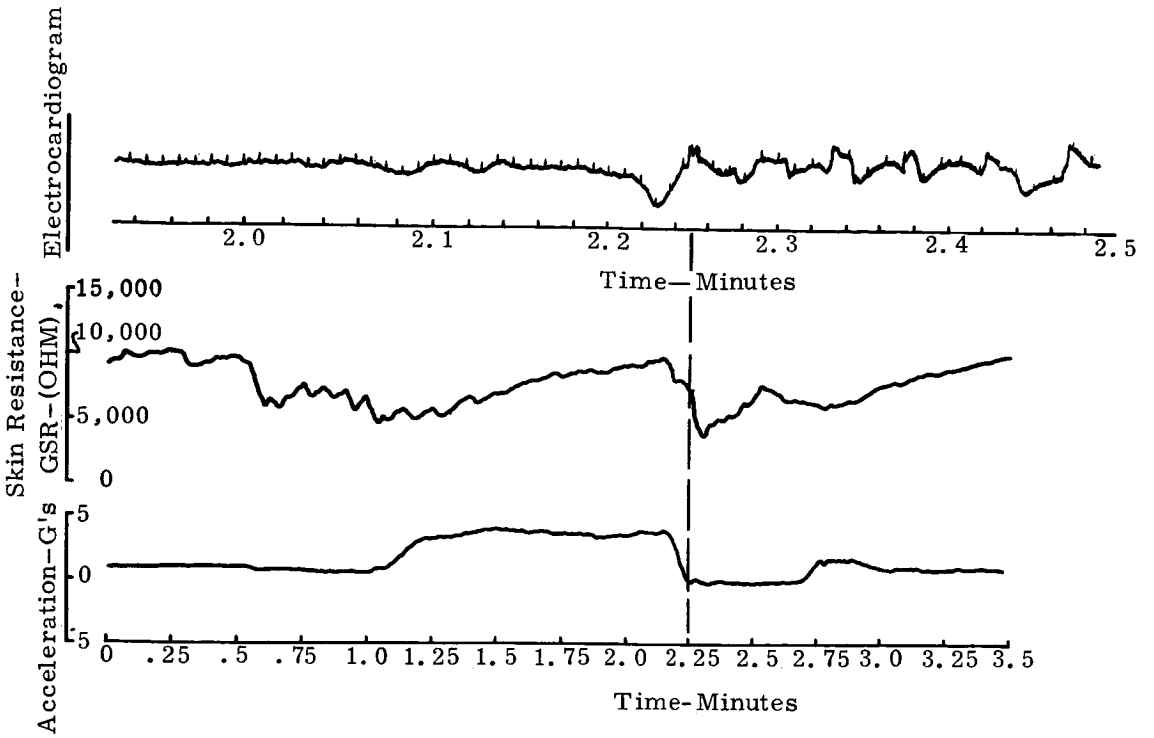


Sensomotor performance during weightlessness. Improvement in accuracy upon repetition.

An eye-hand coordination test was administered first at ground level (1 g) in the cockpit of a T-33A aircraft. The subject tries to hit with a stylus a bull's-eye located 3 feet away. The same experiment was then repeated during increased (3 g) acceleration and during weightlessness (0 g) while flying parabolic maneuvers. Above in figure a, the results of a group of subjects show the trend to hit too low during increased g-forces, and too high during the weightless condition. Figure b diagrams test results. The hit accuracy for the weightlessness curve shows steady improvement during the six trial attempts.

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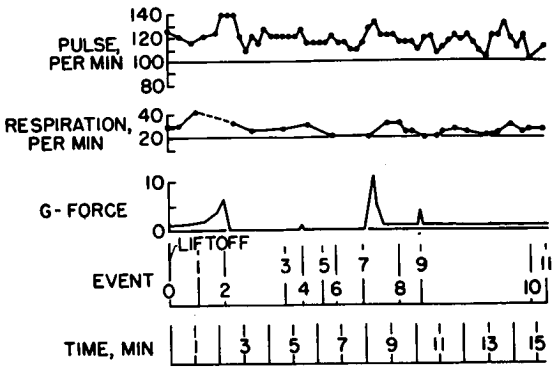
ITEM NO.	SUBJECT AREAS:	SOURCE:
408	SYSTEM - S12, S13 HUMAN - H26	Reference 219, pp. 286-287 Based on Reference 216



Pre-through postweightlessness records of ECG, skin resistance, and acceleration in F-94C flight.

Von Beckh calls attention to the increased arousal of the subject at 0.5 minute when he was warned of the imminent sustained 3 G maneuver preceding weightlessness. The series of undulations in the skin resistance record immediately following announcement of the plan to initiate a spiral (between 0.50 and 1 minute in the figure) present the typical picture of a series of galvanic skin reflex responses characteristic of increased central nervous system (CNS) arousal. The abrupt 2:1 drop in skin resistance concomitant with the transition from 3 G to weightlessness presents the characteristic picture of a strong startle reaction. This could well be the strong arousal of the individual anticipating the crucial weightlessness test, the point of the flight; that is, the GSR changes are probably psychological in origin.

ITEM NO.	SUBJECT AREAS:	SOURCE:
409	SYSTEM - S12, S13 HUMAN - H9, H14, H35	Reference 479, p. 129 Based on Reference 543



Pulse rate, respiration rate, and acceleration in Astronaut Shephard's MR-3 Redstone ballistic trajectory flight.

EVENTS

1. Maximum dynamic pressure
2. Launch-vehicle engine cutoff: Spacecraft separation: Turn-around
3. Retroattitude
4. Retrofire
5. Retrojet
6. Reentry attitude
7. 0.05 g
8. Drogue chute deployment
9. Main chute deployment
10. Impact
11. Loss of signal

ITEM NO.	SUBJECT AREAS:	SOURCE:
410	SYSTEM - S12, S13 HUMAN - H9, H16	Reference 479, p. 132 Based on Reference 106

CLINICAL FINDINGS AND SUSCEPTIBILITY TO MOTION SICKNESS IN SUBJECTS WITH LABYRINTHINE DEFECTS

Subj.	Age	Etiol.	Age Onset	Hearing R	Hearing L	Caloric[1] R	Caloric[1] L	Cntr[2] Roll	Hist. m/s	Exper.[3] m/s
St	20	Men.[4]	2 1/2	130 db	135	Nil	Nil	1.5	Bus[6]	Nil
Gu	21	Men.	4 1/2	145	145	Nil	Nil	1.0	Nil	Nil
Hr	29	Men.	13	Nil	Nil	Nil	Nil	1.0	Boat[7]	Nil
Za	20	Men.	3 1/2	135	130	Nil	Nil	0.8	Nil	Nil
Pe	33	Men.	12	Nil	Nil	Nil	Nil	0.5	Nil	Nil
Pi	22	Men.	3	Nil	Nil	Nil	Nil	1.5	Nil	Nil
Do	43	Men.	13	Nil	Nil	Nil	Nil	1.0	Nil	Nil
My	25	Men.	8	Nil	Nil	Nil	Nil	1.0	Nil	Nil
Gr	48	Mas.[5]	12	Nil	160	Nil	Nil	1.5	Nil	Nil

[1] Obs. Nys. Water 4.5-6°C. - [2] Normal = 3.0°-8.5°. - [3] Air, C131, Sea, SRR (20 RPM), CRR (max). - [4] Meningitis. - [5] Mastoiditis. - [6] Minimal Nausea. - [7] Minimal Malaise.

The extraordinary freedom from functional symptoms under both experimental and non-experimental conditions which may cause motion sickness in normal subjects is proof of the overwhelming etiological significance of the sensory organs of the inner ear.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
411	SYSTEM - S12, S13, S15 HUMAN - H29, H34	Reference 234, p. 332

NUMBER AND SEVERITY OF SYMPTOMS IN AN UNSELECTED GROUP OF NINE MEDICAL STUDENTS UNDER FIVE CONDITIONS

		Std. Air					C 131					Sea			SRR			CRR	
			Sym				Sym			Sym				Sym				Sym	
Subject	Age	Completed	No.	Intensity [1]	# Parab.		No.	Severe	Therapy	No.	Severe	# Dials. 7.5 RPM	No.	Severe	Stress [2]	No.	Severe		
1	20	No	5	3	10^3		8	4	Yes	10	5	11	12	2	1	12	3		
2	21	Yes	9	5					No			8	9	2	1	6	2		
3	24	Yes	7	2	10^3		5	2	Yes	11	2	7	12	3	2	10	3		
4	20	Yes	8	2	10^3		5	2	No	1	1	20	8	3	2	8	3		
5	33	No	8	3	10^4		20	5	Yes	8	2	0	9	3	3	4	2		
6	22	Yes	10	4	40		9	2	No	2	1	11	10	3	5	7	3		
7	23	Yes	5	1	40				No	1	1	20	7	2	6	0			
8	22	Yes	5	1	40		5	1	No	1	1	20	7	2	6	3	1		
9	48	Yes	3	2	40		0		No	3	1	20	3	1	6	2	1		

[1] 5 point scale (1 = minimal).

[2] 6 levels of stress (1 = minimal).

[3] Interruption not requested.

[4] " requested.

The findings summarized in this table typify the results obtained on unselected normal subjects under different experimental conditions. Undoubtedly, we were witness to the fact that functional symptoms may be of psychogenic origin. This observation is not new but the possibility of studying such instances in the laboratory has been extended. The symptomatology is atypical in three important respects: 1) discordance between subjective symptoms and objective signs, the former usually predominating, 2) the same or little change in severity of symptoms with increasing stress, and 3) symptoms either characteristic of anxiety or not fitting into any recognized syndrome.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
412	SYSTEM - S12, S13, S15 HUMAN - H29, H34	Reference 234, p. 334

Subj.	Age	Hist/ms	Air	C 131	Sea	SRR	CRR
1	21	5 [1]	4	5	5	4	5
2	22	5	5			4	5
3	24	5	3	3	3	5	4
4	25	3	3	3	Nil	3	4
5	23	5	4	5	4	5	3
6	24	3	4	3	Nil	5	2
7	23	Nil	2		Nil	2	Nil
8	22	Nil	2	1	Nil	2	1
9	22	Nil	2	Nil	1	1	Nil

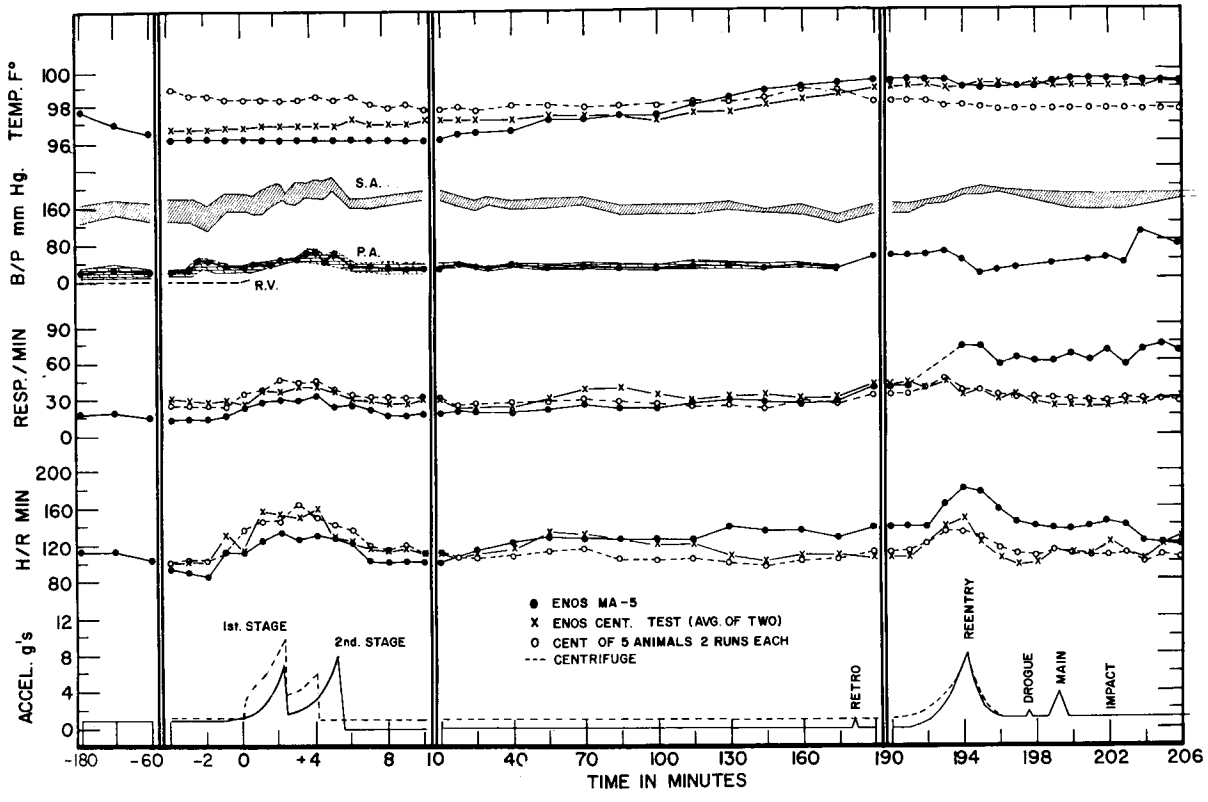
[1] 5 point scale (1 = minimal susceptibility).

Susceptibility to Functional Vestibular Symptoms in Nine Students Based on History and Five Experimental Conditions

It is immediately apparent that those who are highly susceptible to functional symptoms under one condition are highly susceptible under all.

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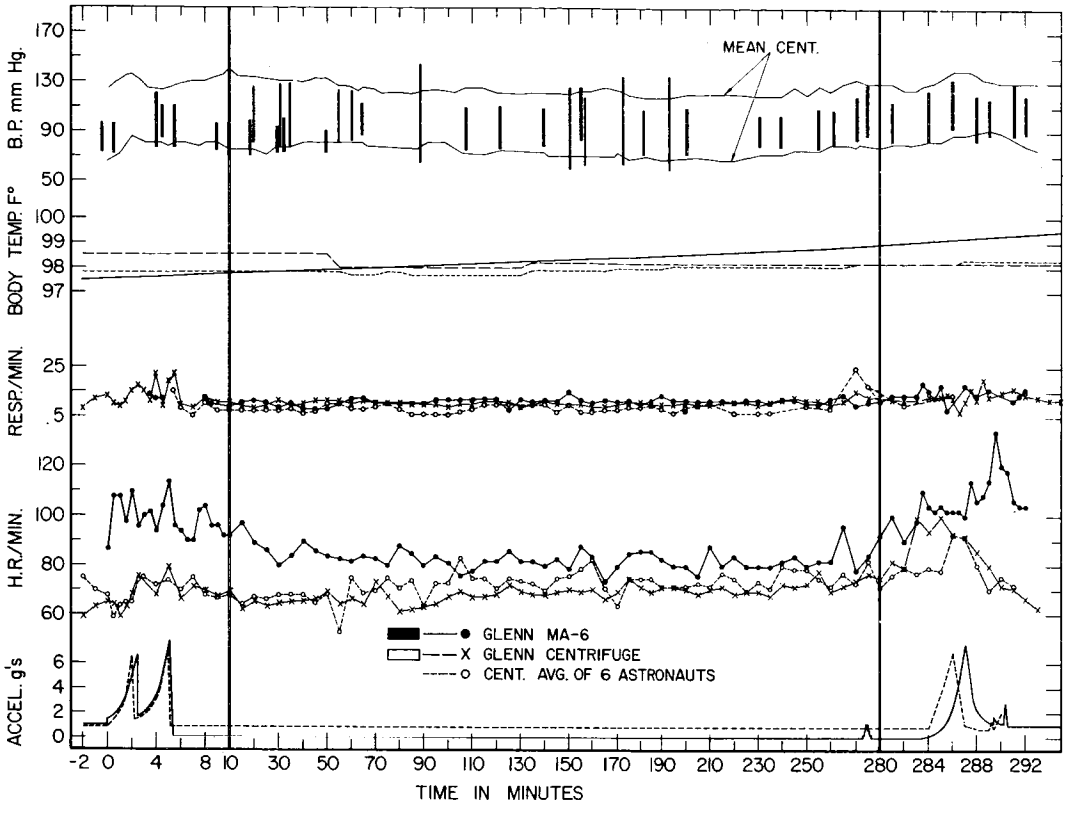
ITEM NO.	SUBJECT AREAS:	SOURCE:
413	SYSTEM - S12, S13, S15 HUMAN - H29, H34	Reference 234, p. 335



Physiological data from the MA-5 chimpanzee flight. At the bottom: acceleration transverse to the subject in g's. Dotted lines represent centrifuge trials. The heart rate, in beats per minute, shows the parallelism of centrifuge and flight data. Respiration shows an increase during and after reentry, possibly due to the oscillation of the spacecraft. PA shows mean values (solid circles) and pulse pressure in the pulmonary artery. RV represents the pressure in the right ventricle during diastole, which was obtained during countdown and, briefly, during flight. SA represents systemic arterial pressure as recorded by direct catheterization. Note high values during three-hour control period prior to launch. Temperature during flight approximately parrallels centrifuge experience.

ITEM NO.	SUBJECT AREAS:	SOURCE:
414	SYSTEM - S12, S13, S15 HUMAN - H9, H16, H18	Reference 270, pp. 320-321

a



Physiological data from the MA-6 flight. At bottom: acceleration transverse to the subject in g's. Dotted line represents centrifuge runs. The heart rate shows a return towards resting preflight values during weightless state. Respiration is unaffected by weightless state. Body temperature stays within normal values during flight (solid line). Blood pressure during the flight (solid bars) differs from centrifuge controls. Open bars show a greater pulse pressure. Continuous lines represent mean of systolic and diastolic centrifuge blood pressure observations on six astronauts.

b

SUMMARY OF FLIGHT DATA

EVENT	PULSE RATE, BEATS/MIN	BLOOD PRESS, mm Hg	RESP. RATE, BREATHS/MIN	BODY TEMP, °F
LIFT-OFF PERIOD (MAXIMUM)	110	-	14	97.6
SPACECRAFT SEP.	114	-	12	97.6
WEIGHTLESSNESS	MEAN 86	MEAN 129/70	8 TO 14	98.6
RETROFIRE	96	-	12	99.2
REENTRY PERIOD (MAXIMUM)	134	-	19	99.3
BIOSENSOR DISCONNECT	104	-	16	99.5

This table summarizes the biomedical data from the MA-6 flight.

Purser, P.E.; Faget, M.A. and Smith, N.F; (editors); MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
415-	SYSTEM - S12, S13, S15 HUMAN - H9,	Reference 270, pp. 324-325 (fig. a) and Reference 421, p.127 (fig.b)

Use of Drugs for Cardiovascular Problems

Cardiac Decelerator

Carbachol (carbaminoyl choline)

Pressor Agents and Cardiac Accelerators

Noradrenaline

Adrenaline

Ephedrine

The dynamics of space flight will necessarily affect the activity of the heart and peripheral blood circulation. Homeostatic balances of heart rate as influenced by blood pressure and states of vasomotion are based on the terrestrial level of 1g. If homeostatic balances are not restored in due time after the deleterious effects of acceleration, weightlessness, or deceleration, pharmacologic aids may again be indicated. Acceleration is expected to produce a high level of tachycardia in the space astronaut. As shown in this table, carbachol may be used to slow the heart in any state of prolonged paroxysmal tachycardia that might occur during either the exit or re-entry phase of space flight. Noradrenaline may be used where prolonged inactivity in the subgravity state results in smooth-muscle atony within the walls of the arterioles, venules, and capillary networks, accompanied by a tendency toward low blood pressure. Vagal slowing of the heart rate could also occur during the subgravity state; the administration of adrenaline would increase tonicity while accelerating the heart rate and force of contraction. Adrenaline, because it decreases capillary permeability, could also be used where circulatory stasis might result in the formation of petechial hemorrhages. Ephedrine acts similarly to adrenaline but at a less intense level of response.

ITEM NO.	SUBJECT AREAS:	SOURCE:
416	SYSTEM - S12, S13, S16 HUMAN - H9, H38	Reference 416, p. 116

HUMAN SENSE MODALITIES AND ORGANS, THEIR STIMULATION AND RESPONSE TO SUB- AND ZERO-GRAVITY

	Mechanoreceptors					*Photoreceptors*
	Specific Gravireceptors	*Non-specific Gravireceptors*				
	Exteroceptors	*Proprioceptors*		*Pressoreceptors*	*Tangoreceptors*	
Name of Sense	Motion and position sense	Muscle sense	Posture sense	Cardiodynamic sense	Touch and pressure sense	Optical sense
Sense Organ and Receptors	Otoliths	Muscle spindles	Vater-Paccini corpuscles	Pressoceptive nerve endings	Nervus plexuses and Meissner corpuscles	Retina (rods and cones)
Normal Stimulus	Changes and motion and linear accelerations	Weight and stress	Elastic tension	Hemodynamic tonus	Touch and pressure	Light
Effect of Sub-Gravity	Displacement of otoliths	Decrease of weight and mechanical stress	Probably no or only slight effect of changed tension	Decrease of hemodynamic tension	Decreased pressure at contact points of body with support	None
Effect of Zero-Gravity	Displacement of otoliths	Lack of mechanical stress		Decrease of hemodynamic tension	Lack of pressure at contact points	None
Sensory Input During Zero-G	No stimulation or zero-G signal	None	Probably no or only slight change of posture due to change of mass-weight ratio	Stimulation of pressoceptive nerve	None	None
Sensory Output During Zero-G	No response or zero-G response	Altered mass-weight ratio signal		Cardiovascular reflex (carotid sinus)	None	None
Sensation During Zero-G	Non-specific agravic sensation	Weightless sensation		None	Weightless sensation	Oculo-agravic illusion in the dark
Psychophysiological Effect of Weightlessness	Loss of vertical orientation without visual reference	Disturbance of neuromuscular coordination		Adaptation to Zero-G condition	Loss of contact and floating	No effect when visual cues available

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ITEM NO.	SUBJECT AREAS:	SOURCE:
417	SYSTEM - S12, S17 HUMAN - H9, H13, H14, H25	Reference 219, p. 230 Based on Reference 217

CONTROLS FOR USE IN HIGH G—SITUATIONS

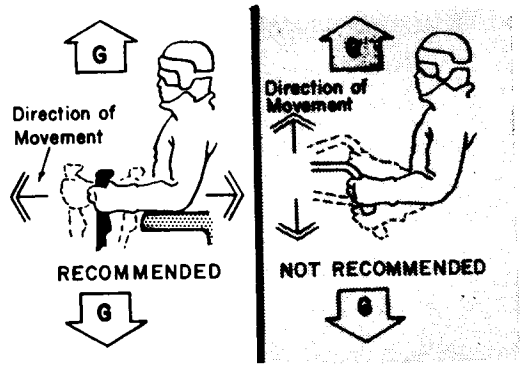
Note: The following statements apply only to the seated and supine positions. The standing position cannot be used when the operator is subjected to abnormal g-forces.

Controls which must be used while the operator is subject to acceleration forces above 2 g* should be placed so that:

a. The operator's limb is always in contact with the control, i.e., no reaching is required.

b. As many controls as possible are assigned to each limb. This is best accomplished by use of combined controls (several control functions mounted on a single shaft) so that movement from one control to another is avoided.

c. Linear controls operate perpendicularly to the direction of g-forces. This eliminates the necessity for the operator to compensate for g-forces acting along the line of control movement. When rotary control movements are made, limbs are least affected by g-forces.



* This applies to the relatively prolonged g-forces in one direction found in aircraft during sharp turns or pull-outs as well as the sudden changes in g-forces (jouncing, pitching) encountered in trucks, tanks, small naval craft, etc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
418 a Page 1 of 2	SYSTEM - S13, S14 HUMAN - H42	Reference 185, p. 55 Based on Reference 494

CONTROLS FOR USE IN HIGH G SITUATIONS (continued)

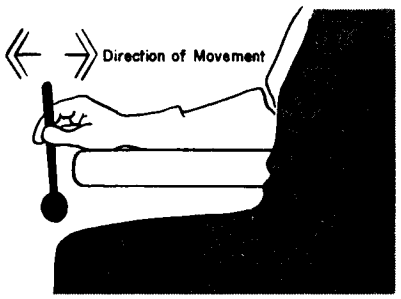
d. For hand controls, when the shoulder, elbow, forearm and wrist are supported:

Arm movements can be made up to 4 g.

Forearm movements can be made up to 4-5 g (up to 8-9 g if the arm is counterbalanced).

Hand movements can be made up to 8 g.

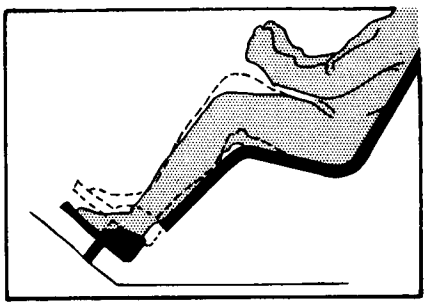
Finger movements can be made up to 10 g.



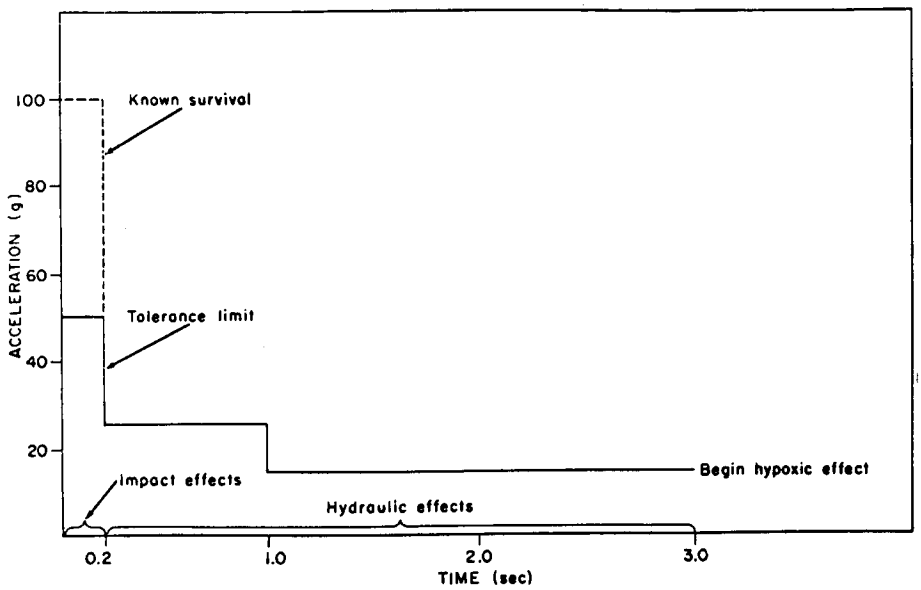
e. For foot controls, when the thigh, lower leg and heel are supported:

Lateral leg movements can be made up to 4 g.

Vertical, up-down leg movements can be made up to 2-3 g.



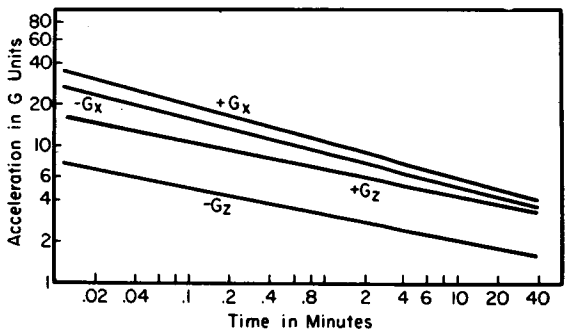
ITEM NO.	SUBJECT AREAS:	SOURCE:
418 b Page 2 of 2	SYSTEM - S13, S14 HUMAN - H42	Reference 185, p. 56 Based on Reference 494



Acceleration effects with time.

At about 0.2 sec duration, hydraulic effects begin. These consist of displacement of fluids in the body cells, changes in the hydrostatic equilibrium between small blood vessels and their surrounding body fluids, changes in permeability and structural failure of blood vessels, and the mechanical displacement or deformation of body structures. Body orientation determines the physiological effect of the hydraulic displacements.

ITEM NO.	SUBJECT AREAS:	SOURCE:
419	SYSTEM - S13, S16 HUMAN - H34	Reference 380, p. 453 Based on Reference 491



Average acceleration for positive acceleration ($+G_z$), negative acceleration ($-G_z$), transverse supine acceleration ($+G_x$), and transverse prone acceleration ($-G_x$).

ITEM NO.	SUBJECT AREAS:	SOURCE:
420	SYSTEM - S13, S16 HUMAN - H34	Reference 116, p. 210

Conventional and Additional Restraint for Maximum Body Support [1]

Direction of acceleration	*Vehicle occupant*	*Body position*	*Conventional restraint*	*Additional restraint for maximum body support*
Spineward	Operator	Seated facing forward	Lap strap Shoulder straps	Thigh straps
	Passenger or crewmember	Seated facing forward	Lap strap	Shoulder straps Thigh straps Armrests and handholds Toe straps
Sternumward	Passenger or crewmember	Seated facing backward	Lap strap	Backrest [2] Headrest [3] Chest strap [4] Leg and foot supports Armrests and handholds
Headward	Operator	Seated facing forward	Lap strap Shoulder straps	Thigh straps Chest strap [4] Headrest [3]
	Passenger or crewmember	Seated facing forward	Lap strap	Shoulder straps Thigh straps Chest strap [4] Headrest [3] Armrests and handholds
		Seated facing backward	Lap strap	Chest strap [4] Headrest [3] Armrests and handholds
Footward	Operator	Seated facing forward	Lap strap Shoulder straps	None
	Passenger or crewmember	Seated facing forward	Lap strap	Shoulder straps Handholds Toe straps
		Seated facing backward	Lap strap	Chest strap [4] Handholds Toe straps
		Supine	Lap strap	Webbed netting [5]

[1] Eiband, 1959.
[2] Rigid with padded "wings."
[3] Full height, integral with backrest.
[4] Arm-pit level.
[5] Full support.

ITEM NO.	SUBJECT AREAS:	SOURCE:
421	SYSTEM - S13, S16 HUMAN - H44	Reference 380, p. 451 Based on Reference 181

TEST VALUES OF HUMAN TOLERANCE TO ACCELERATIONS AND TYPE OF RESTRAINT DEVICES UTILIZED

Body units	Direction of acceleration	Physiological description of acceleration	g	Duration, sec	Onset, g/sec	Restraint system
Head.....	Upward	$+G_z$	16	0.04	.....	Face curtain
	Forward	$+G_x$	22	.....	600	None
			25	1	600	Helmet and straps
			45	0.044	500	None, against chest
	Downward	$-G_z$				
	Backward	$-G_x$	83	0.04	4,000	Rigid headrest
			12	5	.....	Helmet and straps
			10	23	.....	Helmet and straps
Torso*.....	Upward	$+G_z$	28	.....	.....	Upper-torso harness
			40	.....	.....	Torso restraint F-106A
	Forward	$+G_x$	5.5	13	.....	Lap belt, shoulder harness, chest strap, helmet tie-down, crotch strap
			25	1	600	Shoulder harness, lap belt, inverted-V crotch
			18	0.065	.....	Abdominal vest
			45	0.044	500	Stapp's restraint gear (Group H)
	Downward	$-G_z$				
	Backward	$-G_x$	83	0.04	4,000	Group H harness
Arm.....	Upward	$+G_z$	16	0.04	.....	Face curtain
	Forward	$+G_x$	25	1	600	Elbows tied behind back, wrists tied at knees
	Downward	$-G_z$				
	Backward	$-G_x$				
Leg.....	Upward	$+G_z$				
	Forward	$+G_x$	35	0.1	1,156	Toe straps, canted footrests
			25	1	600	Knees and ankles tied together, feet tied to footrests
	Downward	$-G_z$	11	.....	.....	Belt over thighs
	Backward	$-G_x$	35	0.1	1,156	Toe straps, canted footrests

ITEM NO.	SUBJECT AREAS:	SOURCE:
422 a Page 1 of 2	SYSTEM - S13, S16 HUMAN - H34, H44	Reference 163, pp. 176-177 Based on several primary sources, compiled in Reference 473

TEST VALUES OF HUMAN TOLERANCE TO ACCELERATIONS AND TYPE OF RESTRAINT DEVICES UTILIZED

(continued)

Body units	Direction of acceleration	Physiological description of acceleration	g	Duration, sec	Onset, g/sec	Restraint system
Entire body...	Upward	$+G_z$	16	0.04	.....	Lap belt, shoulder straps, face curtain
			28.5	0.020–0.033	.....	Safety belt
			5	240	0.07	Anti-g suit
			16	5	.....	Water immersion
	Forward	$+G_x$	8	1	.....	Bernardini's suit (with vibration at 0.7 cps)
			12	4	.....	Bernardini's suit
			10	120	.....	Supine—net seat
			45	0.044	500	Stapp's restraint gear (Group H)
			55	.....	.....	Safety belt and yielding structure
			31	5	.....	Water immersion
	Downward	$-G_z$	11	.....	.....	Shoulder strap, belt over thighs, lap belt
	Backward	$-G_x$	16.5	.....	.....	Supine—net seat
			10	120	.....	Prone—net
			14	120	.....	Supine, forward tilt, water immersion
			35	0.1	1,156	Lap belt, leg restraint, headrest, chest strap
			31	.....	.....	Water immersion, supine
			25	.....	.....	NASA supine couch
			83	0.04	4,000	Group H restraint
			12	5	.....	Helmet and straps, lap belt, spine forward 25°, rigid seat, legs sharply flexed
			10	23	.....	Helmet and straps, lap belt, spine forward 25°, rigid seat, legs sharply flexed
			16.5	170	.....	Contoured net seat, spine forward 12°, legs at 90°
	Upward	$+G_z$				
	Forward	$+G_x$	162	.....	22,600	None
			209	0.015	27,800	None
			106	0.024	8,333	None
			33	0.061	1,100	None
			28.5	0.073	780	None
	Downward	$-G_z$				
	Backward	$-G_x$	183	0.013	28,000	None
			140	0.012	23,300	None
			123	0.024	10,250	None
			95	0.031	6,100	None

* See also Entire body.

ITEM NO. 422 b
Page 2 of 2

SUBJECT AREAS:
SYSTEM - S13, S16
HUMAN - H34, H44

SOURCE:
Reference 163, pp. 177-178
Based on several primary sources, compiled in Reference 473

a

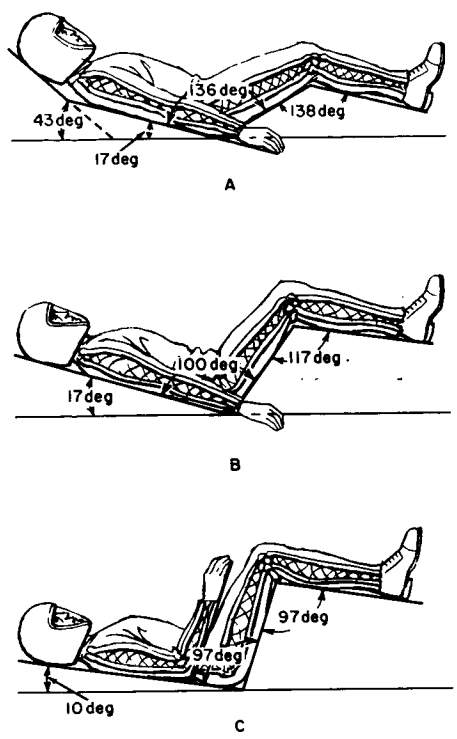
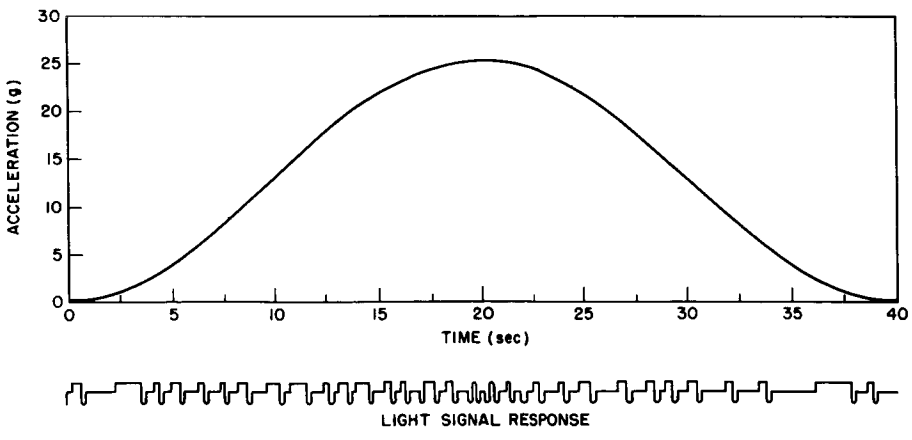
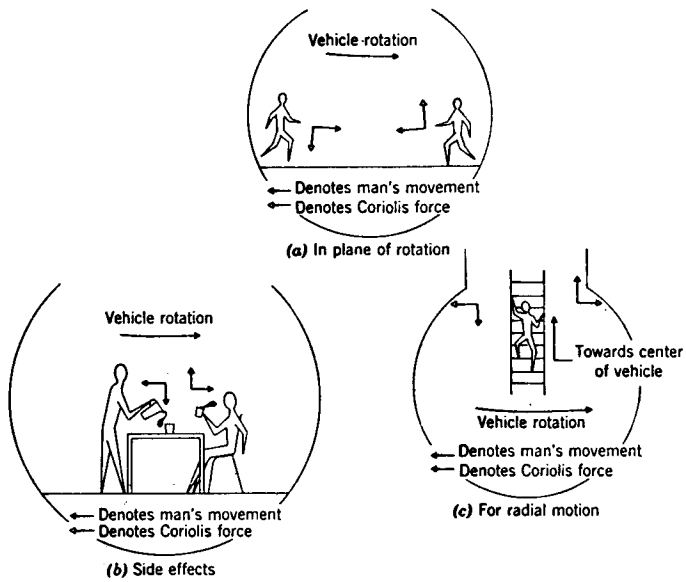


Figure a shows three couch designs that have been studied for increasing tolerance to high acceleration forces. With couch b tipped to an 8-deg back angle, a subject was able to tolerate as high as 25 g in a record run. Figure b (Chambers and Brown, 1959) shows the data obtained with this record run. The baseline data indicate the reaction of the subject to a signal light. It can be seen that he was able to react throughout the entire buildup and decay of acceleration, a total time of 40 sec.

b



ITEM NO.	SUBJECT AREAS:	SOURCE:
423	SYSTEM - S13, S16 HUMAN - H6, H25, H34, H44	Reference 380, p. 464 Based on Reference 117



Coriolis effects.

The magnitude of the Coriolis acceleration is

$$F_c = 2\omega X v$$

where ω is the angular rate of the vehicle
v is velocity relative to the vehicle

The simulated gravity is

$$F_g = ng = \omega^2 r$$

where g is the acceleration of gravity at earth surface
n is the number of g simulated
r is the radial distance of man from the spin axis

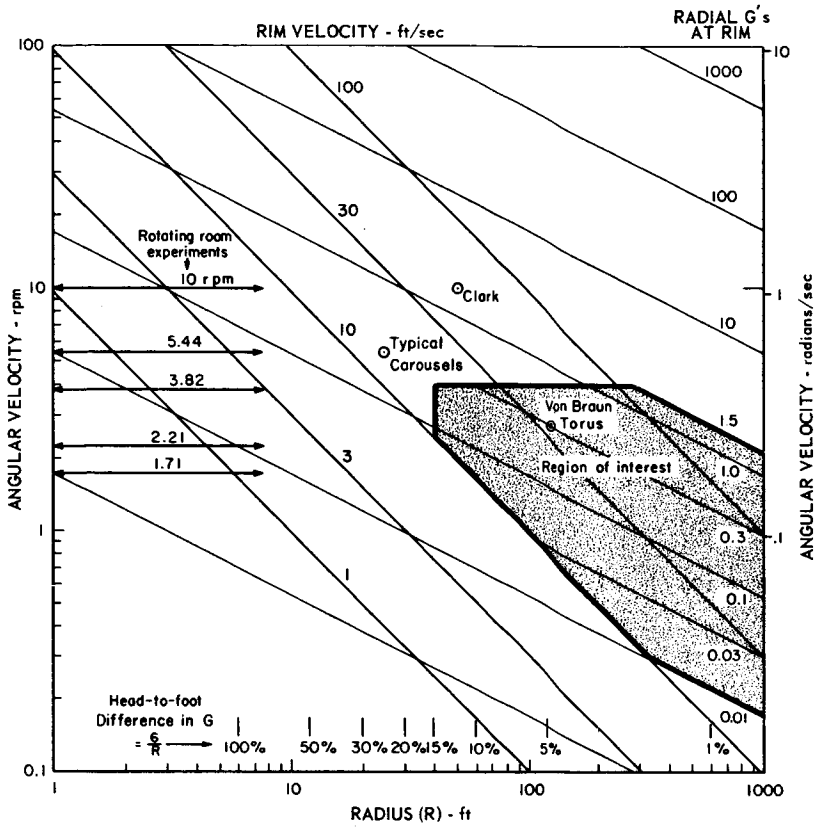
A measure of the change in direction of the force field resulting from v is the ratio of the Coriolis acceleration to the simulated gravity acceleration.

$$\frac{F_c}{F_g} = \frac{2\omega v}{ng} = \frac{2}{\sqrt{ngr}} v$$

where v is the magnitude of the component of v perpendicular to the spin axis. The rate of change of this ratio with v is $2/\sqrt{ngr}$ and may be the design parameter that will determine the suitability of an artificial gravity system. The system would be designed so that this parameter would not exceed some threshold value. It is noted that, if this is so, high values of both n and r would be desirable. There are, of course, practical limitations to the values of n and r, but it may mean that partial gravity simulation would be undesirable and could even lead to the use of artificial gravity larger than 1 g.

ITEM NO.	SUBJECT AREAS:	SOURCE:
424	SYSTEM - S15, S17 HUMAN - H33	Reference 323, p. 539

ROTATION EFFECTS ON SPACE VEHICLE DESIGN



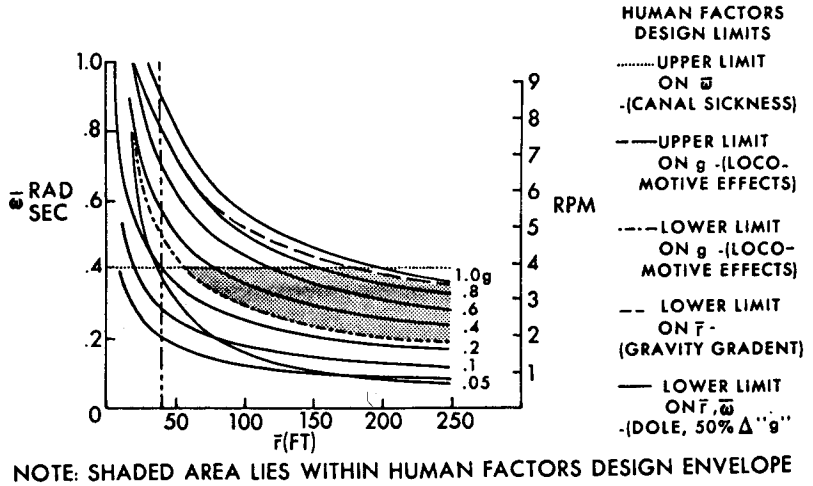
In the figure are presented results of a study which estimated general limits for the various parameters describing a rotating space station on interplanetary probe.

Maximum G level was set at 1.5 to avoid incurring unnecessary fatigue or loss of agility during body movements. Accelerations of 0.01 G and higher will orient liquids against capillary forces, and remove suspended solids from the atmosphere; that value was thus taken as the minimum useful G level.

Minimum rim velocity was set at 10 ft/sec, three or four times walking speed, so that the increase in centrifugal acceleration when walking in the direction of rotation and the decrease when walking against it, would be less than 50%. The ratio of Coriolis to centrifugal acceleration when attempting to move a limb radially is also an inverse function of rim velocity, so that the 10 ft/sec limit represents both factors.

The head to foot difference in G's was set more or less arbitrarily at 15%, with a note that more information is needed.

ITEM NO.	SUBJECT AREAS:	SOURCE:
425	SYSTEM - S15, S17 HUMAN - H33	Reference 554, p. 378 Based on Reference 173



NOTE: SHADED AREA LIES WITHIN HUMAN FACTORS DESIGN ENVELOPE

Human-factors stress-limit curves superimposed on plot of angular velocity ($\bar{w}$) versus radius of rotation ($\bar{r}$) to achieve various levels of artificial gravity in manned orbital satellite vehicles.

The many factors described above combine in a rotating space vehicle to impose considerable design constraints. The shaded area in the figure shows a physiological design envelope for angular velocity and radius.

These limits represent the best values that can be predicted from physiological research in laboratories and aircraft. It must be remembered, as with weightlessness, that complete simulation of the physical dynamic environment of the crew station of a rotating space vehicle cannot be achieved by devices operating in a gravitational field.

Purser, P. E.; Faget, M. A. and Smith, N. F.; (editors); MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
426	SYSTEM - S15, S17 HUMAN - H33, H34	Reference 74, p. 122

Selected Body Measurements for Adults

(In inches)

	Male				Female			
	Group	*Median*	*SD*†	*Range*	*Group*	*Mean or Median**	*SD*†	*Range*
1. Height	*a*	69.1	2.44	59.5–77.6	*e*	63.2	2.48	55.0–73.0§
2. Sitting height: erect‡	*a*	36.0	1.29	29.9–40.2	*f*	34.1	1.02	30.7–34.4
3. Shoulder breadth	*a*	17.9	0.91	14.6–22.8	*e*	13.4	1.22	8.7–19.3
4. Chest depth	*a*	9.0	0.75	6.7–13.0				
5. Hip breadth: standing	*a*	13.2	0.73	8.3–15.8	*f*	15.0	1.03	11.8–18.9
5. Hip breadth: seated	*a*	13.9	0.87	11.4–18.1				
5. Hip breadth: seated	*c*	15.3	1.11	12.0–21.3	*d*	14.6	1.04	12.1–20.6
6. Shoulder height: sitting	*a*	23.3	1.14	18.9–27.2	*e*	24.6	3.02	
7. Back height	*c*	28.6	1.26	23.6–33.1	*d*	26.7	1.11	21.1–30.1
8. Shoulder-elbow	*a*	14.3	0.69	11.4–18.1	*e*	13.3	1.93	
9. Forearm-hand	*a*	18.9	0.81	15.4–22.1				
10. Arm reach	*a*	34.6	1.65	27.6–39.8	*f*	31.8	1.29	28.3–35.4
11. Arm span	*a*	70.8	2.94	58.3–82.3				
12. Elbow height: sitting	*a*	9.1	1.04	4.3–13.0	*d*	9.7	0.89	7.0–12.0
13. Buttock-knee	*a*	23.6	1.06	18.5–27.6	*f*	22.6	0.96	19.7–26.7
14. Seat length	*c*	18.9	0.96	15.4–23.1	*d*	18.2	1.04	15.2–22.2
15. Knee height: sitting	*a*	21.7	0.99	17.3–24.8	*e*	17.2	1.07	
16. Seat height	*c*	19.0	0.89	15.6–22.0	*d*	18.1	0.89	15.4–20.6
17. Knee breadth	*b*	8.1	0.49	6.7–11.0				
18. Foot length	*a*	10.5	0.45	8.9–12.2	*f*	9.6	0.40	8.9–10.9
19. Foot breadth	*a*	3.8	0.19	3.2–4.7				
20. Hand breadth	*a*	3.5	0.16	3.0–4.1				

* Group *d* data are medians; *e* and *f* data are means.
† Standard deviations for groups *b*, *c*, and *d* computed from data.
‡ Normal sitting height is usually about 2 in. lower than erect sitting height.
§ Range for height from Hooten and Staff
SOURCE: Data for group *a* (over 4000 Air Force flying personnel) from Hertzberg, Daniels, and Churchill
Data for group *b* (314 civilian vehicle drivers) from R. A. McFarland et al.

Data for group *c* (1959 civilian males) and group *d* (1908 civilian females) from Hooten and Staff,
Data for group *e* (10,042 civilian females, ages 18 to 82) from R. O'Brien and W. C. Shelton

Data for group *f* (447 female pilots) from Randall, Damon, Benton, and Patt

From HUMAN FACTORS ENGINEERING by Ernest J. McCormick. Copyright 1957, 1964 by McGraw-Hill, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
427	SYSTEM - S20 HUMAN- H2, H5	Reference 362, p. 352 - 353. Based on References 278, 274, 425, 366, 401.

MALE HUMAN BODY DIMENSIONS

Selected dimensions of the human body (ages 18 to 45) suitable for initial design of crew space and equipment.

		DIMENSIONAL ELEMENT	DIMENSION (in inches except where noted) 5th PERCENTILE	95th PERCENTILE
		Weight	132 LB	201 LB
A	1	Vertical reach	77.0	89.0
	2	Stature	65.0	73.0
	3	Eye to floor	61.0	69.0
	4	Side arm reach from CL of body	29.0	34.0
	5	Crotch to floor	30.0	36.0
B	1	Forward arm reach	28.0	33.0
	2	Chest circumference	35.0	43.0
	3	Waist circumference	28.0	38.0
	4	Hip circumference	34.0	42.0
	5	Thigh circumference	20.0	25.0
	6	Calf circumference	13.0	16.0
	7	Ankle circumference	8.0	10.0
	8	Foot length	9.8	11.3
	9	Elbow to floor	41.0	46.0
C	1	Head width	5.7	6.4
	2	Interpupillary distance	2.27	2.74
	3	Head length	7.3	8.2
	4	Head height	—	10.2
	5	Chin to eye	—	5.0
	6	Head circumference	21.5	23.5
D	1	Hand length	6.9	8.0
	2	Hand width	3.7	4.4
	3	Hand thickness	1.05	1.28
	4	Fist circumference	10.7	12.4
	5	Wrist circumference	6.3	7.5
E	1	Arm swing, aft	40 degrees	40 degrees
	2	Foot width	3.5	4.0
F	1	Shoulder width	17.0	19.0
	2	Sitting height to floor (std chair)	52.0	56.0
	3	Eye to floor (std chair)	47.4	51.5
	4	Standard chair	18.0	18.0
	5	Hip breadth	13.0	15.0
	6	Width between elbows	15.0	20.0
G	0	Arm reach (finger grasp)	30.0	35.0
	1	Vertical reach	45.0	53.0
	2	Head to seat	33.8	38.0
	3	Eye to seat	29.4	33.5
	4	Shoulder to seat	21.0	25.0
	5	Elbow rest	7.0	11.0
	6	Thigh clearance	4.8	6.5
	7	Forearm length	13.6	16.2
	8	Knee clearance to floor	20.0	23.0
	9	Lower leg height	15.7	18.2
	10	Seat length	14.8	21.5
	11	Buttock-knee length	21.9	36.7
	12	Buttock-toe clearance	32.0	37.0
	13	Buttock-foot length	39.0	46.0

NOTE: All except critical dimensions have been rounded off to the nearest inch. For more thorough analysis see Hertzberg *et al.*

ITEM NO.	SUBJECT AREAS:	SOURCE:
428 a	SYSTEM- S20	Reference 586, p.5-17.
Page 1 of 2	HUMAN- H2, H5	Based on Reference 274.

FEMALE HUMAN BODY DIMENSIONS

Selected dimensions of the human body (ages 18 to 45) suitable for initial design of workplace and equipment.

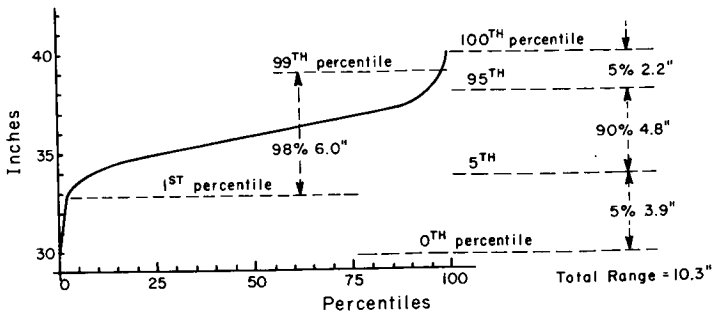
		DIMENSIONAL ELEMENT	DIMENSION (in inches except where noted) 5th PERCENTILE	95th PERCENTILE
		Weight	102 LB	150 LB
A	1	Vertical reach	69.0	81.0
	2	Stature	60.0	69.0
	3	Eye to floor	56.0	64.0
	4	Side arm reach from CL of body	27.0	38.0
	5	Crotch to floor	24.0	30.0
B	1	Forward arm reach	24.0	35.0
	2	Chest circumference (bust)	30.0	37.0
	3	Waist circumference	23.6	28.7
	4	Hip circumference	33.0	40.0
	5	Thigh circumference	19.0	24.0
	6	Calf circumference	11.7	15.0
	7	Ankle circumference	7.8	9.3
	8	Foot length	8.7	10.2
	9	Elbow to floor	34.0	46.0
C	1	Head width	5.4	6.1
	2	Interpupillary distance	1.91	2.94
	3	Head length	6.4	7.3
	4	Head height	—	9.0
	5	Chin to eye	—	4.25
	6	Head circumference	20.4	22.7
D	1	Hand length	6.2	7.3
	2	Hand width	3.2	4.0
	3	Hand thickness	0.84	1.14
	4	Fist circumference	9.1	10.7
	5	Wrist circumference	5.5	6.9
E	1	Arm swing, aft	40 degrees	40 degrees
	2	Foot width	3.2	3.9
F	1	Shoulder width	13.0	19.0
	2	Sitting height to floor (std chair)	45.0	55.0
	3	Eye to floor (std chair)	41.0	51.0
	4	Standard chair	18.0	18.0
	5	Hip breadth	12.5	15.4
	6	Width between elbows	11.0	23.0
G	0	Arm reach (finger grasp)	22.0	33.0
	1	Vertical reach	39.0	50.0
	2	Head to seat	27.0	38.0
	3	Eye to seat	25.0	32.0
	4	Shoulder to seat	18.0	25.0
	5	Elbow rest	4.0	12.0
	6	Thigh clearance	3.5	6.0
	7	Forearm length	14.0	18.0
	8	Knee clearance to floor	17.0	22.0
	9	Lower leg height	13.5	18.8
	10	Seat length	13.0	23.0
	11	Buttock-knee length	18.0	27.0
	12	Buttock-toe clearance	27.0	37.0
	13	Buttock-foot length	34.0	49.0

NOTE: All except critical dimensions have been rounded off to the nearest inch. For more thorough analysis see Daniels *et al.*

ITEM NO. 428 b
Page 2 of 2

SUBJECT AREAS:
SYSTEM - S20
HUMAN - H2, H5

SOURCE:
Reference 586, p. 5-19.
Based on Reference 157.



The percentile curve for sitting height with seat adjustability requirements for various percentile groups

Population Segments Most Likely to Become Space Crews. Because the dimensions of the crew and their range determine to a large extent the size, utility, and comfort of the accommodations, and because of the high cost of weight and space in a spacecraft, manned aerospace systems are customarily designed with reduced consideration for the upper and lower 5 per cent of the crew member population.

An example of the savings in space that can result from such a design philosophy is shown above. Design for 5th and 95th percentile men reduces the seat adjustment height range requirement to 4.2 inches from the 10.3 inches required to accommodate 100 per cent of the possible subjects. In certain cases this philosophy may result in the unsuitability for crew membership of otherwise qualified individuals in the neglected 10 per cent of the population. If people were uniformly proportioned, and if the only problem were to design for the minimum range of adjustment, the design size range might be restricted to, for instance, the central 25 per cent of the population. Other considerations make this solution unattractive, however. There exist very few average men, with respect to dimensions. A man with an 80th percentile trunk length may have a 20th percentile leg length, for example. In addition to the minimum-range problem there are also clearance and reach problems. If such a small percentile range were chosen as 25 per cent, it would be found that an even smaller percentage of the population could be accommodated with reasonable comfort.

ITEM NO.	SUBJECT AREAS:	SOURCE:
429	SYSTEM - S20 HUMAN - H2, H42	Reference 355, p. 239. Based on Reference 273.

TYPICAL CREW AREA REQUIREMENTS

Module	Function	Space Utilization	Space Required (Inches)
Living	Food preparation	Food preparation, standing	30 x 30 x 75
	Eating	Seating and table space (per man)	36 x 30 x 52
	Personal Hygiene	Shower (minimum)	32 diameter
		Standing clearance at lavatory	30 x 30 x 75
	Laundry	Standing clearance for washer/drier operation	30 x 30 x 75
	Human Waste	Utilization of commode and urinal tube	28 x 37 x 55
	Exercise	Sit-ups, arms extended (maximum exercise space requirement)	96 x 30 x 45
	Recreation	Seating and table space (per man)	36 x 30 x 52
	Paper work	Seating and table space (per man)	36 x 30 x 52
	Storage, food	Storage for 21 men and at .13 cu. ft./man/day	81.90 (cu. ft.)

All space dimensions are nominal unless otherwise indicated and all pertain to a 95th percentile crew member, unsuited.

ITEM NO.	SUBJECT AREAS:	SOURCE:
430-a Page 1 of 3	SYSTEM- S20 HUMAN- H33	Reference 378, p. 354.

TYPICAL CREW AREA REQUIREMENTS—Continued

Module	Function	Space Utilization	Space Required (Inches)
Living (Cont)	Storage, water	(with water reclamation subsystem)	6.6 (cu. ft.)
	Storage	Personal clothing storage at 3.57 cu.ft./man	10.57 (cu. ft.)
Laboratory	Laboratory research	Experimenter, clearance seated	36 x 30 x 52
		Experimenter, clearance standing	30 x 30 x 75
		Experimenter, hand clearance	5 x 2.75
		Subject, clearance seated	36 x 30 x 52
		Subject, clearance standing	30 x 30 x 75
		Subject, armspan (R to L fingertips)	75.5
		Subject, maximum overhead reach (measured from floor)	89
		Subject, prone, arms at side	73.7
Command	Command operations	Command center console (each station)	50 cu. ft.
General	Maintenance, Housekeeping	Clearance, standing	30 x 30 x 75
		Clearance, seated	36 x 30 x 52
		Clearance, supine, overhead operation (minimum)	20 x 20 x 73

All space dimensions are nominal unless otherwise indicated and all pertain to a 95th percentile crew member, unsuited.

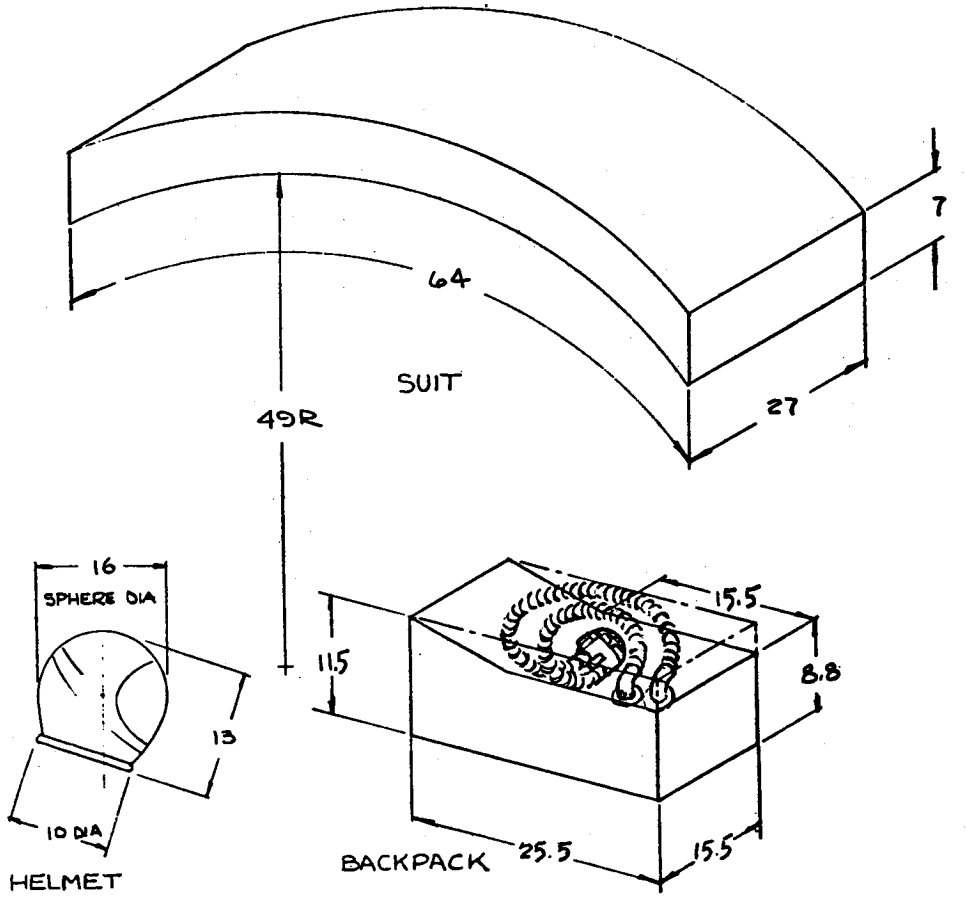
ITEM NO.	SUBJECT AREAS:	SOURCE:
430 b Page 2 of 3	SYSTEM - S20 HUMAN - H33	Reference 378, p.355.

TYPICAL CREW AREA REQUIREMENTS—Continued

Module	Function	Space Utilization	Space Required (Inches)
General (Cont)		Clearance, prone, forward operation (minimum)	17 x 20 x 96
		Clearance, kneeling (minimum)	20 x 42 x 56
		Clearance, squatting (minimum)	20 x 27 x 48
		Overhead reach (maximum) measured from floor	89
	Access to Hub	Access hatch	32 diameter
	Access to areas within module	Door-width (minimum)	20
	Movement place to place	Two men passing abreast (minimum width)	42
		Two men passing face-to-face (minimum width)	30

All space dimensions are nominal unless otherwise indicated and all pertain to a 95th percentile crew member, unsuited.

ITEM NO. 430 c Page 3 of 3	SUBJECT AREAS: SYSTEM - S20 HUMAN - H33	SOURCE: Reference 378, p. 356.



Storage Dimensions for Pressure Suits and Back Packs

ITEM NO.	SUBJECT AREAS:	SOURCE:
431	SYSTEM - S20 HUMAN - H44	Reference 378, p. 323.

INCREASE IN DIMENSIONS FROM CLOTHING

	Civilians		Army				Air Force		
	Men street clothing	Women street clothing	summer uniform	fall uniform	winter uniform	winter combat	full flight gear	light flight assembly	winter flight assembly
weight (lbs)	5.0	3.5	9.4	11.8	18.6	22.9			20.0
stature	1.0	0.5-3.0	2.65	2.65	2.65	2.75	-2.0	3.3	1.9
abdomen depth			0.94	1.18	1.95	2.54	5.0		1.4
arm reach, anterior			0.04	0.08	0.20	0.37			0.4
buttock-knee length			0.20	0.30	0.54	0.70	2.0		0.5
chest breadth							2.5		0.6
chest depth			0.41	0.96	1.80	1.54	4.5	0.8	1.4
elbow breadth			0.56	1.04	1.84	2.12	11.0		4.4
eye level height, sitting			0.04	0.08	0.16	0.22			0.4
foot breadth	0.3		0.20	0.20	0.20	0.20			1.2
foot length	1.2		1.60	1.60	1.60	1.60			2.7
hand breadth						0.30			0.4
hand length						0.15			0.3
head breadth			2.8	2.8	2.8	2.8			0.4
head length			3.5	3.5	3.5	3.5			0.4
head height			1.35	1.35	1.35	1.45			0.2
hip breadth			0.56	0.76	1.08	1.40			1.3
hip breadth, sitting			0.56	0.76	1.08	1.40	5.5	2.9	1.7
knee breadth			0.48	0.48	0.72	1.68	9.5		2.5
knee height, sitting			1.32	1.32	1.44	1.44			1.8
shoulder breadth			0.24	0.88	1.52	1.16	6.0	0.4	1.3
shoulder-elbow length			0.14	0.50	0.94	0.62			0.3
shoulder height, sitting			0.16	0.58	0.92	0.80			0.6
sitting height			1.39	1.43	1.61	1.67		2.1	0.6

(All dimensions are given in inches)

Civilians, men: underwear, shirt, trousers, tie, socks, shoes.
Civilians, women: underwear, dress, or blouse or sweater and skirt, shoes.
Army, summer uniform: underwear, khakis or O. D. 's or fatigues, socks, shoes, helmet and liner.
Army, fall uniform: underwear, khakis or O. D. 's or fatigues, blouse or field jacket, socks, shoes, helmet and liner.
Army, winter uniform: underwear, khakis or O. D. 's or fatigues, blouse or field jacket, overcoat, socks shoes, helmet and liner.
Army, winter combat: underwear, khakis or O. D. 's or fatigues, combat suit, overcoat, socks, shoes, gloves, wool cap, helmet and liner.
Air Force, full flight gear: T-1 partial pressure suit, inflated; ventilation suit, deflated, MD-1 anti-exposure suit and MD 3A liner, long cotton underwear.
Air Force, light flight assembly: T-5 partial pressure suit, uninflated; K-1 pressure helmet and boots.
Air Force, winter flight assembly: World War II heavy winter flying clothing, including jacket, trousers, helmet, boots, and gloves.

Source: Anthropology Branch, 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, 1963.

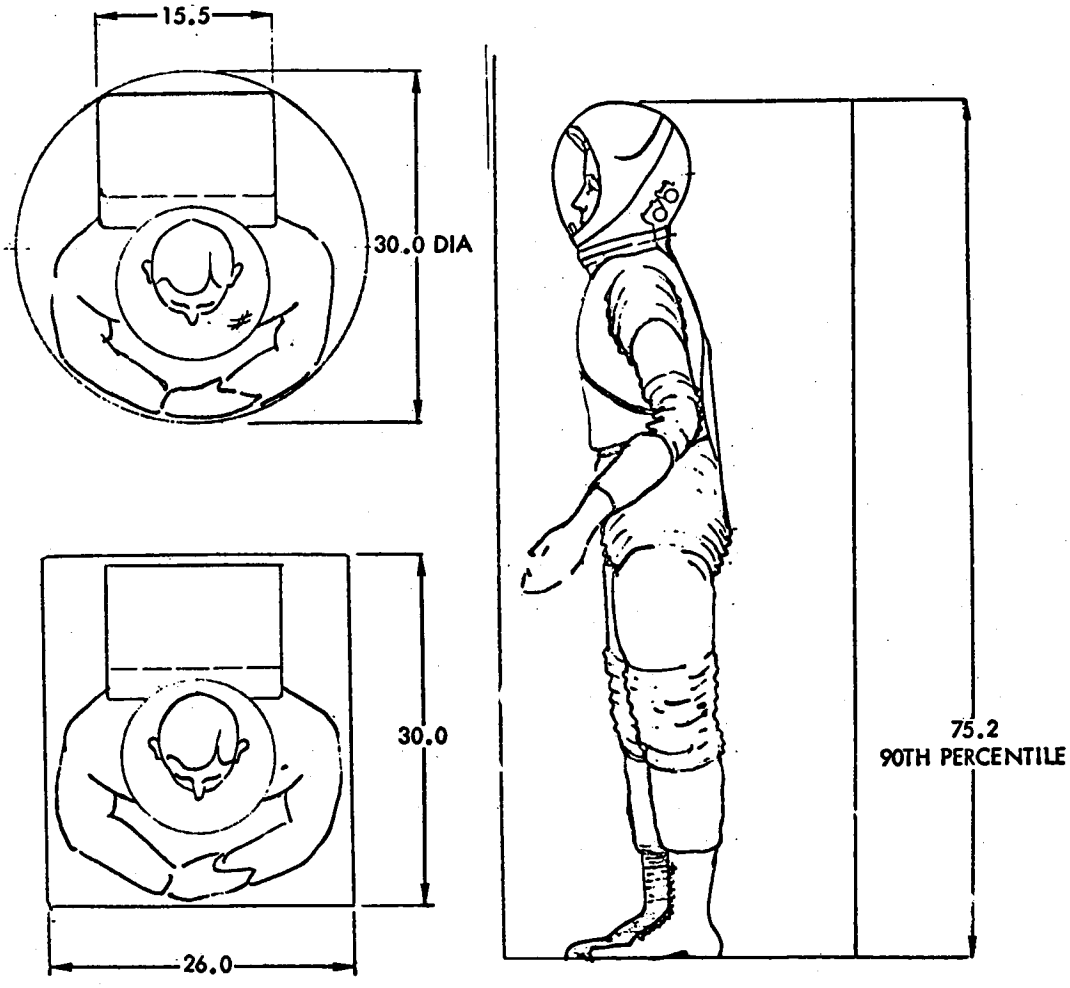
ITEM NO.	SUBJECT AREAS:	SOURCE:
432	SYSTEM - S20 HUMAN - H2, H5, H44	Reference 554, p. 255.

CREW ANTHROPOMETRIC DIMENSIONS

Parameter	Nude Dimension (5th% - 95th%)	Unpressurized Full Pressure Suit Added Increment In Inches	Pressurized Full Pressure Suit Added Increment In Inches
Sitting Height	33.8 - 38.0	1.5 - 2.5	1.5 - 2.5
Shoulder Height, Sitting	21.3 - 25.1	0.25 - 1.0	0.5 - 1.5
Elbow Rest Height, Sitting	7.4 - 10.8	0.0 - (-0.25)	-0.25 - (-1.0)
Thigh Clearance Height, Sitting	4.8 - 6.5	0.0 - (-0.5)	0.25 - 1.0
Popliteal Height, Sitting	15.7 - 18.2	0.5 - 1.0	0.0 - (±1.0)
Knee Height, Sitting	20.1 - 23.3	0.5 - 1.0	1.0 - 2.5
Buttock-Knee Length	21.9 - 25.4	0.25 - 1.0	0.5 - 2.5
Functional Reach	29.7 - 35.0	0.0 - (-1.0)	0.0 - (-3.0)
Elbow-to-Elbow Breadth	15.2 - 19.8	0.5 - 1.0	1.0 - 5.0
Hip Breadth, Sitting	12.7 - 15.4	0.25 - 1.0	1.0 - 2.5
Shoulder Breadth	16.5 - 19.4	0.25 - 1.0	1.0 - 3.0
Chest Depth	8.0 - 10.4	0.25 - 1.0	1.0 - 2.5
Waist Depth	6.7 - 9.5	0.25 - 1.0	1.0 - 3.5
Foot Length	9.8 - 11.3	1.0 - 3.0	1.0 - 3.0
Foot Breadth	3.5 - 4.1	1.0 - 2.0	1.0 - 2.0
Head Length	7.3 - 8.2	3.5 - 5.0	3.5 - 5.0
Head Breadth	5.74 - 6.40	5.6 - 6.5	5.6 - 6.5

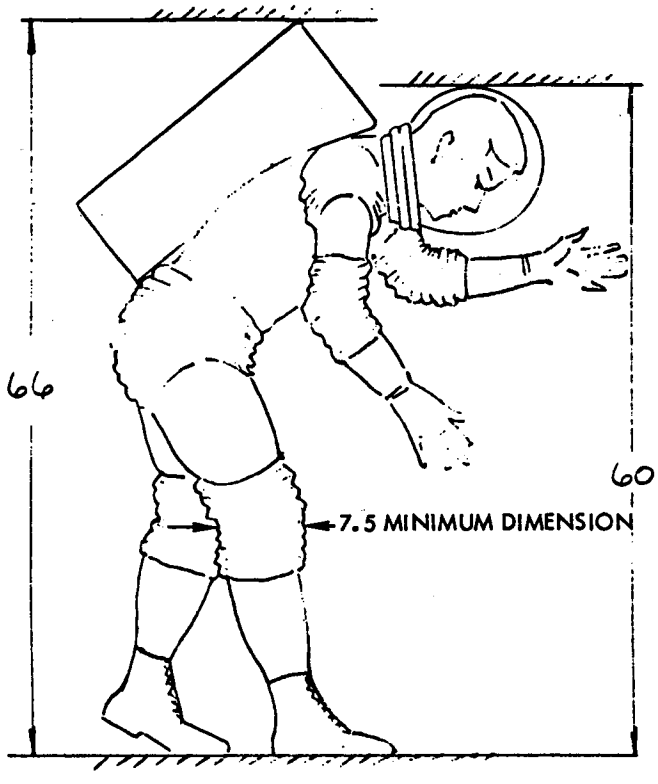
This presents the anthropometric dimensions for the nude male (5th through the 95th percentile). In addition, the increase in inch allowance as a result of wearing the pressure suit unpressurized and pressurized is shown.

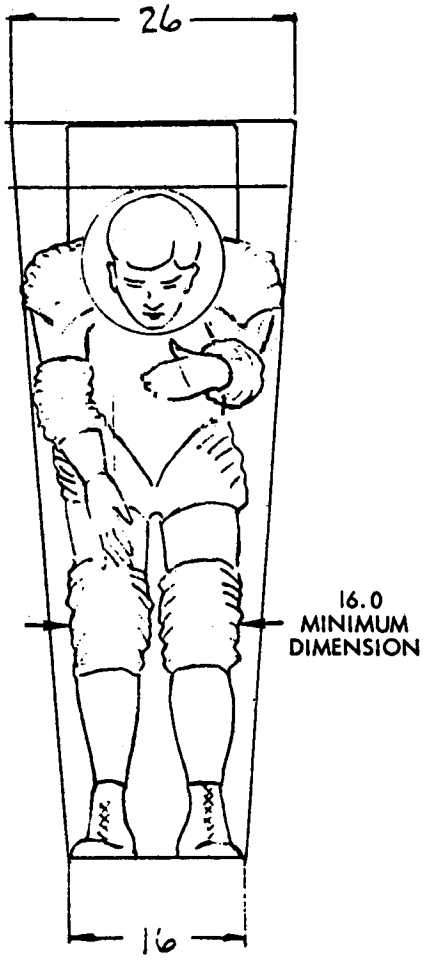
ITEM NO.	SUBJECT AREAS:	SOURCE:
433.	SYSTEM - S20 HUMAN - H2, H44	Reference 378, p. 357.



Ingress and Egress Hatch Dimensions

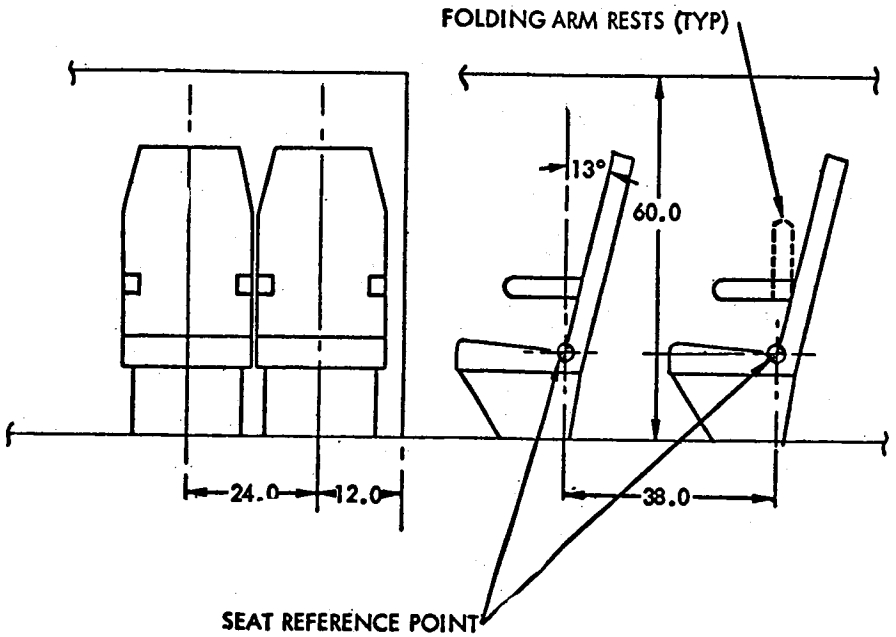
ITEM NO.	SUBJECT AREAS:	SOURCE:
434-	SYSTEM - S20 HUMAN - H2, H44	Reference 378, p. 324.





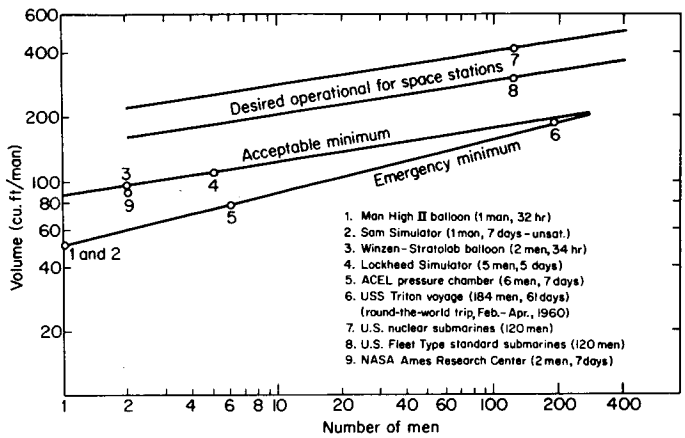
Minimum Aisles and Passageway Dimensions for Pressure-Suited Crewmen

ITEM NO.	SUBJECT AREAS:	SOURCE:
435.	SYSTEM - S20 HUMAN - H2, H44	Reference 378, p. 322



Minimum Dimensions for Seating Passengers in Pressure Suits

ITEM NO.	SUBJECT AREAS:	SOURCE:
436	SYSTEM - S20 HUMAN - H2, H44	Reference 378, p. 321.



Living space per man for several sealed cabin experiments (exclusive of equipment space).

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963.
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ITEM NO.	SUBJECT AREAS:	SOURCE:
437	SYSTEM - S20 HUMAN - H33, H40.	Reference 219, p. 450.

STATURE–WEIGHT–AGE AVERAGES, MEN

HEIGHT FT	HEIGHT IN	AGE 16	17	18	19	20	21	22	23	24	25-29	30-34	35-39	40-44
5	00	101	103	105	107	110	112	114	116	118	122	126	128	131
5	1	106	108	110	112	115	117	119	121	123	124	127	130	133
5	2	111	113	116	117	120	121	122	123	124	126	130	132	135
5	3	115	117	119	121	124	125	126	127	128	129	133	135	138
5	4	119	120	122	124	127	128	129	130	131	133	136	138	140
5	5	124	125	126	128	130	131	132	133	135	137	140	142	145
5	6	128	129	130	132	133	134	135	137	139	141	144	146	149
5	7	133	134	135	136	137	138	140	141	143	145	148	150	153
5	8	137	138	139	140	141	142	144	146	147	149	152	155	158
5	9	141	142	143	144	145	147	148	150	151	153	156	160	163
5	10	145	146	147	148	149	151	153	155	156	157	161	165	168
5	11	150	151	152	153	154	156	158	160	161	162	166	170	174
6	00	155	156	157	158	160	162	164	165	166	167	172	176	180

This table, representing average actual weights, is based on a table published by Florence L. Meridith.

ITEM NO.	SUBJECT AREAS:	SOURCE:
438	SYSTEM - S21 HUMAN - H2, H3, H4	Reference 586, p. 5-22. Based on Reference 370.

SUIT WEIGHT BY COMPONENT

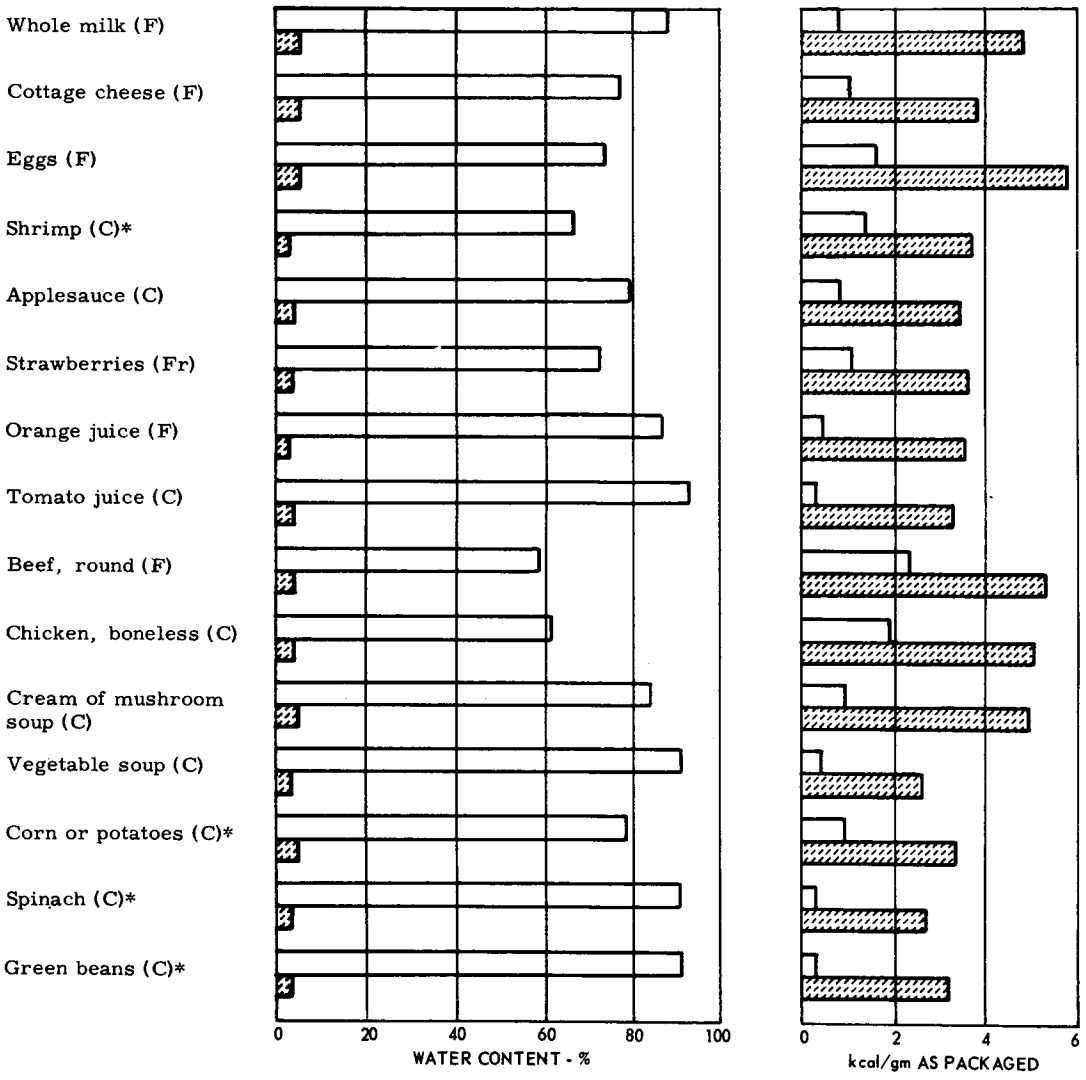
	Suit I		Suit II		Suit III		Suit IV	
	Lb	Oz	Lb	Oz	Lb	Oz	Lb	Oz
Suit	19	6	11	0	9	6	12	0
Helmet	6	4	5	0	6	4	5	0
Gloves	0	12	0	8	1	0	1	0
Boots	5	10	3	6	3	6	3	6
Underwear	1	0	1	0	1	0	1	0
Total weight	33	0	20	14	21	0	22	6

This table compares weights of four full-pressure suits.

From HUMAN FACTORS IN TECHNOLOGY edited by Edward Bennett, James Degan and Joseph Spiegel. Copyright 1963 by the McGraw-Hill Book Company, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
439	SYSTEM - S21 HUMAN - H44	Reference 87, p. 195.

WEIGHT OF FRESH AND DEHYDRATED FOODS



*Data based on drained solids.

(F) Fresh, (C) Canned, (FR) Frozen Food

Dehydrated Food

ITEM NO.	SUBJECT AREAS:	SOURCE:
440	SYSTEM - S21 HUMAN - H43	Reference 554, p. 195. Based on Reference 533.

a

WATER BALANCE (GRAMS)

Water In			*Water Out*
Water in food and drink	2550	1300	Insensible perspiration and lung loss
Water of oxidation	350	1500	Urine
		100	Feces
TOTAL	2900	2900	TOTAL

NOTE: It is assumed that the man is thermally comfortable and that sweat loss is zero.

b

MASS BALANCE (GRAMS)

Mass In			*Mass Out*
Oxygen	850	1000	Carbon Dioxide
Dry Food	600	150	Feces
Water	2550	1550	Urine
		1300	Insensible perspiration and lung loss
TOTAL	4000	4000	TOTAL

NOTE: It is assumed that the man is thermally comfortable and that sweat loss is zero.

The human body loses water by several routes. These are as follows:

a. Insensible perspiration—This is water lost as vapor by diffusion through a dry non-sweating skin. The loss is small, amounting to 0.8 grams per hour per mm Hg water-vapor pressure difference between skin and surrounding gas. The rate of water-vapor loss is unaffected by wind speed.

b. Humidification of the expired air—The amount of water vapor lost from the respiratory system depends primarily on the ambient humidity and on the rate of gas exchange between the lungs and the environment. Under normal circumstances 20 to 25 percent of the metabolic rate is dissipated in the latent heat of vaporization of water taken up by the expired air. An average daily loss would be about 3.0 lbs.

c. Sweating—Frank sweating does not begin until mean skin temperature exceeds 92 to 93° at rest. Sweat rate then rises linearly with skin temperature. Very large quantities of sweat can be produced by the human body (Reference 13-8) although during routine flights in space vehicles the basic aim is to produce an environment which does not cause sweating at all. Sweat can also be produced by psychogenic factors but the amounts here are normally small.

d. Urine—Normal loss of water in urine is about 3 lbs. per day. The kidney is the principal control mechanism for maintaining body water content at the correct level. Thus, if an excess of water is taken in, urinary volume will be higher, and if the body becomes dehydrated, urinary water falls to a minimum value of 1.0 to 1.5 lbs. per day.

e. Feces—Fecal water normally amounts to about 100 grams per day although this may be less with low-residue diets. Water gained by the body comes from that contained in food, that which is drunk, and that which is produced by chemical reactions in the body. (This "water of metabolism" normally amounts to about 350 grams per day.)

The amount of water ingested must equal the amount of water lost by the routes described above, less the metabolic water production if body hydration is to be maintained. This requirement represents the mass of water which has to be supplied per day for each crew member.

A typical water balance sheet is shown and the corresponding mass balance. Both water and mass balances must be equal if the body weight and state of hydration are to remain constant in space flight.

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
441	SYSTEM - S21 HUMAN - H43	Reference 74, p. 108.

AVAILABLE WEIGHT SAVINGS IN PROGRESSIVE CLOSING OF AN ECOLOGICAL SYSTEM

System	Maximum Weight Saving Incentive
Reclaim Wash Water	12.0 lb/Man-Day
Reclaim Water From Respiration and Perspiration	5.5 lb/Man-Day
Reclaim Water From Urine	3.2 lb/Man-Day
Regenerable CO_2 Removal	2.6 lb/Man-Day
Recovery of O_2 From CO_2	1.64 lb/Man-Day
Reclaim Water From Feces	.26 lb/Man-Day

Purser, P. E.; Faget, M. A.; and Smith, N. F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
442	SYS - S21 HUM. N - H47	Reference 483, p. 138.

GENERATION OF FECES

Type of Diet	Wet Weight of Feces				Dry Weight of Feces		Sources
	Mean		Range				
	lbs/day	gms/day	lbs/day	gms/day	lbs/day	gms/day	
Mixed	-	-	0.13-0.55	60-250	-	-	Diem
Mixed	0.33	150	-	-	0.13	61	Goldblith and Wick
Unspecified	0.25	115	0.16-0.29	74-156	-	-	Harrison
Mixed	-	-	0.24-0.37	110-170	0.06-0.10	25-45	Hawk and Bergheim
Mixed	-	-	0.24-0.44	100-200	-	-	Sunderman & Boerner
Unspecified (30 cases)	0.25	115	-	-	0.05-0.07	23.6-30.2	Wozasek and Steigmann
Unspecified (15 cases)	-	-	-	-	0.11-0.17	52-75	Wozasek and Steigmann
Unspecified	0.44	200	-	-	-	-	Davidson and Wells
Unspecified	-	-	-	-	0.06-0.07	25-30	Gradwohl
Unspecified	0.26	120	-	-	0.04	20	Mattoni and Sullivan
Vegetable	0.81	370	-	-	-	-	Diem
Vegetable	0.78	350	-	-	0.16	75	Hawk and Bergheim
Meat	-	-	0.12-0.14	54-64	-	-	Diem
Fasting man	-	-	0.015-0.018	7-8	-	-	Hawk and Bergheim

ITEM NO.	SUBJECT AREAS:	SOURCE:
443	SYSTEM - S21 HUMAN - H11, H43	Reference 554, p. 219. Based on several primary sources.

Laboratory Tests

Test x Fasting Specimen	Astronauts Selected - 12 (2 Dynasoar)	
	Mean	Range
x Hgb-gm/100 ml	16.6	14.5 - 17.6
x Leucocytes-1000/mm^3	6.9	3.9 - 10
x Sed rate-mm/hr	4.3	1 - 8
x Cholesterol-mg/ml	248	184 - 320
x Na in mEq/l	143	139 - 144
x K in mEq/l	4.5	4.0 - 5.5
x Cl in mEq/l	104.6	99 - 108
x CO_2 in mM/l	26.1	23 - 30
x Sugar-mg/100 ml	99	88 - 108
x PBI-micrograms/100 ml	5.6	3.5 - 6.9
x BSP-% retention (45 min)	3.4	2 - 6.9
17 KGS-mg/24 hrs	17.1	11.1 - 23
17 KS-mg/24 hrs	12.1	9.9 - 17.5
Height-cm	176	168 - 180
Weight-Kg	74.4	60.9 - 81
Body surface area-m^2	1.91	1.70 - 2.06
Lean body mass-Kg	65.1	57.0 - 71.1
Total body potassium-gms	173	150 - 199
Total body water-liters	41.4	37 - 44.6
Blood volume-liters	4.97	4.13 - 6.91
Total circ. hgb-gms	0.791	0.674 - 1.120
Total lung capacity-liters	7.00	6.24 - 8.12
Functional residual capacity-liters	3.34	2.78 - 4.23
Vital capacity-liters	5.60	5.11 - 6.24
Residual volume-Liters	1.40	0.93 - 2.00
Maximum breathing capacity-liters	184	155 - 247
Nitrogen clearance equivalent	11.5	9.2 - 17.5
Final O_2 uptake during exercise-1 min	2.48	1.92 - 2.84

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
444.	SYSTEM - S20, S21 HUMAN - H1, H7, H11	Reference 333, p. 50.

Physical Characteristics with Coefficient of Variation for 65 Pilots

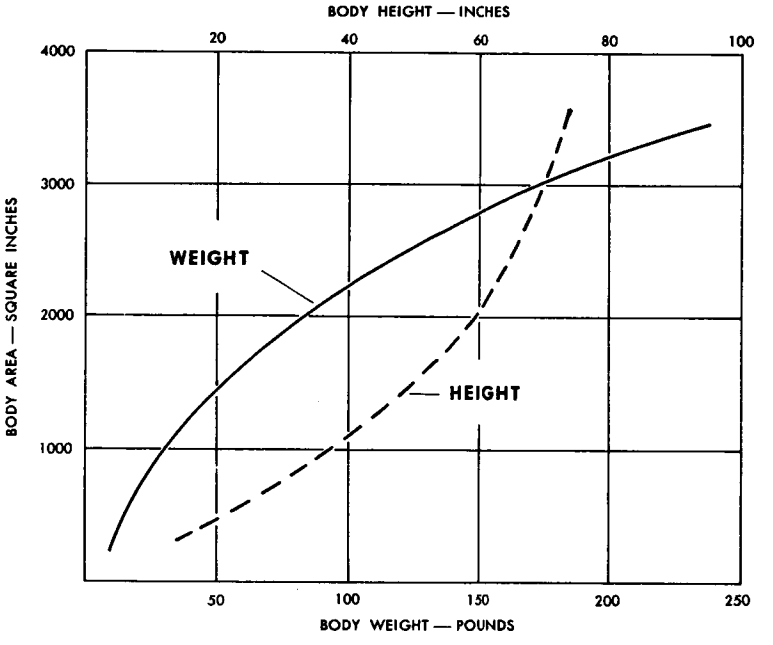
65 Male Subjects

	Mean, S.D.	Coeff. var.
Height, cm	177 ± 4.8	3 %
Weight, kg	75 ± 7.7	10 %
Body Surface Area, m^2	1.92 ± .11	6 %
Age	33 ± 3.5	10 %

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ITEM NO.	SUBJECT AREAS:	SOURCE:
445	SYSTEM - S20, S21 HUMAN - H1, H41	Reference 333, p. 55.

BODY SURFACE AREA



ITEM NO.	SUBJECT AREAS:	SOURCE:
446	SYSTEM - S20, S21 HUMAN - H2, H3	Reference 586, p. 5-24. Based on Reference 91.

EFFECT OF VARIOUS TYPES OF CLOTHING ON HUMAN BODY DIMENSIONS

(All dimensions in parentheses are negative values)

DIMENSION	STREET CLOTHES		WINTER CLOTHES		HEAVY FLIGHT CLOTHING	PRESSURE SUITS[a]	
	MEN	WOMEN	MEN	WOMEN		UNPRES-SURIZED	PRES-SURIZED
Weight	5 lb	3½ lb	10 lb	7 lb	12–15 lb	21 lb	21 lb
Stature	1 in.	½–3¾ in.	1 in.	½–3¾ in.	3 in.	3½ in.	2½ in.
Vertical reach	1	½–3¾	1	½–3¾	i	(–2½)	(–16½)
Eye height, standing	1	½–3¾	1	½–3¾	1	(–3½)	2½
Crotch to floor	1	½–3¾	1	½–3¾	1	(–1)	(–1)
Foot length	1¼	½	1½	½–¾	1	1	1
Foot width	½–¾	¼–(–½)[b]	½–1	¼–½	¾	¾	¾
Head length	—	—	—[c]		4½	4½	4½
Head width	—	—	—[c]		4½	4½	4½
Hand length	—	—	¾	½	½	½	¼
Hand width	—	—	½	¼	½	½	1
Hand thickness	—	—	½	¼	½	¾	1¼
Fist circumference	—	—	1	¾	1	1¼	3
Shoulder width	½	¼	2–3	1	1½	1	½
Hip width	½	¼	2–3	1	1½	1	2¾
Elbow-to-elbow width	¾	¼	2–3½	1–1½	1	6	9
Thigh clearance	½	¼	1	¾	2	1¾	2
Forearm-to-fist length	½	¼	¾	½	1	1½	5½

[a] Certain pressurized garments are designed for seated position and therefore shorten certain dimensions. The helmet however, tends to rise under pressure.

[b] Women's dress shoes confine and shrink foot width.

[c] An Army steel helmet is approximately 12 by 10¼ inches.

ITEM NO.	SUBJECT AREAS:	SOURCE:
447	SYSTEM - S20, S21 HUMAN - H2, H3, H44	Reference 586, p. 5-21.

RECOMMENDED POST-LANDING GLOBAL SURVIVAL KIT

Item	Configuration I Escape Capsule (3 crewmen)			Configuration IA Individual Ejection Seats (3 crewmen)			Configuration II (3 crewmen + 5 passengers)		
	Quantity	Weight (pounds)	Volume (cubic inches)	Quantity	Weight (pounds)	Volume (cubic inches)	Quantity	Weight (pounds)	Volume (cubic inches)
Matches		0.5	35	3	0.9	63		1.0	70
Knife	2	1.8	12	3	2.7	18	3	2.7	18
Signal mirror	1	0.5	4	3	1.5	12	2	1.0	8
Compass	1	0.3	10	3	0.9	30	2	0.6	20
Flares	2	0.5	20	6	1.5	60	4	1.0	40
Whistle	2	0.2	4	3	0.3	6	2	0.2	4
Dye marker	2	0.4	12	3	0.6	18	2	0.4	12
First aid kit	1	0.3	20	3	0.9	60	2	0.6	40
Snare wire	1	0.1	1	3	0.3	3	2	0.2	2
Fishing kit	1	0.3	16	3	0.9	48	2	0.6	32
Plastic water container	3	0.9	9	3	0.9	9	8	2.4	24
Sea water desalt kit	3	4.2	120	3	4.2	120	8	11.2	320
Candle	2	0.3	30	3	0.5	45	4	0.6	60
Rations, ST-5 (3 days)	3	8.25	300	3	8.25	300	8	22.0	800
Rations, RS-11 (4 days)	6	24.0	1,020	6	24.0	1,020	16	64.0	2,720
Radio, URC-11	1	3.0	270	3	9.0	810	2	6.0	540
Battery, BA-1315/U	7	17.5	630	21	52.5	1,890	7	17.5	630

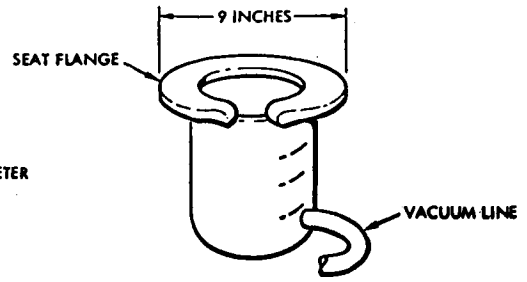
ITEM NO.	SUBJECT AREAS:	SOURCE:
448 a	SYSTEM- S20, S21	Reference 378, p. 394.
Page 1 of 2	HUMAN- H44	

RECOMMENDED POST-LANDING GLOBAL SURVIVAL KIT (continued)

Item	Configuration I Escape Capsule (3 crewmen)			Configuration IA Individual Ejection Seats (3 crewmen)			Configuration II (3 crewmen + 5 passengers)		
	Quantity	Weight (pounds)	Volume (cubic inches)	Quantity	Weight (pounds)	Volume (cubic inches)	Quantity	Weight (pounds)	Volume (cubic inches)
Complete down clothing assembly	3	24.0	1,020	3	24.0	1,020	8	64.0	2,720
Headnet, mosquito	3	0.4	5	3	0.4	5	8	1.1	9
Heat tabs (with stove)	2	0.4	12	3	0.6	18	4	0.8	24
Drinking water 2 quarts	3	12.0	192	3	12.0	192	8	32.0	512
Goggles, ski	3	0.75	36	3	0.75	36	8	2.0	96
Spoon	3	0.27	6	3	0.27	6	8	0.72	16
Razor and case	3	1.23	6	3	1.23	6	8	3.28	16
Whetstone	1	0.17	4	3	0.51	12	2	0.34	8
Salt tablets (40 per tube)	2	0.4	12	3	0.6	18	3	0.6	18
Soap tissues	3	0.8	12	3	0.8	12	8	2.1	32
Monocular (with case)	1	0.75	20	3	2.25	60	2	1.5	40
6-inch flat file	1	0.14	2	3	0.42	6	2	0.28	4
Combination tool and case	1	1.84	35	3	5.52	105	2	3.68	70
Rifle (MK-4)	1	3.6	90	3	10.8	270	2	7.2	180
Ammunition (0.22 Hornet M-67)	1	1.56	17	3	4.68	51	2	3.12	34
Plastic canteen (3 pints)	3	0.18	6	3	0.18	6	8	0.48	16
Survival manual	1	0.44	13	3	1.32	39	2	0.88	26
Pk-2, 1-man life raft				3	21.4	1,060			
A-3B, 4-man life raft	1	20.0	990				2	40.0	1,980
Totals		131.98	4,991		197.58	7,434		296.08	11,141
Weight per man		44.0	0.96 ft^3		65.8	1.32 ft^3		37	0.805 ft^3

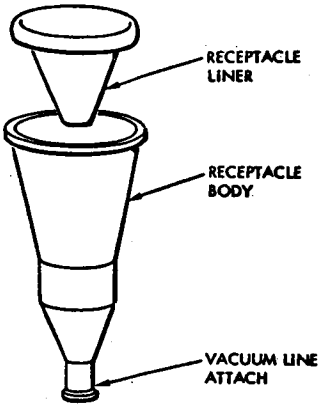
ITEM NO.	SUBJECT AREAS:	SOURCE:
448 b	SYSTEM - S20, S21	Reference 378, pp. 395-396.
Page 2 of 2	HUMAN - H44	

- ALUMINUM
- 8 INCHES HIGH BY 4-1/2 INCH DIAMETER
- 16 POUNDS, INCLUDING BAGS



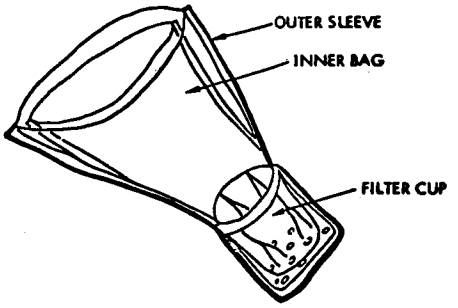
Fecal Canister

- 2-1/2 INCH DIAMETER BY 5 INCHES HIGH
- 1/2 POUND



Urine Receptacle Assembly

- DUAL USE
- 8 INCHES BY 4 INCHES



Fecal-Emesis Bag

ITEM NO.	SUBJECT AREAS:	SOURCE:
449	SYSTEM - S20, S21 HUMAN - H46, H47	Reference 378, p. 326.

GENERATION OF SPACE FEEDING SYSTEMS

Parameter	System
Oxygen	1. Carry as water 2. Carry as compressed oxygen 3. Recycle by chemical treatment 4. Generate using photosynthetic material
CO_2	1. Absorb chemically 2. Absorb using algae 3. Mechanical discard (compression)
Food	1. Carry all dehydrated 2. Carry part and generate part 3. Generate all biologically
Waste	1. Use all as algal food 2. Use part and dehydrate remainder 3. Dehydrate all and store 4. Ash
Water	1. Carry all 2. Recycle through chemical, mechanical, or biological (algal) treatment

ITEM NO.	SUBJECT AREAS:	SOURCE:
450.	SYSTEM - S24 HUMAN - H47	Reference 416, p. 85. Based on Reference 97.

Resupply Requirements for a Six-Man Space Station, in Pounds per Month

Supply	Amount
Oxygen	360
Food	270
Leakage	1,500
Medical	
Crew rotation	600
Electromechanical spares	50
Engine spares	150
Miscellaneous	500
	3,430

ITEM NO.	SUBJECT AREAS:	SOURCE:
451	SYSTEM - S25 HUMAN - H43	Reference 101, p. 435.

A Comparison of the Discrimination Penalty for Unaccustomed Modes of Handling and Judgment. Remote Handling Requires Six to Ten Times Longer for Any Given Task (Pigg, 1961).

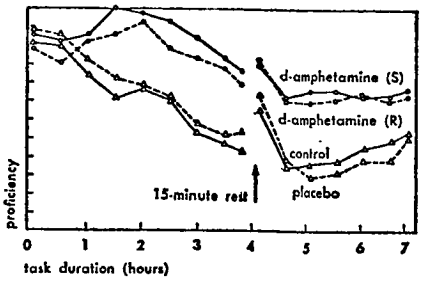
Basis of Judgment	Type of Handling	Difference Ratio
Weight	Direct	0.05
	Remote	0.08
Mass	Direct	0.10
	Remote	0.23

Some estimate of the extent of the handicap man will experience in the space environment can be obtained from this Table. Comparison of the modes of handling indicates the precision penalty imposed by loss of direct contact, while comparison by basis of discrimination indicates the importance of kinesthetic feedback.

Burns, N.M., et al., UNUSUAL ENVIRONMENTS AND HUMAN BEHAVIOR, (c), 1963. Reprinted by permission of The Macmillian Company, New York, New York.

ITEM NO.	SUBJECT AREAS:	SOURCE:
452	SYSTEM - S26 HUMAN - H25, H28	Reference 109, p. 364. Based on Reference 414.

EFFECT OF DRUGS ON PERFORMANCE



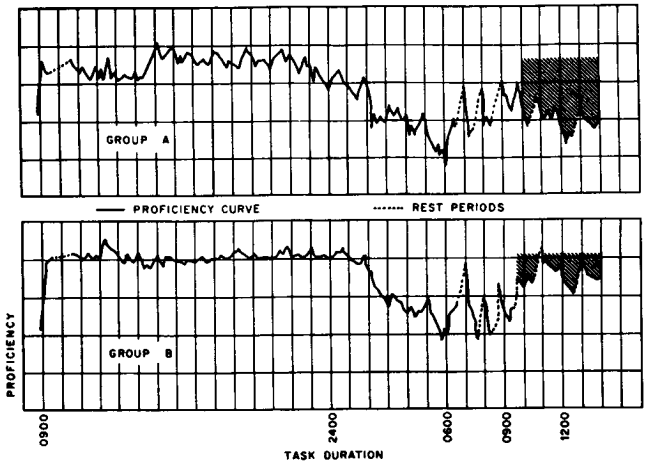
Following task training, d-amphetamine dosages were given to 2 of 4 groups required to perform a 7-hour operator task. The drug had considerable effect in sustaining proficiency. The effects of a single dosage (S) appear to be fully as efficacious as the effects of repetitive dosages (R).

The first question explored concerned the extent to which d-amphetamine (Dexidrene) would postpone the onset of fatigue and the consequent deterioration of proficiency. It was found that a standard dosage (5 mg) had the property of sustaining initial levels of proficiency for from four to seven hours of prolonged work. This was accomplished with no discernible evidence of an increase in physiological costs, which is in keeping with electrophysiological studies that have indicated the effects of d-amphetamine to be confined to those subcortical systems considered to be the physiological correlates of alertness. Finally, with the dissipation of analeptic effects there was no evidence of a letdown effect, that is, a refractory like state due to depletion of energy and manifested in such a case by abrupt loss of proficiency.

The second question concerned the extent to which this preparation would restore proficiency that had already deteriorated as a consequence of prolonged work. In a study designed to answer this question, a standard dosage of the drug was administered following 24 consecutive hours of work. The result was a sharp increase in proficiency. During the six remaining hours of work following this experimental treatment, proficiency was restored to the levels of the preceding day. The proficiency level of the subjects receiving a placebo preparation was approximately one half that of their initial levels of the preceding day.

The third question concerned the possibility of side effects, such as irrationality of judgment, lowered frustration thresholds, etc., which have been popularly ascribed to this and other analeptic preparations. In view of the practical consequences of such side effects, objective and systematic assessment was made. Only negative results were obtained. This indicates that if side effects are occasioned by a standard dosage of d-amphetamine, they are of such a low level as to be undetectable.

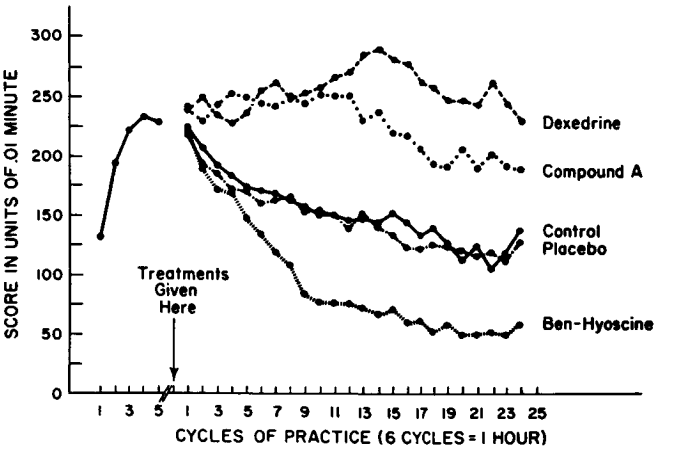
ITEM NO.	SUBJECT AREAS:	SOURCE:
453	SYSTEM- S26 HUMAN- H26, H38	Reference 263, p. 106.



Effect of drugs on performance decrement.

A standard doseage of 5 mg of d-amphetamine was administered to a group of subjects (Group B) following twenty-four hours of consecutive work. The figure shows a sharp increase in proficiency in Group B (lower curve) toward the end of the experiment. During the six remaining hours following the treatment, proficiency was restored to the levels of the preceding day. In contrast, the proficiency level of the subjects receiving a placebo (Group A, no drugs) was approximately one-half of their initial performance.

ITEM NO.	SUBJECT AREAS:	SOURCE:
454	SYSTEM- S26 HUMAN- H26, H38	Reference 219, p. 364. Based on Reference 263.

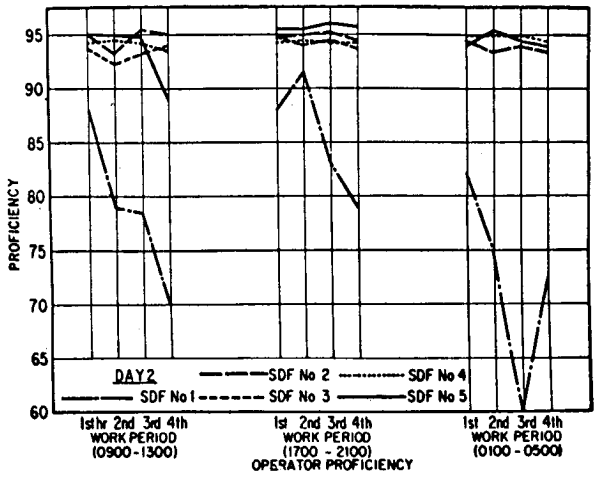


Effects of the pharmacological treatments upon task performance.

(From J. Exp. Psychol., Vol. 47, 1958, p. 271)

In experiments involving complicated compensatory pursuit tasks with simulated aircraft instruments and controls, the effect of drugs on task proficiency was studied. The effects of dexidrene and caffeine (Compound A) are striking and show that they help to maintain performance for about two hours.

ITEM NO.	SUBJECT AREAS:	SOURCE:
455	SYSTEM - S26 HUMAN - H26, H38	Reference 219, p. 364.

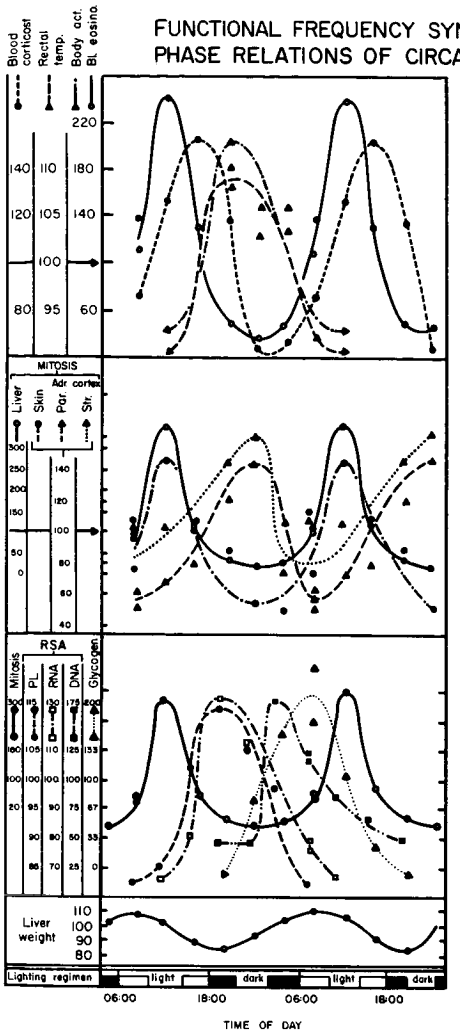


Operational Proficiency on a 4:4 Work-Rest Cycle

(From Steinkamp, et al., 1959.)

Indication of adjustment to the 4:4 ration of work and rest is given by the ability with which operators monitor their system in simulated flights, as shown in the figure above. The results show that, on the second day of the schedule, while one subject was not able to adjust, the other two did. Although the majority of test subjects adjusted to the 4:4 on-off schedule so far, it imposes a certain amount of stress on the operator at least during the conditioning period. There are several possible ways this can be remedied. First of all, the normal proficiency cycle of space pilots should be determined and their work-rest schedule designed accordingly. Secondly, man's normal work-rest cycle of eight hours work and sixteen hours no-work should be considered as a possible schedule.

ITEM NO.	SUBJECT AREAS:	SOURCE:
456	SYSTEM - S26 HUMAN - H29, H45	Reference 219, p. 374.



FUNCTIONAL FREQUENCY SYNCHRONIZATION AND PHASE RELATIONS OF CIRCADIAN RHYTHMS AT DIFFERENT ORGANIZATION LEVELS.

Body as a whole (activity) its core (temperature) and blood (eosinophils, corticosterone).

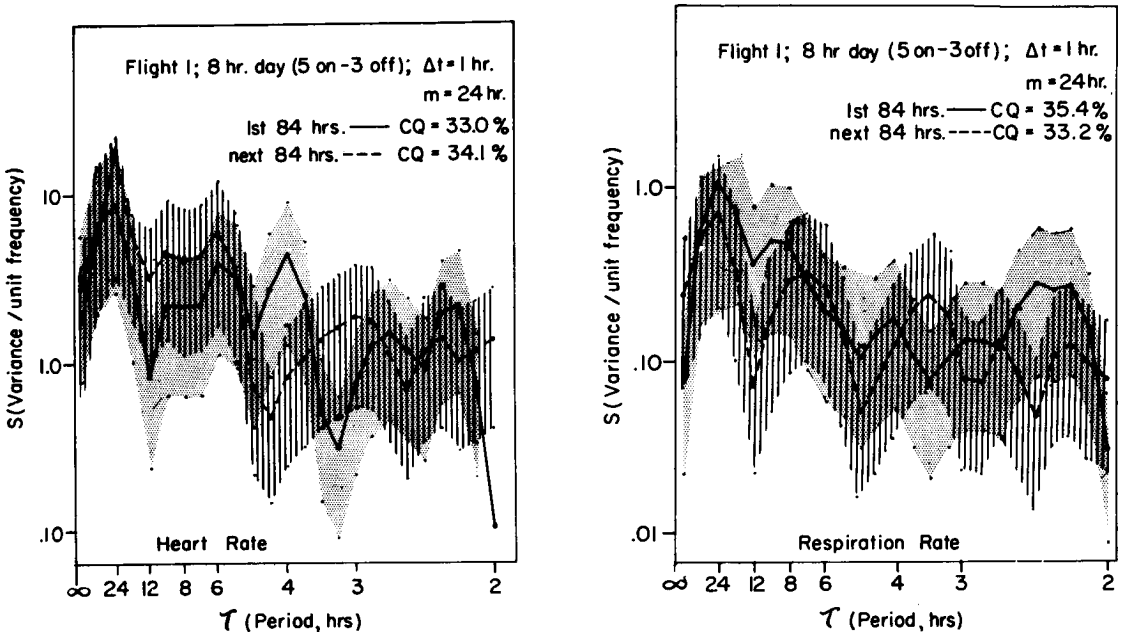
Different organs and tissues, (skin epidermis, liver parenchyma, adrenal cortical parenchyma and stroma).

Organ, different functions, (liver) ("formation" of phospholipid, of RNA, of DNA; glycogen content, mitosis, organ weight).

Circadian frequency synchronization with differences-in-phase—positive, negative, as well as zero. Ordinates are changes as per cent of series mean. RSA = relative specific activity, mouse.

Metabolic changes may be discussed either in terms of the periods involved or as frequencies, i.e., the reciprocals of the periods. Most prominent among such metabolic changes in the records of various body functions, is the circadian component showing one cycle in about 24 hours (see figure). It seems premature to delineate an exact range of circadian frequencies or periods, but tentatively one might set the circadian range from roughly 20 to 28 hours.

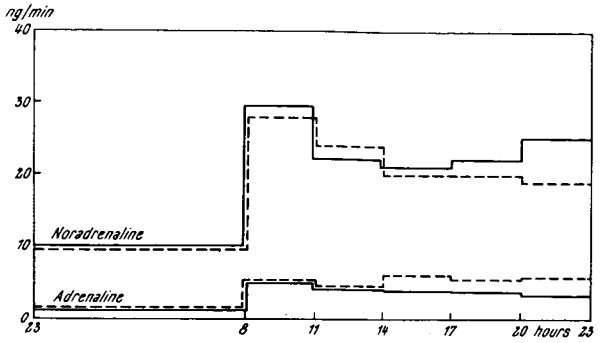
ITEM NO.	SUBJECT AREAS:	SOURCE:
457	SYSTEM - S28 HUMAN - H8, H19, H20	Reference 248, p. 183.



Variance spectra of heart rate (*left*) and respiration rate (*right*) during simulated space flight

It is generally recognized that classical periodicities characterize a given organ-system or organ and also that some of these rhythms, e.g., those of circulation and respiration, influence each other. However, these rhythms and their interactions are usually viewed as phenomena that are relatively independent of metabolic rhythms. The figure reveals, however, that circadian components and other metabolic frequencies are superimposed upon both respiration and circulation and, what seems more important, it allows for evaluation of the statistical uncertainty of such metabolic rhythms from a so-called variance spectrum.

ITEM NO.	SUBJECT AREAS:	SOURCE:
458	SYSTEM - S28 HUMAN - H9, H16, H19	Reference 248, p. 185.

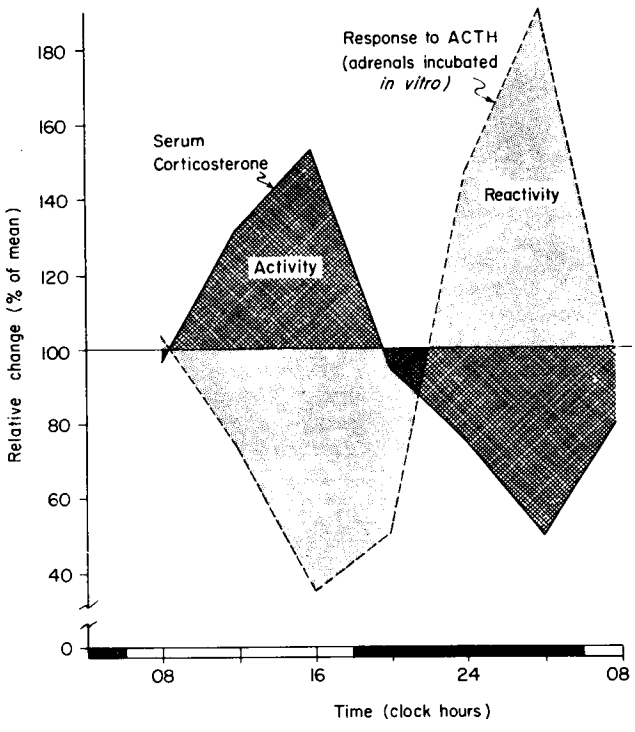


Diurnal variations in urinary excretion of adrenaline and noradrenaline in healty subjects (men, women) in ng/min.

The catecholamine excretion during recumbency and rest shows regularly low figures for both adrenaline and noradrenaline, amounting to 2 - 3 ng adrenaline per minute and 8 - 12 ng noradrenaline per minute (as hydrochloride uncorrected for about 20 per cent loss involved in the analytical procedure). During ordinary daily activity these figures are about twice as high.

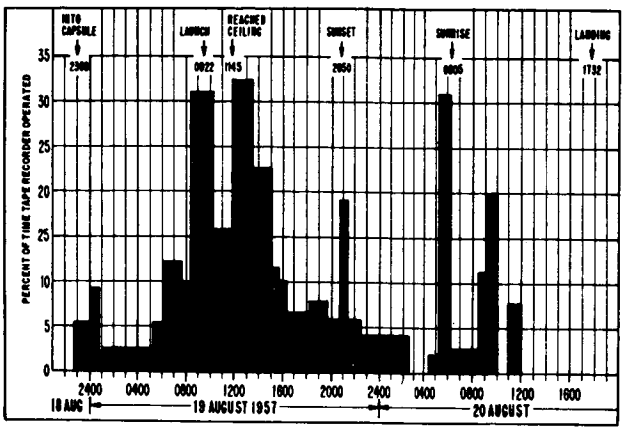
From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
459	SYSTEM- S28 HUMAN- H12, H19	Reference 188, p. 312. Based on Reference 190.



Time relations of circadian rhythms in adrenal reactivity to ACTH tested in vitro and in serum corticosterone. Note difference-in-phase. Inbred male C mice.

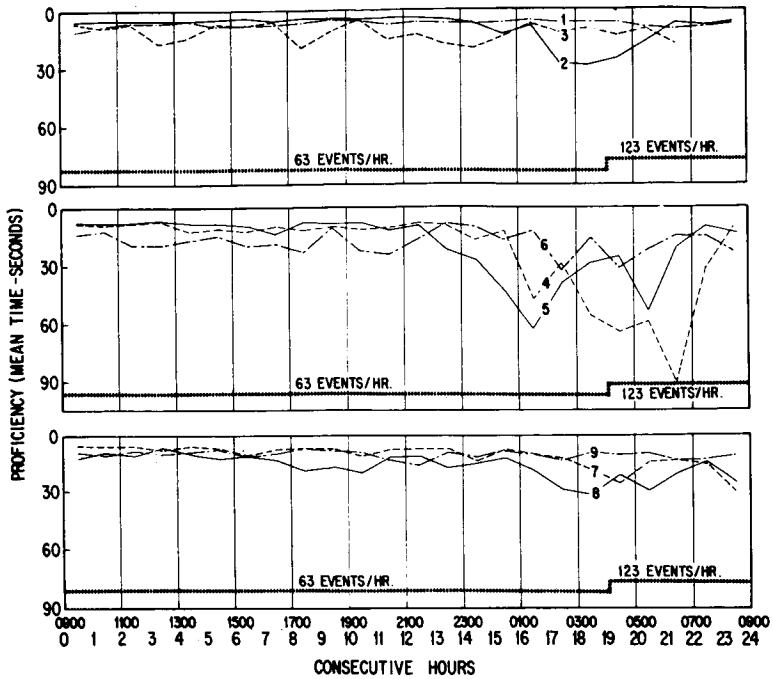
ITEM NO.	SUBJECT AREAS:	SOURCE:
460	SYSTEM - S28 HUMAN - H12, H19	Reference 248, p. 191. Based on Reference 526.



Spontaneous activity of the pilot of the MANHIGH II flight as measured by the per cent of time spent dictating to the on-board tape recorder.

Reliable objective measures of performance in operational situations are difficult to find, particularly measures that do not interfere with, or add additional burdens to, the primary task. One of the prime objectives of the MANHIGH II flight was to take maximum advantage of the opportunity to record as many observations as possible of subjective experiences and physical phenomena during the flight. A miniature tape recorder was reserved just for this purpose. No mandatory comment or scheduled reports were required on it. Thus, any time spent dictating to this recorder represented a form of initiative or spontaneous activity. The figure above is a bar graph in which the percentage of time spent dictating to this recorder is averaged over arbitrary periods selected partly when the time was identified on the tape.

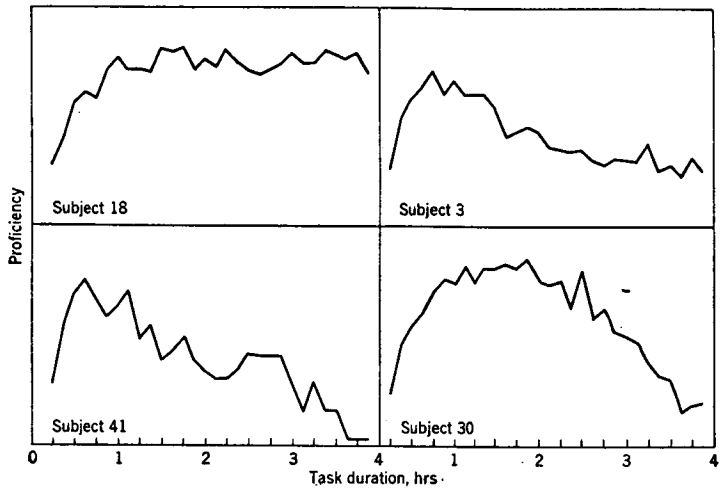
ITEM NO.	SUBJECT AREAS:	SOURCE:
461	SYSTEM - S28 HUMAN - H24	Reference 479, p. 136.



Proficiency achieved by each of the subjects during their 24-hour simulated space flight.

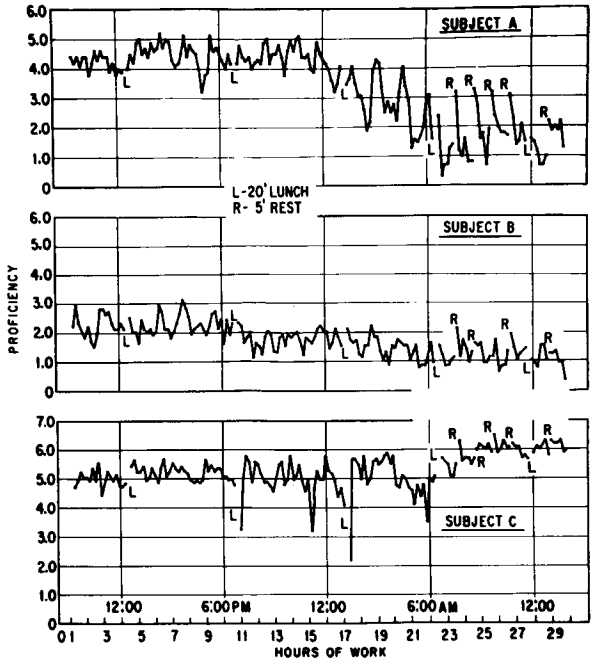
To determine the effects of increased work load upon proficiency, the mean proficiency for all tasks was computed for each subject for each hour of flight. These values were then plotted to yield the proficiency curves shown in the figure. Because of the number of curves, three graphs have been constructed. The curves of the first three subjects are shown at the top; the next three subjects, immediately below; and the last three subjects, in the bottom graph. At the point midway between the eighteenth and twentieth hours indicated on the abscissa, the increase in work load occurred; the effects, if any, should be revealed immediately following this point in time.

ITEM NO.	SUBJECT AREAS:	SOURCE:
462	SYSTEM - S28 HUMAN - H24, H29	Reference 262, p. 205.



Differences in trend of individual proficiency curves of four subjects performing an active task for 4 consecutive hours.

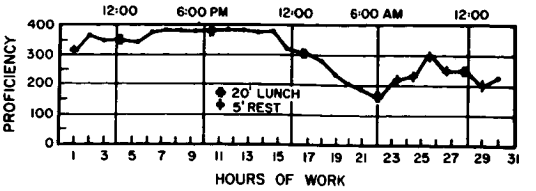
ITEM NO.	SUBJECT AREAS:	SOURCE:
463	SYSTEM - S28 HUMAN - H24, H29	Reference 3, p. 46. Based on Reference 260.



Proficiency of three subjects required to perform an exacting operator task for 30 consecutive hours.

The proficiency curves for three subjects are shown above. The curve for subject A closely approximates the mean of the entire group. The initial level of efficiency was maintained for about sixteen hours of work which required the monitoring of several simulated aircraft indicators for thirty consecutive hours. With the exception of short and infrequent periods for lunch, relief, and exercise, the subjects remained at their tasks and were not permitted to sleep. The same figure shows that A and B fall quite short of their initial proficiency levels, whereas subject C achieved a quite different time course of performance.

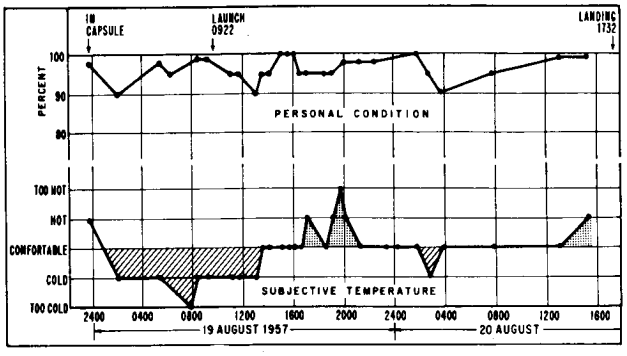
ITEM NO.	SUBJECT AREAS:	SOURCE:
464	SYSTEM - S28 HUMAN - H19, H26, H29	Reference 219, p. 360. Based on Reference 438.



Time-course of proficiency during a 30-hour study of control performance.

A clear indication of performance decrements is provided by experiments with highly motivated individuals who were required to perform a complex operator task continuously for 24 hours. The curve presented above reveals a slight increase during the first half of a thirty-hour experiment but a decline of performance in the second half. The terminal proficiency is far short of the initial level due to fatigue.

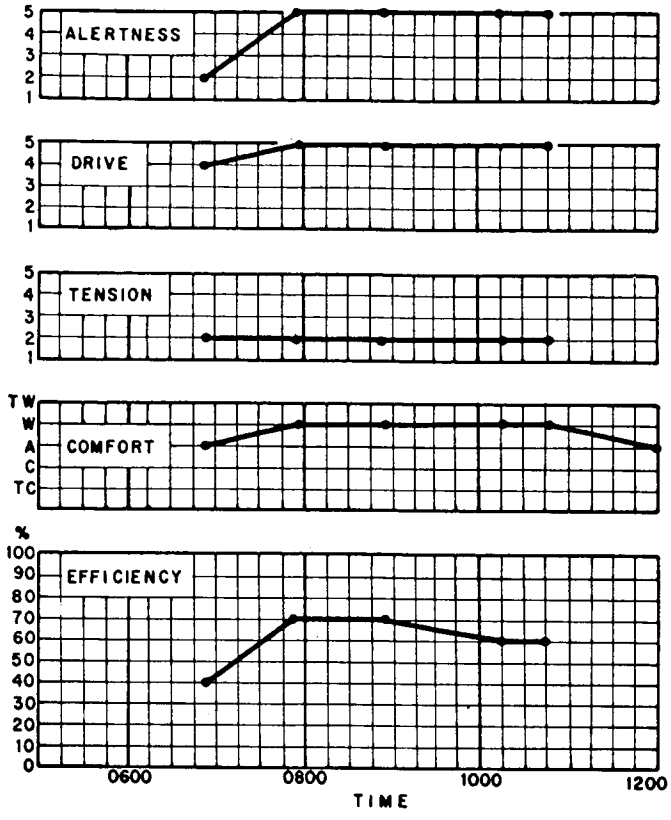
ITEM NO.	SUBJECT AREAS:	SOURCE:
465.	SYSTEM - S28 HUMAN - H19, H26	Reference 219, p. 361. Based on Reference 261.



Subjective ratings by MANHIGH II pilot during a 32-hour high-altitude solo balloon flight, August, 1957.

This figure presents the pilot's subjective assessment of how well he was performing his tasks during the flight. Toward the end of the flight, between 4:00 A.M. and 5:32 P.M., the consistently high ratings above 90 per cent are clearly contrary to the actual level of performance that the pilot exhibited in his state of acute fatigue.

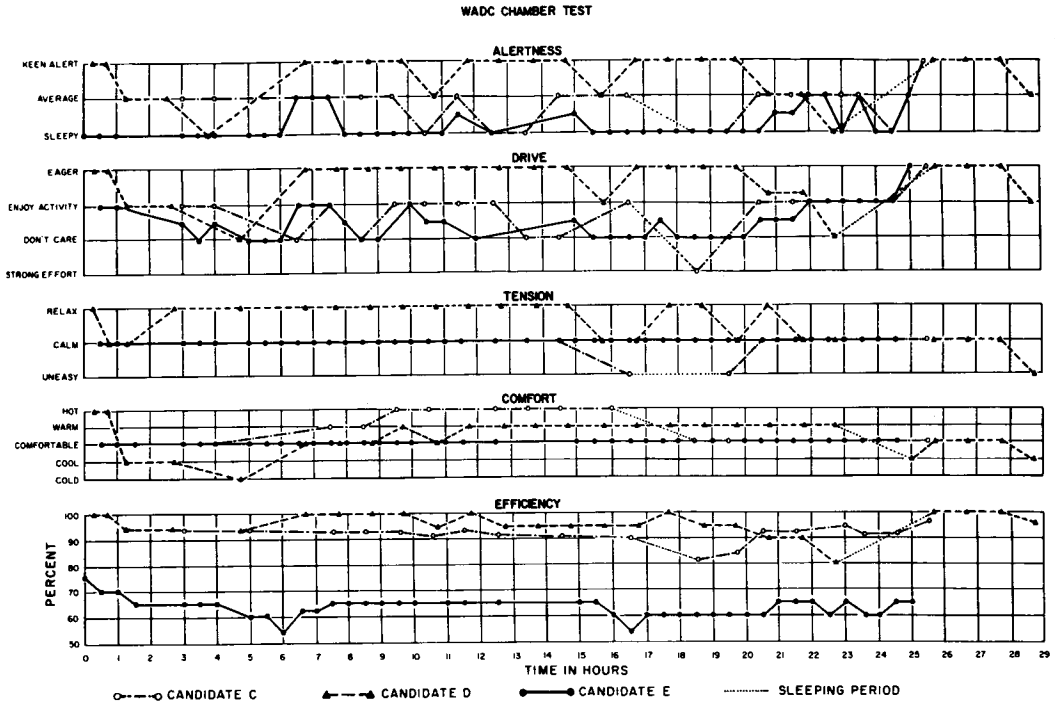
ITEM NO.	SUBJECT AREAS:	SOURCE:
466	SYSTEM - S28 HUMAN - H24, H33	Reference 479, p. 134.



Subjective pilot ratings by the pilot of the MAN-HIGH III high-altitude balloon flight, October, 1958.

Several points should be kept in mind concerning these pilot reports. The pilot was repeatedly impressed with the importance of centering his efficiency ratings around 50 per cent. Readings were not made after 5 hours because a hyperthermia emergency and voice communication failure interrupted this report schedule. This report is remarkable for the lack of awareness by the pilot that he was becoming too warm. It emphasizes unreliability of subjective evaluations, which may be aggravated in a tension-breeding operational situation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
467	SYSTEM - S28 HUMAN - H24, H33, H35	Reference 479, p. 139.



Subjective psychological ratings of candidates during 29-hr WADC confinement tests in Manhigh chamber.

ITEM NO.	SUBJECT AREAS:	SOURCE:
468.	SYSTEM - S28 HUMAN - H24, H33, H35	Reference 219, p. 310. Based on Reference 478.

PROBABLE RANGE OF RELIABLE CREW PERFORMANCE WHEN CONFINED BY SIZE AND MISSION DURATION

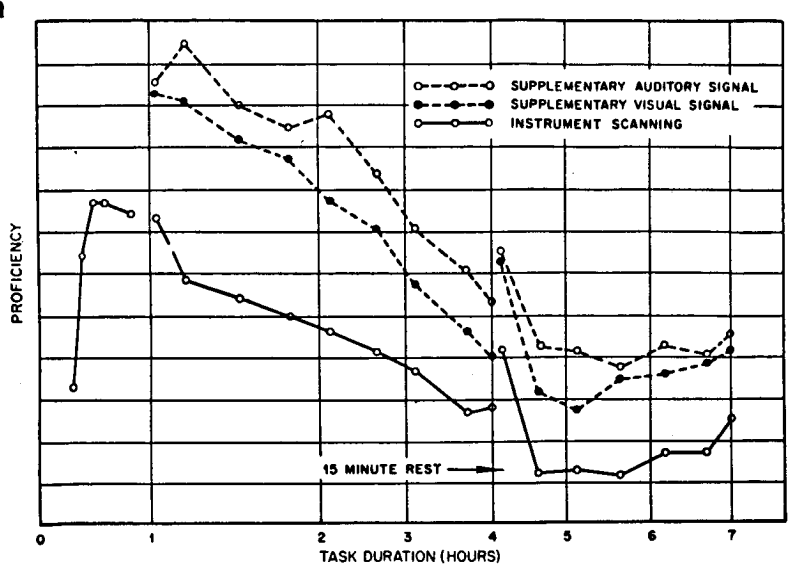
Crew Size	Days		References*
	Performance Maintained	Performance Decrements	
1	1.43	1.50	45, 50
2	7	30+	46, 47, 48, 43, 26
3			
4			
5	5	15	44, 52
6		15	52
7			
8			
9			
10	30		52
11			
12			
13			
14	365		50

* Only studies establishing maximum ranges with minimum crews are given. +performance did not deteriorate, but crew interaction difficulties developed that suggest performance maintenance doubtful under real isolation.

The information needed by the system designer is the size of crew needed to maintain psychological proficiency for given mission durations. A review of the available relevant data indicates a rapidly accelerating curve, with a single isolated man quickly losing his psychological proficiency, but with the period in which psychological proficiency is maintained rapidly increasing with additional crew members until a year or more is achieved with a group of fourteen. A study of the data in the table reveals rather clearly where additional research is needed, and where it is not needed, to determine the upper limit of successful performance by crew size. It is also apparent from the table that increasing crew size does increase length of time at which psychological capability can be maintained, and that excessive crew sizes are not necessary for this purpose.

ITEM NO.	SUBJECT AREAS:	SOURCE:
469	SYSTEM- S28 HUMAN- H24, H40	Reference 418, pp. 100-101. Based on several primary sources (see table).

a

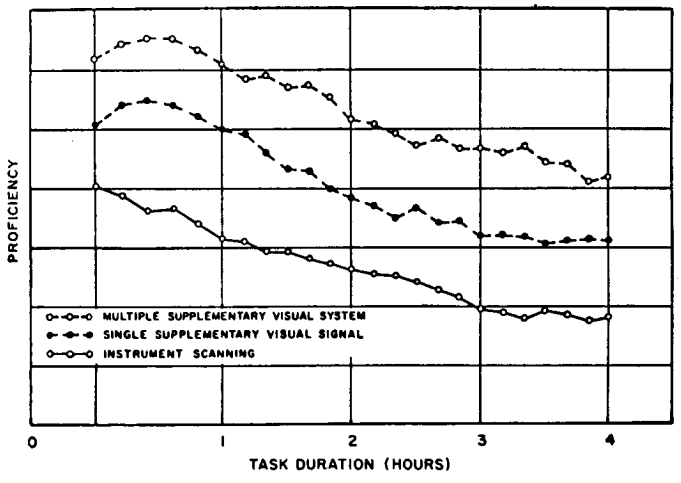


Seven-hour experiment on operator proficiency with supplementary signal input.

(From AU Qtrly. Rev., No. 2, 1958, p. 104.)

Three identically trained groups of test subjects performed a seven-hour instrument-scanning task which required the monitoring of several conventional aircraft indicators by compensating with control movements their driftings from null positions. Two of the three groups were furnished a supplementary signal, namely, one a visual, and the other an auditory warning stimulus. The three proficiency curves indicate the gain in performance resulting from the supplementary signals, while all these curves express the work decrement with increasing time.

b

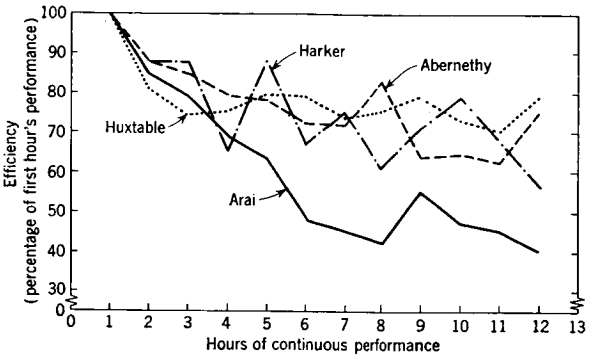


Time-course of operator proficiency with single and multiple supplementary visual signal system.

(From AU Qtrly. Rev., No. 2, 1958, p. 105.)

The effectiveness of a single supplementary visual system was compared with that of a multiple system, that is, a visual signal for each of the different indicators involved. It was found that the gain in proficiency during the four-hour operator task from the multiple-supplementary system was roughly twice the gain resulting from a single supplementary visual signal.

ITEM NO.	SUBJECT AREAS:	SOURCE:
470.	SYSTEM - S28 HUMAN - H26, H45	Reference 219, p. 362-363.



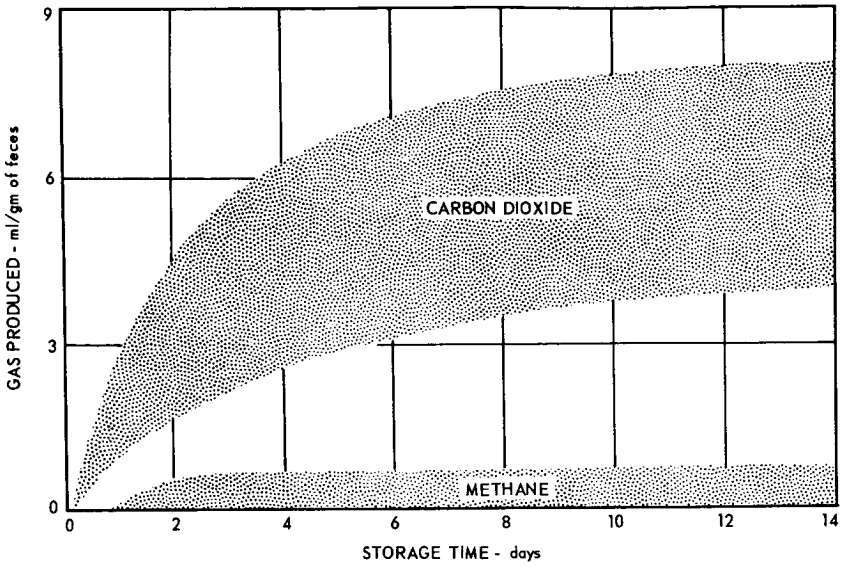
Efficiency (percentage of first hour's performance) attained by Arai and Huxtable et al. during each of 12 consecutive hours spent in mental multiplication of 4-digit numbers. Each point represents the average of a single subject's performance over 4 days as measured by the average time per successful operation.

Many of the results from laboratory studies are sometimes difficult to interpret because of the lack of comparability of tasks and task conditions, the differences in motivational levels of the subjects, and the differences in the number of replications of the performance periods. Huxtable, White, and McCartor, repeating an earlier study by Arai, have published performance curves resulting from 12 hr of continuous mental multiplication of 4-digit numbers on each of 4 successive days. A within-day effect consisting of an increase in time required to solve problems was reported in both studies, but it was less prominent in the Huxtable study (see figure). Also noted was a between-day effect associated with an increase in the speed of problem solving but a decrease in the number of problems solved correctly.

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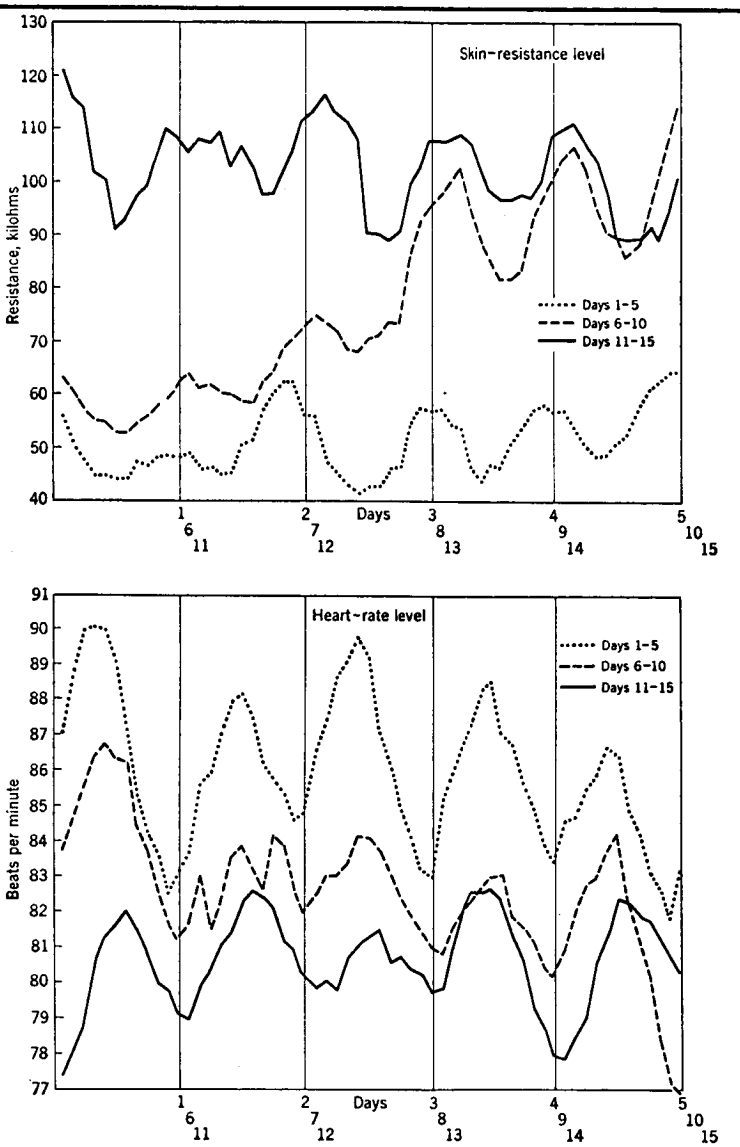
ITEM NO.	SUBJECT AREAS:	SOURCE:
471	SYSTEM - S28 HUMAN - H27, H45	Reference 3, p. 45. Based on References 46, 282, and 427.

STORAGE OF FECES



The shaded areas define the ranges of values for the two major gases produced when feces are stored at 86°F (30°C) for a period of two weeks. Some specimens produced traces of hydrogen and hydrogen sulfide as well.

ITEM NO.	SUBJECT AREAS:	SOURCE:
472	SYSTEM - S28 HUMAN - H47	Reference 554, p. 222. Based on Reference 573.

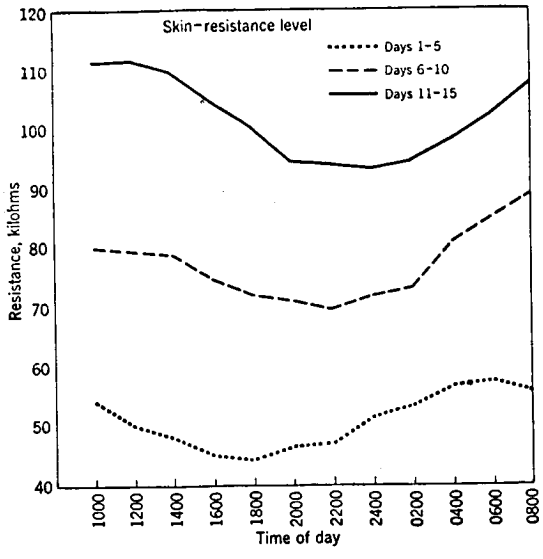


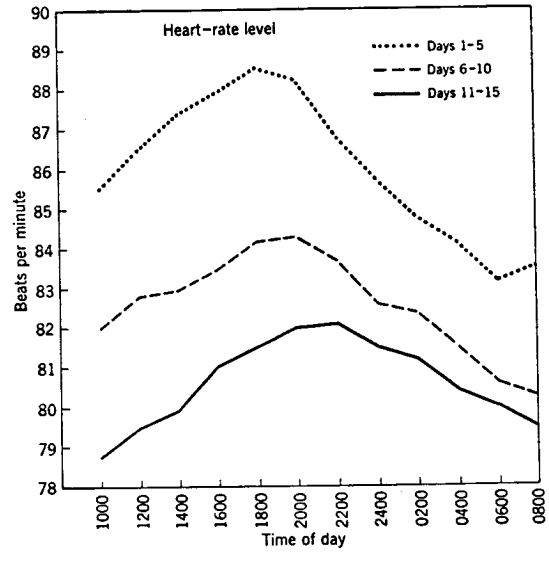
Skin resistance and heart-rate levels of subjects committed to a continuous schedule of 4 hr work and 2 hr rest for 15 consecutive days. Recordings made during period in which subjects performed arithmetic computation and three monitoring tasks concurrently.

Subjects consisted of two B-52 crews. In both cases (skin resistance and heart rate) the group trends are significant over days and in the direction of a decrease in level of autonomic activation (i.e., increased skin resistance and decreased heart rate).

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ITEM NO.	SUBJECT AREAS:	SOURCE:
473	SYSTEM - S29 HUMAN - H9, H14, H19, H45	Reference 3, p. 58.



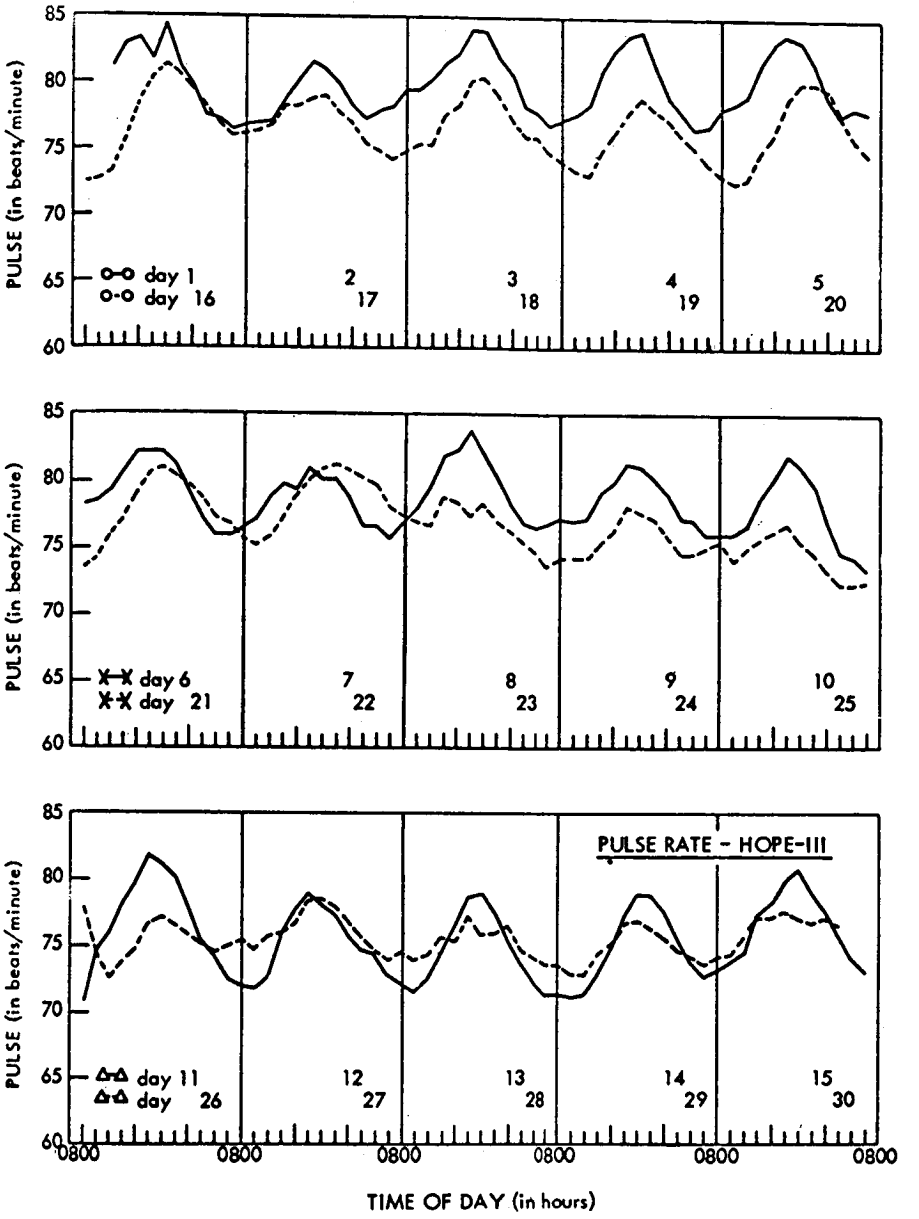


Within-day changes (diurnal variation) in skin resistance and heart-rate levels.

Subjects were committed to a continuous schedule of 4 hr work and 2 hr rest for 15 consecutive days. Subjects consisted of two B-52 crews.

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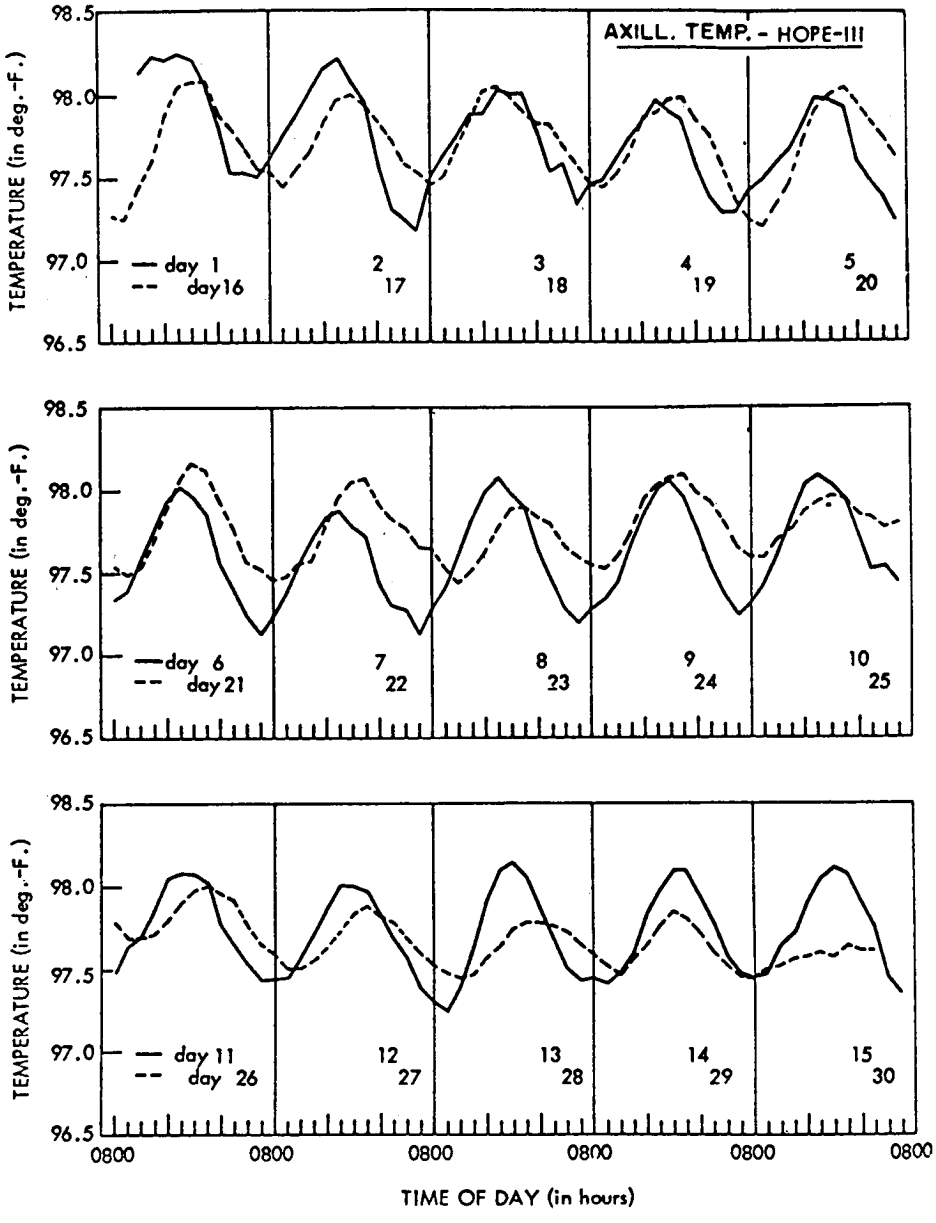
ITEM NO.	SUBJECT AREAS:	SOURCE:
474	SYSTEM- S29 HUMAN- H9, H14, H19, H45	Reference 3, p. 59.



Pulse Rate of Hope III Subjects During 30-Day Confinement on 4-Hours Work/4-Hours Rest Schedule.

Subjects were 10 USAF officers who had graduated from the Air Training Command Pilot Training Class 62-H.

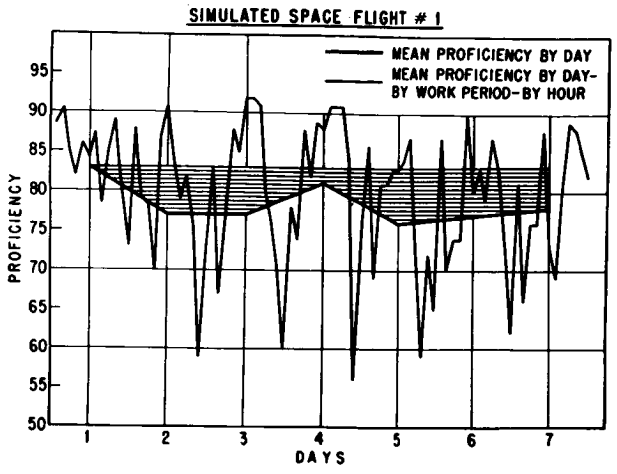
ITEM NO.	SUBJECT AREAS:	SOURCE:
475	SYSTEM - S29 HUMAN - H9, H19, H45	Reference 239, p. 97. Based on References 4 and 12.



Axillary Temperature of Hope III Subjects During 30-Day Confinement on 4-Hours Work/4-Hours Rest Schedule.

Subjects were 10 USAF officers who had graduated from the Air Training Command Pilot Training Class 62-H.

ITEM NO.	SUBJECT AREAS:	SOURCE:
476	SYSTEM - S29 HUMAN - H18, H19, H45	Reference 239, p. 98. Based on References 4 and 12.



Proficiency cycle of one highly motivated test subject during a seven-day simulated space flight.

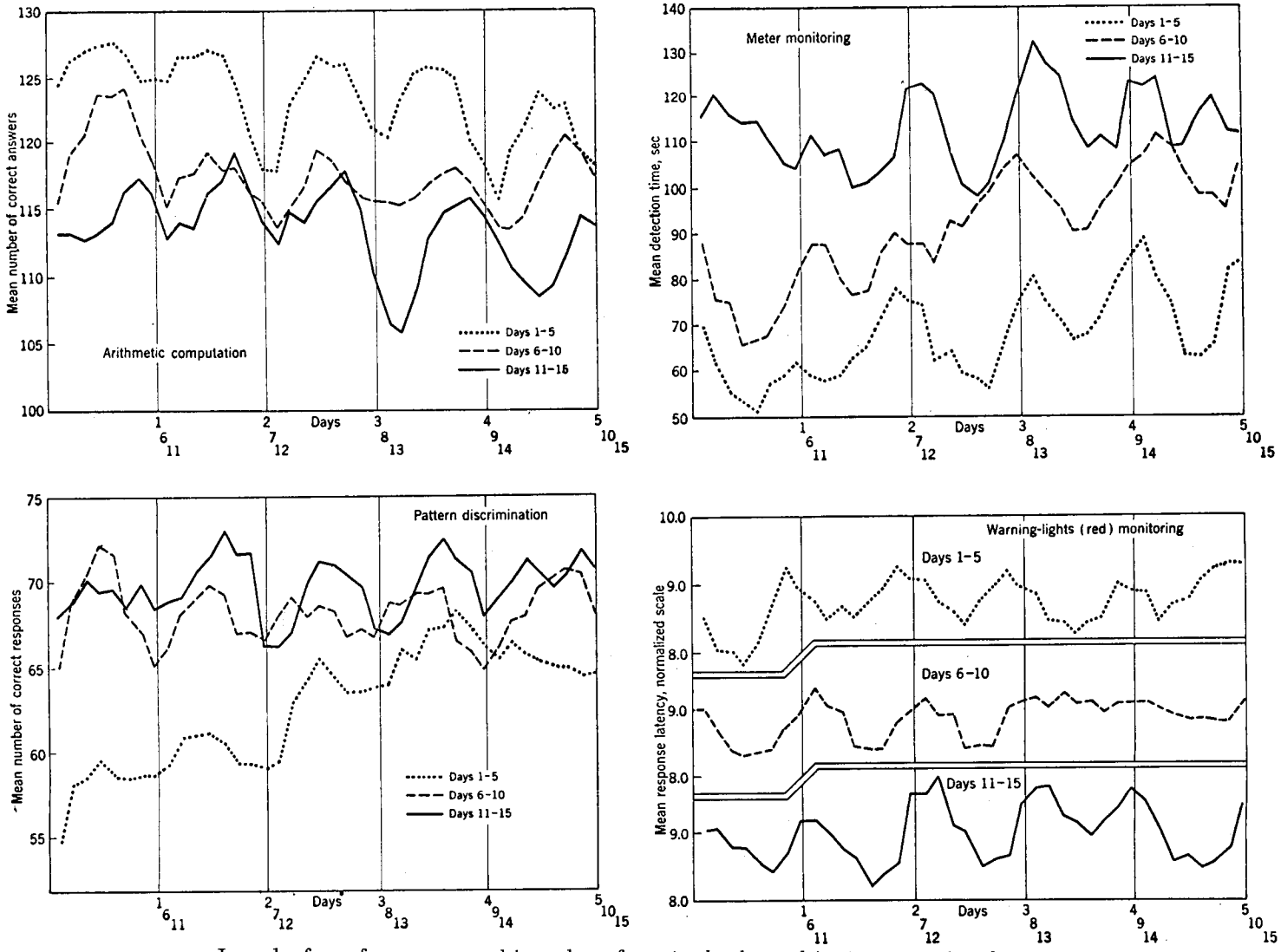
The performance curve of one subject exposed to a 4:4 work-rest cycle is shown in this figure. The areas shaded by horizontal lines indicate the performance decrement from the proficiency mean. The diagram indicates that the subject's performance decreased during the last two days of the seven-day experiment. This means that the subject did not adjust satisfactorily to the four-hour work-rest schedule to which he was committed.

ITEM NO.	SUBJECT AREAS:	SOURCE:
477	SYSTEM - S29 HUMAN - H19, H23	Reference 219, p. 373. Based on Reference 263.

ITEM NO. 478

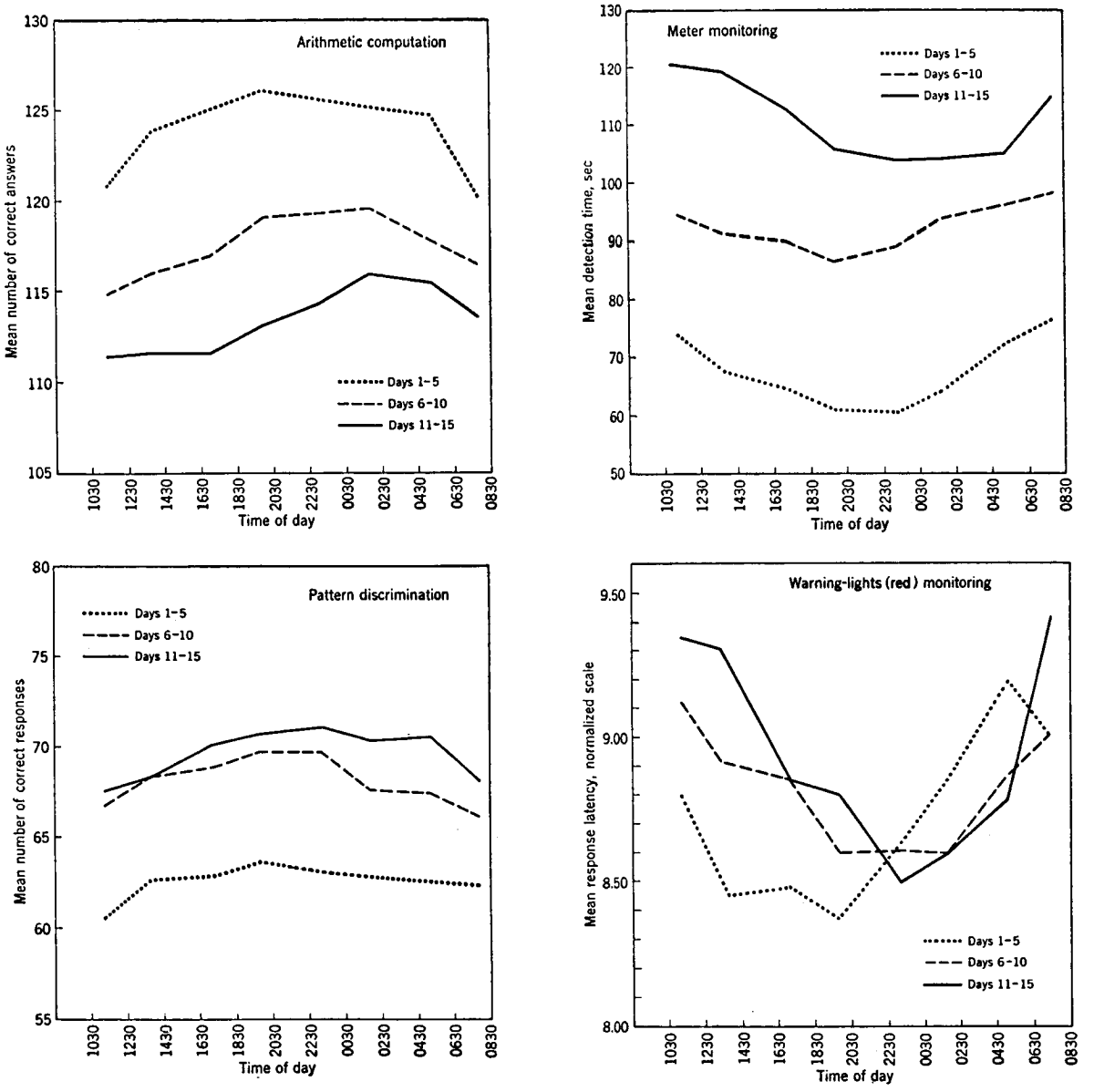
SUBJECT AREAS: SYSTEM - S29; HUMAN - H19, H25, H27, H45

SOURCE: Reference 3, pp. 54-55.



Level of performance achieved on four tasks by subjects committed to a continuous schedule of 4 hr work and 2 hr rest for 15 consecutive days. Subjects consisted of two B-52 crews.

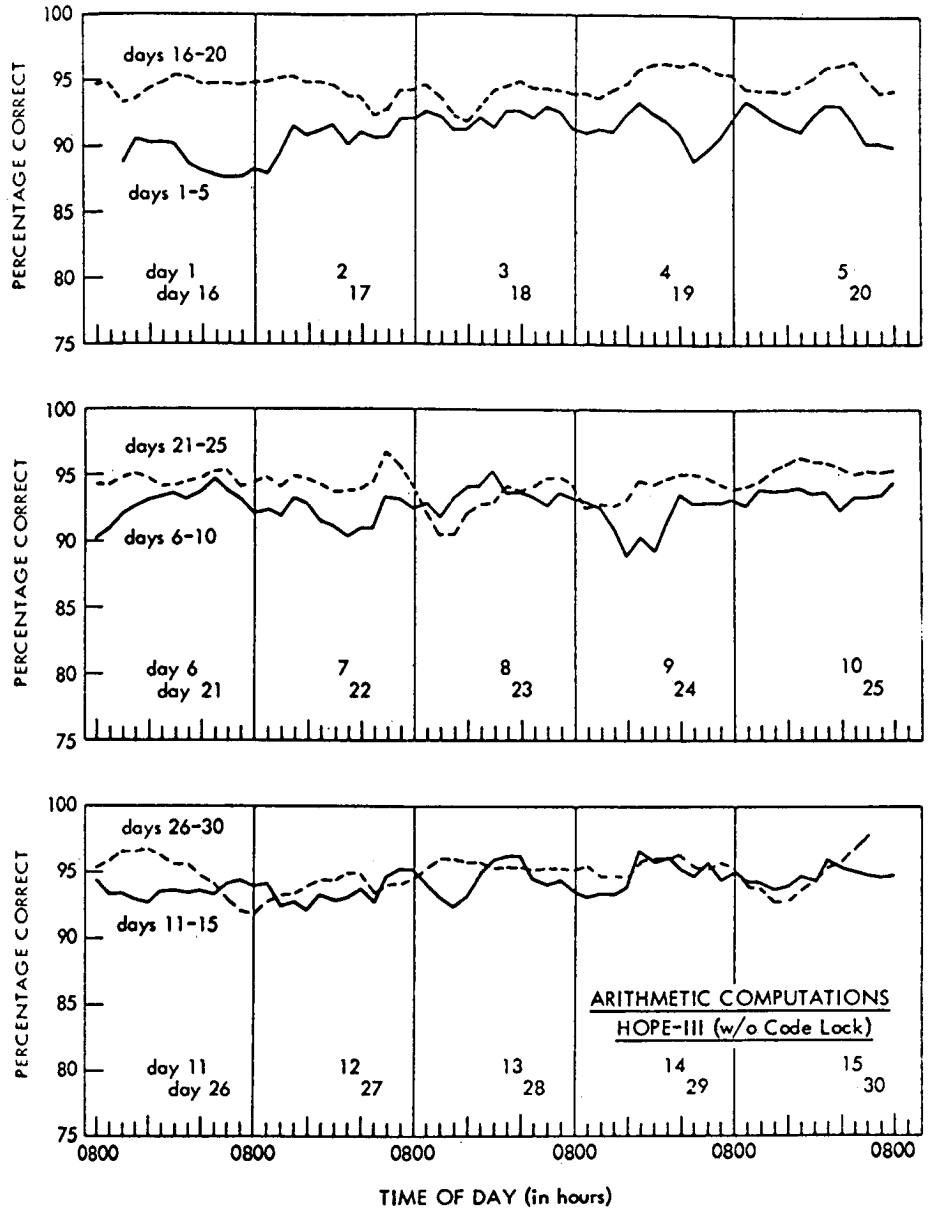
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Within-day changes (diurnal variation) in level of task performance.
Subjects were two B-52 crews.

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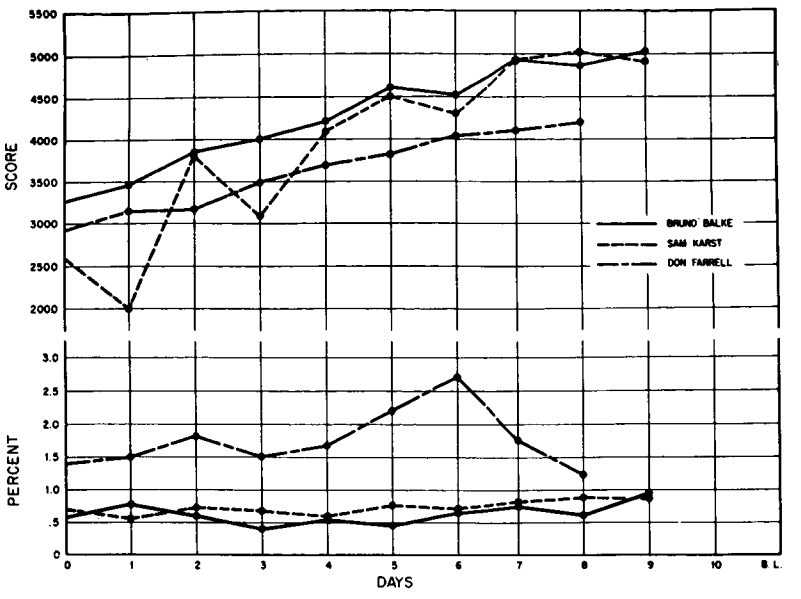
ITEM NO.	SUBJECT AREAS:	SOURCE:
479.	SYSTEM - S29 HUMAN - H19, H25, H27, H45	Reference 3, pp. 56-57.



Performance of Hope III Subjects on Arithmetic Computation During 30-Day Confinement on 4-Hours Work/4-Hours Rest Schedule

Subjects were 10 USAF officers who had graduated from the Air Training Command Pilot Training Class 62-H.

ITEM NO.	SUBJECT AREAS:	SOURCE:
480	SYSTEM - S29 HUMAN - H19, H27, H45	Reference 239, p. 101. Based on References 4 and 12.



Work proficiency in simulated space flight experiments.

Space-Flight Simulation

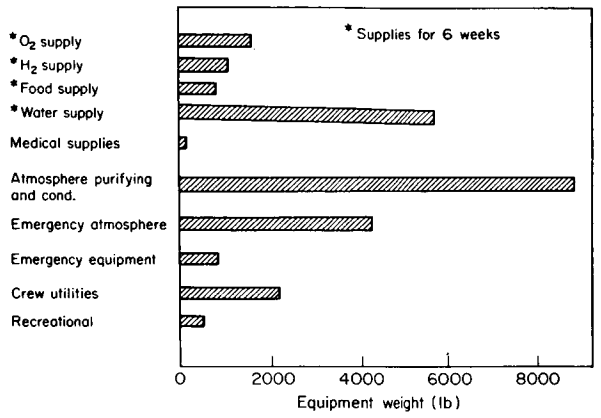
The results of a simple mental task performed daily for one hour during simulated space flights lasting seven and ten days, respectively, are shown in this figure. The number of additions made in the tests increased almost steadily during the simulated flights, but so did the error and correction scores obtained. The subjects became more irritable as time progressed, but they retained learned and useful behavior and even increased their over-all proficiency in this particular task.

ITEM NO.	SUBJECT AREAS:	SOURCE:
481	SYSTEM- S29 HUMAN- H24, H35	Reference 219, p. 367. Based on Reference 214.

SUMMARY OF VEHICLE THERMAL AND ATMOSPHERIC CONTROL SYSTEMS
(ASD TR 61-240 Pt I)

	Vehicle 1A	*Vehicle 1B*	*Vehicle 1C*
Crew	*Five men-Six weeks*	*Two men-One week*	*Two men-Twelve to Thirty-six hrs*
Power, orbital	Nuclear or solar	Nuclear or solar H_2–O_2	Fuel rich H_2–O_2
Power, re-entry	Hydrazine	Hydrazine H_2–O_2	Fuel rich H_2–O_2
Heat sinks: Orbital	Radiator	Radiator Fuel and radiator	H_2 fuel
Re-entry	H_2O and NH_3	H_2O and NH_3 Cryogenic hydrogen	H_2 fuel
CO_2 control	Regenerable	Li(OH)	Li(OH)
O_2 source	Cryogenic converters	Cryogenic converters	Cryogenic converter or high-pressure bottles
Water management	Water recovery from urine and wash water and condensate	Condensate recovery	Stored
Food	Dehydrated	Normal	Normal
Waste management (Toilet)	Yes	Yes	No
Trace toxin	Hopcalite burner 650° F CO removal	Hopcalite burner 650° F CO removal	None required
Odor control	Activated charcoal	Activated charcoal	Activated charcoal
Aerosol removal	Fiber filter	Fiber filter	Fiber filter

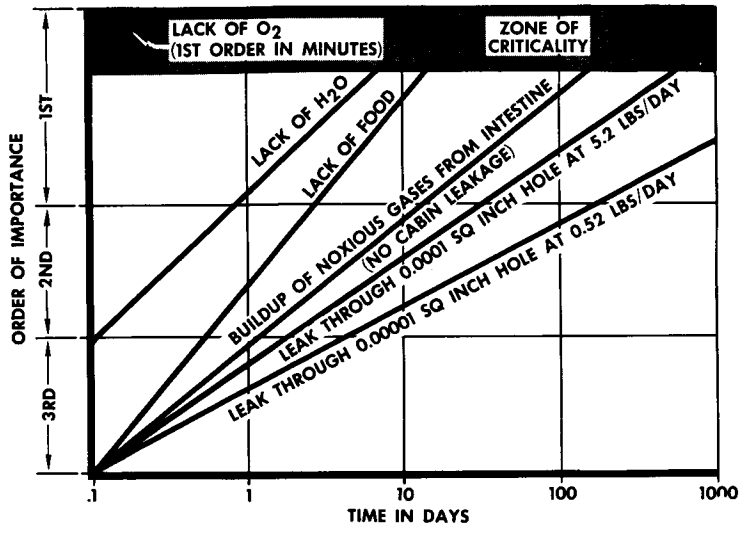
ITEM NO.	SUBJECT AREAS:	SOURCE:
482	SYSTEM - S2, S3, S4, S27 HUMAN - H40, H47	Reference 219, p.415. Based on Reference 398.



Weight requirements of a regenerating system.

By assuming a peak power requirement of 45 kw for a multimanned space station, Kramer and Byers arrive at the weight breakdown as shown above. The figure represents an estimate of the weight for the life support system and its related subsystems. The average working load of the power plant is about 18 kw. The weight of the electrical subsystem is not included.

ITEM NO.	SUBJECT AREAS:	SOURCE:
483	SYSTEM - S2, S3, S21, S24 HUMAN - H33, H43	Reference 219, p . 443



Order of importance of some ecological parameters by mission duration.

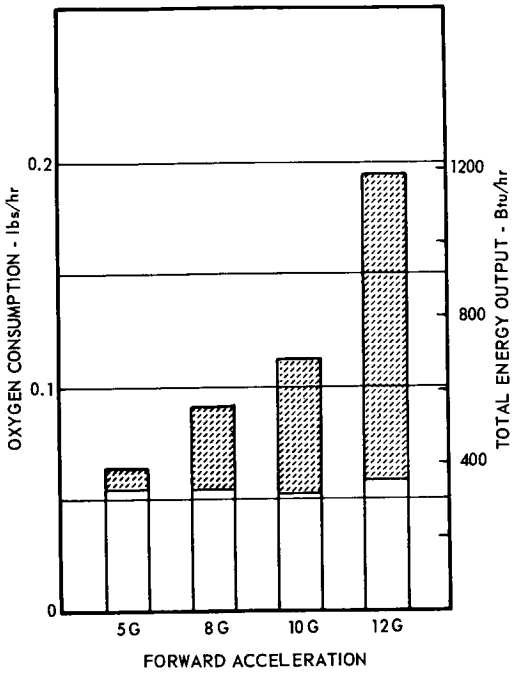
Depending on the mission's duration, certain orders of importance can be assigned to the different parameters involved in ecology. This graph gives the order of importance for oxygen, water, food, build-up of noxious gases from the intestines, and cabin leakage for various flight durations up to 1000 days. Lack of oxygen becomes critical within a matter of minutes. For flights of short duration lack of water is a second-order item, but quickly becomes a first-order item after 1 day and is in the zone of criticality after several days. The lack of food begins as a third-order item, becomes a second-order item within a matter of several hours of flight due to hunger, of first-order importance after about 3 days, and is in the zone of criticality in less than 2 weeks. The build-up of noxious gases present in the flatus is based on a no-leak situation in the cabin and would not become critical for about 150 days.

ITEM NO.	SUBJECT AREAS:	SOURCE:
484	SYSTEM - S2, S3, S27 HUMAN - H33	Reference 309, p. 287.

HEAT PRODUCED BY SATELLITE SYSTEMS

Lighting	~ 15,000 Btu/hr peak
Power (Motors)	~400,000 Btu/hr peak
Utilities	~ 30,000 Btu/hr
Crew	~ 5,000 Btu/hr
Micro-Atmosphere System	~ 20,000 Btu/hr

ITEM NO.	SUBJECT AREAS:	SOURCE:
485	SYSTEM- S2, S4, S6, S22 HUMAN- H18	Reference 219, p. 442 Based on Reference 162.



Average oxygen consumption and heat output at several levels of forward acceleration ($+G_x$), built up at the rate of 1 G/sec. The G level was held for 1-2 minutes while oxygen uptake was determined. The clear portion of each bar indicates control oxygen consumption; the shaded areas show the additional oxygen consumption for 1 minute of G.

ITEM NO.	SUBJECT AREAS:	SOURCE:
486	SYSTEM - S2, S4, S13 HUMAN - H16, H20	Reference 554, p. 181 Based on Reference 596.

DESIGN PARAMETERS FOR LIFE SUPPORT SYSTEM

a

NOMINAL DESIGN PARAMETERS	
REQUIREMENTS	
O_2 METABOLIC	2.0 LB/MAN · DAY
H_2O DRINKING	8.0 LB/MAN · DAY
H_2O WASH	12.0 LB/MAN · DAY
FOOD	1.3 LB/MAN · DAY
WASTE PRODUCTION	
CO_2	2.25 LB/MAN · DAY
H_2O RESPIRATION & PERSPIRATION	5.5 LB/MAN · DAY
H_2O WASH	12.0 LB/MAN · DAY
URINE WATER	3.2 LB/MAN · DAY
FECES	.35 LB/MAN · DAY
METABOLIC HEAT	12,000 BTU/MAN · DAY

Purser, P.E., Faget, M.A. and Smith, N.F.; (editors); MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

b **Daily Metabolic Turnover of an Adult at Light Work**

Man: 70 kg; R.Q. = 0.82; 2830 kg-cal
Food: Protein, 80 gm; carbohydrate, 270 gm; fat, 150 gm

	Input	Output
Total	3585 gm	3585 gm
Water	2200 gm (61.37%)	2542 gm (70.91%)
Oxygen	862 gm (24.04%) 603	—
Carbon dioxide	—	982 gm (27.39%) 496
Solids, food and minerals	523 gm (14.59%)	—
Solids, waste: urea and minerals	—	61 gm (1.70%)

ITEM NO.	SUBJECT AREAS:	SOURCE:
487	SYSTEM - S2, S4, S21 HUMAN - H20, H43	Reference 483, p. 138 (table a). Reference 416, p. 831 (table b). Based on Reference 126 (table b).

Metabolic Data of Man, Adult Male

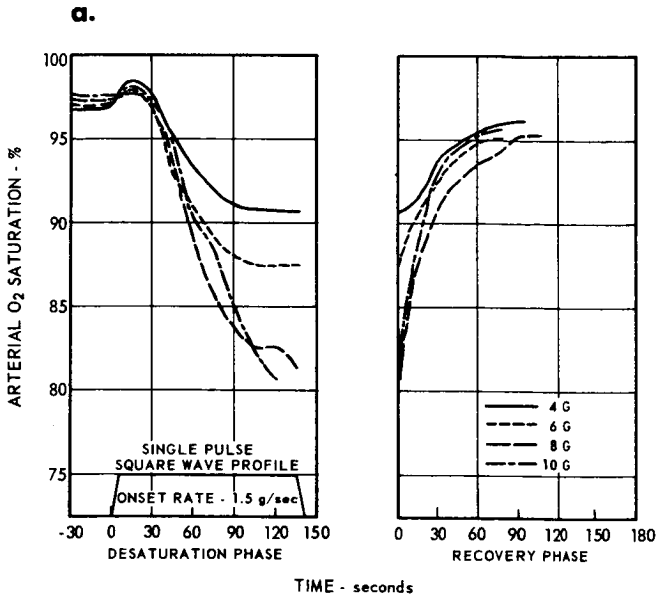
ITEM	ESTIMATED VALUE*	RANGE
Inputs		
Gases		
Oxygen	2.13 lb.	1.62–2.27
Liquid		
Water	6.28 lb.†	4.80–6.71
Solids		
Protein	0.27 lb.	.202–.282
Carbohydrate	0.92 lb.	.698–.978
Fat	0.27 lb.	.195–.274
Total	1.46 lb.	1.095–1.534
Energy	13,200 BTU	9930–13,900
Outputs		
Gases		
Carbon dioxide	2.50 lb.	1.90–2.67
Water vapor	2.92 lb.	1.76–3.20§
Liquid		
Urine	4.02 lb.	1.92–4.55
Feces	0.27 lb.	0.15–0.28
Total	4.29 lb.	2.07–4.83
Solids		
Urine	0.11 lb.	0.10–0.12
Feces	0.05 lb.	0.03–0.06
Total	0.16 lb.	0.13–0.18
Heat (energy − work)	11,220 BTU	7944–12,510
Work	1980 BTU	1190–2500

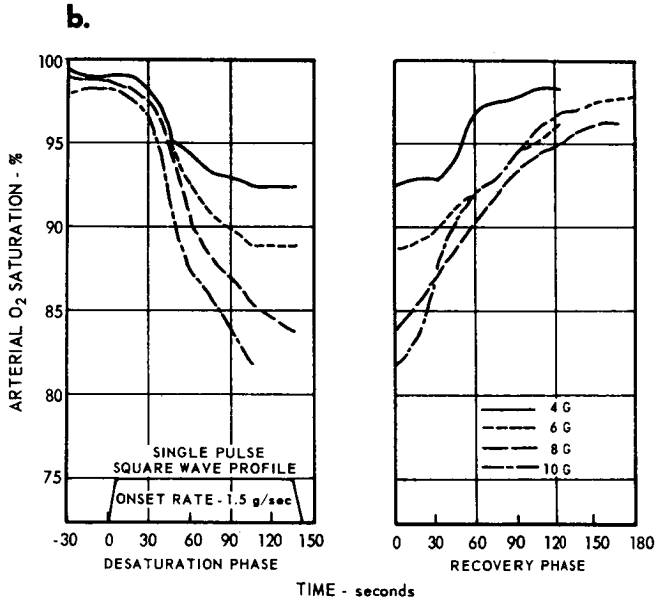
* The estimated value is essentially the 95 percentile, which is considered the most practical for design criteria.

† Including the metabolic water, the total water exchange is 7.22 pounds and the range is 5.51–7.71.

§ The water vapor and urine will vary inversely with each other.

ITEM NO.	SUBJECT AREAS:	SOURCE:
488	SYSTEM – S2, S4, S21 HUMAN – H20, H43	Reference 355, p. 251 Based on Reference 354.





The following four graphs illustrate the effects of sustained transverse acceleration ($+G_x$) on the oxygen saturation of the arterial blood of 25 pilots in a supine position on the centrifuge. An ear oximeter was used to measure oxygen saturation throughout each of the various accelerations illustrated. All pilots breathed through an aviator's face mask from a demand regulator.

Figure a shows the arterial saturations during single pulse square wave profiles of acceleration while breathing air at 14.7 psia.

Figure b is similar except that the pilots breathed pure oxygen at 5 psia, and the gondola of the centrifuge was evacuated to 5 psia, and they had breathed pure oxygen for 1 hour prior to the exposure.

ITEM NO.	SUBJECT AREAS:	SOURCE:
489 a Page 1 of 2	SYSTEM- S2, S13 HUMAN- H9, H16	Reference 554, p. 40 Based on Reference 10.

Figure c shows arterial oxygen saturations breathing either air or oxygen as above during an acceleration profile representing one kind of re-entry pattern.

c.

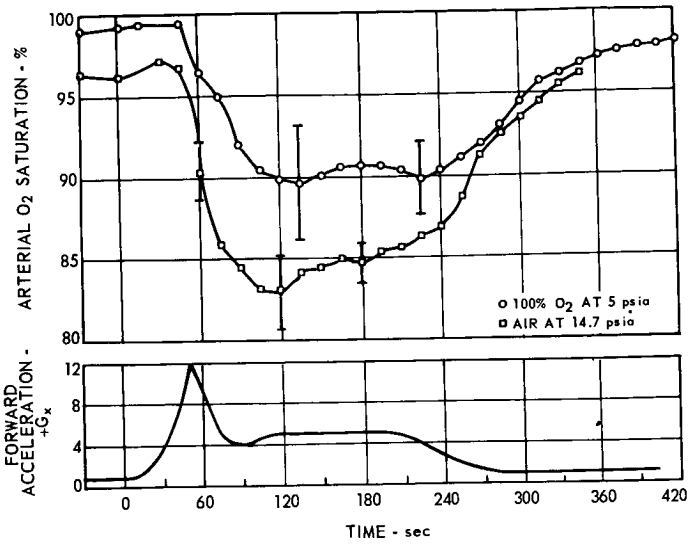
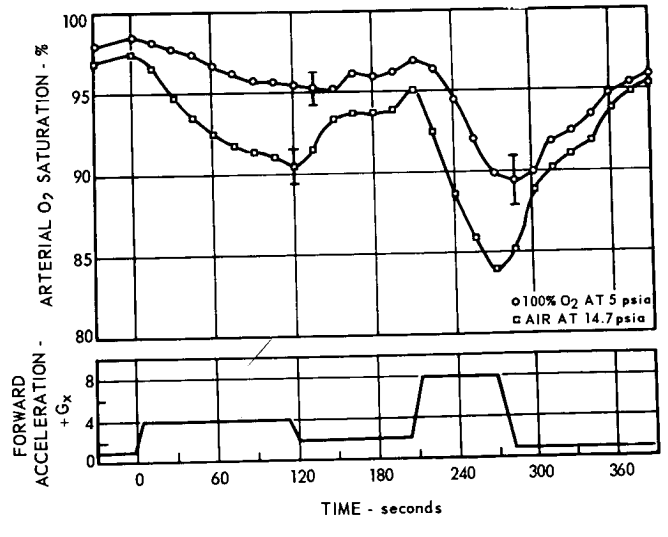
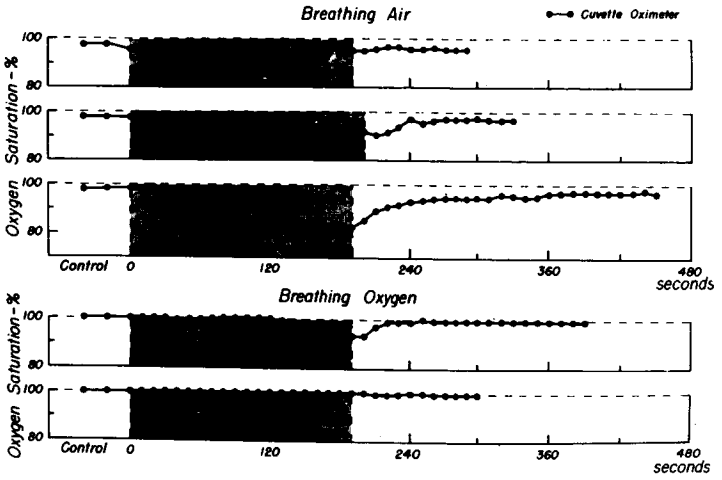


Figure d is similar to c except that a different type of re-entry pattern was simulated.

d.



ITEM NO.	SUBJECT AREAS:	SOURCE:
489 b Page 2 of 2	SYSTEM - S2, S13 HUMAN - H9, H16	Reference 554, P. 41 Based on Reference 10



Changes in arterial oxygen saturation during exposure to forward acceleration ($0^{\uparrow}$ - 37 years, 81 kg).

From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

ITEM NO.	SUBJECT AREAS:	SOURCE:
490	SYSTEM - S2, S13 HUMAN - H9, H16	Reference 276, p. 194 Based on Reference 397.

OXYGEN AND BRIGHTNESS DISCRIMINATION DURING $+G_z$ AND $+G_x$

Comparison of visual brightness discrimination is shown in figure a for subjects during exposure to $+G_z$ accelerations under three breathing conditions: normal breathing air; 100% O_2; and 100% O_2 with positive pressure. The positive pressure ratio was 0.75 inches of water per G.

a.

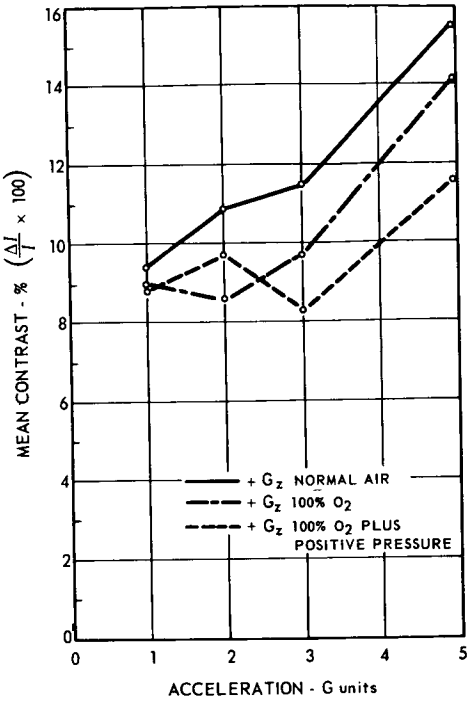
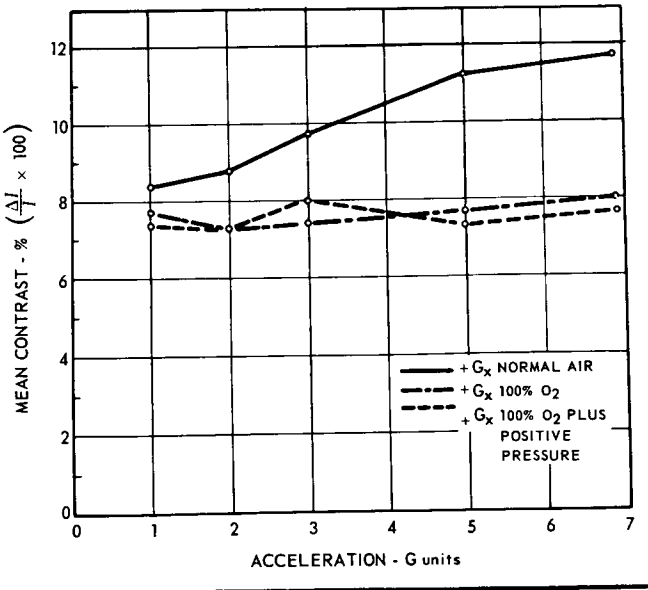


Figure b shows similar data during transverse acceleration ($+G_x$).

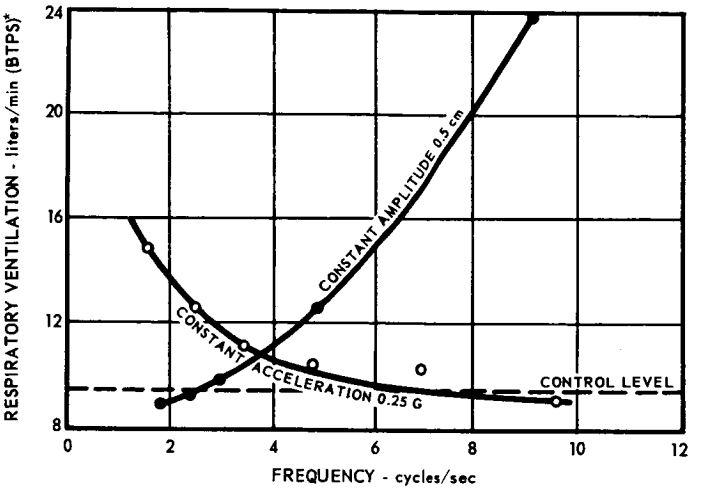
b.



ITEM NO.	SUBJECT AREAS:	SOURCE:
491	SYSTEM - S2, S13 HUMAN - H6, H25	Reference 554, p. 45. Based on Reference 120.

RESPIRATORY VENTILATION DURING VIBRATION

a.

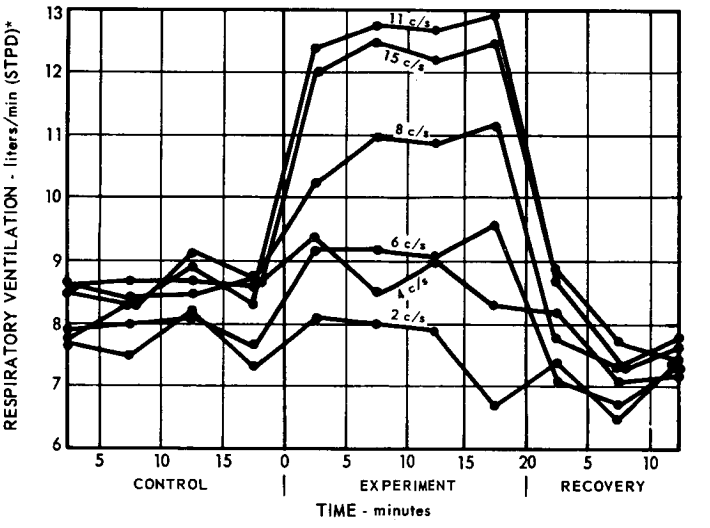


*GAS AT BODY TEMPERATURE, AMBIENT PRESSURE, AND SATURATED

Average respiratory ventilation rates are shown for 12 men who were vibrated while seated on a hard platform at the amplitudes, rates, and accelerations shown.

Source: Ernsting [6].

b.

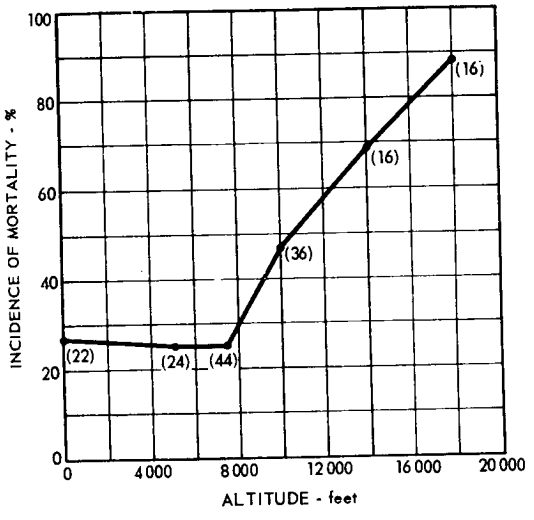


*GAS AT STANDARD TEMPERATURE (°C), PRESSURE (1 atm) AND DRY

This shows mean values of respiratory ventilation for 5 seated men exposed to a 20-minute period of vibration at 0.125 inch amplitude, at frequencies from 2 to 15 cps as marked on each curve.

ITEM NO.	SUBJECT AREAS:	SOURCE:
492	SYSTEM - S2, S14 HUMAN - H16	Reference 554, p. 80 Based on References 187 and 279.

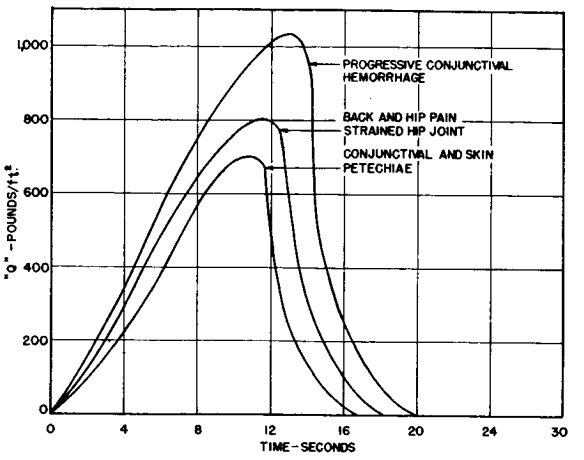
HYPOXIA AND VIBRATION STRESS

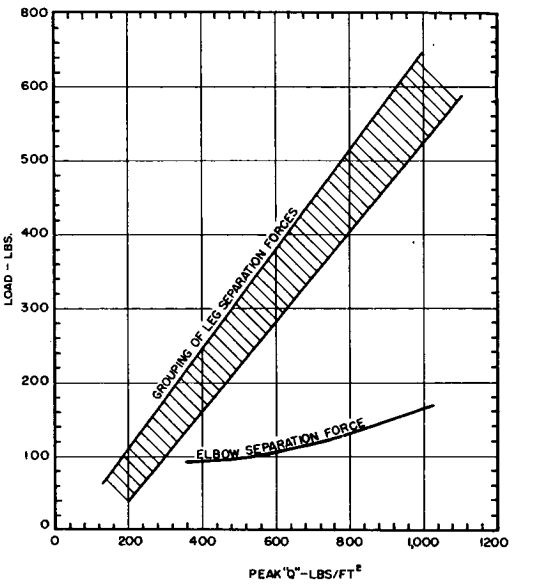


This shows the increased mortality to restrained rats of exposure to increasing hypoxia at simulated altitude combined with vibration at 60 cps, 0.075 inch double amplitude (equivalent to 15 G peak acceleration). The numbers in parentheses at each data point denote how many animals were exposed.

ITEM NO.	SUBJECT AREAS:	SOURCE:
493	SYSTEM - S2, S14 HUMAN - H34	Reference 554, p. 163 Based on Reference 369.

HIGH DYNAMIC PRESSURES





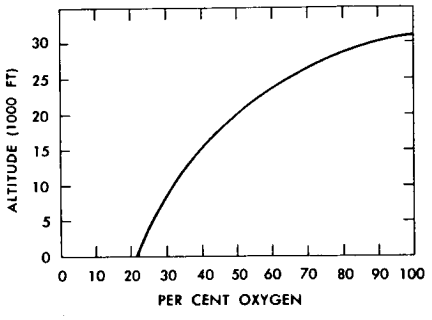
Human exposure to dynamic or ram pressure (Q) produced by accelerating an ejection seat with an underwater centrifuge, which could produce peak speeds up to 32.6 ft/sec, which is equivalent to 515 knots and a dynamic pressure of 1030 lbs per ft^2. The 2 subjects used wore rubber suits, full face helmets, and nose-clip and mouthpiece for underwater breathing. Breathing air was supplied through a demand valve which was referenced to ram pressure incident on the chest. Exhalation valves were similarly loaded by ram pressure. During an acceleration, the subject held his breath.

The subject's arms were restrained on arm rests or else strapped together at wrist and elbow, and the arms raised vertically as if the hands were gripping a face curtain bar at the level of the top of the head. The legs were restrained in the normal seated position. Both the arm and the leg restraints were rigged with strain gauges to measure the forces of separation which developed during the ram pressure experiment. The head was not restrained, but was partially protected by a rigid cowl or hood, open in the front.

The left hand figure shows injuries produced by the more severe exposures, as well as an approximation of the time course of ram pressure loading during the runs. The figure on the right shows the separation forces which developed on the arms and legs plotted against the overall loading forces.

ITEM NO.	SUBJECT AREAS:	SOURCE:
494	SYSTEM - S2, S16 HUMAN - H34	Reference 555, p. 38.

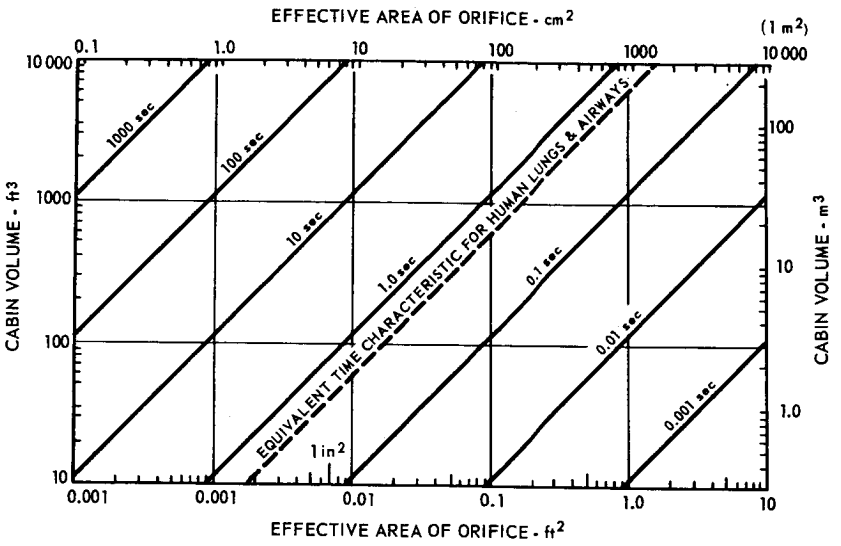
OXYGEN REQUIRED AT VARIOUS ALTITUDES



Per cent of oxygen required in the inspired air for various altitudes in order to maintain a normal alveolar oxygen tension of 28 mm Hg is shown in the graph at the left.

ITEM NO.	SUBJECT AREAS:	SOURCE:
495	SYSTEM - S2, S18 HUMAN - H16	Reference 586, p. 2-232

TIME CHARACTERISTIC OF LUNGS DURING RAPID DECOMPRESSION

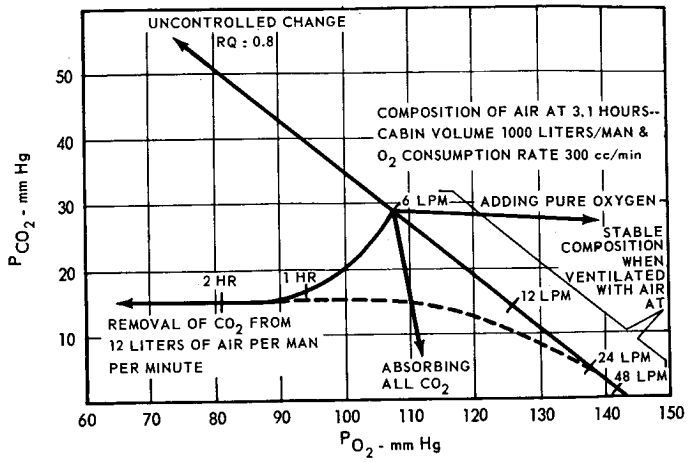


This figure shows the time characteristic as a function of container volume, V, and effective orifice area, A. The time characteristic for one subject is shown. Since the volume of the lungs varies with respiration, it is obvious that the time characteristic of the lungs may vary considerably, depending on the phase of respiration during which a rapid decompression occurs.

ITEM NO.	SUBJECT AREAS:	SOURCE:
496	SYSTEM - S2, S20 HUMAN - H16	Reference 554, p. 95 Based on Reference 337.

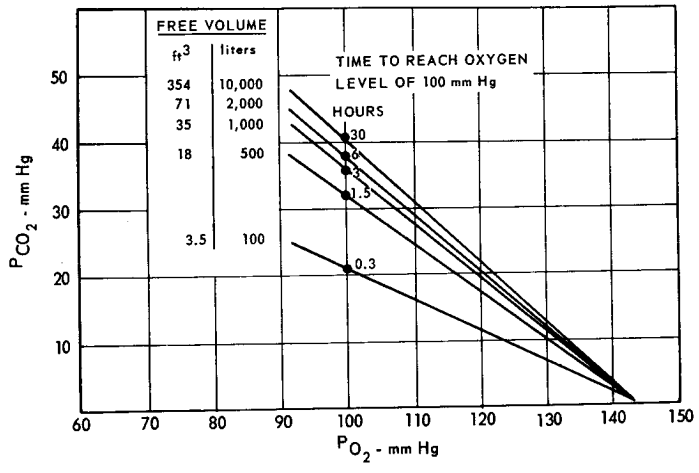
CHANGING GAS COMPOSITION IN A SEALED SPACE

a.



The graph shows how P_{O_2} and P_{CO_2} change within a sealed space. The long straight heavy line shows the progression of oxygen depletion and CO_2 accumulation when the standard respiratory quotient of 0.8 applies and when no corrective measures are used. At 3.1 hours, when the P_{O_2} is 108 mm Hg and the P_{CO_2} is 30 mm Hg (4%), respiratory volume has doubled. Starting from this point on the straight line, various curves show the effects of adding pure oxygen, of absorbing the CO_2, of ventilating the space with various amounts of air, and of clearing the CO_2 with an absorber that handles 12 liters of air per minute per man. The dotted curve shows what happens if the same CO_2 absorber is used from the beginning. •

b.



In the lower figure, several lines of uncontrolled change, like the heavy straight line in the first graph, are drawn for several cabin volumes--from 100 to 10,000 liters per man. As before, the men consume oxygen at the rate of 300 cc/min, and the RQ is 0.8. The dots on the lines mark the intercepts with the line showing 100 mm for P_{O_2}, and the times to reach this critical level are given in hours. The lower values for P_{CO_2} for the smaller amounts of free space, when P_{O_2} is 100 mm Hg, result from the relatively greater tissue storage of the CO_2 being produced by the man. This effect is lessened in the longer exposures in the larger volumes.

ITEM NO.	SUBJECT AREAS:	SOURCE:
497	SYSTEM - S2, S20 HUMAN - H16	Reference 554, p. 12 Based on Reference 423.

Stored-Oxygen Sources

Source	900 gm O_3, kg	900 gm O_3, ft^3	900 gm O_2, kcal	System By-products	Secondary Uses
Gas	2.7	0.128	−0.15	Containers	Refrigerant
Liquid	1.4	0.064	−64	Containers	Refrigerant
H_2O_2	2.6	0.050[a]	1400	H_2O	Power, H_2O 1.36 lb H_2O/ lb O_2 supply
$NaClO_3$	2.7	0.074	500	NaCl	Heat source
KO_2	5.0[b]	0.20	500[c]	K_2CO_3	Dehumidifier, CO_2 absorber, odor remover

[a] Without equipment.
[b] Without blower.
[c] Approximate.

ITEM NO.	SUBJECT AREAS:	SOURCE:
498	SYSTEM - S2, S20, S21 HUMAN - H47	Reference 416, p. 86 Based on Reference 32.

a **Liquid O_2 System**

CONVERTER TYPE	CAPACITY, LITERS	TOTAL VOL. FREE O_2	APPROX. WT. EMPTY, LBS.	APPROX. SPACE REQUIRED IN CU. FT.	APPROX. O_2 QUANTITY FOR AVERAGE MAN USING 1.0 CU. FT./HR. HRS	DAYS
A-3	5	107	15	1.1	107	4.5
ME-1	5	107	15	1.1	107	4.5
A-2	8	177	37	2.0	177	7.5
ME-2	10	239	37	2.0	239	10.0
MA-1	20	517	52	4.9	517	21.5

b **High-Pressure 1800 PSI O_2 System**

CYLINDER TYPE	TOTAL VOL. FREE O_2 CU. FT.	APPROX. WT. EMPTY, LBS.	APPROX. SPACE REQUIRED IN CU. FT.	APPROX. O_2 QUANTITY FOR AVERAGE MAN USING 1.0 CU. FT./HR. HRS.	DAYS
AN6025-205	14	9.1	0.225	14	0.58
-295	22	11.6	0.292	22	0.9
-386	28.8	14.9	0.426	28.8	1.2
-514	38.4	18.5	0.530	38.4	1.6
-646	48.3	21.3	0.648	48.3	2.0

c **Low-Pressure 450 PSI O_2 System**

CYLINDER TYPE	TOTAL VOL. FREE O_2, CU. FT.	APPROX. WT. EMPTY, LBS.	APPROX. SPACE REQUIRED IN CU. FT.	APPROX. O_2 QUANTITY FOR AVERAGE MAN USING 1.0 CU. FT./HR. HRS.	DAYS
B-3	3.8	3.5	0.290	3.8	0.16
B-2	6.9	4.5	0.451	6.9	0.29
F-1	13.8	9.0	1.06	13.8	0.58
F-2	13.8	11.0	0.851	13.8	0.58
G-1	29.0	18.0	2.241	29.0	1.2

ITEM NO.	SUBJECT AREAS:	SOURCE:
499	SYSTEM - S2, S20, S21, S28, S29 HUMAN - H47	Reference 355, pp. 246-247 Based on Reference 308.

METABOLIC MATERIAL BALANCE

MATERIALS	POUNDS PER MAN PER DAY
Water vapor generation	2.20
Oxygen consumption	2.0
Carbon dioxide generation	2.25
Metabolic water generation	0.41
Food (dry)	1.32
Urine production	3.0
Fecal output	0.58
Solid waste from food	0.08
Carbon in food converted by metabolism into CO_2	0.615
Hydrogen in food converted by metabolism into H_2O	0.046
H_2O, derived from food	0.99
Total H_2O output	5.45
Net water intake for drinking and food preparation	4.46

The following over-all balance is obtained (in lb per man per day):

INPUT		OUTPUT	
Food (dry)	1.32 lb	CO_2	2.25 lb
Oxygen	2.00 lb	H_2O vapor	2.20 lb
Water	4.46 lb	Urine	3.00 lb
	7.78 lb		7.78 lb

ITEM NO.	SUBJECT AREAS:	SOURCE:
500	SYSTEM - S2, S21 HUMAN - H20, H43	Reference 586, p. 6-17 Based on Reference 95.

CHANGING THE PROPORTIONS OF NUTRIENTS

a.

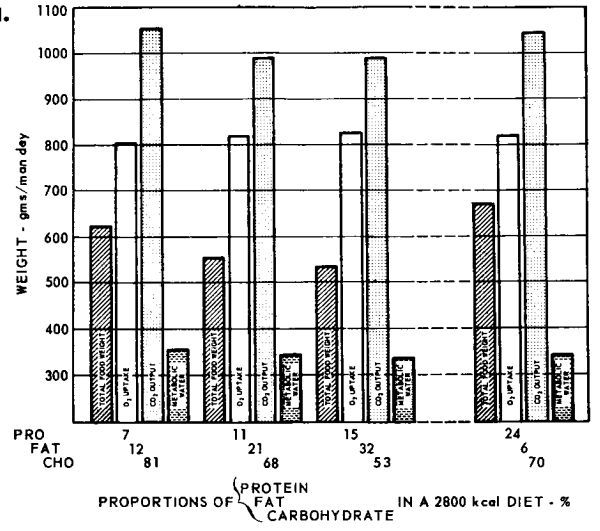
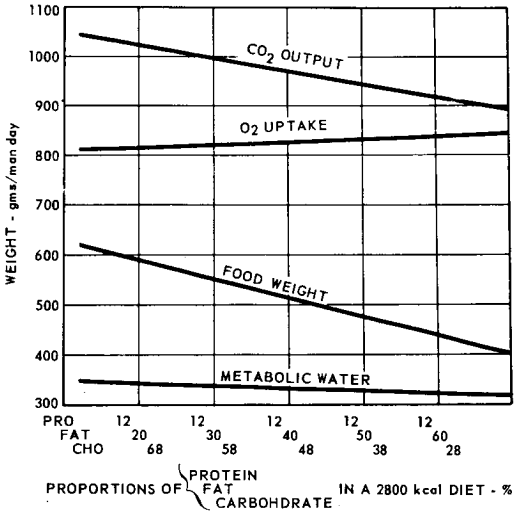
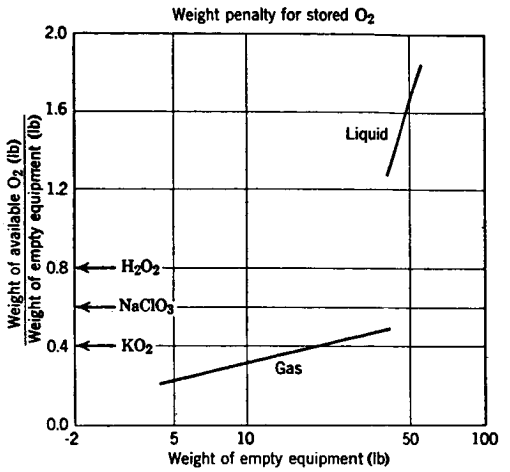


Chart a shows the effect of changing the constituent proportions of a 2800 Calorie (kcal) diet on the weight of the food (without packaging), the oxygen required for metabolism, and the resulting CO_2 and water. In this country people usually choose a diet containing 10 to 12% protein. Chart b shows the changes in food weight, oxygen consumption, CO_2 production, and metabolic water which result from changing the composition of a fixed protein diet. When the protein intake is 12%, the effect of changing the proportions of carbohydrate and fat is that more oxygen is needed to metabolize a high fat diet and less CO_2 is produced. The weights of the food and of the metabolic water decrease as the proportion of fat increases.

b.



ITEM NO.	SUBJECT AREAS:	SOURCE:
501	SYSTEM - S2, S21 HUMAN - H16, H20, H43	Reference 554, p. 196 Adapted from unpublished data.

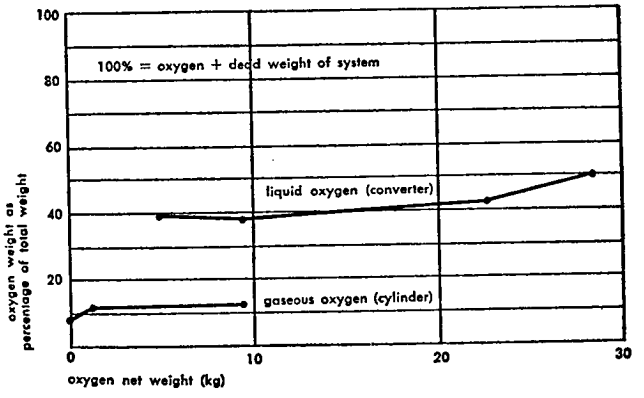


The efficiency of oxygen sources.

This figure describes the efficiency of several oxygen sources as determined by their quantitative availability and the weight of their associated equipment.

ITEM NO.	SUBJECT AREAS:	SOURCE:
502	SYSTEM - S2, S21 HUMAN - H47	Reference 416, p. 86 Based on Reference 176.

Comparative Weight of Oxygen in Two Systems



ITEM NO.	SUBJECT AREAS:	SOURCE:
503	SYSTEM -S2, S21 HUMAN- H47	Reference 128, p. 77

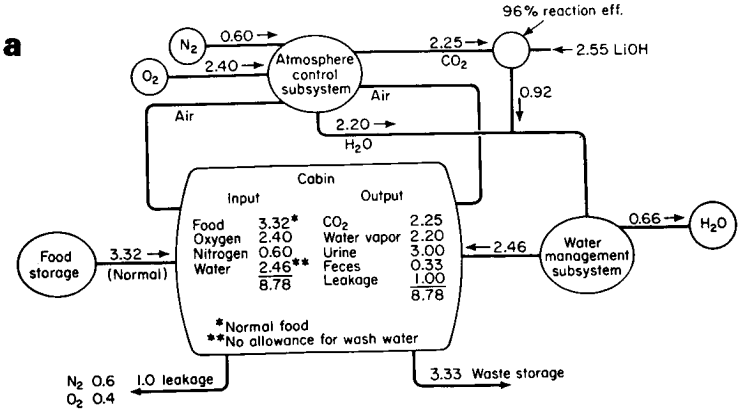
COMPARISON OF LIFE-SUPPORT MATERIAL REQUIREMENTS
(ASD TR 61-240 Pt I)

	Systems	*Water Balance*	*CO_2 Absorbent*	*Food*	*Oxygen*	*Nitrogen*	*Total Material Balance*
(1)	LiOH, normal food, no wash water	+0.66	−2.55	−3.32	−2.40	−0.60	−8.21
(2)	LiOH, dried food, no wash water	−1.34	−2.55	−1.32	−2.40	−0.60	−8.21
(3)	LiOH, normal food, with wash water	−3.34	−2.55	−3.32	−2.40	−0.60	−12.21
(4)	LiOH, dried food, with wash water	−5.34	−2.55	−1.32	−2.40	−0.60	−12.21
(5)	LiOH, normal food, with wash water and water recovery	+3.31	−2.55	−3.32	−2.40	−0.60	−5.56
(6)	LiOH, dried food, with wash water and water recovery	+1.31	−2.55	−1.32	−2.40	−0.60	−5.56
(7)	Regenerable CO_2 sorbent, normal food, wash water and water recovery	+2.39		−3.32	−2.40	−0.60	−3.93
(8)	Regenerable CO_2 sorbent, dried food, wash water and water recovery	+0.39		−1.32	−2.40	−0.60	−3.93
(9)	Oxygen recovering, dried food, regenerable CO_2 sorbent, wash water and water recovery	−1.04		−1.32		−0.60	−2.96

Note: The numbers shown have units of pounds/man-day. The minus sign indicates that the material is being spent. The plus sign indicates that the material is being produced.

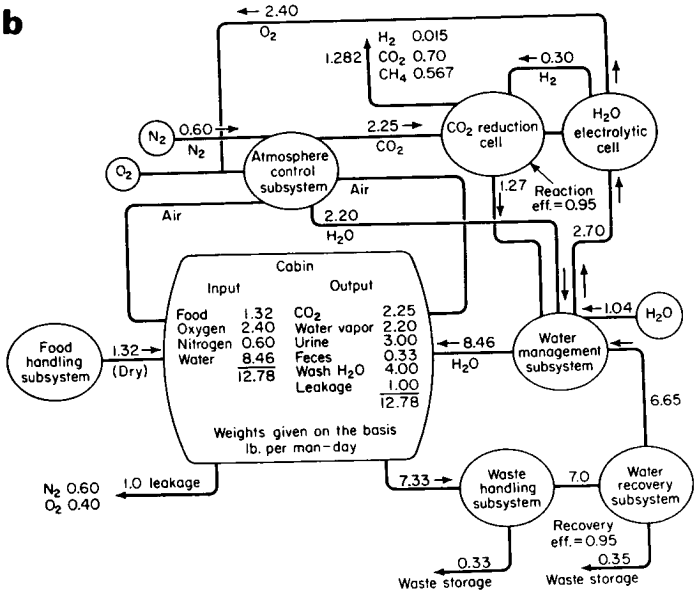
ITEM NO.	SUBJECT AREAS:	SOURCE:
504	SYSTEM - S2, S21 HUMAN - H43, H47	Reference 219, p. 418 Based on Reference 398.

a



Material balance with LiOH, normal food, and no wash water.

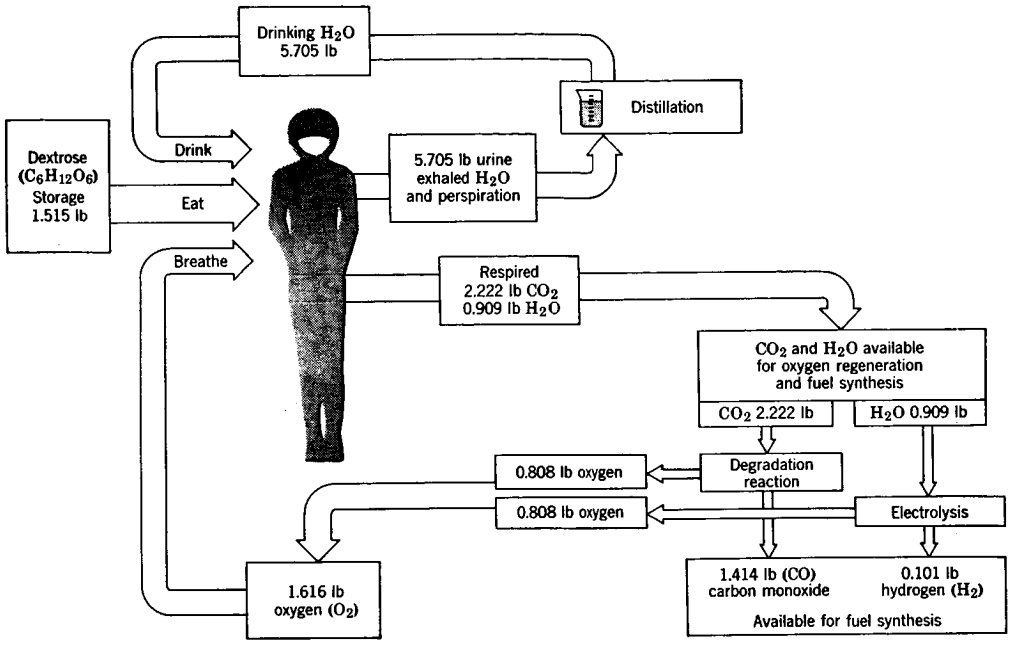
b



Material balance with oxygen recovery, dried food, wash water, and water recovery.

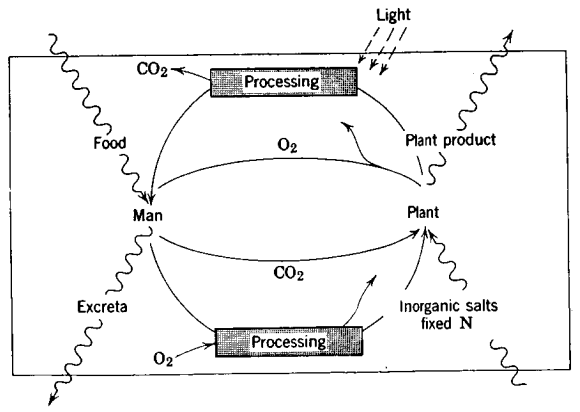
ITEM NO.	SUBJECT AREAS:	SOURCE:
505	SYSTEM - S2, S21 HUMAN - H43, H47	Reference 219, p. 419 Based on Reference 398.

a



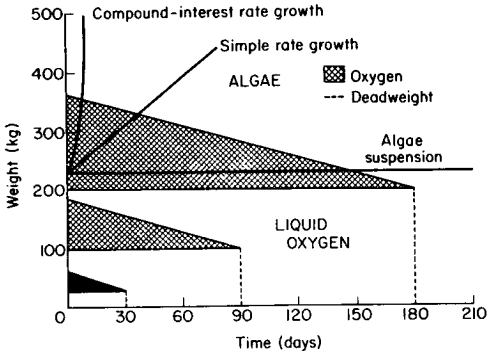
Scheme for daily regeneration of man's oxygen and water requirements.

b



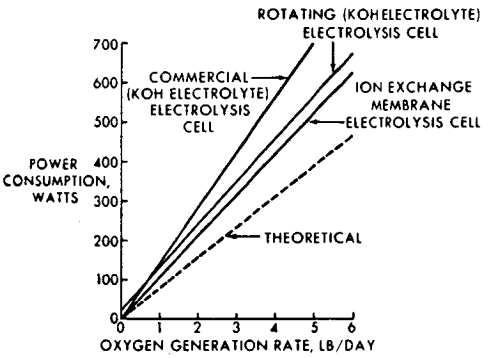
An ecological system, closed or regenerative, for water and gas exchange.

ITEM NO.	SUBJECT AREAS:	SOURCE:
506	SYSTEM - S2, S21 HUMAN - H43, H47	Reference 416, pp. 88-89 Based on References 142 (fig. a) and 32 (fig. b).



Comparison of liquid oxygen system to an ecologically balanced algae oxygen regeneration system. The cross-hatched areas represent weight of oxygen and its utilization; dead weight is shown by height of triangle base above zero line. If weight of algae system remains constant, at some point it becomes a lighter system than liquid O_2 for the same period of time. If growth is allowed, liquid O_2 may remain lighter for all durations. From Hans G. Clamann, personal communication.

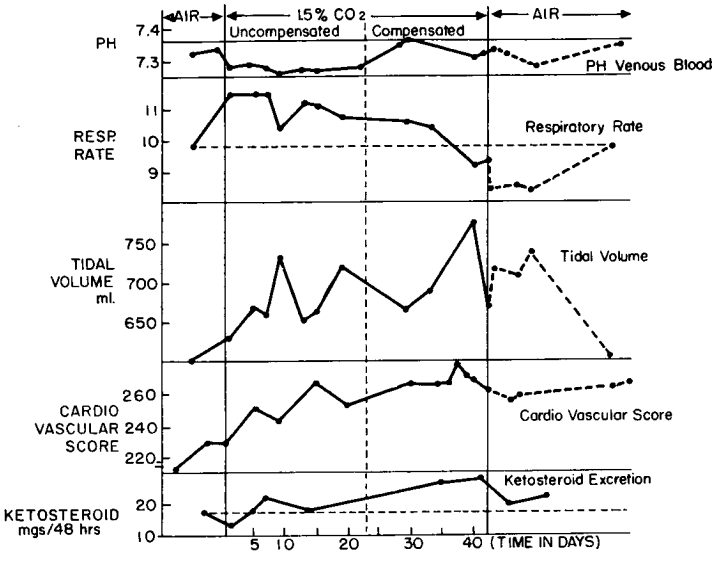
ITEM NO.	SUBJECT AREAS:	SOURCE:
507	SYSTEM - S2, S21, S29 HUMAN - H47	Reference 219, p. 437



Power required for electrolysis of water.

Purser, P.E.; Faget, M.A. and Smith, N.F.; (editors); MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

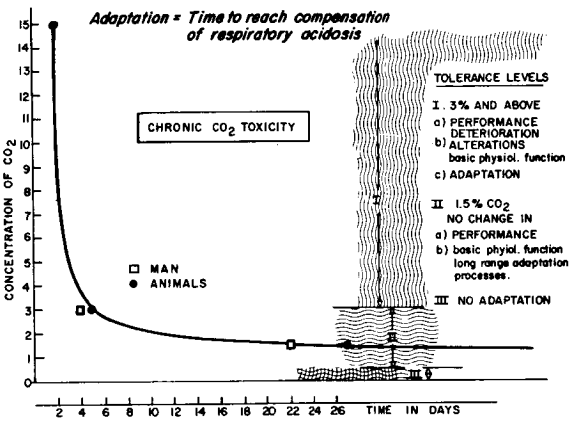
ITEM NO.	SUBJECT AREAS:	SOURCE:
508	SYSTEM - S2, S22 HUMAN - H47	Reference 167, p. 143



Effect of prolonged exposure to 1.5% CO_2 over a period of 42 days on respiratory rate, tidal volume, cardiovascular score, and ketosteroid excretion.

Schaefer, Karl E., BIOASTRONAUTICS, (c) 1964. Reprinted by permission of The Macmillian Company, New York, New York.

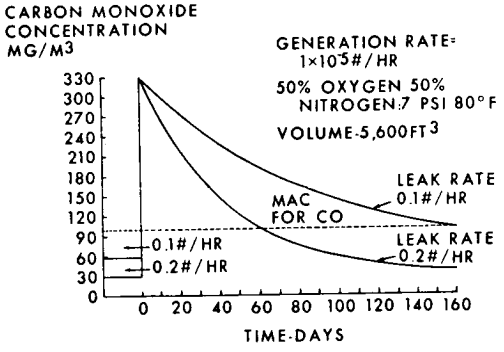
ITEM NO.	SUBJECT AREAS:	SOURCE:
509	SYSTEM - S2, S29 HUMAN - H9, H12, H16	Reference 465, p. 92 Based on Reference 461.



Time-concentration relationship in adaptation to increased carbon dioxide concentration based on experiments in human and animals and tolerance limits for chronic carbon dioxide toxicity based on three different levels of activity.

Schaefer, Karl E., BIOASTRONAUTICS, (c) 1964. Reprinted by permission of The Macmillian Company, New York, New York.

ITEM NO.	SUBJECT AREAS:	SOURCE:
510	SYSTEM- S2, S29 HUMAN- H16, H24, H34	Reference 465, p. 94 Based on Reference 460



Control of CO concentration by cabin leakage.

Purser, P.E.; Faget, M.A. and Smith, N.F.; (editors); MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
511	SYSTEM- S3, S29 HUMAN- H47	Reference 483, p. 154

Nuclear Submarine Threshold Limit Values for Continuous 90-day Exposure

COMPOUND	THRESHOLD LIMIT VALUE
Carbon monoxide	50 ppm
Monoethanolamine	1 ppm
Triaryl phosphate	1 mmg/l
Ozone	0.05 ppm
Freon	500 ppm
(HF, HCl, $COCl_2$)	0.1 ppm
Acetone	25 ppm
Aerosols	0.1 mmg/l

These threshold limit values have been adopted by The Bureau of Medicine and Surgery (Navy).

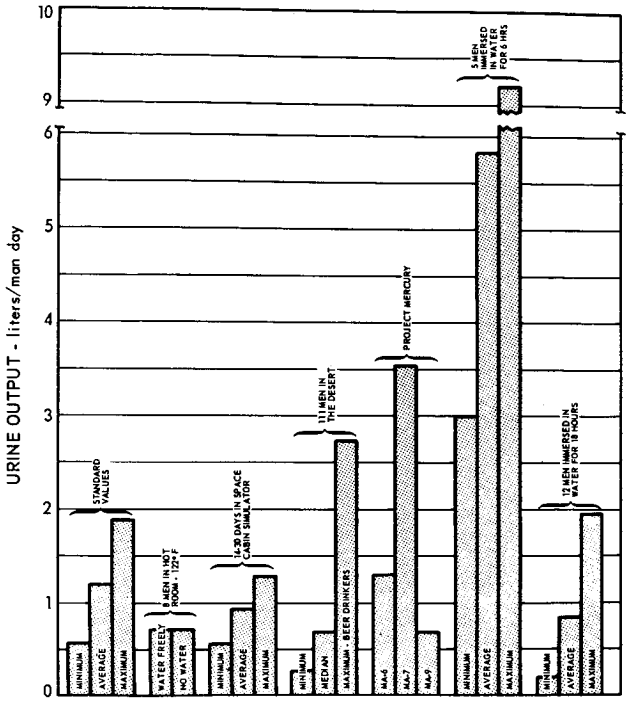
Schaefer, Karl E., BIOASTRONAUTICS, (c) 1964. Reprinted by permission of The Macmillian Company, New York, New York.

ITEM NO.	SUBJECT AREAS:	SOURCE:
512	SYSTEM - S3, S30 HUMAN - H33	Reference 465, p. 95

APPROXIMATE LETHAL CONCENTRATIONS FOR 15 MINUTE EXPOSURE TO VAPORS OF VARIOUS FIRE EXTINGUISHING COMPOUNDS

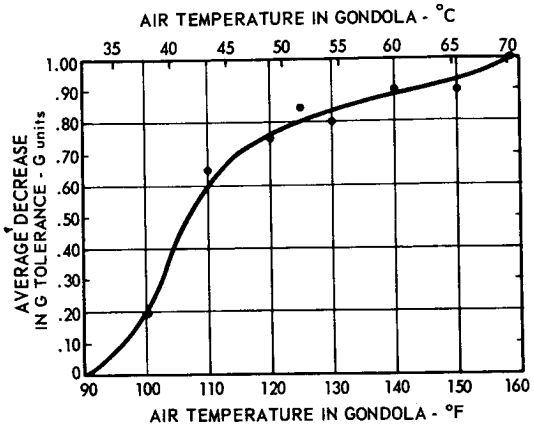
Agent	Vapor Pyrolized in Iron Tube at 800° C		
	mg/Liter	Parts per Million	Anesthetic Effect Time (min)
Bromotrifluoromethane	86	14,000	10
Carbon Tetrafluoride	3220	895,000	2
Bromochlorodifluoroethane	52	7,650	
1, 2-dibromotetrafluoroethane	17	1,600	5
Carbon Dioxide	1200	658,000	0.25
Perfluoromethylcyclohexene	117	7,500	5
Ethyl Bromide	75	16,500	5
Dibromodifluoromethane	16	1,850	3
Chlorobromomethane	20	4,000	10
1, 2-dibromo-2-chlorotrifluoroethane	8	700	8
1, 2-dibromo-1, 1-difluoroethane	110	12,000	
Carbon Tetrachloride	2	300	
Methyl Bromide	60	9,600	
Methyl Iodide	350	60,500	

ITEM NO.	SUBJECT AREAS:	SOURCE:
513	SYSTEM - S3, S32 HUMAN - H34	Reference 378, p. 65



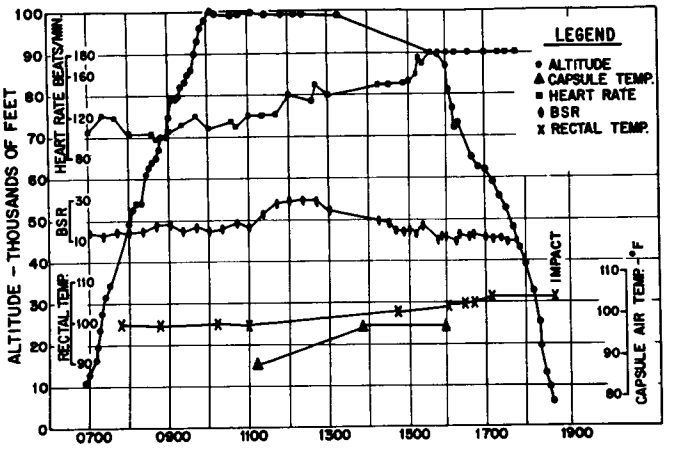
Some of the variability seen in the rate of urine production is shown by the 24-hour urine volumes plotted together on the bar graph. Heat exposure with high sweat rates was accompanied by low urine excretion (except for the men who got in to the tavern for beer at night), and certain experimental situations can cause very great urine excretion, as in the 6-hour experiment with water immersion reported by Graveline. By contrast, another immersion experiment reported by Benson et al. produced low to average urine volumes. In the orbital flights of Project Mercury, urine production is seen to have been quite varied. In one flight, MA-7, there was a real diuresis during the 4.5 hour weightless period. In MA-6 and MA-9 there was a rather low urine volume, which may be related to the high rate of sweating observed. The data for MA-9 show the 24-hour rate calculated from urine volume in 34 hours of weightlessness.

ITEM NO.	SUBJECT AREAS:	SOURCE:
514.	SYSTEM - S4, S12 HUMAN - H11	Reference 554, p. 205 Based on References 68, 232, 486, 388, 389, 387, 569, 7



This shows the average decrease in tolerance to $+G_z$ acceleration, using loss of peripheral vision as the end-point, for six subjects accustomed to riding the centrifuge. They were dressed in light summer flying suits and were exposed to each temperature for a total of one hour, during which tolerance levels were determined.

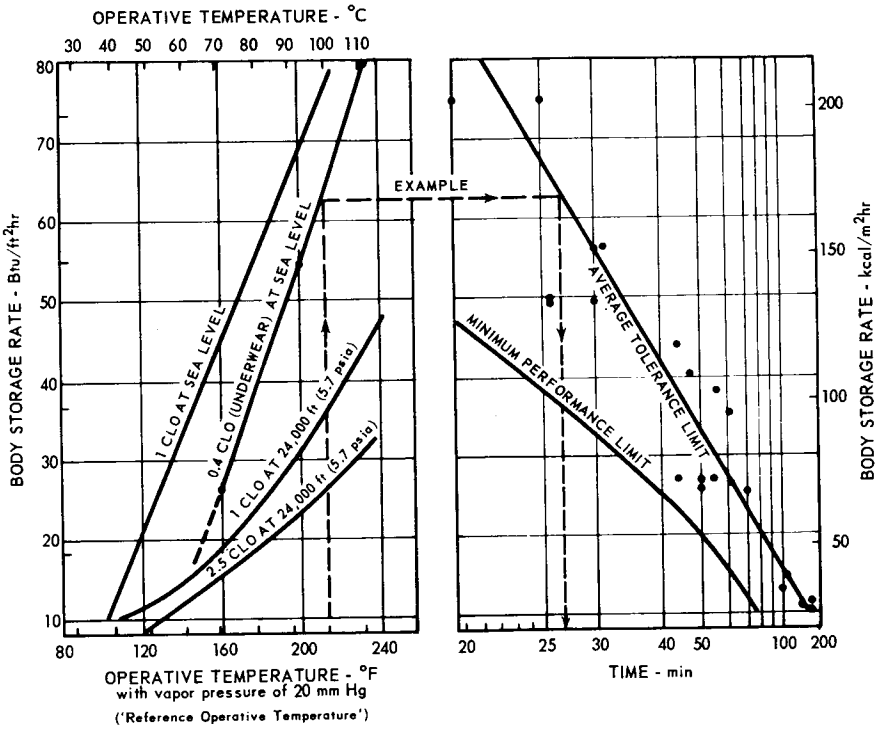
ITEM NO.	SUBJECT AREAS:	SOURCE:
515	SYSTEM - S4, S13 HUMAN - H34	Reference 554, p. 163 Based on Reference 107



Physiological data related to flight altitude observed during the MANHIGH III high-altitude balloon flight.

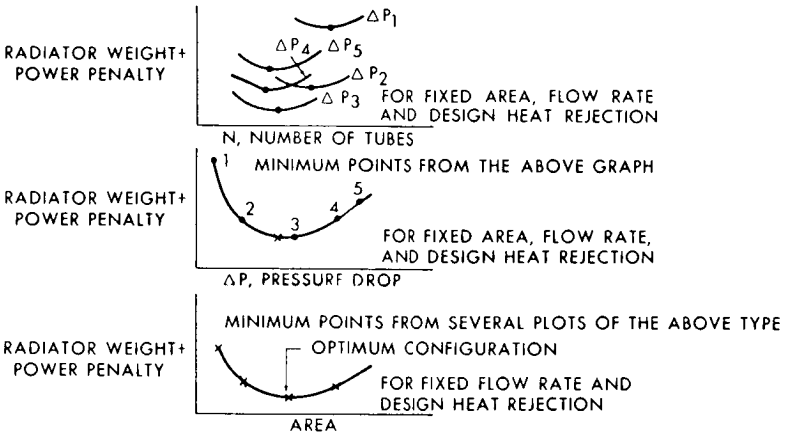
ITEM NO.	SUBJECT AREAS:	SOURCE:
516	SYSTEM- S4, S18 HUMAN- H9, H14, H18	Reference 479, p. 140

HEAT STORAGE AND TOLERANCE



This chart shows the rate of storage of body heat for several conditions of clothing and altitude, where seated and untrained men are exposed to noncompensable heat. Entry is by means of the reference operative temperature, defined as the temperature of air and walls which, in combination with a vapor pressure of 20 mm Hg, has equivalent effects to some other combination of humidity and temperatures. Operative temperature is the weighted mean of air and wall temperature, where the weighting coefficients are the respective heat transfer coefficients for convection and radiation.

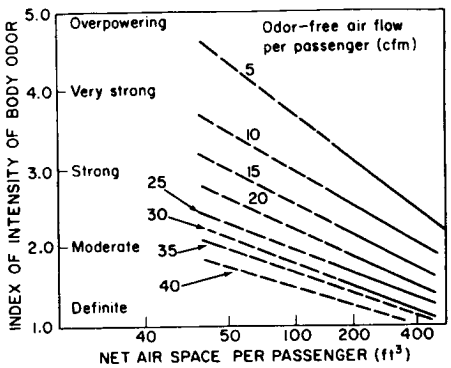
ITEM NO.	SUBJECT AREAS:	SOURCE:
517	SYSTEM - S4, S18 HUMAN - H18, H24, H34, H44	Reference 554, p. 116 Based on Reference 81



Typical graphical procedure for optimizing overall radiation system.

In the design of a radiator system, the effect which each parameter has on the overall system performance must be considered. The system weight includes the weights of radiator sections, manifolds and tubing, coolant loop and fluid, pumps, valves, and power supply. Manufacturing and structural requirements may place constraints of system design and operating parameters, but within practical limits the system should be designed to give the highest possible ratio of net heat radiated to radiator system weight. A radiator system optimizing procedure is shown graphically above.

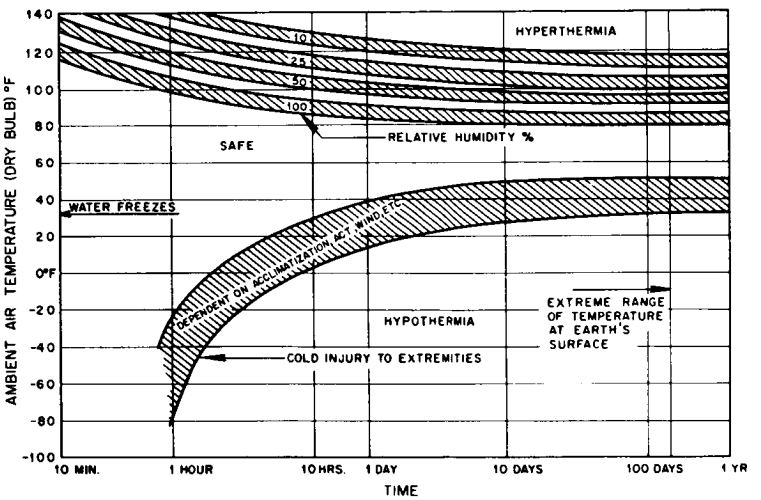
ITEM NO.	SUBJECT AREAS:	SOURCE:
518	SYSTEM- S4, S19 HUMAN- H47	Reference 483, p. 148



Ventilation requirements related to net air space and body odor. Solid parts of curves are based on experimental data; dashed portions are extrapolations of conditions found in aircraft.

Although odors might induce nausea and might have a slight effect on voluntary food consumption in some people and thus are undesirable atmospheric contaminants, they are not known to affect health and are not classed as poisons. Generally, however, it is desirable to eliminate unwanted odors. Often, the production of body odors in an enclosed space requires ventilation. These requirements are illustrated above. The index used is based on the intensity of smell sensations, which are assumed to vary with the logarithm of the concentration.

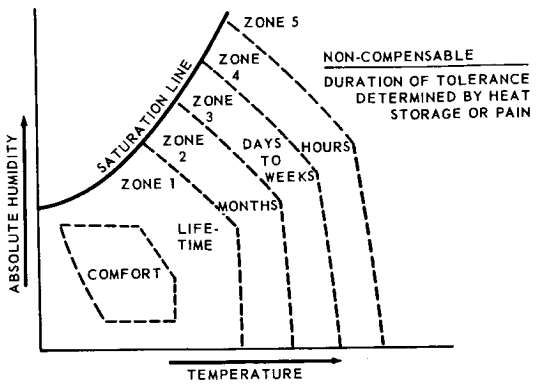
ITEM NO.	SUBJECT AREAS:	SOURCE:
519.	SYSTEM - S4, S20 HUMAN - H35	Reference 380, p. 444 Based on Reference 590.



Approximate human time-tolerance temperature (optimum clothing). (Courtesy Chance-Vought Aircraft Co.)

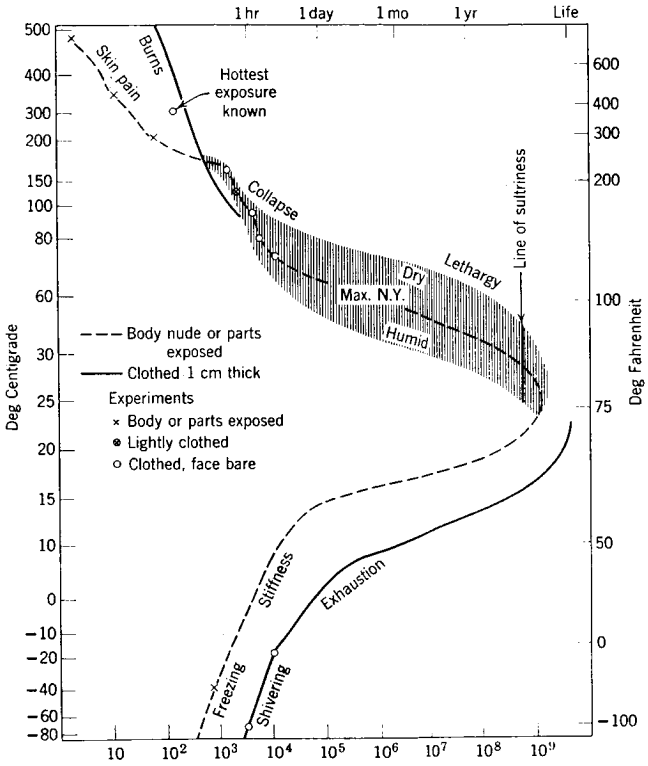
ITEM NO.	SUBJECT AREAS:	SOURCE:
520	SYSTEM - S4, S27 HUMAN - H34	Reference 219, p. 445

SPECTRUM OF HUMAN RESPONSE TO HEAT



The spectrum of human response to heat and humidity is broad, ranging from complete thermal comfort to the upper extremes of pain-limited exposures. One useful way of dividing this broad spectrum into manageable segments is shown in the figure. First is a thermal zone in which a lifetime of continuous exposure should cause no special effects; bordering on it is a zone in which exposures lasting up to months are tolerable by the general population, occasional relief being required to prevent the accumulation of deleterious effects (e.g., seasonal heat waves in tropical countries). A third zone relates exposures which are tolerable or survivable for days to weeks, and a fourth zone includes conditions which lead to breakdown within a few hours. At the extreme end of the spectrum are those environmental situations in which a human is never able, unaided, to establish a thermal equilibrium, so that the duration of exposure which he can survive is determined either by the rate at which his body stores up heat or the development of pain on the surfaces of the body. The actual location of the boundaries will be influenced by the age, health, state of training, experience, clothing, and activity of the individuals concerned.

ITEM NO.	SUBJECT AREAS:	SOURCE:
521	SYSTEM - S4, S27 HUMAN - H34	Reference 554, p. 104



Temperature-time relationship. Safe heat and cold exposure times in seconds for healthy, normal men at rest with body wholly or partly exposed. Room is free from artificial ventilation and radiation; air and wall have identical temperature. Humidity influence is shown by batching. Max. N. Y. = Highest data of temperature and humidity in New York City.

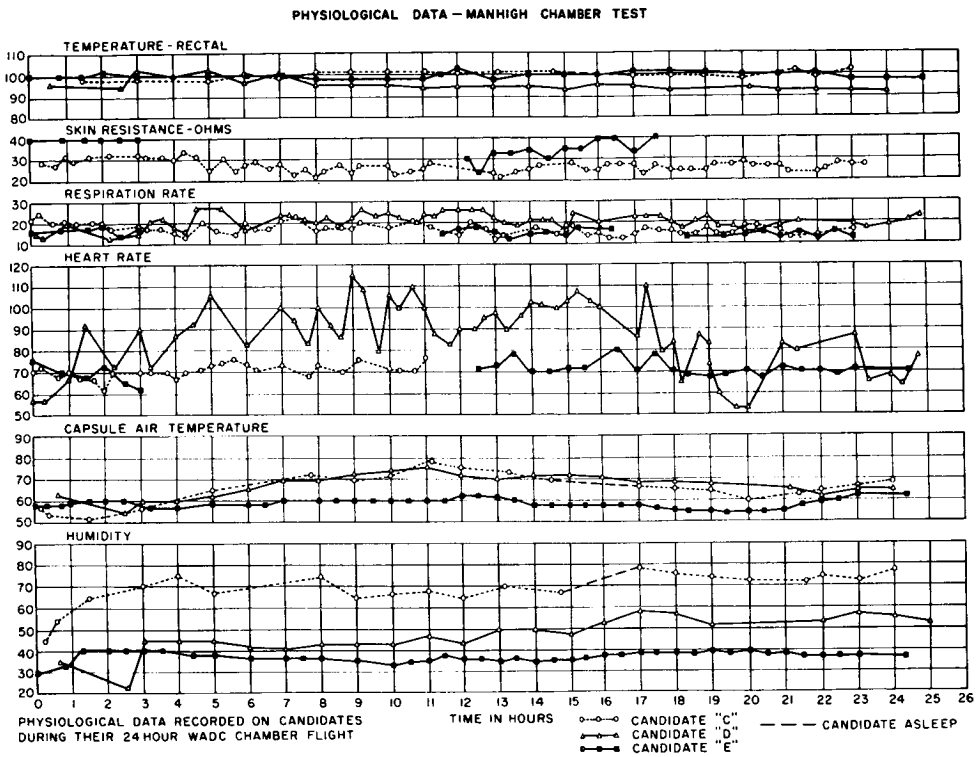
ITEM NO.	SUBJECT AREAS:	SOURCE:
522	SYSTEM - S2, S27 HUMAN - H34, H44	Reference 416, p. 97 Based on Reference 103

Methods of Preserving Thermal Balance

Short trip, minutes	For launch and re-entry heating, heat sinks are the lightest and most efficient
Short trip, hours	Open cycle mass-rejecting evaporative systems
Medium trip, days, weeks, or months	Closed cycle circulating systems of greater fixed weight than conduction paths but more efficient and lighter over-all
Long trip, months or years	Radiation of thermal energy into space, entailing no mass transfer within or from the vehicle

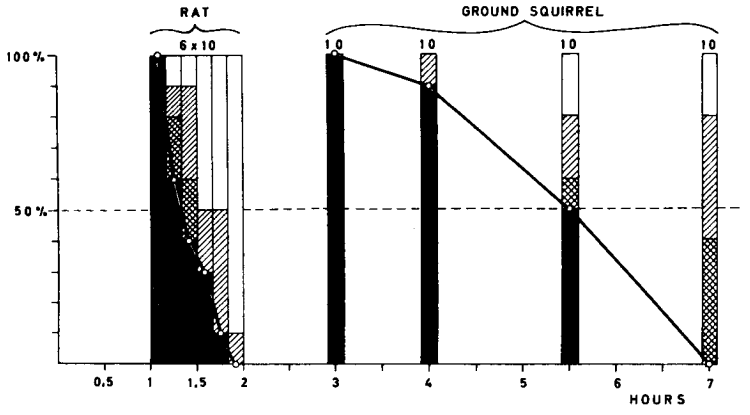
From HUMAN FACTORS ENGINEERING by Ernest J. McCormick. Copyright 1957, 1964 by McGraw-Hill, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
523	SYSTEM - S4, S27 HUMAN - H47	Reference 416, p. 95 Based on Reference 317



Physiological data recorded on candidates during their 24-hr WADC chamber flight.

ITEM NO.	SUBJECT AREAS:	SOURCE:
524	SYSTEM - S4, S28 HUMAN - H9, H16, H17, H18	Reference 219, p. 309 Based on Reference 478.

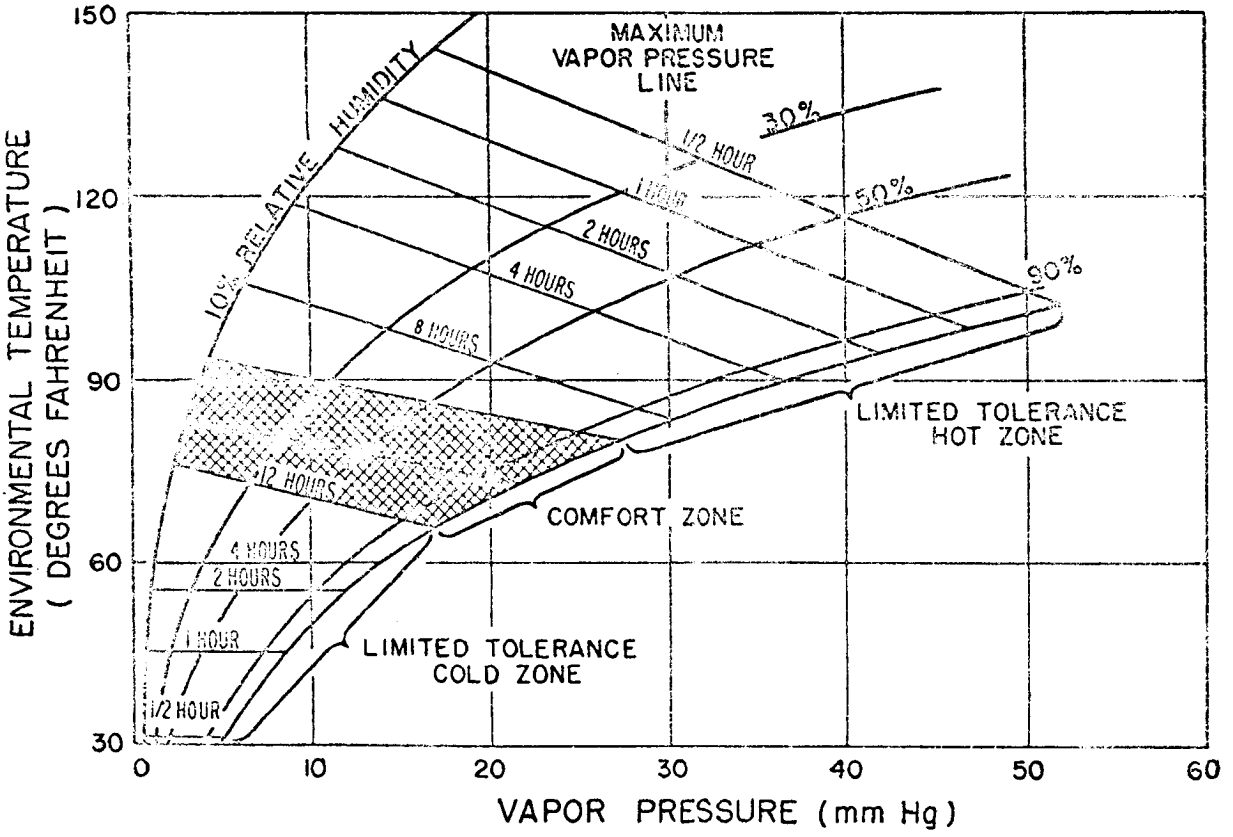


Time limits of suspended animation (respiratory and circulatory arrest) in rats and ground squirrels at 0°C of body temperature.

For two animal species the revival time has been determined with precision in serial experiments, but only for one body temperature level, 0°. The figure above illustrates the limits of tolerance to respiratory and cardiac arrest in the rat and the ground squirrel maintained at 0°C body temperature. These limits were studied by applying special but standardized techniques of cooling and resuscitation, fully described elsewhere, closed vessel technique for inducing deep hypothermia in unanaesthetized animals, followed by further cooling to 0°C in crushed ice; localized microwave diathermy and excessive artificial respiration for reanimation). Revival is expressed on the basis of the percentage of long-term survivors (black portions of the bars) among animals subjected to the standard reanimation procedure, after different time intervals spent in suspended animation at 0°C body temperature with complete cardiac arrest. There were 10 animals in each group. The differently-shaded portions of the bars represent the percentage of animals which died at different intervals after they had been temporarily reanimated, while the remaining white portions show the percentage of animals which failed to revive.

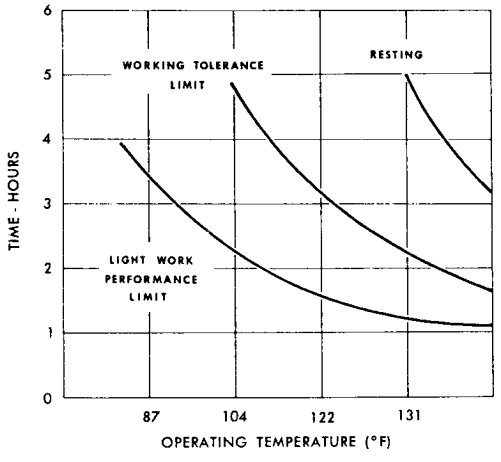
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ITEM NO.	SUBJECT AREAS:	SOURCE:
525	SYSTEM - S4, S28 HUMAN - H9, H16, H18	Reference 18, p. 126 Based on Reference 19



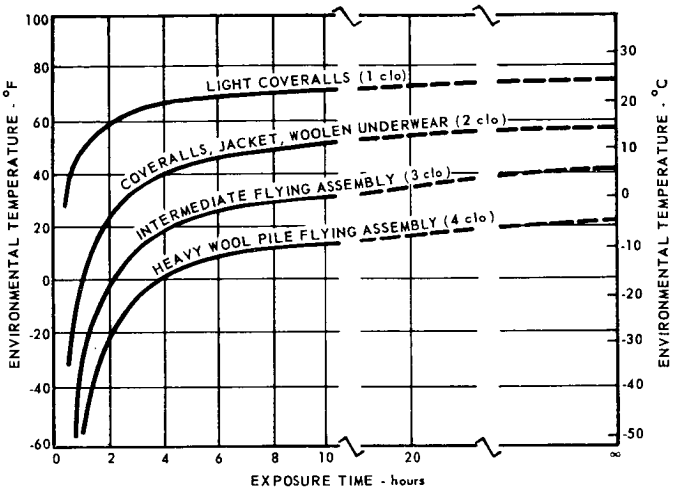
Tolerance limits for combined temperature-vapor pressure.

ITEM NO.	SUBJECT AREAS:	SOURCE:
526	SYSTEM - S4, S28 HUMAN - H33	Reference 267, p. 94 Based on Reference 510.



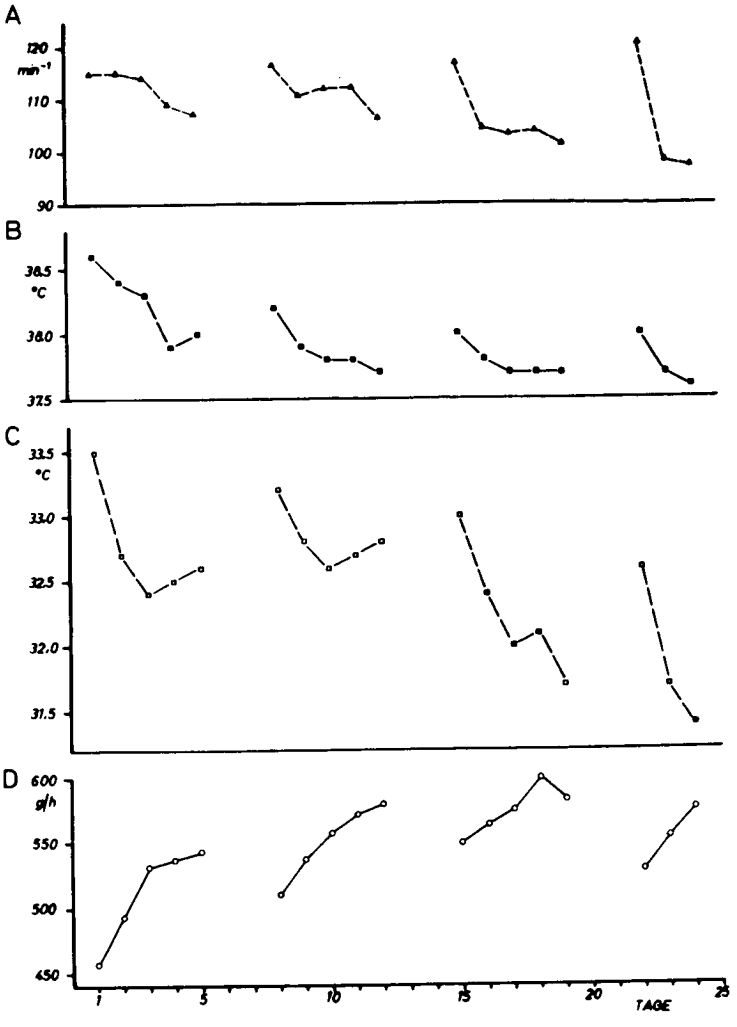
Tolerance to heat.

ITEM NO.	SUBJECT AREAS:	SOURCE:
527	SYSTEM - S4, S28 HUMAN - H22, H34	Reference 586, p. 2-227.



The amount of clothing insulation that is adequate for a particular cold environment depends on the length of time one is to be exposed and the activity level, or metabolic heat production rate. This chart shows the influence of exposure time for low activity, sitting (pilot activity) . The chart is slightly unrealistic because of the uncertainty as to appropriate criteria for tolerance limits.

ITEM NO.	SUBJECT AREAS:	SOURCE:
528.	SYSTEM - S4, S28 HUMAN - H44	Reference 554, p. 125 Based on References 110 and 511.



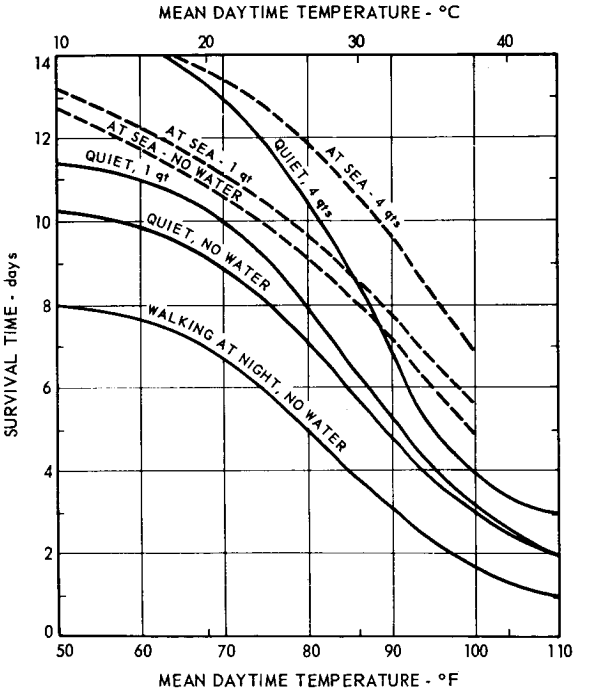
From BASIC ENVIRONMENTAL PROBLEMS OF MAN IN SPACE 1965, edited by H. Bjurstedt, Copyright 1965 by Springer-Verlag/Wien.

Changes in pulse rate (A), rectal temperature (B), skin temperature (C) and sweat output (D) in the course of 18 days of exposure in a subject doing hard work, during adaptation to a hot and humid climate.

Sweating in a man not used to heavy work in the heat is inadequate. Body temperature and pulse rate therefore rise higher than in a man regularly exposed to heat. In the course of two weeks adaptation will occur. But only two days without heat reduce the valuable acclimatisation gained. The same is true for cold-induced vasoconstriction in the skin. Sudden changes of temperature are a training stimulus which preserves a high adaptability to climatic changes, useful to the space explorer, but easily lost, if the private climate in the cabin is evenly maintained over a long period of flight. These biological demands could probably be supplied by technical means.

ITEM NO.	SUBJECT AREAS:	SOURCE:
529	SYSTEM - S4, S29 HUMAN - H9, H18	Reference 383, p. 177

WATER INTAKE AND SURVIVAL



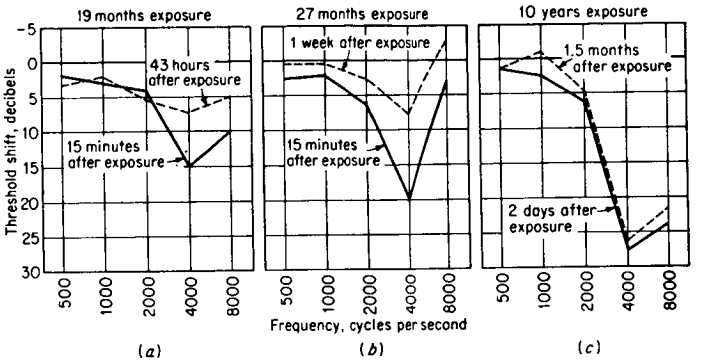
Predicted survival times on land and sea are shown when men have no water, or have 1 qt per man, or 4 qts per man, total supply. Land estimates are shown in solid curves, sea estimates in dashed curves. The man on land is expected to rest, and not to try to walk out of the situation, but to stay in whatever shade he can muster. The effect of walking only at night is shown in the lowest curve. The survival limit is set by dehydration.

ITEM NO.	SUBJECT AREAS:	SOURCE:
530	SYSTEM - S4, S29 HUMAN - H34, H43	Reference 554, p. 209 Based on References 400, 7.

NOISE LIMITS FOR AVOIDING HEARING DAMAGE—DB

TIME	EARS UNPROTECTED	WITH EAR PLUGS	EAR PLUGS AND MUFFS
8 hrs.	100	112	120
1 hr.	108	120	128
5 min.	120	132	140
30 sec.	130	142	150

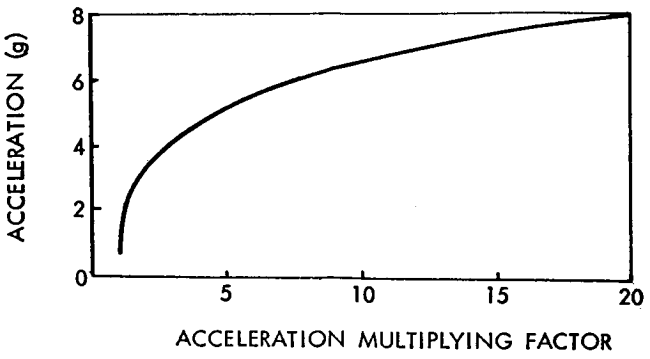
ITEM NO.	SUBJECT AREAS:	SOURCE:
531	SYSTEM - S5, S28 HUMAN - H34, H44	Reference 586, p. 2-225



Comparison of recovery of (temporary) hearing loss for groups of workers exposed to high noise levels for varying periods of time.

The time required for recovery from temporary hearing loss is generally related to the length of the noise exposure that induced it. For short exposures (6 to 12 min of continuous noise) much recovery occurs within a couple of minutes after exposure, and most recovery is achieved within 20 min. A comparison of recovery after various periods of exposure is shown above. This shows recovery for two groups of textile workers who had been exposed to high noise levels for 19 and for 27 months and another group of workers who had been exposed to high noise levels for 10 years. It will be noted that the 19-month exposure group (a) recovered most, and the 10-year exposure group (c) recovered least—even after 1.5 months of elapsed time. These, and other studies, suggest that, with increasing duration of exposure, there is less and less recovery (temporary hearing loss) and increasing permanent hearing loss.

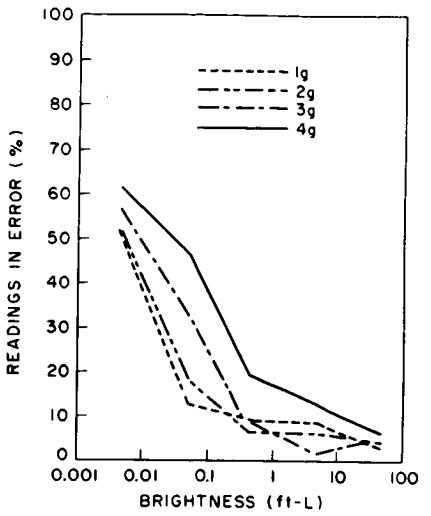
ITEM NO.	SUBJECT AREAS:	SOURCE:
532	SYSTEM - S5, S31 HUMAN - H25	Reference 362, p. 472. Adapted from Reference 42.



Increase in Illumination Required to Compensate for Transverse Acceleration Forces

This curve represents an approximation of positive g as a function of illumination requirements up to 5 g's. The use of pressure suits and direction of the acceleration force applied will vary the relationship and must be considered in using this curve.

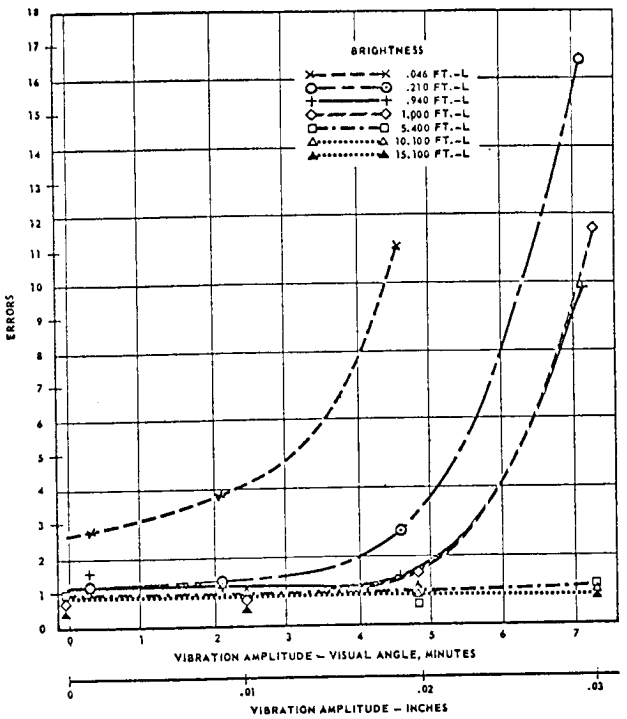
ITEM NO.	SUBJECT AREAS:	SOURCE:
533	SYSTEM- S6, S13 HUMAN- H25	Reference 378, p. 201



Loss of visual function with increased acceleration.

Because both brightness sensitivity and visual acuity decrease with increasing acceleration, it would be expected that an operator subjected to these forces would commit errors in instrument reading. That this does indeed happen is shown above (White and Riley, 1956), which also shows again that, at least up to 3g, the loss of visual function can be importantly counteracted by increases in brightness above 0.1 ft-L. The use of relatively high brightnesses at all levels, however, is clearly indicated.

ITEM NO.	SUBJECT AREAS:	SOURCE:
534	SYSTEM - S6, S13 HUMAN - H25	Reference 380, p. 460 Based on Reference 578.



Effect of vibration amplitude on reading accuracy for various luminances.

This figure shows the increase in errors for reading accuracy as a function of vibration amplitude for seven different levels of brightness (Ft.-L). There is no decrement due to vibration if brightness is great enough (5.400 Ft.-L or greater). For brightness values of 0.21 to 1.00 Ft.-L, the decrement begins the subtended visual angles of about 4 minutes.

ITEM NO.	SUBJECT AREAS:	SOURCE:
535	SYSTEM - S6, S14 HUMAN - H25	Reference 155

Water Balance in Sealed Space Capsule

Input	Output	Cabin Uses
Liquid water	Urine Metabolic oxidations	Source of oxygen Medium for photosynthesis
Preformed water in foods	Water vapor from lungs Insensible perspiration Sensible perspiration Food discards Wash water for hygiene	Radiation shield Better tolerance to acceleration stress Food preparation

Humidity control and water logistics within the sealed cabin would be based on several factors, as seen above. Balancing water output with water intake to avoid dehydration is the ideal for the spaceman, but for the engineer concerned with logistics problems, this balance for man must in turn be balanced against the uses of water within the space cabin in maintaining a constant cycle of operation. Therefore, the ultimate goal of waste control during lengthy missions is to avoid wasting the excreted products and to re-enter them into a cycle for replenishing the input supplies of the spaceman. This is a part of the truly closed cyclic system concept, wherein all molecules entering the body are eventually excreted, purified physiochemically, and then reused by the spaceman.

ITEM NO.	SUBJECT AREAS:	SOURCE:
536	SYSTEM - S2, S4, S7, S11 HUMAN - H44, H47	Reference 416, p. 90

THE FREQUENCY OF CHROMOSOME DISTURBANCES IN THE CELLS OF THE MARROW OF MICE UNDER THE INFLUENCE OF VIBRATION (70 Hz, 15 min) AND X-RAYS (100 r)

	Terms after Effect	The Number of Examined Cells: Normal Cells	Violated Cells	The Total Number of Cells Examined	Percentage of Violated Cells	The Number of Cells with Chromosome Violations: Bridges	Fragments	Total
Vibration	30 min	622	137	759	18.05±1.40	56	5	61
	1 hour	489	149	638	23.35±1.67	40	3	43
	4 hours	601	74	675	10.96±1.20	4	9	13
	1 day	1160	366	1582	23.89±1.09	90	13	103
	2 days	804	214	1018	21.02±1.28	58	6	64
	10 days	357	74	431	17.17±1.82	8	1	9
	Control	2319	207	2526	8.19±0.55	63	19	82
X-rays	1 day	270	55	325	16.92	31	18	49

Percentage of Cells with Chromosome Disturbances	The Number of Cells with Chromosomes Stock Together: Total	Percent of Sticking Together	The Index of Correctness: Violated Cells	Chromosome Violation	Sticking Together of Chromosomes
8.04±0.93	76	10.01±1.09	6.6	4.8	4.3
6.74±0.99	106	16.61±1.47	8.7	8.3	7.6
1.93±0.55	61	9.03±1.11	2.1	2.0	3.4
6.73±0.64	268	17.16±0.96	12.9	4.8	11.6
6.29±0.76	150	14.73±1.11	9.2	3.6	8.2
2.09±0.69	65	15.08±1.72	4.7	1.5	5.7
3.25±0.35	125	4.95±0.44			
15.07					

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ITEM NO.	SUBJECT AREAS:	SOURCE:
537	SYSTEM - S7, S14 HUMAN - H15	Reference 200, p. 259 Based on Reference 48

Shielding Thickness for 200-Mev Protons[a]

Material	Atomic Number	Thickness, cm	Weight per Unit Area, gm/cm^2
Liquid hydrogen	1	176.0	12.3
Carbon	6	12.9	29.0
Aluminum	13	12.1	32.7
Copper	29	4.4	39.0
Tungsten	74	2.7	52.0
Lead	82	4.6	52.0

From Newell and Naugle

[a] Thickness and weight per unit area, as a function of atomic number, for a shield which will just stop 200-Mev protons.

ITEM NO.	SUBJECT AREAS:	SOURCE:
538.	SYSTEM - S7, S21 HUMAN - H44	Reference 416, p. 100 Based on Reference 394.

Distribution Nuclear Vehicle Payload Weight

ITEM	WT IN LBS
Sustenance material 3 men at 15/lb/man/day	19,000
3 Men plus personal equipment	800
All other equipment (communications, etc)	4,200
Main sealed cabin and accessories (e.g. air lock)	1,000
Safety factor (additional structure and equipment)	1,000
Mars reconnaissance and earth re-entry capsule (vehicle)	4,000
Fuel ($H_2 + O_2$ at I_{SP} 400 sec) for capsule	11,000
U^{238} Scatter shield	14,000
Total payload weight	55,000

This table was developed with regard to an investigation of a round-trip Martian journey by a high-thrust nuclear rocket.

ITEM NO.	SUBJECT AREAS:	SOURCE:
539	SYSTEM - S7, S21 HUMAN - H43, H44	Reference 309, p. 295 Based on Reference 310

NASA MAXIMUM PERMISSIBLE EXPOSURE TO RADIATION

a

Critical Organ	Maximum Lifetime Dose (rem)	Average Yearly Dose (rad)	Average Dose for 30 Days (rad)	Maximum Permissible Single Acute Emergency Dose (rad)
Skin of whole body	1630	233	25	500
Blood-forming organs	271	54	5	200
Feet, ankles, and hands	3910	559	50	700
Eyes	271	27	3	100

RECOMMENDED PERMISSIBLE WHOLE-BODY ACUTE EXPOSURE LEVELS

b

Dose (rem)		Expected Effect on Astronaut
Single	Total	
25	250 per year	None; recommended average yearly dose
25	300 per month 1000 per year	Mild radiation exposure symptoms; probably no deaths; mission performance probably acceptable; allowable in emergency situations
100	1500 per month 2000 per year	Radiation sickness; probable survival; mission performance questionable

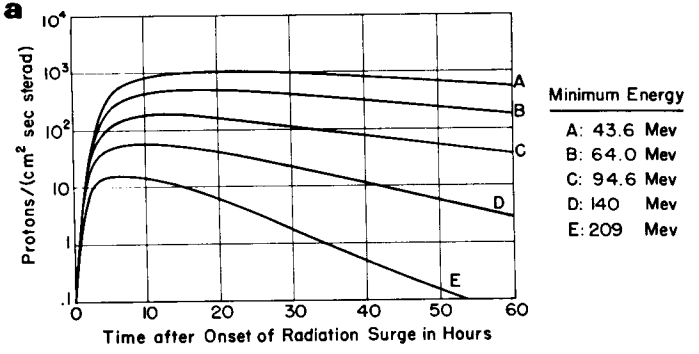
ITEM NO.	SUBJECT AREAS:	SOURCE:
540	SYSTEM - S7, S27 HUMAN - H33, H34	Reference 378, pp. 54-55.

ITEM NO. 541

SUBJECT AREAS: SYSTEM- S7, S28 HUMAN- H34

SOURCE: Reference 459, pp. 148-149, 154.

a



Minimum Energy

A: 43.6 Mev
B: 64.0 Mev
C: 94.6 Mev
D: 140 Mev
E: 209 Mev

Evolution of energy spectrum for proton radiation from a typical large-solar flare. Shown is integral flux from various minimum energies to upper end of spectrum.

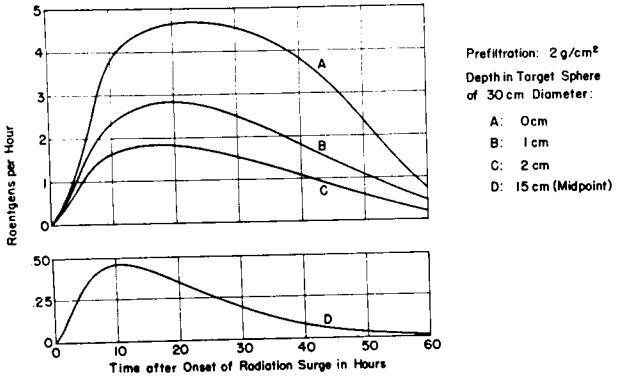
b

Kinetic Energies and Ranges for Protons in Organic Material

CURVE	KINETIC ENERGY, MEV	RANGE, G/CM²
A	43.6	2.0
B	64.0	4.0
C	94.6	8.0
D	140.0	16.0
E	209.0	32.0

The minimum energies shown in Figure a correspond to ranges in organic matter as listed in Table b. It may be seen that particles of higher energies reach their maxima earlier and disappear earlier during the flare event. At the same time, their maxima are considerably smaller than those of particles of lower energies.

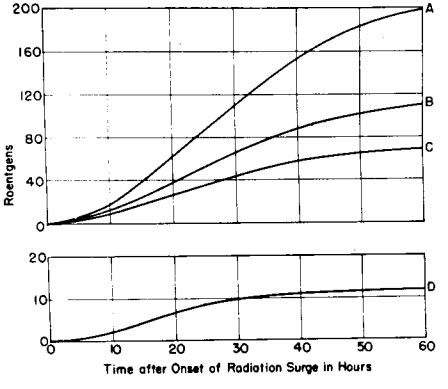
c



Prefiltration: 2 g/cm²
Depth in Target Sphere of 30 cm Diameter:
A: 0 cm
B: 1 cm
C: 2 cm
D: 15 cm (Midpoint)

Time profile of tissue dose rates within a 30 cm diameter tissue sphere exposed to solar particle beam described in figure a.

d



Prefiltration: 2 g/cm²
Depth in Target Sphere of 30 cm Diameter
A: 0 cm
B: 1 cm
C: 2 cm
D: 15 cm (Midpoint)

Time profile of accumulated tissue doses within a 30 cm diameter tissue sphere exposed to solar particle beam described in Figure a.

Schaefer, Karl E., BIOASTRONAUTICS, (c) 1964. Reprinted by permission of The Macmillian Company, New York, New York.

RADIATION EXPOSURE DOSE LIMITS
FOR SPACE MISSIONS NOT EXCEEDING 14 DAYS

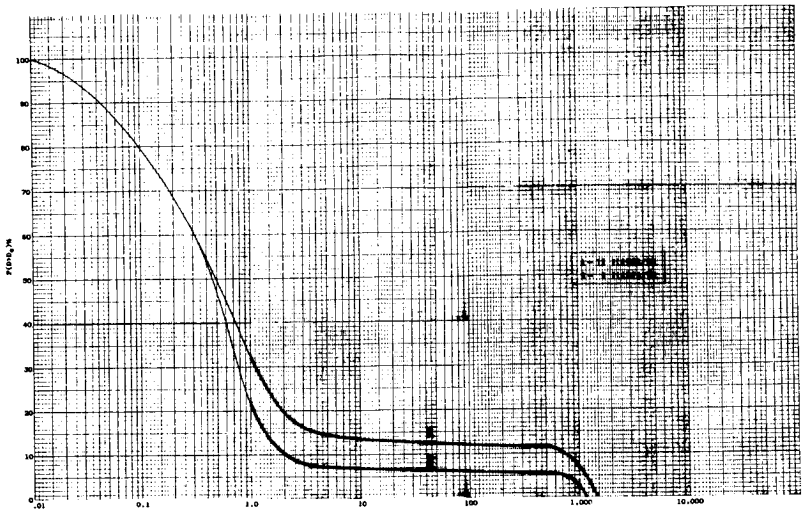
Critical Organ	*Maximum permissible integrated dose, rem*	*RBE rem/rad*	*Average yearly dose, rad*	*Maximum permissible single acute emergency exposure, rad*	*Location of dose point*
Skin of whole body	1,600	1.4 (approx.)	250	500[a]	0.07-mm depth from surface of cylinder of radius 15.0 cm at highest dose-rate point
Blood-forming	270	1.0	55	200	5-cm depth from surface of cylinder of radius 15.0 cm
Feet, ankles, and hands	4,000	1.4	550	700[b]	0.07-mm depth from surface of cylinder of radius 3.8 cm at highest dose point
Eyes	270	2[c]	27	100	3-mm depth from surface of cylinder of radius 7.5 cm along eyeline

[a] Based on skin erythema level
[b] Based on skin erythema level but these appendages are believed to be less radiosensitive
[c] Slightly higher RBE assumed since eyes are believed more radiosensitive

The approach adopted by Gill for missions of duration not exceeding 14 days, has been to take the limits for exposure for workers in the atomic energy industry for a working lifetime of exposure and specify that this total dose shall not be exceeded during a 5-year period during which an astronaut might be expected to be involved in active flying in space missions. One-fifth of this dose should not be exceeded in one year and if it is, then the crew member should not fly further missions until he has remained on earth for a length of time sufficient to bring his mean annual dose down to this limit. For acute radiation exposure during large solar flares certain dose limits known not to produce deleterious changes within the 14-day period were chosen. The figures given do not refer to missions of longer duration where experimental evidence regarding the effects of sustained moderate doses is poor, particularly with reference to continuous exposure to galactic cosmic rays.

Purser, P.E.; Faget, M.A. and Smith, N.F.; (editors); MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
542	SYSTEM - S7, S29 HUMAN - H34	Reference 74, p. 109 Based on Reference 222



Integral Probability Distribution. Probability of exceeding dose D. Two week mission. Dose rate (REM/HR).

The solar flare problem can best be discussed from a probabilistic point of view. One can base estimates on models of the relationship between flare intensity and frequency of occurrence. The hazard represented by flares is a function of the year in which the mission takes place and probably of the time of year in which the mission occurs. Unfortunately, very little information is available on this key relationship owing to the relatively short period of time in which flare spectra have been recorded, and our guesses are necessarily crude. Flares are classified into three categories: (1) high intensity-low energy; (2) extreme intensity-low energy; and (3) high intensity-high energy. Representative of each category are the flares of (1) August 22, 1958; (2) May 10, 1959; and (3) February 23, 1956.

Because of the infrequent occurrence of the third type (five in 21 years), it is not considered in probability estimates. It then becomes a matter of assuming how many of the type 1 and type 2 flares will occur in a given year. For a year of maximum solar activity there would be 12 flares of both types occurring and perhaps three would be of the type 2 category, the remainder type 1. This assumption gives us a basis for evaluating encounter probability for a mission of known duration. Another model of flare behavior for a year of decreased activity, a few years either side of the solar maximum, would be: six flares per year, one type 2, five type 1. Using these two estimates and a mission duration of two weeks, the dose probability distribution can be determined. The results of the calculations based on the above assumptions appear in the figure.

ITEM NO.	SUBJECT AREAS:	SOURCE:
543	SYSTEM - S7, S29 HUMAN - H33	Reference 523, p. 405.

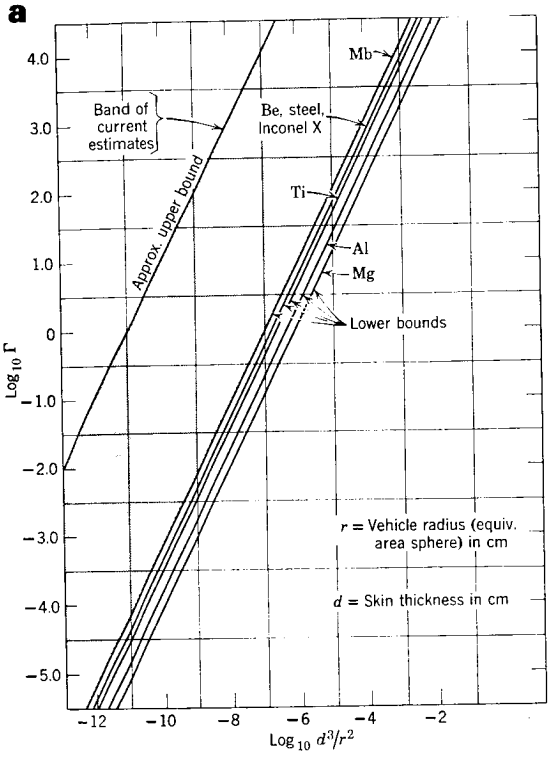
THE INFLUENCE OF RADIOPROTECTIVE SUBSTANCES ON SURVIVAL OF MICE IRRADIATED BY PROTONS WITH ENERGIES OF 660 MEV IN A DOSE OF 1063±65 rad

The Substance, Dose in mg/kg of the Base	The Number of Mice	Survived by 30 Days	Percentage of Survival	The Average Duration of Life (Days)
1. Cystamine, 150	30	17	56.6	17.3±3.4
2. S-β-aminoethylisothiuronium (AET), 150	30	25	83.3	18.4±4.3
3. Serotonin, 50	30	14	43.3	13.4±2.8
4. 5-metoxytriptamine, 75	30	18	60.0	16.4±3.5
5. Triptamine, 100	20	3	15.0	11.8±8.2
6. 5-oxytroptophane, 250	20	2	10.0	10.8±2.4
7. Control 0.2 mm of physiological solution	50	1	2.0	11.6±2.1

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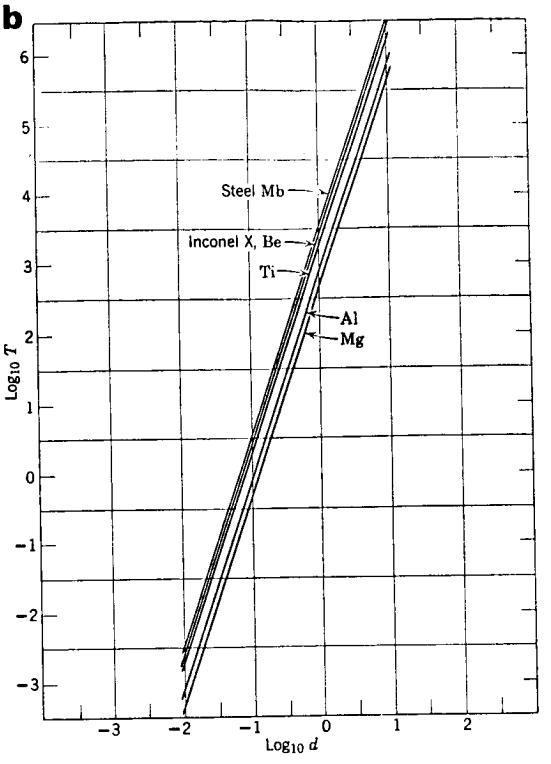
ITEM NO.	SUBJECT AREAS:	SOURCE:
544	SYSTEM-S7, S29 HUMAN- H34, H38	Reference 200, p. 263 Based on Reference 592.

a



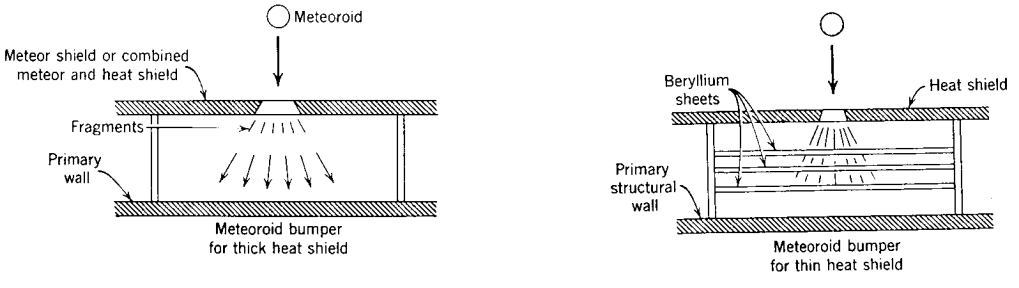
Average time between vehicle skin penetrations in days.

b



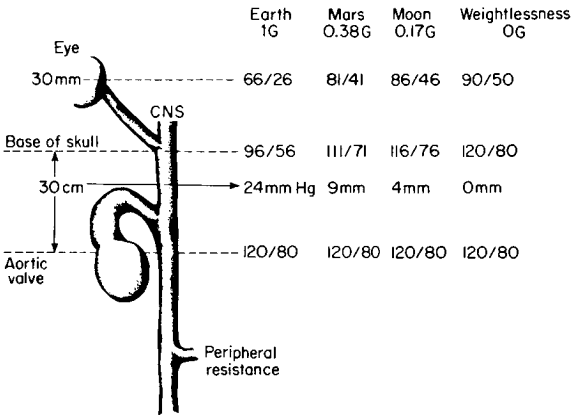
Maximum skin thickness required for safe design for a 10-ft-diameter sphere. Only meteroid penetration is considered here. Most severe estimates give maximum skin thickness. Here T is safe design life, days, taken as average time between penetrations, and d is maximum skin thickness required, cm.

c



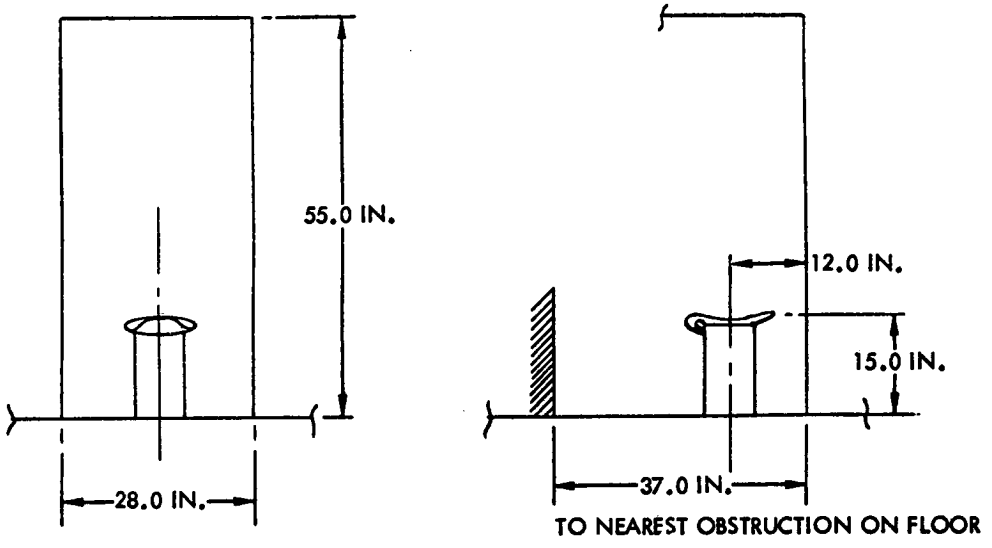
Meteor-shielded wall construction.

ITEM NO.	SUBJECT AREAS:	SOURCE:
545	SYSTEM- S10, S27 HUMAN- H44	Reference 373, pp. 51-53. Based on Reference 439.



Levels of systolic and diastolic blood pressure in man, and their alteration under various sub-gravity conditions. (After Strughold, 1960).

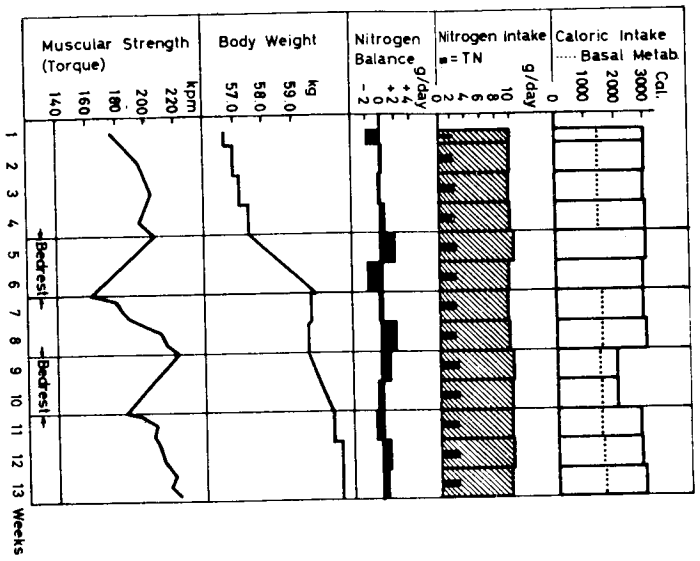
ITEM NO.	SUBJECT AREAS:	SOURCE:
546	SYSTEM - S12, S17, S18 HUMAN - H9	Reference 219, p. 223



Dimensions of Toilet Area for Weightless Conditions.

ITEM NO.	SUBJECT AREAS:	SOURCE:
547	SYSTEM - S12, S20 HUMAN - H46, H47	Reference 378, p. 325

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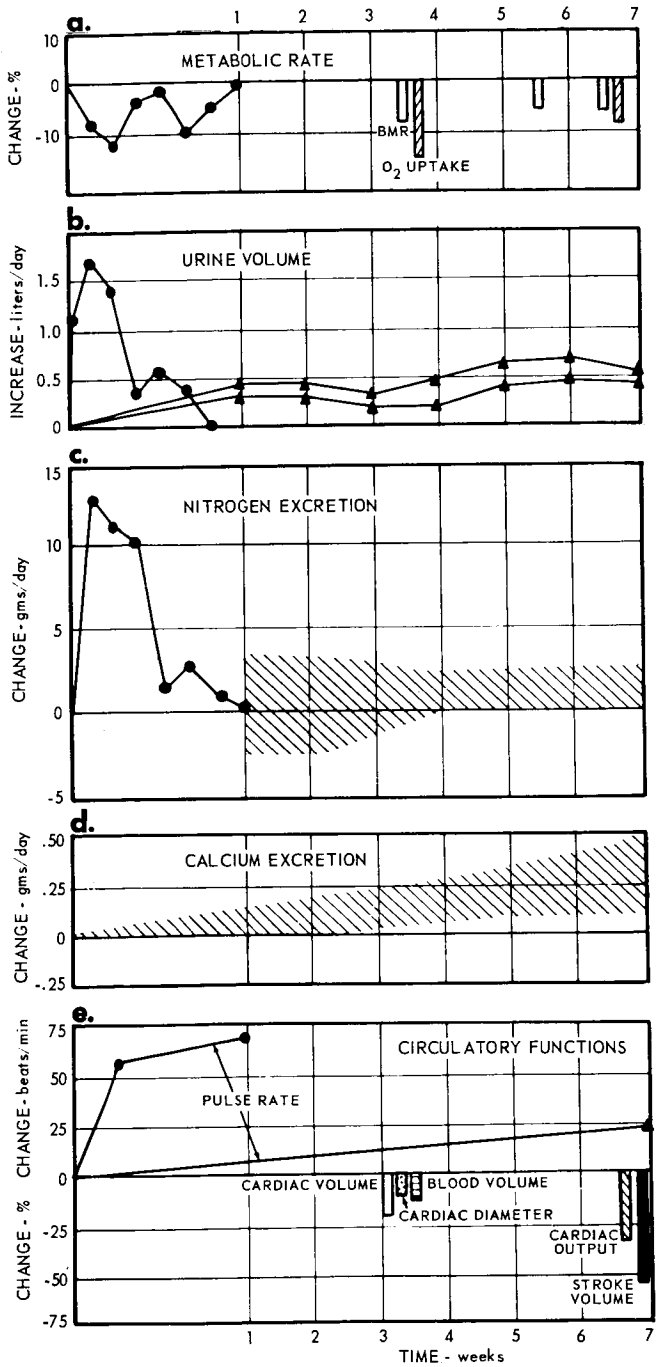
The effect of two weeks of bed rest on muscular strength, body weight, and protein balance. The two upper curves show the caloric intake, the basal metabolic rate (dotted line), and nitrogen intake (TN = animal protein).

A rather phlegmatic student was chosen as subject, his muscular strength was measured and he was put on a constant diet. After four weeks of observations, the subject was put to bed for a fortnight. Voluntary movement was not permitted; he was fed, washed, etc. by others —fortunately for the experiment, he enjoyed this kind of life. The figure indicates what happened. He gained weight, but lost 20 per cent of his muscular power. He lost protein in spite of an adequate protein intake which means he put on fat and lost muscular substance. In a two-week recovery period, the added fat was retained and muscular power and protein restored. The period of idleness was repeated with the same effect, except that the subject stopped gaining fat by simply reducing his food intake.

What has been demonstrated here is a typical example of a general biological effect, atrophy due to disuse. The loss in muscular strength is particularly striking in that it declines rather quickly compared, for example, with the loss of rigidity of unloaded bones.

This changing functional power, which is common to all our capacities physical as well as mental, is the basis of the great adaptability of man.

ITEM NO.	SUBJECT AREAS:	SOURCE:
548	SYSTEM - S12, S29 HUMAN - H3, H13, H20	Reference 383, p. 171



Decreased metabolic rate is observed in water submersion for a week (connected dots, left), in bed rest, and during immobilization in a plaster cast; basal metabolic rate (BMR) (open bars) is reduced and oxygen uptake is lowered during a standard exercise (hatched bars).

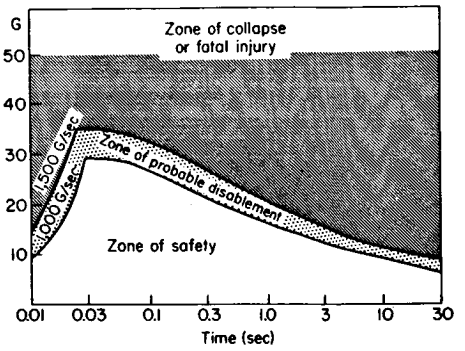
Urine volume increased remarkably during a week of water submersion (connected dots), and was consistently high during 7 weeks of bed rest for the two subjects shown by the triangular symobls.

Nitrogen is excreted by the urine in increased quantity during water submersion (connected dots), and generally during bed rest, or immobilization in a plaster case. The data on individual subjects are quite variable, as suggested by the cross-hatched area, which includes many data points. Muscle girth did not change significantly during prolonged immersion, or bed rest, but was greatly decreased by immobilization.

Calcium excretion in the urine, normally less than 0.25 gram daily, doubles and triples during prolonged bed rest, and during immobilization in a plaster cast.

The various changes in the circulatory system appear as increased pulse response to a 90°tilt during a week of water submersion, a steady increase in resting pulse rate during 7 weeks of bed rest, decreased cardiac diameter and volume by X-ray examination, decreased stroke volume and cardiac output in response to exercise.

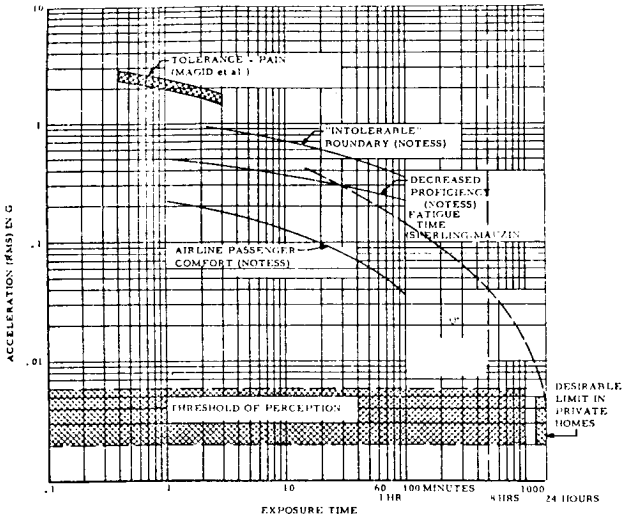
ITEM NO.	SUBJECT AREAS:	SOURCE:
549	SYSTEM - S12, S29 HUMAN - H9, H11, H20	Reference 554, p.58 Based on References 75, 169, 230, 235, 515.



Limits of human tolerance for escape systems.

Short abrupt accelerations are employed in human ejection equipment. The duration of acceleration usually is less than 1 second. In order to go both quickly and safely from any position on or close to the ground, an ejection force of 12 G for 1.75 sec seems to be the optimum. If the man is placed in a supine position in a contour couch, he can be ejected at 30 G without injury. Limits of human tolerance for escape systems are shown above.

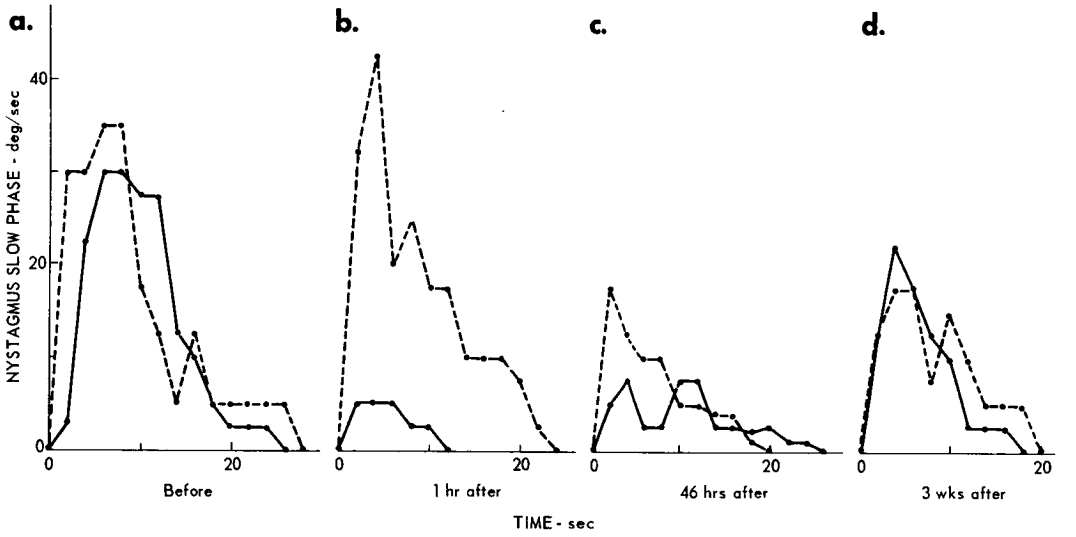
ITEM NO.	SUBJECT AREAS:	SOURCE:
550	SYSTEM - S16, S32 HUMAN - H34	Reference 219, p. 410



Vibration limits as a function of exposure time. (Longitudinal vibrations.) The curves are valid for sinusoidal vibrations of approximately 1 cps.

ITEM NO.	SUBJECT AREAS:	SOURCE:
551	SYSTEM- S14, S28 HUMAN- H33, H34	Reference 547, p. 337. Based on References 539, 487, 330, 399.

HABITUATION TO ROTATION



Habituation to rotation is a reduction of response to repetitive sensory stimulation. Response to conflicting vestibular, visual and proprioceptive information may be measured by recordings of nystagmus and from reports of subjective sensations. Reduction in response may be due to any of three processes:

1) Reduced attention to a repetitive stimulus. Response may be reduced after only two or three stimulus presentations, perhaps through a general loss of alertness. The response may reappear in its original intensity when the subject is aroused, either by a change in the stimulus itself or by an extraneous event.
2) A conditioned reaction which competes with the subject's normal response and may, with repetition, become adequate to nullify subjective or nystagmus responses. Habituation of this type requires many trials to develop, is not abolished by arousal, and usually reduces the incidence of nausea and vomiting, at least for identical vestibular, visual, and proprioceptive stimulus patterns. Change in the conditions, such as stopping the rotation or, especially, reversing its direction, may yield more intense responses, since the conditioned reaction then supplements the reaction to the unaccustomed direction of rotation.
3) A general suppression of response to accustomed and even some unaccustomed patterns of stimulation. This form of habituation can be detected for a period of weeks after the stimulation has ended, and may afford a fairly generalized protection against motion sickness.

Habituation of the second and third types is achieved most rapidly under a particular set of conditions, in which the subject's arousal is maintained, as by a mental task, as he initiates the vestibular stimulation intentionally and makes an active effort to fixate on a visual target under normal illumination.

The figures above show the way in which habituation of the second and third types develops with time. The graphs show nystagmus velocity as a function of time following head tilt to the left during rotation clockwise (dotted line) and counter clockwise (solid line). After initial testing (figure a), the subject lived 12 days in a room rotating 10 rpm in a counterclockwise (ccw) direction. When tested one hour after returning to non-rotating surroundings (figure b), the diminished response to head tilt during ccw rotation and enhanced response during cw rotation are signs of the reaction conditioned during the 12 days to compete with the normal reactions. By 46 hours, responses to head tilt while rotating in either direction (figure c) showed suppression below initial levels. This suppression was still evident three weeks later (figure d).

ITEM NO.	SUBJECT AREAS:	SOURCE:
552	SYSTEM - S15, S29 HUMAN - H33	Reference 554, p. 377. Based on References 243, and 240.

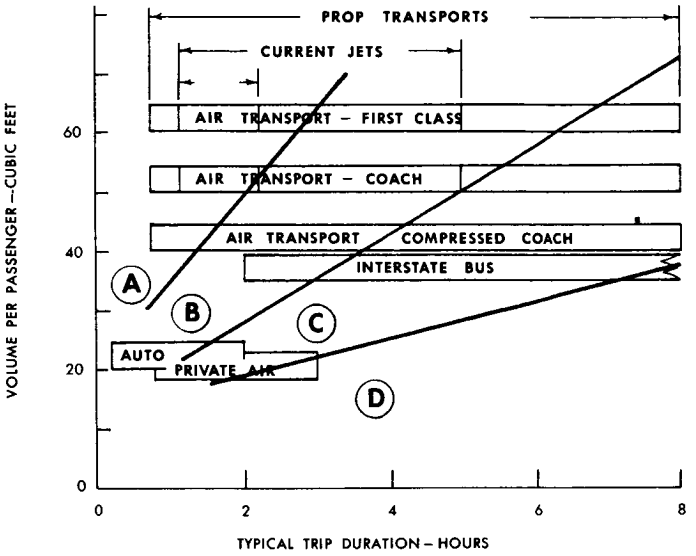
USABLE CARGO DENSITY

Item	Density (lb/cu ft)
Food	22.5
Miscellaneous solid items and spares	25
Oxygen (liquid)	72
Nitrogen liquid	50
Fuel (hydrozine)	63
Oxidizer (nitrogen tetroxide)	90

Gross density (allowing for packaging, insulation, shock isolation, and a hermetically sealed environment) will probably be only 70 to 80 percent of the above listed values.

ITEM NO.	SUBJECT AREAS:	SOURCE:
553	SYSTEM - S20, S21, S23 HUMAN - H43	Reference 378, p. 144

PASSENGER DENSITIES VS TRIP DURATION



A PLUSH

B COMFORTABLE

C CONFINED

D RUGGED

One of the many factors which contribute to fatigue may be found in the space provided for passengers in transportation vehicles. In the illustration above, an estimate of volume per passenger vs duration of exposure has been estimated. Such estimates are based upon experience rather than on the basis of research evidence. One major aircraft manufacturer uses the following typical standards: nominal design compartment-volume per passenger, 50.5 cubic feet; compartment contents proportioned 77.5 per cent for seating, 3 per cent for door aisles, 6 per cent for coatracks, and 7.5 per cent for buffets; seat spacing between seat rows, 38 inches.

ITEM NO.	SUBJECT AREAS:	SOURCE:
554	SYSTEM – S20, S28 HUMAN – H33	Reference 586, p. 2-244.

APPROXIMATE MINIMUM VOLUME REQUIREMENTS
(CUBIC FEET) FOR A THREE-MAN CREW

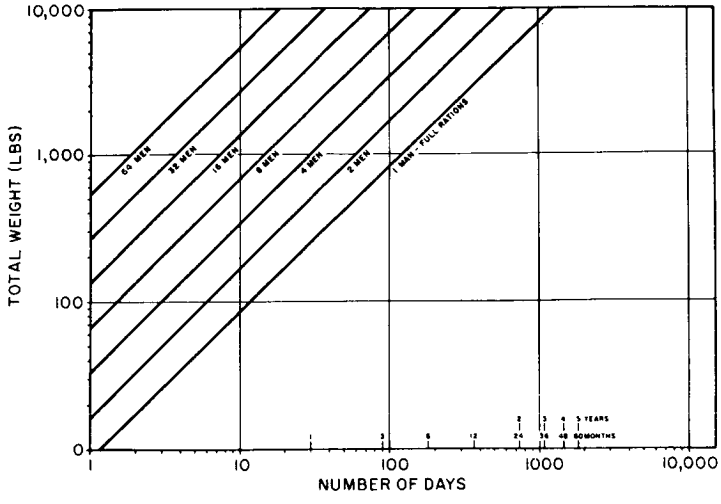
Task	Design Mission Duration (Days)			
	15	60	100	125
System operations	100	100	100	100
Maintenance	15	40	50	55
Mission research	45	65	75	80
Crew personal operations	60	75	75	80
Locomotion and access	40	60	65	65
Sleep, privacy	25	25	25	25
Average per man	95	122	130	135

ITEM NO.	SUBJECT AREAS:	SOURCE:
555	SYSTEM - S20, S29 HUMAN - H33	Reference 378, p. 54 Based on Reference 158.

Approximate Pounds of Food, O_2, and H_2O Required for 1–80 Men for Excursions Up to 4 Years Long

Duration of Excursions		Number of Men				
Days	Years	1	10	20	40	80
1	0.0027	6.3	63	126	252	504
5	0.0137	31.5	315	630	1,260	2,500
10	0.027	63.0	630	1,260	2,520	5,000
182	0.5	1,150	11,500	23,000	46,000	92,000
365	1.0	2,300	23,000	46,000	92,000	184,000
730	2.0	4,540	45,400	90,800	180,000	360,000
1,095	3.0	6,840	68,400	136,800	274,000	550,000
1,460	4.0	9,100	91,000	182,000	364,000	730,000

ITEM NO.	SUBJECT AREAS:	SOURCE:
556	SYSTEM-S21, S27 HUMAN- H40, H43	Reference 416, p. 83. Based on Reference 97.



Weight of food, oxygen, and water when everything is supplied.

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963. Reprinte by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

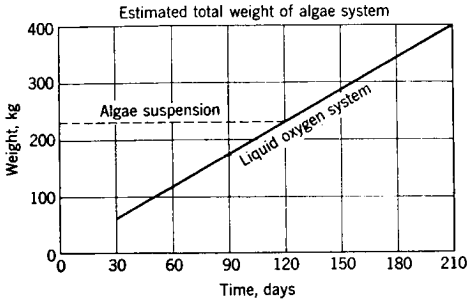
ITEM NO.	SUBJECT AREAS:	SOURCE:
557	SYSTEM - S21, S24, S27 HUMAN - H40, H43	Reference 219, p.433

Average Energy Intake Data

	Intake (kcal/man/day)	Initial body wt. (kg)	Wt. (kg)	kcal/kg body wt. /day
Fourteen-Day	1855	64.75	-1.10	29
Thirty-Day # 1	1537	70.28	-3.02	22
Seventeen-Day	1915	69.83	-1.99	27
Thirty-Day # 2	1160	87.99	-7.42	13

These data represent fairly well the caloric requirements for man in the environmental and physical conditions of the space-cabin simulator. The weight loss measured after the fourteen-day flight was minimal, but it was somewhat more pronounced after the seventeen-day test and due to loss of water. From these data it appears that caloric requirement of 30 kcal/kg body weight is a realistic value in planning the nutritional program of space flight. This represents an increment of about 50 per cent over the BMR.

ITEM NO.	SUBJECT AREAS:	SOURCE:
558	SYSTEM- S21, S29 HUMAN- H3, H43	Reference 219, p. 432. Based on Reference 568.



Comparison of weight of a liquid oxygen system, algae suspension, and total weight of an algae system sufficient to sustain life of man.

The inherent problems for adapting an algal culture system to the sealed space cabin are numerous; they center about illumination engineering. Even a half-inch layer of a 1% suspension is almost opaque to light, so that the algal suspension would have to be spread in a very thin layer over a large area illuminated at low surface intensity. In addition to these questions of practical design, the 100 kg of water needed in such an algal suspension to meet the requirements of one man, its high power requirements (about 10 hp), and the need to balance carefully the ratio of oxygen and carbon dioxide present with the respiratory quotient of man, 0.85, suggest a close scrutiny of the weight saving for long duration missions to see whether it justifies the required research and development. This can be observed in the figure above, and the point of advantageous logistics trade-off with a storable oxygen system can be detected. Beyond 7 months, the recycling algal system with its constant weight is lighter than the stored oxygen system.

ITEM NO.	SUBJECT AREAS:	SOURCE:
559	SYSTEM- S21, S29, S30 HUMAN- H43, H47	Reference 416, p.89. Based on Reference 127.

ESTIMATED WEIGHT OF LOW-ORBIT SPACE STATION

Ecology System Weights
3 Men for 30 Days

ITEM	WT IN LBS
1. Air weight in folded station at 14.7 psi	115
2. High-pressure air system to pressurize station	1055
3. High-pressure (3000 psi) oxygen system	665
4. Atmospheric cooling system—5 ea (fans, ducts, etc)	150
5. KO_2 system	540
6. LiOH system	288
7. Food—2 lbs/man/day	180
8. Water recycling system	235
9. Containers (food, waste, KO_2, LiOH, etc)	100
10. Activated charcoal supply (vacuum regenerated)	28
Total	3356

Ecology System Weights
5 Men for 100 Days

ITEM	WT IN LBS
1. Air weight in folded station at 2 atm	230
2. High-pressure air system to pressurize station	866
3. High-pressure (3000 psi) oxygen system	1085
4. Atmospheric cooling system—5 ea (fans, ducts, etc)	150
5. KO_2 system	3000
6. LiOH system	825
7. Food 2 lbs/man/day	1000
8. Water recycling system	325
9. Containers (food, waste, KO_2, LiOH, etc)	300
10. Activated charcoal supply (vacuum regenerated)	100
Total	7730

ITEM NO.	SUBJECT AREAS:	SOURCE:
560	SYSTEM - S21, S30 HUMAN - H40, H43, H47	Reference 309, p. 292.

Estimated Weight of Low-Orbit Space Station
5 Men for 100 Days

ITEM	WT IN LBS
1. Basic station 36 ft dia 5300 cu ft	2,850
2. Air-lock structure and accessories	1,000
3. Escape-return vehicle (5 men)	4,500
4. Equipment (experimental, communications, etc 75 cu ft at 40 lbs/ cu ft)	3,000
5. Attitude control	2,000
6. Pressure bags with sealant material	405
7. Interiors, seats, displays, etc	500
8. Astronauts—5 at 180 lbs each plus personal equipment at 70 lbs each	1,250
9. Ecological system	7,730
10. Solar turbo-electric power system (5 kw)	100
11. Solar cells (1 kw)	250
Total	23,558

Estimated Weight of Low-Orbit Space Station
3 Men for 30 Days

ITEM	WT IN LBS
1. Basic station 36 ft dia 5300 cu ft	2,850
2. Air-lock structure and accessories	1,000
3. Escape-return vehicle (3 men)	3,900
4. Equipment (experimental, communications, etc, 75 cu ft at 40 lbs/ cu ft	3,000
5. Attitude control	2,000
6. Pressure bags with sealant material	405
7. Interiors, seats, displays, etc	500
8. Astronauts—3 at 180 lbs each plus personal equipment at 70 lbs each	750
9. Ecological system	3,356
10. Solar turbo-electric power system (5 kw)	100
11. Solar cells (1 kw)	250
Total	18,111

ITEM NO.	SUBJECT AREAS:	SOURCE:
561	SYSTEM - S21, S30 HUMAN - H40	Reference 309, p. 291

Weight Statement for a Six-Man Lunar Station

Items	Weight, Tons
Electric generators	25
Launch facility	250
Tracking and comm. stations	15
Housing and personnel	40
Wheeled vehicles (5) plus maint. and repair shop	50
Drill equipment	5
12-in. telescope and mount	0.5
Selenographic sites	0.5
	386.0
Expendables	
Fuel for wheeled vehicles	6/mo.
Food and other personnel requirements	5/mo.
Other	2/mo.
	13/mo.

The items in the upper part of the chart are the more or less fixed items required for establishment of the lunar base at a hundred-man level. The electrical generating equipment is presumed here to be nuclear. Since the base must be resupplied it will be desirable to lift some items off the moon also.

ITEM NO.	SUBJECT AREAS:	SOURCE:
562	SYSTEM - S21, S23 HUMAN - H43, H44	Reference 404, p. 436.

Generation of Space Feeding Systems

Duration of trip	System
Short	System 1 1. Carry all oxygen 2. Chemically absorb all CO_2 3. Carry all food 4. Store or discard liquid and solid waste 5. Carry all water
Medium	System 2 1. Carry all oxygen 2. Absorb chemically all CO_2, possibly regenerating absorbent 3. Carry all food 4. Waste—dehydrate, possibly ash 5. Regenerate water
Long	System 3 1. Regenerate oxygen biologically and/or chemically 2. Absorb CO_2 biologically 3. Food entirely from biological systems 4. Use all waste as nutrient in culture medium 5. Carry all water in cultures or biological systems

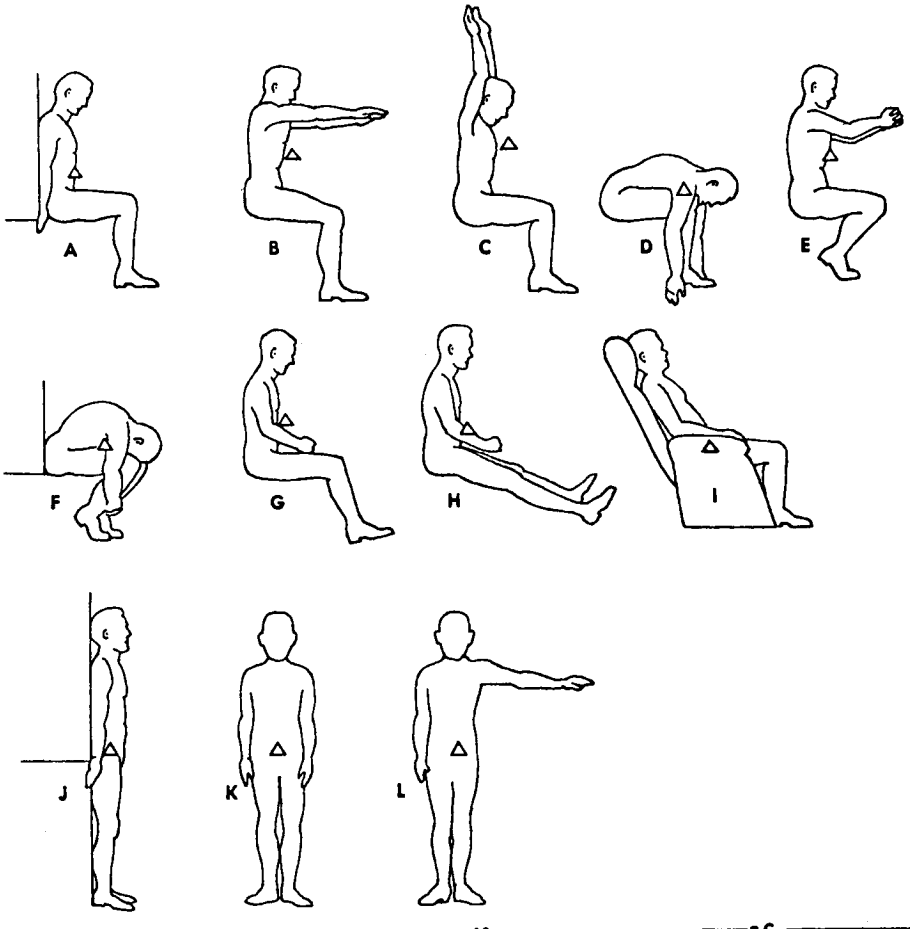
ITEM NO.	SUBJECT AREAS:	SOURCE:
563	SYSTEM - S24, S27 HUMAN - H47	Reference 416, p. 84 Based on Reference 97.

Selected Constituents of the Body in 65 Healthy Males 27-44 Years of Age

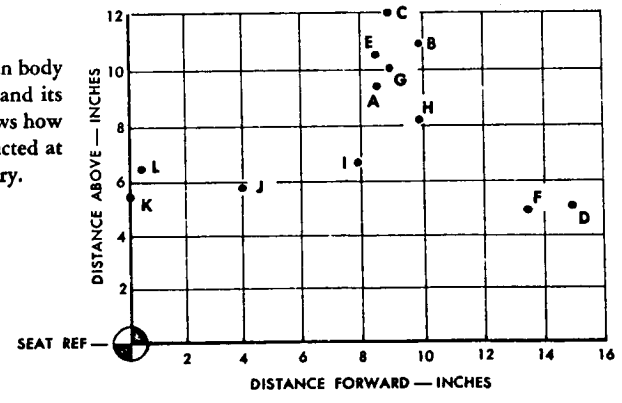
	Mean, S.D.	Coeff. var.	Fraction of Body Mass	Fraction of Lean Body Mass
Lean Body Mass (kilograms)	64.6 ± 5.4	8 %	.86	1.000
Body Water (liters)	42.5 ± 4.1	10 %	.57	.657
Potassium (kilograms)	.166 ± .017	10 %	.0022	.0026
Hemoglobin (kilograms)	.775 ± .110	14 %	.010	.0120
Blood Volume (liters)	4.95 ± .72	15 %	.066	.0766

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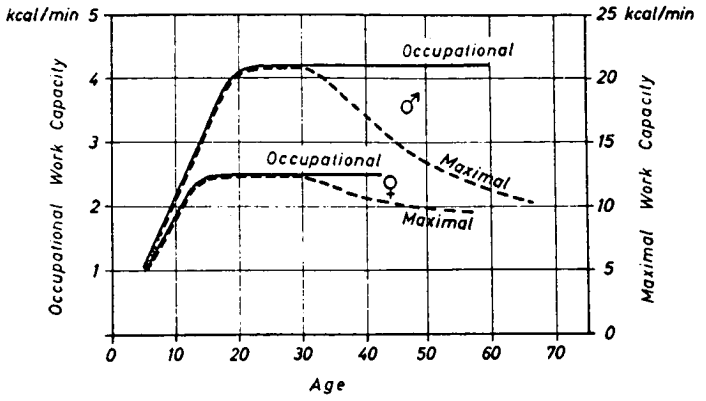
ITEM NO.	SUBJECT AREAS:	SOURCE:
564	SYSTEM - HUMAN- H3, H9, H41	Reference 333, p. 55



Center of Gravity of the human body varies with the position of the body and its extremities. The plot at the right shows how CG varies according to studies conducted at the CAA Medical Research Laboratory.



ITEM NO.	SUBJECT AREAS:	SOURCE:
565	SYSTEM – HUMAN – H3, H6.	Reference 586, p. 5-23. Based on Reference 505.



Normal values of maximal and occupational physical work capacity of men and women at different ages.

In the last year we have been able to demonstrate that the capacity for prolonged work does not necessarily correlate with the capacity for maximal work. The normal values for both levels of work capacity are drawn in the figure above for men and women of all ages. During childhood and adolescence both levels of work capacity are well correlated; after 35 years they dissociate appreciably. The work capacity for enduring work remains constant whilst the one for maximum work falls more and more. But inactivity, even at younger ages, will decrease the maximum work capacity. Studies of policemen in Philadelphia (USA) and Essen (Germany) gave a practically equal capacity for enduring work in both groups, but a very low maximum work capacity for the Philadelphia policemen, who were not active in sports. That means that special training is required to preserve a high maximum capacity for short-term work.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
566	SYSTEM - HUMAN- H4, H5, H22, H45	Reference 383, p. 173.

NRC RECOMMENDED DIET

FOOD AND NUTRITION BOARD, NATIONAL RESEARCH COUNCIL
RECOMMENDED DAILY DIETARY ALLOWANCES

Designed for the maintenance of good nutrition of healthy persons in the U. S. A.*

Allowances are intended for active persons in a temperate climate.

	Age	Cal.**	Protein	Ca	Fe	Thiamine	Riboflavin	Niacin equivalent***	Ascorbic Acid	Vitamin A
	Yr.		gm.	gm.	mg.	mg.	mg.	mg. equivalents	mg.	I. U.
Men										
wt: 70 kg; 154 lbs. ht: 175 cm; 69 in.	25	2900	70	.8	10	1.2	1.7	19	70	5000
	45	2600	70	.8	10	1.0	1.6	17	70	5000
	65	2200	70	.8	10	0.9	1.3	15	70	5000
Women										
wt: 58 kg; 128 lbs. ht: 163 cm; 64 in.	25	2100	58	.8	15	0.8	1.3	14	70	5000
	45	1900	58	.8	15	0.8	1.2	13	70	5000
	65	1600	58	.8	10	0.8	1.2	13	70	5000

I. U. = International Units

* The allowance levels are intended to cover individual variations among most normal persons as they live in the United States under usual environmental stresses. The recommended allowances can be attained with a variety of common foods, which also provide other nutrients for which human requirements have been less well defined.

** Calorie allowances apply to individuals usually engaged in a moderate physical activity. For office workers or others in sedentary occupations they are excessive. Adjustments must be made for variations in body size, age, physical activity, and environmental temperature--

*** Niacin equivalents include dietary sources of the preformed vitamin and the precursor tryptophan. 60 mg tryptophan = 1 mg niacin.

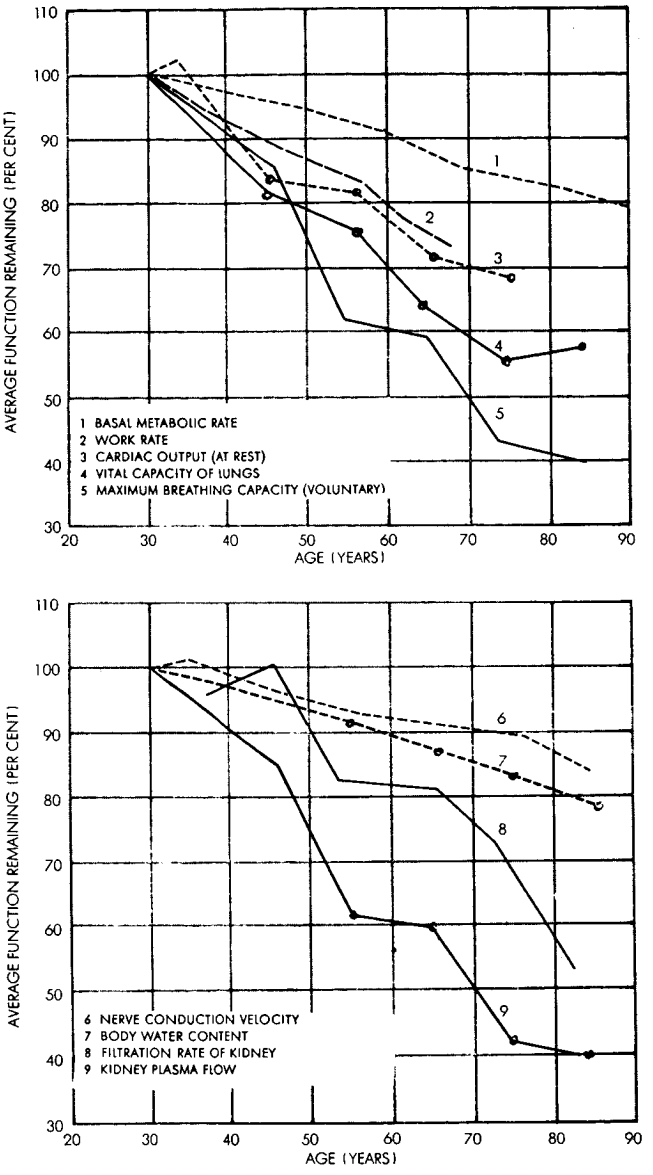
ITEM NO.	SUBJECT AREAS:	SOURCE:
567	SYSTEM - HUMAN - H4, H5, H43.	Reference 554, p. 193. Based on Reference 38.

THE PHYSIOLOGY OF AGING

With the virtual conquest of want and infectious disease in technologically advanced countries, men and women in increasing numbers are living out the promised Biblical life span of three score years and ten. The diseases of age and the fundamental process of aging are moving to the center of interest in the practice of medicine and in medical research. Few people die of old age. Mortality increases rapidly with age—in precise logarithmic ratio to age in the population as a whole—because the elderly become more susceptible to diseases that kill, such as cancer and cardiovascular disease. The diseases of old age are the province of the relatively new medical specialty known as geriatrics. A still younger discipline called gerontology deals with the process of aging itself. This is a process that continues throughout adult life. It goes on in health as well as in sickness and constitutes the primary biological factor underlying the increase in susceptibility to the diseases that are the concern of geriatrics.

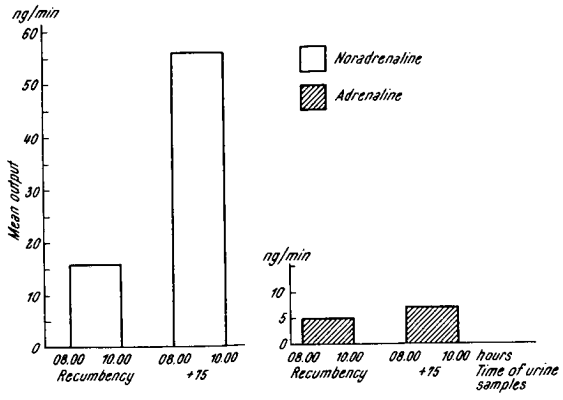
Gerontology is still in the descriptive stage. Investigators have only recently developed objective standards for measurement of the decline in the performance and capacity of the body and its organ systems, and they have just begun to make such measurements on statistically significant samples of the population. The first general finding in gerontology is that the body dies a little every day. Decline in capacity and function over the years correlates directly with a progressive loss of body tissue. The loss of tissue has been shown to be associated in turn with the disappearance of cells from the muscles, the nervous system and many vital organs. To get at the causes of death in the cell gerontology has entered the realm of cellular physiology and chemistry.

to yield results, gerontologists must rely on data accumulated from one-time tests of rather large numbers of different individuals ranging in age from 20 or 30 up to 80 or 90. Although subjects of any specific age differ widely, the average values for many physiological characteristics show a gradual but definite reduction between the ages of 30 and 90.



PERCENTAGE CHANGES WITH AGE for nine different physiological functions are shown in these two diagrams. The average value for each function at age 30 is taken as 100 per cent. Small drop in basal metabolism (1) is probably due simply to loss of cells.

ITEM NO.	SUBJECT AREAS:	SOURCE:
568.	SYSTEM - HUMAN- H4, H7	Reference 43



Catecholamine Excretion in Healthy Subjects During Recumbency And in a + 75° Position on a Tilting Table, in ng/min

The increased noradrenaline excretion during day hours is apparently chiefly due to an increased activity of the vasomotor system induced by the blood pressure homeostatic reflex mechanisms. Thus noradrenaline excretion figures from resting subjects on a tilting table in the position +75° are increased to 35 - 55 ng/min while adrenaline figures are not consistently changed. During muscular work the noradrenaline excretion is likewise increased depending on the degree of muscular activity and the state of training and condition of the subject. This increase is partly caused by the same reflex mechanism as during tilting to upright position.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
569	SYSTEM - HUMAN - H6, H12	Reference 188, p. 313 Based on Reference 504.

Normal Values

I. Clinical Pathology

A. Hematology

1. Hemoglobin (Cyanmethemoglobin method): 14-17 grams per cent
2. Hematocrit (Microhematocrit method): 42-50 per cent
3. Total leukocyte count (Coulter Electronic Counter): 5,000 - 10,000
4. Erythrocyte sedimentation rate (Wintrobe method): 0 - 9 mm./hr

B. Clottology

1. Partial thromboplastin time ("Thrombofax" method): under 100 sec
2. Prothrombin time (Quick's "one stage" method): 11 - 15 sec

C. Gastric Analysis

1. Titration of free acid. Average fasting value equals 30 units.

II. Biochemistry

A. Metabolism

1. Glucose
   a) Fasting blood glucose: 80 - 120 mgs. per cent
   b) Two hour post-prandial blood sugar: less than 150 mgs. per cent
2. Cholesterol: 150-300 mgs. per cent (20-40 years of age)
3. Total serum protein: 6 - 7.7 gms. per cent
4. Total lipids (fasting) : 450 - 1000 mgs. per cent
5. Serum protein fractination (electrophoresis). Normal value as percentage of total dye absorbed :
   Albumin 58 - 76 per cent
   Alpha 1 globulin 1.5 - 5.5 per cent
   Alpha 2 globulin 4.3 - 10.4 per cent
   Beta globulin 5.1 - 12.9 per cent
   Gamma globulin 8.6 - 17.8 per cent
6. Bromsulphalein retention: less than 5 per cent retention in 45 min

B. Liver Function

1. Total serum bilirubin: 0.7 - 1.3 mgs. per cent
2. Serum alkaline phosphatase: 1.5 - 5.0 Bodansky Units

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ITEM NO.	SUBJECT AREAS:	SOURCE:
570 a	SYSTEM -	Reference 333, p. 60.
Page 1 of 2	HUMAN - H8, H20, H41	

Normal Values (Continued)

C. Renal function
   1. Serum (or plasma) urea nitrogen: 10 - 20 mgs. per cent
   2. Serum sodium: 138 - 148 mEq/L
   3. Serum potassium: 3.2 - 5.6 mEq/L
   4. Serum chloride: 95 - 110 mEq/L

D. Pulmonary function
   1. Serum carbon dioxide: 21 - 28 mm/L

E. Endocrine function
   1. Serum protein bound iodine: 3.5 - 8.0 micrograms per cent
   2. Urinary steroids
      a) 17-ketosteroids: 9 - 22 mg./day
      b) 17-ketogenic steroids (corticosteroids): 8-25 mg./day
   3. Urinary catecholamines: 30 - 250 micrograms/day, or vanylmandelic acid: 0.7 - 6.8 mg./day

F. Enzymes
   1. Serum glutamic - oxalecetic transaminase : up to 40 Units
   2. Serum lactic dehydrogenase: 150 - 350 Units

III. Miscellaneous

A. Total circulating hemoglobin (Sjöstrand's carbon monoxide method), average value : 10.4 g/Kg. of body weight.

B. Total blood volume (total circulating hemoglobin divided by the venous hemoglobin concentration), average value : 66 ml/Kg. of body weight.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
570 b Page 2 of 2	SYSTEM - HUMAN- H8, H20, H41	Reference 333, p. 61.

Composition of Urine

a

Constituent	% in urine
Water	96
Urea	2
Creatinine	0.15
Sulphate	0.18
Phosphate	0.27
Uric acid	0.05
Potassium	0.15
Chloride	0.6
Sodium	0.35
Ammonia	0.04

Composition of Feces

b

Indole	Hydrogen
Skatole	Carbon dioxide
Paracresol	Peptone
Hydrogen sulfide	Peptides
Methane	Ammonia
Methymercaptan	Mucus
Fats	Starch
Tissue remnants	Bacteria

ITEM NO.	SUBJECT AREAS:	SOURCE:
571	SYSTEM - HUMAN- H11	Reference 416, pp. 91-92. Based on References 264,(table a) and 285 (table b).

CATECHOLAMINE EXCRETION IN AIR FORCE PERSONNEL DURING REST AND DURING FLIGHT (Mean + S. E. M.)

Group	Activity	Adrenaline ng/min	Noradrenaline ng/min
Privates	On the ground	6.7 ± 0.98	24 ± 3.9
Privates	Air transport	24 ± 3.5	27 ± 4.4
Pilots	On the ground	5.2 ± 1.5	19 ± 3.1
Pilots	Advanced flying	19 ± 3.8	39 ± 4.3

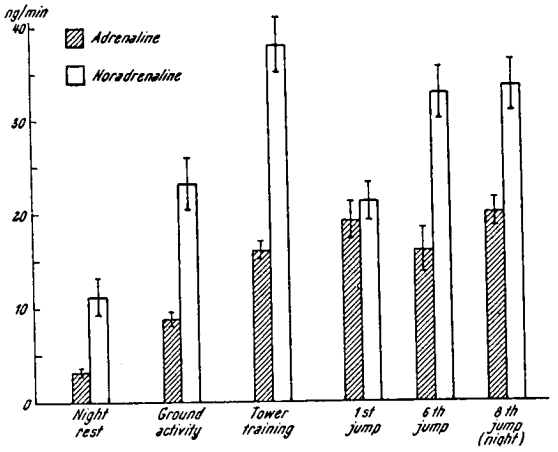
Transportation of military personnel, with no previous experience in flying, causes a marked increase in adrenaline excretion while noradrenaline excretion is unchanged. Pilots performing advanced flying excreted increased amounts of both amines.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
572	SYSTEM - HUMAN- H12, H22, H35	Reference 188, p. 315. Based on Reference 189.

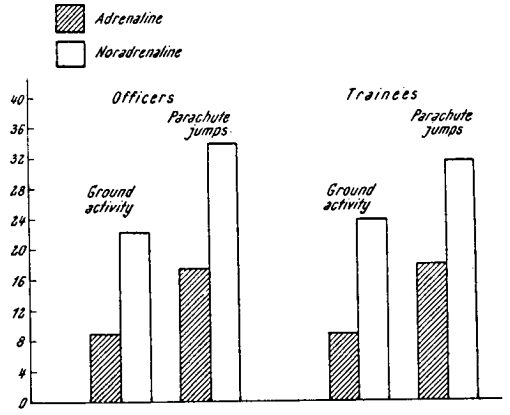
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a



Catecholamine excretion in parachute trainees during night rest, ground activity, tower training and parachute jumps in ng/min + S. E. M.

b



Catecholamine excretion in officer and trainee during ground activity and parachute jumps in ng/min.

During ground activity, involving a certain amount of physical exercise, the excretion rates were about twice as high as during night rest, (figure a). The mean adrenaline values are less than 10 ng/min, indicating a low activity of the adrenal medulla.

The excretion values from periods including tower training and jumps from aircraft on 3 different occasions show significantly higher mean excretion of adrenaline than during ground activity. The noradrenaline values were relatively high in three of the series, but normal in one.

The excretion during the sixth and eighth jump was significantly higher than during ground activity ($P<0.05$).

The catecholamine excretion values obtained from the officers' group did not differ in any respect from those of the trainees as seen in figure b.

ITEM NO.	SUBJECT AREAS:	SOURCE:
573	SYSTEM - HUMAN - H12, H22, H35, H41	Reference 188, p.319 Based on Reference 82.

Effect of Catecholamine Infusion on Performance

Variable	Adrenaline infusion 14.9 μg/min	Noradrenaline infusion 16.2 μg/min
100 - 7 test	79 [1]	108
Colour-word test	92	92
Mirror drawing, time	111	103
Mirror drawing, error	126	106
Peg-washer test, time	108	103

[1] Per cent of performance during infusion of Ringer's solution.

If the catecholamines are released in increased amounts during stress situations, it is clearly of interest to obtain information about their action on physical and mental performance as well as on the subjective reactions of the individuals.

As to the performance of various tasks certain tendencies both toward improvement and to the opposite were noted during infusions of adrenaline, whereas no changes were observed during noradrenaline infusion.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
574	SYSTEM - HUMAN - H12, H24	Reference 188, p. 318. Based on Reference 201.

Catecholamine and 17-OHCS Excretion in Subjects Exposed to Flights in Supersonic Speed Aircraft

a

Variable	Control	Aircraft	
		F-100	F-104
Adrenaline (μg/g creatinine)	2.5	12.8 ($p < 0.005$)	18.2 ($p < 0.001$)
Noradrenaline (μg/g creatinine)	12.3	35.7 ($p < 0.01$)	57.2 ($p < 0.001$)
17-OHCS (mg/g creatinine)	2.8	3.73	2.98

Flying at supersonic speed was associated with a marked increase in both adrenaline and noradrenaline excretion when measured over a 6 hour period including the flight. No consistent change was observed in the excretion of 17-OHCS.

Urinary Excretion of Catecholamines and VMA Before and After Flight in Suborbital Spacecraft

b

	Preflight 4 days	+ 30 min	Postflight + 3 hr	+ 45 hr
Adrenaline (μg/g creatinine)	24.7	33.4	27.4	6.0 [1]
Noradrenaline (μg/g creatinine)	19.9	29.6	23.6	19 [1]
3-methoxy-4-hydroxymandelic acid (VMA) (mg/g creatinine)	1.92	2.63	2.89	2.72 [2]

[1] ng/min (24 hour specimen).
[2] ug/min (24 hour specimen).

Urinary catecholamine values are also available from the first U.S. manned suborbital space flight in 1961. In Table b, the values are given as μg per g creatinine which roughly correspond to the values in ng/min.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
575	SYSTEM - HUMAN- H12, H35	Reference 188, p.316 Based on Reference 251 (table a).

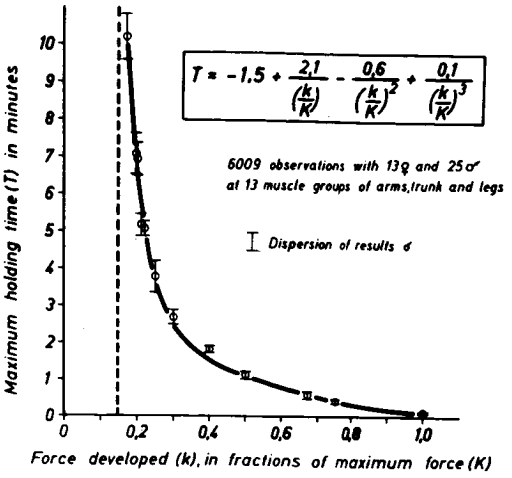
Physical Properties of Human Tissue

	TISSUE, SOFT	BONE, COMPACT FRESH	BONE, COMPACT EMBALMED, DRY
Density, g/cm³	1–1.2	1.93–1.98	1.87
Young's Modulus, dyne/cm²	7.5×10^{4}	2.26×10^{11}	1.84×10^{11}
Volume compressibility,* dyne/cm²	2.6×10^{10}	—	1.3×10^{11}
Shear elasticity,* dyne/cm²	2.5×10^{4}	—	7.1×10^{10}
Shear viscosity,* dyne sec/cm²	1.5×10^{2}	—	—
Sound velocity, cm/sec	$1.5–1.6 \times 10^{5}$	3.36×10^{5}	—
Acoustic impedance, dyne sec/cm³	1.7×10^{5}	6.0×10^{5}	6.0×10^{5}
Tensile strength, dyne/cm²	—	9.75×10^{8}	1.05×10^{9}
Shearing strength, dyne/cm², parallel	—	4.9×10^{8}	—
perpendicular	—	1.16×10^{9}	5.55×10^{8}

* Lamé elastic moduli.

The primary reaction of the human body to a mechanical force environment is a mechanical one: the forces result in displacement of body tissue. Small displacements can result in the stimulation of receptors; larger displacements can bring about, in addition, deformations of body parts or whole organs, influencing their functional capacity. With still greater shifts of body components, structural strength of the body in certain areas can be exceeded, leading to pathological damage. Where the maximum effect from a mechanical stimulus occurs depends on the body's mechanical structure, the mode of force application, and its time pattern, or, in other words, on its frequency content. The human body is a complex structure of bone, which behaves mechanically more or less like a solid, and soft elastic tissues, which resemble in this regard elastomers. Some of the properties of these mechanical building stones are shown above.

ITEM NO.	SUBJECT AREAS:	SOURCE:
576	SYSTEM – HUMAN– H13, H17	Reference 548, p. 42. Based on References 226 and 227.

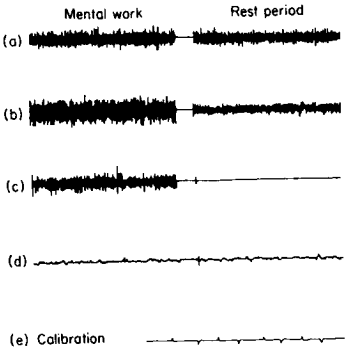


Maximum Holding Time as a Function of Holding Force

This figure shows that a strong correlation exists between maximum muscle strength and endurance for static work, measured as holding time for 40, 50, 60, etc., per cent of maximal strength. This correlation is independent of the absolute strength of muscles, is constant for all the muscles of body, and holds for all people at all stages of muscular training.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
577	SYSTEM - HUMAN- H13, H22	Reference 383, p.175



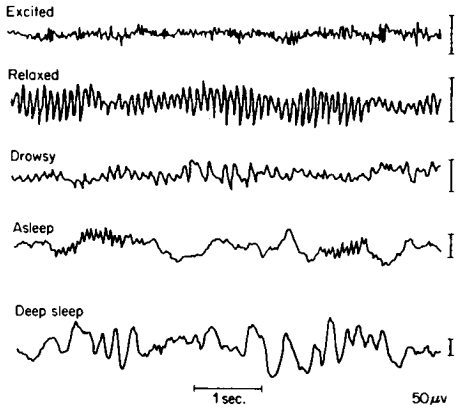
Tension differences in people. Forearm EMG: (a) worker who never relaxes; (b) partial relaxation during rest pause; (c) complete relaxation during rest pause; (d) a worker without tension; (e) 5 microvolt calibration signal.

NOTE: (electromyogram) senses the electrical potential resulting from the stimulation of a muscle.

There are large individual differences among subjects with respect to their muscle tension during times of work and rest. This figure indicates a set of EMG recordings as taken by A. Ford. The subjects were requested to do mental arithmetic while lying on their backs. In his words:

> The curve at the left, reading from left to right, shows the last few seconds of mental work. The horizontal line near the middle of the oscillogram shows where the apparatus was stopped while the worker gave his answer. The section of the curve at the right is the rest period when the worker was told to relax. B shows a case of partial relaxation. In Example C it is clear that the worker was under severe work tension, but when opportunity for rest was given, his relaxation was complete, and dropped the EMG potential to less than 3 microvolts. Example D found a worker who could do mental arithmetic with practically no tension at any time.

ITEM NO.	SUBJECT AREAS:	SOURCE:
578	SYSTEM - HUMAN- H13, H14, H22, H29.	Reference 197, p. 445. Based on Reference 199.

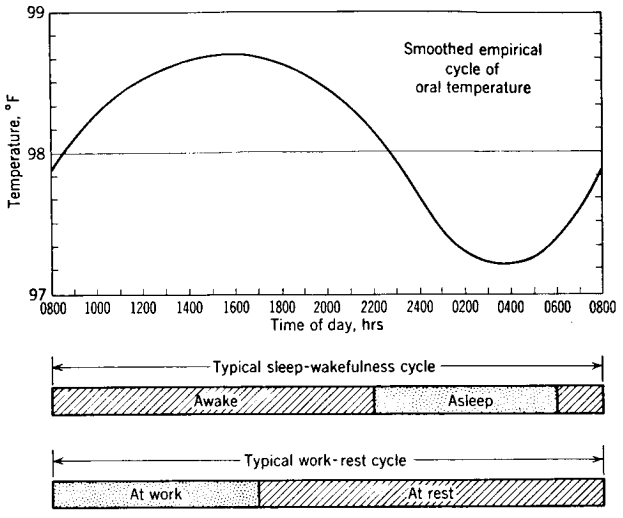


Typical EEG records taken during excitement, relaxation, and varying degrees of sleep. Note that excitement is characterized by a rapid frequency and small amplitude and that varying degrees of sleep are marked by increasing irregularity and by appearance of "slow waves."

The EEG is a direct result of activity within the neural structure of the brain. The complexity of this structure in terms of its interconnections is almost beyond description. The sensed EEG represents the composite behavior of a vast number of neurons acting at the same time, each offering an extremely small contribution to the average signal which is measured. It is important to note that the EEG cannot be related to any single nerve activity. Ford has indicated that the primary EEG potential source is that brain structure which includes "the principal synaptic connection of cerebral spheres located within an outer surface structure less than 1 millimeter deep." Such a mass of almost random connections might be expected to yield only white noise. But such is not the case, however, as is shown in the figure. Certain low frequency components are immediately apparent. In particular, the alpha rhythm is the name given to that strong sinusoidal component which falls between 8 and 13 cycles per second. It is usual to find this rhythm present in the EEG for the normal subject while he is resting with his eyes closed. The beta rhythm falls between 14 and 30 cycles per second and is likely to occur during periods of mental effort. The delta rhythm of between 0.5 and 3.5 cycles per second may be called the "emergency" rhythm, being associated with extreme physical energy and stress. The theta rhythm of between 4 to 7 cycles per second may also appear during mental stress.

Lawrence J. Fogel, BIOTECHNOLOGY: Concepts and Applications. (c) 1963. Reprinted by permission of Prentice-Hall, Inc.

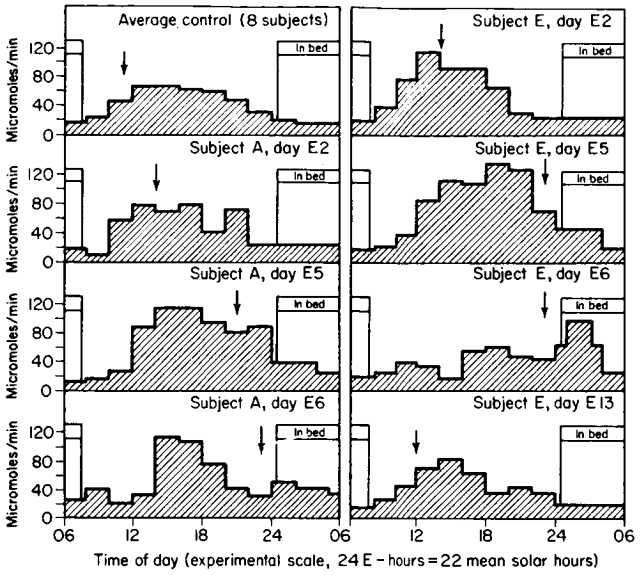
ITEM NO.	SUBJECT AREAS:	SOURCE:
579	SYSTEM - HUMAN - H14, H22	Reference 197, p. 438. Based on Reference 199.



Diurnal variation in man's oral temperature.

Kleitman, who has conducted the most extensive study of diurnal variation has suggested that body temperature is probably the most sensitive index of measurement. This is illustrated above, in which the mean hourly readings of oral temperature have been plotted for a period of 24 hr. These data were obtained from one man over the course of 9 full days. When smoothed, the curve follows a monophasic cycle, with a maximum temperature occurring during the wakefulness period and the minimum temperature occurring during the hours devoted to sleep. It is fairly typical of the physiological diurnal cycle found in adult man and most higher animals.

ITEM NO.	SUBJECT AREAS:	SOURCE:
580	SYSTEM - HUMAN- H18, H19, H45	Reference 3, p. 48. Based on References 305 and 427



Potassium Excretion Rates During
Spitzenbergen Expedition

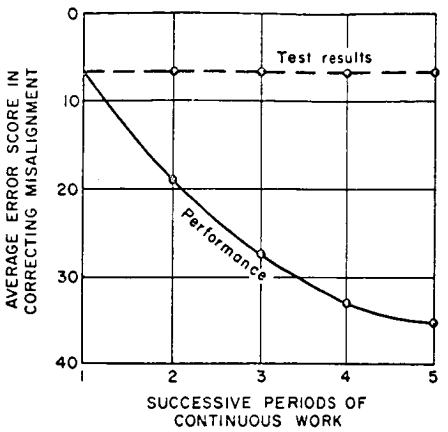
The data represented above show the potassium excretion rate with some evidence of a persistent 24-hour periodicity while the men were on a 22-hour cycle for several weeks. (From Cambridge, 1953).

ITEM NO.	SUBJECT AREAS:	SOURCE:
581	SYSTEM - HUMAN - H19, H20, H45	Reference 219, p. 375.

CLASSIFICATION OF DIURNAL RHYTHMS ACCORDING TO THEIR RELATIVE RESPONSES TO LIFE ON ABNORMAL TIME ROUTINES

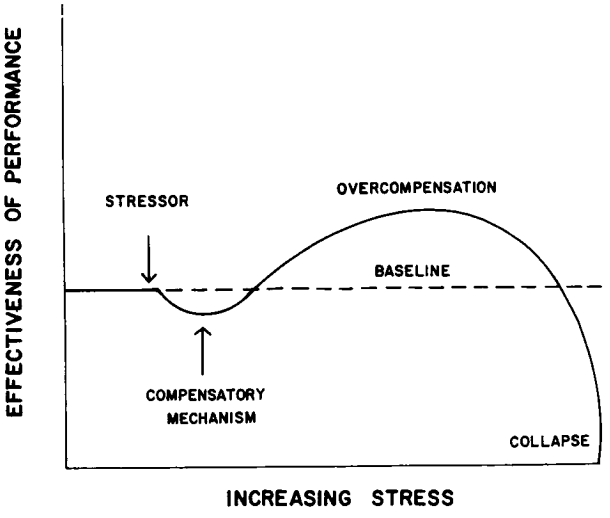
Rhythm	Type of response to an abnormal routine
Heart rate Blood pressure	Entirely environmental
Phosphate excretion Body temperature	Largely environmental, though evidence of an inherent 24-hr rhythm in some subjects
Water excretion Chloride excretion Sodium excretion	Marked inherent 24-hr rhythm, which may be very pronounced in many subjects
Potassium excretion	Very marked 24-hr rhythm, usually predominating over any environmental influence

ITEM NO.	SUBJECT AREAS:	SOURCE:
582	SYSTEM - HUMAN- H9, H16, H19, H20	Reference 3, p. 50 Based on Reference 322.



Difference between performance and capacity. In many kinds of human activity, performance deteriorates as work is continued even though it can be shown with tests that there has been no change in capacity. Difference is attributable to high motivation in tests but lowered motivation in actual work situations.

ITEM NO.	SUBJECT AREAS:	SOURCE:
583	SYSTEM – HUMAN – H26, H35	Reference 380, p. 31 Based on Reference 122.



Schematic representation of the relationship between stress and performance.

The choice of variables used in a study of the effects of physical stressors depends on many factors. The nature of the stressor must be considered first. Peripheral vision, for example, can be used more effectively in studies of positive acceleration---where retinal blood flow is quickly affected -- than in studies on heat--where it is affected much later. In addition, information on the subject's position and activity must be considered in the experimental design. If impairment of central nervous system functions is to be used as a measure of the changes produced by a physical stressor, the task cannot involve a motor response that the subject could not make after the stressor has been applied.

A more important issue, however, concerns the sensitivity of psychological measures to subtle changes in energy input. It is pointless to choose an output variable which will not be measurably affected during the period of stress. This can be illustrated by the above diagram adapted from Selye. The stressor, represented by the descending arrow, tends to displace a function of the subsystem under study away from its equilibrium point. (This function can be anything we choose to measure, let us say a tracking task.) The compensatory response, represented by the ascending arrow, may actually lead to improved performance until the experiment has ended. Unless we choose to continue until the point of collapse is reached, it will be necessary either to measure the compensatory response to show the effect of the stressor or to choose another variable that will be more sensitive.

ITEM NO.	SUBJECT AREAS:	SOURCE:
584	SYSTEM - HUMAN- H24, H34	Reference 448, p. 37 Based on Reference 470.

Type of work determines the length of time an operator can efficiently perform his duties.

Description of Work	RECOMMENDED TIME LIMITS
Task which requires low level motor skills, is highly repetitive and devoid of critical decisions	Up to 12 hours
Highly redundant task using standard procedures, moderate responsibility, and limited manual precision	Up to 8 hours
Heavy, continuous physical labor interspersed with suitable recess	Up to 6 hours
Fairly responsible, decision-making task on a continuous, but random basis	Up to 4 hours
Critical, but monotonous vigilance task	Up to 2 hours
Extremely accurate motor skill with critical reaction time — no time to relax	Up to 30 minutes

NOTE: The time limits suggested above are subject to variations including proper insertion of rest periods or changes in task routines. Work-rest cycles are normally based on a 24-hour day, and as such will reflect variations during this period. It is important to consider the normal variations in planning critical tasks; i.e., efficiency normally drops off about 10 o'clock in the forenoon, and once again in midafternoon, followed by an end spurt just before the worker knows his work period is over. Although we are normally oriented to an 8-hour workday, with 8 hours for sleep, people can adapt to other cycles quite easily.

ITEM NO.	SUBJECT AREAS:	SOURCE:
585	SYSTEM – HUMAN – H24, H45	Reference 586, p. 2-243.

HAND TORQUE AND HAND FLEXION FORCE WHICH THE HUMAN CAN APPLY WITH AND WITHOUT FULL PRESSURE SUIT

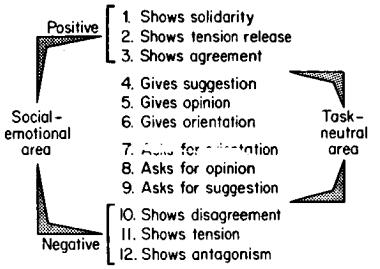
Means of Test Results

	Purdue Pegboard†				*Hand Torque*‡						*Hand Flexion*§	
					Screwdriver		*Ball*		*Knob*			
	Right	*Left*	*Both*	*Assy.**	*Pron.**	*Sup.**	*Pron.**	*Sup.**	*Pron.**	*Sup.**	*Right*	*Left*
Without full-pressure suit	16.83	17.66	27.00	9.79	69.17	57.50	73.33	85.83	118.33	117.50	110.83	111.66
With full-pressure suit, unpressurized	8.16	8.16	12.66	3.63	62.50	45.83	70.00	74.16	118.66	140.83	78.33	80.00
With full-pressure suit, pressurized	6.00	6.83	6.16	2.00	51.66	48.66	56.66	60.83	105.50	105.83	60.00	60.83

* Abbreviations: Assy. = Assembly; Pron. = Pronation; Sup. = Supination.
† Purdue pegboard measurements indicate number of pins placed in holes by right hand, left hand, and both hands in 30 sec, and the number of assemblies completed in 60 sec.
‡ Hand torque measurements in inch-pounds.
§ Hand flexion measurements in pounds.

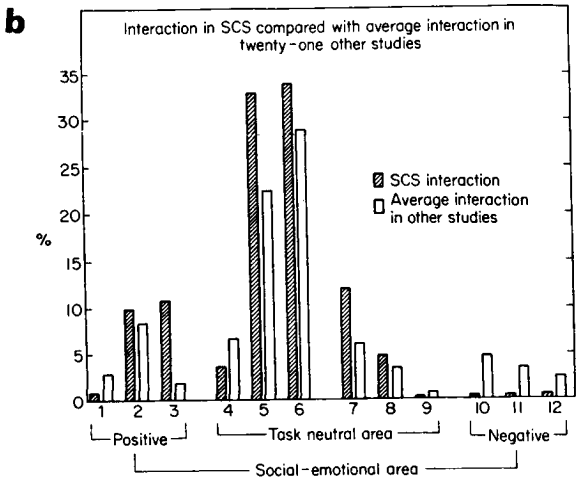
ITEM NO.	SUBJECT AREAS:	SOURCE:
586	SYSTEM - HUMAN- H28, H44	Reference 412

a CATEGORIES OF BEHAVIOR ARE RATED IN THE BALES INTERPERSONAL PROCESS ANALYSIS



Scoring of behavior by means of the Interaction Process Analysis makes it possible to record systematically how group members communicate with one another, in spite of underlying conflicts that might be present. To provide an objective measure of interpersonal interaction, behavior is scored daily for a certain period using the Bales Interpersonal Process Analysis. Each act of communication between the subjects is rated in one of twelve categories as shown in Table a. Since this method has been employed in observing all kinds of groups, it is possible to compare the interaction of space flight crews with that observed under different conditions.

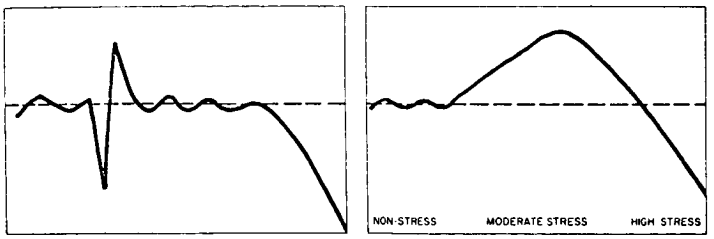
ITEM NO.	SUBJECT AREAS:	SOURCE:
587 a Page 1 of 2	SYSTEM - HUMAN - H30	Reference 219, p. 356 Based on Reference 196



Comparisons of interactions in the space cabin simulator with average interaction in 21 other studies, showing a larger percentage of interaction in the task-neutral area, and a corresponding reduction in the more emotional categories.

Figure b shows the over-all percentage in the twelve interaction categories from one thirty-day experiment in the SAM space flight simulator as compared with the average of twenty-one other small group studies, which have been analyzed in the last decade. Comparing these, certain significant differences will be noted. In the space-cabin study, the more neutral categories in the center, particularly acts of asking for information and suggestion, dominate the profile, whereas the extreme, more emotionally related categories are less frequently represented. It was consistent with subjective observations during the flight that the relationship between the subjects was quite formal and polite. They consciously refrained from expressing negative feelings for fear of disrupting their relationship. Much of the negative feeling expressed was displaced and directed toward the monitoring personnel outside the chamber.

ITEM NO.	SUBJECT AREAS:	SOURCE:
587 b Page 2 of 2	SYSTEM - HUMAN - H30	Reference 219, p. 356 Based on Reference 196.



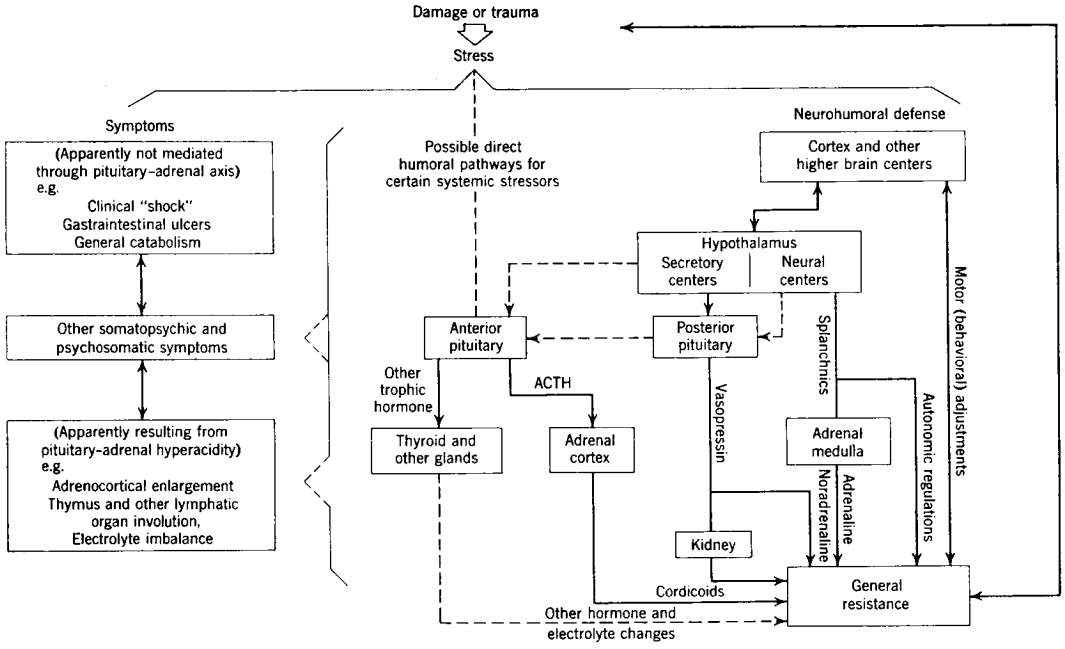
(a) (b)

(a) Affect linkages in isolated groups. (b) Affect linkages under increasing intensity of stress.

In his studies on the sociometric structure in small groups under extreme conditions, Torrance analyzed the changing attitudes and behavior of isolated men. In these situations, groups act like organisms, and the mechanism of adaptation depends upon the linkages and forces which hold the group together. To use emotional linkages (liking-disliking), as an example, the mechanism of the affect linkages in isolated groups over time can be represented by the curve in the figure, part (a). According to this concept there are manifestations and expressions of increased emotional environment after a brief period of dislocation and estrangement. In many groups, strong inter-personal hostilities and repulsions may change to strong positive affect, at least temporarily. This increased affection returns to normalcy in the course of time. However, if the stress continues indefinitely, there is a deterioration of these affectional relationships; people become irritated if their social intercourse is restricted to a few persons only and if no other objects are available upon which to display feelings of aggression resulting from frustration.

The theoretical functioning of the affect linkages under increasing intensity may be represented by part (b). After the intensity increases, the affect linkages become stronger until a certain limit is reached. Thereafter, the strength of these factors decreases more or less steadily. Under moderate stress, goals tend to become more important, more worthwhile to work for, but under intense stress, goals tend to lose importance and subjective demands increase. Power and group relations appear to function in much the same manner. With increasing stress, it is commonly observed that the leader seems to tighten up, delegates authority and responsibility to subordinates, and supervises them more closely. However, at a certain intensity, the leader feels so threatened that he either takes all power away from others or resigns from his post. In some cases he does both concurrently, and this is when the group really falls apart. It is particularly important for space-crew efficiency to maintain communication among members and with other stations under any circumstances.

ITEM NO.	SUBJECT AREAS:	SOURCE:
588	SYSTEM - HUMAN- H30, H35	Reference 219, p. 355. Based on Reference 524.



General scheme of stress syndrome. Solid lines represent known relations, broken lines suspected relations.

ITEM NO.	SUBJECT AREAS:	SOURCE:
589	SYSTEM - HUMAN- H12, H14, H34, H35	Reference 416, p. 105. Based on Reference 45.

Drugs for Psychophysiological Control

Tranquilizers

Reserpine (Serpasil)
Chlorpromazine (Thorazine)
Meprobamate (Miltown, Equanil)
Perphenazine (Trilafon)
Hydroxyzine (Atarax)
Ectylurea (Nostyn)

Stimulants

Amphetamine (Benzedrine)
Methylamphetamine
Caffeine
Metrazole

Space flight of long duration will impose psychological stresses on the human occupant by isolation or other possible forms of sensory deprivation. Tranquilizers or stimulants, depending on the circumstances, may be used to advantage, either to minimize such psychological disturbances, or else to take the astronaut to a higher peak of alertness or performance during an otherwise fatiguing phase of the mission. The table lists the drugs that may be useful in these regards. The most important tranquilizers are reserpine and chlorpromazine.

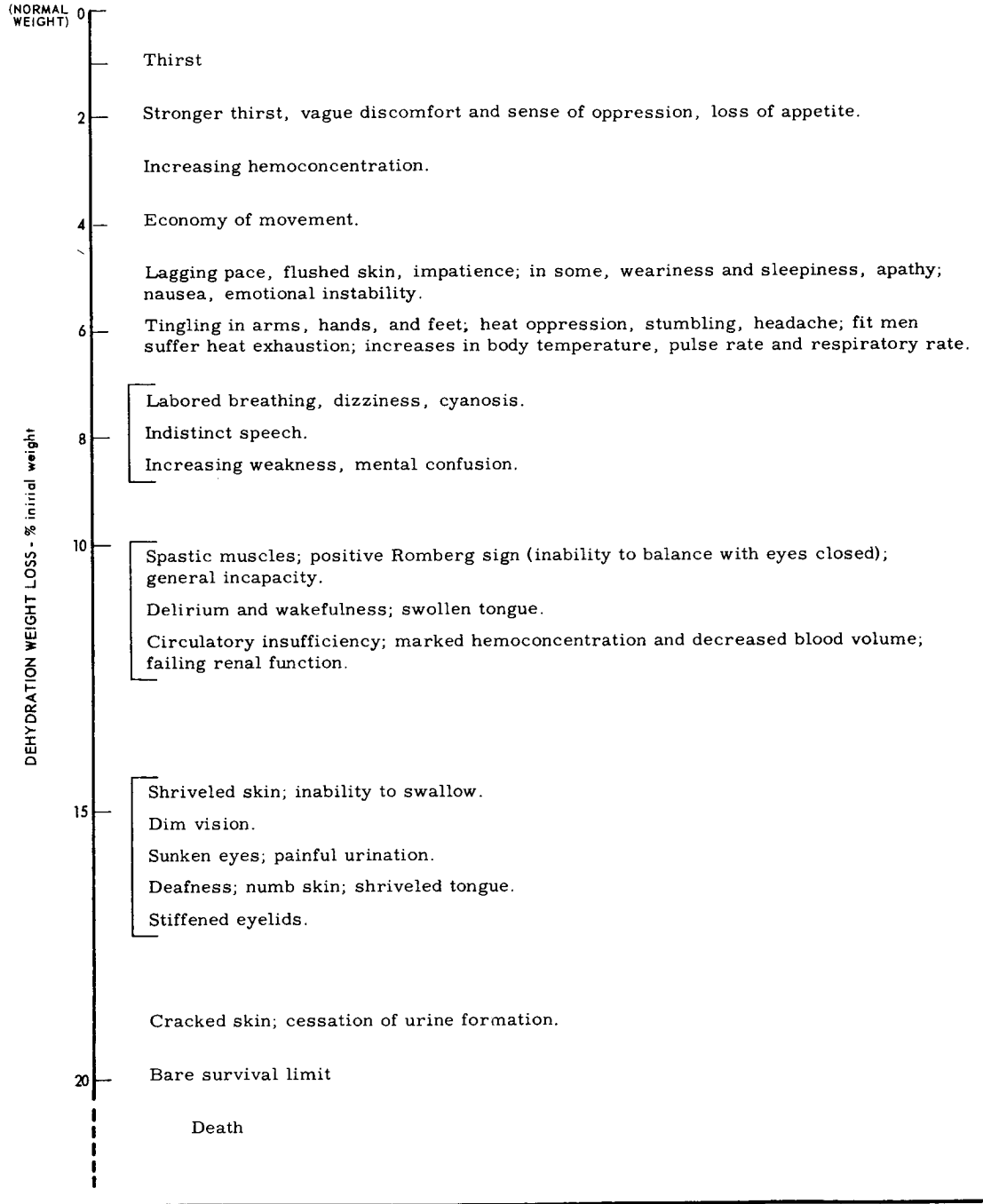
Reserpine is considered to be one of the most potent of the Rauwolfia alkaloids, because of its sedative and antihypertensive effect accompanied by bradycardia. This effect is manifested through action on the vasomotor mechanism and results in decreased peripheral vasoconstriction. In common with other drugs in this group, reserpine suppresses sympathetic activity at the hypothalamic level.

Chlorpromazine's unique pharmacologic action is a preferential inhibition of those parts of the central nervous system which control vomiting, heat regulation, wakefulness, vasomotor tone, muscle tone, and secretory activity of the anterior pituitary. This inhibition of the subcortical centers, the reticular system, the thalamus, and the hypothalamus of the brain, without significant action on the cortex, renders the drug especially useful in alleviation of anxiety, tension, agitation, vomiting from irradiation or motion sickness, and for the induction of hypothermia.

Examples of other tranquilizers include meprobamate, perphenazine, hydroxzine, and ectylurea. The table also lists a few of the stimulants that may be used: Amphetamine and methylamphetamine are drugs that affect the central nervous system and remove fatigue while producing a feeling of greater energy, alertness, and wakefulness. Caffeine produces a similar response and also stimulates the respiratory center. Metrazole may have some use in improving the peripheral circulation through stimulation of the vasomotor centers of the brain. The possible use of such drugs as a protection from psychological stresses could become an important component for man's functional integrity during very extended space missions.

ITEM NO.	SUBJECT AREAS:	SOURCE:
590.	SYSTEM - HUMAN- H35, H38	Reference 416, p. 117

DEHYDRATION



ITEM NO.	SUBJECT AREAS:	SOURCE:
591	SYSTEM - HUMAN - H34, H43	Reference 554, p. 208 Based on References 400, 224, 65 and 121.

PHYSICAL AND MEDICAL EXAMINATION OF MERCURY ASTRONAUTS

Laboratory Tests

Cholesterol	Special hematology smear
Differential	Blood sugar
Hemoglobin	Stool examination for ova and parasites
Leucocytes	Urinalysis
Hematocrit	Gastric analysis
Blood grouping	Electrocardiogram with master 2-step
Rh factor	Ballistocardiogram
Serology	Electroencephalogram
Sedimentation rate	24-hr urinary 17-ketosteroid excretion
Liver function test (BSP)	Electrolyte studies
Sperm count	Catacholamines urinary
Throat culture and smear	Urea clearance
Smear of nasal mucosa	Protein electrophoresis
Serum protein-bound iodine	

X-Ray Examinations

Chest: P-A during inspiration, P-A during expiration, right lateral
Colon: Barium enema (high-kv technique used for compression spotfilms; image intensifier used for fluoroscopy)
Sinuses
Lumbosacral spine: A-P and lateral (obliques when indicated)
Stomach and esophagus: Image intensifier used for fluoroscopy
Teeth

Ophthalmology

History and examination including dilation, visual fields, tonometry, slit-lamp studies, dynamic visual acuity, and depth-perception tests, darkroom examination, photography of conjunctival vessels and retina

Otolaryngology

Examination, indirect laryngoscopy, and nasopharyngoscopy
Audiogram with and without background noise
Speech-discrimination test and tape recording of voice
Labyrinthine sensitivity studies: caloric test

* Courtesy of the Lovelace Foundation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
592	SYSTEM - HUMAN- H41	Reference 219, p. 488

SPECIAL PHYSIOLOGICAL EXAMINATION OF MERCURY ASTRONAUTS *

Clinical Tests
Bicycle ergometer test
Pulmonary function test: Vital capacity and maximum breathing capacity
Total body radiation count
K^{40} method of determination of lean-body mass
Specific gravity of whole body
Blood volume and total circulating hemoglobin
Total body-water determination
Cardiology
Examination by cardiologist
Special vectorcardiogram
Phonocardiogram
Medical History
Complete medical history with special questions on aviation experience
Neurologic and Anthropometric Studies
Standard EEG, using monopolar and bipolar reading**
Study of reflexes, coordination, normalcy of the cerebellar functions and position sense
Conduction velocity of the right ulnar nerve
Electromyogram of the right hypothenar muscles
58 anthropometric measurements
3 standard somatotype photographs
Stereophotograph and somatotype assessment based on Sheldon's typology

* Courtesy of the Lovelace Foundation.

** EEG records obtained on U.S. Mercury astronauts during short periods of weightlessness do not show any abnormalities

ITEM NO.	SUBJECT AREAS:	SOURCE:
593	SYSTEM - HUMAN - H41	Reference 219, p. 490.

SPECIAL PSYCHOPHYSIOLOGICAL EXAMINATION OF MERCURY ASTRONAUTS *

Stress Tests
Acceleration profiles on the human centrifuge, maximum 12 g
Acoustical tests: speech intelligibility under noise and vibration
Position orientation and equilibrium during low-frequency vibration
Heat tests: 130° F at 8% relative humidity with K-2B flying suit
Treadmill test
Harvard step test
Flack test
Valsalva overshoot test
Cold-pressure test: 7-min exposure of both feet to ice water
MC-1 partial-pressure suit test: Worn at 42 mm Hg for 1 hr
Isolation test: 3-hr exposure in soundproof darkroom
Complex behavioral simulator

Psychiatric Interview—Criteria	
Drive and instinctive energy	Dependency
Freedom from conflict and anxiety	Adaptability
Psychological defense	Freedom from impulsivity
Quantity of neutral energy	Need for activity
Identity	Psychosomatic symptoms under stress
Object relationship	Motivation
Social relationship	Frustration tolerance
Reality	Over-all qualification for mission

Personality Tests	
Rorschach test	Edwards personal-preference schedule
Thematic apperception test	Shipley personal inventory
Draw-a-person test	Outer-inner preferences
Sentence completion test	Pensacola Z attitude test
Minnesota multiphasic personality inventory (MMPI)	"Who am I?"
	Officer effectiveness inventory
Gordon personal profile	Peer rating

Intelligence and Special Aptitudes	
Wechsler adult intelligence scale	Air Force officer qualification test
Miller analogies	Aviation qualification test (USN)
Raven progressive matrices	Space memory
Doppelt mathematical reasoning test	Spatial orientation
Engineering analogies	Gottschaldt hidden-figure test
Mechanical comprehension	Guilford-Zimmerman spatial visualization

* Courtesy of the Lovelace Foundation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
594	SYSTEM – HUMAN – H41	Reference 219, p. 491

MINIMUM DAILY REQUIREMENTS OF
ESSENTIAL AMINO ACIDS

Adult Males, at 2500–2800 Calories

Amino Acid	*Milligrams*
Isoleucine	700
Leucine	1100
Lysine	800
Methionine, if 810 mg. cystine is present Methionine with Cystine low or missing	200 1100
Phenylalanine, if 1100 mg. Tyrosine is present Phenylalanine with Tyrosine low or missing	300 1100
Threonine	500
Tryptophan	250
Valine	800

In addition to energy-producing organic foodstuffs a minimum quantity of protein is required for the supply of nitrogen to the body and this protein must contain minimum quantities of specific amino acids which are essential for tissue protein and enzyme synthesis but which the body cannot manufacture itself. On flights of one or two weeks, supplies of these amino acids are not particularly important; but for durations of months or years it is necessary to insure that the protein supplied in the diet contains the minimum amounts of the amino acids given in the table.

Purser, P.E.; Faget, M.A. and Smith, N.F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
595	SYSTEM - HUMAN - H43	Reference 74, p. 107 Based on Reference 26

PLASTIC FILMS FOR FOOD PACKAGING

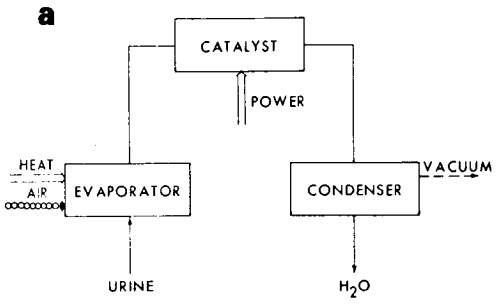
PLASTIC FILMS FOR FOOD PACKAGING
(1 mil thick)

Characteristics	Polytri-fluorochloro ethylene (Aclar 33-C)	Polyester (Mylar)	Polyamide (Nylon)	Polyethyl-ene, low density (Marlex)	Vinyl-idene chloride (Saran)	Poly-vinyl chloride (Pliovic)
Weight (in^2/lb)	13,000	20,000	24,000	30,000	16,000-23,000	20,000-23,000
Tensile strength* (lb/in of width)	5-6	23-40	9	1.3-2.5	8-20	1.4-5.6
Elongation* (%)	35	35-100	orients	200-800	20-140	150-500
Burst strength; Mullen Test** (points)	35	45-60	-	-	23-35	20
Tear strength; Elmendorf Test*** (grams)	200-350	10-27	-	100-300	10-100	60-1400
Moisture vapor transmission rate (gm mil/day, 100 in^2, atm)	0.4 (at 100°F)	24 (at 103°F)	300-320 (at 100°F)	7-15 (at 77°F)	3 (at 100°F)	70-170 (at 100°F)
Permeability to oxygen cc (STP) mil/day, 100 in^2, atm.	7 (at 75°F)	1.1 (at 70°F and 0% RH)	2.6 (at 73°F and 0% RH)	750	1.0 (at 73°F)	625

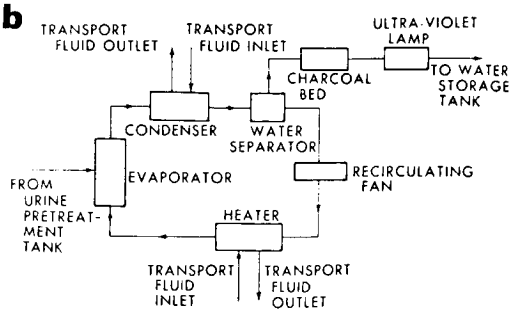
*Tensile strength and elongation: American Society of Testing Materials D-882, Procedure 3.
**Mullen Test: American Society of Testing Materials D-774.
***Elmendorf Test: Figures represent pull to continue tear after starting.
Note: The names Aclar, Mylar, Marlex, Saran, and Pliovic are registered trademarks.

To obtain the best all around physical properties, various thicknesses of several different film materials are usually laminated together by either extrusion or adhesion. Approximate properties can be estimated by adding the separate properties of each part of the laminate. Actual properties can be obtained only by testing each complete laminate, as the techniques of each converter will cause variances.

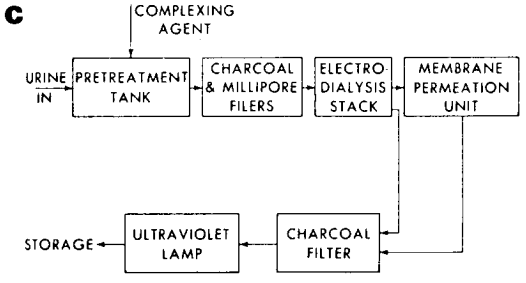
ITEM NO.	SUBJECT AREAS:	SOURCE:
596	SYSTEM - HUMAN- H43, H47	Reference 554, p. 198 Based on References 24, 136, 35.



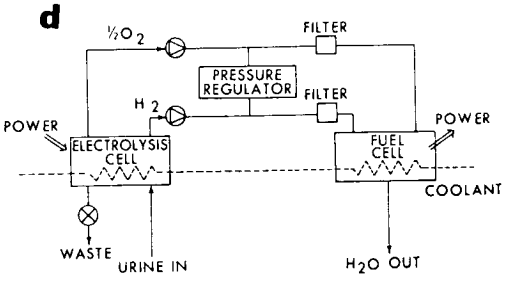
Schematic of vacuum-pyrolysis unit



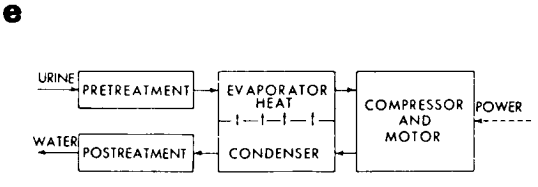
Air-evaporation H_2O reclamation unit



Schematic of electrodialysis system



ELF urine-reclamation system



Schematic of vapor-compression unit

Purser, P.E.; Faget, M.A. and Smith, N.F.; (editors): MANNED SPACECRAFT: Engineering Design and Operation. (c) 1964. Reprinted by permission of Fairchild Publications, Inc.

ITEM NO.	SUBJECT AREAS:	SOURCE:
597	SYSTEM - HUMAN - H47	Reference 483, p. 157

a

PERTINENT PHYSICAL DATA OF THE MOON

Mass	7.35×10^{25} g (1/82 of Earth)
Radius	1,738 km (app. 1/4 of Earth)
Mean surface gravity	162 cm/sec² (0.17 of Earth)
Escape velocity	2.38 km/sec (1/5 of Earth)
Albedo	0.07 (1/4 of Earth)
Mean distance from Earth	384,403 km
Orbital eccentricity	0.0549°
Axial rotation	27.32 days
Atmospheric pressure	less than 10^{-12} atm
Magnetic force field	less than 0.001 gauss
Cosmic ray density on surface	6 primary particles/cm²/min

b

PERTINENT PHYSICAL DATA OF MARS

Mass	5.97×10^{26} g (0.11 of Earth)
Radius	3310.00 km (0.52 of Earth)
Mean surface gravity	392 cm/sec² (0.40 of Earth)
Escape velocity	6.4 km/sec (0.57 of Earth)
Minimum distance from Earth	54.05×10^6 km
Semimajor axis	1.523688 A.U.
Orbital eccentricity	0.09333
Sidereal day on Mars	$24^h37^m22.7^s$
Solar day on Mars	$24^h39^m35.0^s$
Solar constant	0.84 cal/(cm²)(min)
Atmospheric pressure	70 mm Hg (1/12 of Earth)

c

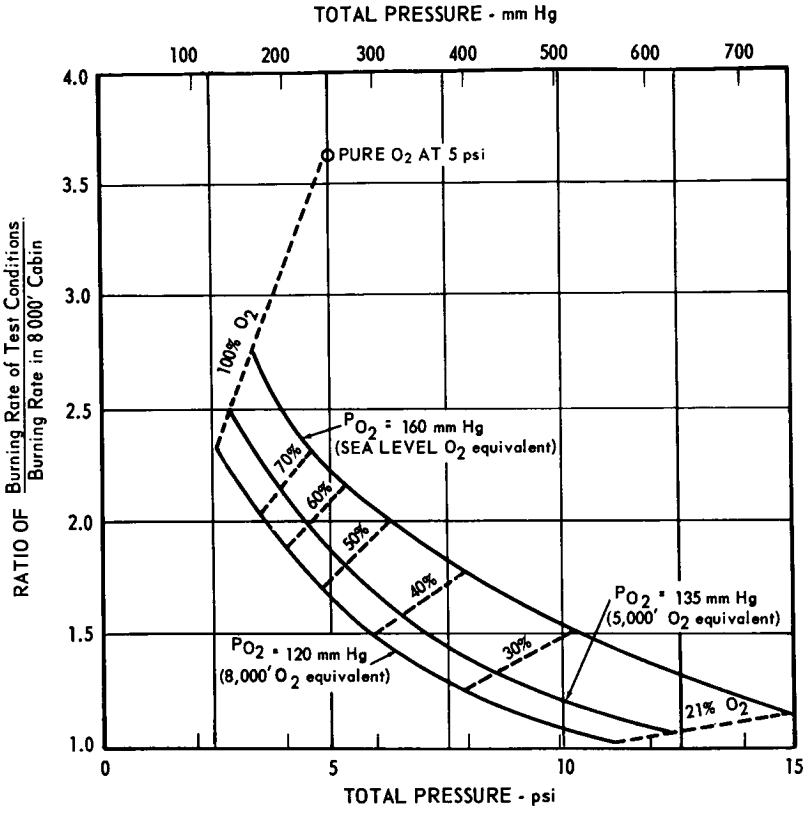
PERTINENT PHYSICAL DATA OF VENUS

Mass	4.89×10^{27} (0.82 of Earth)
Radius	3,100 km (0.97 of Earth)
Mean surface gravity	843 cm/sec² (0.86 of Earth)
Escape velocity	10.3 km/sec (0.91 of Earth)
Minimum distance from Earth	41.6×10^6 km
Major axis	0.72 A.U.
Albedo	0.68 (Kuiper)
Sidereal period	224.7^d
Orbital eccentricity	0.007
Solar constant	3.69 cal/(cm²)(min)
Upper cloud layer temperature	−38° C
Atmospheric temperature range	16-27° C
Surface temperature (estim.)	300° C and less
Atmospheric pressure	8 to 10 atm (estim.)
Mean density	4.87
Inclination of orbit to ecliptic.	3°23'38"

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963.
Reprinted by permission of Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

ITEM NO.	SUBJECT AREAS:	SOURCE:
598	SYSTEM - S1, S18 HUMAN -	Reference 219, pp. 174, 176, and 178.

BURNING RATES OF COTTON FABRICS



Burning rate of cotton fabric is only one of many approaches to quantitation of fire hazard. In the graph, the burning rates in atmospheres of varied total pressure and percentage O_2 are compared with those in a standard aircraft cabin at 8,000 feet. Oxygen isopleths are shown for three partial pressures. The diluent effect of inert gas (nitrogen) is apparent.

ITEM NO.	SUBJECT AREAS:	SOURCE:
599	SYSTEM - S2 HUMAN -	Reference 554, p.13 Based on Reference 304.

PROPERTIES OF INERT GASES

Property	Helium (He)	Neon (Ne)	Argon (A)	Krypton (Kr)	Xenon (Xe)	Nitrogen (N_2)
Atomic number	2	10	18	36	54	7
Molecular weight	4.00	20.18	39.93	82.92	130.2	28.02
Density (gm/liter)	.178	.889	1.78	3.71	5.85	1.25
Boiling point (°C)	-268.8	-245.9	-185.8	-151.8	-106.9	-195.8
Solubility coefficient in water, 38°C	.0086	.0097	.026	.045	.085	.013
Solubility coefficient in oil, 38°C	.018	(.046)*	.14	.43	1.7	.067
Oil/water solubility ratio	0.21	(4.7)**	5.3	9.6	20.0	5.2
Relative diffusion through gelatin, 23°C	1.0	(.45)***	.30	.21	.13	.36

*Interpolated from molecular weight factors.
**Calculated from this table.
***Calculated from factors of Graham's law.

Gases other than nitrogen have been suggested as oxygen diluents in aerospace cabins. Such factors as cabin leak rate, weight and volume efficiency of storage, burning rates, and susceptibility to decompression sickness depend on the physical properties. Both oil/water solubility ratios and diffusivity are factors involved in decompression hazard. Oil solubility and diffusivity of neon were not available and were calculated.

ITEM NO.	SUBJECT AREAS:	SOURCE:
600	SYSTEM - S2 HUMAN -	Reference 554, p. 14 Based on References 83, 431, and 444.

SEA LEVEL ATMOSPHERIC COMPOSITION

Constituent	*Mol Fraction Per cent*	*Molecular Weight (O=16.00)*
N_2	78.09	28.016
O_2	20.95	32.000
A	0.93	39.944
CO_2	0.03	44.010
Ne	1.8×10^{-3}	20.183
He	5.24×10^{-4}	4.003
Kn	1.0×10^{-4}	83.7
H_2	5×10^{-5}	2.016
Xe	8.0×10^{-6}	131.3
CH_4	5×10^{-6}	16.035
H_2O 1	0 to 2.0	18.016
O_3 2	0 to 7×10^{-6}	48.000

The atmosphere is defined as the gaseous envelope, the chemical composition of which is listed in the table. The various gases are distributed in the given proportion up to an altitude of about 60 miles except for H_2O, CH_4, O_2 and CO_2, which are dissociated by ultraviolet (UV) radiation at altitudes between twenty and fifty miles. Ozone (O_3) reaches a maximum of 1 to 3 X 10^{-4} per cent between fifteen and twenty miles and acts to absorb a considerable amount of the ultraviolet radiation.

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963.
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ITEM NO.	SUBJECT AREAS:	SOURCE:
601	SYSTEM - S2 HUMAN -	Reference 219, p. 121

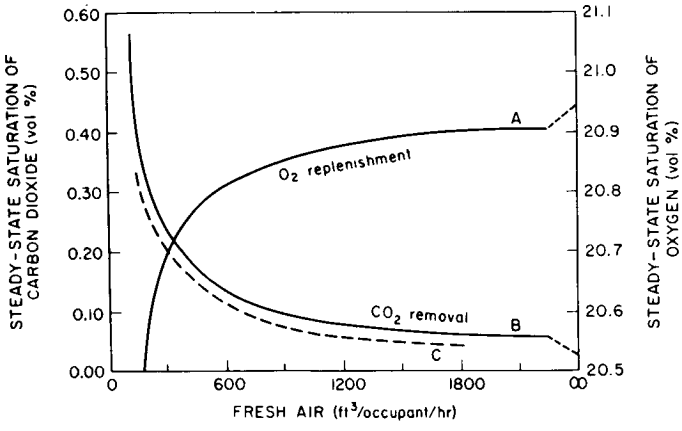
OZONE CONCENTRATION*

Altitude (ft)	Ozone concentration (cm/km)	Relative air density	Ozone concentration (ppm)
0	0.005	1.000	0.05
30, 000	0.010	0.375	0.3
50, 000	0.030	0.153	2.0
70, 000	0.040	0.059	7
90, 000	0.024	0.022	11
110, 000	0.009	0.0084	11
130, 000	0.002	0.0034	6
150, 000	0.0005	0.0015	4

*DiTaranto and Lamb, 1958.

The stratosphere has a nominally constant temperature on the order of arctic-winter temperatures (about -67°F). Maximum ozone concentration (see table) is found near the stratopause, which is at about 25 km (82, 025 ft) in the middle latitudes. (In some systems of nomenclature, the region between about 56, 000 and 100, 000 ft is called the ozonosphere.)

ITEM NO.	SUBJECT AREAS:	SOURCE:
602	SYSTEM - S2, S3, S18 HUMAN -	Reference 380, p. 416 Based on Reference 171.



Steady-state concentrations of oxygen and CO_2 per occupant as function of fresh-air ventilation. Curves A and B determined by calculation; curve C experimentally determined by Yaglou, Riley, and Coggins.

This figure presents the effect of ventilation rates on CO_2 removal and oxygen replenishment. This graph shows that very low ventilating rates are adequate to maintain CO_2 within the maximum allowable concentration. Thus, under ideal conditions, ventilation for CO_2 removal is a minor problem at best. If other sources of CO_2 are present, and if body odors and the like are to be removed, the required rate of ventilation is 2.5 times that shown above.

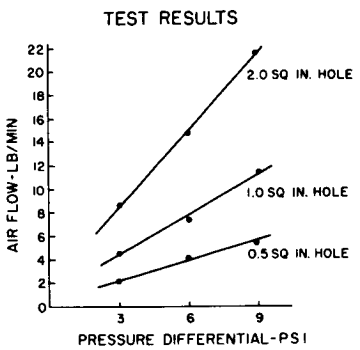
ITEM NO.	SUBJECT AREAS:	SOURCE:
603	SYSTEM-S2 HUMAN-	Reference 380, p. 438. Based on Reference 508.

SOME PROPERTIES OF THE U.S. STANDARD ATMOSPHERE

Altitude		Pressure			Temperature		Density
ft	m	mmHg	mbar	psi	°C	°F	Ratio
0	0	760.0	1,013.2	14.696	15.0	59.0	1.000
2,000	609.6	706.65	942.1	13.665	11.0	51.9	0.9428
4,000	1,219.2	656.41	875.0	12.692	7.1	44.7	0.8881
6,000	1,828.8	609.09	811.9	11.778	3.1	37.6	0.8358
8,000	2,438.4	564.59	752.5	10.917	−0.8	30.5	0.7859
10,000	3,048.0	522.76	696.7	10.108	−4.8	23.3	0.7384
12,000	3,657.6	483.46	644.3	9.349	−8.8	16.2	0.6931
14,000	4,267.2	446.63	595.1	8.636	−12.7	9.1	0.6499
16,000	4,876.8	412.09	549.0	7.969	−16.7	1.9	0.6088
18,000	5,486.4	379.78	505.8	7.344	−20.7	−5.3	0.5698
20,000	6,096.0	349.53	465.4	6.759	−24.6	−12.3	0.5327
22,000	6,705.6	321.28	427.7	6.212	−28.6	−19.5	0.4947
24,000	7,315.2	294.89	392.5	5.702	−32.5	−26.6	0.4640
26,000	7,924.8	270.33	359.7	5.227	−36.5	−33.7	0.4323
28,000	8,534.4	247.43	329.2	4.784	−40.5	−40.9	0.4023
30,000	9,144.0	226.13	300.8	4.373	−44.4	−48.0	0.3740
32,000	9,753.6	206.35	274.4	3.990	−48.4	−55.1	0.3472
34,000	10,363	188.00	249.8	3.635	−52.4	−62.3	0.3218
35,332	10,565	176.63	234.5	3.415	−55.0	−67.0	0.3058
36,000	10,973	170.99	227.2	3.306	"	"	0.2962
38,000	11,582	155.37	206.5	3.004	"	"	0.2692
40,000	12,192	141.18	187.6	2.730	"	"	0.2447
42,000	12,802	128.29	170.5	2.481	"	"	0.2224
44,000	13,411	116.58	155.1	2.254	"	"	0.2021
46,000	14,021	105.94	140.9	2.049	"	"	0.1838
48,000	14,630	96.27	128.1	1.862	"	"	0.1670
50,000	15,240	87.49	116.4	1.692	"	"	0.1518
52,000	15,850	79.51	105.8	1.537	"	"	0.1379
54,000	16,459	72.26	96.15	1.397	"	"	0.1254
56,000	17,069	65.66	87.39	1.270	"	"	0.1140
58,000	17,678	59.68	79.43	1.154	"	"	0.1036
60,000	18,288	54.24	72.19	1.049	"	"	0.0941

From HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN edited by Clifford T. Morgan, et al. Copyright 1963 by the McGraw-Hill Book Company, Inc. Used by permission.

ITEM NO.	SUBJECT AREAS:	SOURCE:
604	SYSTEM - S2 HUMAN -	Reference 380, p. 418



Test results. Air requirements in lbs/min to maintain 3, 6, and 9 psi cabin pressure differentials in a 450 cu ft cabin with simulated meteorite holes of 0.5, 1.0, and 2.0 sq in.; holes were sharp edged. Ambient pressure of 0.868 psi (63, 850 ft altitude); air temperature, 75°F. (Courtesy Douglas Aircraft Co., Tulsa Division, 1958.)

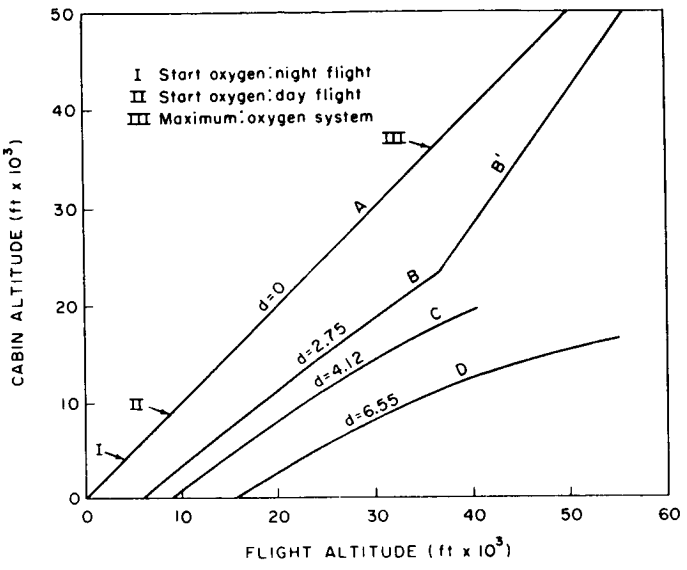
ITEM NO.	SUBJECT AREAS:	SOURCE:
605	SYSTEM - S2, S10 HUMAN -	Reference 219, p. 428

THEORETICAL CALCULATIONS* OF DECOMPRESSION TIMES AND RATES OF CHANGE OF AIR FROM A 500 CUBIT FT CABIN IN SPACE WITH A ONE SQUARE INCH METEORITE HOLE

Cabin		Cabin Air			Time from the Beginning of Decompression in Seconds
Altitude in ft	Pressure in psi	Enclosed Weight in lbs	Rate of Weight Change		
			lbs/sec	lbs/min	
Sea level	14.7	37.5	.520	31.20	0
5,000	12.23	31.2	.433	25.98	13.1
7,000	11.33	28.9	.401	24.06	18.9
9,000	10.49	26.7	.371	22.26	24.2
12,000	9.34	23.8	.331	19.86	32.5
15,000	8.29	21.1	.290	17.40	41.2
20,000	6.75	17.2	.239	14.34	55.9
25,000	5.45	13.9	.193	11.58	71.5
30,000	4.36	11.1	.154	9.24	87.5
40,000	2.72	6.94	.096	5.76	121.5
50,000	1.69	4.30	.0598	3.59	156.0
60,000	1.05	2.67	.0372	2.23	190
70,000	0.649	1.65	.0230	1.38	225
80,000	0.403	1.03	.0143	0.858	259
90,000	0.250	0.638	.0089	0.534	293
100,000	0.150	0.395	.0055	0.336	324
200,000	0.0046	0.0117	.0002	0.012	580

*An isothermal condition was assumed in the calculations because of the slow rate of decompression and continued control of temperature by the air conditioning system in the space cabin. Integrations involving the cabin temperature variations indicate an error of less than one percent if the temperature is assumed to remain constant. The coefficient of the orifice was considered as 1.0.

ITEM NO.	SUBJECT AREAS:	SOURCE:
606-	SYSTEM- S2, S10, S18, S21 HUMAN-	Reference 219, p. 429 Based on Reference 307.



Oxygen and pressurization standards for aircraft. Curve A is for unpressurized aircraft; curves B and B' are for fighter aircraft (d = 2.75 to 37,000 ft, then changes to 2.3 to avoid dangerous explosive decompression); curve C is for commercial aircraft; and curve D is for bomber aircraft.

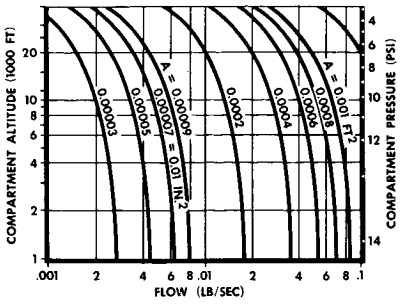
Differential Between Cabin and Flight Pressure in Major U. S. Passenger Aircraft

Aircraft	Operating altitude (ft)			Cabin altitude[2] (ft)	Differential pressure (psi)
	Cruising	Ceiling	Maximum		
Boeing 377		25,000		5,500	6.55
Boeing 707	35,000	40,000	45,000	5,000–8,000	8.6
Boeing 720	25,000	40,000	45,000	4,000–7,000	8.6
Convair 240	8,000		16,000	0–6,000	3.75
Convair 340	9,000	16,000	17,000	0–6,000	4.16
Convair 440	9,000	14,000	20,000	0–8,000	4.16
Convair 880	21,000	35,000	40,000	0–8,000	8.2
Douglas DC-6	18,000	20,000	25,000	6,000–11,300	4.16
Douglas DC-7	22,000			6,000	5.4
Douglas DC-8	35,000	40,000	45,000	5,000–8,000	8.6
Lockheed Constellation		20,000		8,000	4.07
Lockheed Super G		20,000		5,000	5.36
Lockheed Electra		25,000	30,000	5,000–8,000	6.55

[2] Range indicates cabin altitude at lowest to highest operating altitude shown.

ITEM NO.	SUBJECT AREAS:	SOURCE:
607	SYSTEM - S2, S18 HUMAN -	Reference 380, p. 427 Based on References 508, (fig. a) and 23, (fig. b).

a



Flow rates from space cabin with different orifices (A) to cabin altitude and pressure at 70°F. and orifice coefficient of 1.0.(Note: change orifices (A) in sq ft and flow in lb/sec by factor of 10 for each higher or lower order of magnitude.)

b

Space Cabin Leak Rates for Varying Hole Sizes at Different Pressures, and Mission Durations

CABIN PRESSURE IN PSI	LEAK RATES IN POUNDS 1 DAY	10 DAYS	30 DAYS	100 DAYS	1,000 DAYS
10^{-3} sq in. hole					
14	54	544	1,633	5,443	54,432
10	40.6	406	1,218	4,061	40,608
8	34.6	346	1,037	3,456	34,560
5	25.9	259	778	2,592	25,920
10^{-4} sq in. hole					
14	5.4	54	163	544	5,443
10	4.06	40.6	122	406	4,061
8	3.46	34.6	104	346	3,456
5	2.59	25.9	78	259	2,592
10^{-5} sq in. hole					
14	.54	5.4	16	54	544
10	.406	4.1	12	40.6	406
8	.346	3.5	10	34.6	346
5	.259	2.6	78	25.9	259
10^{-6} sq in. hole					
14	.054	.54	1.6	5.4	54
10	.041	.41	1.2	4.06	40.6
8	.035	.35	1.0	3.46	34.6
5	.026	.26	7.8	2.59	25.9

The importance of small leaks cannot be overemphasized. A family of curves giving flow rates in lbs./sec. for different orifice openings in sq. ft. at different compartment pressures is given in figure a. The orifices (A) are in sq. ft., flow rate in lbs./ sec. The examples given can be multiplied or divided by factors of 10 to get higher or lower flow values than those shown in figure a. For convenience, table b gives the flow rates in lbs. per various missions from 1 day to 1000 at varying compartment pressures for different hole sizes in square inches. For mission durations of 100 days, a leak in the order of 10^{-5} sq. in. might be acceptable, since between 26 and 54 pounds of air would be lost, depending on cabin pressure. Low leak rates will not become a reality without a concentrated developmental effort to perfect sealing techniques.

ITEM NO.	SUBJECT AREAS:	SOURCE:
608	SYSTEM- S2, S18, S27 HUMAN-	Reference 355, p. 288 Based on Reference 307.

A LIST OF SOME OF THE TOXIC AND NOXIOUS GASES THAT MIGHT BE FOUND IN A SPACE CABIN, WITH THEIR FREEZING AND BOILING POINTS

COMPOUND	FREEZING POINT* (°C)	BOILING POINT* (°C)
Hydrogen (H_2)	−259	−253
Carbon monoxide (CO)	−207	−190
Ozone (O_3)	−192	−112
Methane (CH_4)	−184	−162
Oxygen (O_2) (for comparison)		−183
Nitric oxide (NO)	−164	−152
Dichlorodifluoromethane (CCl_2F_2)	−160	− 28
Methyl mercaptan (CH_3SH)	−121	5.8^{752mm}
Nitrous oxide (N_2O)	−102	− 88
Hydrogen fluoride (HF)	− 92	19
Acrolein (CH_2CHCHO)	− 88	52
Hydrogen sulfide (H_2S)	− 83	− 62
Ammonia (NH_3)	− 78	− 33
Carbon tetrachloride (CCl_4)	− 23	77
Propionic acid (CH_3CH_2COOH)	− 22	141
Nitrogen dioxide (NO_2)	− 9	21
Butyric acid ($CH_3CH_2CH_2COOH$)	− 8	164^{757mm}
Formic acid (HCOOH)	8	101
Acetic acid (CH_3COOH)	17	118
Indole ($C_6H_4NHCHCH$)	52	254
Skatole (C_9H_9)	95	266
Bacteria	?	?

*At 760 mm. mercury pressure unless otherwise noted.

ITEM NO.	SUBJECT AREAS:	SOURCE:
609	SYSTEM - S3 HUMAN -	Reference 355, p. 249 Based on Reference 579.

CONTAMINANTS IN SUBMARINE ATMOSPHERES

Compounds Identified or Suspected in Submarine Atmospheres

Compound	Chemical Formula	Suspected Source	Limit (max.) for 90-day dive	Remarks
Acetylene	C_2H_2		2.5%	limit based on lower explosive limit
Acrolein	CH_2CHCHO	cooking		
Arsine	AsH_3	battery gassing	0.01 ppm	
Ammonia	NH_3	scrubbers	25 ppm	limit noted is for 60 day dive
Carbon dioxide	CO_2	breathing	1%	
Carbon monoxide	CO	smoking	25 ppm	
Chlorine	Cl_2	chlorate candles	0.5 ppm	
Ethylene	C_2H_4	polyethylene decomposition		
Formaldehyde	CH_2O	cooking, combustion		
Freon-12	CCl_2F_2	air conditioning	500 ppm	see also HCl, HF, and $COCl_2$
Hydrocarbons (other than CH_4)	-	paints		
Hydrogen	H_2	battery gassing	3%	limit based on lower combustible limit
Hydrogen chloride	HCl	Freon decomposition	0.1 ppm	
Hydrogen fluoride	HF	Freon decomposition	0.1 ppm	
Mercury	Hg		0.05 mg/m^3	
Methane	CH_4	sanitary tanks	5.3%	limit based on lower explosive limit
Methyl alcohol	CH_3OH		3 ppm	
Monoethanolamine	$OHCH_2CH_2NH_2$	CO_2 scrubbers	1 ppm	
Nitrogen	N_2			
Nitrogen dioxide	NO_2	burners, smoking	0.5 ppm	
Nitric oxide	NO	burners, smoking		
Oxygen	O_2		17% min.	
Ozone	O_3	precipitators	0.05 ppm	
Phosgene	$COCl_2$	Freon decomposition	0.1 ppm	
Stibine	SbH_3	battery gassing		highly unstable; limits: 1 hr-1 ppm; over 24 hrs-.05 ppm
Sulfur dioxide	SO_2	oxidation sanitary tank gases		
Triarylphosphate		compressors	0.06 ppm 1 mg/m^3	

ITEM NO.	SUBJECT AREAS:	SOURCE:
610	SYSTEM - S3 HUMAN -	Reference 554, p. 26

CONTAMINANTS IN MERCURY SPACECRAFT

Contaminants Identified in the Atmospheres of Mercury Spacecraft

Contaminant	Formula	Concentration ppm **	Limit (max.) for 90 days
1. Freon-114*	$CF_2Cl–CF_2Cl$	60-6000	
2. Ethylene dichloride	$CH_2Cl–CH_2Cl$	0-40	
3. Toluene*	$C_6H_5CH_3$	3-20	
4. n-Butyl alcohol	C_4H_9OH	0-4	
5. Freon-11	$CFCl_3$	0-3	
6. Vinyl chloride	$CH_2= CHCl$	0-3	
7. Ethyl alcohol*	C_2H_5OH	0-3	
8. m-Xylene	$C_6H_4(CH_3)_2$	0-3	
9. Vinylidene chloride*	$CH_2=CCL_2$	0-2	
10. Methylene chloride*	CH_2Cl_2	0-2	
11. o-Xylene	$C_6H_4(CH_3)_2$	0-1	
12. Benzene*	C_6H_6	0-1	
13. Methylchloroform	CH_3CCl_3	0-1	
14. Trichloroethylene	$CHCl=CCl_2$	0-1	
15. Acetone	CH_3COCH_3	0-1	
16. Methyl ethyl ketone	$CH_3COC_2H_5$	0-1	
17. Methyl isopropyl ketone	$CH_3COC_3H_7$	0-1	
18. Ethylene	$CH_2= CH_2$	0-1	
19. n-Propyl alcohol	C_3H_7OH	0-1	
20. Acetaldehyde	CH_3CHO	0-1	
21. Ethyl acetate	$CH_3COOC_2H_5$	0-1	
22. Freon-114, unsym.	$CFCl_2CF_3$	0-1	
23. Methyl alcohol*	CH_3OH	0-1	3 ppm
24. 1,4-dioxane*	$(CH_2)_4O_2$	0-1	
25. Cyclohexane*	$(CH_2)_6$	-	
26. Formaldehyde	CH_2O	-	
27. Hexamethylcyclo-trisiloxane	$(CH_3)_6(SiO)_3$	-	
28. Freon-22	CHF_2Cl	-	
29. Freon-23	CHF_3	-	
30. Freon-12	CF_2CCl_2	-	500 ppm

ITEM NO.	SUBJECT AREAS:	SOURCE:
611 a Page 1 of 2	SYSTEM - S3 HUMAN -	Reference 554, p. 24 Based on Reference 453.

CONTAMINANTS IN MERCURY SPACECRAFT, continued

Contaminants Identified in the Atmospheres of Mercury Spacecraft

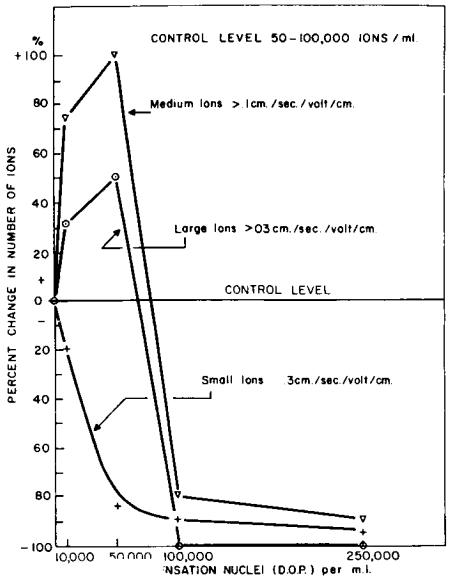
Contaminant	Formula	Concentration (ppm)**	Limit (max.) for 90 days
31. Freon-125	CF_3CF_2H	-	
32. Hexene	C_6H_{12}	-	
33. Propylene	C_3H_6	-	
34. n-Butane	C_4H_{10}	-	
35. Butene-1	C_4H_8	-	
36. iso-Pentane	C_5H_{12}	-	
37. n-Pentane	C_5H_{12}	-	
38. Propane	C_3H_8	-	
39. n-Hexane	C_6H_{14}	-	
40. 2,2-Dimethylbutane	C_6H_{14}	-	
41. trans-Butene-2	C_4H_8	-	
42. cis-Butene-2	C_4H_8	-	
43. Acetylene	C_2H_2	-	2-1/2%
44. 3-Methylpentane	C_6H_{14}	-	
45. Carbon dioxide*	CO_2	-	1%
46. Di-oxene	$(CH_2)_2(CH)_2O_2$	-	

* These contaminants were common to the atmospheres of the first three U. S. manned orbital flights.

** The values listed represent the approximate minimum concentrations which would have ensued had all of the recovered contaminant been dispersed in the free volume of the cabin at one time. A dash indicates that quantitative values were not determined.

Practically all of the contaminants listed were evolved in the outer cabin as distinct from the separate atmosphere in the pilot's pressure suit. They originate from such sources as plastics, lubricating compounds, insulations, paints, cements, and residual solvents from degreasing treatments. Most of the aliphatic and olefinic hydrocarbons listed were detected at very low concentrations in one suit atmosphere and probably originated as impurities in a batch of contaminated breathing oxygen. The presence of these compounds in compressed gases stems from the cracking of hydrocarbon compressor oils. The various Freons listed either were used as refrigerants or were present as impurities in those which were. Specific sources for most of the other contaminants can only be surmised at this time. Of this list, only four compounds, acetylene, Freon-12, CO_2, and methyl alcohol have 90-day maximum allowable limits as used by the Navy.

ITEM NO.	SUBJECT AREAS:	SOURCE:
611 b Page 2 of 2	SYSTEM - S3 HUMAN-	Reference 554, p. 25. Based on Reference 453.

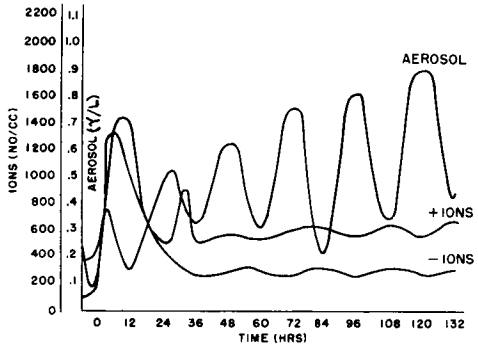


Effect of increasing levels of aerosols (D. O. P.) particle size diameter (0. 3 micron) on concentrations of ions with various mobilities. Per cent change of ions from control levels. Control level: 50-100, 000 ions / ml.

Results of recent studies on the interaction of aerosols and ions showed a shift in the spectrum of ions when aerosols of uniform size were added to the atmosphere containing ions. When smaller numbers of aerosols were introduced, an immediate decrease of the small ions was observed, while medium and large ions increased. Further increases in the number of aerosols led to a general decrease of small and large ions.

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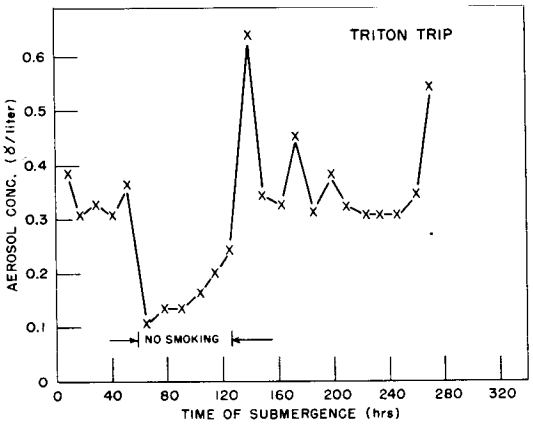
ITEM NO.	SUBJECT AREAS:	SOURCE:
612	SYSTEM - S3, S7 HUMAN-	Reference 465, p. 102. Based on Reference 467.



Air ions and aerosol concentrations on nuclear submarines.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
613	SYSTEM- S3, S7, S28, S29 HUMAN-	Reference 465, p. 101.



Effect of smoking on submarine aerosol concentration.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
614	SYSTEM - S3, S28, S29 HUMAN -	Reference 465, p. 98. Based on Reference 424.

a

Moist Air with a Constant Water Vapor Pressure of 10 mm Hg Has the Following Relative Humidities at the Various Temperatures (Dry Bulb) Shown

TEMPERATURE (FAHRENHEIT)	RELATIVE HUMIDITY (PER CENT)
52.0°	100
55.0°	90
58.3°	80
62.0°	70
66.3°	60
71.8°	50
78.3°	40
87.2°	30
100.5°	20
124.7°	10

b

Moist Air Having a Relative Humidity of 50 per cent, but at Several (Dry Bulb) Temperatures, Has the Water Vapor Pressures Shown

TEMPERATURE OF AIR, 50% SATURATED (FAHRENHEIT)	MOISTURE OF THE AIR EXPRESSED AS WATER VAPOR PRESSURE
50°	4.6 mm Hg
60°	6.6
70°	9.3
80°	12.8
90°	17.9
100°	24.5
110°	33.0
120°	43.8

Tables a and b illustrate the difference between relative and absolute humidity terminology. The absolute scale is expressed in millimeters of mercury because the various components of an artificial atmosphere are best expressed in the same terminology—partial pressures of oxygen, carbon dioxide, nitrogen, and water vapor in mm Hg.

A physiologically sound control point for humidity, expressed in absolute terms, in 10 mm Hg vapor pressure under all temperature conditions.

The range around 10 mm can be given as ±5 mm Hg. This figure has been part of Air Force specifications for some time, and the figure is backed up by experimental experience.

The special problem in controlling humidity in a space vehicle comes from the absence of atmosphere outside. One is forced to control a small volume of air rapidly and with considerable precision, with no outside atmosphere to use as a purse gas or diluent.

ITEM NO.	SUBJECT AREAS:	SOURCE:
615	SYSTEM - S4 HUMAN -	Reference 553, pp. 115-116.

MATERIAL ABSORPTIVITY AND EMISSIVITY

MATERIAL	SOLAR ABSORPTIVITY (α)	RADIANT EMISSIVITY (ϵ) *	α/ϵ
410 Stainless steel (bare)	0.258	0.416	0.616
410 Stainless steel (sand blasted)	0.276	0.502	5.5
410 Stainess steel (etched)	0.377	0.186	2.02
Aluminum (polished)	0.20	0.4	0.5
Copper (polished)	0.26	0.04	6.5
Silver (polished)	0.11	0.02	5.5
Nickel (polished)	0.4	0.06	6.67
Magnesium alloy	0.3	0.07	4.29
Chromium	0.49	0.08	6.12
White paint (ZnO)	0.18	0.97	0.186

* At 100°F.

The heat balance of the cabin must be maintained by radiating waste heat from external surfaces to free space. Therefore, when possible, it is attractive to use the surface of the primary structure as a heat radiator in order to minimize the need for additional radiators. The nature of the radiant surface is particularly important in providing maximum heat transfer. The table above is a list of surface emissivity values for comparison. Heat may be transferred to and from the radiant surface by circulation of fluids to the radiating surface, by use of pressurized refrigerants, or by electrical pumping using the Peltier effect.

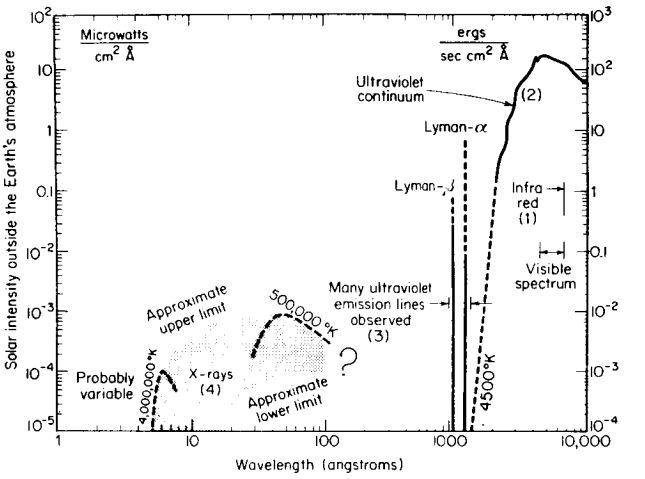
ITEM NO.	SUBJECT AREAS:	SOURCE:
616	SYSTEM - S4 HUMAN -	Reference 355, p. 250. Based on Reference 375.

a

SUN'S EMISSIONS

Nature of Process	*Wavelength*	*Representative Flux at Earth, ergs cm^{-2} sec^{-1}*	*Magnitude of Variations*
Radio waves	0.1 cm-30 meters	3×10^{-7}	$\times10^{3}$
Infrared radiation	3-600μ	3×10^{4}	Very small
Optical radiation	300-30,000 Å	1.4×10^{6}	Very small
Near ultraviolet	1,500-3,000 Å	2×10^{4}	Very small
Lyman-ultraviolet	1,216 Å	5 to 10	$\times3$
Far ultraviolet	10-1,000 Å	1 (?)	Large
Soft X rays	1-10 Å	10^{-3} to 10^{-4}	Large
Hard X rays and γ rays	1 Å	Uncertain	Large
Particles (corpuscular emission)	Protons and electrons of 10^{4} to 10^{5} ev	10^{4} (and possibly up to 10^{6}) ergs cm^{-2} sec^{-1} over small areas in auroral zone; enormous variations	
Thermal conduction	Values are uncertain, but temperature of interplanetary gas, on simplified models, in the Earth's environs as high as 10^{5} may be possible; variations are probably large		

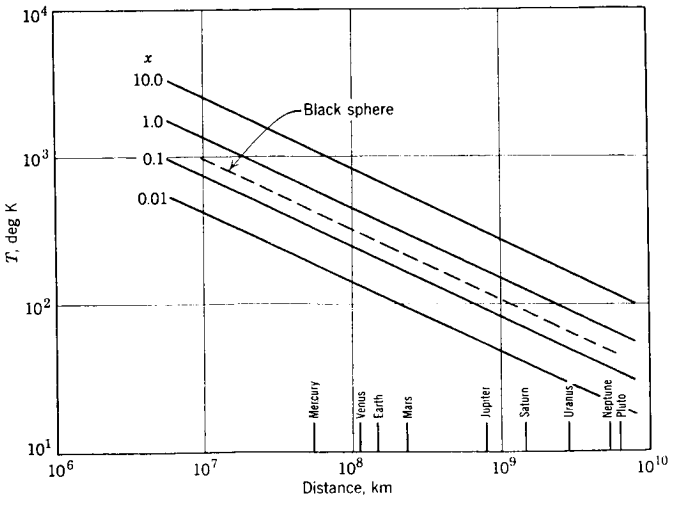
b



The solar spectrum from 1 Å to 1 micron.

Solar electromagnetic radiation includes the range from X rays of about 10 Angstrom, ultraviolet rays, visible light rays, and infrared rays, to radio wave lengths of more than 10 m (see table a and b). The electromagnetic radiation has its maximum intensity in the visible spectrum. The total energy emitted is about 3.9 x 10^{33} ergs/sec. In the estimated five billion years of the past history of the Sun only a small percentage of its mass has been consumed through this conversion of energy. The heat generated by infrared and visible light in the upper layer of the terrestrial atmosphere averages 2 cal/cm2 per minute (solar constant). The thermal irradiance on the Earth's surface at noon under favorable weather conditions is only about two-thirds of this value because one-third is reflected back into space or absorbed by atmospheric water vapor and carbon dioxide.

ITEM NO.	SUBJECT AREAS:	SOURCE:
617	SYSTEM - S4, S7 HUMAN -	Reference 219, pp. 126-127. Based on References 433 (table a) and 61 (fig. b).



Equilibrium temperature in the solar system as a function of the distance from the sun.

The equilibrium temperature for an orbiting vehicle, which it will assume in the radiation field of the sun and in the absence of internal heat sinks or sources, follows from Stephan-Boltzmann's law

$$T = \sqrt[4]{\frac{a}{e}\,\frac{A}{E}\,\frac{Sr}{\sigma}}$$

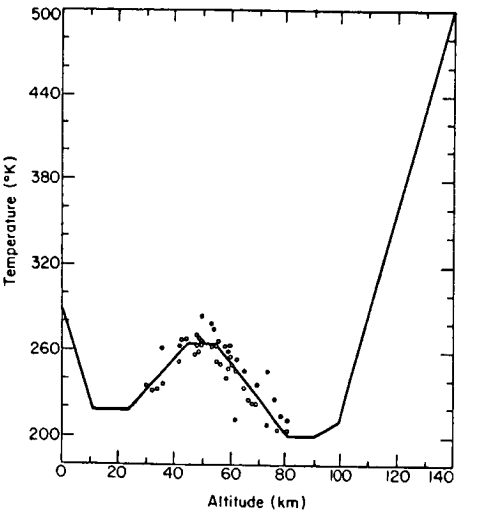
where a and e are the absorption and emission coefficients of the surface material of the vehicle, A and E the effective absorption and emission areas of the surface, σ the Boltzmann constant, and S_r the solar constant at the distance r from the sun.

The figure shows the equilibrium temperature of vehilces as a function of the distance from the sun and for different values of $a/e \cdot A/E = x$ as a parameter. Also shown is the equilibrium temperature for a perfectly black sphere ($a/e = 1$). For most metals $a/e > 1$, and the equilibrium temperature will be higher; even a slight increase of a/e beyond 1 will produce an intolerably high temperature. Temperature control of space vehicles is therefore essential. Heat dissipation can be increased by a surface structure that decreases the ratio of the illuminated and re-emitting surface areas. A different way of dissipating the undesired heat would be to use suitable cooling mechanisms, evaporation of fluids, and structures employing a number of shells and heat pumps, and so to keep the outer-surface temperature higher than that of the vehicle interior.

The equilibrium temperature varies considerably through the solar system; interplanetary vehicles may require control provisions to adjust the internal temperature to the operating level of the payload. The black sphere, for example, would assume an equilibrium temperature of over 400°K near Mercury, about 250°K near the earth, and only 90°K near Saturn.

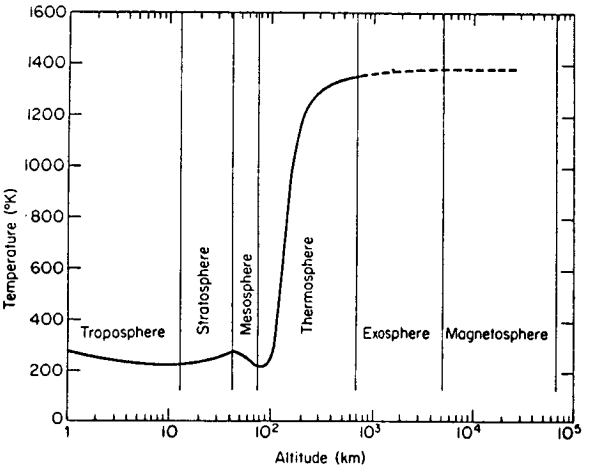
ITEM NO.	SUBJECT AREAS:	SOURCE:
618	SYSTEM - S4, S18 HUMAN -	Reference 373, p. 34.

a



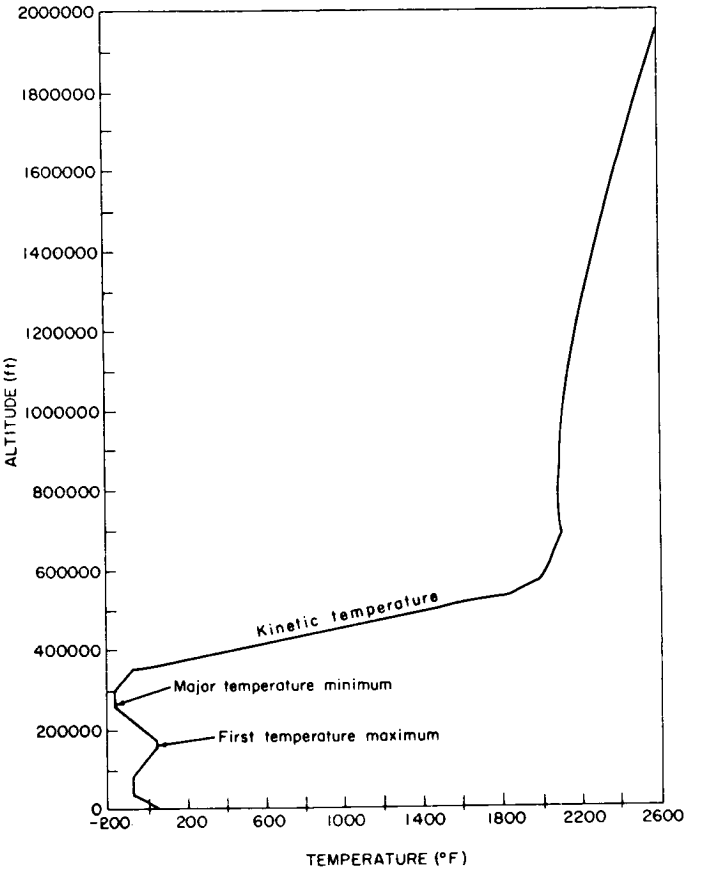
Atmospheric temperature from ground to 140 km. The dates below 30 km represent average balloon data for the U.S., taken from the 1959 ARDC model atmosphere. From 30 to 85 km the profile represents the average over grenade data. Individual grenade measurements are plotted to show the day-to-day variations in this altitude range. From 85 to 140 km the temperature is adjusted in conjunction with the molecular weight in order to fit smoothly together the density data at 85 and 200 km.

b



The temperature profile of the Earth's atmosphere. Up to 85 km the curve represents an average of balloon and rocket temperature measurements. Above 85 km the temperature was deduced from rocket and satellite density measurements. The average daytime temperature is indicated above 200 km. The atmospheric regions shown are defined by changes in sign of the temperature gradient.

ITEM NO.	SUBJECT AREAS:	SOURCE:
619	SYSTEM - S4, S18 HUMAN -	Reference 219, pp. 128-129. Based on Reference 287.



The mesosphere is the region of the first temperature maximum (see figure) and lies above the stratosphere and below the major temperature minimum, which is found at altitudes of from 70 to 85 km and constitutes the mesopause.

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ITEM NO.	SUBJECT AREAS:	SOURCE:
620	SYSTEM - S4, S18 HUMAN -	Reference 380, p. 417

ITEM NO. 621

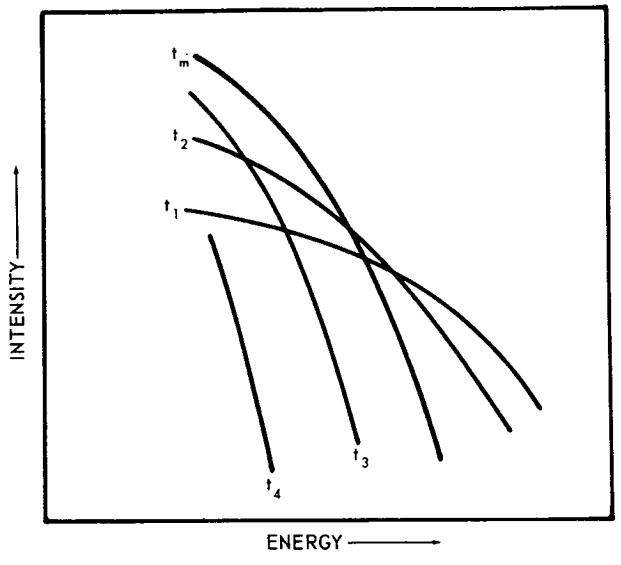
SUBJECT AREAS: SYSTEM- S6 HUMAN-

SOURCE: Reference 53, p. 73.

CONVERSION FACTORS FOR BRIGHTNESS UNITS

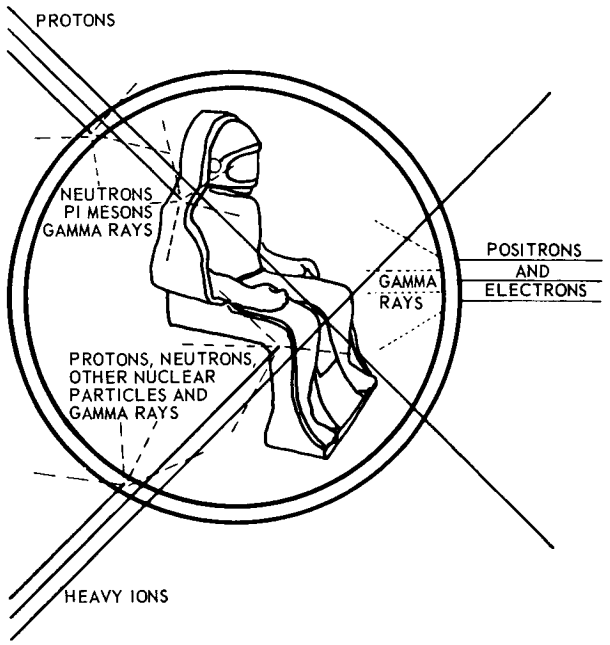
	Ft.-L	L	mL	C/in^2	C/ft^2	C/cm^2
Foot-Lamberts (Apparent or equivalent foot candles)	1.0	1.076×10^{-3}	1.076	2.210×10^{-3}	3.183×10^{-1}	3.426×10^{-4}
Lamberts	9.290×10^{2}	1.0	1×10^{3}	2.054	2.957×10^{2}	3.183×10^{-1}
Millilamberts	9.290×10^{-1}	1×10^{-3}	1.0	2.054×10^{-3}	2.957×10^{-1}	3.183×10^{-4}
Candles per Square Inch	4.524×10^{2}	4.869×10^{-1}	4.869×10^{2}	1.0	1.440×10^{2}	1.550×10^{-1}
Candles per Square Foot	3.142	3.382×10^{-3}	3.382	6.944×10^{-3}	1.0	1.076×10^{-3}
Candles per Square Centimeter	2.919×10^{3}	3.142	3.142×10^{3}	6.45^{2}	9.290×10^{2}	1.0

Value in Unit in Left Hand Column Times the Conversion Factor Equals the Value in Unit Shown at the Top of the Column.



Typical energy spectra are shown for different times ($t_1 < t_2 < t_m < t_3 < t_4$) during a single flare event.

ITEM NO.	SUBJECT AREAS:	SOURCE:
622	SYSTEM - S7 HUMAN -	Reference 554, p. 138. Based on Reference 363.



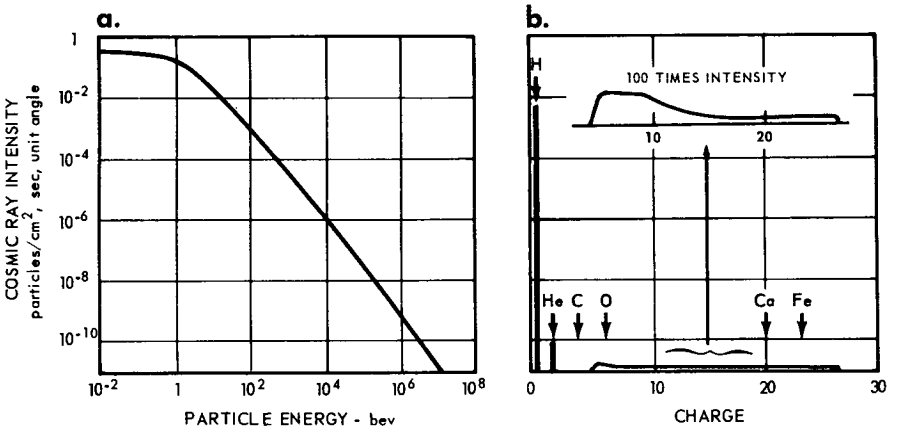
The fates of particles meeting a manned vehicle. Electrons and positrons are stopped by the vehicle wall, which then emits the brehms-strahlung (gamma rays). Protons and heavy ions may hit a target in the wall, or within the cabin, or they may pass right through. Wherever a target is hit, these particles produce characteristic showers of secondary particles, as shown.

Nature and Location of Electromagnetic and Particulate Ionizing Radiations in Space

Name	Nature of Radiation	Charge	Mass	Where Found
Photon	Electromagnetic	0	0	Radiation belts, solar radiation (produced by nuclear reactions and by stopping electrons) and everywhere in space.
X-ray	Electromagnetic	0	0	
Gamma ray	Electromagnetic	0	0	
Electron	Particle	-e	1 m^e	Radiation belt and elsewhere.
Proton	Particle	+e	1840 m^e or 1 amu	Primary cosmic rays, radiation belt, solar flares
Neutron	Particle	0	1841 m^e	Secondary particles produced by nuclear interactions involving primary particle flux
Alpha particle	Particle	+2 e	4 amu	Primary cosmic radiation (nucleus of helium atom)
Heavy primary nuclei	Particle	$\geq$ + 3 e	$\geq$ 6 amu	Primary cosmic radiation (nuclei of heavier atoms)

ITEM NO.	SUBJECT AREAS:	SOURCE:
623	SYSTEM - S7 HUMAN -	Reference 554, p. 134. Based on Reference 394.

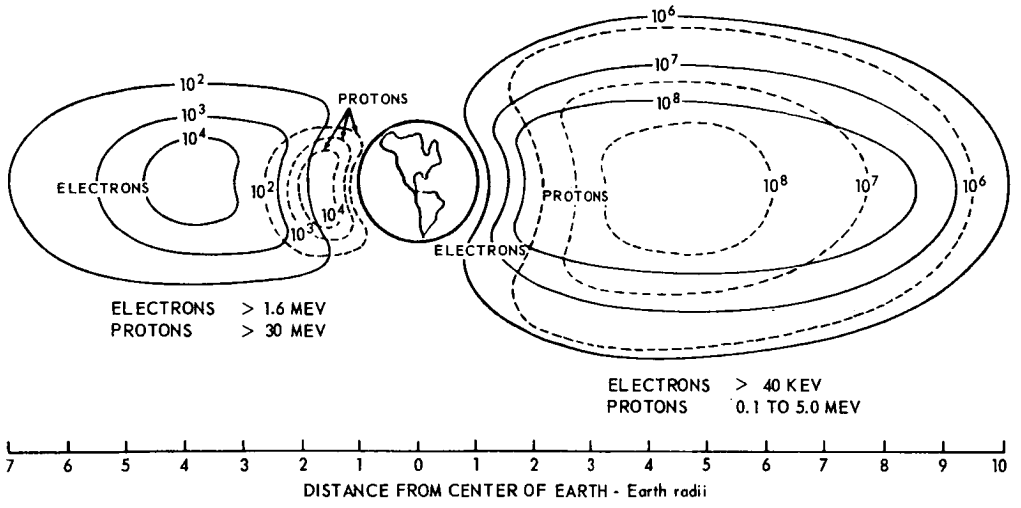
PRIMARY COSMIC RADIATION



The energies and charges of primary cosmic particles in billions of electron volts (bev) are shown as a function of their intensities. Note the inset in the bar graph at the right. The intensities of the particles with higher charges, C, O, Ca, and Fe, are so much less than those of H and He as to be barely perceptible on the base line of the graph. The inset shows a profile for these charges, magnified to 100 times intensity.

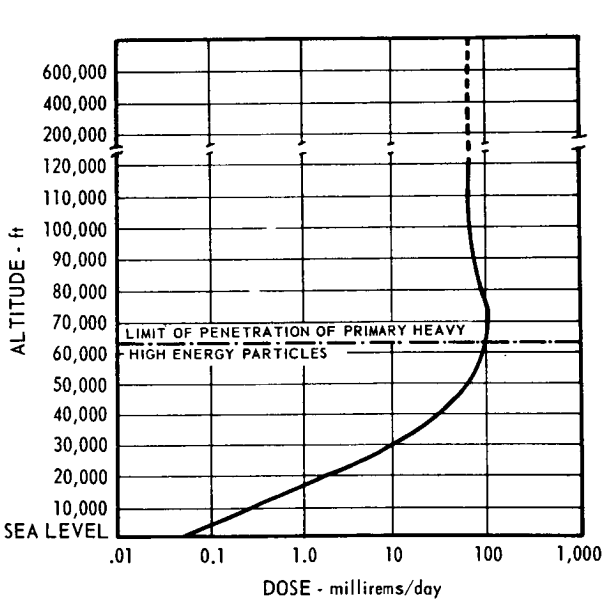
ITEM NO.	SUBJECT AREAS:	SOURCE:
624	SYSTEM - S7 HUMAN -	Reference 554, p. 137. Based on Reference 394.

a



This is a representation of the radiations trapped in the earth's magnetic field, known as the "Van Allen belts."

b



The estimated whole-body dose to an unshielded man from primary cosmic radiations is shown in the graph above.

ITEM NO.	SUBJECT AREAS:	SOURCE:
625	SYSTEM - S7, S18 HUMAN -	Reference 554, pp. 137, 138. Based on Reference 90, (fig. a), 356 (fig. b).

Van Allen's Estimates on Particle Flux

HEART OF INNER ZONE

(3,600 km on geomagnetic equator)

(a) Electrons, $E = 20$ kev: maximum unidirectional intensity:
2×10^{9} cm^{-2} sec^{-1} ster^{-1}

(b) Electrons, $E = 600$ kev: maximum unidirectional intensity:
1×10^{7} cm^{-2} sec^{-1} ster^{-1}

(c) Protons, $E = 40$ Mev: maximum omnidirectional intensity:
2×10^{4} cm^{-2} sec^{-1}

HEART OF OUTER ZONE

(16,000 km on geomagnetic equator)

(a) Electrons, $E = 20$ kev: omnidirectional intensity:
1×10^{11} cm^{-2} sec^{-1}

(b) Electrons, $E = 200$ kev: omnidirectional intensity:
1×10^{8} cm^{-2} sec^{-1}

(c) Protons, $E = 60$ Mev: omnidirectional intensity:
10^{2} cm^{-2} sec^{-1}

(d) Protons, $E = 30$ Mev: no information

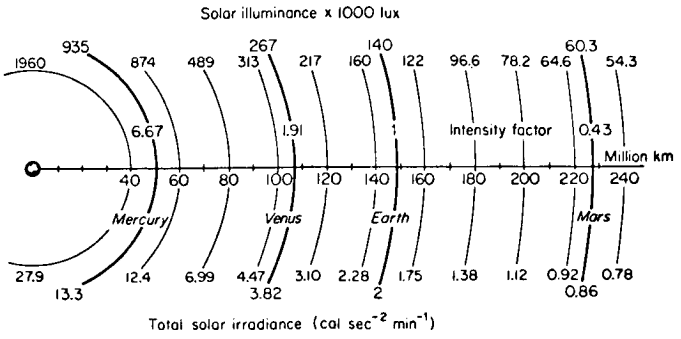
ITEM NO.	SUBJECT AREAS:	SOURCE:
626	SYSTEM - S7, S18 HUMAN -	Reference 523, p. 400.

SOLAR IRRADIANCE FROM MERCURY TO PLUTO

	Distance from Sun 10^6 km	Intensity Factor	Total Irradiance (cal cm^{-2} min^{-1})	Illuminance (lux)
	10	224	447	31,300,000
	20	55.9	112	7,820,000
	30	24.8	49.7	3,480,000
	40	13.97	27.9	1,960,000
	46.0	10.57	21.1	1,480,000
	50	8.94	17.9	1,250,000
Mercury	57.9	6.67	13.3	935,000
	60	6.21	12.4	874,000
	69.8	4.59	9.18	643,000
	70	4.56	9.13	639,000
	80	3.49	6.99	489,000
	90	2.76	5.52	386,000
	100	2.24	4.47	313,000
Venus	108.2	1.91	3.82	267,000
	110	1.847	3.70	258,000
	120	1.552	3.10	217,000
	130	1.322	2.64	185,000
	140	1.140	2.28	160,000
	147.1	1.034	2.07	145,000
Earth	149.6	1.000	2.0	140,000
	150	.994	1.987	139,000
	152.1	.967	1.935	135,000
	160	.874	1.746	122,000
	180	.690	1.380	96,600
	200	.559	1.118	78,200
	206.6	.524	1.047	73,300
	220	.462	.923	64,600
Mars	227.9	.431	.861	60,300
	240	.388	.776	54,300
	249.2	.360	.720	50,400
	260	.331	.662	46,300
	300	.248	.497	34,800
	400	.1397	.279	19,600
	500	.0894	.179	12,500
	600	.0621	.124	8,740
	700	.0456	.0913	6,390
Jupiter	778.3	.0369	.0739	5,170
	800	.0349	.0699	4,890
	1000	.0224	.0447	3,130
	1200	.0155	.0310	2,170
	1400	.0114	.0228	1,600
Saturn	1428	.01096	.0219	1,530
	1600	.00874	.0175	1,220
	2000	.00559	.0112	782
	2500	.00358	.00715	501
Uranus	2872	.00271	.00542	380
	3000	.00248	.00497	348
	4000	.00140	.00279	196
Neptune	4493	.00111	.00222	155
	5000	.000894	.00179	125
Pluto	5910	.000640	.00128	90

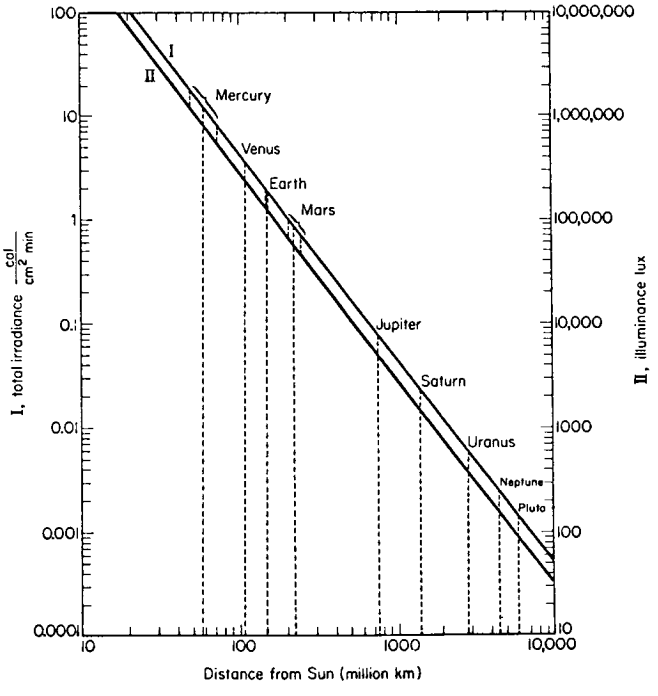
ITEM NO.	SUBJECT AREAS:	SOURCE:
627	SYSTEM- S6, S7, S18 HUMAN-	Reference 219, pp. 130-131. Based on Reference 501.

a



Solar distance irradiance table.

b



Radiation intensities for solar system.

ITEM NO.	SUBJECT AREAS:	SOURCE:
628	SYSTEM - S6, S7, S18 HUMAN -	Reference 219, p. 132 Based on Reference 501.

PROBABILITY OF SOLAR FLARE

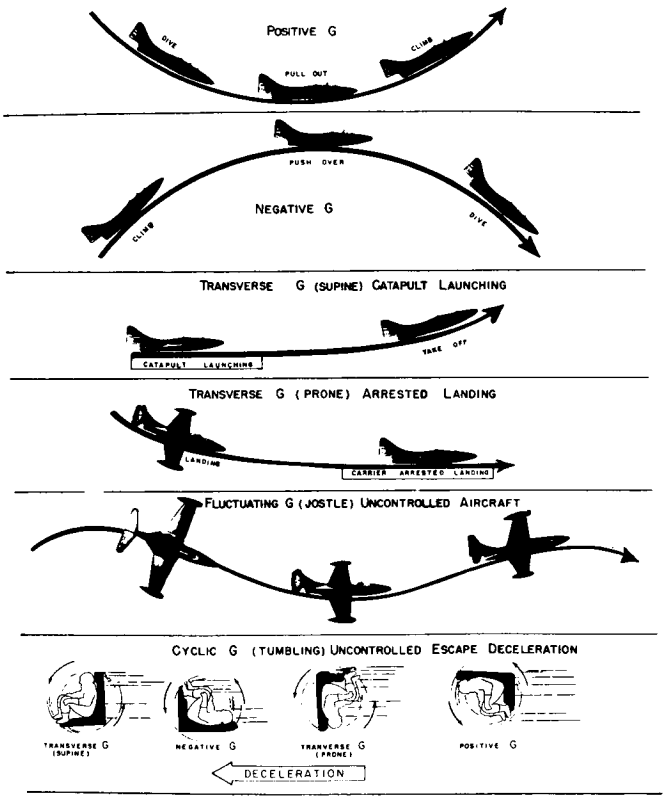
Character of flare	Example (date)	Frequency per year	The probability of getting in a flare with a flight duration of one week
Low energy of particles and high intensity	August 22, 1958	9	16 %
Low energy of particles and extremely high intensity	May 10, 1959	3	5.8 %
High energy of particles and high intensity	February 23, 1956	1/4	0.3 %

The appearance of solar flares has no definite regularity in time. Therefore, the probability of getting in a flare of this or that class depends on the average probability of its appearance and the duration of the flight.

The probability of getting a space ship in a flare with a flight duration of one week is indicated above.

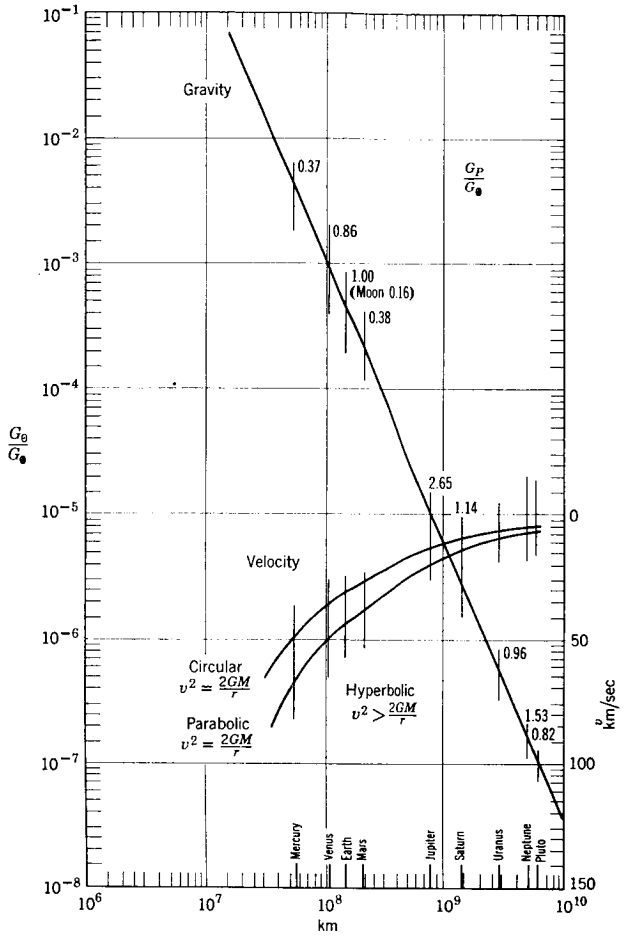
The more powerful a solar flare, the less the probability of its appearance. Thus, flights designed for one week or more the danger of solar flares for the crew is fairly great. It should be noted that in periods of increased solar activity (eleven-year cycle) the probability of the appearance of flares considerably increases. However, data on the biological action of space radiation are necessary for solving the problem of radiation safety during space flights.

ITEM NO.	SUBJECT AREAS:	SOURCE:
629	SYSTEM - S7, S29 HUMAN -	Reference 542, p. 97.



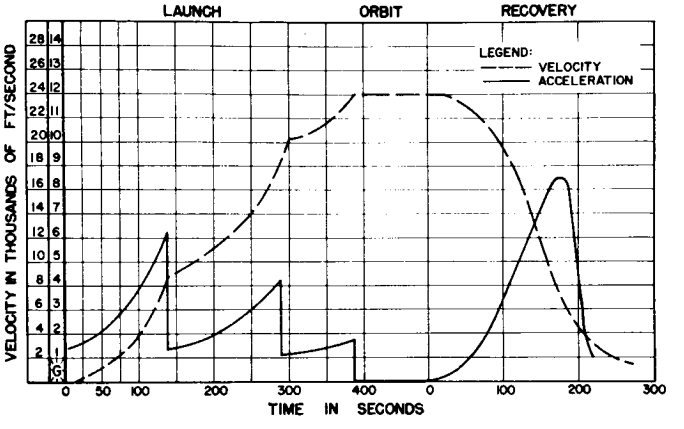
Examples of some G-environments. Accelerations encountered in flight and escape.

ITEM NO.	SUBJECT AREAS:	SOURCE:
630	SYSTEM - S11 HUMAN -	Reference 116, p. 200.



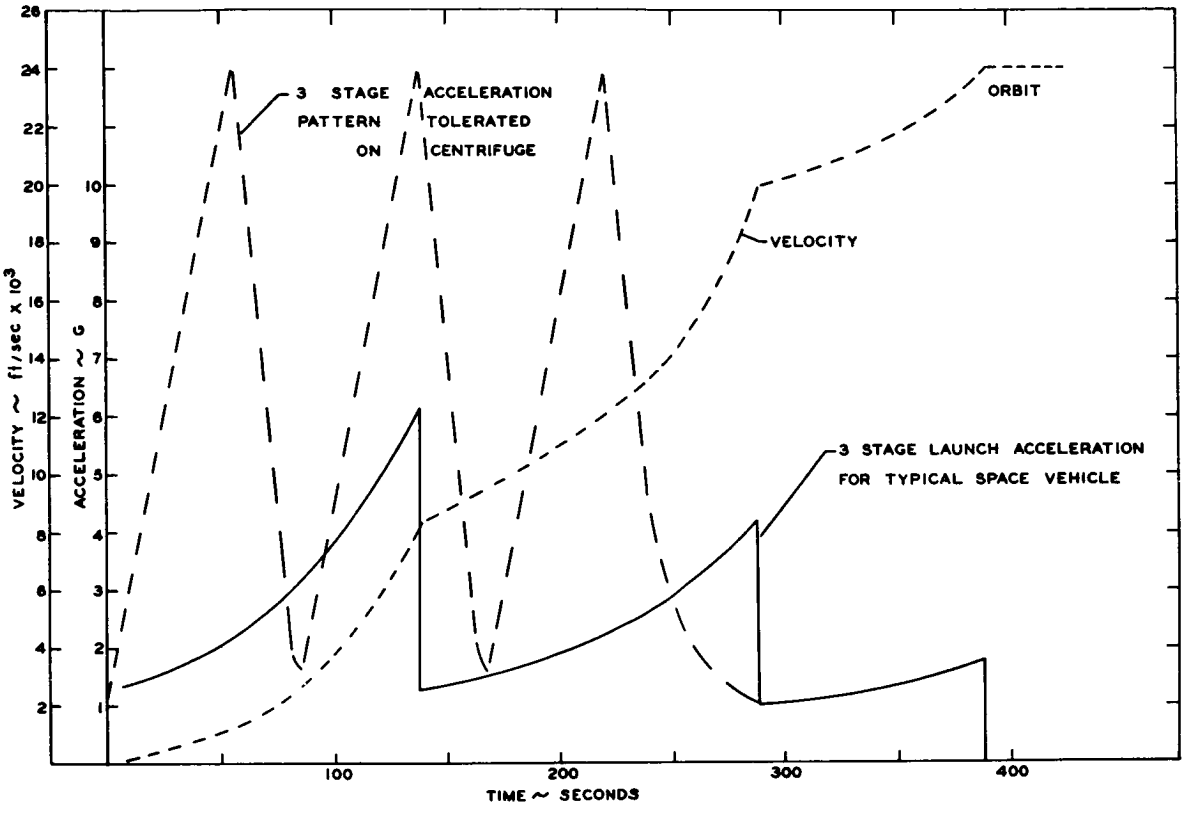
Solar gravitational field $G_\odot/G_\oplus$ as a function of the distance from the sun in units of the surface gravity of the earth. Numbers along the $G_P/G_\oplus$ curve give the surface gravity of the planets in units of the surface gravity of earth. In the lower right corner is the circular and parabolic velocity in the solar system as a function of the distance from the sun.

ITEM NO.	SUBJECT AREAS:	SOURCE:
631	SYSTEM - S11, S18 HUMAN-	Reference 373, p. 30.



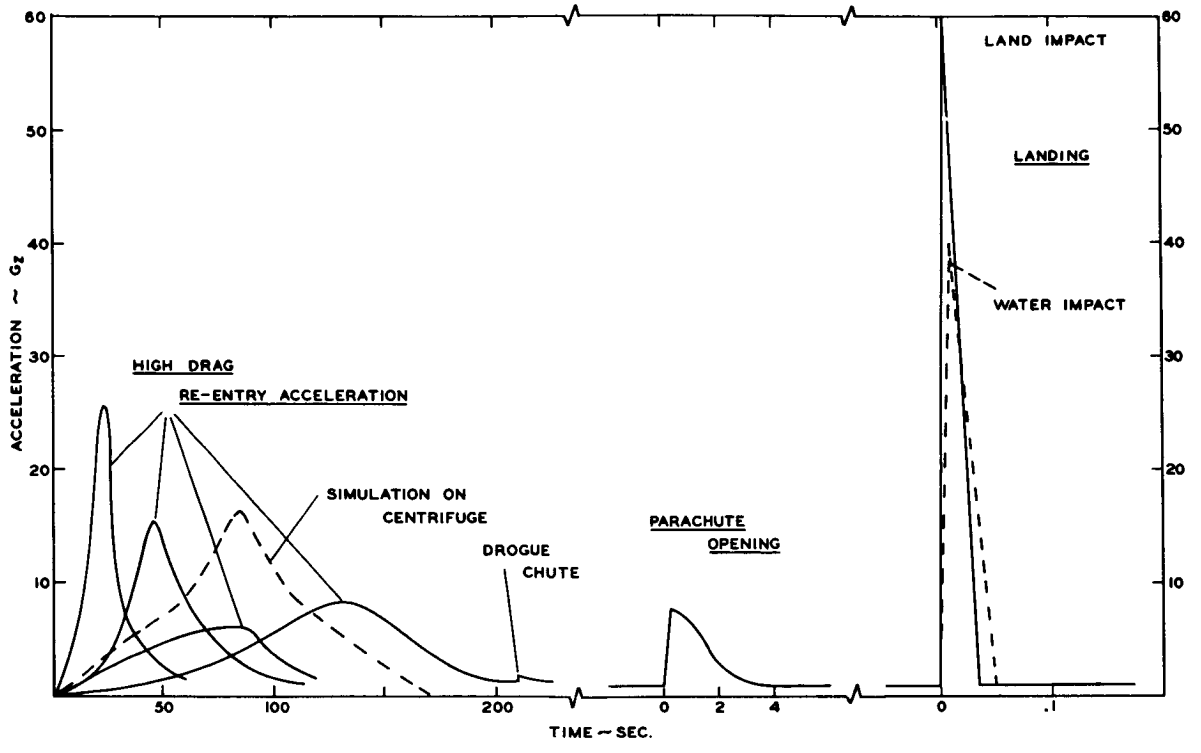
A typical acceleration and velocity profile of the type required for orbital flight. The peaks on the left time scale indicate burn-out of boost engines. The re-entry illustrated is for a ballistic vehicle. Note that approximately fifteen g-minutes are required to achieve or return from orbit.

ITEM NO.	SUBJECT AREAS:	SOURCE:
632	SYSTEM - S12, S13, S16 HUMAN -	Reference 331, p. 354.



Launch acceleration of typical space vehicle with three booster stages: A more severe three-stage acceleration pattern sufficient to exceed orbital velocity, which has been tolerated on the centrifuge by human subjects, is illustrated by the broken line.

ITEM NO.	SUBJECT AREAS:	SOURCE:
633	SYSTEM - S13 HUMAN-	Reference 548, p. 30. Based on Reference 135.



Re-entry, recovery, and landing accelerations (schematic) of a low-lift, high-drag vehicle. The broken profile represents a pattern simulated and tolerated by subjects on a centrifuge (velocity change 24,500 mph). Present-day plans operate with the re-entry patterns of longer duration; an entry angle of 1.5^{o} below the local horizon limits a decayed satellite to 8.5 G acceleration. Shorter duration profiles may be tolerable in the future. Vehicles returning vertically at sub-orbital speeds will reach a maximum slightly above 100 G; 300 G can be experienced by vehicles entering vertically from space.

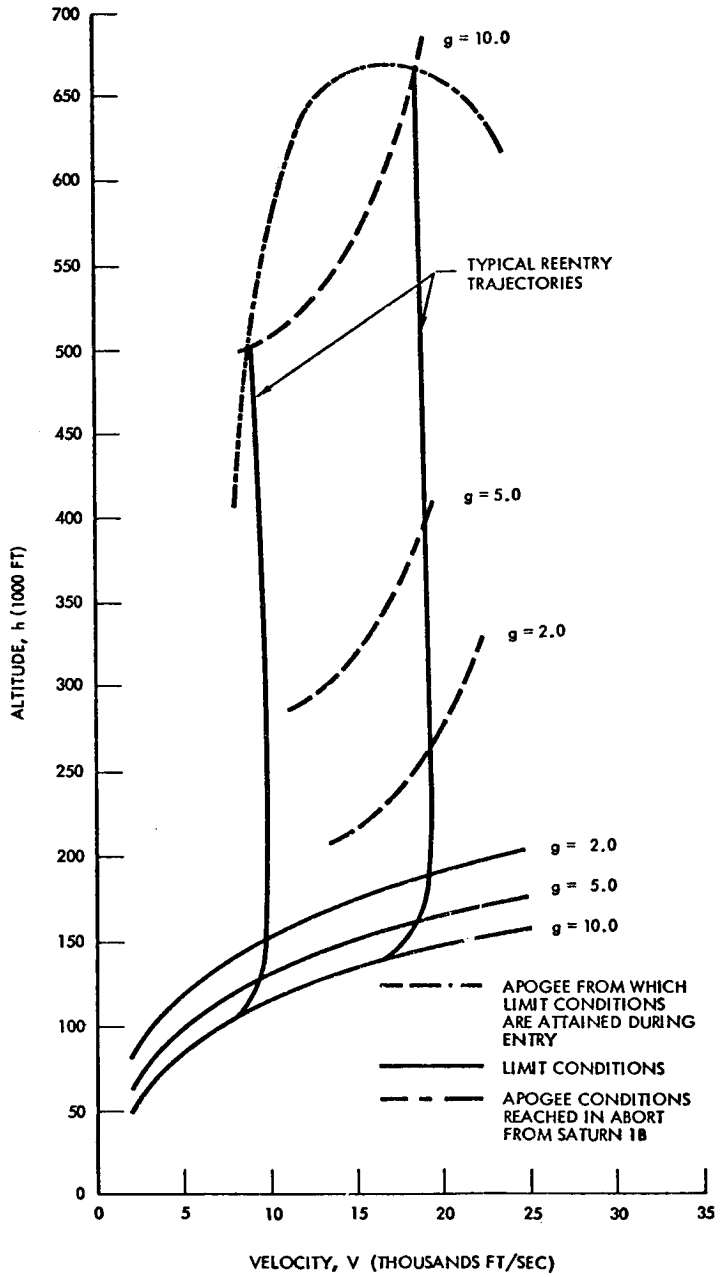
ITEM NO.	SUBJECT AREAS:	SOURCE:
634	SYSTEM - S13, S16 HUMAN-	Reference 553, p. 32. Based on Reference 135.

Approximate Duration and Magnitude of Some Accelerations *

Vehicle	Activity	Acceleration: Duration (sec)	Acceleration: Magnitude (g)
Elevator	Average acceleration in "fast service"	1–5	0.1–0.2
	Comfort limit for acceleration		0.3
	Emergency deceleration		2.5
Train	Normal acceleration and deceleration	5	0.1–0.2
	Emergency stop (braking from 70 mph)	2.5	0.4
Automobile	Normal stop	5–8	0.25
	Quick stop	3–5	0.45
	Emergency stop	3	0.7
	Crash (potentially survivable)	<0.1	20–100
Aircraft	Normal takeoff	>10	0.5
	Catapult takeoff	1.5	2.5–6
	Crash landing (potentially survivable)		20–100
	Seat ejection	0.25	10–15
	Parachute opening at 40,000 ft	0.2–0.5	33
	Parachute opening at 6,000 ft	0.5	8.5
	Parachute landing	0.1–0.2	3–4

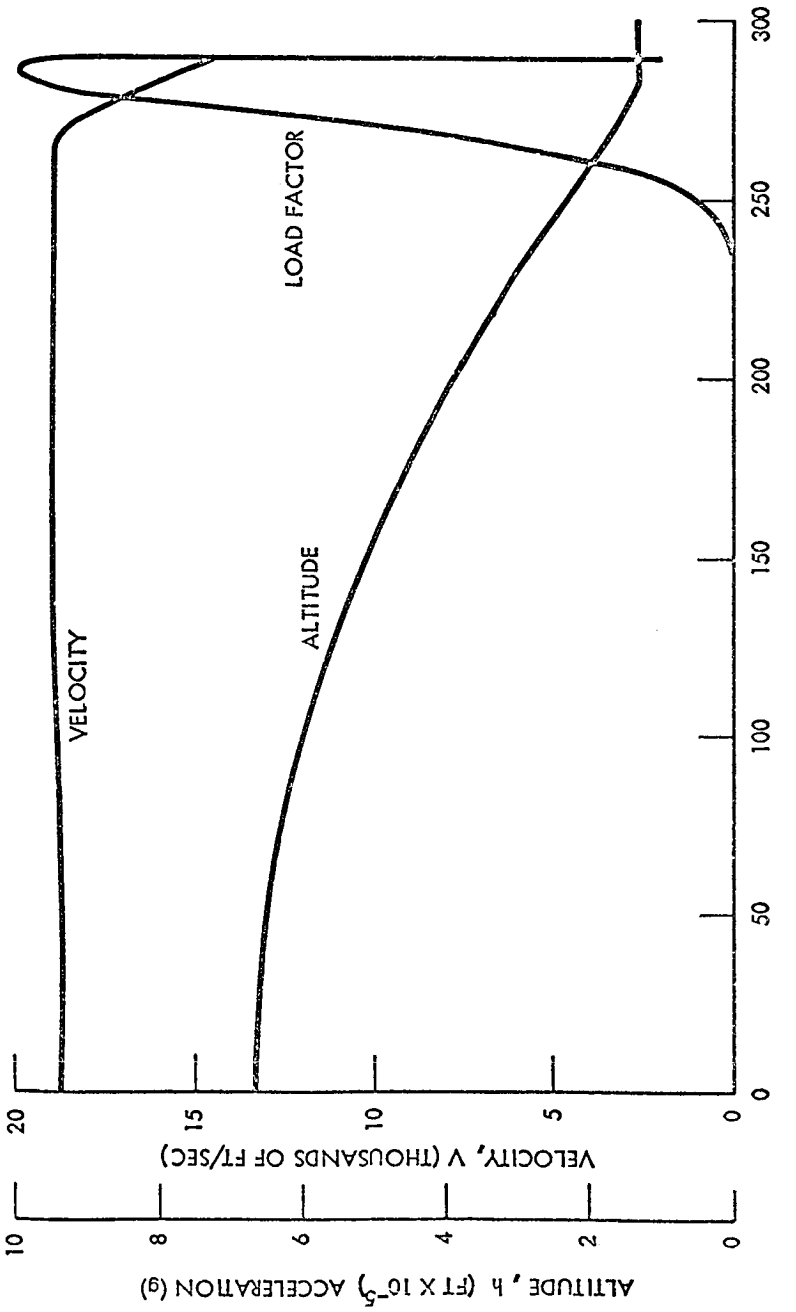
* Goldman and von Gierke, 1960.

ITEM NO.	SUBJECT AREAS:	SOURCE:
635	SYSTEM - S13, S16 HUMAN -	Reference 380, p. 447. Based on Reference 226.



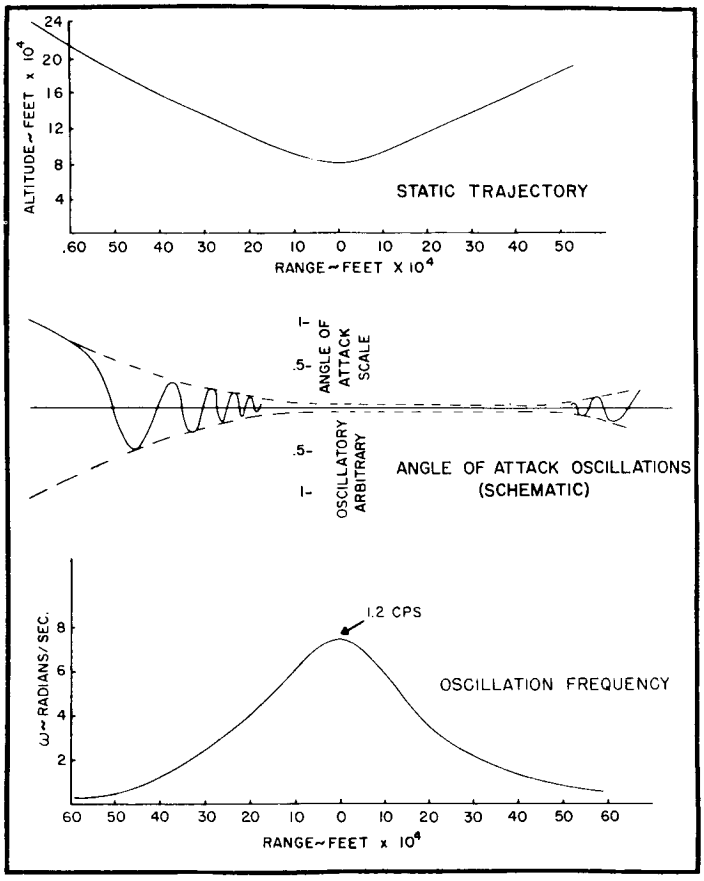
Altitude - Velocity Limits for Abort Trajectories
(C_L/C_D = 0.7 and W/S = 75.0)

ITEM NO.	SUBJECT AREAS:	SOURCE:
636-	SYSTEM - S13, S18, S32 HUMAN -	Reference 378, p. 24.



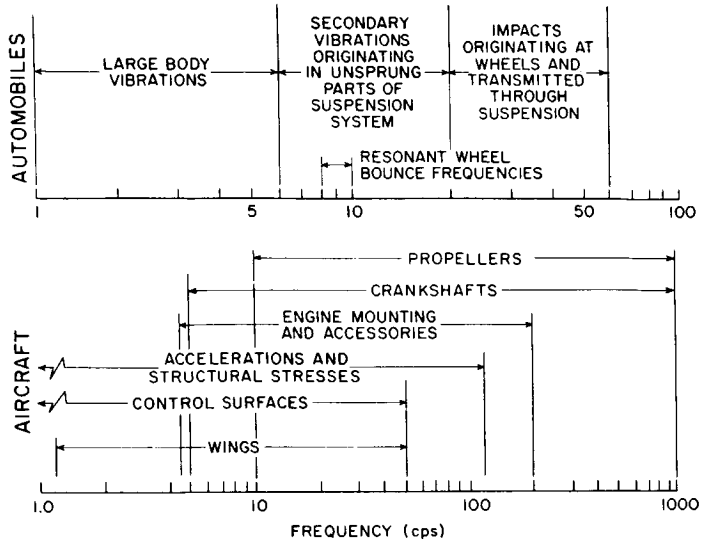
Typical Abort Reentry From Saturn IB Boost

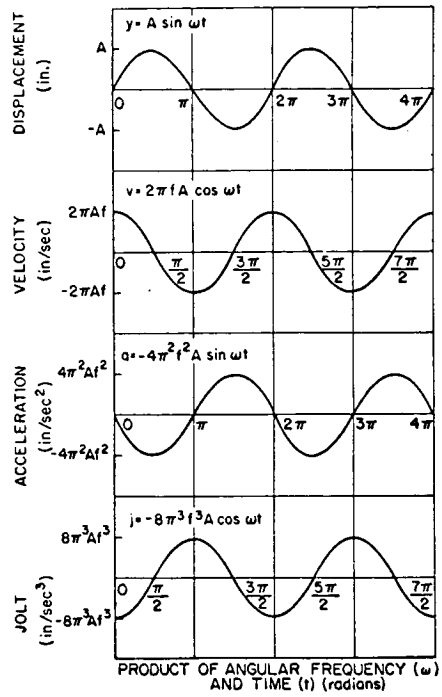
ITEM NO.	SUBJECT AREAS:	SOURCE:
637	SYSTEM - S13, S18, S32 HUMAN -	Reference 378, p. 27.



Example of angle of attack oscillation during skip-glide re-entry of a space vehicle. In this typical case the maximum oscillation frequency is 1.2 cps. Oscillation frequencies up to 11 cps with amplitudes of $\pm 3^{o}$, at the low frequencies up to $\pm 8^{o}$, might have to be expected during certain atmospheric re-entry maneuvers.

ITEM NO.	SUBJECT AREAS:	SOURCE:
638	SYSTEM - S14 HUMAN -	Reference 548, p. 34. Based on Reference 521.



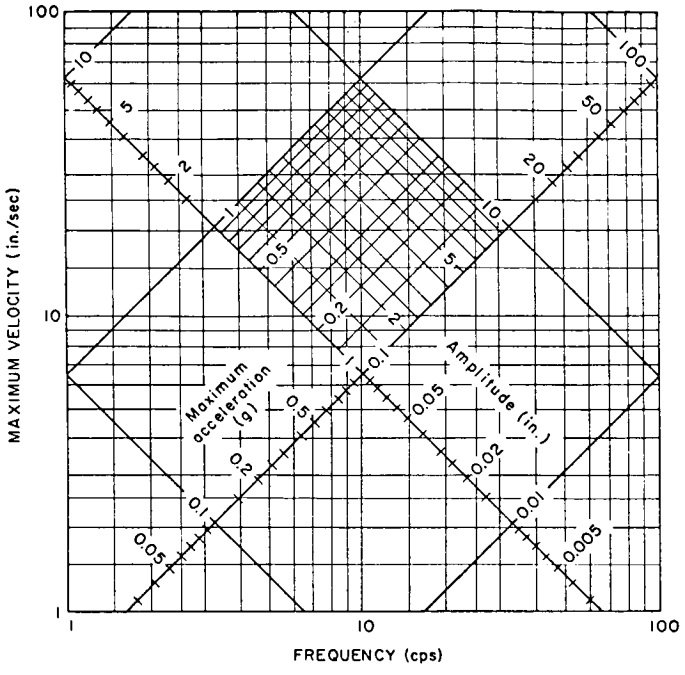


The biological problems of vibration are concerned with the effects on human performance of periodic mechanical forces impinging on body tissue. Of interest are vibratory forces the effects of which displace or damage bodily organs or tissue other than those involved in ordinary hearing and/or those that produce perceptible feelings of pain, annoyance, or fatigue. In general, these are high-amplitude, low-frequency vibrations generated by machines of some sort.

The most common sources of these vibrations are automobiles and aircraft; a representative spectrum for each of which is shown above (Janeway, 1948 and Critchlow, 1944). Vibration amplitudes in these vehicles depend, for the most part, on the power of the propulsion system and aerodynamic forces; natural frequencies depend on the mass of the vehicle. Thus, in the figure (left), the aircraft is seen to have a wider range of frequencies than the automobile. High-performance aircraft and manned space vehicles present higher-order problems associated with their larger masses and very-high-power propulsion systems.

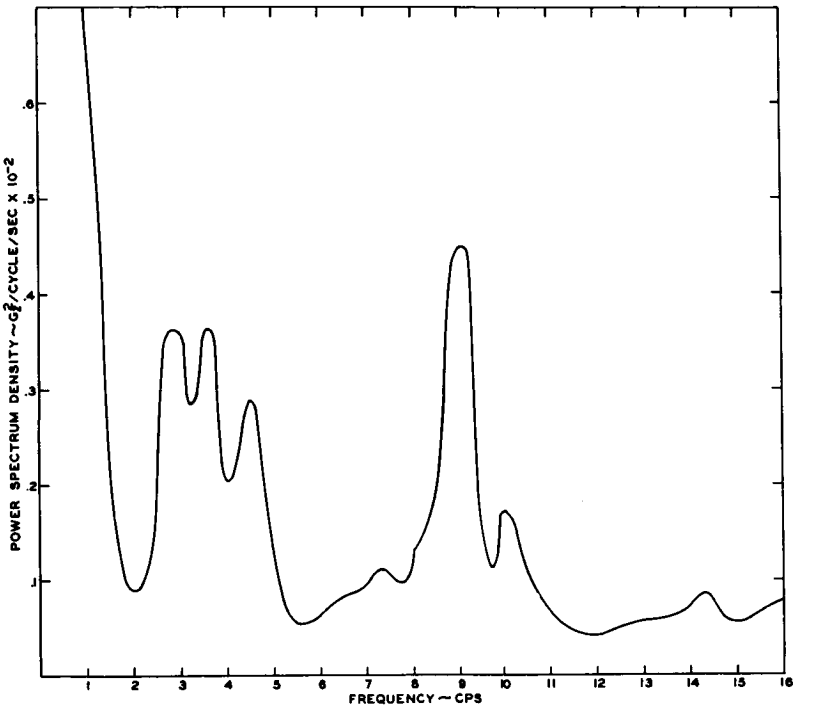
The parameters of vibration are frequency, amplitude (displacement), velocity, acceleration, and jolt. For a fixed frequency, the last three terms are successive derivatives of amplitude with respect to time. This fact is illustrated in the figure above (right).

ITEM NO.	SUBJECT AREAS:	SOURCE:
639	SYSTEM - S14 HUMAN -	Reference 380, p. 467. Based on References 286 and 153



This figure shows the interrelation among maximum velocity, maximum acceleration, amplitude, and frequency of simple harmonic motion. For an object with an amplitude of 1 in. and a maximum velocity of 10 in./sec., for example, the frequency and maximum acceleration can be obtained by finding the intersection of the horizontal maximum-velocity line at 10 in./sec. and the diagonal line of amplitude at 1 in. Reading vertically down from this point, the frequency turns out to be about 6.0 cps; reading along the acceleration diagonal, the acceleration turns out to be about 0.26g.

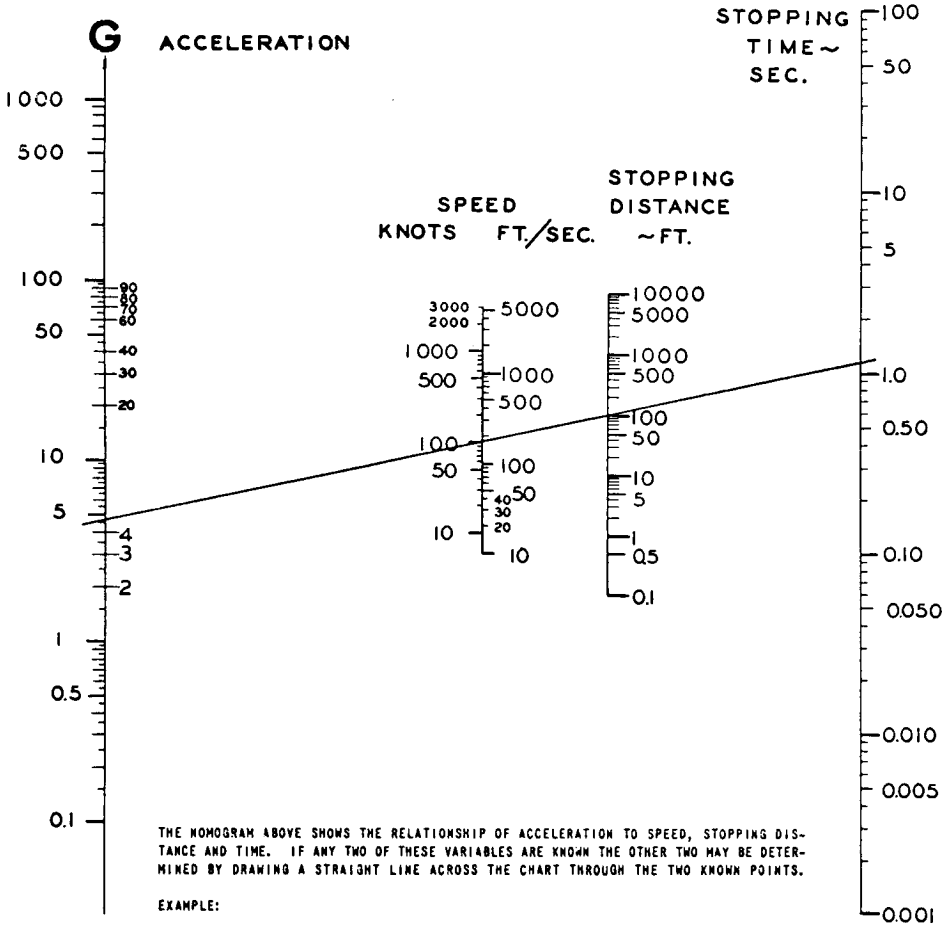
ITEM NO.	SUBJECT AREAS:	SOURCE:
640	SYSTEM- S14 HUMAN-	Reference 380, p. 468. Based on Reference 39.

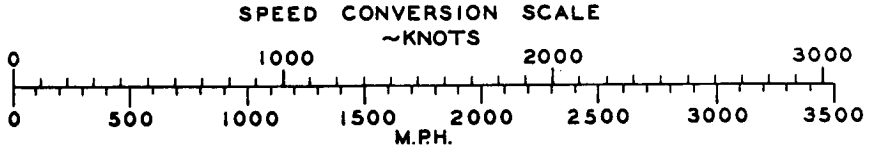


Example of power spectrum of acceleration load during severe, random aircraft buffeting (vertical component). Data were measured at pilot's seat during high-speed, low-altitude flights. Pilot's subjective rating of the gust loads: "severe turbulence." The RMS value of the acceleration pattern was .33 G. Instantaneous acceleration peaks exceeded 2 G approximately 1 per cent of the time.

Example of power spectrum of acceleration load during severe, random aircraft buffeting (vertical component). Data were measured at pilot's seat during high-speed, low-altitude flights. Pilot's subjective rating of the gust loads: "severe turbulence." The RMS value of the acceleration pattern was . 33 G. Instantaneous acceleration peaks exceeded 2 G approximately 1 per cent of the time.

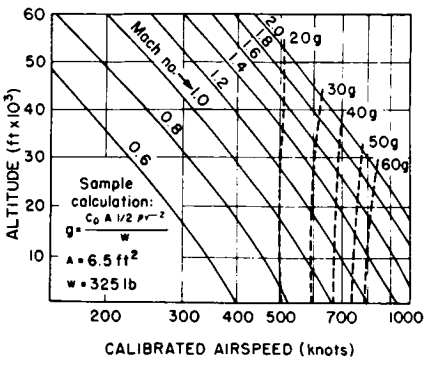
ITEM NO.	SUBJECT AREAS:	SOURCE:
641	SYSTEM - S14 HUMAN -	Reference 548, p. 33.



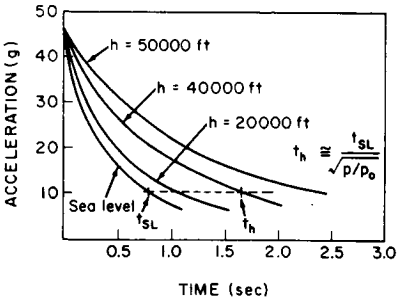


ITEM NO.	SUBJECT AREAS:	SOURCE:
642	SYSTEM - S16 HUMAN -	Reference 332

a



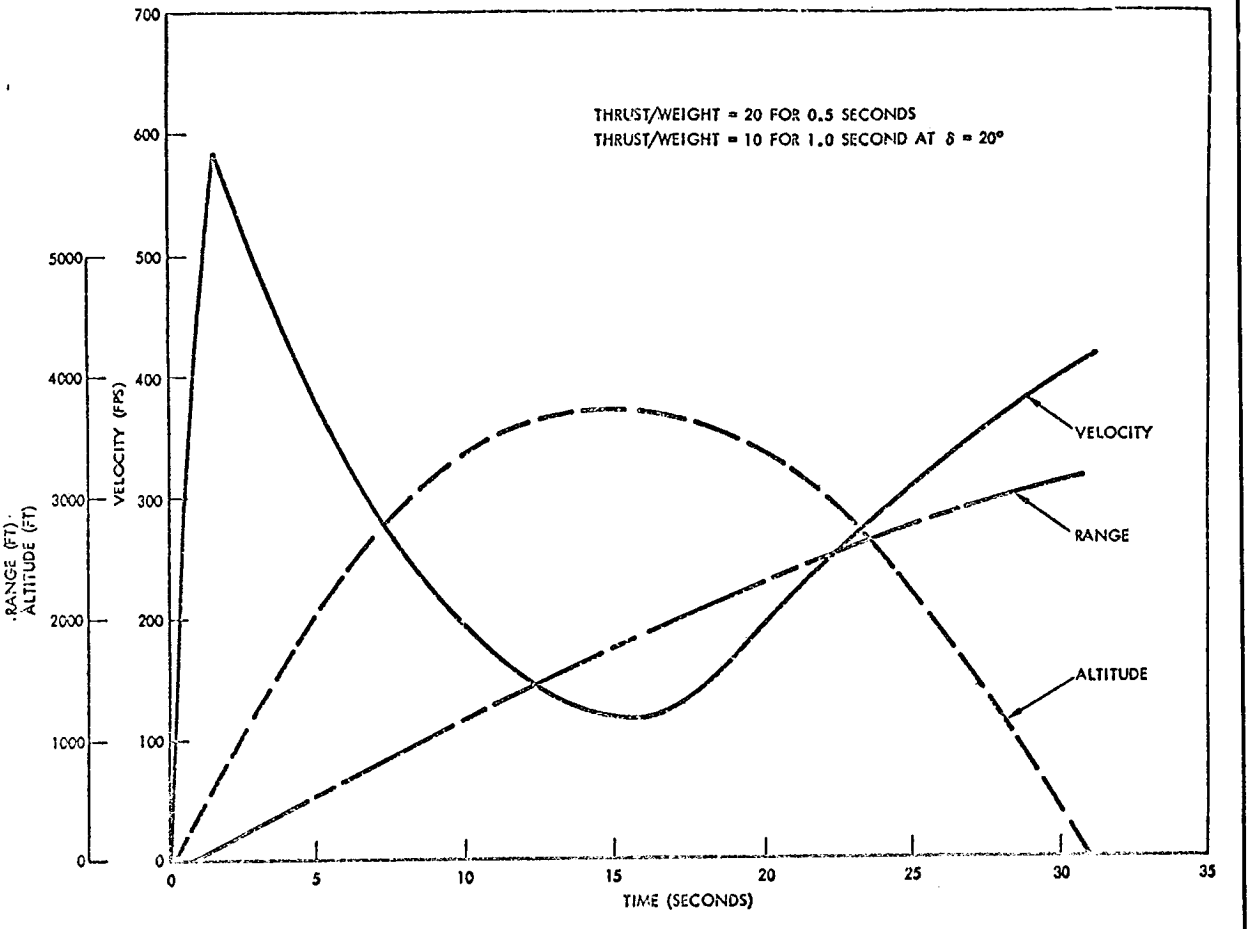
b



The phenomenon of epicyclic tumbling occurs primarily after emergency ejection from high-speed aircraft. Rates of tumbling as high as 200 rpm can be expected, and the winddrag superimposes a decelerative g field. An idea of the magnitude of the decelerative forces involved can be had by looking at Figs. a and b (Goodrich, 1956). These decelerative forces are dangerous if encountered alone, but when superimposed on head-over-heels tumbling, the type of damage that results is qualitatively different from either the effects of deceleration alone or of tumbling alone or of a mere summation of these effects. For example, at 60 rpm in a 30g field, the force exerted on the body is 30g, the vector of this force changes direction by 180 deg every 1/2 sec., and the result is a severe, low-frequency vibration.

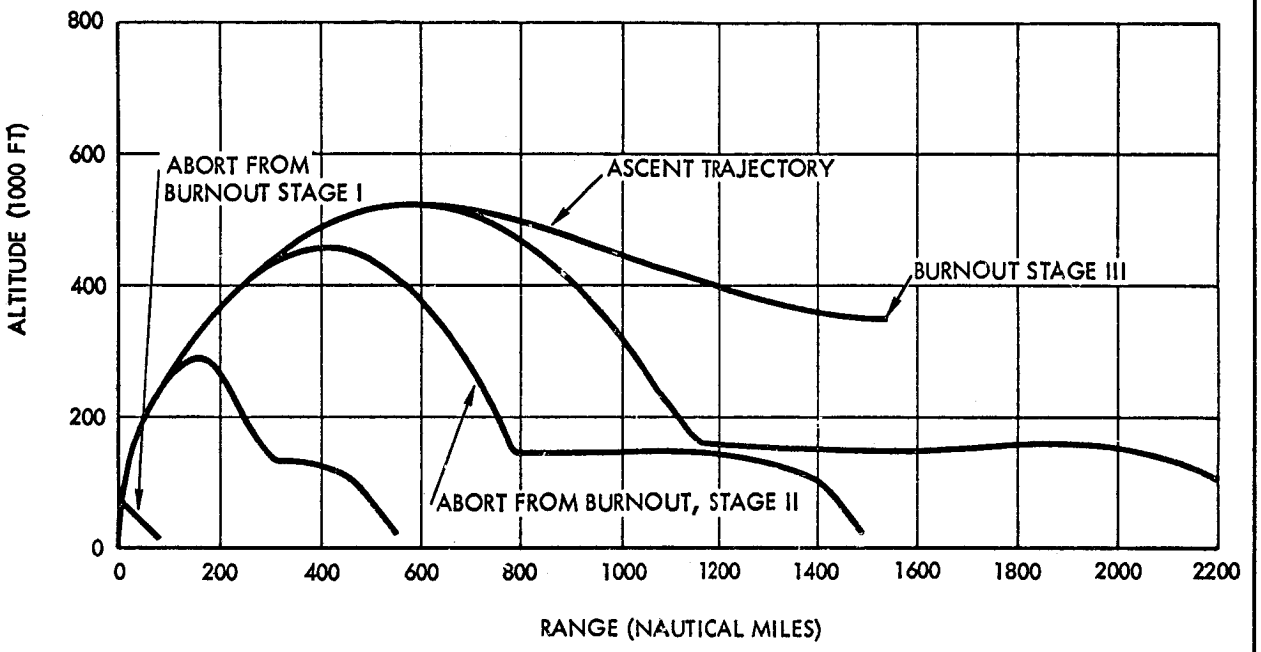
Under 50,000 ft in altitude, deceleration should decay to less than 10g within 5 sec., but, at higher altitudes, where air density is lower, a longer time will be required for it to decay to an insignificant level (see Fig. b)—as much as 30 sec might be required, which is a period of time sufficient to produce the circulatory effects described above. At moderate altitudes, circulatory interruption will not be a problem unless tumbling is prolonged. In this case, the violent shaking is the more dangerous aspect of the situation.

ITEM NO.	SUBJECT AREAS:	SOURCE:
643	SYSTEM - S15, S16, S18, S32 HUMAN -	Reference 380, p. 457. Based on Reference 228.



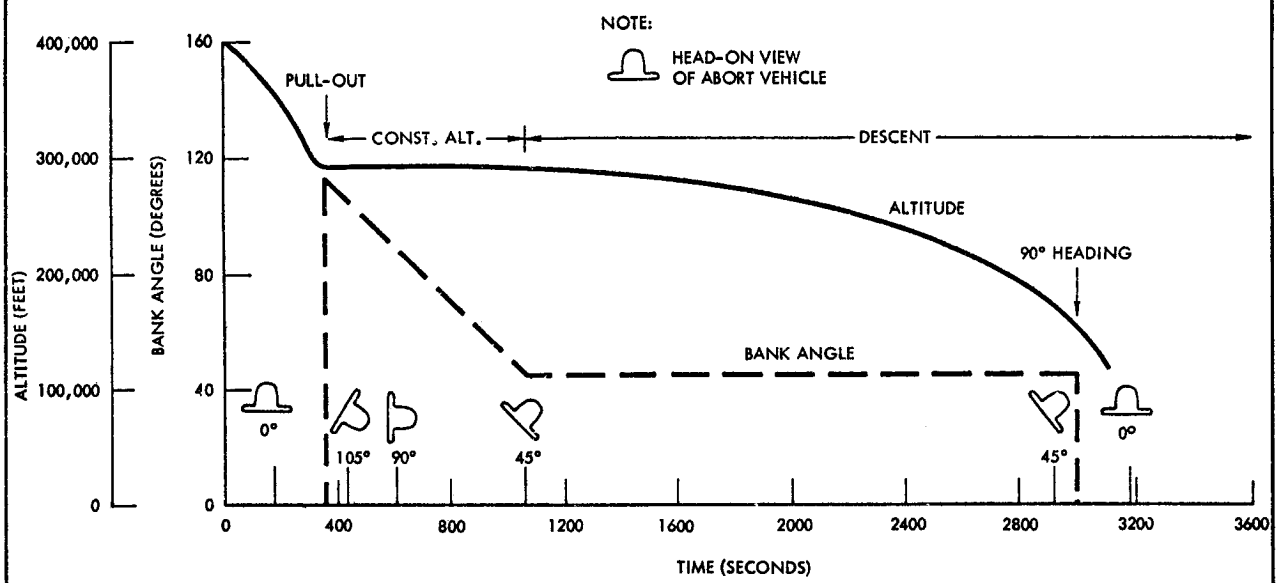
Typical Pad Abort

ITEM NO.	SUBJECT AREAS:	SOURCE:
644	SYSTEM - S18, S32 HUMAN -	Reference 378, p. 23.



Vehicle Abort Characteristics

ITEM NO.	SUBJECT AREAS:	SOURCE:
645	SYSTEM - S18, S32 HUMAN -	Reference 378, p. 28.



Typical Banked Entry

ITEM NO.	SUBJECT AREAS:	SOURCE:
646	SYSTEM - S18, S32 HUMAN -	Reference 378. p. 29.

a

TRANSMITTER POWER--WATTS

	Distance km	*Time Lag (one way)*	*Speech* (a)	(b)	*Telegraphy* (a)	(b)	*Beacon* (a)	(b)
Moon	400,000	1:3s	16	0:16	0:016	0:1	0:001	0.1
	1,000,000	3:3s	100	1	0:1	0:1	0:001	0.1
	10,000,000	33s	10,000	100	10	0:1	0:001	0.1
Venus	42,000,000	2m 20s	180,000	1,800	180	1:8	0:002	1.8
Mars	78,000,000	4m 20s	600,000	6,000	600	6	0:006	6
	100,000,000	5m 30s	10^4	10,000	1,000	10	0:01	10
Jupiter	630,000,000	35m	40×10^4	400,000	40,000	400	0:04	400

b

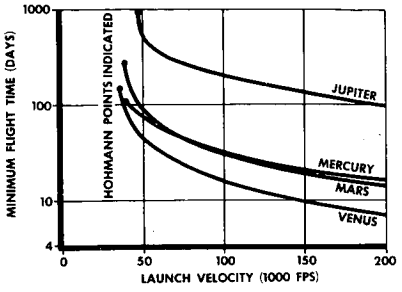
IDEAL MINIMUM VALUES OF AVERAGE TRANSMITTED POWER FOR GIVEN RANGE AND REQUIRED CHANNEL CAPACITY

Range	*Minimum Required Values of Average Transmitted Power*		
	C=10 bits/sec	*10^3 bits/sec*	*10^6 bits/sec*
5×10^4 kilometers (distant earth satellite)	4×10^{-6} watt	4×10^{-4} watt	0.4 watt
5×10^5 kilometers (lunar distance)	4×10^{-4} watt	4×10^{-2} watt	40 watts
10^7 kilometers (near asteroid)	0.2 watt	20 watts	2×10^4 watts
10^8 kilometers (Mars at close approach)	20 watts	2×10^3 watts	2×10^5 watts

Regardless of the physical and sensory part, communication is possible only to the extent to which coding and decoding are adequate. Although telephone circuits have been considered in Table a, there are some difficulties in actual speech communication over long distances because of the time-lags involved. They may amount to several minutes between the planets; this would put conversations out of the question. There is no way around this difficulty. The ideal minimum power requirements for some interplanetary communications are given in Table b.

Siegfried Gerathewohl, PRINCIPLES OF BIOASTRONAUTICS, (c) 1963.
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ITEM NO.	SUBJECT AREAS:	SOURCE:
647	SYSTEM- S18, S22 HUMAN-	Reference 219, p. 349



Minimum flight times for transfer from earth to other planets.

Minimum flight times for transfer from earth to other planets.

This figure gives the minimum flight times from earth to various planets. It can be seen that even with minimum energy (Hohmann) transfers, it takes about 100 to 300 days to go from Earth to Mercury, Mars, or Venus. However, with increases in launch velocity the flight times are significantly reduced. As an example, launch velocities of between 100 and 150 thousand ft./sec. would cut the flight between Earth and Venus to about 15 to 10 days; the flight to Mars would be in the neighborhood of 1 month or less. If the Martian voyage was performed at minimum energy the flight time would be 9 months each way, and this operation at minimum energy could be performed once every 780 days. But, with a capability of 100 thousand ft./sec., the flight time would be in the order of 1 month, and with 200 thousand ft./sec., the minimum flight time would only be about 2 weeks. This indicates that the requirements for vehicle ecological systems may be different than for a permanent lunar or planetary base, since we might expect longer duration capabilities in the base complex.

ITEM NO.	SUBJECT AREAS:	SOURCE:
648	SYSTEM - S18, S27 HUMAN -	Reference 309, p. 278.

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