Title

A Method for the Analysis of Man-Machine Systems

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OF A
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for

LOCKHEED CALIFORNIA COMPANY
SPACECRAFT

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Approved by George L Murphy
George L. Murphy, Director

THIOKOL CHEMICAL CORPORATION
HUMETRICS DIVISION

FOREWORD

This report covers the work performed between September 1962 and January 1963, under Purchase Order No. 71-66739, "Identification of Human Factors Problems Related to a Manned Military System." The project was administered for the Lockheed California Company, Spacecraft, by Dr. Earl Ends, Technical Engineering.

The work was greatly aided by the continuous support, advice and critical comments of Mr. R. Geller and Dr. Ends. Many key suggestions and comments were made at various briefings conducted for the purpose of discussing study progress. The authors are indepted to the Lockheed staff members who participated in these briefings.

The project was administered at Humetrics Division by Dr. George Murphy. Mr. Joel Cooper was responsible for the technical direction and integration of the final report. The analytic method was developed by Mr. James Goff and Mr. Kenneth Caines. Dr. Sol Roshal was responsible for the implications and applications to personnel training. Technical support was given by Dr. Arthur Tamplin, Mr. Claude Ware, Mr. Harvey Glassner, Dr. Harley Mowry, Dr. G. Kasten Tallmadge and Mr. Dan Peterson.

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I. INTRODUCTION

Background

In the past, system design has been an iterative process, that is, it has been a learning process in which a design configuration was established, produced in some form, tested, redesigned, and reworked. In large production runs the costs of this process could be amortized without great burden. By contrast, space systems being presently considered or developed will generally be produced in small quantities. Each will be costly, complicated and operationally demanding. As a consequence, there is a criterion of "right the first time" being imposed on these systems.

The need to meet this criterion seems likely to continue and, in fact becomes more critical as time goes on. Compounded with this is an increased complexity in systems, demand for extreme accuracy of response, and the imposition of extraordinary environmental constraints. Without the freedom to "cut and try" in the design process as in the past, the system designer must be able to examine all of the consequences and interactions of a design decision before he makes the decision.

In this sort of process the design process becomes an abstract decision process. To attempt an abstract decision process such as this demands an extremely logical form of analysis. The analytical method must be capable of examining the system interactions and reiterating the decision before any system component configuration is predicted. Essentially the design process itself is delayed as far down the development stream as possible. Eventually the abstract decisions must be made concrete, but the bases for hardening the concepts are available before the hardening begins.

System Elements

Since there is a point in the decision process where the actual design process begins and system component configuration is established, it is necessary to determine what the system components are. Although there have been attempts to talk about unmanned systems, essentially any total system is a man-machine system, that is, somewhere there must be a man in the system loop even if his only function is to press the button that initiates the system.

Based on this concept, any system is a man-machine system, the system components become men, machines and facilities. There are, however, other system elements which must be considered since these elements link and constrain the components. Shapero and Bates (1960) offer a convenient notation for these elements. They describe men, machines, and facilities as described here, i.e., system components; mission, resource and environmental constraints, etc., as system determinants; communication, organization structure, decision rules, etc., as system integrators.

The integration of man and machine carries the further requirement of the integration of man and man, that is, the crewing process. Two possible approaches to this integration present themselves in this analysis, (1) start from the assumption that there will be a reasonable number of men in the system, the number depending on the system under consideration, or (2) start from a mission and refine the analysis until a determination can be made as to logical system needs. The amount and quality of men that are needed are then a natural fallout.

These system elements are the factors which an analytical method must be able to handle and integrate. The balance of this report is concerned with the development and demonstration of such a method.

Problem Approaches

In order to develop the proposed analytical method the problem was proposed thus:

> Provide a rational method of establishing man-machine relationships and allocation of functions in an earth-to-earth orbit vehicle system.

It was proposed that this rational method of analysis be established and demonstrated by applying the method to a sample system. Accordingly, a system was selected in which one or more men would be interacting with the machine.

Choice of a System

The system selected was based on an analysis of the possible likely missions for earth-to-earth orbit system. Ten possible space missions as shown in Table I were examined. All possible mission segments for each mission were detailed and analyzed to determine which mission segments were necessary to any mission, which segments would not be used in specific missions, and which segments were questionable for specific missions. The basis for the analysis is shown in Table I.

It was decided to base the demonstration of the analysis on the mission which would use the greatest number of mission segments, in order to demonstrate versatility of the method as well as further application of the analysis itself. It was found that the "Intercept" mission yielded the greatest number of mission segments used, actually including fifteen mission segments, four possible mission segments, and one mission segment not included out of a total possible twenty mission segments for all missions. The tabulation for all missions is included in Table I.

The method of analysis is explained and demonstrated in Chapter III, "Development of a Method of Analysis," while the actual analysis of the Intercept mission is developed in Appendix A.

Background for Analysis

To implement an analysis it is necessary that there be a background of information and data on which to base design choices. Since this report is concerned with a method for allocation of man-machine functions with an emphasis placed on human factors considerations, the data concentration is oriented to the human. While it is recognized that the human cannot be considered in this context without considering the machine, it is assumed that machine data are available.

Accordingly, Chapter II of this report provides a general background for the consideration of man's role in the system, Chapter III develops the method of analysis and Chapter IV offers a model as a basis for collecting and organizing data in terms which are useful for consideration in man-machine allocation. As noted before, the actual analysis is provided in Appendix A, while Appendix B contains an annotated bibliography of pertinent documents, a bibliography of peripheral documents and a brief discussion of previous research in work-rest cycle.

MISSION SEGMENTS	SURVEILLANCE	COMMUNICATIONS	MILITARY ANTI-ICBM	RECONNAISSANCE	SCIENTIFIC	DEV. TEST BED	INTERCEPT	MILITARY ANTI-SATELLITE	MILITARY EARTH BOMB	SPACE BASE
PRE-LAUNCH	X	X	X	X	X	X	X	X	X	X
COUNTDOWN	X	X	X	X	X	X	X	X	X	X
BOOST	X	X	X	X	X	X	X	X	X	X
ORBIT	X	X	X	X	X	X	X	X	X	X
ORBIT CHANGE	0	0	0	P	P	P	X	X	P	0
MACRO-RENDEZVOUS	0	0	0	P	0	P	X	X	0	0
MICRO-RENDEZVOUS	0	0	0	P	0	P	X	0	0	0
DOCKING	0	0	0	P	0	P	P	0	0	0
ORBIT LAUNCH	0	0	X	P	P	P	P	X	P	X
SCIENTIFIC/ENG. TEST	0	X	0	0	X	X	0	0	0	X
TARGET SEARCH/IDENT.	X	0	X	X	0	P	X	X	X	X
TARGET INVESTIGATE	P	0	0	X	0	P	X	X	0	X
TARGET DISPOSE	0	0	X	0	0	0	X	X	X	P
EVASIVE MANEUVER	0	0	P	P	0	0	P	P	P	0
RE-SUPPLY	X	X	P	0	P	X	P	P	P	X
DE-ORBIT	X	X	X	X	X	X	X	X	X	X
RE-ENTRY	X	X	X	X	X	X	X	X	X	X
LANDING	X	X	X	X	X	X	X	X	X	X
RECOVERY	X	X	X	X	X	X	X	X	X	X
ABORT	X	X	X	X	X	X	X	X	X	X

TOTALS

USED	11	11	12	11	10	11	15	15	11	14
NOT USED	1	0	2	6	3	7	4	2	4	1
POSSIBLE	8	9	6	3	7	2	1	3	5	5

LEGEND X = USED
0 = NOT USED
P = POSSIBLE

TABLE I - MISSION SELECTION ANALYSIS

III. THE ROLE OF MAN IN THE SYSTEM

Assuming the establishment of a mission requirement, there is the question as to whether to design a man system, a machine system, or a combined man-machine system. In the context of space systems, the notion of a man (no machine) system may be dismissed out of hand. There can be no serious argument for such a concept, but there is considerable argument current about whether space systems, particularly military space systems, should be manned at all.

On one side it can be argued: Why bother with all the costs and problems of putting men in space and supporting them there? Why even jeopardize men by exposing them to such a hostile environment? On the other side, it can be argued that man can provide a large array of capabilities in a single package and, of much more importance, is more flexible than machines. He is easier to reprogram and can design programs to accommodate new or unforeseen requirements.

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

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.

On the other hand, definite positions can be taken in favor of military space systems being completely unmanned. Completely unmanned systems have been built and it has often been proposed that future systems should also be unmanned. It can be argued that the machine can be built that will do the job better than man, given sufficient time, dollars, physical resources and talent.

This latter argument has, indeed, had a very strong influence on system design practice. The trend has been toward making systems more and more automatic, and the trend will, undoubtedly, continue. Certainly, there are other reasons for automation, but the trend has also been influenced by the simple motivation to make systems as automated as possible. The idea is to push man out of the system wherever possible and to leave him in only when machines cannot be available.

How is this controversy to be resolved? Actually, the nature of the resolution is implied in both arguments. Both are really talking about man-machine systems. Both are saying that there are conditions which justify using man and conditions which justify the choice of machines.

One reason for making a vehicle recallable is that it is expensive. That is, the machine cannot be made cheap enough and if the versatility of man is taken advantage of, the recallability feature becomes available. Given sufficient time, resources recallability can be automated. But this is a circular argument and even its most extreme proponents given cognizance to the circularity in practice, if not in discourse. In the meantime man keeps man up his sleeve to take over those functions which cannot, for one reason or another, be automated. In other words, as long as man's versatility is needed to take up the slack, there is implicitly a man-machine system.

Without the requisite further development, the proposition is now introduced that it is best to think of every system as a man-machine system with the man and machine contributions to be determined. Though system manning might go to zero, the determination should be part of the system development process. There is the implied agreement that man will be used for some functions under some conditions and machines for some functions under other conditions.

The obvious conditions would be to use man where man can perform the function better and use machines where machines do better. First, it neglects the possibility that an integration of man and machine may supply some function "better" than either alone. Second, as long as "better" is undefined the answer begs the question.

The questioning of the definition of such a simple and common word as "better" may seem meticulous. The reason is that there is a temptation, and many have been tempted, to define the term as greater or more dependable capacity for the performance of the particular function under consideration. For instance, can men or machines aim some rocket launcher more accurately? This may very well not be an appropriate question at all. Suppose the rocket is given (exists and must be used) and it has very good homing capability and a very large lethal range. It might be that much accuracy in aiming would not be necessary for an acceptable kill probability. Choice between man and machine might, then, be quite irrelevant.

However, suppose any increment in aiming accuracy will increase the kill probability. How far to go would depend on the cost -- the direct cost of implementing this choice and the indirect costs resulting from the implications on the other system functions. That is, the allocation of the aiming function to man or machine is a system cost-effectiveness trade-off decision. Further, this decision function should follow the system evaluation model and include, in addition to capability, considerations such as size, weight, reliability, availability, maintainability, and time and dollar acquisition costs.

Though man has many characteristics which are desirable and useful in space systems, the only analytical justification for man in a particular system is the demonstration of payoff in a more desirable system configuration. A parallel statement applies to justifying hardware in the system. It is now redundant to say that the best system configuration will be that one which has the best man-machine function allocation.

It is to this key problem of function allocation that this study is addressed. The new method which was developed and is described in this report is believed to be a powerful new tool for system development. Of course, the design of a tool, of itself, does not assure good products. Wise and creative exploitation of the state-of-the-art which is controlled by the goal of an integrated man-machine system is required for successful function allocation.

The function allocation results in a set of specifications. These specifications are, in effect, a set of predictions of what the several subsystems and components should be. Presumably, these predictions have been made in accord with the bounds inherent in the state-of-the-art and available resources. However, it is also assumed that the art and the resources will be exploited skillfully by the designers who follow. Moreover, it is hoped that methodology and the general state-of-the-art will be advanced during the time of and in the course of developing the subject system.

On the man side of the design effort which is to result in the integrated man-machine system, the need for improvements in methodology is indeed great. However, this study has not been mainly concerned with further development of human factors analysis and design techniques. Such problems form a reference context for function allocation, but they were not treated exhaustively.

Assuming an ideal allocation of man and machine, there still is a requirement for some adaptation of the human to the machine, environment, and other men with whom he will interact. The actual integration of man and machine and environment is accomplished in reality through training.

Historically, it has been common practice to take up training problems after equipment is developed and available. At that point the training planner can look at the operation and maintenance of real, existing hardware. However, in order to shorten the period between the recognition of a military requirement and the operational qualification of a system, the concept of concurrent availability of man and equipment was introduced. Under this concept training requirements have to be anticipated and training programs developed during the hardware development cycle. With increasing sophistication of system development concepts, consideration of training enters the development cycle earlier and earlier.

It is now becoming recognized that training planning must take place during the earliest function allocation phases. Training considerations are central to the estimation of the human capability parameters needed in making the man-machine allocation decisions. Both the availability and the costs of human capabilities to the system depend heavily upon the training program.

If, in the process of functions allocation, it becomes evident that personnel with the required skills may not be available in the manpower pool of the proposed using agency, the analyst must determine whether the skills can be made available and at what cost. This is usually a training problem. Sometimes, the definite judgment can be made that the required human characteristics are not available in any known manpower supply. Even when this obtains, it is often profitable to consider whether new training procedures might not extend the known human limitations.

This analysis for human performance is directly analogous to the system hardware questions. Are components available off-the-shelf which will perform specified functions in a fashion compatible with the conceived system? If not, can components be developed in a timely and economical manner which will trade-off favorably with other possible system solutions? Similarly, the same questions are asked about the human components. The answer to the development question for human performance is usually in terms of training.

Sometimes there are possible solutions other than training. For instance, fatigue can be expected to degrade the reliability of human performance. The implications of fatigue can be evaluated in terms of alternative system configurations and in terms of alternative development actions. Alternate system solutions (e.g., a different function allocation) might involve lower skill requirements which are less susceptible to degradation with fatigue, or work-rest cycles which will reduce fatigue. Development solutions might involve the use of drugs to overcome fatigue, or overlearning which makes skills less vulnerable to fatigue. Nevertheless, in practically all cases some training solution should be considered.

In the early stages of system development, detailed analysis of training is not always possible because the system is not defined, nor is it always needed because estimates of sufficient accuracy can be derived from relevant experience and good training principles when a sound system training strategy is conceptualized. Detailed analysis is, however, required when highly critical skills are involved or quite unusual skills are called out. These analyses require far more extensive and specific design, task analysis, and definition of training methods and equipment than is the general practice in the function allocation development phase.

None of this is intended to say that the best system will be achieved when integration is maximized. Integration, too, must be subjected to trade-off analysis and it is still true that a system cannot be designed in a piece and that different people and talents are required to work on different parts. Also, more is implied than in the statement of the philosophical position that "system" means "integration". Rather it is proposed that capability and effectiveness should be sought, and can be found, in the integration of man and machine.

It was suggested earlier that function allocation cannot be limited to routing functions to man and machine categories -- that the allocation to a man-machine combination might be best. In general, these involve machine assists for human performance and man-machine reciprocal monitoring. A good example is quickened displays. Here a machine function is introduced to change the normal error signal so that human control may more accurately anticipate and avoid error build-up.

The training analysis also interacts with the crew composition analysis. The performance must not only be developable in the available population but reasonable skill aggregates must be considered for individual crew members. Costs in both dollars and time are affected by the distribution of the training load among proposed crew members. Heavy imposition of training requirements on a single individual may result in training incompatibilities which are difficult to overcome. Further, as the training required for a single individual becomes inordinately heavy, the costs can be very much higher than for the same burden distributed among more people.

Among the system integration tasks, the task of Manning or Crew Composition is in an unusual position. It is related to and enters into all the other processes. The crew composition involves a kind of summary of all other tasks and at the same time controls the other tasks. Changes in crew composition may perturb, possibly quite extensively, all of the other personnel subsystem design tasks. The crew composition task has this central and ubiquitous position because it represents both the resources for function allocation and the final repository of the personnel subsystem. And the characteristics of the available pool define many system constraints.

The manning analysis may, however, perturb the rest of the personnel subsystem design process when better methodology is developed. At present too many cuts and iterations are involved. Independent of how sophisticated a function allocation may be planned, an estimate of crew composition is usually required very early by the customer. He wants immediate estimates on the demands upon his manpower resources, since he has far fewer degrees of freedom in manipulating these resources than any others. Since this estimate has to be based on meager data, it has low reliability. Low reliability, in itself, is not fatal (we wish it were better), but these estimates tend to "get set in concrete." Then there may be real trouble.

As design progresses and new information becomes available, new estimates can be made. If these result in quantitative or qualitative changes in the composition, a new iteration of the function allocation may be justified. If different kinds of people are now called out, there may be other functions which should be allocated or taken away from the man side of the ledger. Also, quantitative changes may force review since men come in increments of one. The last man may have been added for a work load which hardly taxes him. It is now proper to assign some functions to machine to get rid of the last man or is it best to re-assign some functions from machine to make more efficient use of this last man?

The solution to the crew composition analysis difficulties may lie in the development of a procedure which is more closely tied to the function allocation and system effectiveness evaluation models. Then the manning decisions would enter the system decision more directly than with present crude sub-optimization procedures.

Since it seems logical to initially consider any system as a man-machine system, the problem is not one of deciding whether man shall be used in the system, but what is the best allocation of man and machine and what method(s) can be used to make this determination. The next chapter, "Development of a Method of Analysis" describes a method for the logical allocation of men and machines.

III. DEVELOPMENT OF A METHOD OF ANALYSIS

The determination of a method of analysis must consider five basic areas:

1. Problems of previous methods
2. Problems of new method development
3. Criteria for method specifics
4. Problems of method implementation
5. Statement of the method

The problems of new method development are fundamentally derived from the problems of previous methods and in turn determine the criteria for the specifics of the methods. Where the problems of previous methods can be stated separately the problems of new method development are so inter-related with the criteria for the specifics of the method that it is extremely difficult to consider them separately. As a consequence, these two areas will be treated together in this report.

Though the statement of the method is the key concern, it is necessary to consider problems of method implementation if the method is to be usable and used. Academic methodology may be an interesting exercise but if it is not implementable is not useful in the present context.

Problems of Previous Methods

Developing a method of analysis without considering the work, success, and pitfalls of previously proposed methods would be presumptuous. There have been several documents, e.g., (Van Cott & Altman, 1956) (Shapero & Bates, 1959) (Rabideau, Cooper & Bates, 1960) (McGrath & Nordlie, 1959) which have attempted to provide a basis for the analysis of a system and eventual allocation of functions. Yet in 1961(Swain & Wohl,(1961) emphasize that, "there is no adequate methodology in existence for allocating functions between men and machines."

Van Cott & Altman (1956) generally provided a series of procedural steps leading to the allocation of functions. Two problems exist in this method, (1) the analysis prior to the allocation of functions starts from a premise of hardware, and (2) there is no method given for the allocation of functions. Most investigators have dismissed this area by simply saying there are things at which man excels and there are things in which machines excel. From there they have left it to the skill of the analyst to make an intuitive decision on allocation.

Rabideau, Cooper & Bates (1960) attempted to provide a guide to function and task analysis. The process indicates a series of procedural steps to be followed moving from statement of mission requirements to a detailed task analysis. Although the method for allocation, based on a choice between design alternatives, is more explicit and detailed, they still start from a hardware preconcept.

In the main, previous methods have generally suffered from the following shortcomings:

1. They started from a preconceived notion of hardware.
2. They assumed hardware limitations and capabilities thus limiting the possibility of determining the real acute development needs.
3. They used terms interchangeably according to the specific investigator or author.
4. The terms used had different, and sometimes contradictory, meanings for different users.
5. They failed to point to advancement of the state-of-the-art as a result of specification of needs.
6. They did not integrate men and machines thus causing one or the other to adapt, depending on the starting concept or orientation of the author.

In a general sense, it is quite difficult to find where mission requirements end and system requirements begin in these previous methods. For the most part it appears that function allocations for both mission requirements and system requirements occur at the same time. Further, there are few specific definitions of functions, operations, etc., throughout these methods and as a consequence these terms are used interchangeably.

Problems of New Method Development and Criteria for Method-Specifics

To develop a method for such a logical analysis some specific requirements must be met. It is not sufficient that the method be different or new; it must satisfy the needs for which it is designed. Further, though it is certainly necessary that it avoid the traps and pitfalls of previous methods, it must additionally not present inherent traps and pitfalls of its own. It also must avoid the ambiguities caused by using familiar language in different contexts or specific unusual meanings. Additionally, it must present a way of dealing with each item of interest which it enumerates. Also, it must be specific, usable from a statement of the method alone, and understandable by all potential users. Finally it must be sufficiently flexible to be used at any level of specificity or generality. In summary, the criteria for the development of a method are that it:

1. Satisfy the needs for which it is designed,
2. Avoid old and new pitfalls,
3. Avoid language ambiguities,
4. Present a way of handling items of interest,
5. Be specific in its statements,
6. Be usable from a statement of the method,
7. Be understandable by all potential users,
8. Be capable of being used at general or specific levels.

Initially, this study attempted to more closely define terms that were used in previous methods as a basis for new method development. It soon became apparent that the criterion of non-ambiguity would not be met and it was decided to write a set of terms which would be specific definitions of generally used terms, where possible, and a new set of terms with specific definitions where needed.

It is recognized that imposition of the requirement to learn all of the terms and meanings in order to follow the methodology is difficult. To provide a ready reference to these terms and meanings a fold-out sheet has been included on the last page of this report. The page can be exposed without having to refer back and forth.

It is suggested that the reader, at least initially, use the fold-out page while following the methodology section. The terms with their definitions are:

Mission: A definite statement of a desired goal or end condition.

Example 1: Intercept an unidentified earth satellite.

Example 2: Intercept an unidentified earth satellite in the range of 100 to 12,000 miles above the earth, using a manned, winged, space vehicle capable of being returned to earth within the continental United States and capable of being sustained for a four day orbital mission.

Mission Segment: One of a series of temporal, sequential steps having a sub-goal, being internally coherent and having a recognizable and defineable start and end point.

Purposive Operation (PO): One of a series of the things which must be done in order to complete a mission segment or to prepare for a succeeding segment. Note: The statement of a PO should not contain any reference as to how these needs are to be implemented (i.e., man or machine requirements). Example: Provide attitude control; determine re-entry window; determine system status; determine deceleration time and start point.

Purposive Operation Cluster (POC): The result of grouping together PO's from all mission segments on the basis of their commonalities or similarities of action or intent.

Example: To guide; to propel; to navigate; to preserve crew.*

Purposive Operation Sub-Cluster POSC): The result of resolving the POC's into individual sets of elements within each POC. The criterion of a set is that the elements within it affect one common factor across all segments. Example: Attitude (this includes all of the PO's in the "To Guide" POC which are concerned with attitude).

Purposive Sub-Operation (PSO): The smallest unit to which a PO can be resolved before it is necessary to make man-machine allocations in order to continue the analysis further. The PSO is analyzed within the POC orientation. The allocation of man or machine (the next step in the analysis) uses the PSO as a base.

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* This POC is deliberately chosen to illustrate the effect of the mission statement. Here it is assumed that the mission is a manned orbital mission. If the mission had not been specified as manned, this POC would not appear unless the analysis had shown that the mission should be manned.

Problems of Method Implementation

Any method which is developed, implicitly carries with it the requirement that it can be implementable. Additionally, there is an obligation that provisions be made, either in the method or accompanying it, for indicating what must be done to implement the method. Although the investigative work and the development of the method in this report was provided by a specific discipline, the use of the method demands an interdisciplinary team approach to assure successful implementation.

It can be assumed that analysts are more sensitive to problems within their respective discipline than they are to problems within other disciplines. Further, they often have encountered these problems, tackled them and eventually overcome them. It is also true that analysts will feel that a problem exists which is within the domain of another discipline. Quite often they try to circumvent the problem and then attempt results in a tedious, costly and unnecessary exercise in that a ready made solution of which they are unaware already exists. Since, in effect, the value of the method is limited completely by its implementation, it cannot be urged too strongly that an interdisciplinary team be used in applying the method.

There is a requirement that the team used re-orient its thinking from the type of analysis to which they are accustomed. As pointed out earlier, previous methods generally started from a hardware or man concept. It is difficult to avoid the trap of relating PO's to known or familiar components, but the method objective is to arrive at system requirements through the analysis rather than allow assumed requirements to constrain the analysis. Thus it must be stressed continuously that there be no component concept until the system requirements are derived.

Statement of the Method

The method employed for analysis is illustrated in Figure 1. For purposes of explanation, a copy of Figure 1 is included as a fold-out on the last page of this report. Additionally, the fold-out contains a set of definitions of terms as previously indicated. It is suggested that the fold-out be spread as an aid in following the text on the method.

MISSION ANALYSIS METHOD

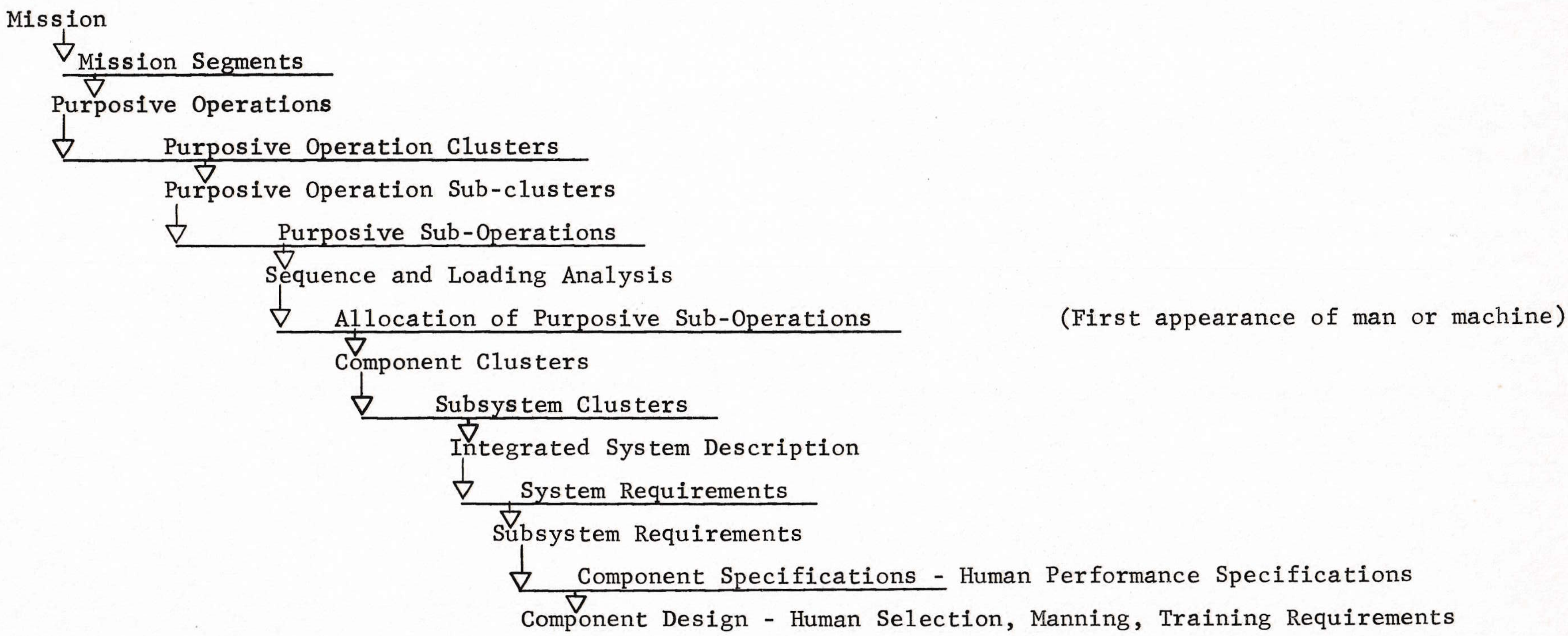

FIGURE I

Step 1 - Obtain mission statement:

To initiate the analysis it is necessary to obtain an explicit statement of the mission as available. Mission statements can run the gamut from a very general broad statement such as "Intercept unidentified satellites" to highly detailed statements that contain range, configuration, velocity, mannning, etc., requirements. The mission statement should contain a complete list of all determinants and constraints that are actually given, but should not contain any assumptions about system parameters which have not been specifically imposed.

Step 2 - Determine mission segments:

Develop a list of the segments which will sequentially accomplish the missions. The choice of what constitutes a segment is somewhat arbitrary. However, the choice should be based on the following criteria:

(1) The segment purpose or goal can be defined.
(2) Convenient and explicit start and end points can be stated.
(3) The happenings within the segment bear a unity.
(4) There is temporal and sequential relationship within the segment and between segments.

For example, one segment of the space mission analyzed in this report is shown thus:

Macro-Rendezvous
Goal: Track & Intercept
Start: Locate Target
End: Proximal Track

Once the mission segments have been determined they should be set down in a flow diagram, indicating the segment title, goal, start, and end point as illustrated above. (For a complete breakdown of the segmenting of the selected space mission see Appendix A.)

Step 3 - Analyze segments to determine purposive operations (PO's): Prepare for each segment a list of those PO's which are contained in the segment. Though it may be convenient to extract the events sequentially, at this point the exhaustiveness of the listing is paramount, not the time phasing.

The PO's are shown in terms of what must be done in order to complete one segment and to prepare for any other. It is important that no equipment or man concepts be included other than those which may have been specifically given in the mission statement. For example, a PO could be:

Determine vehicle attitude, direction, and velocity
to effect micro-rendezvous

NOT

Pilot determines etc., etc.

The PO's should be written in action statements, e.g., determine....., monitor....., provide....., sense....., maneuver...... Each PO should then be examined to determine whether it contributes to the goal of the particular mission segment in which it is listed. A PO should not be listed in one segment if it does not contribute to the purpose of that segment.

Step 4 - Group PO's into clusters (POC's): The PO's which have been listed across all mission segments should now be gathered and grouped on the basis of commonality of purpose and similarity of action or intent. For example, one grouping might be "To Guide", which would include all of the PO's which are concerned with the guiding of the vehicle. This grouping process should be carried on until all PO's have been classified. The number of groups that will arise will vary, with the kind of mission more so than with the number of segments.

A complete clustering for the intercept mission is shown in Appendix A. This should provide an insight into the way clustering is carried out.

Step 5 - Extract a set of PO sub-clusters (POSC's): Each POC should now be analyzed to determine which PO's within the cluster can be grouped in the sense of having common elements. The elements for grouping in sub-clusters are much narrower and more cohesive than the elements in clustering. For example, in the cluster "To Guide", a sub-cluster would be "Attitude" or "Propulsion" both being elements of "To Guide" but encompassing a different set of cohesive elements.

Having identified the sub-clusters, they are then gathered into groups and labeled with the title by which they have been grouped. This provides a set of PO's which have been categorized by some set of common attributes.

It will be found that in many cases the same PO will appear in different mission segments or sometimes in the same segment. These should be shown as one PO and noted as to the segments in which they appear.

Step 6 - Determine purposive sub-operations (PSO's): Each PO is now subdivided into elements as far as possible without the requirement for allocating to man or machine. The purpose of this step is to reduce the PO's to a point where the analyst is ready to assign man-machine allocations. Once the PSO's have been extracted they should be arranged in each mission segment in terms of the time sequence of their occurrence. This provides a basis for loading examination.

Step 7 - Allocate man or machine to PSO's:

At this point the analyst is ready to allocate man or machine to PSO's. For this process the analyst needs:

1 - A mission statement including specifications as far as they have been detailed.

2 - A complete set of the constraints that are applicable to the mission. These include the constraints imposed on man and machine by hostile environments, unusual conditions, etc.

3 - An organized data set on the capabilities of man and machine. (A method for collecting such data is considered later under the "Data Accumulation Matrix.")

The man or machine allocation to PSO's is an iterative process in which tentative allocations are made, examined, modified, and re-allocated. The process, as outlined here, consists of six sub-steps.

1 - Inspect mission statement for specifications which could affect allocations. Set these down noting what kinds of PO's these specifications are likely to affect. Indicate and refer these to mission segments, POC's and PO's.

2 - Make preliminary allocations in accordance with specifications. List each PSO in a column. Form a matrix by listing "Man", "Machine", and "Man and Machine" as headings in three more columns. (See Figure 2.) Make a tentative allocation by filling the interspaces in with the following terms:

Only
Best Choice
Possible
Not Possible

It is very important that this step be handled by an interdisciplinary group as previously suggested.

3 - Apply all constraints specified to each PSO.- Re-examine the decisions made in the preliminary allocation in light of the constraints that have been applied in sub-step 1. Examine each PSO and make necessary changes.

4 - Compare redefined PSO's with capabilities of man or machine within the context of extra-mission constraints. Evaluate each PSO against data available in the Data Accumulation Matrix (if available), or human engineering source books, engineering source books, etc., to determine those constraints imposed by natural limitations, resource limitations or state-of-the-art limitations.

5 - Assign tasks or equipment to each PSO. As far as possibly can be determined assign a specific man task or specific equipment type to each PSO.

6 - Compare and modify. Compare allocations to mission segment and POC requirements and modify allocations as necessary.

Step 8 - Cluster components for subsystems:

The purpose of this step is to provide a statement of subsystems which will essentially be used as a basis for the system description. The step consists of three substeps as follows:

1 - Combine man and machine allocations - Each PSO has now been allocated to man or machine. These PSO's should now be gathered under the POC's from which they were originally derived. The POC's are now displayed in terms of the man-machine allocations.

2.- Determine the effectiveness of the allocations - Select out those combinations of allocations that form natural relationships to the state-of-the-art information on subsystem design. Determine the effectiveness of the allocations in terms of their inter-relationships within the POC's. Organize the allocations in terms of their operating sequence within the segments. There are two factors of consideration involved here. One is the related PO's within mission segments, and the other is the

PRELIMINARY ANALYSIS MATRIX

	Purposive Sub-Operations	Man	Machine	Man-Machine
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				

Figure 2

Code

O - Only
BP - Best Possible
P - Possible
NP - Not Possible

related PO's across all segments. It is important that POC's not be construed as systems when clustering components. Segment requirements override POC considerations. The PO may be basically the same in two segments, but the required method of accomplishing may be different from one segment to the other. For example, during the boost phase, attitude control may have to be automatic. However, during the landing phase attitude control is likely to be manual. The PO during these two segments is the same but the method of handling it is different. Therefore, different combinations of components are required, which may possibly result in a need for different subsystems.

3 - Describe final selected combinations (subsystems) - The clustered components should be analyzed in relation to the segment sequence and loading requirements. This permits a finer description of clustering requirements in terms of component - component working relationships with respect to inputs-outputs, time phasing and mechanical layout requirements.

Once the sequence analysis is accomplished, subsystems should be described and inter-relationship requirements between components within a subsystem should be listed. Completion of this step should result in a set of subsystems that are integrated within themselves but not between. For example, a need may be established for a navigation subsystem which would require a computer. It may be also necessary to provide an onboard computer for a guidance system. At this point, it is not established whether one computer would suffice for both.

Step 9 - Provide system description:

The purpose of this step is to integrate the various subsystems that have been described into a total system. The end product should be a complete and fairly detailed description of the system. The step is composed of two as follows:

1 - Determine inter-relationships between subsystems - Compare subsystems (selected combinations) inputs and outputs to determine inter-relationships within the orientation of the POC's. This should be done by a point-by-point comparison of subsystem outputs for each segment. Subsystems can now be arranged in accordance with the requirements that can be established from the inter-relationships. These subsystems and requirements should be described in terms of a time base and all necessary links.

2 - Prepare flow diagram - Gather the subsystem descriptions that have been determined in (1) above into a flow diagram on a time base indicating all necessary links. This provides a basis for a detailed, integrated system description which should now be explicitly stated.

Step 10 - Develop system specifications:

To develop system specifications it is necessary to determine the criteria for performance, space, weight, etc. The system description should be analyzed by subsystem to provide general information on the subsystem to responsible design groups. The various design specialists must now specify the exact components required per demonstrated mission and system operational requirements. This all should be accomplished using existing systems analysis techniques.

Step 11 - Provide subsystem specifications:

This step divides into lines of analysis. One line considers equipment and the other human factors elements. Initially the subsystem descriptions are analyzed and equipment component specifications are described as required for specific information to design groups. For purposes of this report the two substeps detailed below are considered only in human factors requirements.

1 - Analyze man tasks - Select out all man tasks. Using the system specifications that have been established as a base, derive the task requirements by standard task analysis techniques. Analyze all man tasks individually and collectively in relation to the system and equipment requirements. This will provide the performance criteria for the human factors.

2 - Determine other human factors areas - Standard techniques exist for determining manning, skill, and training requirements from developed task analyses. Human factors engineers are well acquainted with the techniques and literature available on the subject.

These eleven steps, then, provide a sound, implementable method for a logical analysis. Further, they contain sufficient inherent flexibility to works at any level of specificity, a minimum of language ambiguities, and are easily understood by their users.

IV. DATA ACCUMULATION MATRIX

The potential of any analysis method cannot be realized unless the data needed to support the method are immediately available to the analyst. The analytic method developed in this study is a good case in point. Data pertaining to man-machine capabilities, and to other parameters involved in the allocation of functions to man and/or machine, have limited availability. They are either not available at all or are so widely dispersed throughout the literature that they cannot be made available in a timely manner.

Two things are needed to solve this problem. First, a method must be developed for organizing and storing data which are available to expedite application of the analytic method. Second, research must be performed to develop information in the areas where data are not presently available. This section describes the former, herein called the Data Accumulation Matrix (DAM), and recommends research which should be performed to satisfy the latter.

The fundamental problem in the organization of data is the choice of factors on which to organize. The Data Accumulation Matrix (DAM) has been developed to handle data relative to the constraints placed on man-machine systems in terms of man or machine factors, with equal facility.

A basic function capable of being accomplished by man or machine, in terms carrying implications for neither, is the primary categorical breakdown used in DAM. Examples of these functions are:

Sensing
Comparing
Deciding
Transmitting

The secondary categorical breakdown is the system consideration. Examples of system constraints are:

Time
Cost
Availability
Accuracy
Reliability

Figure 3 describes how these categories and their inter-relation result in the Data Accumulation Matrix. It is now possible to compare the effects of Time and Cost factors on the function of sensing by selecting the proper cell from the DAM. Selection of any unit should provide sufficient information on the related man or machine factors available to accomplish logical trade-offs. If this particular selection has insufficient information, an additional research program is indicated.

The matrix has been constructed so that it is easily expandable in all three directions. The categorical examples given are by no means exhaustive. Furthermore, DAM is flexible. The units of both the primary and the secondary categories can be interchanged within the category to provide the inter-relationships of most importance to the user.

The terms used for categorical breakdown are fairly general and were intended to be so. Within each of the sections, such as sensing, a further breakdown is required (not shown in Figure 3). This breakdown is related to the type of operation with which the categorical section could be connected. An example of this is:

- Sensing (Function)
  - Velocity
  - Acceleration
  - Temperature
  - Pressure
- Time (Consideration)
  - Operational reaction
  - Development
  - Operating
  - Production

The various units of the Data Accumulation Matrix may be considered as file boxes. The information in each file box is concerned with data on man or machine capabilities and limitations related to the constraints bordering that particular unit.

While there will be no attempt to fill the matrix in this report, general consideration can be given to what is needed to fill the "boxes." The actual acquisition and sorting is a fairly large undertaking and can only be accomplished through a directed research program. Further, the program must be continuously updated as changes, innovations and breakthroughs occur. Using the "file box" of "pattern recognition" previously extracted, data might be collected and/or sorted in these categories.

DATA ACCUMULATION MATRIX

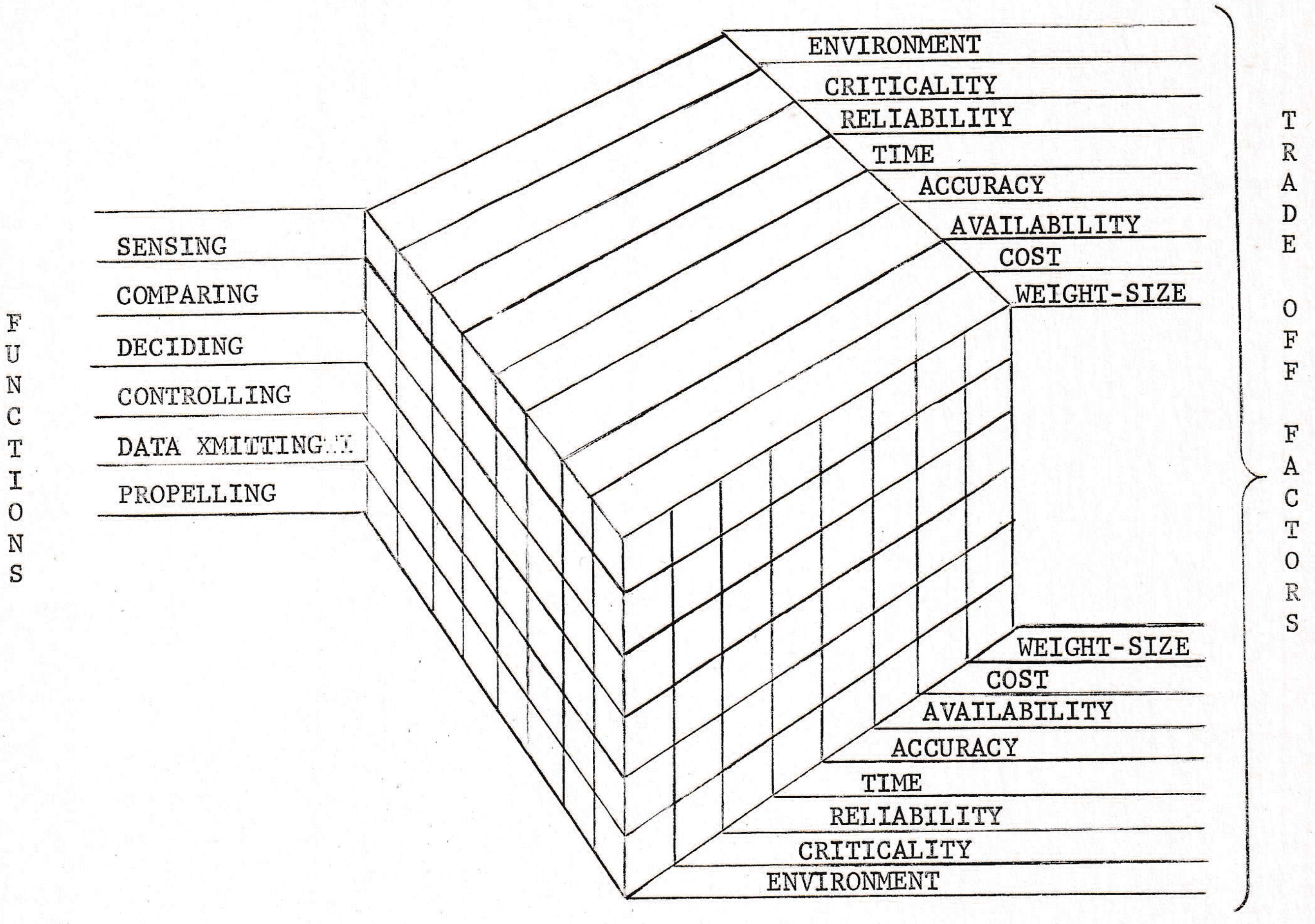

FIGURE 3

Lists of devices that can be used to recognize patterns
Time considerations in their ability to recognize patterns
Attributes of patterns on which the human organizes
Reaction time to various display media for pattern types
Methods for changing patterns to quicken man or machine response
Any relations that can be stated as to the relationships between criticality, time, and type of pattern.

As information begins to be classified, other areas of data for classification will become evident. As the state-of-the-art advances, basic research in the human factors field will be able to supply data on the human ability to recognize patterns, for instance, and further state this in terms of reliability or probability of success. The same information in terms of machines would also be required.

The Data Accumulation Matrix is a tool and if properly completed with timely data, will provide a logical method to easily accomplish man-machine trade-offs prior to system design.

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APPENDIX A

Mission Analysis

The material included in this appendix represents a rough cut analysis of a proposed manned space mission using the analytic method presented in the main body of this report.

The analysis is not complete since it does not include all phases described in the proposed method nor is any particular phase analyzed in depth. The proposed analytic method requires a team of analysts, to work efficiently. It also requires a considerable amount of time. Neither of these were available to the authors. However, there is sufficient detail, through the phases prior to the assignment of man or machine, to permit an understanding of how the proposed method is implemented. Analysis of the PSO Allocation Phase and subsequent phases requires information not possessed by the originators of the analytic method.

Mission:

Intercept unidentified satellite.

Determinants:

Crew:	One to four men
Landing:	Manual control Specified sites
Comm:	Air/Grd Radio Silence
Orbit:	Hohmann Transfer from park
Vehicle:	Winged, space
Duration:	Four days maximum
Altitude:	200 to 20,000 miles
Primary Mission:	Classified

MISSION SEGMENT

To render the mission into more easily analyzed positions, the mission was analyzed and 12 segments defined. By applying the mission determinants as parameters for the analysis, the delineation of the mission segments was almost automatic.

The mission is to get a crew into space using Hohmann transfer methods, intercept a target, and return the crew safely to a specified landing site in a winged vehicle. The vehicle must be propelled; must attain an approximately co-planar waiting orbit below the target's orbit; must again be propelled in a Hohmann transfer to the target's orbit; must find the target; attain proximity to the target (dependent on primary mission); return to a waiting orbit; re-enter the atmosphere; fly aerodynamically and locate a specific landing site, and land safely with the crew intact.

An inspection of the mission segments on the opposite page will demonstrate the relationship between it and the description above. It should be noted that each segment is an entity unto itself and has its own goal. Therefore it may be analyzed separately. However, if the segment is not placed in its proper sequence it has no value to the mission.

I

Boost 2
Goal:
Orbital injection
Start: T=0
End: Enter orbit

II

Parking Orbit "A"
Goal:
Prepare for booster
Start: Enter orbit
End: Begin booster 2

III

Boost 2
Goal:
Hohmann transfer
Start: Begin propulsion
End: Enter circuit

IV

Rendezvous Orbit
Goal:
Search for target
Start: Enter orbit
End: Acq. target

V

Macro-Rendezvous
Goal:
Track & Intercept
Start: Locate target
End: Proximal track

VI

Micro-Rendezvous
Goal:
Attain close proximity
Start: Proximal track
End: Begin primary mission

VII

Primary
Mission
(classified)

VIII

De-Orbit
Goal:
Orbital injection
Start: Retro-thrust
End: Enter orbit

IX

Parking Orbit
Goal:
Prepare for entry
Start: Enter orbit
End: Retro-thrust

X

Re-entry
Goal: Return to earth atmosphere
Start: Retro-thrust
End: Airfoil control

XI

Recovery
Goal: Controlled atmospheric flight
Start: Transfer to airfoil control
End: Acq. Land. Strip

XII

Landing
Goal:
Safe vehicle return
Start: Land. strip acq.
End: Touchdown

Purposive Operation

The next step in the Mission analysis was to determine what was required to achieve the goals of each mission segment. Examples of purposive operations for each segment are described on the succeeding pages. The purposive operations are determined by going through the segments analytically beginning with the start point and reasoning out the steps required to attain the finish or end point. The original mission determinants were used as constraints in developing the purposive operations.

Purposive Operations

Mission Segment: I - Boost No. 1

(1) Provide required thrust
(2) Determine required terminal velocity
(3) Determine length of acceleration time
(4) Determine proper attitude
(5) Provide attitude control
(6) Determine vehicle acceleration
(7) Provide for abort
(8) Keep air crew alive
(9) Determine all systems in tolerance
(10) Provide safe escape method
(11) Determine hazardous conditions approach

Mission Segment: II - Parking Orbit "A"

(1) Keep man alive
(2) Acquire reference point
(3) Determine location, direction, and velocity of vehicle relative to reference point
(4) Determine estimated location, direction, and velocity of target relative to reference point
(5) Determine attitude
(6) Provide attitude control
(7) Determine vehicle attitude, direction, and terminal velocity required for intercept
(8) Determine point at which to apply thrust
(9) Determine acceleration length
(10) Maintain orbital attitude
(11) Provide for abort
(12) Provide intravehicular communication
(13) Determine required attitude
(14) Determine systems status
(15) Determine onset of hazardous conditions

Mission Segment: III - Boost No. 2

(1) Provide required thrust
(2) Determine required terminal velocity
(3) Determine length of acceleration time
(4) Determine proper attitude
(5) Provide attitude control
(6) Determine vehicle acceleration
(7) Provide for abort
(8) Keep air crew alive
(9) Determine all systems in tolerance
(10) Provide safe escape method
(11) Determine hazardous conditions approach

Mission Segment: IV - Rendezvous Orbit

(1) Determine required attitude
(2) Provide attitude control
(3) Determine search area, pattern & mode
(4) Determine systems' status
(5) Determine estimated target direction, velocity, attitude
(6) Keep air crew alive
(7) Provide intravehicular communication
(8) Provide for search
(9) Acquire reference point
(10) Determine attitude, direction and velocity required to effect Macro-Rendezvous
(11) Determine required acceleration/deceleration
(12) Provide required thrust
(13) Determine vehicle-target relation to reference point
(14) Maintain orbital attitude
(15) Provide for abort
(16) Provide for continuous search and tracking

Mission Segment: V - Macro-Rendezvous

(1) Keep air crew alive
(2) Determine relative target-vehicle range, direction and velocity
(3) Determine attitude, direction and velocity required to effect Micro-Rendezvous
(4) Determine system status
(5) Determine acceleration/deceleration required
(6) Provide intravehicular communication
(7) Provide for continuous tracking

Mission Segment: VI - Micro-Rendezvous

(1) Maintain orbital attitude
(2) Provide for Micro-thrust
(3) Provide vernier control of thrust
(4) Provide for proximal tracking
(5) Provide for abort
(6) Keep air crew alive
(7) Provide for escape
(8) Determine required relative velocity
(9) Provide attitude control
(10) Determine required attitude
(11) Provide intravehicular communication
(12) Determine required acceleration/deceleration

Mission Segment: VII - Mission Objective

(Classified)

Mission Segment: VIII - De-Orbit

(1) Acquire reference point
(2) Determine vehicle attitude
(3) Keep air crew alive
(4) Provide for escape
(5) Provide thrust
(6) Provide attitude control
(7) Determine acceleration/deceleration points
(8) Determine correct orbit relative to landing site
(9) Determine the approach of hazardous conditions
(10) Provide intravehicle communication

Mission Segment: IX - Parking Orbit "B"

(1) Determine estimated range and direction of specified landing site
(2) Determine vehicle attitude
(3) Determine re-entry window
(4) Determine re-entry attitude
(5) Determine required deceleration
(6) Provide thrust
(7) Provide attitude control
(8) Acquire reference point
(9) Maintain orbital attitude
(10) Determine status of all systems
(11) Provide for escape

Mission Segment: X - Re-Entry

(1) Determine vehicle attitude
(2) Determine required attitude
(3) Provide attitude control
(4) Maintain re-entry attitude
(5) Determine required deceleration
(6) Maintain deceleration
(7) Determine approach of hazardous conditions
(8) Provide for escape
(9) Provide for re-entry heat dissipation
(10) Keep air crew alive

Mission Segment: XI - Recovery

(1) Keep air crew alive
(2) Provide for aerodynamic flight
(3) Provide for aerodynamic control
(4) Determine required attitude
(5) Maintain required attitude
(6) Determine range and direction of specified landing site
(7) Provide for search
(8) Provide for continuous tracking to landing site
(9) Determine rate of descent
(10) Provide for safe escape
(11) Determine system status

Mission Segment: XII - Landing

(1) Provide for safe landing

(2) Keep crew alive

(3) Provide attitude control

(4) Determine required attitude, velocity, rate of descent direction and altitude

(5) Provide directional and rate of descent control

(6) Provide for safe escape

(7) Determine required landing approach

(8) Determine system status

Purposive Operation Clusters

An inspection of the purposive operations across all segments brings out clusters of P.O.'s that fulfill certain gross requirements of the mission. For example, in order to achieve desired orbits and trajectories, there is a requirement to guide the vehicle. To determine what the desired orbits, trajectories, etc., should be, requires an ability to navigate. To get the vehicle out of the atmosphere and return it requires propulsion of some sort. The purposive operations that fulfilled these gross requirements are brought together into clusters to more efficiently accomplish a complete analysis. An example of these clusters is on the succeeding pages.

Clustering of Purposive Operations

Attitude Control:

(1) Determine required attitude
(2) Determine attitude
(3) Provide attitude control
(4) Maintain orbital attitude
(5) Maintain re-entry attitude

Clustering of Purposive Operation

To Guide:

(1) Length of acceleration-deceleration time
(2) Vehicle acceleration-deceleration
(3) Required acceleration-deceleration
(4) Maintain deceleration
(5) Provide for aerodynamic control
(6) Provide directional and rate of descent control
(7) Determine rate of descent
(8) Determine required attitude
(9) Provide for attitude - direction control
(10) Provide accurate time reference

Clustering Purposive Operations

To Propel:

(1) Provide for Macro-thrust
(2) Provide for Micro-thrust
(3) Provide for vernier control of thrust
(4) Provide for direction of thrust
(5) Provide for thrust duration control

Clustering Purposive Operations

Miscellaneous:

(1) Provide for abort
(2) Provide intravehicular communication
(3) Provide for re-entry heat dissipation
(4) Provide for aerodynamic flight
(5) Provide for safe landing

Clustering of Purposive Operations

System Status:

(1) Determine all systems operating in tolerance
(2) Determine approach of system failure

Clustering of Purposive Operation

Crew Preservation:

(1) Keep air crew alive
(2) Provide safe escape
(3) Determine approach of hazardous conditions

Clustering of Purposive Operations

To Navigate:

(1) Determine terminal velocity
(2) Determine estimated velocity of target
(3) Determine velocity required for intercept
(4) Acquire reference point
(5) Determine target-vehicle relative velocity
(6) Determine correct orbit relative to landing site
(7) Determine direction of target
(8) Determine location and direction relative to reference point
(9) Determine direction of landing site
(10) Determine vehicle direction
(11) Determine required landing approach

Clustering of Purposive Operations

To Search:

(1) Determine search area, pattern, mode
(2) Provide for continuous search
(3) Provide for continuous tracking
(4) Provide for proximal tracking

Purposive Operation Sub Clusters

Purposive operation sub clusters have been derived by pulling together those purposive operations that contain a common major factor. An example of this appears on the following pages. Combining these sub clusters provides for the efficient breakdown of purposive operations to their elements within the orientation of the purposive operation cluster.

Clustering of Purposive Sub-Operation

Attitude Control:

(1) Determine required attitude	Attitude Derivation
(2) Determine attitude	
(3) Provide attitude control	Control of Attitude
(4) Maintain orbital attitude	
(5) Maintain re-entry attitude	

Clustering of Purposive Sub-Operation

Miscellaneous:

(1) Provide for abort -- Abort
(2) Provide intravehicular communications -- Communications
(3) Provide for re-entry heat dissipation -- Re-entry Heat
(4) Provide for aerodynamic flight -- Aerodynamics
(5) Provide for safe landing -- Landing

Clustering Purposive Sub-Operations

Systems Status:

(1) Determine all systems operating in tolerance
(2) Determine approach of system failure

Status

Clustering Purposive Sub-Operations

Crew Preservation:

(1)	Keep air crew alive	Life Support
(2)	Provide safe escape	Escape
(3)	Determine approach of hazardous conditions	Hazard Warning

Clustering of Purposive Sub-Operations

To Propel:

(1) Provide for Macro-thrust	Thrust Magnitude
(2) Provide for Micro-thrust	
(3) Provide for vernier control of thrust	
(4) Provide for direction of thrust	Thrust Direction
(5) Provide control of thrust duration	Thrust Duration

Clustering of Purposive Sub-Operations

To Guide:

(1) Length of acceleration time	Acceleration Deceleration
(2) Vehicle acceleration	
(3) Required acceleration/deceleration	
(4) Maintain deceleration	
(5) Provide for aerodynamic control	Altitude
(6) Provide directional and rate of descent control	
(7) Determine rate of descent	
(8) Determine required attitude	Attitude
(9) Provide for attitude-direction control	
(10) Provide accurate time reference	Time

Clustering of Purposive Sub-Operation

To Search:

(1) Determine search area, pattern, mode	Search
(2) Provide for continuous search	
(3) Provide for continuous tracking	Tracking
(4) Provide for proximal tracking	

Clustering of Purposive Sub-Operations

To Navigate:

(1)	Determine required terminal velocity	Velocity
(2)	Determine estimated velocity of target	
(3)	Determine velocity required for intercept	
(4)	Determine target-vehicle relative velocity	
(5)	Acquire reference point	Standard Spatial Reference
(6)	Determine location and direction relative to reference point	
(7)	Determine correct orbit relative to landing site	
(8)	Determine direction of target	Direction
(9)	Determine direction of landing site	
(10)	Determine vehicle direction	
(11)	Determine required landing approach	
(12)	Determine range of target	Range
(13)	Determine range of landing site	
(14)	Determine vehicle location relative to reference point	Spatial Position
(15)	Determine re-entry window	
(16)	Determine target location	
(17)	Determine correct orbit	
(18)	Accurate time reference	Time

Purposive Sub-Operations

Analysis of the requirements to accomplish the purposive sub-operation clusters results in basic operations that cannot be analyzed further without the assignment of man or machine. The succeeding pages demonstrate the origination of purposive sub-operations for this mission.

Sequence and Loading Analysis

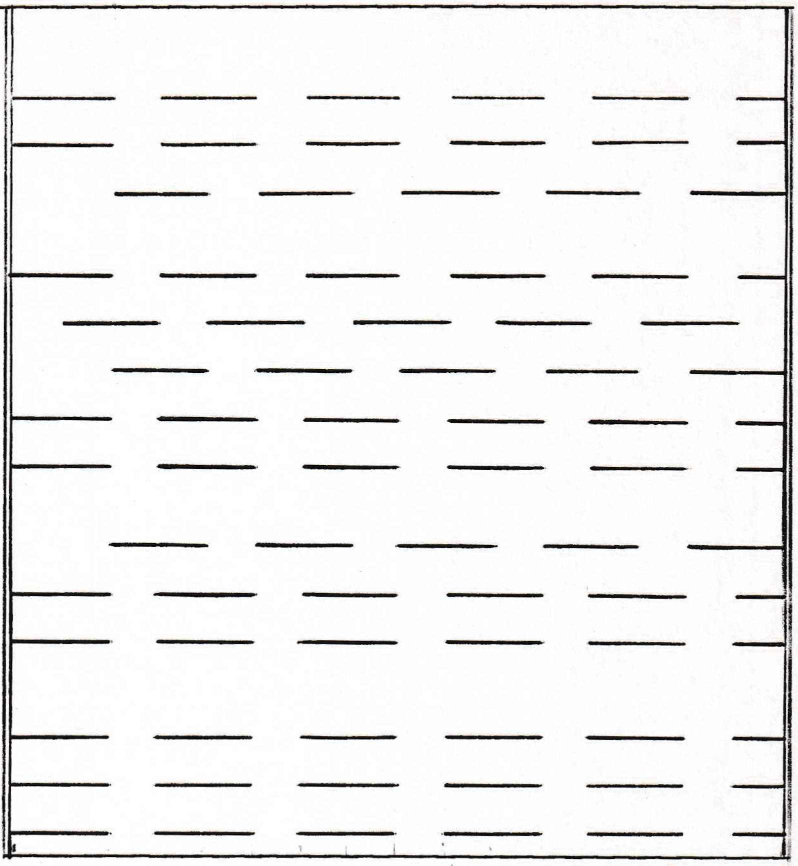
The Purposive Sub-Operation were then oriented to each mission segment. A graph, including a list of all PSO's within a segment and an indication of the relationship of the PSO's to each other in terms of sequence, was constructed. An example of such a graph is shown on the opposite page. The example does not describe all PSO's in the segment presented because of space limitations.

SEQUENCE AND LOADING ANALYSIS

(MACRO RENDEZVOUS)

Purposive Sub-Operations

1) Actual vehicle velocity
2) Required vehicle velocity
3) Compare actual & req. velocity
4) Determine quantity of accel/decel. req.
5) Determine quantity of thrust
6) Instruction to thrust control
7) Actual vehicle direction
8) Required vehicle direction
9) Compare actual & required direction
10) Present thrust magnitude
11) Required thrust magnitude
12) Obtain environmental conditions
13) Obtain 0_2 partial pressure
14) Obtain atmospheric temperature
15) Determine if escape required



Succeeding Analytic Phases

After the sequencing and loading analysis is completed, the next step is allocation to man or machine. This analysis has not proceeded beyond this point due to the constraints of time and knowledge limitations relative to equipment.

APPENDIX B

The material presented in this appendix is a portion of the material covered by the authors to provide them with a broad background for the analysis presented in Appendix A.

WORK - REST BIBLIOGRAPHICAL SUMMARY

Summary and Conclusions

Findings reported in studies spanning the years from 1894 to 1960 are in general agreement that both man's performance and his physiological processes exhibit variations that are a function of his being adapted to a 24 hour day. Within broad limits, conclusions do not show that performance varies significantly as a function of the work-rest cycle, provided the work-rest and sleep-wakefulness ratios are held constant and the period of performance observation does not exceed one week.

Consideration has been given to the work-tasks and the measurements in change of personnel performance resulting in varying the work-rest schedule. For example, passive tasks such as monitoring and vigilance have been found to be more sensitive to decrement than tasks which engage the worker more actively. If performance is to be measured most effectively, appropriate tests should be administered under conditions as comparable as possible to the operational situation. The tests should measure not only performance but also contributing factors such as motivation, learning and skills under realistic work conditions.

Until investigations of personal individual processes of adjustments to change in work-rest cycles, accurate descriptions of the apparently complex relations between these processes and the durations and activities of the work, rest and sleep periods will not be possible.

It may be hypothesized, however, that in many experiments various adaptive and motivational factors might be preventing the occurrence of differences in performance, especially under the conditions of short-term study. These factors are of decided importance and may account for some of the conflicting results obtained in the laboratory, field and industrial studies reviewed. When attempting to realistically simulate space flight conditions for research and training purposes, acute or chronic psychological impairment of the test subjects have distracted from a realistic, operational situation. Studies thus far have dealt with space flights of extended duration, but with a minimum crew. Larger vehicles, with more diverse crew performance in various specialized roles, present a greater field of research. Conversly, small crews of two or three men performing redundant operations of monitoring and problem solving - where systems and human performance redundancy has been imposed as a defense security measure - present a monotonous situation. During these long duty hours boredom is magnified, thus intensifying psychological stress and ultimately contributing to performance degradation. For example, some of the following are questions which would stimulate further research.

- Should there be a "rigid" assignment of tasks and responsibilities among the crew members, or would some rotational plan afford a measure of needed physical and mental variety and flexibility?
- Should all crew members be kept equally active during all phases of the flight even if it requires some "busy work" which, if recognized as such by the crew, might adversely influence their attitudes?

There are many research questions which should be asked - and answered - in relation to manning and scheduling for advanced spacecrafts. These deal with the cumulative effects of stress, very intense motivation, and the extent of over-and cross-training of crew members to meet unknown situations. Intensive research, simulation, and progressive operational experience must give us answers to these problems before flights of longer duration than we now know can be undertaken.

Peters, George A. and Dendl, Hans J., "Personnel Requirements in Manned Space Vehicles." Astro. Sciences Review, 1960, 9-12.

This paper illustrates our preliminary approach to determining an optimum scheduling of space crews and the basic considerations such as work periods, rest, feeding, dressing, relaxation, exercise, and the eliminative functions of man in extended space travel. One of the major assumptions is the necessity of closely following the time pattern already used by man on earth. According to Thompson, it is possible for man to make adjustments to diurnal cycles within the range of 18 to 28 hours. Accordingly, the minimum day-night cycle would provide 8 hours sleep, 8 hours work, and 2 hours for other activities.

Recent research on work periods may be summarized as follows:

1. There is a characteristic decline and increased variability in the performance of human operators under most vigilance conditions as the elapsed time increases - manifest in more frequent errors, longer reaction time, and complete failure to respond to certain signals.
2. During the most crucial phases of equipment operation, the operators may be in a state of bored inattention or under great stress.
3. In the interpretation of complex displays, the human operator is an imperfect receiver and subject to certain biases which distort his perception - attitudes, expectancies, prior output, pseudo-confirmation, etc.
4. The more complex the displays and the less action-oriented the indicators, the more prone the system is to delay and error from its human system.
5. The "perfect" equipment is rarely realized in operational equipment. It is too often "cluttered up" by additional superimposed requirements, limitations in engineering state-of-the-art, developmental modifications, artifacts, and supplemental equipment. At what point can it be known that crew members may be given more and more tasks to perform until they are overburdened?
6. In order for sustained efficiency in the performance of monotonous perceptual tasks, provisions should be made to counteract performance deterioration. The provisions can be noted as; (1) providing rest periods, job rotation, (2) unburdening of the operator during critical mission phases, (3) adequate QC of flight personnel, (4) special proficiency training, proper human engineering of displays, and (5)

adequate reliability and redundancy within the system.

7. The influence of minimal stress (externally created - e.g., noise; or internally created - e.g., fear), during critical phases of the flight should be minimized by proper design of the system. Some allowances should be made for possible loss of efficiency and fatigue when these are further compounded by other adverse factors.

Personnel assignments of primary work stations is illustrated by a chart showing the work schedules for an "8-8-8" stagger system (3-man crew), and "8-8-8" stagger system (6-man crew) and a "4-2-4" stagger system (6-man crew). For the "8-8-8" 3-man crew work-rest cycle is required by 8-on/16-off with command responsibility for the full 8-hour duty period. The "8-8-8" 6-man crew work-rest cycle is also required by 8-on/16-off with a staggered command responsibility only four hours out of the eight.

The "4-2-4" stagger system for a 6-man crew shows a work-rest cycle of 10-on/14-off; however, during the 10-hours of duty, two 4-hour work periods are separated by a 2-hour rest period and the command responsibility is for two hours of each 4-hour work period. This "4-2-4" stagger system should prove to be the most effective when compared to a single 8-hour period, although further research evidence is needed in this general area.

Ray, J. T., Martin, O. E., Jr., Alluisi, E. A. Human Performance as a Function of the Work-Rest Cycle (a review of selected studies). National Academy of Sciences - National Research Council Publication 882.

Studies relating to the effects of different work-rest cycles and man's performance are reviewed in this report. Included are only those studies in which; (a) observations on performance extended for 24-hours or longer, and (b) results pertaining to the general problem of optimizing performance through the scheduling of work and rest periods were given.

While several specific conclusions are supported by the studies reviewed, the number of generalizations are limited. It is not yet possible to describe accurately the complex relations among performance variables, work-rest cycles, sleep-wakefulness cycles and the durations of the work, rest and sleep periods. The need for additional long-term experimentation is evident.

This review cites two studies by Adams and Chiles in addition to WADD TR 60-248. In one of these college students were also tested over a 96-hour period. In one experiment, 12 subjects worked a 4-on/2-off schedule; and in the other, 10 subjects worked a 6-on/2-off schedule. The performance data indicated no superiority of the 4:2 schedule over the 6:2 schedule. However, the questionnaire data suggested that severe decrements would probably result from prolongation of the experimental period in the case of the 6:2 schedule, but probably not in the 4:2 schedule.

In the other study, members of two Air Force B-52 bomber crews were tested on a 4:2 schedule over a 360-hour (15 day) period. The general conclusion drawn by Adams and Chiles from this series of studies was that it is feasible to expect a highly motivated man to maintain acceptable performance levels on a 4:2 schedule for (isolation periods) as long as 15 days and probably 30 days.

In contrast to some agreement evident among investigators of mental efficiency during work-rest cycle studies, other investigators of watch-keeping performance or vigilance have arrived at conflicting results. Some have indicated that man is capable of sustained schedules of work and rest with the occurrence of little or no decrement in vigilance. Other studies have reported that performance decrements do occur during prolonged periods of watch-keeping.

Adams, O. S. and Chiles, W. D., Human Performance as a Function of the Work-Rest Cycle. WADD TR 60-248, March 1960.

This study is designed to investigate the effect on performance of four different work-rest period schedules: (1) 2-off/2-on; (2) 4-off/4-on; (3) 6-off/6-on; and, (4) 8-off/8-on. These comparisons were made over a 96 hour duty assignment. The subject sample consisted of 16 male college students with four subjects assigned to each of the four work-rest period schedules.

Performance was measured by the means of a battery of psychomotor tasks involving arithmetic computation, pattern discrimination, monitoring, and vigilance. Additional data were obtained from responses to environmental questions asked of each subject. These subjective techniques were administered at the end of the psychomotor tests. Responses of "yes" and "no" or weights indicating the extent of positive responses were scored to questions of the follow types:

- Did you get enough sleep?
- At any time did you feel that you could not continue with the experiment?
- Do you feel that your performance suffered at any particular time or times during the 96 hours?
- Did you at any time feel resentment toward the experiment?
- Do you feel that your work-rest cycle would be a good one to aircrews?
- Were the tasks, as a group: Very difficult
  Moderately difficult
  Reasonably easy
  Extremely easy

Although the performance tasks failed to differentiate among the four experimental groups, the observational evidence suggested that the subjects in the 2-hour and 4-hour groups achieved a more favorable adjustment than those in the other two groups.

ANNOTATED BIBLIOGRAPHY

Spacecraft Maintenance

Caines, K. L. D. The feasibility of manned orbital maintenance. Douglas Aircraft Co., Tech Rep., SM-41449, 1962.

Manned and unmanned space vehicles will have to be repaired while in the orbital environment. This can be accomplished in a limited fashion by machines. However, the most efficient system for performance of maintenance in space will utilize directly the capabilities of the human operator. Machines cannot replace man in versatility and capability when we hold constant such dimensions as volume, weight, and reliability. The latter are important considerations for space systems. This report is the result of a literature search, with accompanied analysis and evaluation. It is primarily concerned with man in the extraterrestrial environment. It describes many of the prime factors that will influence the use of man in an orbital repair system. Physical, psychological, physiological, and mechanical problems are discussed. Recommendations are presented which are pertinent to the design of system, components, and procedures for the efficient preparation and utilization of the orbital maintenance man.

Dzendolet, E. Manual application of impulses while tractionless. Human Factors, 4, November 1960.

When a man anchored by one handhold in a tractionless situation, applies a large-force impulse, he places himself directly behind the point of application. The shape of the graphic representation of the tractionless impulse is saw-toothed with an approximate area of 3/4 the rectangle formed by the time base and the force height. The duration of the impulse (range 5-40 lbs) is a function of the increase in required force. Pull-out impulses are statistically and practically shorter than push-in impulses. Maximum duration of impulse for 40 lb force is .5 secs for push-in and .3 secs for pull-out impulses. A man can seat a piece of equipment in this force range without a handhold by gradual release of the rebound forces by muscular control such that no single muscular impulse exceeds the frictional forces of the equipment.

Dzendolet, E. and Rievley, J. F. Man's ability to apply certain torques while weightless. WADD TR 59-94, WPAFB, Ohio, April 1959.

Tentatively concluded that standard anthropometric data can legitimately be extrapolated to the weightless condition. Suggestions are advanced regarding (a) the optimum body position for a simple tightening task without using a handhold, (b) the use and location of handholds, (c) maximum torque limitations, (d) the use of impulse, (e) the design of handholds.

Isakob, P. K. Problems of weightlessness. Nauka i Zhizn, 22, 17-20, Appendix XX, RM 1760, 1955.

This is a discussion of weightlessness and its total effects also directing additional studies in various specific areas. Of most importance was the description of a task oriented experiment in a weightless environment. A man was given a paper and pencil task to accomplish under 0 G environment. First attempts to complete the task proved fruitless. However, repeated attempts resulted in successful and efficient task completion. Results indicate that man can adapt his coordination to the weightless state and with sufficient training accomplish most manipulative tasks.

Peters, G. A., et al. J-2 space maintenance: preliminary study, Rocketdyne Div., North American Aviation, ROM 2181-1004, July 1962.

A preliminary study of the feasibility of performing space maintenance on space propulsion systems was conducted at Rocketdyne. Two pressurized, soft anthropomorphic suits were utilized in the performance of selected maintenance tasks on a J-2 engine of the latest R&D configuration. The results indicated that the present design of tools and space suits is insufficient for efficient maintenance activities.

Reynolds, J. B., et al. Study in the utilization of hand tools in space, NAA, Missile Division, WADD TR 60-535, August 1960.

This study attempted to utilize present hand tools for space maintenance and to present parameters for special space tools. Insufficient attention was given to environmental conditions other than weightlessness. It concluded that most hand tools would be used but only after extensive modification. Recommendations were made for a zero-reaction tool.

Spacecraft Environment

Gunn, W. H. Human engineering. Air Line Pilot, 30, 151:4-6, 22 July 1961.

An experienced pilot discusses potential hazards built into the design of some aircraft because engineers did not take into account the human factor. The majority of these potential hazards are related to visual information presentation, in such areas as instrument design, systems and control design, etc. Other factors are related to design of comfort factors where fatigue can result from discomfort. More human engineering is recommended to eliminate these hazards.

Kelley, C. R. Engineering psychology and human factors in design. V: man and the control process. Electro-Technol., 67 5:119, May 1961.

The following topics are discussed: (1) devices which extend man's capabilities (measuring, transitional, and control devices); (2) important characteristics of controls (location-identification, transmission of energy, and transmission of information); (3) some of the factors which influence the effectiveness of a control in transmitting information from a man into a system; and (4) man and the control system involving open vs. closed-loop control, man as a control system operator, and man as a control system element. This stresses two quite different roles that man plays with respect to the control system: (a) he supplies the control system input and (b) he may serve as an element in the system. Despite his limitations, in many systems man still forms the finest control element available. Consequently, the time is not near when the control system director will be the sole focus of attention in human factors engineering.

Krimshtein, A. E. A method for studying occupational proficiency and individual apptitudes of pilots in the evaluation of position in space. Military Medical Journal, 1:97, 1961.

A method of employing simulated instrument panels and projection of airplane silhouettes on slides is described for use in the evaluation of a pilot's aptitude and proficiency in determining his own position in space by instrument readings and the flight direction of enemy aircraft from silhouettes.

Ritchie, L. F., et al. Some control-display aspects of manual attitude control in space. Advances Astronaut Sci., 6:170, 1961.

An investigation was conducted to determine the ability of a human operator to control the attitude of a simulated exo-atmospheric vehicle using several different combinations of displays, controllers, and control systems. The displays were a three-axis moving sphere type attitude indicator with and without body-axis rate indicators. Three controller arrangements were studied -- individual hand controls for each of the three axes, a three-axis integrated controller, and a combination of the integrated controller and foot pedals. Proportional and on-off controls were used with the integrated controller. The operators were instructed either (1) to stop the attitude spin or (2) to stop the spin at a particular attitude. They were able to stop the spin with an efficiency of about 90 percent and in less than 10 seconds with the best control-display combinations. Detailed suggestions are made for further precise experimentation.

Schubert, J. E. and Bovee, H. H. Sanitation problems in space flight. The Sanitarian, 24:5, March 1962.

This article discusses the sanitation problems relating to food, water and waste disposal in manned spacecrafts, and the increasing complexity of these problems with an increase in duration of space flights. Operation of the biomedical sensors for an algae supported manned test is discussed.

Shearer, Jack E., and Downey, Peter. Design study for cabin lighting of orbital flight vehicles. WADD TR 60-122, April 1960.

The factors involved in the design of a general lighting system for the cabin of a completely enclosed space vehicle are discussed and evaluated. These factors establish the criteria and requirements for a suitable lighting system which may be used in space vehicles required to orbit for prolonged periods (30 days or longer).

U. S. Senate (87th Congress, 2nd Session) Staff Report. Manned space flight program of the NASA: Projects Mercury, Gemini and Apollo. U. S. Government Printing Office, Washington, D. C., September 1962.

This staff report and study is derived from unclassified information released by NASA and testimony concerning the manned space flight program given during committee hearings. The program expands Project Mercury to consist of the following major elements:

Mercury suborbital flights
Mercury orbital flights
One-day manned missions
Project Gemini
Project Apollo:
Earth orbital flights
Circumlunar
Lunar landing

Figures show the various spacecrafts, launch vehicles and engines required to achieve lunar landings. Also included is the program that might be expected to follow the lunar landing: a manned orbiting scientific laboratory. An appendix to the report gives a brief description of the Dyna-Soar manned space flight project from its inception in 1958 until it was redesignated in mid-1962 as the X-20 project. The appendix also includes a sampling of some events which developed into present U. S. space programs.

Van Wart, F. D. Human factors in long-range aerospace flight. Advances Astronaut Sci., 6:404, 1961.

The human-factor results of an 8-hour 36 minute flight in a B-47 aircraft are described. Some aspects of terrestrial-flight simulators and associated human factors are related to extraterrestrial flight. In particular, human factor problems of comfort and efficiency are compared for a standard ejection seat and an experimental long-range ejection seat having a dynamic cushion and lumbar support pad as special features. Discussions of human performance and methods of assessing it are included along with data on nutrition, excretion, and crew performance.

Personnel Requirements

Adams, O. S., and Chiles, W. D. Human performance as a function of the work-rest cycle. WADD TR 60-248, ARDC, WPAFB, Ohio.

This study was designed to investigate the effect on performance of four different work-rest period schedules (2 on and 2 off, 4 on and 4 off, 6 on and 6 off, and 8 on and 8 off) followed over a period of 96 hours. The subject sample consisted of 16 male college students with 4 subjects assigned to each of the four work-rest period schedules. Performance was measured by means of a battery of psychomotor tasks involving arithmetic computation, pattern discrimination, monitoring, and vigilance. Additional data were obtained from information recorded in an experimenter's logbook and from responses to a subject questionnaire administered at the end of testing. Although the performance tasks failed to differentiate among the four experimental groups, the observational evidence suggested that the subjects in the 2-hour and 4-hour groups achieved a more favorable adjustment than those in the other two groups.

Berry, H. A., and Payne, T. A. Displays in space vehicles. Douglas Aircraft Co., Final Report LB 30299, September 1959.

This report is concerned with the display system to be used by the human operator in orbital vehicles. The mission and vehicle and hypothetical and general, and emphasis is placed upon displays for guidance and control of the vehicle. The operators functions are divided into two groups: (1) the control of flight attitude; and, (2) control of vehicle position. A third group of purely mechanical functions are treated in a broad sense only. The system describes a 2-man crew and individual and crew responsibilities. The primary attitude control problem emphasizes the need, in the primary control man-function, for speed and accuracy of operator responses during the boost phase of the flight.

Broadbent, D. E. Human arousal and efficiency in performing vigilance tasks. Discovery, 22, 7:314, 320, July 1961.

Studies of work efficiency in various vigilance tasks have uncovered several factors, important in the maintenance of an optimum level of arousal. The probability of a signal was found to be significant to its efficiency apart from its arousal properties. The efficiency is high with a high signal rate but deteriorates under low signal probability. Efficiency is affected [illegible] by the diurnal rhythm of many physiological functions, state of sleeplessness, fatigue, and level of background stimulation. Highly arousing conditions also tend to produce a deterioration in efficiency with time, probably as a consequence of the increased amount of errors in over-arousal states.

Dryden, Hugh L. Impact of progress in space and science. U. S. Government Printing Office, 1962.

Arguments for the need for man in space are presented in this report. Some scientists have questioned the necessity of man's role in space in view of the economy of added weight-equipment to support them. Men aboard spacecraft will provide increased ability to observe phenomena in space. Instruments can gather and transmit only information which they are programmed to obtain. Many X-15 missions which have penetrated the fringes of space would have failed had there not been a pilot in the cockpit to correct equipment malfunctions. Space exploration is a firmly established activity of the human race. None of us knows the capacity of man to grow and adapt. Space travel opens a brilliant new stage in man's evaluation.

Ely, J. H., et al. The measurement of Advanced flight vehicle crew proficiency in synthetic ground environments. Behavioral Sciences Laboratory, 6570 Aerospace Med. Research Labs, MRL TDR-62-2, AMD, AFSC, WPAFB, Ohio, February 1962.

This report is devoted to the presentation and discussion of major considerations in the design of systems for measuring the proficiency of advanced flight vehicle crews in synthetic ground environments. Emphasis is given throughout to the logic of proficiency measurement and the general problems involved rather than to the analysis of specific details. Successive portions of the report deal with general measurement concepts, procedures and steps in designing measurement systems, an example application of the material presented, and the anticipated characteristics of advanced flight vehicle simulation equipment related to proficiency measurement. In addition, a historical overview of aircrew proficiency measurement emphasizing early work and a list of study references on rating methods are appended. As it provides a considerable background of information on proficiency measurement, this report will be of interest to individuals directly concerned with simulator training programs, proficiency evaluation and standardization, training standards, and training equipment procurement for advanced flight systems.

King, B. G., et al. Weightlessness, training requirements and solutions, Operations Research, Inc.

This is a discussion of weightlessness and the problem of training men for space flight. Included are discussions and experiments concerned with bio-mechanics, psychodynamics, psychophysiological principles and mechanisms, training requirements, techniques and equipment. This is an excellent reference re zero gravity and man in space because it covers both the general and specific bio-physical and psychophysiological problems. Of particular note is the author's references to using a water tank as a weightless trainer.

Kling, J. W., and Schlosberg, H. Relation of skin conductance and rotary pursuit during extended practice. Perceptual and Motor Skills, 12, 3:270, June 1961.

The relationship of changes in skin conductance during alternate blocks of practice and rest to the work-rest cycle is discussed. In a previous investigation, naive subjects showed a sharp increase in conductance when warned to get ready to work, and again when warned to stop work and rest. The possibility existed that the "ready" and "rest" rises may have represented surprise or startle of unsophisticated subjects at the reception of unexpected commands. Data are herein presented of a subject who served in nine sessions, each of which included three 5-min. blocks of massed (continuous) rotary pursuit practice, separated by 5-min. rests. The sharp increases in conductance observed for this subject at the start of the task, and again at the beginning of the rest period (which cannot be due to unfamiliarity with the routine) are concluded to be representative of general features of a work-rest cycle.

Physiological Aspects

Anstis, S. M., Shopland, C. D., and Gregory, R. L. Measuring visual constancy for stationary or moving objects. Nature, 191 (4786):416, London, July 1961.

A method is described which is used in the study of size and shape perception of stationary and moving objects. It is known that continuous perception of movement produces an aftereffect of apparent movement in the opposite direction. The authors observed a similar phenomenon after viewing expanding shadows on a series of screens for one minute; as an aftereffect, the shadow appeared to contract. This effect may be important in the interpretation of perceptual judgments in flying or driving.

Barron, R. D. Occupational injuries to the eye resulting from exposure to the electromagnetic spectrum. Med. Services Jour. Canada, 16, 6:487, Ottawa, June 1960.

The physical properties of the major divisions of the electromagnetic spectrum are reviewed. Known hazards to the visual organs from these major divisions (cosmic, nuclear, ultraviolet, visible light, infrared, and microwave radiations) are related to current occupational problems and injuries. Methods are suggested to prevent and control these injuries.

Bogan, R. H., Chapman, D. D., and Ericsson, L. H. Aerobic biological degradation of human waste in closed systems. Advanced Astronaut Sci., 6:390, 1961.

An investigation was made of the susceptibility of human waste matter to biological degradation over a 25° to 50° C. temperature range. The activated sludge process offers many advantages over alternative methods of treatment of human waste. In a bench-scale pilot facility designed about the activated sludge process, data were obtained on reaction velocity constants, chemical oxygen demand, and carbon dioxide and ammonia production at the various temperatures. The cultures were subjected to loads ranging over 3- to 25-day retention times. Based on these data, design criteria for inclusion of such systems in a closed environment have been developed. The results indicate that such a biological combustion unit, with supporting apparatus, may entail only 1 ft. per man.

Bond, A. F., Del Duca, M. G., and Babinsky, A. D. Methods of predicting Radiation dosage in space flights. Advances Astronaut Sci., 6:302, 1961.

Two computational methods are discussed which have been used to predict total radiation dosages received in passing through the Van Allen radiation tests in flights departing from Earth. A fully automatic analog computer technique is presented which can be used for computation of radiation doses received in trajectories in the equatorial plane. For trajectories inclined to the equator, a combined mechanical and electronic system is described in which instantaneous trajectory parameters are inserted manually. Preliminary results of the total integrated radiation dose received in various low thrust and ballistic trajectories inclined to the equator are also presented and discussed. The results suggest the possibility of developing devices which may aid safe navigation through radiation fields.

Bullard, R. W., and Crise, J. R. Effects of carbon dioxide on cold-exposed human subjects. Jour. Applied Physiol., 16, 4:633-638, July 1961.

Human subjects were exposed to an ambient temperature of 5° C. for 75-minute periods. Subjects breathed 2.5%-6% carbon dioxide for selected time periods during the exposure. Carbon dioxide appeared to inhibit shivering. After carbon dioxide inhalation, shivering and metabolism were greatly increased. When 6% carbon dioxide was inhaled for 30 minutes, the inhibition was overcome and shivering and metabolism approached high levels. The increased respiratory heat loss associated with carbon dioxide breathing may be one factor causing the breakthrough of the inhibition.

Chandler, K. A. The effect of monaural and vinaural tones of different invensity on the visual perception of verticality. Amer. Jour. Psychol., 74, 2:260, June 1961.

The present study was designed to investigate the effect of monaural and binaural auditory stimulation upon the visual perception of verticality. Apparent verticality was determined while subjects were stimulated under nine different conditions of auditory stimulation and five different starting positions of the visual object. Forty-eight subjects, 24 men and 24 women, were tested. The results are (a) that the apparent vertical was shifted away from the side of monaural stimulation and away from the side of greater intensity in dichotic stimulation; (b) that the magnitude of shifts in the apparent vertical are related in a direct fashion to the intensity of the auditory stimulus; and (c) that dichotic stimulation did not induce shifts in the apparent vertical different from those obtained with no tone, used as a control-condition. These results are in general agreement with the notion that different types of stimuli are functionally equivalent and may interact in a summative fashion.

Coermann, Rolf R., et al. Human performance under vibrational stress. Human Factors, 4, 315, 1962.

Blindfolded subjects, restrained by standard harness, sat on a modified Air Force chair, which was programmed to move in random patterns in pitch and roll, the subjects counteracting these motions by using a control stick. The whole device was mounted on a mechanical shake table producing vertical sinusoidal motion at frequencies ranging from 2 c/s to 20 c/s and at amplitúdes corresponding to about one-third of the subjective tolerance limits. The angular deviations from the upright position were evaluated relative to the the disturbing input for both pitch and roll, one minute during the vibration experience and one minute after cessation of the vibration. Some individual subjects were not influenced by the vibrations; others showed performance decrements. In the mean, these measures of human performance reflect all mechanical resonances within the body, previously established by other methods. The frequencies most affecting performance were found to be between 3 and 12 c/s. Residual effects were detected by the measurements after vibration.

Ellis, O., Steinman, L., and Ludwig, F. The tunnel display concept. Advances Astronaut Sci., 6:357, 1961.

One of the problems of space travel is to provide the astronaut with a suitable frame of reference and other visual displays or auditory signals to enable him to keep his craft on course and to inform him of significant events. One means of doing so is the use of the tunnel display concept, which relates to an advanced integrated format for the display of pilot/navigator (or spacecraft controller/occupant) information. In this display, the status of system constraints in their entirety is presented in a visual form perceptually natural to the controller; namely, in terms of dynamic alterations of spatio-temporal relationships. Mission profiles in consonance with system limitations are preprogrammed and become effective upon selection by the controller. In addition, various three-dimensional displays and the use of words and sounds as directive or altering signals are described and various critical situations are illustrated. Means of mechanizing the control equations and implementing the system are given.

Franken, P. A. Methods of space vehicle noise prediction. WADC TR 58-343, WADD, WPAFB, September 1960.

The effects of rocket engine noise on communication and hearing are considered in detail. General comments are made concerning vehicle and equipment design for noise control.

Gell, C. F. Biological stressors in atmospheric and extra-atmospheric flight. Jour. Internat. Coll. Surgeons, 36, 1:8-14, July 1961.

The problems of aerospace flight are briefly described, especially those concerning biologic stresses. The historical discoveries of aeromedical problems are reviewed with emphasis on the need for continued research in order to overcome them.

Gerathewohl, S. J. Zero-G devices and weightlessness simulators. National Academy of Sciences - National Research Council, Publication No. 781:143, Washington D. C., 1961.

A comprehensive report is given on zero-G devices and weightlessness simulators. The zero-G devices covered are vertical motion devices (e.g., the drop tower), various aircraft, and ballistic missiles. The weightlessness simulators discussed are the null-gravity simulator, the NASA weightlessness simulator, the WADC frictionless device, the orbital air bearing simulator, the multi-axis test facility, and the Martin reaction control simulator. Suggested areas are given for research in subgravity and zero gravity effects.

Hori, H., and Negasawa, A. An experimental investigation on Reaction Time -- especially, on the results of visual accoustic-reaction times by hand and foot. Report of the Aero Medical Experimental Group, Japan, No. 31, March 1960.

The reaction times of the hands and feet of 75 subjects were measured with repeating auditory and visual stimuli at various intervals of recurrence. Acoustic stimuli produced reaction times about 20 milliseconds shorter than visual stimuli, and hand reaction times. There were no observable differences in reaction times between the right and left extremities. The shortest reaction times were observed for 1-2 second intervals between stimuli.

Klein, S. J. Relation of muscle action potentials variously induced to breakdown of work in task-oriented subjects. Perceptual and Motor Skills, 12, 2:131-141, April 1961.

The object was to determine whether the relationship between MAP (muscle action potentials) and breakdown of work are dependent upon how MAP are induced. Different levels of MAP were induced within the same subject by varying the rate at which he lifted a constant weight in an erographic task and the temperature of a thermal stimulus applied to the working hand. Breakdown of work, i.e., the extent to which the subject held weight suspended against gravity, was measured in millimeters and correlated with the concomitant MAP under eight separate conditions. The results indicate that, regardless of how induced the relationships between MAP and breakdown of work are generally in the same direction. That is, increased MAP were associated with increased breakdown. The results are discussed in terms of their implications for the phenomenon of "freezing" in stressful situations as well as for other theoretical considerations.

Lange, Karl O., and Coermann, Rolf R. Visual acuity under vibration. Human Factors, 4, 291, 1962.

The influence of vertical sinusoidal vibration on the visual acuity of 12 human subjects sitting restrained and without padding in an airplane seat mounted on a shake table, was investigated in the frequency range of 1 to 20 c/s. A novel visual acuity tester was developed to achieve high accuracy of measurement and to obtain a great many observations in short time periods. The decrement of visual acuity normalized to a shake table acceleration at 1 G (vector) was determined. Maximum decrements occurred at those frequencies where resonances of the whole body and organ complexes had been determined by other methods. Below 12 c/s the decrements were due mainly to the physiological stress produced in the body, and above 12 c/s to the image displacement on the retina which had more increasingly blurred effect. Measurements one minute after cessation of vibration indicated residual effects only at frequencies up to 12 c/s, peak, being at the same resonant frequencies.

Metzger, C. A., and Hearld, A. B. Crew accommodations for aerospace missions. HQ 6570 AMRL, AMD, WPAFT, MRC Memo V-6, May 1962.

This report contains specific and general recommendations for the feeding and waste disposal of Astronauts in space missions from three to fourteen days. It describes somewhat the capability of the Accommodations Section of the Systems Branch, Life Support Systems Lab.

Pigg, L. D., and Kama, W. N. The effect of transient weightlessness on visual acuity. WADD TR 61-184.

Visual acuity was measured on 5 subjects while they were exposed for short periods of weightlessness aboard an aircraft flown through "zero-G" trajectories involving transition from 1 g to 2-1/2 g to 0 G. No significant changes were noted.

Roman, J. A., et al. Some observations on the behavior of a visual target and a visual after-image during parabolic flight maneuvers. SAM TDR 62-66.

A real target appears to be displaced upward from center for accelerations greater than one G positive, and appears to be displaced downward for accelerations less than on G positive. A visual after-image, when observed in the absence of a real target, appears to be displaced from center in a direction opposite to that observed for a real target.

Vacca, C., Sparvieri, F., Comignani, L. Observations on a respiratory and cardiovascular function test based on maximum voluntary work performed on a cycloergometer. Rivista di Medicina Aeronautica e Spaziale, 24, 2:178, Rome, April 1961.

The relationships were studied between percent increase per minute of muscular work performed on a cycloergometer, percent increase of oxygen intake, and percent increase of pulmonary ventilation in the phase of adaption. These parameters, together with other elements of a cardio-respiratory function test (Cal/liter, duration of work, cardiac frequency, arterial pressure, etc.), may be used to determine the sensitivity of central cardio-respiratory regulating mechanisms under conditions of maximum voluntary muscular work especially as related to the type of work performed by pilots and other flying personnel.

Vogelsang, C. J. The perception of a visual object during stimulation of the vestibular system. Acta oto-laryngologica, 53, 4-5:461, Stockholm, May 1961.

The localization of a visual objective in space is not only determined by the image on the retina but also by extra-retinal factors. Several of these factors concern the interpretation of observed phenomena. However, the labyrinth too contributes to the perception of the visual sphere. Examples are given of oculogravic and opto-gyral illusions elicited respectively by stimulation of the otoliths and of the semicircular canals. As contrasted with the general accepted explanation, arguments can be advanced which show that the opto-gyral illusions are independent of the nystagmus. According to the author, both kinds of illusions are considered as a tendency to correlate optical, haptic and vestibular cues as an expression of a cerebral correlative function. In the absence of optical orientational cues containing a factor of experience, which is also the fact with a mere light point in the dark, the vestibular impression will be dominant. Within certain limits the adaptation of the optical impression to the vestibular information is perfect. In stronger stimulation of the vestibular apparatus dissociation appears. Highly nonphysiologic stimulation gives a complete absence of correlation which results in a disorientation penetrating into the consciousness.

von Beckh, H. Flight experiments about human reactions to accelerations which are followed or preceeded by the weightless state. Air Force Missile Development Center, Holloman AFB, *AD 154 108*, 1958.

The author has determined through physiological research how experimentation describes changes in accelerations reduce the tolerance of the human operator to withstand G Forces. If these accelerative forces are preceeded or followed by the weightless state, the ability to withstand G forces is further reduced. He suggests that we should provide protection against physiological failure to reduced tolerance.

Psychological Aspects

Fitzpatrick, W. H., and DeLong, C. W. *Soviet medical research related to human stress (a review of the literature)*. U. S. Dept. of Health, Ed. and Welfare, Washington, D. C., 1961.

Primarily a study of radiation effects on physiology. However, psychological elements are summed: "Soviets have been .... unproductive during past 25-30 years .... largely because of concerted effort .... to reduce airman behavior to a mere summation of reflexes."

Hagen, D. H. Crew interaction during a thirty-day simulated space flight. School of Aerospace Medicine, Brooks AFB, Texas, *61-66*, June 1961.

An analysis made of crew interaction during a two man simulated space chamber flight. By use of the well known Bales Interaction Process Analysis, the behavior of two subjects was rated during two hours of observation each day throughout the 30-day flight. Over 80% of the interaction was asking for opinion, giving opinion, asking for information, and giving information.

Hori, H., et al. A Study of the mental function during stress of low atmosphere pressure. I: Especially on the results of the maze learning, figure-ground reversion and blocking tests. Report of the Aero Medical Experiment Group, No. 32:25, Japan, March 1961.

Five subjects were observed at altitudes of 2000, 3000 and 4000 meters in tests of maze learning, figure-ground reversal, and color naming blocking. As altitude increased, the subjects' ability to solve the mazes decreased, figure-ground reversal inclined toward the dominant side, and frequency of blocking and oversight tended to increase. At altitudes of 3000 to 4000 m. these stress effects become very evident along with other altitude phenomena such as dulling of memory, fatigue, anxiety, etc.

Muecher, H., and Ungeheuer, H. Meteorological influence on reaction time, flicker fusion frequency, job accidents and use of medical treatment. Perceptual and Motor Skills, 12, 2:163, April 1961.

Data representing reaction time, critical flicker fusion frequency, job accidents, and visits to a plant dispensary, were obtained from large groups of persons. These data proved to be significantly related to six qualitatively discriminable weather phases. Some of the heuristic and methodological aspects of classifying weather phenomena for biometeorological purposes are discussed.

Newman, M. T. Biological adaptation of man to his environment: heat, cold, altitude, and nutrition. Annals New York Acad. Sci., 91, 3:617, June 1961.

This cursory survey of human adaptation to environmental extremes involves phenotypic alterations of morphological and physiological traits that are largely continuous variables. Heat and cold tolerance are discussed in terms of individual body size and proportions, skin surface area and pigmentation, subcutaneous fat, sweat glands, and physiologic adjustment (e.g., vasoconstriction). Morphologic and physiologic adjustments to high altitudes may include large blood and lung volume and large red cell size and number. Nutritional adjustments are discussed in terms of hypo- and hyper-caloric intake. It seems clear, at least in general outline, that the nature as well as the degree of human adaptations to those facets of the environment, unrelated in a direct sense to disease, may indeed reflect upon disease situations.

Rains, J. D. Reaction time to onset and cessation of a visual stimulus. Psychol. Record, 11, 3:265, July 1961.

An experiment was conducted to determine if differences exist in reaction time to onset and cessation of a large, bright, foveal light. Out of 21 replications of the experiment, eight differences, split equally between two types of reactions, were significant. These findings are attributed to the trained subjects' sensitivity to momentary fluctuations in their physiological and psychological states. It is concluded that no differences between the two types of reaction are apparent at these parameters.

Reed, G. F. Audiometric response consistency, auditory fatigue and personality. Perceptual and Motor Skills, 12, 2:126, April 1961.

The suggestion was investigated that, in prolonged sessions of audiometric tests, hysteric subjects will build up reactive inhibition more rapidly than anxious subjects and therefore show progressively more inconsistency and decline in response accuracy. Thirty school children (15 predominantly hysteric and 15 predominantly anxious) were each subjected to a 15-minute session limited to high-frequency tones after a routine binaural pre-tone audiometric test. The hysteric group tended to be less consistent than the anxious group, and the majority showed elevation of threshold as the task was prolonged. These findings may be relevant to considerations of auditory fatigue.

Rees, D. W., and Copeland, N. K. Discrimination of differences in mass of weightless objects, WADD TR 60-601, WPAFB, Ohio, December 1960.

Absence of gravity results in the loss of many familiar kinesthetic cases of weight and friction necessary to man for object discrimination and manipulation. Man's ability to discriminate small differences in mass opposed to small differences in weight was studied. Four weight series were used, each consisting of a standard (1000, 3000, 5000 or 7000 grams) and nine comparison stimuli. Judgments for mass differences were made with the same weights supported by compressed air on an air-bearing table. Thus, the frictionless aspect of a weightless environment was stimulated. Results show that the mean differences, mean standard deviation, and Weber ratio for each standard are much larger for mass than for weight. Thus, to be detected under a weightless condition, mass increments must be at least twice as large as the weight increments required for discrimination in a normal weight lifting situation. Results indicate that mean differences for mass tend to be at least twice the size of those for weight discrimination. The greater number of errors for mass probably resulted from the relative unfamiliarity of most subjects with mass judgments and weightless situations.

Silverman, A. J., et al. Psychophysiological investigations in sensory deprivation: the body-field dimension. Psychosomatic Med., 23, 1:48, January 1961.

Five body-oriented and six field-oriented subjects were exposed to a situation containing the elements of uncertainty, social isolation, low sensory input, and restraint from active movement to test the hypothesis that persons who rely more on external rather than internal cues would react differently to a situation in which external cues were lacking. The data tend to agree with the hypothesis. Field dependent subjects initially and at the conclusion of the experiment revealed less of an ability to discriminate sensory cues, remained more aroused, were more uncomfortable about the experiment, and, when various interview responses were grouped to obtain a rough ego function index, showed a greater degree of disorientation.

Volkor, I. F. Method of studying fatigue in flight personnel. Military Medical Journal, 1:108. Washington: U. S. Joint Pub. Research Serv., No. 9169 (1374-N/38), April 1961.

Two methods of employing the same apparatus are proposed for the detection of fatigue in flight personnel. The first determines the rate of perception and distribution of attention by the subject as he goes about the task of locating and naming consecutive numbers on tables of random numbers. The time needed to locate all the numbers is taken as an index of the rate of perception. In the second test the subject positions and drops a metal rod into holes of successively smaller diameter, ending with the one in which contact occurs upon positioning because of finger tremor. In the majority of pilots the time for finding all numbers was less than 40 seconds. A time exceeding 50 seconds is indicative of fatigue. In the second test excessive tremor is shown if the contact occurs in a hole of 4.5 mm. or larger in diameter.

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