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AMRL-TDR-63-81

PSYCHOLOGICAL ASPECTS OF EXTENDED MANNED SPACE FLIGHT

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TECHNICAL DOCUMENTARY REPORT No. AMRL-TDR-63-81

SEPTEMBER 1963

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AIR FORCE SYSTEMS COMMAND
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20061012125

Project No. 7184

203

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900 - November 1963 - 162-16-238

FOREWORD

This report was prepared by Julien M. Christensen, Chief, Human Engineering Division, Behavioral Sciences Laboratory, 6570th Aerospace Medical Research Laboratories, under Project No. 7184, "Human Performance in Advanced Systems." The report covers literature from 1944 through April 1963 and was prepared for presentation at the "Symposium on the Exploration of Mars," presented by The American Astronautical Society, Denver, Colorado, 6 and 7 June 1963. The report appears also in the Proceedings of the American Astronautical Society.

ABSTRACT

As is the case with virtually all of the other scientific disciplines, the adequacy of available psychological knowledge and principles will receive a severe test from the demands attendant to the development of a successful mission to Mars. A sampling of some of the relevant information available in psychology is offered and areas that will require further attention before predictions in the behavioral area for the Mars trip can be made with confidence are identified. A twofold thesis is developed. First, psychology has legitimate and important contributions to make to the Mars trip. Second, the advantages, however, are mutual; i.e., it is confidently predicted that participation in this venture will force psychologists to reexamine their traditional principles and theoretical positions and will stimulate an attack on the basic issues of human behavior with refreshing insights gained from new points of vantage.

PUBLICATION REVIEW

This technical documentary report is approved.

Walter F. Grether

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Technical Director
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PSYCHOLOGICAL ASPECTS OF EXTENDED MANNED SPACE FLIGHT

Julien M. Christensen

INTRODUCTION

Among the most fascinating recurrent discoveries of mankind is man. Fortunately, the possibility that man might serve as a competent, functioning element in space vehicles was revealed in Year One of the Space Age. The orbital missions of Glenn and Carpenter, for example, could not have been completed (at least not with the same measure of success) without the direct contributions each made to the accomplishment of his mission. Glenn dealt successfully with a problem in the stabilization system; Carpenter manually fired the retrorockets when a condition developed that the automatic system could not handle. Both made numerous scientific observations that could not have been instrumented or automated.

To the psychologist, these experiences are among the most significant results of these two missions because they help to settle the controversy that might have developed as to whether or not man is needed in space vehicles. Hopefully, we can now devote our energies to the more fruitful task of determining exactly how man should be used in space vehicles to maximize the effectiveness of selected systems rather than perpetuate a pointless argument as to whether or not man has a place in space. The psychologist must attempt to verify and extend many traditional, earthbound principles of behavior and must inquire into new areas that perhaps never would have occurred to him had he not been confronted by the challenge of space. Man will be used to investigate space, and in the process, will learn more about himself. We term this the "use of space to investigate man."

We think that recognition of this "space to investigate man" is of utmost importance. In fact, if the report has a central thesis, it is simply that the challenges generated by contemplated space explorations will force us to make inquiries into man's behavior that would not otherwise have been made in the foreseeable future and that such inquiry will enormously broaden our understanding of man's behavior not only in space but also on earth. The physicist and the chemist do not now have the knowledge that will be available in their respective areas one hundred years hence; this is even more true of the psychologist. In terms of our understanding of behavior, man is undergoing at least apparent changes that, in retrospect from the year 2063, may be as startling as a comparison of the behavior of twentieth century man with that of Cro-Magnon.

NATURE OF CONTRIBUTIONS OF PSYCHOLOGY TO THE MARS MISSION

General Contributions

For better understanding, the relevant areas of psychology must be shown in their proper perspective to the accomplishment of a mission such as this. Selection and training experts traditionally have accepted the jobs as assigned to men in a specific situation and have attempted to select and train men who could do those jobs best. The success of these experts is widely recognized; for example, during World War II they did an excellent job of selecting and classifying candidates for pilot, bombardier, and navigation training in the Navy and in the Air Force. The engineering psychologist, on the other hand, attempts to furnish the design engineer knowledge about human capabilities and limitations so that the engineer can design the equipment, work situations, work stations, and systems in such a way as to maximize man's contribution to the effectiveness of the system. The social psychologist has a contribution to make in terms of selecting men who will form compatible crews for extended missions. The clinical psychologist with his knowledge of human personality assists in the selection process. The industrial psychologist contributes with his support of the manufacturing process. Finally, there is the experimental psychologist who conducts experiments and delivers the data and principles of human behavior on which the other psychologists base their decisions and recommendations.

General Operations of the Mars Mission

Techniques are available for analyzing and defining mission profiles such as this one and for estimating generally, but with increasing specificity as development proceeds, the functions and tasks to be performed by men and machines. Such an analysis, performed now, would yield specific, definitive information that could dramatically reduce the number of ambiguous generalizations that characterize current topical discussions, including this one. The job can (and hopefully will) be done by a team of engineers, physicists, biological, and behavioral scientists. But lacking this specificity, and with apologies, I too must don the impregnable cloak of generality.

The design engineers will have to exercise their technical and creative talents to the utmost to fulfill the requirements of the Mars mission. Man can help achieve the required reliability and effectiveness by active involvement in most if not all of the necessary operations. Examples of such operations are: rendezvous, guidance and control, visual inspection of objects outside the vehicle, maintenance, emergency procedures, reconnaissance, monitoring of subsystems and decision-making. Voas (ref. 54), for example, has stated that "Man's primary role in the operation of space vehicles will be to increase system reliability." Konecci (ref. 28), using the classic studies of Lusser, has shown conclusively that even with the highest component reliabilities conceivable at the present time, man would still be required to perform maintenance in a trip the duration of this one. In addition to the skills required to operate the vehicle, a Mars crew will have to be able to do many of the jobs traditionally performed by ground support crews. This fact is often overlooked but it greatly complicates design, selection, and training. Careful consideration must be given to simplicity of design, allowing man directly to perform many operations (perhaps, for example, automatic navigation systems would be turned on only a few minutes each day as a check on the manual operations) and using man as a redundant element wherever possible.

Several writers (refs. 8, 54) have made the point that we may find it desirable to provide the operators with control and display systems that strictly from the standpoint of performance are somewhat less than optimal, if they will thus be more reliable or easier to maintain or both. Westbrook (ref. 55) has estimated that, based on current technology, an automatic control system (three-axes) for a round trip between earth and moon would have a reliability of 0.22. By simply adding an operator on standby the reliability jumps to 0.70. With a very modest amount of spare parts and a competent crewmember, the reliability becomes 0.93. There is thus a real practical need to determine the simplest system (taking advantage of man's capabilities) that can do the Mars job; complexity and reliability must constantly be questioned.

Planning and designing for a flight to Mars requires the most detailed knowledge of man's perceptual, motor, and intellectual skills and of the effects that a variety of truly unusual environments has on these skills. Interacting intimately with these are such variables as motivation, personality, and inter- and intra-human variability. Man is a flexible, versatile, adaptable subsystem capable of performing well over a tremendous spectrum of complexity from handling a screwdriver to dealing with abstractions incapable of quantification. But we cannot capitalize on these attributes unless we plan carefully for them from the conceptual design stages through operational test.

Available Data

Although engineering psychology is only about two decades old, the experimental psychology on which it rests is acknowledged as being at least 85 years old. Like many ladies, experimental psychology is somewhat older than is publicly acknowledged; however, like true gentleman, we will not press this issue. There is, and for years has been, a respectable amount of information available regarding man's nature and capabilities that will be of use in the Mars mission. For example, while still not completely understood, some of the basic "laws" of depth perception were laid down by da Vinci almost 500 years ago and have been periodically worked on ever since.

The purpose of this report is not to review the vast store of information available in experimental and engineering psychology. This has been done by experts (refs. 36, 37, 39, 51, 56). Rather, the remainder of this paper will be devoted to the examination of experiments that either had space applications as their chief impetus or had some other genesis but are considered particularly relevant to space operations. This review is not exhaustive; we hope only that it is reasonably representative.

Timely Consideration of Man

As with other disciplines, we find that the contributions of psychology are most helpful if introduced in a timely manner. The engineering psychologist's recommendations should be considered during the conceptual stage and continuously thereafter during the phases of design, manufacture, and test. Under no circumstances should man be considered as a subsystem that does what is left over after the design engineers have reached the end of their current technological rope; nor should man be inserted as an afterthought and handed a few superficial duties simply to keep him busy. Man, like any other subsystem, has certain capabilities that, if intelligently considered, will do much to enhance systems effectiveness. I have emphasized elsewhere the importance of timely consideration of man's capabilities simultaneously with consideration of the other resources available to design engineers (refs. 11, 12, 13, 14). This is of utmost importance in a mission as complex as the Mars mission. General Schriever has called this the "Doctrine of Concurrency." Any other approach, at best, will result in inefficiencies in design or operation and, at the worst, could result in failure or catastrophe.

SELECTION AND TRAINING OF THE SPACECREW

Selection

The procedures used to select our original seven astronauts have been reviewed elsewhere and will only be summarized here (refs. 38, 54). The seven were all military test pilots less than 6 feet tall in height. All were of superior intelligence, exceptionally stable emotionally, and unusually capable of withstanding severe physical stresses. I believe we can agree that the flights to date have vindicated the judgment of the physicians, psychiatrists, and psychologists who helped select the original seven. We should recognize, however, that in the interests of safety and because of a lack of knowledge regarding job requirements, we may have tended to establish selection criteria that were too stringent. As more is learned about space operations, perhaps some of the initial requirements can be relaxed, at least for some of the less demanding missions. I feel equally certain that we are going to find that some of the future missions will demand men with specialized training in areas other than test piloting and engineering——navigation, astronomy, mineralogy, and biology, to mention only a few.

Training

The training of the original seven astronauts has also been reported many times and a description may be found elsewhere (ref. 21). Briefly, the training was designed to acquaint the astronauts with as many of the unfamiliar circumstances and sensations (e.g., weightlessness) as could be foreseen and simulated on earth; to keep them in excellent physical shape so that they could withstand the rigors of blast-off and reentry, and could endure the discomfort of many hours at their work stations; to familiarize them with virtually every engineering detail of their space vehicle and the booster that would lift it into space; and, finally, to assure complete knowledgeability of the details of the job they were to perform. The familiarization with unfamiliar situations and overlearning of their jobs appears to have been particularly appreciated by the astronauts (refs. 43, 44, 45). The soundness of this from the psychological point of view is obvious; in preparing for a space mission, as with love, it is infinitely better, for example, to have experienced weightlessness for even a few minutes than never to have experienced it at all. Mueller has designed a zero-gravity indoctrination program (ref. 42). With respect to the overlearning, there is evidence suggesting that the expected deterioration of performance under stress can be partially prevented by overtraining the incumbents in the jobs they are expected to perform and, if feasible, by training them under conditions that approach as closely as possible those under which the job actually will be performed. The introduction of stress during learning enables one better to adapt to stress in the actual situation (ref. 27).

There is a close interrelationship between selection, training, and engineering psychology. One can often simplify the job to such an extent that the incumbent need not have either special talents or training. On the other hand, proper training often will enable operators to compensate for poor engineering or will simplify the job of the design engineer. The trick, of course, is to strike the optimal balance among factors such as quality and quantity of candidates, amount, expense and type of training, amount of maintenance associated with various designs, effect on resources, time schedules in design and manufacture, and the myriad of other factors that must be considered in the design of a complex system.

On a trip of this duration, the problem of maintaining adequate proficiency in all of the skills required could become acute. Unfortunately, there has not been sufficient work on the long-term retention of skills. Dr. Morgan of our Laboratory, however, has kindly given me a few suggestions based on the information that is available in this important area.

For verbal/symbolic tasks (intellectual, procedural, etc.) any factor that influences learning is likely to have the same effect on retention. If a factor facilitates learning, it generally will facilitate retention. Tasks that have a high degree of motor involvement as compared to verbal/symbolic involvement tend to be retained better. This may be because such tasks generally are learned better. In fact, extensive overlearning may be the best single safeguard against any deterioration of skills that may be due either to duration or to stress.

Rehearsal of highly skilled tasks should probably occur on at least a daily basis. I believe it was Paderewski who said that if he did not practice at the piano for a period of 24 hours he could tell it, and that if he did not practice for a period of 48 hours, the audience could tell it.

It is unlikely that the designers will permit us to install any significant amount of training equipment in the Mars vehicle. However, practice may be possible by means of synthetic inputs into the real equipment. Even "imaginative rehearsal" as Morgan calls it is probably effective. I can't offer scientific evidence regarding the effectiveness of this method, but I do know that when I used to rehearse for musical contests I thought it useful while walking to school to run through the entire solo several times, drumming the finger patterns out on the palms of my hand, while simultaneously "tonguing" against the back of my front teeth, which substituted for a mouthpiece. Techniques such as these, "dry runs" with actual controls, verbal rehearsal, etc., should be used liberally. If any small simulators are required, their programming and scoring problems can probably be handled by one of the on-board computers that will be available.

Finally, we often have a choice as to whether to store selected information in the operator's central nervous system or in performance aids such as checklists, manuals, etc. We recommend heavy reliance on the latter; they do not deteriorate with time and they are not affected by stressful situations.

Some Lessons from Mercury for Mars

I hope that I do not appear to be attempting to detract from the superb performance of our astronauts when I mention that even these outstanding specimens have occasionally forgotten to perform certain tasks during their missions. This does more than convince me that these men are human; it points up a principle that must not be neglected in preparing for the Mars mission. It is simply that cross-checks must be provided for every task and operation, whether that task or operation is performed by man or by machine or a combination of the two. There is no doubt that errors, machine and human, will be made on a mission as complex and as extended as this one. Provisions in design or procedures must assure that these do not develop into catastrophes.

ENGINEERING PSYCHOLOGY

Definition and Explanation

As stated previously, the engineering psychologist (sometimes called "human engineer") works closely in support of the design engineer, appraising him of the capabilities of man with respect to the functions that must be performed if system requirements are to be met. All design engineers know only too well that they must be prepared to deal with many elements that never were brought to their attention in engineering school. The Honorable Brockway McMillan, Assistant Secretary of the Air Force for Research and Development, has stated it this way (ref. 32): "Engineering is a creative process, one whose characteristic elements scarcely have names;

they are certainly not the parts of the process usually packaged into courses and taught in the engineering curriculum. Yet until the engineer masters these characteristically creative steps he no more deserves the title 'engineer' than a plasterer deserves the title 'architect.'" It is with those creative aspects which involve the human being that the engineering psychologist feels he may be of some assistance to the design engineer. Engineering psychology appears to be that branch of psychology where the engineer and psychologist come closest together.

Visual Perception in the Space Environment

Man will perform visual tasks in space that will require acute perception in depth. Terminal guidance for rendezvous in space is an example of where this skill will be required. Messrs. Baker and Steedman of our Laboratory have considered several aspects of this problem. Figure 1, for example, shows 75% threshold data (i.e., 50% better than chance) for percent distance travelled (from an original distance of 25 feet) as a function of brightness of the stimulus object. The sensitivity at the higher levels is rather remarkable (approximately 6 inches in 25 feet) and is attributed to changes in retinal size. In view of the fact that this stimulus-impoverished field provided no (obvious) convergence cues or no stereoscopic cues, it is difficult to interpret the remarkable superiority of binocular viewing over monocular viewing at the low levels of brightness; the authors feel that it may be due to binocular summation (refs. 5, 6).

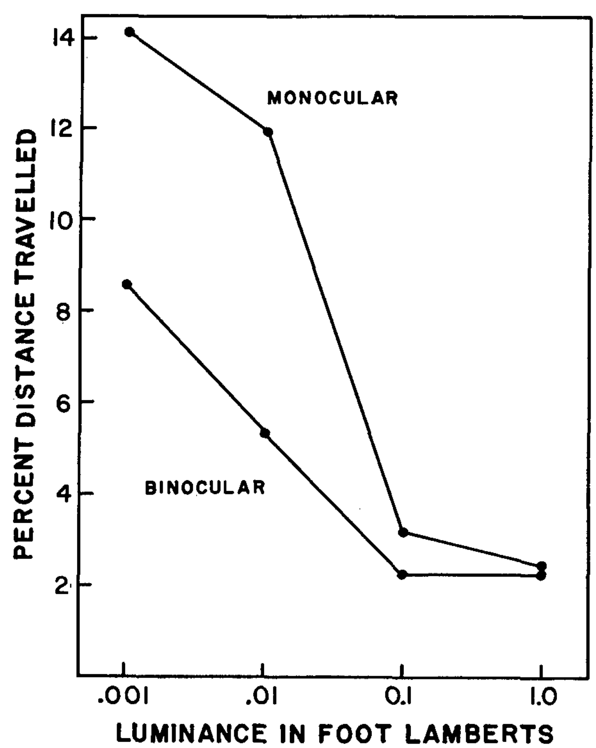

Figure 1

Percent Distance Travelled Required for 75% Detection of Movement in Depth as a Function of Luminance Level (Baker and Steedman, 1961)

Figure 2 shows threshold values in terms of percent distance travelled as a function of visual angle of the stimulus. The break in the curve at 12 minutes of visual angle has been interpreted as a manifestation of Ricco's Law; i.e., at visual angles of 12 minutes or less, subjects base their judgments on changes in apparent brightness.

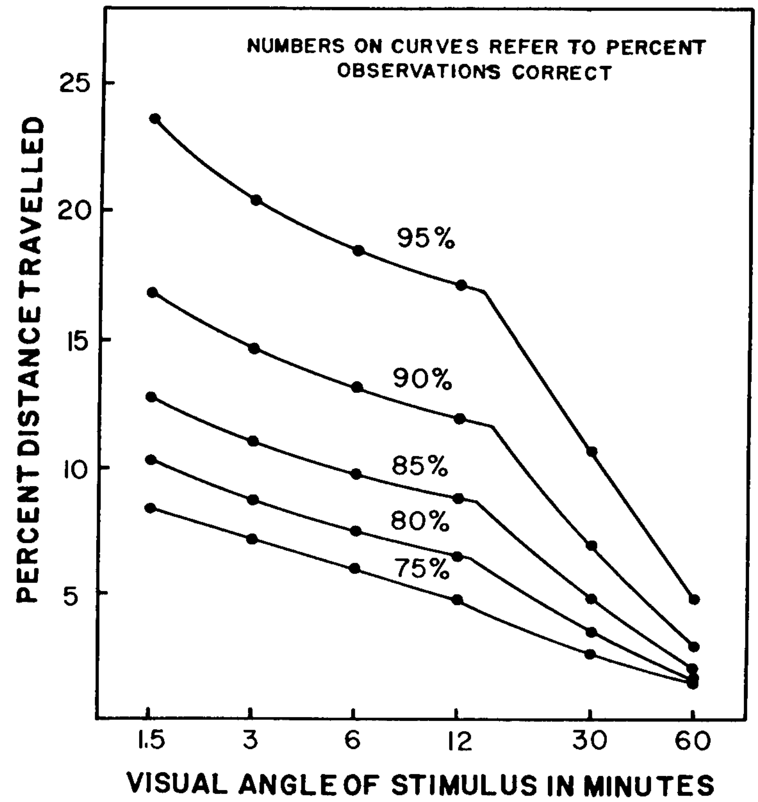

Figure 2. Percent Distance Travelled Required to Achieve Various Threshold Levels As a Function of the Initial Angular Subtense of the Stimulus (Baker and Steedman, 1962)

From these and associated studies Baker and Steedman can make reasonable inferences regarding man's ability to perform the functions required in terminal navigation and in rendezvous with another vehicle in space, using only direct vision. To quote them "With no training, man can perceive with considerable precision under certain conditions, whether an object is approaching or departing. As the luminance of the object is reduced below 0.1 foot-Lambert, however, his accuracy in making these perceptual judgments decreases rapidly. As the angular size of the stimulus is reduced, man's performance also deteriorates. His ability to perceive movement in depth extends over a reasonably large range of absolute rates of movement. An untrained man, however, is poor at estimating closure rates when the rate of change of the angular subtense of the stimulus is the only perceptual cue. Large variable and mean constant errors are evident in the data obtained from the performance of such a task" (ref. 8). However, with intensive training, these errors are reduced considerably.

Houbolt, Bird, and Queijo (ref. 25) report on a simulator study of the rendezvous action that seems partially to confirm Baker and Steedman. The operation was started at a simulated distance of 40 feet with a thrust of 0.1 to 1.0 foot per second. Rendezvous required about 5 minutes and velocity at contact was approximately 0.1 foot per second. This performance is judged satisfactory and was performed with visual cues only. The authors do not report how much training, if any, the subjects required for this type of performance.

Display and Control Requirements for Manned Space Flight

Such factors as lack of a meaningful horizon, lack of conventional reference points, lack of "up" and "down," etc., challenge the ingenuity of the engineer and the psychologist to present both an accurate and meaningful display. Hopkins et al (ref. 32) have considered these problems and it is instructive to consider one of their examples. Consider the case of attitude display. These writers, in contrasting the requirements of an aerodynamic and an orbiting vehicle, point out that an orbiting vehicle can ... "(1) roll without changing heading, (2) pitch without changing altitude or vertical flight path angle, (3) yaw so as to point in a direction opposite to the velocity vector, (4) pitch, roll, and yaw simultaneously at either high or low rates and through a full 360 degrees in all dimensions without influencing the velocity vector, (5) maintain, for practical purposes, if there are no attitude rates, any attitude with reference to a set of inertial space coordinates, (6) maintain, if the pitch rate is appropriate to the angular rate of local vertical, any attitude with reference to the local vertical and the plane of the orbit." None of these is possible with an aerodynamic vehicle, and conventional displays (moving horizon, moving airplane) are completely inadequate.

A seemingly obvious solution——a sphere with relevant vehicles, celestial, and planetary bodies shown——is exceedingly difficult to instrument, at least in a way that renders it interpretable in a straightforward manner by a space pilot or navigator. To complicate the matter further, some have suggested that it may be desirable to design the interior of the space vehicle so that there is no consistent "up" or "down" (ref. 17). If this is done, then all displays will have to be internally coherent; that is, each will have to be readily interpretable without reference to the plane of the vehicle. At the same time care must be taken not to make the design of the control subsystems so complex as to increase the maintenance problem. Why not start with the design approach that equipment will be included only when necessary to do things man cannot do? This is the approach that Bauerschmidt and Besco (ref. 8) took in a contract with our Laboratory. Their report is rich with ideas for making maximum use of man in control problems associated with vehicle orientation and vehicle translation and for orbital navigation.

With respect to the controls area, the Air Force for many years has sponsored an intensive effort to develop a mathematical description of the human operator's dynamic responses. McRuer and Krendel (refs. 34, 35) considered primarily manual tracking situations in which continuous closed-loop control was exerted, with inputs consisting of randomly appearing forcing functions. After an unusually penetrating and comprehensive treatment of the tracking data then available to them, McRuer and Krendel were able to handle most cases with an equation consisting of two major parts. The data of the first part could be handled with a linear descriptive function relating output to input, the second ("remnant") could not, as had been suggested by Tustin somewhat earlier (ref. 55). It is no surprise to psychologists that the remnant term was of such nature that it had to be handled by descriptive statistics. The operator describing function (Y_p), taken from reference 34, follows:

$$Y_p = \frac{K_p e^{-\tau s} (T_L s + 1)}{(T_I s + 1)(T_N s + 1)} + R$$

where

e is the natural logarithm, 2.7182818284...

s is the operator "d/dt"

τ is the reaction time delay

T_N corresponds to neuromuscular lags

$\frac{T_L s + 1}{T_I s + 1}$ is the pilot's equalization characteristic

K_p is the pilot gain

R is the remnant term

The authors recognized that the human is a highly adaptive nonlinear controller who changes his response characteristics to maintain what he considers to be good performance. (The descriptive function will also change as a result of transient effects, such as fatigue, stress, etc.) This "optimalizing," as McRuer and Krendel term it, is imperfectly understood. The operator's criterion apparently is not too different from that of minimization of root-mean-square error.

The application of this general approach is being successfully employed. Frost (ref. 18) used a dynamic model of the pilot along with the airframe and flight control dynamics of the X-20 (Dyna-Soar), and was able to put the entire problem on a computer and thus evaluate the total closed loop system at a very early stage of design. McRuer, Ashkenas, and Guerre (ref. 33) were able to use the model both for estimating the dynamic behavior of the pilots who served as subjects and for forecasting their opinions of the system. See also Ashkenas and McRuer (ref. 4).

This approach is strongly recommended for evaluating the total closed-loop system for the Mars vehicle for each of the problems that requires primary or backup control by the human operator. We have in mind such operations as rendezvous, course corrections, and planetary approach and reentry.

Personal Tethering and Propulsion

Members of our Laboratory have conducted a number of studies designed to disclose how to tether a man working inside or outside of a weightless space vehicle. Tethering outside the vehicle will be necessary to prevent man from drifting dangerously far from the vehicle. If the vehicle is weightless, tethering inside and outside the vehicle will be necessary to prevent the man from floating away from surfaces and from his work station.

It has been suggested that a simple tether line could be used to reel the astronaut in in a fish-like fashion should his personal propulsion system fail. However, an analysis by Mueller (ref. 40) showed that this represents a dangerous oversimplification of the problem. The paths the astronaut would follow for the constant speed condition, the initial impulse condition, and the constant line tension condition are shown in figures 3, 4, and 5. The problem reduces itself to one of the conservation of angular momentum in inertial space, and unless this momentum is reduced nearly to zero, the vehicle and the man will collide with horrible consequences for the man. At this time, we recommend that tether lines for retrieval purposes not be used if the distances between vehicle and man are substantial. In those cases where the personal propulsion system has failed retrieval probably is best accomplished by maneuvering the parent vehicle toward the isolated astronaut.

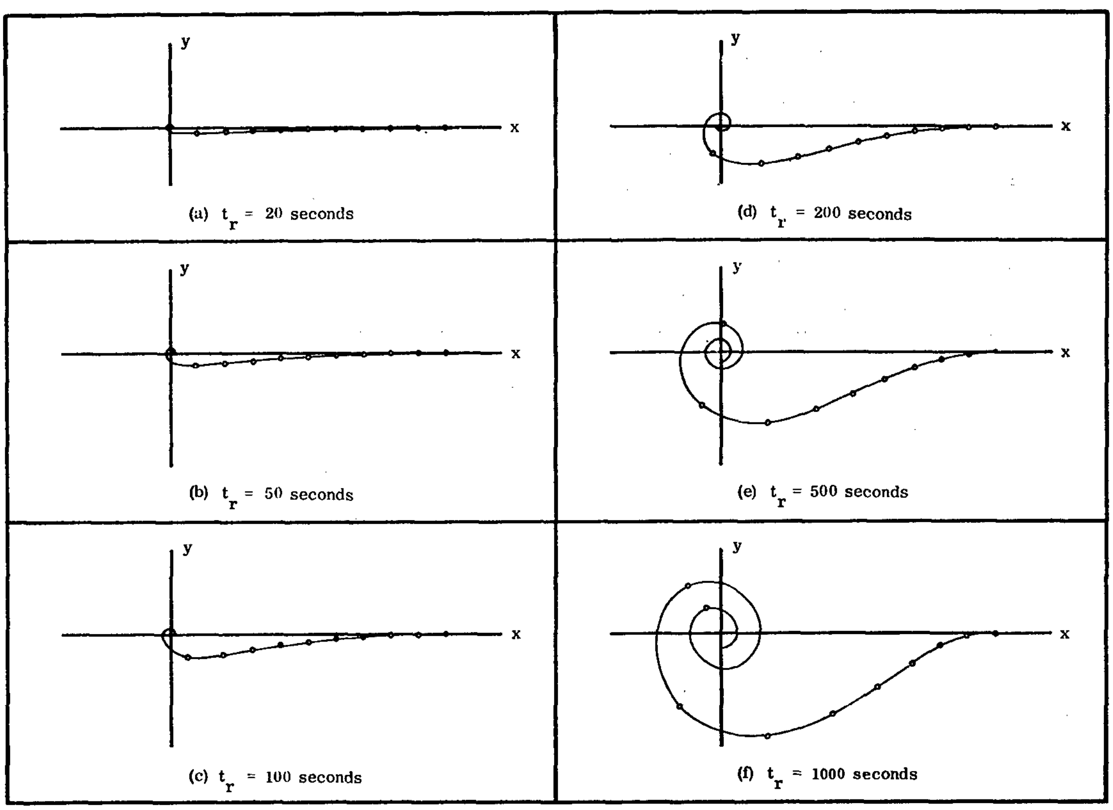

Figure 3. Path of a Mass on the End of a Tetherline if Line Is Reeled in at Constant Speed (Mueller, 1962)

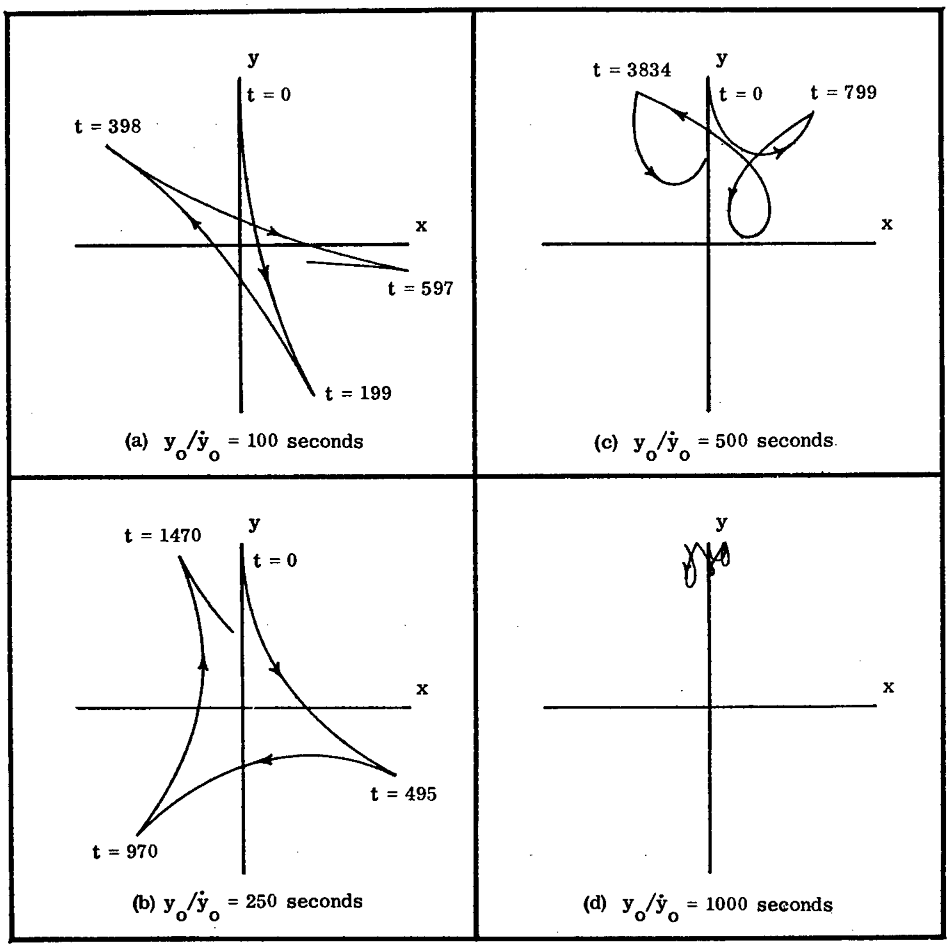

Figure 4. Path of a Mass on the End of a Slack Tetherline after an Impulse (Mass Initially above Vehicle) (Mueller, 1962)

Unfortunately, personal propulsion systems will not be the simple rocket gun devices that served Buck Rogers so well. Because of the difficulty of locating the center of gravity of the body and, further, because the center of gravity of an active human is constantly shifting, single-point propulsion generally results in uncontrollable tumbling (ref. 41). Simons and Gardner (ref. 49) have developed requirements for a personal propulsion system. Agencies such as Bell Aircraft and Chance-Vought are working on devices that may eventually solve the personal propulsion problem.

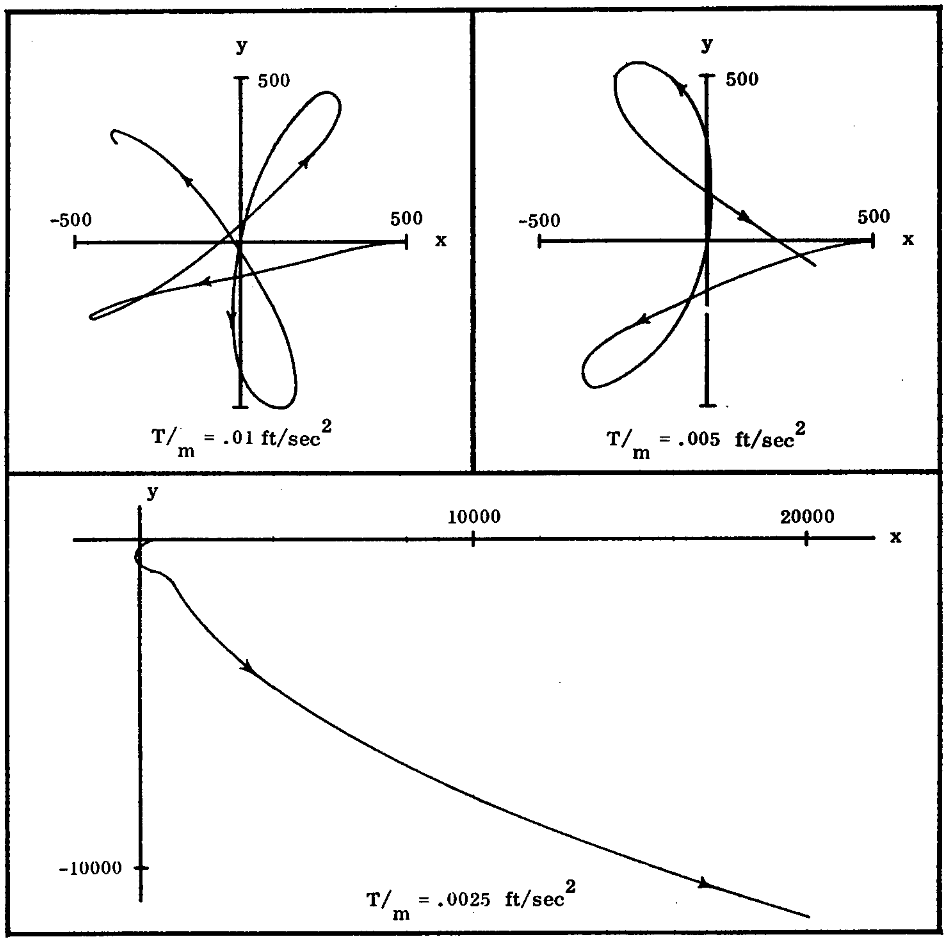

Figure 5. Path of a Mass on the End of a Tetherline if Line Tension is Kept Constant (Mueller, 1962)

Kasten (ref. 26) has compared two possible systems for enabling man to propel himself from one vehicle to another. The subjects were quite successful with one of the systems (measuring success in terms of accuracy, time and fuel consumption). This system employed two control sticks, the left controlling thrust in the fore-aft dimension and the right controlling thrust in the vertical dimension. The subjects expressed strong preferences for the system on which they performed better.

Walking, as a means of propulsion under zero-gravity, presents many interesting problems (ref. 48). Various devices involving magnets, suction-cups, adhesive materials, etc., have been tried with varying degrees of success. One point is of special interest, although the conclusion is based on only four subjects. These four, when asked to walk on the ceiling of the aircraft, stated that "down" shifted toward the direction of their feet as soon as their feet became attached to the ceiling (ref. 48). Everyone and everything else in the airplane was upside down! This strong feeling was independent of whether their eyes were open or shut. In this case the kinesthetic sense is dominant over the visual sense.

But why should man walk at all under weightless conditions? It may be simpler and more efficient for him to soar. Experiments in our C-131 Flying Laboratory show that most men can attain velocities of approximately 9 miles per hour simply by pushing off from the side of a weightless vehicle. We have conducted contests in our zero-g aircraft, and the current world's record holder, Sgt. Harold Espensen, attained a velocity of 13.2 miles per hour! While this is not as fast as a man can sprint, nevertheless it is approximately as fast as he can run for an extended distance, much faster than he can walk, and at only a small fraction of the energy.

To maintain or change his body orientation in space man must learn to control his body movements under weightlessness. Kulwicki, Schlei, and Vergamini have performed a theoretical analysis of the problem of self-rotation (ref. 29), and W.G. Bennett of our Laboratory has verified it in our C-131 and KC-135 aircraft. Proficiency in self-rotation and soaring techniques would enable a man to control himself within space vehicles and even aid in moving from one vehicle to another. However, do not be misled; self-rotation is not easy. At present it appears feasible only if the operator is unencumbered. Many of the required movements can't be executed efficiently, if at all, when the operator is clothed in one of today's pressure suits.

As man moves around his workplace he will find it inconvenient to repeatedly tether himself to the work sites. Dzendolet (ref. 17) has determined by theoretical analysis and by experimentation the body positions that the weightless worker should assume with respect to his work. For example, to exert torque with minimum body movement Dzendolet recommends that the untethered maintenance man position himself so that "...his body is at right angles to the axis of rotation of that which he is to turn..."

Grether (ref. 20) reminds us that, although, with the exception of Titov, no cosmonaut or astronaut has experienced nausea, we still should be cautious about predicting what will happen on extended flights when the crewmembers will be required to move around extensively in the space craft.

Other Effects of Weightlessness

The human's ability to detect differences among weights was one of the first problems to challenge psychologists. In space, however, unless accelerations are induced, objects have no weight. Further, it is probable that many objects will be handled remotely to avoid exposing man unnecessarily to radiation, the danger of suit puncture, etc. In fact, unless there is a significant improvement in the design of pressure suits, there is every indication that working in a space suit outside the vehicle may be restricted to a few emergency operations (ref. 47). As of today, remote manipulation is at least as efficient for many tasks. Crawford and Kama (ref. 15) have studied the direct and remote handling of weights and masses. See figure 6. Note, first, that the difference limen (differential threshold) increases appreciably when a weight is lifted remotely as compared with lifting it directly. Crawford and Kama think this decrease in sensitivity is probably due to the weight and friction of the remote manipulator, which in effect translocates points on the curve out to a position of relative insensitivity.

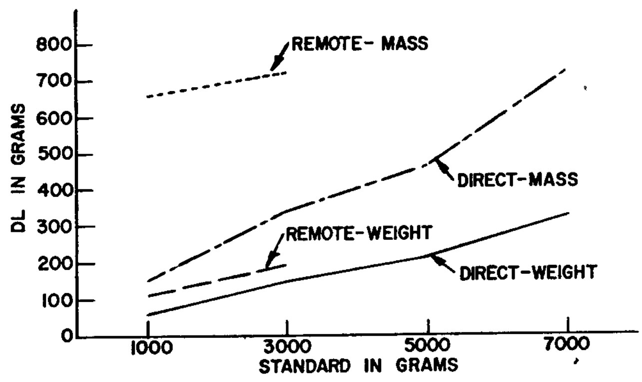

Figure 6. Differential Thresholds for Direct and Remote Handling of Masses and Weights (Crawford and Kama, 1961)

Similar results were obtained when masses were moved (not lifted) directly and remotely. Crawford and Kama note that the loss in sensitivity is roughly proportional to the mass of the components of the manipulator used in the experiments.

Our experience indicates that operations with current remote manipulators generally require six to eight times as long to perform as the same operation performed by direct manipulation. The report by Peters, et al (ref. 47) also suggests that performance in a pressurized space suit may be no better than this in terms of time and certainly would be infinitely more fatiguing. Two conclusions seem inescapable: there must be a vast improvement in the mobility afforded workers in pressurized pressure suits, and we must continue to attempt to improve remote manipulators. The improvements in manipulators and particularly attention to designing equipment that is compatible with the requirements of remote manipulations may make this mode of operation unusually attractive in a wide variety of space operations.

A review of other work on weightlessness done in our Laboratory through 1960 may be found in Hammer (ref. 22) and Loftus and Hammer (ref. 30).

Effects of Other Unusual Environments on Performance

The Mars mission will no doubt find men thrust into the space environment for longer periods than they have ever experienced previously. Unfortunately, it is not an environment one would consider friendly to man. It lacks gravity; in some places it is infested with radiation; it has no oxygen, food, or water; in fact, it even throws stones at him! Fortunately, it appears that precautions can be taken to protect man against all but the most catastrophic of these conditions. That is not to say, however, that we have all the information we need to specify design requirements that will enable man to perform satisfactorily for the entire Mars mission. Review of much of the relevant physiological and psychological information may be found in

Thompson (ref. 52) and in Gerathewohl and Gernandt (ref. 19). As scientists, you are fully aware of the dangers of extrapolation, and while we don't know that extended weightlessness will have any adverse effects on man's health or performance, most assuredly we don't know that it won't. For example, no one is foolish enough to predict exactly what effect extended periods of weightlessness will have on a man's ability to withstand the accelerations that will be experienced during reentry, and, if there is an effect, what might be done to counteract it. Perhaps a regime of selected exercises will be necessary—a "space 5BX program"!

Should experiments in orbital laboratories show that angular acceleration must be induced in our Mars vehicle to provide an artificial gravity, a lower limit of 0.2 G appears to be sufficient (ref. 31). This is not a purely arbitrary figure; it is based on experiments in our C-131 aircraft, and it represents the minimum necessary for essentially normal walking behavior. Although the angular velocity could be increased, even say to 1 G, the Coriolis effect would also increase and with it a greater likelihood of Canal Sickness. There is also evidence from the Naval Aviation Medical Acceleration Laboratory (ref. 10) that a rotation of only 0.06 radians per second (about 1/2 rev/min) may cause the crew to experience illusions. Long booms, radii, etc., also complicate the control problems and limit maneuverability. It certainly appears desirable to hold angular velocity to a minimum and to zero if possible.

Consideration has been given to using the pilot as a backup for the control system even during blastoff. If this is done, the manual control element will probably have to be a device that can be manipulated by only wrist and finger movements. Arm movements are not very precise above 6 G (ref. 10), while wrist and finger movements are still possible at 12 G. Simply holding buttons down or deflecting switches by an amount proportional to the required corrective action would appear to be a possibility, although I have found no data as to the efficacy of this mode.

To summarize this section; while there is considerably information on the physiological effects of accelerations of varying degree and duration, there is not a comparable amount on behavioral effects. One serious limiting factor has been the lack of a battery of tests that could be used to measure these effects.

Any deviation from near-optimum conditions with respect to such fundamentals as temperature, oxygen, and nutrition cannot be tolerated on a mission the duration of our trip to Mars. We expect the engineers to meet the physiologists' requirements with respect to these matters.

In general the effects of radiation on human performance have been negative, even at acute levels of exposures (ref. 46). While the final word has not been written on this matter, it seems safe to conclude that protection sufficient from the physiological standpoint will be sufficient from the behavioral standpoint.

Under a contract with our Laboratory, scientists at Lockheed-Marietta have uncovered some very interesting information regarding work-rest cycles (refs. 1, 2, 3). In one of these experiments five-man crews from the Strategic Air Command spent 15 days in a space-like capsule on a work-rest cycle of 4 hours work and 2 hours rest. Actually these men seldom got over 4 or 5 hours sleep in a 24-hour day during this 15-day period.

Several performance and physiological measures were taken. Two of them are shown in figures 7 and 8. Notice how well performance was maintained for the 15-day period and how a low point in performance was reached each day at approximately 0930. (Perhaps this is the ideal time for a coffee break!) In fact the intra-daily variability is significantly greater than the quotidian variability. Alluisi, et al., at Lockheed also found that by knowing when performance tends to deteriorate, properly motivated crewmembers can overcome the expected performance decrement by extra effort. These decremental effects are subtle, however, and it might require clear, objective evidence to convince a crewmember that there were periods during which his performance was not up to par.

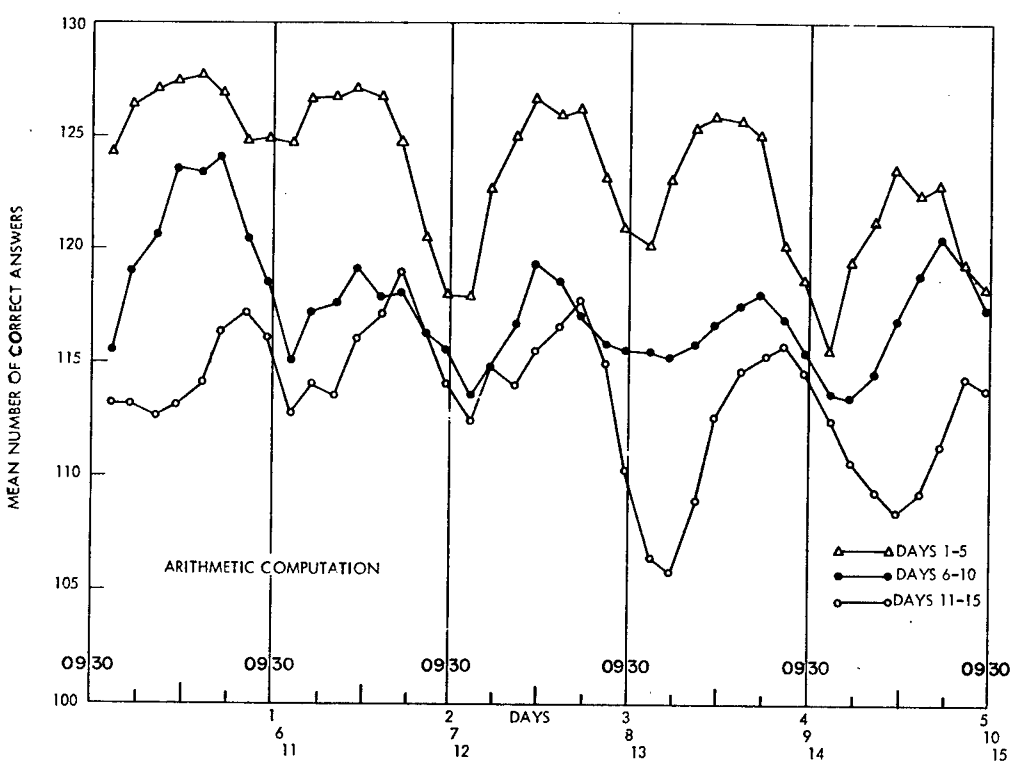

Figure 7. Mean Levels Achieved on the Measures of Task Performance (Adams and Chiles, 1961)

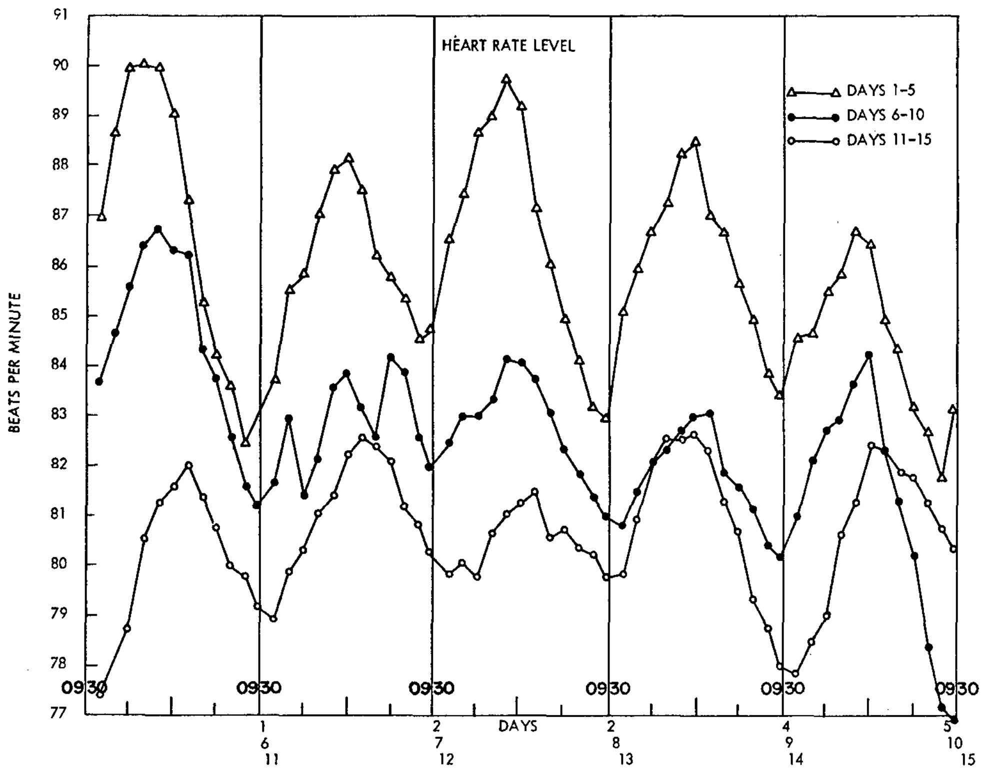

Figure 8. Mean Heart Rate Levels for the 15 Days (Adams and Chiles, 1961)

They also found an element of boredom setting in after the men learned their tasks well. Boredom probably will set in on a trip as long as the Mars journey, although the status that such a trip confers on this select crew should tend to counteract this. Nevertheless, it might be well to give consideration to the possibility of varying the tasks, switching jobs, etc. This, of course, complicates the selection and training program.

Notice also how remarkably the heart rate parallels the performance measures (figure 8). Chiles and Adams demonstrated that two jobs can be manned full time (i.e., 24 hours per day) by only three men. The significance of this finding for the Mars mission is obvious. For a mission the duration of this one, it would appear that a minimum crew of four would be required. A schedule of "4-on" and "4-off" apparently would be quite acceptable and apparently could be maintained for the necessary period.

Chiles also reported that some of the crewmembers revealed in post-mission interviews that although marked interpersonal antagonisms existed among some of the members, these antagonisms were never revealed during the experiment. They simply did not permit personal feelings to interfere seriously with the accomplishment of their tasks. These results suggest that the present screening procedures may be adequate for selecting and assigning men to the Mars mission. This statement may place me in a position of disfavor with many psychologists and psychiatrists because some suggest that fatal frictions may develop unless greatly improved methods for examining the personalities of the crewmembers are developed and applied. One author (ref. 23) states, "The direct effects of confinement, irritability and hostility, and boredom and fatigue could be intensified to detrimental levels. On prolonged flights, the monotony of an unchanging environment may produce striking mental abnormalities in normal human passengers, like impaired thinking, childish emotional responses, disturbed visual perception and hallucinations." This may be so. On the other hand, these men are highly motivated and they have previous experience in trying (difficult) and even hazardous tasks.

Konecci (ref. 28) has summarized what he terms basic human "wants." Some of these, such as desire for recognition, desire for adventure, desire to overcome obstacles, satisfaction from exercising intelligence, will be abundantly satisfied by this mission. Some, such as freedom from discomfort, desire for security, and desire for sexual gratification will not be satisfied (the latter could be if the composition of the crew is changed!). In general, we feel that this mission will satisfy some of man's nobler needs and we believe that these will sustain the crew.

Isolation and confinement are other areas where I take what some might consider to be a dangerous minority view. Without minimizing the importance of these problems, I believe that the results of certain experiences and laboratory experiments have been uncritically accepted as being relevant to a mission such as the one we have under consideration when, in fact, they are irrelevant. If we recognize the problems that might develop, I believe that we can design aroung them.

The present state of apprehension concerning isolation has arisen from such sources as Admiral Byrd's confinement in the Antarctic; Bombard's 65 days on a life raft; solitarily confined prisoners of war; volunteers isolated in dark, anechoic chambers, or suspended under water with nothing to do, etc. I feel that all of these experiences are of considerable scientific interest, but completely irrelevant to the Mars mission. Our crew will be physically confined, but it will not be mentally confined nor will it be isolated. There must be facilities for communicating with earth stations and with each other. The members will not suffer stimulus impoverishment (in fact, perhaps just the opposite) if their vehicle and their jobs are properly designed (and probably even if they are not!). I hope that it doesn't require a series of experiments to convince us that the crew should be provided with a clean, well-lighted vehicle with comfortable and attractive work stations and rest areas, good food, and palatable liquids. "Good food" here means the food each personally prefers. If nutritional problems are apt to develop as a result of their selections (and I doubt that such would be the case), send along some vitamin-mineral capsules.

The real challenge will be to design a system that will require and will use the crewmembers in essential jobs that are challenging enough to prevent monotony and boredom, yet sufficiently below their maximum level of capability to allow for possible performance deterioration or for emergencies. Chambers (ref 10) has concluded, after years of research on the effects of acceleration on performance, that deterioration in performance will occur as measured in terms of our usual criteria of speed, accuracy and variability. And, significantly, this deterioration appears to affect performance along the entire spectrum of complexity, from the simplest of tasks to those involving integration and judgment. Unfortunately, the excellent Naval program has not been duplicated with other stressors, so we cannot be certain to what extent the results Chambers reports are due to the accelerative components as contrasted to what may be termed a "general stress factor." Undoubtedly, some is due to the latter.

Jobs should be designed so that the majority of a man's waking hours, other than the time required for personal necessities and short rest periods, is filled. But the jobs must not entail the performance of sham tasks that are included simply to keep the crew busy. This would be degrading and repulsive to the type of men who will participate in this mission.

Some writers seem ready to accept the position that automatic systems will do most of the work in space vehicles. To quote directly from one of them (ref. 7), "As personnel may have little to do other than keep a constant watch on banks of instruments, it may be assumed that the problem of monotony will become acute." And later in the same report, "Automatic devices may leave crewmembers with very little to do. Under such circumstances—viz., prolonged inactivity and greatly reduced sensory input—hallucinations are not unlikely." I thoroughly agree; under such conditions, hallucinations are almost <u>certain</u> to develop. The point is that this sort of design philosophy is completely unacceptable for a <u>manned</u> vehicle. If systems designers do the job this way then they either should leave man out of the system completely or make him a completely passive passenger by knocking him out until the vehicle reaches Mars and doing the same on the return trip.

Finally, there must be crew discipline and one man must be in charge. Crises probably will develop, and a well-trained, well-disciplined crew acting under the leadership of a mature, respected man will have the best chance of surviving.

The most challenging question with respect to the effects of unusual environmental circumstances on performance has received very little attention; that is, what are the effects of multiple stresses on performance? Are such effects described by a simple summation of the individual effects, or are the effects less or greater than a simple additive relationship would suggest? The following general formulation was adapted from material prepared by Dean and McGlothlen of Boeing (ref. 16), who are engaged in research in this area.

$$\text{additive: } E_{a',b\ldots n} = E_a + \ldots E_n$$

$$\text{less than additive: } E_{a',b\ldots n} < E_a + E_b + \ldots E_n$$

$$\text{more than additive: } E_{a',b\ldots n} > E_a + E_b$$

Where

$E_{a',b\ldots n}$ = total effect of selected stressors and E_a, E_b and E_n are measures of the effects of individual stressors.

Dean and McGlothlen worked with three stressors (hypoxia, noise, and elevated temperature), using performance on a primary task (tracking) and secondary tasks (meter monitoring and radar warning) as their criteria. They found a "less than" additive effect on the primary task and a "more than" additive effect on the secondary tasks. In other words, combining stresses had the effect of causing the human operator to overcompensate on the primary task at the expense of the secondary tasks. This result is consistent with the view held by many that undue fatigue and/or stress causes a pilot to neglect peripheral tasks (e.g., checking engine instruments) in order that performance on his primary task (e.g., attention to the artificial horizon) may be maintained. More work is urgently needed in this area.

Interestingly, and unfortunately, Dean and McGlothlen found a consistent additive effect on three physiological measures (heart rate, respiration rate, and rectal temperature). Thus, even if all the individual stresses are within some "safe" region, we cannot be sure that their combined effect will still be tolerable. The additive effect has been found also at the USAF School of Aviation Medicine (ref. 50). Death is produced in animals exposed simultaneously to a dose of radiation and to a concentration of oxygen, neither of which alone would have produced death. However, that this is not the entire story is shown by the fact (SAM study also) that when an animal is exposed to a dose of radiation that ordinarily would be lethal plus a reduced concentration of oxygen that would be harmful but not lethal, the animal does not die! Clearly, we had better get "back to the laboratory" in the area of effects of simultaneous exposures to various environmental factors.

Intellectual Skills

If man's only contributions to this mission were the sensitivity of his sensors and his motor capabilities, it would be foolish to include him. His greatest contribution will be in that realm which we term "intellectual." Some of the more important qualities in this area that we might mention are monitoring, flexibility, adaptability, judgment, redundancy, and long-term memory.

Monitoring, unfortunately, has been treated (and equipment so designed as to make it so) as a monotonous, humdrum task. If our monitoring tasks are comprised of no more than an awareness of the presence or absence of a simple signal, we feel strongly that every effort should be made to accomplish the task with equipment. Man should be used to interpret the meaning of attention-demanding signals and determining suitable courses of action. If man is expected to determine and pursue courses of corrective action, every effort must be made to keep him apprised of the situation as it develops. Bray of the Smithsonian Institution terms this "development of context." It is believed to be a necessary condition for the exercise of judgment. What do we mean by "judgment"? If, in a given situation, one makes a decision and it turns out well, we say that he has "good judgment"; if things turn out unsatisfactorily, we say that he has "poor judgment." We feel that a simple, working definition of judgment could be the following: Judgment is the process of selecting those factors that one feels are relevant in a given situation, applying weights to each factor, and using these weighted factors to arrive at a solution. If the selections and weightings are judicious, one will arrive at a satisfactory solution, and people will say that he exercised "good judgment." Unfortunately, the converse is also possible. The point is, good judgment can result only if one has sufficient knowledge regarding the relevant variables and their relative importance. The designer must provide for this—the design for the development of context.

I do not mean to imply that our crew on the Mars mission will be only "decision-makers." There will be many mundane tasks that they can perform as well or better than machines. Let this one point be made unequivocally clear: as engineering psychologists, it is not our desire necessarily to make man's lot an easy one on the Mars mission; he must be used so as to contribute maximally to the effectiveness of the mission. The screwdriver and pliers or their space counterparts will form an essential part of the spaceman's armamentarium.

One such task that man will perform will be maintenance. Fortunately, the specimens who will be selected to fly this mission will require very little physiological maintenance themselves because Nature has provided an enormously efficient and sophisticated set of repair mechanisms within man that require very little attention in the healthy adult. They require only some food, water, elimination, a little rest, and maybe an occasional aspirin! Attempts have been made to do something similar to this with equipment, of course, by the use of redundant circuitry and feedback mechanisms, but the comparative reliability and efficiency in terms of weight, attention required, etc., is still heavily in favor of the human. This is particularly true if functions other than the simplest sensing and reaction are required. Man, however, will require psychological maintenance—proficiency in skills, morale, etc.

Physical Anthropology

The role of the physical anthropologist in increasing mission effectiveness and in combating the effect of unusual environments is important. While I am not qualified in this field, perhaps my nonprofessional comments will be better than none.

The design of protective garments and workplaces for extended space missions demands a knowledge of body dimensions that has become available even in preliminary form only in the past few years.

Figure 9 is essentially a contour map of the human body. When refinements such as these in the techniques of body measurement are perfected, they will represent an enormous advancement in precision over the length and girth measurements of the past. Theoretically, essentially similar human contours may cover rather different masses with respect to ratios of bone, tissue, fat, and other body constitutents. Body proportions are easily studied by this means also. Our physical anthropologists are at work on this problem. But the technique is only a means to an end, not an end in itself. One major goal of the physical anthropologists is the accurate and detailed description of human body size, proportion, and typology throughout the spectrum of flying personnel to assure that aerospace garments and cockpits will properly fit the using populations and enhance the effectiveness of each crewmember.

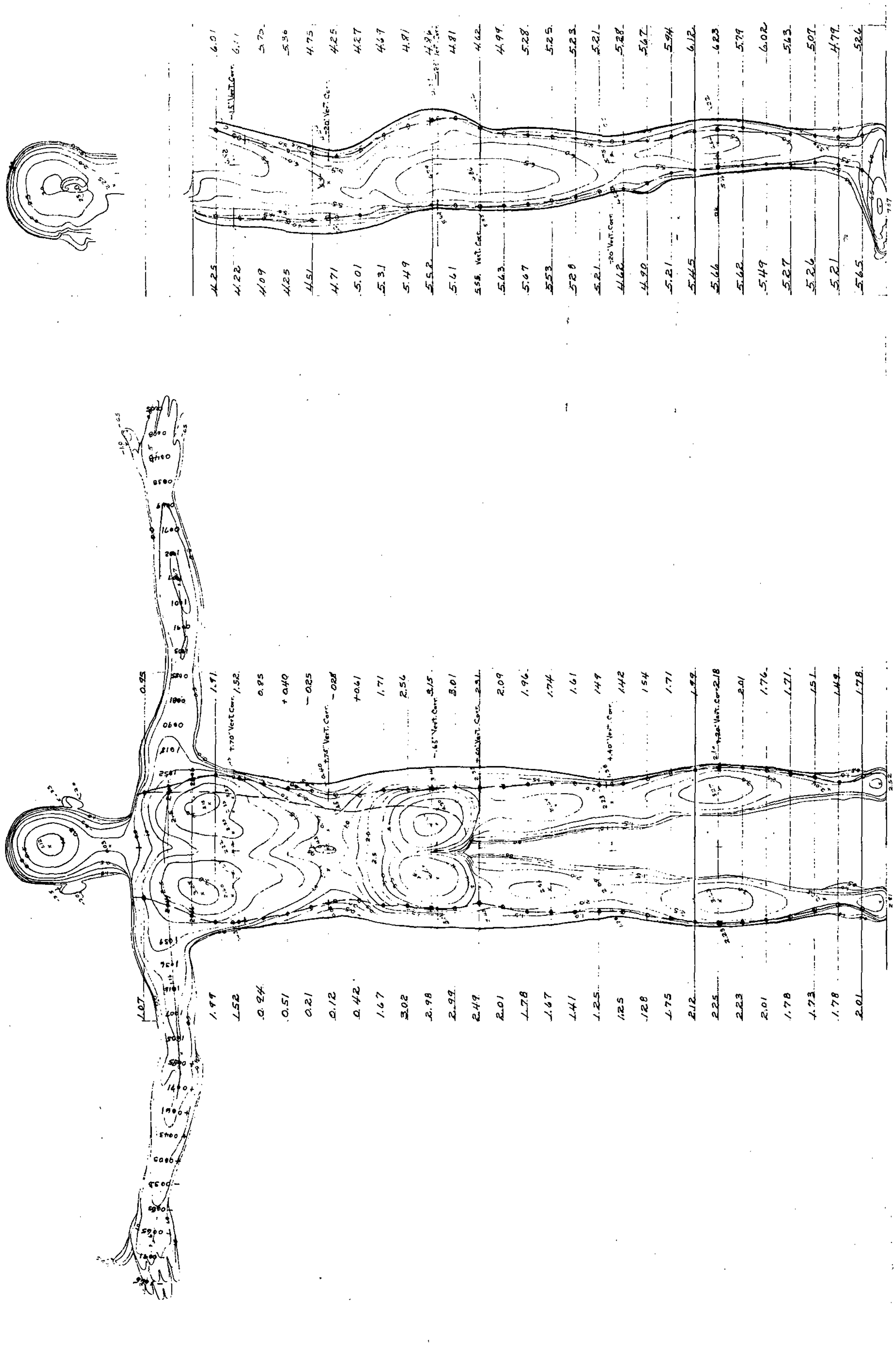

Figure 9. Contour Map of the Human Body

Human Variability

Finally, I would like to say a word in defense of human variability. It is natural for a design engineer to decry the fact that humans are so variable, among individuals even within the same individual at different times. I remind you that without this variability there would be no human learning nor would we have the advantages of such human traits as adaptability and flexibility. Instead of decrying human variability, I suggest we determine best how to take advantage of it.

CONCLUDING REMARKS

The Use of Man to Study Space

Even a cursory consideration of the Mars mission will convince most that man has certain qualities that will enhance both the chances of completing the mission and of obtaining useful information from the exploration. It is imperative, however, that an analysis, as detailed as possible, be made immediately of the exact nature and requirements of the mission so that representatives of the behavioral sciences can help systems planners estimate where and how man will be used and so the behavioral scientists can, if necessary, conduct additional research. While there is an enormous amount of applicable research, certain questions still cannot be answered. Particular emphasis is due the design of suitable controls and displays, design for ease of maintenance, the effects of long-term weightlessness and the effects of multiple stresses.

The Use of Space to Study Man

Finally, it is confidently predicted that the research that space travel will inspire in the behavioral sciences will significantly broaden our understanding of the nature and meaning of human behavior. My bias compels me to suggest that these constitute the greatest mystery of all and their eventual solution will be more rewarding than any physical phenomena that may be uncovered on Mars or anywhere else in space.

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Rpt. No. AMRL-TDR-63-81. PSYCHOLOGICAL ASPECTS OF EXTENDED MANNED SPACE FLIGHT. Final report, September 1963, v + 29 pp. incl. illus., 56 refs. Unclassified report

As is the case with virtually all of the other scientific disciplines, the adequacy of available psychological knowledge and principles will receive a severe test from the demands attendant to the development of a successful mission to Mars. A sampling of some of the relevant information available in psychology is offered and areas that will require further attention before predictions in the behavioral area for the Mars trip

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