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BIOMEDICAL AND HUMAN FACTORS REQUIREMENTS FOR A MANNED EARTH-ORBITING STATION

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FOREWORD

The Biomedical and Human Factors Requirements Study was performed under NASA contract NASw-775 by the Life Sciences Department of North American Aviation, Space and Information Systems Division. The Study effort was directed by Dr. J. B. Reynolds. The biomedical effort was the responsibility of J. T. Celentano, M. D.; the behavioral effort was the responsibility of Reuben Baer, Ph. D., in association with J. J. Wulff, Ph. D. Mr. L. V. Jensen was responsible for the human engineering portion. C. G. Battig, M. D., was responsible for biomedical instrumentation. Mr. B. B. Adams was assistant to the program manager.

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I. INTRODUCTION

REQUIREMENTS

Weightlessness remains the single variable of interest for manned space flight that cannot be studied in any situation short of orbital flight. Radiation, temperature, pressure, high-G loading, noise, vibration, environmental control system parameters, isolation, and confinement can be manipulated and controlled on the ground for determination of their effects upon man, at least to a degree where reasonable projections to space operations can be made. As a consequence, human response to extended weightlessness remains unknown and will continue so until extended orbital flights have been accomplished. Whether man can survive under conditions of extended weightlessness is only one of several questions that can be asked. Of equal, if not greater importance, are such questions as: (1) Given certain effects, less than lethal, what are the exact nature of these effects? (2) What steps can be taken to alleviate observed effects that degrade human functioning and how effective are such procedures? (3) What are the long-term effects following exposure to extended weightlessness? With this knowledge, space systems and conditioning regimens can be designed for crews exposed to weightlessness. Where long-term, irreversible effects following exposure are known, the occupational hazards of space flight can be evaluated; and realistic decisions can be made with respect to them by both space program management and the crew participants.

Human response to acceleration offers a parallel to response to weightlessness. The most pertinent question is not whether man can survive accelerations greater than 1 G. The question has no unequivocal answer; he can survive some but not others. The questions of greatest importance are what are the effects of acceleration upon the human organism and its performance, and how can systems be designed to ameliorate the effects and compensate for human response limitations under acceleration? Acceleration devices and experimental test programs provided data relevant to such questions that have guided design of Mercury, Gemini, and Apollo systems. A test vehicle, a laboratory, and an experimental program to provide comparable data for weightlessness are required to provide the basis upon which the safe and effective use of crews in long-duration space missions can be firmly established.

The requirements for the test vehicle and its associated subsystems, the laboratory facility, the experimental personnel and subjects, and the experimental program are interdependent elements in the total program for

assaying weightlessness effects. None can be specified exactly since all are subject to trade-off decisions. The experimental program determines requirements for laboratory facilities, personnel, vehicles, and support systems and is the natural point of departure for the life scientist concerned with the weightlessness problem. Experimental programs must inevitably change in time; and if laboratory facilities are too exactly tailored to predetermined programs, they may not be readily adaptable to changes in program. This sets requirements for laboratory facilities viewed independently of program requirements. Since the development and production of a space station laboratory facility; the development and management of the experimental programs; and the unique research operations including selection and training of personnel, ground testing and simulation, in-orbit testing, and data handling; and ground surveillance would represent not more than 10 percent of total program costs, hardware systems and logistics support costs must inevitably set constraints for realistic programs. A realistic experimental program, however, must be realistic not only from the standpoint of minimizing costs but must be realistic in the sense of providing data upon which decisions can be made with the greatest confidence. Costs of a space station program, then, cannot be the overriding determinant. An inexpensive program that does not provide adequate data to answer the questions and make the decisions may turn out to be very expensive indeed.

An experimental program must be realistic not only from the programmatic objectives and costs point of view, it must be realistic in the sense of being limited to essentials. Experimental features that are nice to have in the interest of precise design of tests and investigations must be carefully evaluated to ensure that they are more than experimental niceties. Continuous variation and precise separation in the values of an experimental variable, avoidance of the confounding of the effects of several variables, separation of clinical and experimental objectives in research, and limiting of subjects to a reasonable minimum of testing are all features that contribute to precision in interpretation of results. In a realistic program, however, these features may present unattainable objectives without expenditures beyond any reasonable program budget.

For the determination of the long-term effects of weightlessness, the requirements are for a realistic experimental program, a laboratory facility of which the main component is a biomedical and human factors measurement system, and a space station system for the implementation of the experimental program. The study reported here was directed at providing data on such a realistic experimental program with its facilities and systems requirements.

STUDY OBJECTIVES

The study had three main objectives. The first was the development and evaluation of measurement programs for the assessment of long term

effects of exposure of crews to weightlessness. The second was the determination of requirements imposed on space stations by the measurement programs. The third was the performance of trade-off studies between the requirements imposed by measurement programs and the constraints imposed by space station parameters.

Measurement Programs

The objective of the measurement program study was the development of (1) lists of biomedical and behavioral measures, (2) the rationale in terms of the theoretical and empirical bases for selection and evaluation, (3) criteria and techniques for evaluation of measures of weightlessness effects, and (4) lists of equipment to perform measurements.

Systems Requirements

The objective of the systems requirements studies was the specification of such requirements as (1) power, weight, and volume for measurement packages; (2) time for performance of measurements; (3) frequency of measurement; (4) number and kinds of subjects; (5) qualifications of experimental personnel; (6) rotation schedules for experimental subjects.

Trade-Off Studies

The objective of the trade-off studies was the determination of the effect of the measurement program upon space station system parameters, the effects of station parameters upon the confidence of the data derived from the measurement system, and the specification of optimum measurement systems given specific station system constraints.

APPROACH

The approach taken in this study is analytical rather than experimental and systems oriented rather than centered solely upon instrumentation problems. This latter was dictated not only by the importance of systems considerations but because the study was aimed towards the development of a crew measurement system which could be integrated into an orbital space station. The analyses fell within the tasks described in the following paragraphs. It should be kept in mind, however that in a study of this type it is often difficult to separate activities into definitive tasks.

Task I. Background Analysis

Environments Analysis

Environmental factors relevant to space station design and operation were considered, with an end to identifying: (1) behavioral and biomedical measures to detect weightlessness effects; (2) interactive effects of weightlessness and other variables upon crew behavior and physiological integrity; (3) measurement devices and techniques compatible with on-board station environments.

Configuration Study

The configuration study served to identify important systems constraints such as power, weight, volume, layout, crew size, mission profile, and to provide examples for determining feasibility of integrating crew measurement systems into representative stations.

Task-Function Analysis

Stations such as Apollo, MORL, and MOSS, and other station types and planetary missions were analyzed. The task-function analysis was intended to identify: (1) performance to be predicted in future missions, (2) tasks to be used for measurement purposes, (3) time available for crews to act as subjects and experimenters for measurement activities.

Task II. Measurement Analysis

Initial Ranking of Measures

The ranking of measures involved an initial determination of all measures likely to be required to detect the effects of weightlessness upon physiological functioning and performance including a preliminary ranking based upon such criteria as relevance and reliability.

Measurement List Development

Complete lists of biomedical and behavioral measures were developed together with associated confidence ratings.

Techniques and Equipment

Techniques and associated equipment were identified for each measure, and alternate techniques evaluated. The use of mission tasks, simulation, and laboratory tests for assessment of crew performance was evaluated.

Requirements

Requirements placed on space station systems were identified with particular reference to power, weight, volume, crew size and composition, and time and frequency of measurements.

Task III. Selected Station Analysis

Specific crew measurement systems were developed for selected space station configurations, their feasibility evaluated and trade-off studies conducted.

Task IV. Crew Measurement System Development

This task involved the development and evaluation of a crew measurement system in terms of confidence levels, experimental programs and designs, equipment, instrumentation, configuration, support elements, data treatment, and crew requirements. The performance of systems trade-off studies was evaluated to maximize confidence in prediction and minimize requirements placed on systems.

SYSTEM CONSIDERATIONS

The selection of a system for measuring weightlessness effects is determined to a great extent by the space station system into which it is integrated. The obverse is also true in that the choice of station is in large part determined by the demands of the measurement system. The more significant aspects of system choice are outlined below and developed more fully elsewhere in this report (Section IV).

Large Versus Interim Stations

The term "interim stations" refers to stations of moderate size of which the Manned Orbital Research Laboratory (MORL) is representative. Implicit in the designation "interim" is the tacit recognition that such stations provide a link between manned orbital vehicles and large space stations designed for indefinitely long-term periods of occupancy.

Large stations now under study in both the rotating and the zero-G configurations are identified as Manned Orbital Space Stations (MOSS). Since these are contrasted with interim stations, they can be presumed to be intended for long-term use. They are considered more costly than interim stations (particularly in terms of initial hardware procurement). The total cost of a space station program depends very heavily upon the mission and the operational requirement. Cost differences between large and interim

stations are neither obvious nor necessarily sizable and are determined by the interpretation of what constitutes significant differences.

There are two questions with respect to large and interim stations as far as measurement systems are concerned. The first is whether a realistic measurement program can be achieved within either type of station. The term "realistic" is used advisedly since it is obvious that programs which are possible when incorporating a large station are not possible using an interim station. Several experimental groups, employing different treatments or measurement programs, may be exposed to weightlessness simultaneously with both MOSS systems. Exposure of groups to zero-G and varying levels of artificial G can be achieved under optimal conditions with a large radial station.

If the same programs cannot be accomplished by interim and large station systems, the extent of loss of confidence in data obtained must be considered when the measurement programs are compared.

It has been felt that the first decision to be made, with respect to stations, will be the selection of either large or interim stations. As a consequence, data have been accumulated and evaluated with relevance to this decision uppermost.

Interim Station Alternatives

If the decision is for an interim station, the question immediately arising is which station is most appropriate for measurement programs? Three alternatives can be identified: (1) the MORL currently under study by NASA contractors; (2) what can be designated augmented Apollo, based upon the Apollo capsule, but modified and supplemented by additional modules or by joining capsules; (3) what can be designated minimal Apollo. (Minimal Apollo is essentially the basic Apollo capsule modified for longer term orbital flight and has been called Concept I in studies of extended Apollo missions.)

The choice between interim stations as far as measurement systems is concerned is not as straightforward as that between interim and large stations. In the studies which have been conducted on the measurement system requirements the interim stations have been categorized into two classes, with the augmented Apollo and MORL stations in one and Apollo Concept I in the other. This differentiation was made in terms of system constraints (e.g., volume, mission profile, crew size) and not on costs or other systems considerations.

Incremental Versus Complete Approaches

Two approaches in studying long-term effects of weightlessness can be distinguished. First, is what has been termed the incremental approach. In

this approach the proving out of man's capabilities under long-term weightlessness proceeds by steps, with each step representing increasing exposure to whatever hazards are presented by weightlessness. Following the Gemini and Apollo orbital flights could come flights of one to two months, the period of exposure increasing with increasing flights. With the demonstration of man's capabilities, the isolation of problems and the development of solutions, the move would then be made to longer flights and more elaborate systems. The incremental approach is implicit in the interim station concepts and is illustrated by the Mercury, Gemini, Apollo progression.

The second approach is what may be termed the complete approach. In this the procedure is to go directly to the more advanced system, using it to prove out man's capabilities and to perform all other missions planned for stations.

The safety considerations in the two approaches as far as space stations are concerned are not as important as they might be with other systems. Crews can be exposed initially to long-term weightlessness with a large, sophisticated station as safely as with an interim station, provided the facilities for recovering crews are comparable. To make them comparable can involve differences in cost in time and money.

As far as the measurement system is concerned, the data pertinent to the choice between large and interim stations are pertinent to the choice between interim and complete approaches. Apollo Concept I flights must be considered the seventh step in an incremental approach with aircraft parabolic, X-15, downrange Mercury, orbital Mercury, orbital Gemini, and orbital Apollo flights respectively as the first six. The question to be answered relevant to the measurement system is what information needs to be obtained in the next step and what is required to obtain it?

CONSIDERATIONS OTHER THAN WEIGHTLESSNESS

The studies reported here have centered on the problem of weightlessness. Other factors have been evaluated, however, and continued consideration will need to be given to these as the measurement programs are developed.

Crew Status Assessment

It may be impossible to develop a measurement system for detecting the effects of weightlessness unique to that purpose. An acceptable measurement system will certainly be capable of assessing crew status from a biomedical and behavioral point of view, whatever stresses are involved. This fact has been kept in mind in specifying crew measurement system requirements.

In particular, attention has been directed towards measures that will allow ground flight crews to assess the status of on-board crews and to make abort decisions confidently.

Environment Factors

Environment factors other than weightlessness have been considered for two reasons. First, the emphasis upon weightlessness in the experimental programs for space stations requires the establishment of the environment most likely to prevent the emergence of other variables as significant determinents of degradation. Second, other environmental factors had to be studied to identify variables which could interact with weightlessness or whose effects could be mistaken for those ascribed to weightlessness. A discussion of some of these factors follows.

Radiation

The types and energies of radiation that will be encountered in orbital flights are reasonably well defined and their effects well known. Earth orbital flights with apogees less than 600 km will avoid the bands of trapped radiation and have to deal only with cosmic and galactic radiations of lesser intensities. There are no good evidence or well-considered hypotheses to suggest that weightlessness will lower the body's tolerance to radiation so that limits that are considered safe at sea level may pertain to space flight. To control the experimental conditions, radiation levels should be selected which produce no measurable change rather than those which produce no lasting damage.

Oxygen

Although humans can easily adapt to concentrations of oxygen in the breathing mixture below that found at sea level, the adaptive mechanisms initiated by this change to reestablish homeostasis would be undesirable as active mechanisms during an investigation of the effects of weightlessness. Oxygen does not become usable by the body until it reaches the blood stream. It is, therefore, the oxygen content of the blood that governs the activity of the compensatory reflexes. These reflexes result in a change in heart rate and an alteration of vascular resistance in specific areas of the body.

Some reduction of the oxygen tension could be tolerated without measurable changes occurring in the respiratory or cardiovascular systems. However, if the inspired pO_2 drops below approximately 167 mm Hg (3.23 psi), corresponding to a pO_2 of approximately 80 mm Hg for the alveoli, the compensatory changes become significant and probably occlude or confuse any changes initiated by weightlessness.

Inert Gas

There is considerable controversy over the efficiency of including an inert gas in the breathing mixture. Arguments for its inclusion involve the avoidance of possible alveolar collapse thought by some to be possible when a subject is breathing 100-percent oxygen, the reduction of the fire hazard of a pure oxygen environment, and the resultant ability to increase the over-all environmental pressure without having to increase the pO_2 beyond tolerable limits. The arguments against the use of an inert gas include the greater engineering complexities of a two-gas system and the greater possibility of bends if a sudden, further decompression occurs during mixed-gas breathing. It is felt here that, although investigations to date have not definitely confirmed any of the deleterious effects attributed to breathing 100-percent oxygen at pressures between 3.5 and 5 psia, there has been an insufficient number of such investigations to eliminate the possibility that such effects exists. Therefore, to eliminate the possibility of confusing the effects of breathing undiluted oxygen with those caused by weightlessness, it has been assumed, an inert gas will be included in the breathing mixture.

Over-All Pressure

A reduction in the over-all environmental pressure below that found at sea level will probably be accepted by the subjects without physiological change as long as the pO_2 remains essentially unaltered. Reductions below 5 psia would be undesirable because the incidence of bends increases at such pressures. But above this figure, no effects attributable to low pressure per se have been noted in the many simulations which have been performed. It should, however, be repeated again that the closer the spacecraft environment can approach that of earth and allow the lack of gravity to be the only independent variable, the more controlled will be the experiment and the more dependable the results.

Carbon Dioxide

The problem of CO_2 removal presents some difficulties. This gas is contained in the atmosphere in small quantities (0.03 volumes percent, or about 0.23 mm Hg). Although increases in the concentration of CO_2 in the atmosphere up to 15 mm Hg can be tolerated for prolonged periods without deleterious effect, even slight increases of 0.1 mm Hg can significantly affect the respiratory rate. It will probably be beyond the capabilities of any presently developed CO_2 removal system to reduce the CO_2 in the cabin atmosphere to terrestrial concentrations; however, the system should be so designed to restrict the CO_2 concentration to levels below 3.5 mm Hg. Careful studies will, of course, have to be made on the crew prior to the flight to establish physiological baselines for the changes induced by any resulting increase in the CO_2 concentration.

II. MEASUREMENT ANALYSIS

RATIONALE FOR SELECTION AND EVALUATION

G EFFECTS

Biomedical Aspects

Zero-G Effects

One of the prime objectives of placing a space station in orbit is to study the effects on man of long-term exposure to zero G. At present such data are lacking. Necessarily then, the biomedical analysis represented in this report is in part the result of speculation based upon the limited experimental data available on the subject. Information on the physiological effects of weightlessness has been obtained from the following sources:

1. Animal and human exposures to short-term weightlessness in ballistic vehicles, aircraft flying Keplerian trajectories, and drop towers

2. Short-term orbital space flights

3. Studies of prolonged bed rest, immobilization, and water immersion—these being construed as in part physiologically analogous to weightlessness

4. Reverse extrapolations of data obtained from biological systems exposed to increased G's.

In addition, it is possible to speculate as to the presumed logical consequences of zero-G exposure upon a number of basic physiological systems on account of their gravity dependence.

It appears fairly safe to say that exposure of man to weightlessness for short periods of time has not proved intolerable or permanently injurious. However, the quantity, types, and completeness of the information does not satisfactorily permit an extrapolation to prolonged flights of months or years. Moreover, the findings reported to date may very well be the result of individual idiosyncracies, because the number of subjects exposed to this

new environment is too small to provide statistically valid data upon which to form reliable conclusions. Hence, this study was initiated as part of a zero-G manned space station program.

What, then, are the real and conjectured difficulties anticipated with prolonged weightlessness? So far, there is direct experimental evidence of only a few physiological aberrations:

1. A temporary loss of cardiovascular reflex adaptability upon return to earth, expressed as a tendency to postural hypotension with a decrease in systolic blood pressure, tachycardia, and venous distension in the lower extremities

2. A redistribution of fluid among the various body fluid compartments with inappropriate urinary output in the face of dehydration occurring in at least one flight

3. Increased urinary calcium excretion (Here, however, the data are admittedly equivocal.)

The aspect of weightlessness most provacative of speculation and concern is its possible long-term cumulative effect in producing adaptive changes in basic body systems. Presumably, these adaptations would enable the body to function better in its new environment. Of concern, however, is the possible loss through disuse of those adaptive mechanisms acquired through continuous exposure to the earth's gravitational force. While this loss should cause no difficulty in the weightless state, a sudden increase in gravitational forces during reentry or the return to normal earth gravity may find the body ill adapted to respond to this stress. One example of this is the transient loss of cardiovascular reflex response upon return to earth noted in at least one astronaut.

Further speculation based upon assumptions and analogies with states felt comparable with weightlessness in their effects on physiological systems suggests other conditions of possible concern. Prolonged bed rest, water immersion, and physical inactivity have been employed by a variety of investigators to simulate the effects of weightlessness on certain systems, notably the cardiovascular and musculoskeletal. Although these situations are at best only analogous with weightlessness and not valid simulations, observed physiologic changes may be postulated as also occurring, to various degrees, during exposure to prolonged weightlessness, and are discussed in the following paragraphs.

Circulatory System. The circulatory system possesses characteristics that are significantly influenced by changes in the direction and

strength of related inertial or gravitational forces. As the longitudinal axis of man is shifted in the earth's gravitational field, the influence of this force is reflected in the pressures and in the compensatory activities of the circulatory system. When man is in an upright position, a differential exists between the pressure in the superior arteries and that in the lower arteries, the hydrostatic pressure of the column of blood combining with the vis a tergo from the heart to produce the higher pressure in the lower vessels. This differential disappears when man assumes a prone position. Further, when the body axis is reoriented from the horizontal to the vertical, a pooling of blood can be observed in the veins and capillaries of the lower extremities and viscera. This pooling is accompanied by a reflexogenic increase in heart rate and a vasoconstriction particularly in the areas of the pooling. These changes may be demonstrated most dramatically by means of a tilt table, which can reorient the individual passively, and to a lesser extent when an individual rises from a prone position through muscular effort.

The compensatory activities of the heart and blood vessels are directed toward the maintenance of blood pressure, not withstanding the reduction of venous return engendered by the pooling; they are supplemented in this effort by tonic contractions of the musculature of the legs and abdomen. Although normally adequate, these compensatory activities are sufficiently reduced by prolonged bed rest and the passive reorientation of the tilt table that subjects frequently feel dizzy or lose consciousness.

The normal daily activities of man; his frequent shifts among the supine, sitting, and standing positions; and the relative lengthy periods that he spends in the upright position continually activate his compensatory reflexes and maintain a tone sufficient to satisfy all normal demands. The inability of these reflexes to respond adequately after prolonged bed rest or water immersion indicates that the normal tone is lost when the demands placed on the system are extendedly decreased.

In consideration of these observations, the following questions arise concerning the function of the circulatory system ensuent upon prolonged exposure to zero-G.

1. Would any deterioration occur in the circulatory system which would interfere with the routine activities of man in the space environment?

2. Would any deterioration occur in the circulatory system which would interfere with the rapid mobilization of circulatory reserve in such cases of stress as hypoxia or severe muscular exercise?

3. Would any deterioration occur in the circulatory system which would interfere with the return to earth and successful readaptation to a one-G environment?

As previously discussed, no experiment performed to date has given a definitive answer to any of these questions, either because of the short duration of the experiment or because of complicating parameters intrinsic to the study or simulation. The most rigorous and complete information has been obtained from the manned orbital flights; and, although limited in scope, this information, when combined with information obtained from previous studies (with which it is in general agreement) does emphasize some areas for future examination.

None of the Mercury astronauts has evidenced any difficulties during his flight which would indicate that the circulatory system would not continue to function adequately under prolonged exposure to zero G. A decrease in heart rate, a rise in systolic blood pressure, and an increase in pulse pressure—all within normal limits—were all the changes observed in the longer flights. These changes, however, were predictable on a theoretical basis and had previously been produced in tilt-table experiments, prolonged bed rest, water-immersion studies, and in all other circumstances in which the orthostatic load on the circulatory system was significantly reduced.

Whether or not prolonged exposure to the weightless state will produce any impairment in the ability of the circulatory system to respond to a challenging stress cannot be answered on the basis of any data gathered in past experiments. Either the duration of the zero-G exposure has been insufficient or the experimental design has precluded the imposition of a significant circulatory stress. There are, however, theoretical grounds for doubting that the circulatory system fully adapted to weightlessness will respond with the same adequacy as one adapted to a one-G environment.

There is a large amount of evidence from prolonged bed rest and water-immersion studies which indicates that severe problems will be encountered upon exposure to the acceleration forces involved in reentry and upon return to a one-G environment. This evidence was underlined most dramatically by tests performed on Schirra, the third Mercury astronaut, following his exposure to some nine hours of weightlessness. As reported in the NASA document on the flight, Schirra had an increased lability of blood pressure and pulse with change in body position, a change in heart rate from 70 to 100+ beats per minute, and a significant drop in systolic pressure when changing from the supine to the upright position. As he stood up, all his dependent leg veins became engorged and his feet and legs rapidly took on a dusky, reddish purple color. Astronaut Glenn hadalso shown a tendency toward the same blood-pressure and heart-rate changes. Similar studies were not made on Carpenter.

If such changes followed such short term exposures to zero G as that of the Mercury astronauts, careful investigations of the cardiovascular system will have to be made during the prolonged exposure planned for the crew of the space station.

Musculoskeletal System. Terrestrial gravity plays a large part in the maintenance of the normal tone of the muscles. The tendency of the joints to collapse under the influence of gravity is reflected in the stretch of the muscles which support the joints. Receptors in the muscles called interfusal fibers and in the tendons called golgi organs sense their stretching and initiate reflexes resulting in the continued, steady contraction of the muscles. In the absence of gravity, these receptors will not be stimulated and any muscle tone will result only from voluntary contractions and certain postural reflexes.

Studies on individuals involved in water-immersion tests and prolonged bed rest, as well as on limbs immobilized in a cast, have shown a significant reduction in muscular strength, sometimes leading to atrophy. It would appear reasonable that the same effects would occur during prolonged exposure to zero G's. Whether or not this effect will actually occur and whether a program of exercises can be designed to prevent it will only be answered by future studies as there is no data presently available to confirm or refute these speculations.

The reduction of muscular tension in zero G on the bones may cause an upset in the skeletal metabolism and result in bone resorption and osteoporosis. Evidence has been furnished by water-immersion experiments in which an abnormally high level of calcium excretion was noted. Although the Mercury flights were too short to produce such effects, there have been reports that these phenomena occurred during at least one of the Russian orbital flights.

Systems Involved in Spatial Orientation. From a theoretical point of view, sensory perception and spatial orientation may also be modified by prolonged weightlessness exposure. The human body has three major sensory mechanisms for appreciating weight:

1. General mechanoreceptors, sensory organs (located in the skin, which respond to inertial forces associated with acceleration, pressure, and tension) subcutaneous tissues, muscles, joints, and tendons

2. Specialized receptors in the vestibule of the membranous labyrinth of the internal ear

3. Indirectly, vision

Under conditions of weightlessness, the somatic sensory receptors which respond to external touch and pressure will not be stimulated. Hence, the perception of clothing and the sensation of the actual weight of the limbs will be decreased. Sensations due to postural reflexes, muscle tension, and joint position, however, will be present.

The stimulation of the macula, the sensory receptor of the utricle in the inner ear which depends on the weight of granules called otoliths, will not take place except during periods of linear acceleration. The semicircular canals, however, which depend upon angular accelerations for their stimulation, will still be responsive. It is possible that the lack of differential response from the semicircular canals and the utricle may be a factor in aiding the cortical interpretation of the sensation of weightlessness.

Weightlessness should not influence vision directly as a medium for sensory reception. Substantial variations in gravity as produced by changes in acceleration may cause the crew to experience visual illusions. However, these illusions are related to the perceptual interpretation of information received from the eyes and the otoliths, rather than impairment of the sense of vision. Under conditions of weightlessness, the eyes will be the main, intact, functioning receptor; so that vision will be the primary means of spatial orientation during weightlessness.

Spatial orientation is a complex function involving all of the above receptors. It is usually retained if two of the three modalities function normally, but becomes disturbed if only one remains. Whenever a crew member is not strapped to a seat during space flight, his vision becomes his only means of spatial orientation, and his initial exposure to this condition is expected to produce severe disorientation. Data indicate, however, that orientation by vision alone can be learned and that it should be sufficient to prevent space sickness, vertigo, and spatial disorientation from occurring during prolonged weightlessness. Extensive studies are required to determine the types of training required and to delineate the rules and procedures that will enable man to adapt most effectively to this new environment.

Alertness and attention in neurophysiology seem to result from the activity of an area of the brainstem called the reticular formation acting on the cortex. The reticular formation is in turn stimulated by all sensory impulses from all receptors of the body traveling to the cortex through classical sensory pathways. It has been shown that an experimental reduction of these sensory impulses will reduce the level of consciousness or alertness of the subject. Some questions arise concerning the ability of the space traveler to maintain his normal level of alertness in the absence of stimuli from his otoliths and the somatic gravoreceptors. Thus far,

there has been no definitive evidence of a lowered conscious level, but the durations of exposure have been short and the investigations have not been designed with this as an objective.

No other serious effects to zero G's are anticipated and, according to the data presently available, none have been observed. The respiratory system should be relatively free from zero-G effects; however, due to the lack of natural convection in the air, a reliable system of forced convection will have to be introduced to maintain a constant availability of fresh air. No difficulties are expected in the digestion of food, but eating and defecatior may require mechanical aids. The excretory system should remain unaffected. Some renal calculi could develop from the possibly high calcium level. Early reports of a lack of urge for urination have not been confirmed in the longer Mercury flights. Some indications of metabolic imbalance have resulted from some of the water-immersion studies. The occurrence of this in an active situation in space, however, does not appear likely. Constant monitoring and observing of these systems is still felt necessary, however, to prevent any unexpected deleterious occurrences.

Reentry-G Considerations

There is less concern about the ability of a spacecraft crewman to tolerate prolonged residence in a zero-G environment than about his ability to tolerate a return to a one-G environment, particularly when this return is complicated by the additional G forces imposed during reentry. The deterioration anticipated in vascular tone and in the reactivity of the circulatory compensatory reflexes, described earlier, is not expected to reduce circulatory performance when the movement of the blood is not resisted by hydrostatic pressure. However, orthostatic pooling of blood, accompanied by a decreased venous return, reduced blood pressure, increased pulse rate, and reduced stroke volume, can be hypothesized as a natural adjunct of the redevelopment of vascular hydrostatics. The degree of debility to be suffered by a crewman and the additional difficulties imposed by reentry G's are, as yet, conjectural.

The studies that may be of value in determining the seriousness of these effects are the various water-immersion studies, particularly those in which the subject's G tolerance was tested on a centrifuge following immersion. Unfortunately, factors such as fluid loss due to negative pressure breathing, undesirably short periods of immersion, and a significant time lapse between emergence from the water and the onset of centrifugation prevent most of the data from being directly applied to the space situation. The most satisfactory generalization possible is that the most valid studies showed a small but significant reduction in G tolerance to headward acceleration and a significant deterioration in cardiovascular adaptability, as reflected in an increased pulse rate and reduced blood pressure.

The G forces encountered during reentry will, of course, be primarily transverse forces (eyeballs in - eyeballs out) rather than longitudinal forces (eyeballs up - eyeballs down). Such forces can be tolerated in much greater magnitude than longitudinal forces because they cause insignificant blood pooling and have, therefore, little effect on circulatory dynamics. Transverse forces are not, however, without their undesirable effects. Arterial oxygen saturation levels are dependent upon the ability of the lungs and pulmonary circulation to transport oxygen from the environment to the blood. This ability is impaired under transverse acceleration because of the mechanical effects of the forces on the chest wall, the hydrostatic effects of acceleration on pulmonary circulation, and the impairment of cardiac function. Low levels of arterial oxygen saturation may produce impairment of higher mental functions but play little or no part in other psychophysiological disorders encountered during longitudinal acceleration (e.g., blackout or decrease in mobility). Although classical G tolerance cannot be overlooked in evaluating the effects of reentry G's, the loss of consciousness, blackout, or some similar debility cannot alone be used as the criterion of tolerance. The only study of significance yet reported on the effect of transverse G's following water immersion revealed no significant decrease in the subject's ability to perform tracking tasks while exposed to the Mercury reentry profile. The peak transverse level encountered was eight G.

For any valid conclusion in this area more data is needed, as well as the cognizance that the reentry profile for each type of vehicle will differ both in its peak G loadings and the manner in which these forces are applied to the transverse and longitudinal axes of any crew member's body.

Behavioral

The data on man's behavior under weightless conditions and rotation afford little reason to believe that performance will be degraded because of weightlessness, provided the man is adequately restrained when he is weightless. However, because of the observed physiological changes that have resulted from orbital and suborbital flights, from brief exposure to weightlessness in the Keplerian trajectory flights, and from simulated weightlessness in water-immersion studies, the possibility of significant physiological deterioration resulting from prolonged exposure to the space environment cannot be discounted. The long-term effects, the combined effects, and the potentiation effects of weightlessness and other atypical conditions of the space environment may so degrade the astronaut biomedically as to severely impair his performance capability. Since almost any component of performance could be affected, a wide range of behavior should be sampled.

Most behavioral scientists view man as an integrated psycho-biological entity. His behavior and his organic state are inextricably interwoven. In this scheme of thinking, if the organism is physiologically altered, his behavior will be altered. In the broadest sense, all human response is interdependent with some biological substructure and its functions.

However, this view of man as a psycho-biological entity is only a concept. In actual practice, it is not tenable to even attempt to identify the biological functions that underly complex real-life behavior. This means that neither empirical nor theoretical information about the long-term biomedical effects of weightlessness, or artificial G, provides any firm guidelines for selection and evaluation of performance measurements.

Current practice in human factors measurement is based on the idea that behavior can be observed and measured but not always accounted for in terms of physiological mechanisms. That is, observed behavior can be studied as empirical phenomena without describing the molecular substructure of the organism that effected or affected the behavior. When behavior is altered, there is an inferred change in the environment or internal state of the organism, but this change does not have to be described for purposes of measurement.

On the other hand, it is tenable, by engineering analogy, to speculate about the relationships among environmental conditions, biomedical status, and behavior. For purposes of analogy, let physiological mechanisms be represented by a black box. The input to the black box is the interaction of the sensory system with the environment. The output of the black box is the full spectrum of the results of behavior, including psychomotor performance, problem-solving, decision-making, and verbalization. To add realism to the analogy, it must be noted that this particular black box has extraordinary self-adjusting, self-corrective, and adaptive capacity. For example, a change in input may lead to automatic adjustments within the black box that result in no change in the output. In general, however, if the magnitude and duration of the change of input exceeds the adaptive capacity of the black box, the output will be changed. In this case, it is reasonable to suppose that prolonged weightlessness will exceed the adaptive capacity of man's physiological mechanisms, and behavior will be altered. The analogy may then be elaborated upon to derive working generalizations and hypotheses.

One general approach for selecting human factors measurements may follow this rationale. Prolonged weightlessness will alter the input to the black box and will change the output of the system. Without regard for the specific changes that may occur within the box, it may be hypothesized that any or all behavior (output) may be altered. In order to verify this hypothesis, a cross section of behavior would have to be sampled at regularly recurring intervals.

A second general approach to behavior measurement might disregard the internal alteration of the black box. This rationale suggests that man is designed to operate in a prescribed environment, and when this environment is dramatically altered, man simply cannot function properly. In this case, there is no inference that man is altered biomedically. Behavior change can be explained as a result of change and duration of change in the environment. Such reasoning leads to the same hypothesis—that any or all behavior may be changed under conditions of prolonged exposure to weightlessness. Here again, in order to verify this hypothesis, a cross section of behavior should be sampled.

A third approach might be to attempt to spell out probable biomedical responses induced by weightlessness and then speculate about relationships between physiological changes and behavior changes. Since there is general interaction among all physiological systems, this line of reasoning would also lead to the hypothesis that any or all behavior may be affected. Again, in order to test the hypothesis, a cross section of human behavior would have to be sampled at regular intervals.

This discussion is intended to point up the requirement for an extensive behavior measurement program. In order to evaluate satisfactory performance or performance proficiency in the space environment, an adequate sampling of the full spectrum of behavior must be measured. Comprehensive coverage is therefore the overriding consideration in the selection of functions for behavior measurement.

For purposes of assuring that all pertinent human performance functions were adequately sampled in this study, human behavior was classified in three functional areas: stimulus functions, medial functions, and response functions. Stimulus functions include sensory and perceptual functions. Medial functions include complex, higher-level, central nervous system processes; the absence of heavily weighted confounding stimulus or response components is assumed. Response functions consist of effector and perceptual-motor behavior. This classification can be symbolized by a simple paradigm as shown in Figure 1.

This categorization of functions is arbitrary, but serves the purpose of assuring comprehensive coverage of human behavior with minimum overlap. In this scheme of classification, stimulus functions are discontinuous with medial processes, and there is a functional separation of sensation and perception. Sensation is restricted to stimulus events that impinge on the central nervous system as a more or less direct analog of a particular receptor activity. For example, detection of a temperature change on some part of the body surface would represent a sensory response. Complex perception encompasses, but is restricted to, complex stimulus

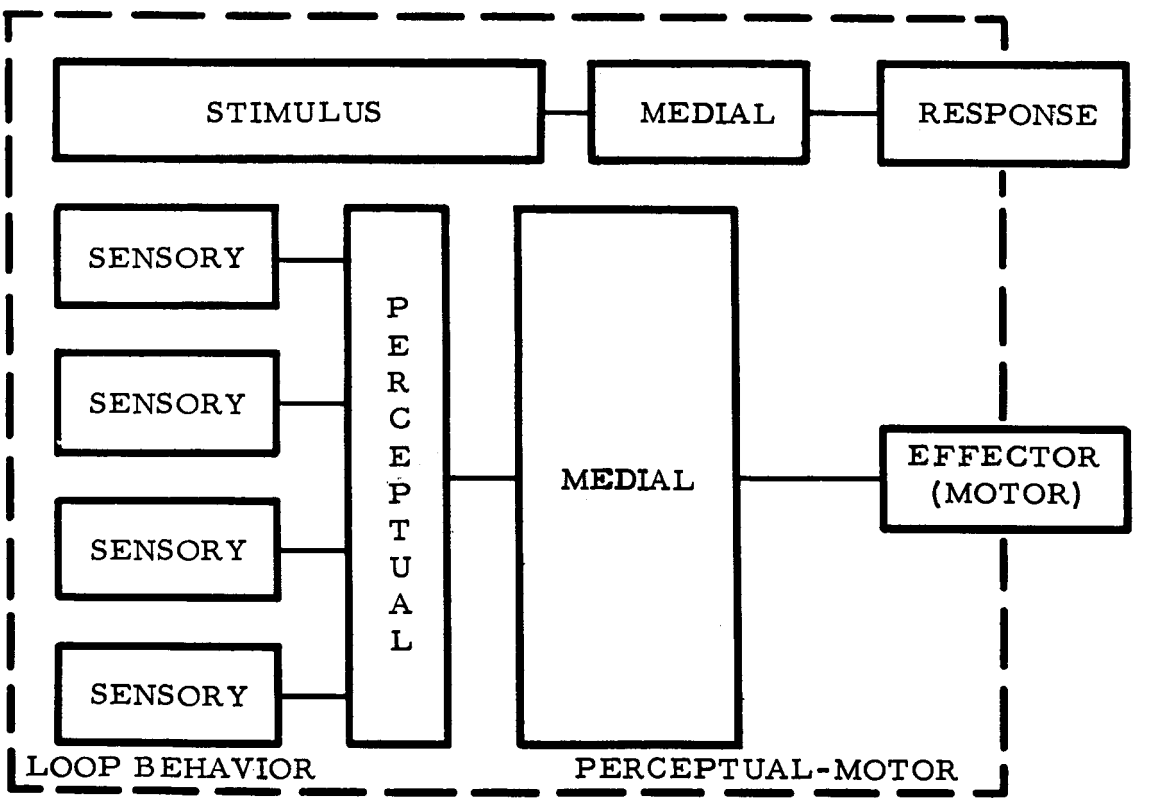


Figure 1. Paradigm of Human Behavior Functions

events that involve integration and organization of diverse receptor activity. For example, a spoken word is a stimulus event and consists of a complex organization and integration of auditory effector inputs. Medial functions are not directly measureable. Occurrences between known stimulus events and observed responses are inferred to be higher-level or medial processes. Response functions are observed and directly measureable motor activities, such as speech and writing. To ensure the purity of the motor response category, perceptual-motor (loop) functions are assigned a separate category.

This system of classification provides, above all, a practical basis for the design of measurement tasks from which it will be possible to infer particular functions that are impaired when performance is degraded. That is, most real mission tasks are extremely complex and involve the interaction of a set of functions. With this system of classification, it is possible to select and design tasks, real and simulated, that measure particular behavior components that can also be measured discretely.

MISSION REQUIREMENTS

An extended mission analysis was accomplished to identify the factors and situations pertinent to predicting crew performance on extended space missions. This analysis included the definition of the most probable types of crew activity. The information could then be used in the selection of certain crew tasks that would indicate the general performance of the crew and would yield maximum data for the prediction of mission success. In addition, a careful selection could assist in the determination of the level of confidence that may be assigned to the measurements obtained.

Major emphasis in the analysis directed toward representative earth orbiting missions and the manned Martian mission. In the absence of specific design information and related operating characteristics, it was necessary to formulate a set of working assumptions basic to the analysis. Information in this section summarizes the assumptions, rationale, and conclusions of the extended mission analyses. The results of a detailed analysis of human requirements anticipated in the earth orbital mission and the manned Martian missions are presented under Performance Requirements in this section

Earth Orbital Missions

The manned earth orbiting systems that have been proposed or have been a subject for study are many and varied. They may be classified as recoverable, nonrecoverable, low earth orbital, high earth orbital, winged reentry, or lifting body reentry. System spacecraft may be used in personnel transport, resupply, rescue, communication, command control,

reconnaissance, surveillance, or testing. Mission durations may vary from a few orbits to that of a permanent space station in which crews will be rotated on a tour-of-duty basis. Table 1 illustrates the possible variation in vehicle classes and design parameters.

It seems reasonable to assume that research and development will continue to be a function of large space stations for many years to come. In addition to basic space research, a space station could be used as a test and development facility for new space systems, components, equipment, procedures, and techniques. It could also serve as a staging base for the indoctrination and training of astronauts, the final checkout of special tools and equipment, and the increasing of crew proficiency in operating and maintenance skills.

Reconnaissance may be required to obtain information on enemy or potential enemy activities and capabilities. This could require the surveillance of the entire global surface.

Defensive and offensive applications could involve the detection and tracking of missiles and satellites and the destruction of hostile surface targets, underwater targets, and above-surface targets including space vehicles and perhaps lunar bases.

Martian Mission

The immediate objective of a Martian mission is assumed to be the scientific exploration of the planet, its satellite moons (Deimos and Phobos), and the intervening deep space areas.

Exploration may include surveillance and mapping of the Martian surface, including the Martian lunar surfaces, by means of recoverable and nonrecoverable probes and excursions by rover vehicle or on foot. This exploration will amplify present theories about the planet's surface, geological features, life forms, and atmosphere and will provide a foundation for eventual establishment of a Martian base.

The Martian environment is assumed to be more hospitable than that of the earth's moon because it possesses a gaseous atmosphere and is characterized by relatively even temperatures. In terms of foreseeable technology, it is difficult to visualize the establishment of a Martian base for the purpose of providing a military advantage or capability at considerable planetary distances. It is thought, therefore, that a Martian base will be used primarily for peaceful and scientific purposes.

The actual Mars landing mission will be preceded by a Mars fly-by mission and a Mars orbit mission similar to the manner in which landing

Table 1. Possible Vehicle Classes And Design Parameters

	Vehicle Class			
	Low Earth Orbital	High Earth Orbital	Recoverable	Nonrecoverable
Possible mission	Reconnaissance Research	Reconnaissance Research Communications	Transport Resupply	Reconnaissance Research
Crew size	4 to 21	3 to 10	2 to 4 plus 4 to 10 passengers	4 to 21
Mission duration	Estimated 6 weeks tour of duty	Several days to 6 weeks tour of duty	3 orbits to 3 days	Approximately 6 weeks tour of duty
Launch	Vertical Boosted	Vertical Boosted	Horizontal	Vertical
Reentry	Not applicable	Lifting body	Winged (controlled tangential)	Not applicable
Cabin volume	1,500 to 60,000 cubic feet	420 to 4,000 cubic feet	1,000 cubic feet	1,500 to 60,000 cubic feet
Docking, rendezvous and transfer	Yes	Yes	Yes	Yes

on the moon is planned. The Martian spacecraft will undoubtedly consist of several modules including a basic interplanetary space vehicle, a Mars landing module, a planetary excursion module, an earth reentry module, and possibly a ferry vehicle to transport the crew from the earth to the orbiting interplanetary vehicle.

Crew size estimates range from 3 to 10 men. It is expected that 5 will be closest to optimum.

Conditions favorable to a mission to Mars will exist for the next 10 to 12 years. However, because of the Apollo schedule, program costs, funding commitments technical difficulties, etc., it seems unlikely that a Mars expedition can be accomplished prior to the 1975-1985 time period. This period will be comparatively unfavorably because the position of Mars will make it necessary to travel farther and faster and because solar radiation will be more severe during that time.

The fly-by mission will be accomplished with a single launch vehicle of more than one stage. After achieving an earth parking orbit, the upper stage will be used to inject the interplanetary space vehicle into the Mars fly-by trajectory. If artificial gravity is required, deployment of a rotatable personnel chamber will occur after staging. As the space vehicle flies past Mars, a nonrecoverable probe will be landed. Upon return to earth, the reentry module will be separated from the space vehicle and the main space vehicle would be permitted to remain in solar orbit. The fly-by mission will require approximately one year. The total energy required to accomplish the one-year orbit will vary as a function of the relative positions of Mars and earth at the time of launch.

The Mars orbit mission will require two launch vehicles, one for each of two sections of the space vehicle to be assembled in earth parking orbit. The crew will be transported to the space vehicle in a ferry vehicle suitable for earth reentry (or the actual reentry module itself). The space vehicle will be injected into the Mars trajectory and retroed into orbit about Mars. A probe will be landed and may be returned to the orbiting space vehicle. Injection into earth-return trajectory will be accomplished; the separation and landing of the reentry module will be accomplished similarly to that for the fly-by mission. The Mars orbit mission will require in excess of two-and-a-half years. The spacecraft will remain in a Mars parking orbit for approximately one year to allow earth and Mars to move into position for a minimum-energy injection into an earth-return trajectory.

The Mars landing mission will utilize three launch vehicles for the three sections of the interplanetary space vehicle to be assembled in earth orbit. The crew will be transported, via the reentry vehicle, to the main

space vehicle. The space vehicle will establish an orbit around Mars, and the Mars landing (or planetary excursion) module will separate and land. This module will return to the space vehicle and it will be left in Mars orbit as the main space vehicle returns to earth in much the same manner as in the previous two missions. Total trip time for the Mars landing mission should be comparable to the orbital mission. Stay time on the surface of Mars will be limited by weight penalties and booster capabilities of the launch system. Thirty days is probably a reasonable estimate.

PERFORMANCE REQUIREMENTS

The precise mission roles to be assigned orbital space stations are not entirely clear at present. However, it can be assumed that the crew members will have to be able to respond to emergency situations; means for abort, evacuation of the station, and malfunction correction must be provided. To accomplish these things safely, the crew must be provided with means for monitoring the status of the station and its environment and subsystems and the tools, skills, and controls necessary for appropriate action. In general, it can be stated that the crew will be required to function in a back-up capacity (and in some cases will have primary control) for all flight and stability control operations and may be required to perform highly complex maintenance tasks, depending on the duration of the mission.

The Mars missions will require crew participation, or the capability to participate, in all levels of maintenance, including inspection, trouble shooting, removal, repair, replacement, and bench maintenance. Limited manufacturing or fabrication of parts will probably be advisable because of the mission duration and the fact that there will be no logistics support as in the case of earth orbital systems. The Mars missions will also require on-board crew members to perform navigation duties with a great deal of precision. This will not be the case with earth orbital systems since ground tracking stations can provide this capability.

It can reasonably be assumed that system operation and maintenance tasks will be assigned to crew members in a biomedical and human-factors research orbital space station on an availability basis. In other words, manpower will be utilized primarily in the performance of measurement tasks, data collection, and related duties. Only to the extent that these functions will not be interfered with will other duties be assigned to the crew.

An additional fact that tends to limit the usefulness of mission tasks for purposes of measuring crew performance is that crew members will not be required to perform measurement tasks or be exposed to situations that unnecessarily jeopardize crew safety.

On the basis of these considerations, it appears likely that only a small portion of the crew tasks performed in an orbiting laboratory are representative of those that will be performed in an interplanetary system or future orbiting space systems. Table 2 shows the types of functions that the different systems have in common. It can be seen that all systems have systems operations functions in common. This pertains specifically to subsystem monitoring, operation of environmental-control and life support systems, and performance of communications duties. Almost all systems will involve rendezvous, docking, and crew-transfer operations. Of the 16 categories of mission functions indicated, only 4 can be considered to have a 1-to-1 relationship for purposes of predicting probability of mission success from crew performance measurement.

Although it was realized that the tasks implied by these functions may not all be directly useful for crew performance measurements, it was felt that a major consideration in determining the composition of a human-factors measurement program could derive from an analysis of crew tasks and functions. The analysis of job tasks and subtasks that follows is representative of those required to operate and maintain the Apollo, the MORL, the MOSS, and protracted-orbiting and interplanetary systems. Each task is further analyzed for its behavior content, which is expressed as behavior functions or components. Also, each task is classified as to criticality and whether it can be measured as a real operational task, a simulated task, or an experimental measure. This analysis provided the background information for much of the human-factors measurement analysis, which included the following:

Translation of human functions into measures

Selection of the appropriate mode of measurement—real taks, simulation, or experimental

Rank ordering of functions to be measured

The objectives of the task analysis were to develop tasks to be utilized for behavioral performance measurement and to assist in the integration of operational and measurement requirements of the space station program. The measurement aspect of the task analysis has been predominant.

The relationship between the task analysis and performance measurement is shown in Figure 2. Figure 2 shows a parallel and interselective derivation of tasks and man functions (e.g., depth perception, manipulative dexterity), which results in a task performance analysis that generates behavioral performance measurements. Certain other behavioral performance measurements are derived directly from consideration of man functions

Table 2. Comparison of Laboratory and Operational Systems Showing Commonality of Functions

Mission Functions	MORL	MOSS	100-day Apollo	Earth orbital systems	Interplanetary systems
Manned Launch			X		Possibly
Crew Transportation	X	X		Probably	Probably
Rendezvous, Docking, and Crew Transfer	X	X		X	Probably
System Activation	X	X		Probably	Probably
Spin Control				Possibly	Possibly
Enroute Navigation					X
Extravehicular Activities	Possibly	Possibly		Probably	Possibly
Research Functions	X	X	X		
System Operations Functions	X	X	X	X	X
Operational Mission Functions				X	X
Planetary Orbit, Land, and Launch					X
Resupply	X	X		Probably	
Remote Rendezvous and Docking Control	Probably	Probably		Probably	Possibly
Crew Rotation	X	X		Probably	
Reentry and Survival	X	X	X	X	X
Post-Mission Crew Evaluation			X		X

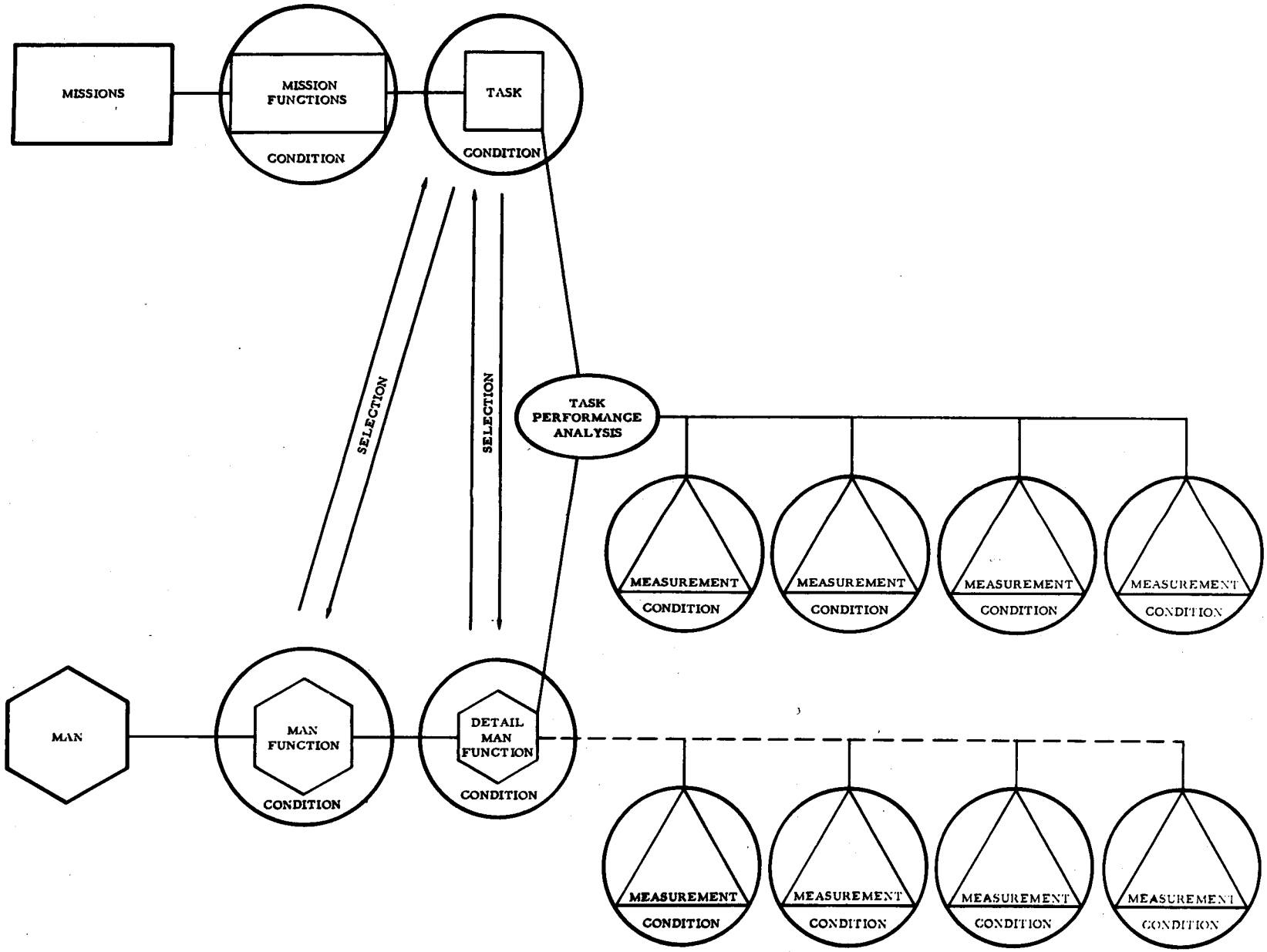


Figure 2. Task Analysis—Performance Measurement Relationship

without reference to specific tasks. All of the developmental stages shown in Figure 2 are derived in the context of space station conditions, especially weightlessness.

The task analysis was carried out in six stages as follows:

1. Selection of mission functions
2. Preliminary task survey
3. Measurement task pool selection
4. Subtask analysis
5. Matching human functions with tasks
6. Selection and evaluation of measurement tasks (operational measurement tasks, simulation measurement tasks, and laboratory experiment fallout)

The mission functions that constituted the point of departure for the task analysis were those major functions (e.g., rendezvous and dock, extravehicular activities) that were relevant to one or more of the mission systems within the cognizance of the present study (extended-mission Apollo, MORL, MOSS, operational earth orbital (EO), and Mars landing (IP) missions systems). From these mission functions, a preliminary task survey was derived which encompassed approximately 154 tasks and was relevant to all missions including some hypothetical EO missions.

From the preliminary task survey, 51 tasks were selected to serve as a task pool from which measurement tasks might be drawn. The selection criteria consisted of rough judgments of mission coverage, human function coverage, task criticality, and suitability for measurement use. Each of these 51 tasks was then broken down into subtasks, evaluated as to functional criticality, matched with performance measurement components drawn from the NASA behavioral performance measurement lists, and initially evaluated as to suitability for type of measurement use, i.e., as operational or as simulated tasks. The 51 tasks, along with the associated information indicated, are shown in Table 3.

The first of the table lists the tasks by systems to which they are common and in general order of functional criticality as described below. Each task has been analyzed into subtasks.

The second column of the table refers to estimates of the functional criticality of each task. Functional criticality for each task was determined

by two indexes: the result of task performance failure and the immediacy of the result. The result code is as follows:

1. Nonsurvival of personnel

2. Mission abort

3. Mission degradation

The immediacy code is as follows:

1. Immediate result

2. Result after a short time

3. Eventual result

Thus, for example, a task, performance failure of which would result in nonsurvival of personnel as an immediate consequence, would receive a function criticality code of 1-1; a task, performance failure of which would bring about mission abort as an eventual result (not immediately or shortly), would receive a code of 2-3.

The third column of the table shows the performance components (for the NASA behavioral measurement list) for each task. Components marked with an asterisk are those that were judged to involve a relatively high performance level requirement.

The last column of the table indicates the performance measurement approach that seems most feasible for each task, i.e., operational task performance (T) or simulated task performance (S). For each task, the priority of measurement approach is indicated, i.e., 1 - primary, 2 - secondary, and N - not applicable.

The measurement pool task data were used in the preparation of the human functions list, which was a preliminary step in the development of performance measurements in the present study. This human functions list was compared item by item with each of the subtasks in the measurement pool. This comparison resulted in a cross tabulation that showed the human function details, i.e., the human function list items directly involved in the performance of each of the 51 measurement pool tasks.

On the basis of the subtask human-function cross tabulation, two categories of performance measurement tasks were selected: (1) tasks that could serve as measurement vehicles during their on-board space station performance (operational tasks), and (2) tasks that could more

reasonably be simulated. The criteria for the selection of tasks as measurement tasks, regardless of category, were as follows:

Human function coverage

Mission relevance

Relevance to weightlessness exposure

Experimental design, including the availability of prelaunch baseline measurements

Equipment feasibility

The principal basis for assignment of selected tasks to an operational or simulation category was the predictability or control feasibility of task occurrence (scheduling), under nominal space station operational conditions.

The tasks considered for simulation are of two types: those to be incorporated in a simulation device and those involving certain auxiliary simulation items. Those tasks which were considered for incorporation into a simulation device subject to later determination of associated power, volume, and weight requirements were as follows:

Monitoring

Special systems checkout tasks

Docking (including terminal phase of rendezvous)

Attitude stabilization

Navigation fix

The selection of these tasks was based on the following considerations:

Task criticality (the effect, and the immediacy of the effect, of task failure upon the mission in terms of personnel survival, possibility of mission abortion, and possibility of mission modification even if mission abortion does not occur)

Mission coverage

Human function coverage and isolation

Relevance of the task to duration of exposure to weightlessness (how

Table 3. Measurement Tasks

Apollo, MORL, MOSS, IP				
Task and Subtask	Functional Criticality	Component	Measurement T	Measurement S
Don-Doff Pressure Suit	1-1		1	N
1. Remove suit from storage		Body position		
2. Position suit for donning		*Gross manipulative dexterity		
3. Insert legs into suit through top		Fine manipulative dexterity		
4. Continue to insert body into suit until feet are secured in boots		Long-term memory		
5. Insert arms in sleeves				
6. Don and secure handwear				
7. Prepare neck of suit for helmet				
8. Position and secure helmet				
9. Connect umbilical for pressurization				
10. Pressurize suit				
11. Check pressurization				
12. Depressurize				
13. Remove handwear				
14. Unlock and remove helmet				
15. Ease out of suit				
Leak Seal	2-1		2	1
1. Locate leak for coordinates		Logical reasoning		
2. Apply sealant		Mobility		
3. Leak test		*Body position		
4. Report - structured		Gross dexterity		
		Fine dexterity		
		Short-term memory		
		Visual acuity		
		Speech perception		

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
Part Replacement Maintenance	2-2		1	N
1. Obtain part from storage		Mobility		
2. Take part to maintenance site		Body position		
3. Safe equipment to be maintained		Gross manipulation		
4. Remove defective part		Fine manipulation		
5. Install replacement		Visual acuity		
6. Secure replacement		Depth perception		
7. Reactivate maintained equipment		Form discrimination		
8. Check out maintained system		Long-term memory		
9. Store replaced part		Short-term memory		
Troubleshoot	2-2		2	1
1. Confirm out of tolerence condition on display		*Logical reasoning		
2. Proceed to IFTP		Short-term memory		
3. Consult manual		Visual acuity		
4. Check system points on IFTP		Fine manipulative dexterity		
5. Readout GO, NO GO indicator patterns on IFTP				
6. Fault isolation logic				
Medical Treatment - Other	2-2		2	1
1. Transport patient		Fine manipulative dexterity		
2. Position patient		Gross manipulative dexterity		
3. Inspect patient		Data transfer		
4. Consult manual		Logical reasoning		

*High performance level requirements

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
5. Obtain treatment items		Short-term memory		
6. Apply treatment items		Long-term memory		
7. Confirm treatment		Speech perception		
8. Report - unstructured		Visual acuity		
9. Record				
Leak Detection	2-2		T	S
1. Monitor display		Visual acuity		
2. Detect leak warning indicator ON		Pattern discrimination		
3. Determine leak location		Reaction time		
4. Report leak location coordinates				
Medical Treatment - Self	2-3		2	1
1. Diagnose		Body position		
2. Consult manual		Fine manipulative dexterity		
3. Select treatment		Gross manipulative dexterity		
4. Position for treatment		Tactual perception		
5. Apply treatment equipment		Long-term memory		
6. Confirm treatment		Short-term memory		
7. Report - unstructured		Logical reasoning		
8. Record		Visual field		
Scientific Data Storage	2-3		1	N
1. Activate storage mode		Computation		
2. Check original data form		Logical reasoning		
3. Convert data		Short-term memory		
4. Put in data		Long-term memory		

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
5. Secure input		Data transfer		
6. Deactivate storage mode				
Scientific Data Collection - Other Subject	3-2		1	2
1. Position subject		Fine manipulative dexterity		
2. Obtain equipment		Gross manipulative dexterity		
3. Check equipment		Data transfer		
4. Install or attach equipment to subject		Short-term memory		
5. Instruct subject		Long-term memory		
6. Activate and operate equipment				
7. Readings or other observations				
8. Record				
9. Deactivate system				
10. Remove equipment				
11. Safe equipment				
12. Return equipment to storage				
Scientific Data Collection - Self Subject	3-2		1	2
1. Obtain equipment		Body position		
2. Check equipment		Fine manipulative dexterity		
3. Install or attach equipment to self		Gross manipulative dexterity		
4. Activate and operate equipment		Visual field		
5. Take readings or other observations		Data transfer		
6. Record		Long-term memory		
7. Deactivate equipment		Short-term memory		
8. Remove equipment				
9. Safe equipment				
10. Return to storage				

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
Inventory Control	2-3		1	N
1. Confirm item supply		Logical reasoning		
2. Confirm current use rate		Short-term memory		
3. Determine anticipated use rate		Long-term memory		
4. Predict excess or insufficiency		Computation		
Monitor	3-2		1	2
1. Visual scan		Visual acuity		
2. Note significant indicators		Body position		
3. Maintain monitoring rate		Visual field		
4. Decide in or out of tolerance		Color vision		
Adjust and Control System Status	2-3		2	1
1. Readout system status		Fine manipulative dexterity		
2. Determine tolerances or status desired		Short-term memory		
3. Correct (switch) to status desired		Long-term memory		
4. Confirm new status or status within tolerance				
Checkout Systems Status	2-3		1	N
1. Select system or subsystem to be checked		Short-term memory		
2. Observe readout		Fine manipulative dexterity		
3. Determine in or out of tolerance		Long-term memory		
4. Return to primary status or current operational mode				

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement T	Measurement S
Wobble Control 1. Determine wobble rate and magnitude 2. Initiate manual stabilization control 3. Damp wobble 4. Confirm wobble damping by feel or by indicator 5. Return attitude stabilization to dead band	2-3	Visual or kinesthetic/ tactual *Fine manipulative dexterity	1	N
Inventory Substitution 1. Check items for insufficiency or excess 2. Check item characteristics 3. Check item utilization 4. Determine interitem commonality 5. Preliminary determination of possible substitutions 6. Revise records to reflect new item use	3-3	*Logical reasoning Short-term memory Long-term memory Computation	2	1
MORL, MOSS, EO, IP				
Dock With Inert Satellite 1. Acquire satellite 2. Determine docking flight parameters	2-1	Visual acuity *Depth perception	2	1
*High performance level requirement				

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
3. Control velocity, attitude, flight path		Angular motion judgement		
4. Judge closure rates		*Closure-rate judgement		
5. Fine control for final dock		Form discrimination		
6. Secure dock		*Fine manipulative dexterity		
		Reaction time		
Extravehicular Mobility	1-2		1	N
1. Select destination		Body position		
2. Judge path parameters to destination		Visual acuity		
3. Initiate movement		Visual field		
4. Control movement		*Depth perception		
5. Halt at destination		Form perception		
		Kinesthetic judgement		
		*Closure-rate judgement		
		Angular movement perception		
		Short-term memory		
		*Spacial orientation		
Transit Air Lock for Extravehicular	1-2		1	N
1. Open inner air lock hatch		Gross manipulative dexterity		
2. Enter air lock		Fine manipulative dexterity		
3. Close inner hatch		*Mobility		
4. Depressurize air lock		*Body position		

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
5. Verbal communication - structured		Speech perception		
6. Open external hatch				
7. Exit air lock				
Extravehicular Attachment	1-2		1	N
1. Arrange tether line		Body position		
2. Secure tether line		Gross manipulative dexterity		
3. Test tether line		Fine manipulative dexterity		
		Visual acuity		
On-Board Initial Activate Satellite Systems	2-1		N	1
1. Check activate sequence		Fine manipulative dexterity		
2. Activate in sequence		Short-term memory		
3. Confirm activate		Long-term memory		
4. Verbal communication - structured		Speech perception		
Remote Activate Selected Systems - Ferry Vehicle to Satellite	2-1		N	1
1. Confirm lock-on for activation		Fine manipulative dexterity		
2. Activate		Long-term memory		
3. Confirm activate		Short-term memory		
		Reaction time		

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
Open-Wire Verbal Communication	1-2		N	1
1. Establish communication		*Speech perception		
2. Communication test - structured		Logical reasoning		
3. Verbal communication- unstructured		Short-term memory		
4. Record				
Initial Checkout Systems Status	2-1		N	1
1. Switch to all systems and subsystems		Fine manipulative dexterity		
2. Observe readings		Short-term memory		
3. Confirm in or out of tolerance		Long-term memory		
4. Switch to scheduled operational systems		Logical reasoning		
Ready Air Lock for Extravehicular Activity	2-2		1	N
1. Position air lock		Body position		
2. Check depressurization system		Gross manipulative dexterity		
3. Check air lock hatch seal		Fine manipulative dexterity		
4. Check air lock hatch operation		Short-term memory		
5. Consult manual				
Scientific Apparatus Maintenance	3-2		2	1
1. Transfer apparatus to maintenance area		Mobility		
2. Obtain tools and supplies		Gross manipulative dexterity		

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
3. Consult manual		*Fine manipulative dexterity		
4. Prepare apparatus for maintenance		Logical reasoning		
5. Bench maintenance		Visual acuity		
6. Reassemble apparatus		Depth perception		
7. Return apparatus storage or place of use		Form perception		
8. Return tools and supplies to storage		Color vision		
9. Waste or used parts disposed		Short-term memory		
10. Record		Long-term memory		
Initiate Spin	2-3		N	1
1. Preliminary checkout spin system		Fine manipulative dexterity		
2. Initiate spin		Long-term memory		
3. Monitor spin rate buildup		Visual or kinesthetic		
4. Stabilize spin at desired rate		Reaction time		
Extravehicular Tool Use	3-3		1	N
1. Release tool from personal storage		*Fine manipulative dexterity		
2. Position tool		Depth perception		
3. Manipulate tool		*Visual acuity		
4. Reposition tool		Form perception		
5. Return tool to personal storage location		Body position		

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement T	Measurement S
Extravehicular Inspect	3-3		1	N
1. Locate item for inspection		Visual field		
2. Inspect		*Visual acuity		
3. Report - unstructured		Fine manipulative dexterity		
		Depth perception		
Terminate Spin	?		2	1
1. Switch system to "terminate" mode		Fine manipulative dexterity		
2. Initiate contraspin		Visual or kinesthetic		
3. Monitor spin rate		Reaction time		
4. Confirm spin terminated		Angular motion perception		
		Long-term memory		
MORL, MOSS, EO				
Ferry Vehicle Dock	1-1		2	1
1. Attitude control		Fine manipulative dexterity		
2. Velocity control		*Fine manipulative dexterity		
3. Check vehicle - satellite position		Reaction time		
4. Judge and control closure rates		Visual acuity		
5. Final line-up adjustment		*Depth perception		
6. Make docking contact		*Closure-rate judgement		
7. Communication - structured		Form perception		
		Speech perception		
		Angular motion judgement		

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement T	Measurement S
Remote Control Dock - Cargo Vehicle	1-1		2	1
1. Determine vehicle position		*Fine manipulative dexterity		
2. Initiate dock approach		Reaction time		
3. Control dock approach parameters		Visual acuity		
4. Monitor dock approach parameters		*Depth perception		
5. Judge and control closure rates		*Closure-rate judgement		
6. Dock contact control		Angular motion judgement		
		Form perception		
Cargo Transfer	2-1		2	1
1. Grasp cargo item		*Mobility		
2. Remove cargo item to satellite		Body position		
3. Place in airlock		*Gross manipulative dexterity		
4. Seal outer hatch of air lock		Fine manipulative dexterity		
5. Report to satellite - structured		*Closure-rate control		
6. Open inner air lock hatch		Angular motion perception		
7. Remove item		Visual field		
		Speech perception		
		Form perception		
Waste Transfer to Cargo Vehicle	2-2		1	N
1. Check waste container secure		Body position		
2. Consult handling instructions		Short-term memory		
3. Protective measures		Long-term memory		
4. Cargo transfer		Form perception		

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
5. Decontamination		Visual acuity *Depth perception Color perception *Closure-rate judgement Angular motion judgement Pattern discrimination *Mobility		
Secure Ferry Vehicle Dock	2-2		2	1
1. Confirm dock		Fine manipulative dexterity		
2. Proceed to dock location		Gross manipulative dexterity		
3. Inspect docking lock device		Visual acuity		
4. Manually adjust docking lock if not secure		Mobility		
5. Check for pressure deal				
Ferry Vehicle Transfer to Rendezvous Orbit	2-2		2	1
1. Confirm earth orbit parameters		Computation		
2. Confirm satellite orbit		Fine manipulative dexterity		
3. Initiate transfer		Short-term memory		
4. Control flight path		Long-term memory		
5. Monitor-satellite-vehicle relationship				
6. Communication-structured				

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement T	Measurement S
Transfer Ferry Vehicle to Park	2-3		2	1
1. Disengage dock		*Fine manipulative dexterity		
2. Manual control attitude		Visual acuity		
3. Manual control flight parameters		Angular motion perception		
4. Manual control parking dock		*Closure-rate judgement		
		Form discrimination		
		*Depth perception		
Detect Logistics Vehicle - Remote Control Rendezvous	3-2		2	1
1. Determine area of probable vehicle location		Computation		
2. Initiate scanning		Fine manipulative dexterity		
3. Control scanning		Angular motion detection		
4. Monitor display for target		*Reaction time		
		Visual acuity		
Secure Dock - Remote Control Dock	2-3		2	1
1. Confirm dock		Mobility		
2. Proceed to dock location		Body position		
3. Manually lock docking device		Fine manipulative dexterity		
		Gross manipulative dexterity		
		Long-term memory		
		Short-term memory		

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
Evaluate Rendezvous - Remote Rendezvous	2-3		2	1
1. Determine orbital tolerances		*Computation		
2. Check logistics vehicle position against orbital tolerances		Logical reasoning		
3. Compute necessary orbital changes		*Short-term memory Long-term memory		
Inventory Replenishment	2-3		2	1
1. Determine item status		Computation		
2. Consult manual		Short-term memory		
3. Order item in quantity needed		Long-term memory		
4. Confirm order received		Logical reasoning		
5. Record				
Satellite Attitude Control-Post Dock	3-2		1	N
1. Determine attitude deviation		Fine manipulative dexterity		
2. Initiate manual control		Visual and/or kinesthetic		
3. Manually return to desired attitude		Reaction time		
4. Confirm attitude stabilization				
5. Return attitude stabilization to dead band				

*High performance level requirement

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
Verbal Communication - Ferry Vehicle	3-2		2	1
1. Initiate communication		Speech perception		
2. Respond communication		Logical reasoning		
3. Communicate - structured		Long-term memory		
4. Terminate				
5. Record and confirm record				
Complete Rendezvous - Remote Control rendezvous	2-3		2	1
1. Determine vehicle position		Computation		
2. Determine required rendezvous position		Fine manipulative dexterity		
3. Compute course change parameters				
4. Control and monitor vehicle rendezvous position change				
MORL, MOSS APOLLO				
Sample Analysis	3-2		1	N
1. Size sample		Fine manipulative dexterity		
2. Position sample		Long-term memory		
3. Consult manual		Short-term memory		
4. Add testing items to sample		Visual acuity		
5. Utilize apparatus		Form discrimination		
6. Take readings				

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
Scientific Data Transmission 1. Check data form 2. Check data conversion required 3. Initiate transmission 4. Monitor transmission 5. Confirm transmission received	3-3	Computation Long-term memory Short-term memory	1	2
MOSS, EO, IP				
Spin Rate Control 1. Check current spin rate 2. Determine required spin rate 3. Manually control thrust parameters for required spin rate 4. Confirm required spin rate achieved 5. Shut down spin rate control system or return to auto mode	1-2	*Fine manipulative ability Visual or kinesthetic Angular motion judgement Short-term memory Reaction time	2	1
*High performance level required				

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
Bench Maintenance 1. Transport defective part to shop area 2. Obtain tools and supplies 3. Position and secure for maintenance 4. Consult manual 5. Troubleshoot 6. Tool use 7. Test repaired part 8. Record 9. Return tools, etc., to storage 10. Secure shop area 11. Return or store repaired part	3-3	Mobility Gross manipulative dexterity *Fine manipulative dexterity Logical reasoning Depth perception Form perception Color vision Short-term memory Long-term memory	2	1
MORL, EO				
Extravehicular Transfer - Ferry Vehicle to Satellite 1. Vehicle decompression 2. Open exit hatch 3. Secure tether line 4. Proceed to satellite	1-2	*Mobility Body position Gross manipulative dexterity Long-term memory Angular motion perception	1	N
*High performance level required				

Table 3. Measurement Tasks (Cont)

Task and Subtask	Functional Criticality	Component	Measurement	
			T	S
5. Open external air lock hatch 6. Communicate - structured		*Closure-rate judgement Form perception Speech perception		
APOLLO, IP				
On-Board Prelaunch Systems Check 1. Activate systems 2. Switch to systems and subsystems 3. Observe systems in or cut of tolerance 4. Switch back to prelaunch systems	2-1	Fine manipulative dexterity Short-term memory Logical reasoning Visual field	N	1
IP				
Navigation Fix 1. Obtain data from manuals, etc. 2. Compute 3. Attitude control 4. Star sighting 5. Compute 6. Repeat for another star sighting	1-3	Tracking Body position *Manipulation-fine Visual acuity *Pattern discrimination Computation *Data transfer Short-term memory	N	1
*High performance level required				

long the operator is likely to be exposed to weightlessness before performing the task)

Simulator control and display design requirements

THEORETICAL CONSIDERATIONS

In the development of a rationale for selection and evaluation of measures to determine the effect of weightlessness, certain facts must be taken into account. No data on the effect long-term weightlessness exists. Such data on weightlessness as exist are from very brief exposures and to not show clear-cut effects. There is some theoretical basis for predicting physiological changes in certain systems, and findings to date are not inconsistent with these predictions. For behavioral measures, no reasonable prediction can be made with any certainty. Some measures can be considered more important than others because they reveal states of the organism which are critical for survival. In thinking about measures for detecting weightlessness effects, it is useful to consider certain models for relating confidence that significant weightlessness effects have been detected and the measures used for detection.

Logarithmic

A model based upon the assumption that a relatively limited number of measures provides most of the required data and that relatively little information accrues with increasing measures beyond this limit has intuitive appeal and is not inconsistent with the facts noted above. A logarithmic model satisfies these requirements. Figure 3 presents a theoretical logarithmic cumulative curve for the confidence versus the ordinal position of the measure, i.e., the ranking. The parameters of such a curve are not known and the curve has only theoretical significance.

Correlational

If it is assumed that the aim of a measurement program is to predict weightlessness effects in terms of selected measures, a multiple-regression model can be considered appropriate. In typical applications of multiple-regression techniques, an initial minimal set of measures with relatively high correlations with the dependent variables is selected first, and later measures are taken so as to maximize increments in the multiple-correlation coefficient. This usually means identifying measures with some appreciable correlations with the dependent variable and the minimal correlation with the other variables in the set. Under the usually encountered situations, the growth of the multiple-correlation coefficient is consistent with a logarithmic model.

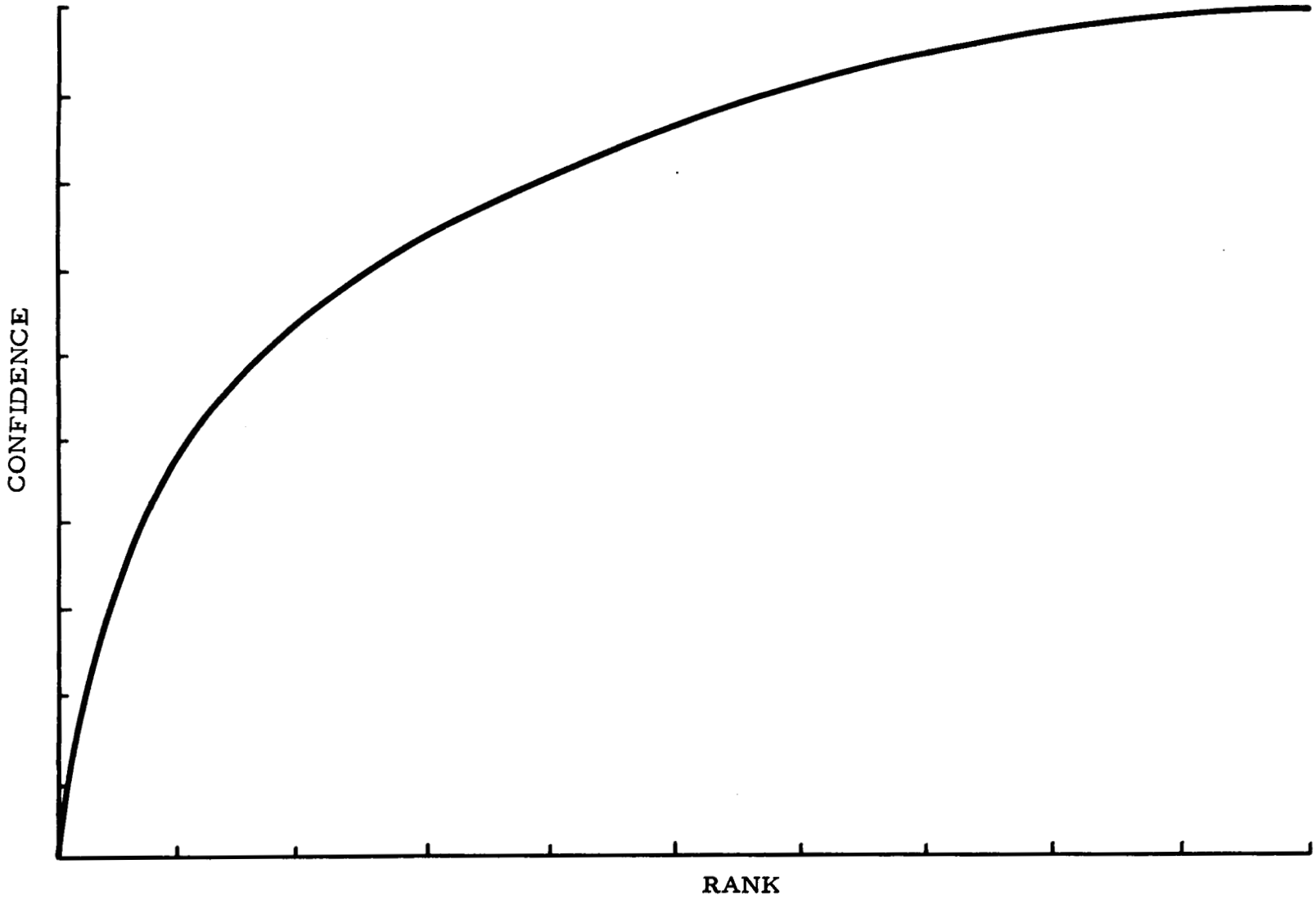


Figure 3. Theoretical Logarithmic Curve of Cumulative Confidence Versus Rank Order

Stratified Models

In the models discussed above, measures are considered as taken either in order according to rank or in terms of their correlation with the dependent variable and with each other. In the first case, the model is most applicable if the measures are ordered along the same dimension; in actuality measures are based on different systems. In the second case, the assumption is that the correlations exist and are determinable; when the measures are from different organic systems the assumption of correlation is tenuous. A stratified model, however, can be considered appropriate with strata representing functions or systems. If the strata are assumed ordered or ranked with respect to their relevance for the detection of weightlessness effects, and samplings made within the strata, the logarithmic model can be considered applicable.

OTHER CONSIDERATIONS IN SELECTION OF BEHAVIOR MEASURES

Mission Tasks

By observation of selected crew performance on a regularly recurring schedule, performance adequacy can be determined. So long as each member of the crew is accomplishing his assigned tasks satisfactorily, his performance can be judged adequate. However, the information derived from observation of performance on real mission tasks is limited.

In the first place, the usual regularly recurring crew mission tasks are designed to derate the individual's maximum performance ability. Only occasionally will a crew be challenged by such demanding performance as rendezvous and docking, bench maintenance of technical equipment, and emergency trouble shooting. For the most part, the crew will perform fairly routing tasks that involve vigilance, detection of out-of-tolerance displays, adjustment of dials, turning of knobs, serving as observer or subject in scientific data collection, and such. It is likely that space crew personnel will be able to perform these tasks satisfactorily even in the presence of some impairment. In short, adequate performance on real tasks will provide little information about general well-being or performance on future, more demanding and more critical tasks.

In the second place, real tasks do not lend themselves to refined quantification. It is not tenable to engineer operational displays and controls so as to record all movements, latencies, errors, and omissions of the operator. In fact, it is axiomatic that the operational panel will be engineered to insure reliable human performance and will not be confounded with behavior-recording instruments. Also, recurring crew duties such as data recording, reporting, housekeeping, manipulation, and ambulation are most reasonably evaluated qualitatively. This means that comparison of past and

present performance on real tasks will involve essentially subjective judgments. Only categorically degraded performance can be considered other than satisfactory.

This discussion is not intended to suggest that measurement of real mission tasks is not significant. On the contrary, determination that the crew is performing adequately at any time is the essence of performance measurement and defines the probability of mission success. Failure to perform adequately will, of course, cause mission failure. However, data obtained from real task performance will provide little basis for diagnosis of a subject's well-being, for prediction of future performance or performance on other tasks, or for correction of deficiencies in man-machine relationships for future space missions.

Simulation

An analysis of space crew functions suggests that some critical and demanding tasks will occur infrequently during prolonged orbiting or interplanetary space missions. There is no sound measurement logic for predicting performance on such infrequent and challenging tasks from adequate performance on routine recurring tasks. For example, demonstrated capability to respond to occasional signals on a watch-keeping assignment offers little assurance that the subject will be able to respond successfully to an emergency leak repair requirement. Also, such infrequent tasks as rendezvous and docking, navigational fixes that require complex computation, and emergency trouble shooting and maintenance will require a high degree of proficiency and will be critical to crew survival and mission success. Assurance that proficiency will be retained in such challenging but infrequently utilized skills is a problem unique to prolonged space missions.

It is inevitable that complex and demanding skills will tend to degrade because of disuse. No amount of over training can ensure retention of proficiency for extended periods. This means that some critical skills that are unscheduled or scheduled infrequently will have to be practiced on-board. Some tasks, such as donning and doffing the pressure suit, can be practiced as fire-drill exercises. However, assurance of proficiency in tasks such as docking or navigation fix will require a practice console on-board with some features similar to the operational display and control panel.

A well-designed, on-board, proficiency-assurance device can serve a dual function. First, the device can serve as a trainer/simulator. Most importantly, for this study, the device can serve as a versatile performance-measurement console. The trainer/simulator can be tailored to measure a wide range of real tasks with immediate relevance to the mission of an orbiting vehicle as well as tasks that will be required in protracted space

missions. In addition, this device can be designed to record scores automatically and quantitatively; it can be designed to automatically increase difficulty to a level for each subject that challenges his maximum capability short of overloading; it can be designed to detect subtle behavior changes, such as pressure on controls and tremor. By optimal use of film, tape, multipurpose indicators, and computer support along with adaptive response devices such as keyboards and controllers with variable-spring loading, the device will be able to sample a determined cross section of behavior components in the sensory, perceptual, cognitive, and motor areas.

Based upon the analysis presented under Performance Requirements and the preceding discussion, a feasibility study of a spaceborne simulator was accomplished. This study (Section III) indicates that an on-board simulator/measurement device is reasonable for any of the space-station configurations under consideration except the smallest Apollo.

Experimental Testing

Real mission tasks and simulated real mission tasks are necessarily forms of complex integrated behavior. Even a task as elemental and fundamental as discrimination reaction time involves components of sensory response, perception, motor response, and indeterminate higher-level central nervous system interaction. In complex tasks such as trouble shooting, the interplay among behavior components involves so many sequences, combinations, and permutations that it is fruitless to attempt refined analysis. Since many components of behavior are involved in complex tasks, a component may be degraded without causing any measurable change in performance. This means that adequate performance or even optimum performance of a complex task may not indicate that all components of behavior are adequate or optimum. Yet, if the long-range effects of weightlessness are to be determined, a cross section of components of behavior must be sampled. That is, subjects must be exposed from time to time to forthright experimental testing of components of behavior and if the effects of prolonged weightlessness on man are to be known.

Fine screening of behavior components is necessary regardless of quality of performance on complex integrated tasks. If such performance is degraded, component measurement is required to identify the particular areas of behavior that are affected. If performance on complex tasks is not degraded, it is still necessary to verify that component behaviors are not degraded.

Performance Measurement and Human Reliability

A measurement program that incorporates real tasks, simulated tasks, and behavior components has far-reaching implications for the development

of projected manned interplanetary space vehicles. Until now, orbital flights have had a very high probability of success because the reliability of the machine and its subsystems were enhanced by the presence of a human. Conversely, if the human proved to be unreliable, the machine could carry on automatically. In longer space missions, the probability of material failure will be greater because of increased subsystem complexity as well as longer operational use. Also, human reliability may be threatened by both complexity and variability of tasks as well as the insidious effects of increased exposure to an atypical environment. In order to more nearly assure mission success, human reliability for all assigned mission tasks must be extremely high.

This means that human reliability for space crew tasks must be derived by means of repeated evaluation of mission tasks, by evaluation of simulated tasks, and by experimental measurement of fundamental behavior components. Reliability for operational and simulated real tasks can be determined by means of the proportion of measurements that equal or exceed the performance standard for each task. From performance curves based upon measurement over time, it will be possible to extrapolate performance for the duration of interplanetary missions. In addition, performance trends on behavioral components may be interpolated and extrapolated to real tasks and provide verification of reliability estimates for human performance in subsequent prolonged space missions. The ultimate payoff for information derived from on-board space station performance measurement will be the design of space vehicles in which the mission tasks of the crew can be accomplished with high reliability.

CRITERIA FOR EVALUATION

Biomedical

The development of the initial list of biomedical measures was based upon a consensus of opinion of medical and physiological personnel by utilizing a sequential analysis technique and employing a set of measurement-selection criteria.

Initially, a set of questions or hypotheses concerning the possible effects of zero G upon human physiological system functioning were developed. These questions or hypotheses were derived from a review of the literature on the results of space flight accomplishments to date and the analyses of the results of space simulation experiments. Where hypotheses could not be established on the basis of empirical information or suggested by extrapolation from obtained empirical data, professional judgments as to probable effects were made on the basis of underlying medical knowledge concerning the interaction of physiological system functions. Hypotheses so formulated could be generally grouped on the basis of the effects of

zero G on physiological system functioning as follows: hypotheses based upon predicted effects and hypotheses based upon probable effects of zero G on physiological system functioning.

Following the formulation of general hypotheses. a list of possible measures for each hypothesis was developed based upon consideration of established medical measures. In formulating the list of measures, no attempt was made to assess available measurement techniques or to consider equipment characteristics such as weight, power, and volume. Measurement selection criteria employed were as follows:

Feasibility of the measurement under zero-G conditions, including consideration of gross over-all constraints placed upon medical measurements in typical space stations

Ability of the measure to detect effects of zero G

Clinical validity of the measure

Availability of hardware for obtaining the measurement

The development of the initial list of biomedical measures was accomplished independently from review of the NASA-provided list and was accomplished separately by participating biomedical personnel. Following the development of individual lists, these lists were combined and merged with the NASA-provided list to ensure comprehensive measures coverage of physiological system functions.

The initial list consisting of 102 biomedical measures is presented in Table 4.

Behavioral

The development of the initial list of behavioral functions was based primarily upon the paradigm and system of classification of human behavior described previously and the concept of comprehensive coverage of human behavior with a minimum of overlapping of behavioral functions.

The initial list was intended to include all of the basic behavioral functions that might reasonably be expected to be found in job performance associated with projected space missions. The functions to be listed were selected by considering four sources of data:

The NASA list of suggested measures

An analysis of space mission tasks (see Measurement Equipment Performance Requirements)

Table 4. Initial List of Biomedical Measures (Nonranked)

Systems	Objective Measurements	Subjective Measurements
Cardiovascular	Heart rate Blood pressure Bleeding time Clotting time Hematocrit Prothrombin time Reticulocyte count WBC RBC Differential Platelet count Sedimentation rate Serum electrolytes Serum osmolarity Blood volume Circulation time Cardiac output Arterial pO_2 Arterial pCO_2 Venous pO_2 Venous pH Arterial pH Serum Ca++ Serum PO_4 Pulse wave velocity Blood urea nitrogen Rheoencephalogram Electrocardiogram Phonocardiogram Pulse rate	Venous distention Color of skin, nailbed, mucous membranes Liver size

Table 4. Initial List of Biomedical Measures (Nonranked) (Cont)

Systems	Objective Measurements	Subjective Measurements
Respiratory	Respiratory rate Breath holding time Chest circumference Expiratory and inspiratory force Tidal volume Minute volume Maximum breathing capacity Inspiratory end volume Expiratory end volume Inspiratory reserve Expiratory reserve Respiratory quotient and basal metabolic rate Hypoxia Hypercarbia Oxygen uptake	Chest pain Dyspnea
Muscular	Muscle mass Muscle force Muscle power Muscle endurance	Muscle tonus
Skeletal	Bone density Bone strength Joint motion range	Bone pain Joint pain

Table 4. Initial List of Biomedical Measures (Nonranked) (Cont)

Systems	Objective Measurements	Subjective Measurements
Nervous	Electroencephalogram Sleep cycles Ocular tonometry Visual field measurement Color vision tests	Tremors Clonus Proprioception tests Alertness Deep tendon reflexes Retinal examination Incidence of aerotitis media Caloric stimulation of vestibular response Incidence of sleepiness
Excretory	Volume of urine per voiding Frequency of voiding Urinalysis Urine culture and sensitivity Urine electrolytes Urine Ca++ Urine PO_4 Urine creatinine	Discomfort Difficulty in micturition Incidence of perspiration
Digestive	Food input Incidence of regurgitation Use of dye markers in food Stool amounts Absorption tests Fecal flora and chemistry	Appetite Eating habits Food preference Gas formation and passage Stool characteristics Incidence of nausea Incidence of salivation Abdominal sounds

Table 4. Initial List of Biomedical Measures (Nonranked) (Cont)

Systems	Objective Measurements	Subjective Measurements
Integumentary	Skin thickness	Mucosal integrity
Endocrine	Urinary 17-Ketosteroids	

Review of the literature relevant to performance under weightlessness conditions and near zero-G simulation studies

Consideration of the types of performance functions identified in the experimental and theoretical literature

The initial list of behavioral functions to be measured are presented in Table 5. The functions so listed are intended to adequately sample the full spectrum of human behavior and are categorized as sensory, perceptual, medial, motor, and perceptual motor functions.

Table 5. Initial List of Behavioral Functions for Measurement Consideration (Nonranked)

Function	Measurement	
Sensory	Visual acuity Peripheral detection—visual Location and movement of limb Discrimination of force on subject Detection of angular acceleration Brightness discrimination Color discrimination Sound detection/discrimination Stereognosis Linear acceleration Vibration	Stereopsis/convergence Sound localization Sound duration Detection of light touch Texture discrimination Sound pattern discrimination Detection of motion—auditory Olfaction Detection of heat/cold Pain threshold
Perceptual	Speech perception Static depth perception (monocular) Compound pattern discrimination (form and brightness) Set (monitoring)	Dynamic depth perception Reading Estimate of volume of space Time perception Cue abstraction
Medial	Computation Learned procedure Decision Association Deductive reasoning	Recording Guided performance Invention Inductive reasoning
Motor	Arm-hand manipulation Body positioning Speaking Hand manipulation	Finger manipulation Writing Leg manipulation
Perceptual-Motor	Docking	Tracking

INITIAL MEASURE RANKINGS

Following the selection of biomedical and behavioral measure, an initial rank ordering of the individual selected measures was accomplished separately for the list of biomedical measures and the list of behavioral functions. This preliminary ranking permits: further definition of the measures; the preliminary specification of possible techniques; and the initial delineation of equipment (including weight, volume, and power characteristics), time requirements, and identification of personnel skills required to obtain the measures specified by the lists. Thus, the preliminary specification of measures provided the basis for collecting and assembling supplementary methodological and engineering data required for subsequent trade-off studies in a manner independent of the effort required in detailed definition and evaluation of the individual measures and techniques.

A brief discussion of the methods and criteria used to develop the initial rankings, and the listing of the preliminary rank orderings for the biomedical and behavorial measures are presented in this section.

PRELIMINARY BIOMEDICAL MEASURE RANKINGS

Development of the preliminary rank ordering of the biomedical measure list was accomplished in essentially the same manner as the development of the initial non-ranked list (see Biomedical Criteria for Evaluation).

Subjective rankings of the measures in the initial measure list were accomplished independently by medical and physiologist personnel followed by a combination of the separate listings and a final initial ranking list developed on the basis of opinion consensus.

Emphasis of the ranking process was consideration of individual measure ability to detect effects of zero G on body system functioning. Criticality of system functions and justification of the measure in relation to known ability to detect changes in body system function were considered as paramount criteria in establishing the rank-ordering. Validity of the measures as related to clinical practice and the ability of the individual measure to reflect the physiological change reliably were considered. The assessment of relative rank order was made with the assumption that the measure would be made by an adequately trained operator.

The following list presents the initial biomedical measure ranking. It will be noted that there are 82 measures listed in the referenced list as opposed to the initial non-ranked listing of 102 measures. The reduction of measures is caused by the combination of similar or equivalent measures appearing in the initial non-ranked list.

Cardiac output and stroke volume (indirect)
Blood pressure
Electrocardiogram (pulse rate, heart rate)
Oxygen uptake
Hemoglobin
Response to stress, exercise of CV and Respiratory System
Venous pressure
Circulatory time
Calcium Balance Study (serum Ca and PO_4, Ca intake, urine Ga and PO_4, stool Ca and PO_4)
Alkaline phosphatase
Respiratory quotient and BMR
Urine voiding (difficulty, frequency, and volume)
Bone X-rays (density, strength)
Muscle endurance, mass, force, power
Vestibular response and caloric stimulation
Maximum breathing capacity
GI series - barium swallow
Appetite, eating habits, food preference, food input
Fluid intake and output
Kidney stone formation study
Urine creatinine (24 hour)
Urinalysis for protein, sugar, blood, acetone
Urinalysis microscopic
RBC survival time and mass
Body temperature
Blood volume
Hematocrit
Bowel habits, stool color and occult blood, stool amount
Bowel motility
Incidence of regurgitation and nausea
Chest film (atolectosis and heart size)
Electromyogram (muscle tone, tremor)
Deep tendon reflex
Electroencephologram
Rheoencephologram (cerebral blood flow)
Eosinophil count
Total body water
GI absorption tests
Tidal volume, vital capacity and respiration rate

Minute volume, inspiratory and expiratory reserve, inspiratory and expiratory end volume
Sleep cycles
Venous pH
Venous pCO_2 and pO_2
Serum electrolytes (Na, K)
Urine electrolytes (Na, K)
Plasma proteins
Serum osmolarity
Phonocardiogram
Abdominal sounds
Mucosal integrity
Joint motion and pain, bone pain
Alertness, incidence of sleepiness
Skin thickness
Hypoxia and hypercarbia
Blood urea nitrogen
Complete blood count (WBC, RBC, Diff, platelet estimation)
Chest circumference
Breath holding time
Dyspnea and chest pain
Serum ATP
Bleeding time
Liver size
Clonus
Retinal exam
Visual fields
Proprioception tests
Urinary 17 - KGS
Urinary catecholamines
Color skin, mucous membranes, nail
RBC uptake T_3
Pulse wave velocity
Incidence of aerotitus media
Reticulocyte count
Arterial pH
Arterial pO_2 and PCO_2
Visual illusion
Color vision
Bacteriological studies (N-P, stool, urine)
Ballistocardiogram
Incidence of perspiration
Incidence of salivation
Clotting time
Protime
Sedrate
Ocular tonometry

PRELIMINARY BEHAVIORAL FUNCTION RANKING

The initial ranking of the behavioral functions was accomplished by considering the list of selected behavioral functions and applying a set of selected criteria against each function. The criteria used in justifying each selected function were as follows:

Degree of mission criticality relative to the orbital station of operation
Degree of mission criticality relative to extended orbital and interplanetary missions
Expectation of degradation of the function
Specification of the function by the NASA provided list
Inclusion of the function to ensure comprehensive coverage of human behavior
Data relating to the function as reported in the literature on space-flight and simulated spaceflight experimentation
Percentage of mission tasks which involve the function
Relationship to biomedical measures

Using the listed criteria, the performance functions were rank ordered without regard to behavior category. The following list presents the preliminary behavioral functions ranking. Consisting of forty-nine (49) functions.

Behavior	Function
Motor	Arm-hand manipulation
Medial	Computation
Perceptual-motor	Docking
Sensory	Visual acuity
Sensory	Peripheral detection—visual
Perceptual	Speech perception
Perceptual	Static depth perception — monocular
Perceptual	Compound pattern discrimination—form and brightness
Sensory	Recognition of location and movement of limb
Perceptual	Monitoring (set)
Perceptual	Detection/discrimination of force on observer
Perceptual	Detection of angular acceleration
Perceptual	Dynamic depth perception (one moving body, O. static)
Motor	Body positioning

Behavior	Function
Motor	Speaking
Medial	Learned procedure
Medial	Decision making
Perceptual-motor	Tracking
Sensory	Brightness discrimination
Sensory	Color discrimination
Sensory	Sound detection/discrimination—non-speech
Sensory	Stereognosis
Sensory	Detection of linear acceleration
Sensory	Detection
Motor	Hand manipulation
Motor	Finger manipulation
Medial	Association (memory)
Medial	Deductive reasoning
Medial	Recording
Medial	Guided performance
Medial	Problem solving (invention)
Perceptual-motor	Mass handling
Sensory	Reading
Sensory	Stereopsis (convergence)
Motor	Writing
Motor	Leg manipulation
Medial	Inductive reasoning
Perceptual	Estimate of volume of space—visual
Perceptual	Time perception
Perceptual	Sound localization
Sensory	Sound duration
Perceptual	Cue abstraction
Sensory	Detection of light touch
Sensory	Texture discrimination
Sensory	Sound pattern discrimination (non-speech)
Sensory	Detection of motion—auditory
Sensory	Olfaction
Sensory	Detection of heat/cold
Sensory	Detection of pain

It must be emphasized that this ordering was tentative in nature. The primary value of deriving this list from a measurement point of view was to emphasize the complexity of assigning value to a single function. At least three additional considerations are fundamental to evaluating each function when it is translated into a measure and incorporated into a measurement package.

First there is the factor of functional discreteness. For example, sensory functions are relatively unrelated to each other. The weightless state can conceivably affect one sensory modality and not another. It is less likely that inductive reasoning or inventiveness will be affected unless other medial processes are affected. This means that the rank order of functions to be measured must be adjusted to insure sampling of a full cross-section of behavior.

Second is the factor of branching. In complex integrated tasks a great many behavior functions are involved, and in some instances the measurement of one function may adequately define the status of another or others. For example a writing task may be designed to measure motor behavior, but if the content of the writing task is well structured, it may also measure certain medial functions. The list must be adjusted to take advantage of the interaction and interdependence among performance functions in complex behavior.

The third factor is that of measurement technique and measurement device. It is feasible, for example, to measure a variety of visual and perceptual functions with a single device. This means that some functions of relatively low value would be retained because they can be measured with little additional cost in weight, volume, power, and time.

The central theme of this discussion emphasizes the extreme complexity of placing a definitive judgment on the value of any particular behavior function in a measurement program. As the study progressed, changes in rank ordering were made as more restraints and criteria were introduced.

FINAL EVALUATIONS

BIOMEDICAL

Criteria

The final evaluation of the biomedical measures was based upon a more detailed consideration of the initial list. This encompassed the NASA list of measures and the initial subjective rating of the biomedical personnel of the BAHFR contract. Using this initial raw data, the biomedical measures were grouped by major body systems. These basic functional systems are considered to be complete systems. In some cases, one or two systems are grouped together where they have a specific functional relationship. These nine systems are as follows:

1. The cardiovascular system - the heart, blood vessels, blood as it relates to circulatory factors, and blood clotting mechanisms as they relate to vascular factors.

2. The digestive system - digestive function as well as habits evaluation.

3. The endocrine-metabolic system - a functional evaluation of all the endocrine organs as well as evaluation of metabolism. (The relationship of metabolism and endocrine functions is such that it is not realistic to separate the two functions.)

4. The hematopoetic system and blood - the hematopoetic system, composed of the blood-forming organs as well as blood and those factors related to blood as a transport mechanism. (Substances transported by the blood that are primarily related to other organ systems are not included in this category.)

5. The integument (skin and appendages) - only gross skin evaluation.

6. The musculoskeletal system and articulation - voluntary musculature, skeleton and interrelations. (Because of the obvious interrelationship of the skeleton and muscles, this is evaluated as one basic system.)

7. The nervous system - central peripheral and autonomic functions. The biomedical evaluation here is primarily concerned with physiological rather than behavioral status.

8. The respiratory system - lungs and respiratory tract. These measures primarily evaluate pulmonary (lung) function.

9. The urinary system and body fluids - the kidney system, and fluids other than blood. The function of the kidney system and the status of body fluids other than blood are evaluated; since the renal (kidney) system is the primary homeostatic mechanism system (fluid regulatory system) of the body, it is most reasonable to evaluate these functions as one system.

Within each major system, the individual measures were also divided into functional categories or subgroups so that measures that definitely overlap or give information about the same function are grouped together under subheadings of the major systems. For example, venous circulation is a major subheading under cardiovascular system; and the measures of venous pressure and circulation time, liver size, and venous distention, which are related to venous circulation, are grouped under the one heading relative to venous circulation. It should be noted that these overlapping measures do not give separate amounts of information but give information that overlaps to varying degrees. It is these subgroups of measures that, where the elimination of a measure is necessary, provide a basis for substitution of measures to make up, at least in part, the information lost by the elimination of the measure.

The final list of measures chosen represents the entire battery of measurements that, in the evaluation of the biomedical personnel, was determined necessary to give the maximum information concerning the effects of zero gravity upon man. This list, developed from the initial list of measures, is from the NASA list and from a more detailed analysis of the hypotheses and justifications already discussed under Rationale for Selection of Evaluation of Measures. There is no attempt to eliminate measures at this point on the assumption that all measures listed are believed to be necessary for a complete biomedical evaluation. It will be noted that the measures in this final list vary considerably from the initial list developed. This was because the initial listing represented a hodge-podge of measures, techniques, and equipments all listed under "Measurements". Thus, the following definitions are basic to the final list of measures:

1. Measure refers to a number or specific bit of information obtained about a particular biomedical function.

2. Technique refers to the method by which the measure is obtained.

3. Equipment refers to those hardware items required for a specific technique.

In a number of instances, measurements are combined where the techniques employed or where the way in which the measures are evaluated logically become a single operation. For example, venous pressure and circulation time, even though two different measures, are always obtained simultaneously using a single technique and, as such, really represent a single measurement. Table 6 is a listing of all measurements proposed, grouped by major body systems with subgroupings, within the major systems and includes the alternate techniques considered for each measurement and the data for the measurements and techniques evaluation.

Technique of Evaluation

This section provides a discussion of the method by which the individual measures were evaluated, referring again to Table 6.

Characteristics

The section entitled Characteristics indicates the basic criteria for the evaluation of the measures as follows:

1. Validity - the degree to which the particular number obtained by the measure or the bit of information really reflects the measure; for example, that cc/really tells about cardiac output.

2. Sensitivity - the degree to which the particular measure can detect small changes.

3. Predictability - the value of a particular measurement for indicating the biomedical status of the individual at some future time during this mission, his status at some future zero-G mission, or the status of another astronaut in some other zero-G mission.

4. Crew Status - how well the particular measure can be used as an indicator of a crewman's biomedical status; i.e., how well will it tell his condition at this time or in the immediate future.

These four characteristics were each evaluated on a five-point grading scale by all the biomedical personnel of the BAHFER study. The rating scale values are L = 10 percent; LM = 30 percent; M = 50 percent; MH = 70 percent; H = 90 percent. The maximum value, then, is 90 percent. The

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
1. Cardiovascular System																					
1.1 Cardiac output																					
1.1.1 Cerebral blood flow	M	M	H	H	70	5		350	9.0	3150		3150	Rheocenphalography	L	L	L	M	X			20
1.1.2 Cardiac output	H	H	H	H	90	35		3150	9.0	28350		28350	a. Exercise tolerance test	M	M	M	H			X	60
													b. Dye dilution T1824 for cardiac output	H	M	H	H			X	80
													c. Cardiac catherterization	H	H	H	L			X	70
													d. Electrode gas analysis of arterial and venous blood sample	L	M	M-H	M			X	45
1.1.3 Heart movement (force)	L	L-M	L	L	15	5	35	75	9.0	675		675	Ballistocardiography	L	L	L-M	L-M		X		20
1.2 Venous circulation																					
1.2.1 Venous pH, pCO_2, pO_2	M	M	M	M	50	1		50	9.0	450	4.3.2	See 4.3.2	Electrode gas analysis of venous blood sample	H	H	H	H		X		90
1.2.2 Liver size	L	L	L	L-M	15	2.5		38	9.0	342		342	Manual percussion and palpation	L	L	M	H			X	40
1.2.3 Venous pressure and circulation time	M	M	M-H	M-H	60	8		480	9.0	4320		4320	a. Manometric determination and decholin test (venipuncture)	H	M-H	M	H	X			75
													b. Strain gauge determination and decholin test	H	M-H	M	H	X			75
													c. Differential pressure transducer determination and decholin test	H	M-H	M	H	X			75
													d. Opthalmoscopic examination for venoustasis	M	L	M	H			X	50
1.2.4 Venous distention	L-M	L	L	L	15	2.5	10	38	9.0	342		342	a. Visual and manual examination for venoustasis	M	M	L	H		X		50
													b. Opthalmoscopic examination for venoustasis	L	L	L	H			X	30
1.3 Blood pressure																					
1.3.1 Pulse wave velocity	L	L-M	L	L	15	2.5		38	9.0	342		342	a. Transmission time determination of pulse	M	M	M	H		X		60
													b. Transmission time of externally induced pulsation	M	M	M	H		X		60

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics: Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Information Content: Coverage of System (%)	Coverage of Related Measures (%)	Measure Value Totals: Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value	Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required: Astronaut	Technician	Physician	Technique Total Average
1.3.2 Blood pressure (before and after exercise)	H	H	M-H	M-H	80	10.0	10	800.0	9.0	7200	3.1.3	7913	Auscultatory determination of blood pressure	H	M	H	H	X			80
1.4 Cardiac activity																					
1.4.1 Cardiac electrical activity and state (before and after exercise)	M	M	M	M	50	10.0		500.0	9.0	4500		4500	Electrocardiography	H	M	H	H	X			80
1.4.2 Heart rate (before and after exercise)	M	M	L	L-M	35	3		105	9.0	945		945	a. Electrocardiography	H	H	H	H	X			90
													b. Stethoscopic examination for heart rate	M-H	M	M	H	X			65
1.4.3 Pulse rate	M	H	L	L-M	45	7	10	315	9.0	2835		2835	a. Manual counting of pulse rate	M	M	M	H	X			60
													b. Pulse tachometry	H	M-H	H	H	X			85
1.5 Heart sounds	M	M	M	L-M	45	5.0	5	225	9.0	2025		2025	a. Phonocardiography	H	H	H	H	X			90
													b. Stethoscopic examination	M	M	M	H			X	60
1.6 Response to stress																					
1.6.1 Exercise test	M	M	M	M	50	8.0		400	9.0	3600	3.12.1 8.7.1	4663	Exercise test	M	M	M	M-H			X	55
1.6.2 Centrifuge test	M	M	H	H	70	12.0	15	840	9.0	7560	3.12.2 8.7.2	9048	Centrifuge test	M	M	M	M			X	50
1.7 Skin, nailbed, mucous membrane color	M	L	M	L	30	2.5	2.5	75	9.0	675	5.1	See 5.1	Observation of skin, nailbed, mucous membrane color	L	L	M	H	X			40
1.8 Pulmonary pathology - heart size	H	M	M	M	60	2.5	2.5	150	9.0	1350	8.4	See 8.4	a. Clinical evaluation of heart size	M	L	M	H			X	50
													b. X-ray of chest	H	H	H	H			X	90
1.9 Clotting																					
1.9.1 Capillary fragility	M	L	M	L	30	2.5		85	9.0	765	4.8.4	See 4.8.4	Tourniquet test	M	L	M	H	X			50
1.9.2 Bleeding time	M	L	M	L	30	2.5	5.0	85	9.0	765	4.8.3	See 4.8.3	Ivy test	M	M	M	H		X		60
1.10 Plasma (blood) volume																					
1.10.1 Circulating blood volume	H	M	H	H	80	2.5	2.5	200	9.0	1800	4.4	See 4.4	a. Dye dilution T-1824 for plasma volume	M	M	M	H			X	60
													b. Radioisotopic RBC mass and hematocrit estimation of plasma volume	M	L	M	M		X		40
													c. Radioisotopic total body water determination of plasma volume	L	L	M	M		X		30

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics: Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Information Content: Coverage of System (%)	Coverage of Related Measures (%)	Measure Value Totals: Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value	Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required: Astronaut	Technician	Physician	Technique Total Average
1.11 Cardiopulmonary symptoms	M	M	L	M	40	2.5	2.5	100	9.0	900	8.5	See 8.5	Subjective observation of cardiopul..onary symptoms	M	M	M	M	X			50
2. Digestive System																					
2.1 Eating habits evaluation	M	M	L	L-M	3[illegible]	10	10	350	3.0	1050		1050	Checklist recording of food intake and subjective evaluation of appeti[illegible]	M-H	M	M	H	X			65
2.2 Nausea-regurgitation evaluation	M	M	L	M	40	5	5	200	3.0	600		600	Subjective evaluation of nausea (checklist) and observation of emesis	H	M	M	H	X			70
2.3 Gastrointestinal tract motility																					
2.3.1 Gastrointestinal tract motility	M	L-M	L	M	35	24		840	3.0	2520		2520	a. Endoradiosonde technique	M	M	M	M		X		50
													b. Dye markers in food	M	L	M	H	X			50
													c. X-ray studies (fluoroscope, photographic, record image intensifier)	M	M	M	M-H			X	55
													d. Abdominal sounds with stethoscope	L	L	M	H		X		40
2.3.2 Gas formation and passage	L	L	L	L	10	6	25	60	3.0	180		180	Observation of flatus, etc.	M	L	L	H	X			40
2.4 Gastrointestinal absorption test	M-H	M	M	M	55	20	20	1100	3.0	3300		3300	a. D-Xylose test	H	M	M	H		X		70
													b. Glucose absorption test	M	M	M	H		X		60
2.5 Protein assimilation and production	M	L	M	L	30	5	5	150	3.0	450		450	Microanalytic determination of serum albumin and globulin	M	L	M	H		X		50
2.6 Liver function																					
2.6.1 BSP	H	M	L	H	60	4		240	3.0	720		720	Microanalytic colorimetric determination of BSP excretion	H	H	H	H		X		90
2.6.2 Serum bilirubin	M	M	L	M	40	4	8	160	3.0	480		480	Microanalytic determination of serum bilirubin	H	H	H	H		X		90
2.7 Fecal flora sampling	H	L-M	L-M	L	40	10	10	400	3.0	1200		1200	Bacteria: culture (on earth)	M	M	M	L	X			40
2.8 Bowel function - evaluation and stool characteristics	M-H	L-M	L	L-M	35	17	17	700	3.0	2100		2100	Checklist of frequency of defecation, quantity and quality observation of stool, and occult blood (one-shot tablet test)	M-H	M	M	H	X			65

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
3. Endocrine-Metabolic System																					
3.1 Adrenal medulla																					
3.1.1 Serum catecholamine	M	H	L	M	50	6		300	4.75	1425		1425	a. Calsul determination of serum catecholamine	H	M	H	H		X		80
													b. Determination of serum catecholamine by extraction and fluorometry	H	H	H	L		X		70
3.1.2 Urine catecholamine	H	M	L	L	40	6		240	4.75	1140		1140	a. Calsul determination of urine catecholamine	H	M	H	M-H		X		75
													b. Determination of urine catecholamine by extraction and fluorometry	H	M-H	H	L-M		X		70
3.1.3 Blood pressure	H	M	M	L	50	3	8	150	4.75	713	1.3.2	See 1.3.2	Auscultatory determination of blood pressure	H	M	H	H	X			80
3.2 Adrenal cortical																					
3.2.1 Serum 17 kg steroid	H	M	L	L	40	6		240	4.75	1140		1140	a. Calsul determination of serum 17-kg	H	M	H	H		X		80
													b. Microanalytic determination of serum 17-kg	H	H	H	I		X		70
3.2.2 Urine 17 kg steroid	M	L-M	L	L	25	8		200	4.75	950		950	a. Calsul determination of urine 17-kg	H	M	H	M-H		X		75
													b. Microanalytic determination of urine 17-kg	H	M-H	H	L		X		65
3.2.3 Eosinophil count	M	M	L	L	30	10		300	4.75	1425		1425	Blood smear count of eosinophils	M	M	M	H		X		60
3.2.4 Serum and urine potassium, sodium	H	L	M	L	40	5		200	4.75	950	9.5	See 9.5	Microanalytic determination of serum and urine potassium and sodium	H	H	H	H	X	X		90
3.2.5 Fluid intake and output evaluation (including blood volume total body water and serum osmolarity)	M	L	M	L	30	5	18	150	4.75	713	9.6	See 9.6	Checklist of fluid intake and output	M	M	M	H	X			60
3.3 Pancreatic																					
3.3.1 Blood (and urine) sugar	H	M	M	M	60	5		300	4.75	1425	9.1.3	3045	a. Calsul determination of blood sugar	H	H	H	H		X		90
													b. Microanalytic determination of blood sugar	H	H	H	H		X		90

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
3.3.2 Urine sugar (urinalysis)	M	M	M	M	50	3		150	4.75	713	9.1.1	See 9.1.1	Color test for urine sugar	M	M	H	H	X			70
3.3.3 Urine ketones (urinalysis)	H	M	M	L-M	55	2	7	110	4.75	523	9.1.1	See 9.1.1	Color test for urine ketones	M	M	H	H	X			70
3.4 Parathyroid																					
3.4.1 Serum and urine Calcium and phosphate	H	M	M	M	60	6		360	4.75	1710	6.1.2	See 6.1.2	Microanalytic determination of serum and urine calcium and phosphate	H	H	H	H		X		90
3.4.2 Bone density	H	L	L	L	30	3	9	90	4.75	428	6.2	See 6.2	X-ray of longbones	M	L	M	H			X	50
3.5 Thyroid (oxygen consumption)																					
3.5.1 BMR (oxygen consumption)	H	M	M	H	70	5		350	4.75	1663	8.2	See 8.2	Servo—spirometric determination of oxygen consumption	H	H	M	H		X		80
3.5.2 RBC uptake I_{125}	H	L-M	M	M	55	5	8	275	4.75	1306		1306	Radioisotope study, T-3, I-125, uptake by RBC	H	M	H	H		X		80
3.6 Growth hormone																					
3.6.1 Muscle mass	M	L	L	L	20	2.5		50	4.75	238	6.5	See 6.5	Tape measurement	M	L	M	H	X			50
3.6.2 Serum, urine creatinine	M	M	L-M	L-M	40	2.5	3	100	4.75	475	6.8	See 6.5	a. Calsul determination of serum and urine creatinine	H	H	H	H		X		90
													b. Microanalytic determination of serum and urine creatinine	H	H	H	H		X		90
3.7 Urine nitrogen determination																					
3.7.1 Urine urea	M	M	M	L-M	45	3.0		135	4.75	641		641	a. Calsul determination of urine urea	H	H	H	H		X		90
													b. Microanalytic determination of urine urea	H	H	H	H		X		90
3.7.2 Urine and fecal nitrogen	H	M	M	L-M	55	8.0	9	440	4.75	2090		2090	a. Kjeldahl chemical determination of nitrogen	H	H	H	L		X		70
													b. Coleman automatic analyzer for nitrogen	H	H	H	L		X		70
3.8 Serum ATP	H	M	M	L	50	5.0	5	250	4.75	1188		1188	Calsul determination of serum ATP	H	H	H	H		X		90

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
3.9 Metabolic rate																					
3.9.1 Oxygen consumption and CO_2 production	H	M	M	H	70	10.0		700	4.75	3325	8.2	See 8.2	Servo—spirometric determination of oxygen consumption and thermal conductivity analysis for CO_2	M	M-H	H	H	X			75
3.9.2 Energy requirements	M	M	M	M	50	4.0		200	4.75	950		950	Evaluation of energy requirements from food, etc.	H	M	H	H	X			80
3.9.3 Respiration rate	M	L	L	L	20	4.0	16	80	4.75	380	8.1.1	See 8.1.1	a. Manual count	H	H	M	H	X			80
													b. Pneumotachometry	H	H	H	H	X			90
													c. Impedance pneumotachometry	H	H	H	H	X			90
3.10 Urine metabolites																					
3.10.1 Urine ketones (urinalysis)	H	M	M	L-M	55	3.0		165	4.75	784	9.1.1	See 9.1.1	Color test	M	H	H	H	X			80
3.10.2 Urine and serum creatinine	M	M	L-M	M	45	4.0	5	180	4.75	855	6.8	See 6.8	a. Calsul determination of serum and urine creatinine	H	H	H	H		X		90
													b. Microanalytic determination of serum and urine creatinine	H	H	H	H		X		90
3.11 Body temperature	M	M	M	M	50	10	10	500	4.75	2375		2375	Thermometry	H	H	H	H	X			90
3.12 Response to stress																					
3.12.1 Exercise test	M	M	M	M	50	1.0		50	4.75	238	1.6.1	See 1.6.1	Exercise test	M	M	M	H			X	60
3.12.2 Centrifuge test	M	M	H	H	70	1.0	2.0	70	4.75	333	1.6.2	See 1.6.2	Centrifuge test	M	M	M	M			X	50
4. Hematopoetic System and Blood																					
4.1 Complete blood cell count (red and white, reticulocyte and different	H	H	M	M	70	20	20	1400	4.75	6650		6650	Optical count for complete blood count	M	M	H	H		X		70
4.2 RBC data																					
4.2.1 RBC mass	H	H	M	L-M	65	5.0		325	4.75	1544		1544	Radioisotope study, Cr 51, for RBC mass	H	H	H	M		X		80
4.2.2 Hemoglobin and hematocrit	H	H	M	M	70	15		1050	4.75	4988		4988	a. Cyanmethemoglobin, capillary tube and centrifuge	H	H	H	M-H		X		85
													b. Hemaglobinometer, capillary tube and centrifuge	M	M	H	H	X			70

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
4.2.3 RBC survival	H	M	M	L	50	5.0	20	250	4.75	1188		1188	Radioisotope study, Cr 51, for RBC survival	H	H	M	M		X		70
4.3 Respiratory — metabolic effects																					
4.3.1 End expiratory pCO_2, pO_2	H	M	M	H	70	5.0		350	4.75	1663	8.6.1	See 8.6.1	a. Thermal conductivity analysis for end expiratory pO_2 and pCO_2	M	M-H	H	H	X			75
													b. Mass spectrographic analysis for end expiratory pO_2 and pCO_2	H	H	H	H	X			90
4.3.2 Venous pCO_2, pO_2, pH	H	M	M	H	70	5.0	8	350	4.75	1663	8.6.2 9.1.4 1.2.1	6043	Electrode gas analysis of venous blood sample	H	H	H	H		X		90
4.4 Plasma (blood) volume	H	H	M	M	70	10.0	10	700	4.75	3325	1.10	5125	a. Dye dilution, T1824, for plasma volume	M	M	M	H		X		60
													b. Radioisotopic method — estimation of plasma volume	M	M	M	M		X		50
4.5 Serum osmolarity	H	H	M	L	60	5.0	5	300	4.75	1425		1425	Freezing point depression osmometry	H	H	H	H		X		90
4.6 Blood plasma protein fractionation	H	M	L-M	L	45	10.0	10	450	4.75	2138		2138	Microanalytic determination of blood proteins with paper electrophorens	H	H	H	H		X		90
4.7 Sedimentation rate	M	L-M	M	L-M	40	2.5	2.5	100	4.75	475		475	No technique feasible	-	-	-	-	-	-	-	-
4.8 Clotting characteristics																					
4.8.1 Prothrombin time	M	M	M	L-M	45	5		225	4.75	1069		1069	a. Quick test for prothrombin time	M	M	H	H		X		70
													b. Prothrometer determination	M	M	H	H	X			70
4.8.2 Clotting time	M	M	M	M	50	5		250	4.75	1188		1188	Capillary tube method for clotting time	M	M	M	H		X		60
4.8.3 Bleeding time	M	L-M	M	L-M	40	5		200	4.75	950	1.9.2	1715	Ivy test for bleeding time	M	M	M	H	X			60
4.8.4 Capillary fragility	M	L	L	L	20	7	19.5	140	4.75	665	1.9.1	1430	Tourniquet test of capillary fragility	L	M	M	H	X			50
4.9 O_2 uptake by RBC	H	M	M	M	60	5	5	300	4.75	1425		1425	Electrode analysis for O_2 uptake by RBC	H	M	H	H		X		80
5. Integument																					
5.1 Skin nailbed and mucous membrane color	L	L	L	L	10	15	15	150	1.0	150	1.7	825	*Observation of skin mucous* membrane and nailbed	L	L	M	H	X			40

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
5.2 Mucosal integrity evaluation	M	M	L	L	30	15	15	450	1.0	450		450	Visual inspection of oral mucosa	M	M	M	H	X			60
5.3 Skin thickness	M	L-M	M	L-M	40	10	10	400	1.0	400		400	Caliper measure of skin fold, thickness of skin over abdomen, thigh, and upper arm	M	M	M	H	X			60
6. Musculoskeletal System and Articulation																					
6.1 Calcium balance																					
6.1.1 Calcium balance study	H	H	M-H	M	75	35		2625	5.0	13125		13125	Microanalytic determination of calcium balance	H	H	H	H		X		90
6.1.2 Serum, urine calcium and phosphate	M	M	M	M	50	8	35	400	5.0	2000	3.4.1 9.4.2	4385	Microanalytic determination of calcium balance	H	H	H	H		X		90
6.2 Bone density	H	M	M	L-M	55	13	13	650	5.0	3250	3.4.2	3678	X-ray of long bones	H	M	H	H			X	80
6.3 Joint motion range	M-H	M	M	L-M	50	5	5	250	5.0	1250		1250	Kinesthetic determination of joint motion range	M-H	M	M-H	H	X			70
6.4 Muscle function (force, power, endurance)	H	M	M	L-M	55	15	15	825	5.0	4125		4125	Resistive test with spring for muscle function	H	H	H	H	X			90
6.5 Muscle size	M	M	M	L	40	5	5	200	5.0	1000	3.6.1 7.6.2	2078	Muscle size measurement	M	M	H	H	X			70
6.6 Muscle status									5.0												
6.6.1 Muscle activity and state	M	M	M	L	40	10		400	5.0	2000	7.6.3	3680	Electromyographic evaluation of muscle activity	M	H	M	H	X			70
6.6.2 Tremor	M	L-M	L	L	25	8	12	125	5.0	625		625	a. Clinical examination for tremor	M	M	M	H			X	60
													b. Electromyographic evaluation for muscle tremor	M	H	H	H		X		80
6.7 Serum alkaline phosphatase	M	M	M	L-M	45	10	10	450	5.0	2250		2250	Calsul determination of serum alkaline phosphatase	H	H	H	H		X		90
6.8 Urine and serum creatinine	H	M	H	M	70	5	5	350	5.0	1750	3.6.2 3.10.2 9.2.1	4430	a. Calsul determination of serum and urine creatinine	H	H	H	H		X		90
													b. Microanalytic determination of serum and urine creatinine	H	H	H	H		X		90

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
7. Nervous System																					
7.1 Sensation (pain, temperature, pressure, touch)	H	M	M	M	60	15	15	900	5.25	4725		4725	Clinical-neurological examination of superficial sensation	M	M	M	H			X	60
7.2 Hearing evaluation	H	M	M	L	50	5	5	250	5.25	1313		1313	Audiometric evaluation of hearing	M	M	H	H	X			70
7.3 Vision evaluation																					
7.3.1 Visual acuity, depth perception, and accommodation	H	M	M	M	60	10		600	5.25	3150		3150	Optical evaluation of visual acuity	H	H	H	H	X			90
7.3.2 Visual fields evaluation	H	M	M	M	60	5		300	5.25	1570		1570	Perimetric evaluation of visual fields	H	M	H	H	X			80
7.3.3 Color vision evaluation	M	H	L	L	40	5		200	5.25	1050		1050	a. Optical evaluation of color vision	H	M	H	H	X			80
													b. Evaluation of color vision with color charts	H	M	H	H	X			80
7.3.4 Visual illusion evaluation	M	M	M	M	50	5		250	5.25	1313		1313	Subjective evaluation of visual illusions	M	M	M	H	X			60
7.3.5 Retinal examination	M	M	M	L-M	45	5	28	225	5.25	1181		1181	Opthalmoscopic examination	H	M	M	H			X	70
7.4 Inner and outer ear evaluation																					
7.4.1 Vestibular reaction	M	M	M	M	50	8		400	5.25	2100		2100	Caloric stimulation test for vestibular response	M	M	M	H		X		60
7.4.2 Incidence of acrotitis media	L-M	M	L	L	25	4	9	100	5.25	525		525	Subjective evaluation and otoscopic examination	M	M	M	H				60
7.5 Cerebral activity																					
7.5.1 Cortical activity	H	M	L-M	M	55	9		495	5.25	2599		2599	Electroencephalographic evaluation of cortical activity	M	M	H	H				70
7.5.2 State of arousal (alertness, sleep depth, and cycles)	M	M	M	M	50	11	17	550	5.25	2888		2888	a. Subjective evaluation and observation of state of arousal	M	M	M	H	X			60
													b. Electroencephalographic evaluation of state of arousal	L-M	L-M	M	H		X		50

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
7.6 Peripheral motor evaluation																					
7.6.1 Reflex response and clonus evaluation	M	M	M	M	50	8	8	400	5.25	2100		2100	Clinical evaluation of deep tendon reflexes	M	M	H	H			X	70
7.6.2 Muscle mass	M	L	M	M	40	4		160	5.25	840	6.5	See 6.5	Muscle size measurement	M	L	H	H	X			60
7.6.3 Muscle activity	M	M	M	L	40	8	10	320	5.25	1680	6.6.1	See 6.6.1	Electromyographic evaluation of muscle activity	M	M	M	H	X			60
7.7 Autonomic hyperactivity	M	M	M	M	50	10	10	500	5.25	2625		2625	Subjective and objective evaluation of autonomic hyperactivity (nausea, sleeplessness, etc.)	M	M	M	H	X			60
8. Respiratory System																					
8.1 Pulmonary function																					
8.1.1 Respiratory rate	M	M	M	M	50	5		250	5.5	1375	3.9.3	1755	a. Manual counting of respiration rate	H	H	M	H	X			80
													b. Pneumotachometry	H	H	H	H	X			90
													c. Strain gauge determination of respiration rate	H	H	H	H	X			90
													d. Impedance pneumographic determination of respiration rate	H	H	H	H	X			90
8.1.2 Respiratory volumes	H	H	H	H	90	40	45	3600	5.5	19800		19800	a. Mass flow - strain gauge determination of respiration rate	M	M	M	M	X			50
													b. Mass flow - flowmeter determination of respiration rate	M-H	M-H	H	M-H	X			75
													c. Strain gauge determination of respiratory volume	M	M	M	M	X			50
													d. Impedance pneumographic determination of respiratory volume	M	H	M	L-M	X			55
													e. Servo-spirometric determination of respiratory volume	H	H	H	H		X		90
													f. Spirometric determination of respiratory volume	H	H	H	H		X		90

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
8.2 Oxygen uptake and CO_2 production	H	M	M	H	70	10	10	700	5.5	3850	3.5.1 3.9.1	8838	a. Servo-spirometric determination of oxygen consumption and thermal conductivity analysis of CO_2 production	H	H	H	H		X		90
													b. Mass spectrographic determination of O_2 consumption and CO_2 production	M	M	H	H	X			70
8.3 Ventilation characteristics																					
8.3.1 Breath-holding time	M	M	L	L	30	2.5		75	5.5	413		413	Manual timing of breath holding time	M	M	H	H	X			70
8.3.2 Chest circumference	M	L	L	L	20	2.5		50	5.5	275		275	Manual tape measurement of chest circumference	M	L-M	M	H	X			55
8.3.3 Expiratory-inspiratory force (flack test)	M	M	M	L	40	10	15	400	5.5	2200		2200	Flack test of expiratory-inspiratory force	M	M	H	H	X			70
8.4 Pulmonary pathology - heart size (X-ray)	H	M	M	M	60	10	10	600	5.5	3300	1.8	4650	Chest X-ray	M	M	M	H			X	60
8.5 Cardiopulmonary symptoms - dyspnea, etc.	M	M	L	M	40	5	5	200	5.5	1100	1.11	2000	Subjective observation of cardiopulmonary symptoms	M	M	M	H	X			60
8.6 Respiration - metabolic evaluation																					
8.6.1 End expiratory pCO_2, pO_2	H	M	M	H	70	6		420	5.5	2310	4.3.1	3973	Polaragraphic analysis for end expiratory pO_2, pCO_2	H	H	H	H	X			90
8.6.2 Venous pCO_2, pO_2, pH	H	M	M	H	70	6	10	420	5.5	2310	4.3.2	See 4.3.2	Electrode gas analysis of venous blood sample	H	H	H	H		X		90
8.7 Response to stress																					
8.7.1 Exercise test	M	M	M	M	50	3		150	5.5	825	1.6.1	See 1.6.1	Exercise test	M	M	M	H			X	60
8.7.2 Centrifuge test	M	M	H	H	70	3	5	210	5.5	1155	1.6.2	See 1.6.2	Centrifuge	M	M	M	M			X	50
9. Urinary System and Body Fluids																					
9.1 Urinalysis																					
9.1.1 Urinalysis (WBC, RBC, pH, sugar, protein, osmolarity, acetone)	H	M	M	M	60	10		600	6.75	4050	3.3.2 3.3.3 3.10.1	6070	Microscopic and color test urinalysis (combistix, hematest, acetest)	M	M	H	H		X		70

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics: Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Information Content: Coverage of System (%)	Coverage of Related Measures (%)	Measure Value Totals: Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value	Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required: Astronaut	Technician	Physician	Technique Total Average
9.1.2 Urinary albumin	M	M	M	L-M	45	4		180	6.75	1215		1215	a. Calsul determination of urinary albumin	H	H	H	H		X		90
													b. Microanalytic determination of urinary albumin	H	H	H	H		X		90
9.1.3 Blood (and urine) sugar	H	M	M	M	60	4		240	6.75	1620	3.3.1	See 3.3.1	a. Calsul determination of blood sugar	H	H	H	H		X		90
													b. Microanalytic determination of blood sugar	H	H	H	H		X		90
9.1.4 Venous pH, pO_2, pCO_2	H	M	M	M	60	4	21	240	6.75	1620	4.3.2	See 4.3.2	Electrode gas analysis of venous blood sample	H	H	H	H		X		90
9.2 Renal function									6.75												
9.2.1 Urine and serum creatinine	H	M	M	L	50	4		200	6.75	1350	6.8	See 6.8	a. Calsul determination of serum and urine creatinine	H	H	H	H		X		90
													b. Microanalytic determination of serum and urine creatinine	H	H	H	H		X		90
9.2.2 Glomerular filtration test	H	M	M	M	60	6		360	6.75	2430		2430	a. Urea clearance test - calsul method	M-H	M	M	M		X		55
													b. Urea clearance test - microanalytic method	M-H	M	M	M		X		55
9.2.3 Tubular readsorption test	H	M	M	M	60	6		360	6.75	2430		2430	Fishberg concentration test	M	M	H	M	X			60
9.2.4 Tubular excretion test	H	M	M	M	60	6		360	6.75	2430		2430	PSP test	M	M	H	H		X		70
9.2.5 Blood urea nitrogen	M	L	M	M	40	5	25	200	6.75	1350		1350	a. Calsul determination of blood urea nitrogen	H	H	H	H		X		90
													b. Microanalytic determination of blood urea nitrogen	H	H	H	H		X		90
9.3 Voiding evaluation	M	L-M	M	L-M	40	6	6	240	6.75	1620		1620	Checklist for urine volume, frequency, and complaints	M	M	M	H	X			60
9.4 Stone formation evaluation									6.75												
9.4.1 Kidney stone formation (X-ray)	M	M	H	M	60	4		240	6.75	1620		1620	X-ray - abdominal film for kidney and bladder stones	M	M	M	H			X	60
9.4.2 Serum and urine calcium and phosphate	H	M	M	L	50	2	5	100	6.75	675	6.1.2	See 6.1.2	Microanalytic determination of serum and urine calcium and phosphate	H	H	H	H		X		90

Table 6. Biomedical Measures and Techniques Data Sheets by Major Body System (Cont)

Measure Title	Characteristics					Information Content		Measure Value Totals					Technique Title	Accuracy	Sensitivity	Reliability	Feasibility	Level of Training Required			
	Validity	Sensitivity	Predictability	Crew Status	Subtotal Average	Coverage of System (%)	Coverage of Related Measures (%)	Measure Value	System Weight Factor	Weighted Measure Value	Reference to Replicative Measures	Total Measure Value						Astronaut	Technician	Physician	Technique Total Average
9.5 Serum and urine potassium and sodium	M	M	M	M	50	8	8	400	6.75	2700	3.2.4	3650	Microanalytic determination of serum and urine potassium and sodium	H	H	H	H		X		90
9.6 Fluid intake and output evaluation	M-H	M	M	M	55	20	20	1100	6.75	7425	3.2.5	8138	Checklist of fluid intake and output	M	M	M	H	X			60
9.7 Body water circulation									6.75												
9.7.1 Ocular tonometry	M	L-M	M	M	45	5		225	6.75	1519		1519	Tonometric evaluation of intraocular pressure	M	M	M	L-M			X	45
9.7.2 Total body water	M	M	H	M	60	15	15	900	6.75	6075		6075	a. Radioisotope studies, H-3, determination of total body water	M-H	M-H	H	L		X		60
													b. Urea dilution determination of total body water	M	M	M	M		X		50

scores of each evaluator was recorded, and an average was obtained for each of the four characteristics of every measure. This average value is shown in Table 6. The value for each of the four characteristics was then averaged; and this is shown in Table 6 in the column entitled "Subtotal Average".

Information Content

The column headed "Information Content" in Table 6 represents an estimation of the amount of information that a particular measure gives about the major system that the measure is related to; for example, what percent of the total information about the cardiovascular system does the measure blood pressure contribute. These values represent averages of the biomedical personnel and are shown in Table 6 under the column "Coverage of System". As noted earlier, measures that overlap to any notable extent are arranged under subgroups. Because of this overlapping, it is obvious that the sum of the percentages of the individual measures will be greater than 100 percent. This factor is considered under the column "Coverage of Related Measures," where the total information content that each subgroup contributes is listed. The total of this column must be 100 percent for each major system. By this method, the total value of the individual measures of each system is not too much in variance with each other system. This allows one to estimate the effect on the total information obtained about any major system when an individual measure is omitted and indicates how the remaining measures in a subgroup can make up this information depict subgroup "Venous Circulation." The information content for this is best exemplified by the three individual measures venous pressure and circulation time, liver size, and venous distention is 10, 2.5 and 2.5 percent respectively. The total information content that venous circulation contributes about the cardiovascular system is 10 percent. It is obvious, then, that the measure venous pressure and circulation time gives a maximum amount of information about venous circulation, and that liver size, and venous distention provide only a poor evaluation of venous circulation; and that, if the measure venous pressure and circulation time are omitted, the other measures would only provide about half of the information for venous circulation evaluation.

Measurement Evaluation

A product was made of the characteristics average and the information content for each individual measure to give an estimate of the value of each measure within each particular body system. At this point, had the only concern been the obtaining of data for the sake of data alone, without considering the meaning of the particular measures to an evaluation of zero G, it would have been sufficient to evaluate all 97 measures on this basis.

However, this is hardly realistic in the light of the rationale for the BAHFER study which is concerned with obtaining information relative to the effects of long-duration zero G on the ability of the human to survive and perform. It was necessary, therefore, to consider weighting each of the nine major body systems to obtain a more reasonable evaluation of each measure in relation to each other measure bearing this concept of zero G analysis in mind. The following two criteria were used for evaluation of the body systems:

1. Criticality of the System - that is, how important the particular system is to survival and thus to performance or, for example, what would be the effect upon a person if a 10-percent decrement in function of the particular body system occurred.

2. Justification - that is, the importance of obtaining information about a particular body system based upon the results of zero G flights or hypotheses developed about the effects of zero G.

The systems were ranked by the biomedical personnel of the BAHFER project on a 1 through 9 basis, both for criticality and justification. Criticality and justification ranks were then averaged for each system, and a final rank order was obtained. Since it was assumed that a logarithmic distribution of measures should be expected such that the value of the first measure would probably be about one-hundred times greater than the value of the last measure, weighting factors were developed on the basis of 9 for the most important body system and 1 for the least important body system. The other body system values being determined proportionately to the ranked averages obtained. The weights, then, were as follows:

Cardiovascular system	9.00
Urinary system and body fluids	6.75
Respiratory system	5.50
Nervous system	5.25
Musculoskeletal system	5.00
Endocrine system and metabolism	4.75
Hematopoetic and blood	4.75
Digestive system	3.00
Integument	1.00

The value of each individual measure as listed under column "Measure Value" in Table 6 was then multiplied by the weight factor for that particular system and then the weighted measure value recorded as shown under column headed "Weighted Measure Value." Where a particular measure is applicable to several systems, its value is thereby increased, for the total value for such a repetitive measure is the sum of the values found for that measure under each different system where it is located. The column in

Table 6 entitled "Repetitive Measure References" refers to other locations in the table for these repetitive measures. The final evaluation of the individual measures, then, as shown in the column "Total Measure Value" represents the product of characteristics, information content, and body system weight factor and includes a single total value for repetitive measures.

A rank order can now be established for the 97 measures, based on the total measure value obtained for each measure. The sum of the total measure values of all 97 measures, then, represents the maximum value of the entire list of biomedical measurements and can be considered to represent 100-percent confidence in obtaining data for the evaluation of the zero G effects upon man. In the case of tied values the measures involved were ranked separately by the biomedical personnel.

Results

Considering the sum of total measure values as 100 percent, each individual measure is given a percentage value proportionate to its "Total Measure Value" reflected in Table 6. Table 7 represents a rank order of the measures on the basis of Total Measure Values in Table 6. The column of percentages indicates the percentage value of each measure relative to 100 percent for the 97 measures. This percentage for each measure represents the percentage value or the confidence value for that particular measure to tell about the effects of zero G upon man. It should be noted once more that this is a logarithmic distribution with the first measure value approximately one hundred fold greater than the last; that is, cardiac output (No. 1) equals 9.88 percent, and gas formation and passage (No. 97) equals 0.06 percent.

Several important factors are worth noting about the confidence rankings. The first 15 measures contribute approximately 50 percent of the total confidence to be obtained from all the biomedical measures. If cardiac output could not be done because a physician was not included in the crew, about 10 percent of the total confidence would be lost which could not be made up practically in any other way. Once major equipment is included in the measurement package, such as the microanalytic system, the cost in terms of weight-volume-power values for repeated measures is negligible, as can be noted from Table 7. A large percentage of the total confidence derived from the biochemical measurements. Using Tables 6 and 7 together, for example, venous pressure and circulation time could be eliminated with a loss in confidence of only about 1.5 percent. This can be replaced by the combination of measures venous distention and liver size but with a confidence of only about 0.26 percent. Looking ahead slightly at this point, measure No. 45, urine-fecal-nitrogen; measure No. 55, ocular tonometry; measure No. 82, heart movement; measure No. 88, sedimentation

Table 7. Individual Biomedical Measure Ranking

Rank	Measure	Weighted Percentage Values
1	Cardiac Output	9.88
2	Respiratory volumes	6.90
3	Calcium balance study	4.57
4	Centrifuge test	3.15
5	Oxygen uptake and CO_2 production	3.07
6	Fluid intake and output evaluation	2.84
7	Blood pressure (before and after excerise)	2.76
8	Complete blood cell count (red and white reticulocyte and differential)	2.32
9	Total body water	2.12
10	Urinalysis (WBC, RBC, pH, sugar, protein, osmolarity)	2.11
11	Venous pCO_2, pO_2, pH	2.11
12	Plasma (blood) volume	1.79
13	Hemoglobin and hematocrit	1.74
14	Sensation (pain, temperature, pressure, touch)	1.65
15	Exercise test	1.62
16	Plumonary pathology (heart size) X-ray	1.62
17	Cardiac electrical activity and state (before and after exercise)	1.57
18	Serum and urine creatinine	1.54
19	Serum, urine and fecal Ca and PO_4	1.53
20	Venous pressure and circulation time	1.51
21	Muscle function	1.44
22	End expiratory pCO_2, pO_2	1.38
23	Muscle activity and state	1.28
24	Bone density	1.28
25	Serum and urine potassium and sodium	1.27
26	Gastro-intestinal absorption test	1.15
27	Cerebral blood flow	1.10
28	Visual acuity, depth perception and accommodation	1.10
29	Blood (and urine) sugar	1.06
30	State of arousal (alertness, sleep depth, and cycles)	1.01
31	Pulse rate	0.99
32	Autonomic hyperactivity	0.91
33	Cortical activity	0.91
34	Gastro-intestinal tract motility	0.88
35	Tubular readsorption test	0.85

Table 7. Individual Biomedical Measure Ranking (Cont)

Rank	Measure	Weighted Percentage Values
36	Tubular excretion test	0.85
37	Glomerular filtration test	0.85
38	Body temperature	0.83
39	Serum alkaline phosphatates	0.78
40	Expiratory-inspiratory force (flack test)	0.77
41	Blood plasma protein fractionation	0.74
42	Vestibular reaction	0.73
43	Bowel function evaluation and stool characteristics	0.73
44	Reflex response and clonus evaluation	0.73
45	Urine and fecal nitrogen	0.73
46	Muscle size	0.72
47	Heart sounds	0.71
48	Cardiopulmonary symptoms (dyspnea, etc.)	0.70
49	Respiratory rate	0.61
50	Bleeding time	0.60
51	Voiding evaluation	0.56
52	Kidney stone formation (X-ray)	0.56
53	Visual fields evaluation	0.55
54	RBC mass	0.54
55	Ocular tonometry	0.53
56	Capillary fragility	0.50
57	Eosinophil count	0.50
58	Serum catecholamine	0.50
59	Serum osmolarity	0.50
60	O_2 uptake by RBC	0.50
61	Blood-urea nitrogen	0.47
62	Visual illusion evaluation	0.46
63	Hearing	0.46
64	RBC uptake I_{125}	0.46
65	Joint motion range	0.44
66	Urinary albumin	0.42
67	Fecal flora sampling	0.42
68	RBC survival	0.41
69	Clotting time	0.41
70	Serum adenosine triphosphate (ATP)	0.41
71	Retinal examination	0.41
72	Urine catecholamine (24-hour sample)	0.40
73	Serum 17 kg steroid	0.40
74	Prothromein time	0.37

Table 7. Individual Biomedical Measure Ranking (Cont)

Rank	Measure	Weighted Percentage Values
75	Eating habits evaluation	0.37
76	Color vision evaluation	0.37
77	Urine 17 kg steroid (24-hour sample)	0.33
78	Energy requirements	0.33
79	Heart rate (before and after exercise)	0.33
80	Skin, nailbed and mucous membrane color	0.29
81	BSP	0.25
82	Heart movement (force)	0.24
83	Urine urea	0.22
84	Tremor	0.22
85	Nausea-regurgitation evaluation	0.21
86	Incidence of aerotitis media	0.18
87	Serum bilirubin	0.17
88	Sedimentation rate	0.17
89	Protein assimilation test	0.16
90	Mucosal integrity evaluation	0.16
91	Breath holding time	0.14
92	Skin thickness	0.14
93	Venous distention	0.12
94	Liver size	0.12
95	Pulse-wave velocity	0.12
96	Chest circumference	0.10
97	Gas formation and passage	0.06

rate; and measure No. 95, pulse-wave velocity are all not feasible at this time because of lack of technique or lack of validation, representing a total reduction in confidence of only about 0.81 percent. Figure 4 is a graphic representation of Table 7 showing measure rank on the abscissa versus percentage of confidence on the ordinate.

Discussion

The system for ranking the 97 measures, as outlined above, with the confidence values determined therefrom provides the basic means of choosing the measurements that will be included in the crew measurement system. While this evaluation is admittedly partly objective and partly subjective, it represents the best approximation available within the state of the art and capabilities of the personnel involved in the BAHFER project. It is fraught with the errors involved in mathematical approximations; however, as with any mathematical approximation of this kind, it offers a better estimation of the real situation than a purely subjective evaluation or concensus of opinion. The confidence data developed therefrom (from the basis for the selection of the crew measurement system; that is, where weight, power, volume, and time constraints of the various techniques) restrict the number of measures. The confidence value of the particular measure is then the major deciding factor.

BEHAVIORAL

Final Complete Set of Behavioral Functions That Are Study Candidates

The initial listing of behavioral functions in this section contained 49 items. The criteria used in developing this list were given and will not be repeated here. The same criteria were employed in determining the final list of behavioral functions. The list recommended for investigation of change under weightlessness contains 50 items rather than 49 because one of the original questions was found to be a two-part question and was split into two items in the final listing. The primary question to be answered by experimentation in space is the same for each of the listed functions. That question is, "Will a change in the function be found under conditions of weightlessness?"

Measure Selected for Each Function

At the time of the initial listing of functions, the measure that was to be employed to reflect the performance of each function was also listed. In the development of the final data, several of the measures initially selected were changed. In the main, changes were made for the purpose of selecting measures that would better reflect performance than those initially listed. The measures finally selected are given in the Appendix.

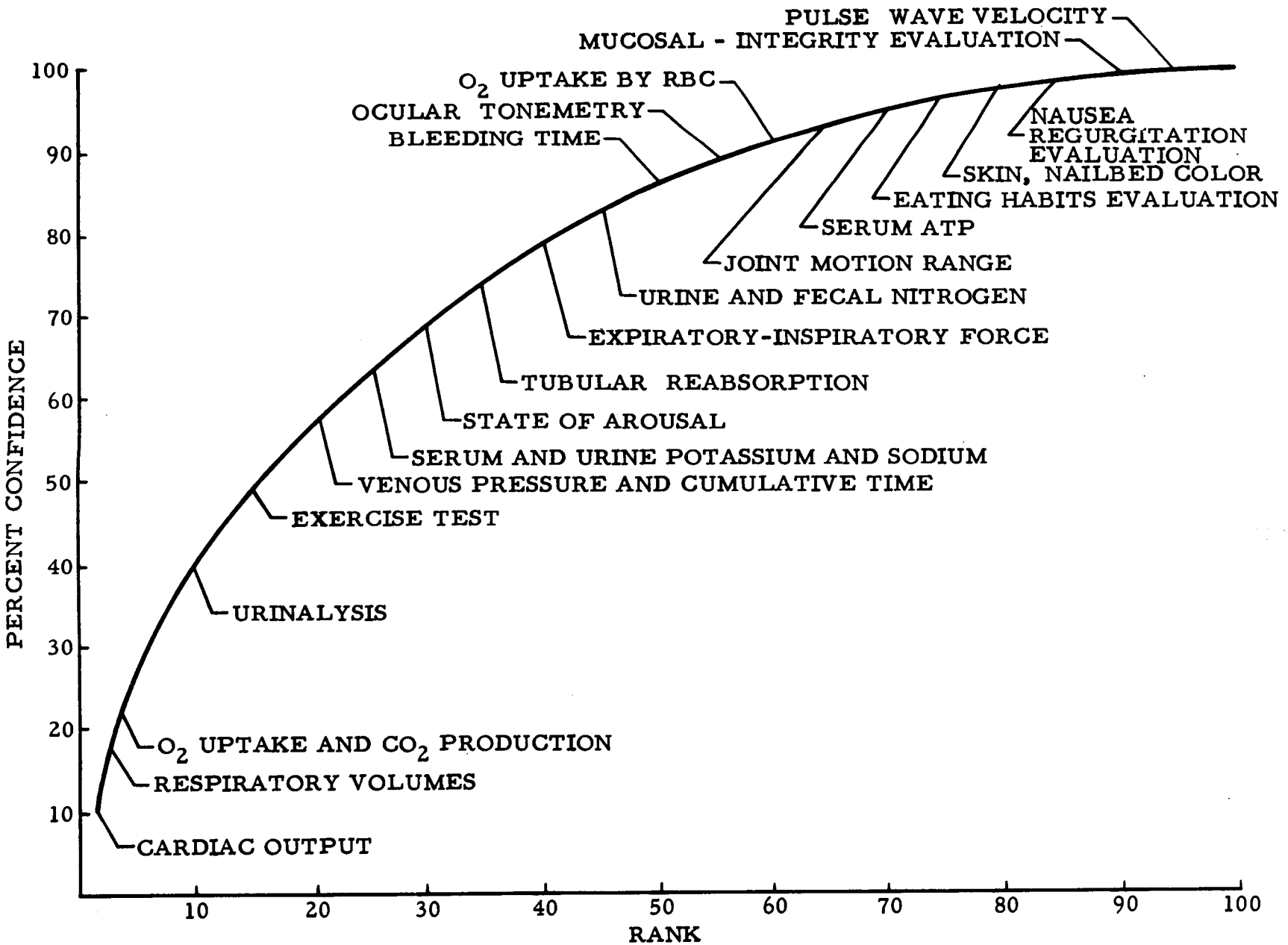


Figure 4. Cumulative Confidence Value Relative to Rank Order of Biomedical Measures

Final List of Tests Selected to Obtain Measurement of Each Function

There was considerable revision between the development of the initial and the final lists of behavioral tests. The principal reason for the changes in the recommended tests derived from the study of weight, power, volume, and time costs associated with the initial lists of tests. As explained in detail in Section IV, the evaluation of the costs of the initial list revealed that the critical cost would probably be in terms of time for carrying out testing rather than in terms of weight, power, or volume. Therefore, the review and refinement of the initial list concentrated on obtaining more realistic time estimates and on reducing the time cost of each test wherever possible. To reduce the time costs, two principal techniques were used:

1. Wherever possible, tests were devised that could be presented in a programmed manner so that observer time would not be required.

2. Wherever possible, steps were taken to increase the quality of tests so that fewer repetitions and, thus, less time would be required to obtain stable mean values.

Unfortunately, in becoming more concerned with the quality of tests, it was necessary to recognize that the number of testings required to achieve a given high level of confidence in the detection of degradation increases as the quality of the test decreases. In the case of many tests, the outcome of this concern, which derived from a need to reduce total testing time, was to actually increase total testing time because it was found necessary to increase the number of measurements recommended in the light of test quality. A more detailed discussion of this problem is contained in Section IV.

For the final revised list of tests, weight, power, volume, and time costs were estimated and are presented under Measurement Requirements in this Section. The final list of tests includes 50 items; that is, one test for each of the questions asked about the effect of weightlessness upon behavioral functions.

Confidence Weighting

The final listing of behavioral functions identifies the set of all questions concerning degradation in behavior that must be answered to achieve very high probability that all degradations due to weightlessness will be detected. Thus, as previously explained, a principal criterion for the development of the list of functions was that the list be so comprehensive that further questions concerning behavior could only add very small increments of probability of detection. In practice, however, it will not be possible to answer every question in this final list with complete confidence simply because of the high cost of doing so. Instead, some subset of the questions will be selected that will be compatible with constraints for a real space laboratory.

Unfortunately it is not possible at this time to identify the specific subset of lists that will be drawn for this purpose. Therefore, it is not possible to calculate the worth of whatever subset will be drawn. In short, since some presently undeterminable subset will be used, it is desirable to develop data and techniques for estimating confidence in the detection of zero G effects for any subset of tests that might be drawn from the final complete set of behavioral functions. The data and techniques that were developed for this purpose are discussed in the following paragraphs

In the simplest, case we might have 50 questions with a perfect measure for each question and with a perfect test for each measure. By perfect measure, we mean one that will reflect any change in the function. By perfect test, we mean one that gives information only about the question for which it is directed and which gives a value of the measure that is without error. Assuming this kind of perfection, we might say that if all the questions were answered, the total confidence achieved would be 1.000. (It would be more becoming to assume a total less than 1, but 1 is easily divisible by 50 and so we shall proceed with 1 as the assumed total.) If we further assume that the questions are independent and that they are of equal importance, the contribution to total confidence of each question would be 1.00/50 or 0.02. Thus, if our measures were perfect and our tests were perfect, we could calculate the contribution of each test to any subset simply by counting the number of tests and multiplying by 0.02. Thus, if 25 questions were answered the total confidence associated with the subset would be 50 percent.

But the task of developing confidence values for any subset is not so easy. Unfortunately, the measures and the tests that we have selected are not perfect, and this lack of perfection must be taken into account in calculating the confidence value of any subset of tests. In developing a confidence weighting system, confidence is defined by saying: Perfect confidence would reflect detection of all degradations in performance that might result under weightlessness. Thus, the confidence question is directed toward detecting effects of zero G on behavior; it is not directed toward describing the shape of the curve of degradation nor the variance in the population response. It is then assumed that each of the questions were independent (an assumption that cannot be justified in every case but one that is convenient), and it is also assumed that every question is of equal importance. (The assumption of equal importance is at odds with knowledge that some changes in performance are of less importance than others; but for the purpose of developing confidence weights, it was useful to set aside the question of relative importance to simplify the confidence weighting procedure. To take care of unequal importance of questions, a ranking procedure independent of the confidence weighting procedure was developed and is subsequently described.) Making the foregoing assumptions an allocation of confidence was made to each question of 0.02.

The worth of the measure selected for each function (question) was then estimated. That is, a probability value of p was assigned to each measure to indicate the probability that the measure will reflect any change in the function identified by the question. It is to be noted that the probability value, p, is unrelated in any way to the test associated with that function. Rather, the value of each test was considered in a separate step to answer the question, "What is the quality of the selected test as a means of obtaining a true value for the selected measure?" The estimated quality of each test is designated by the letter q. The contribution to confidence, w, provided by each test was calculated by the formula $w = pq(0.02)$. For example, the estimates and calculations for olfaction are the following:

1. What is the probability that the selected measure will reflect any change in the olfactory function?

   Estimate of $p = 0.99$

2. What is the quality of the chosen test as a means of providing a true value for the selected measure?

   Estimate of $q = 0.90$

   Thus $pq = 0.89$ and

   $w = pq(0.02) = 0.0178$ = the contribution to confidence of the measure and test of olfaction when olfaction is the only function tested or when olfaction is incorporated into the full set of 50 behavior measurements.

Using these values for all 50 functions and tests, the total confidence that change in performance due to zero G will be detected was calculated to be 80.2 percent.

The preceding example is for a test that is specific to a function. That is, the measure and test of olfaction provides no information about other functions, but most of the performance tests answer some part of a number of other questions. For example, the test for docking provides some information about 15 other functions. Therefore, for each test, a list of functions were developed that would be answered in part by the test; and for each of these functions, an estimate of p and q values associated with the test were made. That is, for each of the functions secondarily answered by a test, the questions were asked, "How good is the measure used?" and "How good is the test for all of these related functions?"; and the increment of confidence that would be bought by using the test to answer each secondary question was calculated. The results of this exercise are tabled for each of the tests in the section that presents basic information about behavioral tests. (Refer to Appendix B.)

The tabled confidence rates permit the evaluation of the confidence associated with any subset of behavioral tests simply by using the rule of summing only the highest confidence weights for each question covered by the subset of tests. Using this rule, the sum of the weights for a given subset can never exceed 1.00.

For example, the tabular information for Test No. 43, sound localization, will appear as follows:

	p	Q	pQ	w
Sound localization	0.90	0.80	0.72	0.0144
Sound movement	0.80	0.40	0.32	0.0064

In this example the data for sound localization have the same meaning as the data for olfaction previously described. The data for sound movement have the following meanings:

p = 0.80 means that the probability of the measure used for sound localization and for detecting any change in sound movement is 80 percent.

q = 0.40 means that the quality of the test selected to measure sound localization will provide a true value of the measure of sound movement is only 0.40.

w = 0.0064 is the straightforward application of the formula w = pq (0.02).

This data means further that if sound localization were the only test used to measure performance, the confidence value for this single measure would be 0.0144 + 0.0064 = 0.0208.

A confidence value for any subset of tests can be derived by the following procedure:

1. Examine the tabular information for every test included in the subset, that is, the p, q, and w data (Appendix B).

2. Cross check all functions listed under each of the tests and eliminate all duplications retaining only the highest w for each function. This means there will be only one w value for every test and function.

3. Add all of the remaining w's, and this sum represents the confidence value for the probability that this subset of tests will identify any degradation in performance due to weightlessness.

Ranking

As previously noted, the determination of confidence weights was made without considering the relative importance of the questions; all questions were assumed to be of equal importance. However, the assumption of equal importance was for temporary convenience only. Next importance was deliberately considered. The initial list of functions had been ranked in importance as described earlier in this section. The initial ranking was to provide a basis for selecting subsets such that any subset would include the most important tests first. This ranking was done in expectation of finding that weight, power, and volume constraints would make it impossible to include instrumentation for all tests on an orbiting laboratory. However, subsequent to the initial ranking, it was discovered that except for the very smallest station, weight, power, and volume would not significantly restrict the size of the instrumentation package to be put on board. Rather, it was found that time for experimentation would be the principal constraint. Therefore, the need for a ranking changed in nature from ranking for the purpose of selecting instrumentation to be included in a subset to ranking for the purpose of determining how to use experimental time. (The question of time is treated more fully in Section IV where it is advocated that a procedure be used for determining the use of experimental time on a week by week basis as data are gathered from the orbiting station.) With this approach in mind, the ranking of the behavioral tests was accomplished for the purpose of determining how to use experimental time during the first period of experimental operations. Only the first period was considered because it was assumed that the data gathered in the first period would determine the use of time in the second period. The meaning of the ranking is that the first rank items must be included for measurement during the first period even if the time allowed for experimentation is extremely small. With intermediate and larger stations that may have more time available for experimentation, tests ranked lower and lower in the list can be picked up in order for inclusion in the measurement schedule for the first period.

The 50 tests were ranked by blocks. In the first block were included 10 tests that gave maximum coverage of questions in terms of spread across questions even though the confidence achieved for any one question might be relatively low. Thus, it was reasoned that for purposes of safety that time should be used first to obtain broad coverage for behavioral functions so that any gross degradation might be observed as a warning signal even if the reason for the degradation could not be determined. The second block was allocated to tests having to do with functions that could be expected to show change during the first period of experimental operations. Thus, after safety considerations were taken care of, it was considered important to gather data about functions that would change in the first period so that the course of change could be plotted. The third block was allocated to

tests that extended the coverage of the tests in the initial block. Thus, although the initial block of tests gave wide coverage, it left a few significant gaps; and without coverage of these, degradation might occur during the first period and go undetected. If degradation were to go undetected, consideration of the degradation could not be entertained in determining the measurement schedule for the second period. The fourth block of tests included all of the remaining tests that related to job critical performance. The final block of tests include those tests related to performance that was not considered job critical. Within each block, expert opinion was used for ranking on the basis of order of importance of consideration. The ranking of the tests achieved in this manner is shown in Table 8.

In using the Table 8, it must be remembered that the ranking of the tests was not accomplished simply for the purpose of providing order to the data. Rather, the ranking was done to serve a purpose—to provide guidance with respect to how to allocate measurement time during the first period of station operation. Thus, the implication of the ranking is that if the time for measurement during the first period of operation is less than that required for implementation of the total set of tests, then the subset of tests selected for measurement should be chosen by working down the list from rank one accumulating time cost until that rank is achieved that is associated with the maximum allowable time for measurement. It is possible to rank the measures for other purposes. For example, for the purpose of showing the order in which tests should be selected within a weight constraint. For different purposes, different rankings would be required. Table 8 reflects ranking for the purpose of allocating measurement time within time constraints.

It is of some interest to ask how confidence in the effects of zero G is accumulated as one proceeds down the list of tests by rank. Table 9 shows the accumulation of confidence as tests are added to the measurement set one at a time in order of the ranking given in Figure 5.

Table 8. Behavioral Functions Ranked by Blocks

Block	Rank	Name of Test
BLOCK I BROAD COVERAGE, GROSS SAFETY		
I	1	Arm/hand/finger/manipulation
I	2	Computation
I	3	Docking
I	4	Complex pattern discrimination
I	5	Handling mass
I	6	Body positioning
I	7	Learned procedure
I	8	Perceptual (set)
I	9	Speaking
I	10	Speech perception
BLOCK II EXPECTED TO DEGRADE EARLY		
II	11	Arm/hand/finger control of force
II	12	Detection/discrimination angular acceleration
II	13	Detection/discrimination linear acceleration
II	14	Arm/hand/finger control of speed of motion including reaction time
II	15	Detection/discrimination of force against a limb
II	16	Detection of movement of limb
II	17	Recognition of location of limb
II	18	Leg control of force
II	19	Tracking, visual-motor
BLOCK III EXTENSION OF COVERAGE, BEYOND BLOCK I		
III	20	Visual resolution of detail
III	21	Near depth perception
III	22	Peripheral/visual detection/discrimination
III	23	Tone audition
III	24	Stereognosis
III	25	Detection/discrimination vibration
III	26	Detection/discrimination color
III	27	Deduction
III	28	Recording
III	29	Time perception

Table 8. Ranks by Blocks (Cont)

Block	Rank	Name of Test
BLOCK IV REMAINING TESTS, TASK RELATED		
IV	30	Distant static depth perception
IV	31	Dynamic depth perception
IV	32	Decision making
IV	33	Cue abstration
IV	34	Problem solving
IV	35	Guided performance
IV	36	Detection of light touch
IV	37	Brightness detection/discrimination
IV	38	Association
IV	39	Reading
IV	40	Writing
BLOCK V REMAINING TESTS, NOT TASK CRITICAL		
V	41	Tone pattern discrimination
V	42	Assessment of volume of space
V	43	Sound localization
V	44	Pain detection
V	45	Detection of heat/cold
V	46	Texture discrimination
V	47	Auditory detection/discrimination of motion
V	48	Detection of tone duration
V	49	Olfaction
V	50	Inductive reasoning

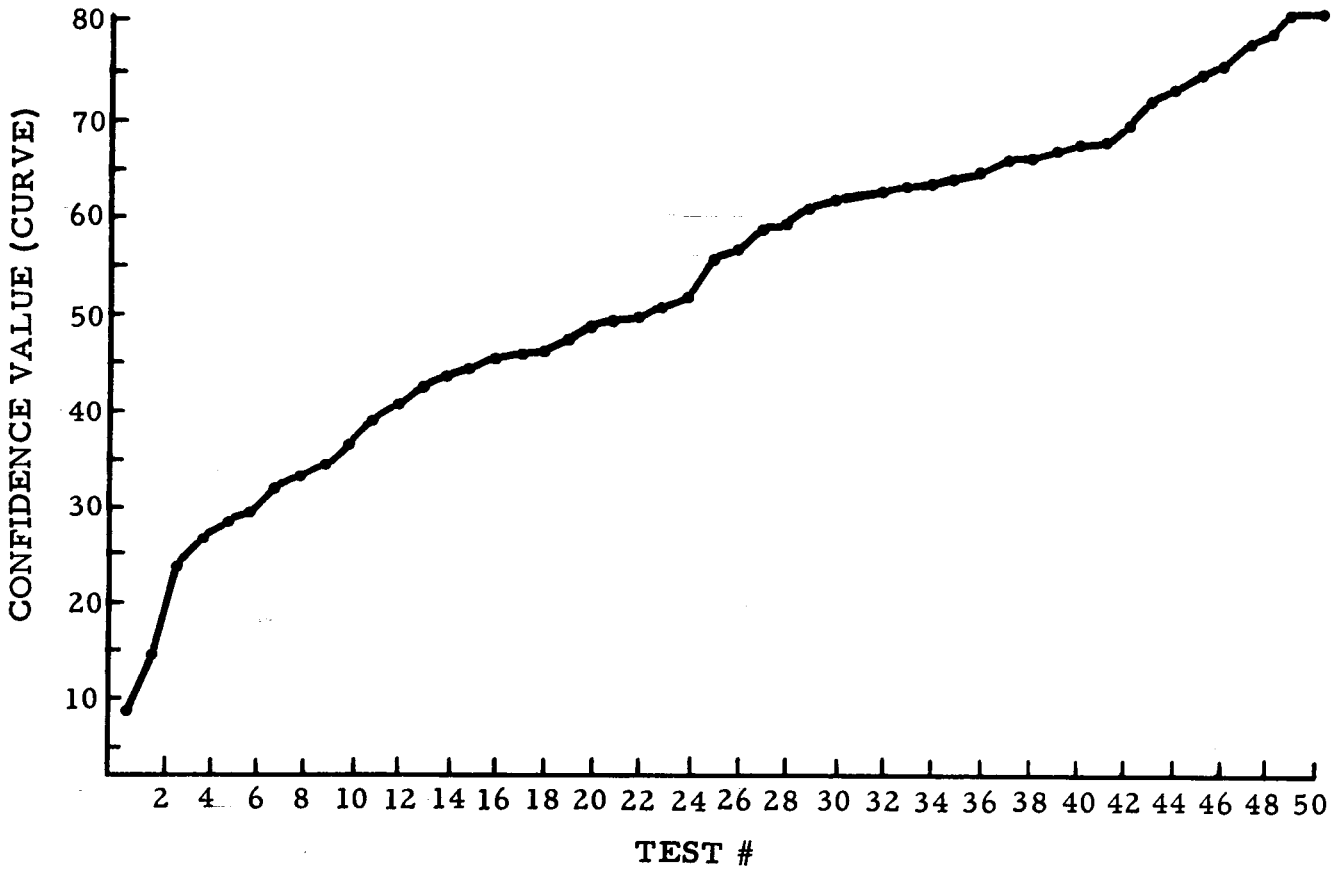


Figure 5. Cumulative Confidence Values Behavioral Tests

MEASUREMENT TECHNIQUES

The term measurement technique is defined as the method and procedures used to obtain a quantitative value or qualitative description of a phenomena. The equipment, supplies, and recording documents (i.e., recording checklists) used to obtain the end value or description of a phenomena were considered an integral part of the technique in this report. They were given primary consideration in the determination and evaluation of techniques appropriate to each measure and the selection of the technique considered most appropriate to each measure.

This section is concerned with the methodology and criteria used to establish alternative techniques for each measure, and the final selection of the technique considered as most appropriate to each measure. Also included in this section is a presentation of the final lists of recommended techniques for the biomedical measure list and the behavioral functions list. A brief discussion of selected techniques list and a summary notation of special problems encountered in definition of the measurement techniques for obtaining on-board biomedical and behavioral measures are also presented.

Appendixes A and B present the summary description data concerning each measurement technique. These summaries provided the basic data for the measurement technique analysis. Included in each summary is the name of the technique, the name of the associated measure, and a brief description of the technique (i.e., what the technique is and what it is intended to accomplish). Additional information in Appendixes A and B give a brief evaluation of the technique relative to alternative techniques for a specified measure, the required qualifications (training) of the subject and/or observer for technique accomplishment, and the data form in which the results of the measurement are provided.

The Appendixes also provide summary data of frequency and time required for measurement (test) for each technique, and summary data for equipment and supplies associated with each technique. Time estimates are provided on the assumption of a ninety-day mission and include an estimate of how often the measurement is taken, total test time required, and a breakdown into subject and observer time per day which is required by the measurement technique. Included in the summary data for equipment and supplies is a description of the item and estimate of the weight, power requirements, and volume of each item.

A separate discussion of the centrifuge as a special technique is presented in Section III, special equipment because of the importance and problems associated with the utilization of a centrifuge within a space station.

BIOMEDICAL MEASUREMENT TECHNIQUES

Each biomedical measure was studied in detail to determine all possible techniques that might be applied to a specific measure. The specification of individual techniques applicable to each measure was accomplished by review of the medical and physiological literature for accepted experimental techniques and/or clinically validated techniques for obtaining measurements equivalent or similar to the specified measures. This review was conducted independently by study participant personnel with an end list of techniques formulated by combination of the independent listings. Tables 6 and 7 in Section III-C denote the techniques appropriate to each measure. Although the techniques listed in both tables are the same, Table 5 is based upon the individual measures listed by body functional systems whereas Table 7 is based upon the individual measures listed on a rank-order of assigned importance.

Technique Evaluation Criteria and Methodology

Subsequent to the delineation of possible measurement techniques for each measure, a further analysis evaluated the relative appropriateness of alternative techniques to each measure. (See Table 6 in Section II-C.) To aid in the evaluative analyses supplemental data was collected and assembled for each technique. The supplemental data consisted of definition of items of equipment and supplies with attendant weight, power, and volume data; measurement time estimates for subject and observer participation in each technique; and estimation of the minimum skill level required of personnel to obtain the measure. Minimum skill levels were defined as the minimum amount of training required and were classified as: 1) Astronaut—basic astronaut training only with familiarity with the technique; 2) Biomedical Technician—specialized short duration training in specialized procedures and/or equipment operation; and 3) Professional—training normally received through completion of medical school training and receipt of an M. D. degree. (See the Appendix for summary descriptive data and requirements relative to each individual measurement technique.)

Value estimates for each technique were developed according to a set of pre-established criteria. (Refer to Table 6 in Section II for values estimation factors and total values.) Criteria considered for analysis were:

Accuracy—an estimate of the goodness of the value obtained by the measurement technique as an approximation of the true mean value

of the measure. The estimate of how well the technique measures what it is supposed to measure is usually compared to a measure value standard.

Sensitivity—an estimate of the ability of the measurement technique to detect small changes in the function which is being measured.

Reliability—an estimate of how precise the measurement technique is in relation to obtaining the same measure value on repeated occasions.

Feasibility—an estimate as to the relative difficulity and/or practicability of performing the measurement technique or adapted version of the techniques within a typical space station and under zero-G conditions.

Determination of a final value for each technique was based upon a rated value assigned to each of the criteria for each technique considered. These ratings were based upon the assumption that the technique under consideration would be performed by an adequately trained operater under favorable measurement conditions. Criteria ratings for each technique were made by study medical personnel with the final assigned rating based upon a composite rating of individual judgments.

A three-point scale (high, medium, and low) was used for individual technique (criteria ratings according to the level of confidence in the technique when compared to the criterion attribute). In the composite rating, differences in individual rating judgments were resolved by an assignment of an intermediate point on the rating scale (e.g., a rating of a technique as Low (L) on the criterion of Reliability by one rater, and Medium (M) by another rater would be assigned a point scale rating of Low-Medium (L-M) on the composite rating).

The composite criterion rating consisted of a given point rating scale with each point assigned a numerical equivalent value. The five scale points with respective numerical values assigned were:

Low	10
Low-Medium	30
Medium	50
Medium-High	70
High	90

The total value for each technique was established by adding the numerical equivalent for the composite rating assigned to each of the four criteria (accuracy, sensitivity, reliability, and feasibility).

General rules formulated for selection of the most appropriate technique for each measure were as follows:

The value of the technique as calculated above was the principal factor in evaluation and was the deciding factor in cases where weight, power, volume, and time were nearly equivalent in competing techniques with the remaining techniques considered as alternative means.

Where competing techniques possessed a nearly equivalent value rating, but differed substantially in relation to weight, power, volume, or time characteristics, the technique possessing the more favorable characteristics (minimum) was selected.

Techniques possessing a low composite rating on feasibility were eliminated. For example, cardiac catherization was eliminated as a technique for measuring cardiac output because the technique requires a surgical suite.

Results and Discussion

Information in Table 9 presents the techniques selected as most appropriate for each measure. The Appendix presents the listing of all biomedical measurement techniques for each measure including the selected technique and alternative techniques.

It is noted that the group of selected measurement and alternative measurement techniques constitutes a basic "package" of measurement techniques corresponding to a set of given measures. The selected techniques have been chosen to yield the largest degree of confidence in the measurements obtained from the associated measures. However, the decision to use a selected technique as contrasted with an alternative is a function of many factors (i.e., composition of the crew). For example, a crew consisting only of astronaut personnel would eliminate from consideration the Dye Dilution technique for measurement of cardiac output because of the high skill level required for accomplishment of the technique. However the above measure and associated technique are rated high in importance and recommended for inclusion in the crew measurement system package.

Table 9. Ranked Biomedical Measures and Selected Techniques

Rank Order Number	Rank Order Percentage	Basic Biomedical Measures and Selected Techniques	Total Test Time (man-minutes)	Level of Training	Frequency (per day) for a 90-Day Mission	Time Per Subject-Day for a 90-Day Mission (minutes)			Equipment and Instruments			90-Day, 1-Man Supplies and Spares	
						Subject	Observer	Total	Weight (pounds)	Power (watts)	Volume (cubic feet)	Weight (pounds)	Volume (cubic feet)
M1	9.88	Cardiac output Technique: dye dilution T-1824	42	P	1/7	2	4	6	18.0	85.0	0.8084	8.795	0.2233
M2	6.90	Respiratory volumes Technique: servospriometric determination of respiratory volumes	35	T	1/7	1	4	5	105.5	320.0	3.5391	13.6	0.6440
M3	4.57	Calcium balance study Technique: microanalytic determination of calcium balance-programmed determination of serum and urine calcium and phosphate	63	T	1/14	1/2	4	4-1/2	Included in M1			4.96	0.1651
M4	3.15	Centrifuge test Technique: centrifuge test	84	P	1/7	4	8	12	See Section III				
M5	3.08	Oxygen uptake and carbon dioxide production Technique: servospirometric determination of oxygen consumption and thermal conductivity analysis for carbon dioxide	21	T	1/7	1	2	3	Included in M2				
M6	2.84	Fluid intake and output evaluation Technique: record on fluid intake and output	3	A	1	3		3				2.905	0.0392
M7	2.76	Blood pressure (before and after exercise) Technique: auscultatory determination of blood pressure	6	A	2	4	8	12	1.25		0.0486	0.125	0.0049
M8	2.32	Complete blood cell count (red, white, reticulocyte, and differential) Technique: optical count for complete blood count	33	T	1/3	1	10	11	5.0	25.0	0.5700	Also in M1 and M6 0.50	0.0570
M9	2.12	Total body water Technique: urea dilution determination of total body water	30	T	1/14	1/7	2	2-1/7	Included in M1			Included in M1 and M6	
M10	2.11	Urinalysis (wbc, rbc, pH, sugar, protein, osmolarity) Technique: microscopic and color-test urinalysis	12	T	1/3	1	3	4	Included in M1 and M8			Included in M6	
M11	2.11	Venous pCO_2, pO_2, pH Technique: electrode gas analysis of venous blood sample	28	T	1/7	1	3	4	20.0	140.0	0.8640	Also in M1 2.0	0.0864
M12	1.79	Plasma (blood) volume Technique: dye dilution, T1824, for plasma volume	84	T	1/14	2	4	6	Included in M1			Included in M1	
M13	1.74	Hemoglobin and hematocrit Technique: cyanmethemoglobin and capillary tube methods	16	T	1/3	1/3	5	5-1/3	Included in M1			Included in M1, M3, and M6	
M14	1.65	Sensation (pain, temperature, pressure, and touch) Technique: clinical neurological examination of superficial sensation	12	P	1/7	5/7	1	1-5/7	0.5		0.0116	0.05	0.0012
M15	1.62	Exercise test Technique: exercise test	84	P	1/7	4	8	12	10.625	5.02 Also in M1, M2, and M7	2.0584	Also in M1 and M2 1.06	0.2058
M16	1.62	Pulmonary pathology & heart size Technique: X-ray of chest	17-1/2	P	1/14	1/4	1	1-1/4	76.0	550	1.3072	15.6	0.3390
M17	1.57	Cardiac electrical activity and state (before and after exercise) Technique: electrocardiography	25	A	1	10	15	25	Included in M15				
M18	1.54	Serum and urine creatinine Technique: calsul determination of serum and urine creatinine	9	T	1/7	2/7	1	1-2/7	Included in M1			Included in M3	
M19	1.53	Serum, urine, and fecal Ca and PO_4 Technique: microanalytic determination of serum and urine calcium and phosphates	29	T	1/7	1/7	4	4-1/7	Included in M1			Included in M3	
M20	1.51	Venous pressure and circulation time Technique: manometric determination and decholin test using venipuncture	21	A	1/7	1	2	3	0.5		0.0231	Also in M1 0.05	0.0023

Table 9. Ranked Biomedical Measures and Selected Techniques (Cont)

Rank Order Number	Rank Order Percentage	Basic Biomedical Measures and Selected Techniques	Total Test Time (man-minutes)	Level of Training	Frequency (per day) for a 90-Day Mission	Time Per Subject-Day for a 90-Day Mission (minutes)			Equipment and Instruments			90-Day, 1-Man Supplies and Spares	
						Subject	Observer	Total	Weight (pounds)	Power (watts)	Volume (cubic feet)	Weight (pounds)	Volume (cubic feet)
M21	1.44	Muscle function Technique: resistive test with spring for muscle function	36	A	1/3	12		12	10.125		1.0003	1.01	0.1000
M22	1.38	End expiratory pCO_2 and pO_2 Technique: mass spectrographic analysis for end expiratory pO_2 and pCO_2	15	A	1/3	2	3	5	26.281	52.0	1.1760	2.6	0.1176
M23	1.28	Muscle activity and state Technique: electromyographic evaluation of muscle activity	21	A	1/14	1	2	3	0.125	0.02	0.0005	0.01	0.0001
M24	1.28	Bone density Technique: X-ray of long bones	21	P	1/21	1/3	2/3	1	Included in M16			Included in M16	
M25	1.27	Serum and urine potassium and sodium Technique: microanalytic determination of serum and urine potassium and sodium	22	T	1/7	1/7	3	3-1/7	Included in M1			Included in M1 and M3	
M26	1.15	*GI Absorption test* Technique: D-xylose test of GI absorption	56	T	1/14	1	3	4	Included in M1			Included in M3	
M27	1.10	Cerebral blood flow Technique: rheocenphalography	42	A	1/7	2	4	6	8.0	50.0	0.4630	0.8	0.0463
M28	1.10	Visual acuity, depth perception and accommodation Technique: optical evaluation of visual acuity, depth perception and accommodation	14	A	1/7	1	1	2	40.0	225.0	2.4000	4.0	0.2400
M29	1.06	Blood (and urine) sugar Technique: calsul determination of blood (and urine) sugar	7	T	1/3	1/3	2	2-1/3	Included in M1			Included in M3	
M30	1.01	State of arousal (alertness, sleep depth, and cyles) Technique: Subjective evaluation and observation of state of arousal	6	A	1/7	3/7	3/7	6/7					
M31	0.99	Pulse rate Technique: manual counting of pulse rate	2	A	2	2	2	4	Included in M21				
M32	0.91	Autonomic hyperactivity Technique: subjective and objective evaluation of autonomic hyperactivity (nausea, sleepiness, etc.)	2	A	1	2		2					
M33	0.91	Cortical activity Technique: electroencephalographic evaluation of cortical activity	42	A	1/14	1	2	3	0.125	0.02	0.0005	0.01	0.0001
M34	0.88	Gastro-intestinal tract motility Technique: X-ray of GI series	90	P	1/60	1/2	1	1-1/2	Included in M16			Included in M3 and M16	
M35	0.85	Tubular readsorption test Technique: Fishberg concentration test	4	A	1/14	1/7	1/7	2/7	68.0	150.0	1.3750	Also in M6 6.8	0.13570
M36	0.85	Tubular excretion test Technique: PSP test	9	T	1/14	1/14	1/2	9/14	Included in M1			Included in M1 and M3	
M37	0.85	Glomerular filtration test Technique: urea clearance test-calsul method	21	T	1/14	1/2	1	1-1/2	Included in M1			Included in M3	
M38	0.83	Body temperature Technique: thermometry	3	A	4	12		12	0.0625		0.0012	0.01	0.0001
M39	0.78	Serum alkaline phosphatase Technique: calsul determination of serum alkaline	8	T	1/7	1/7	1	1-1/7	Included in M1			Included in M1 and M3	
M40	0.77	Expiratory-inspiratory force (Flack Test) Technique: Flack Test of expiratory-inspiratory force	10-1/2	A	1/7	1/2	1	1-1/2	1.0		0.0116	0.10	0.0012
M41	0.74	Blood plasma protein fractionation Technique: microanalytic determination of blood proteins with paper electrophoresis	21	T	1		21	21	Included in M1			Included in M1 and M3	
M42	0.73	Vestibular reaction Technique: caloric stimulation test for vestibular response	35	T	1/14	1	1-1/2	2-1/2	0.125		0.0058	0.01	0.0006

Table 9. Ranked Biomedical Measures and Selected Techniques (Cont)

Rank Order Number	Rank Order Percentage	Basic Biomedical Measures and Selected Techniques	Total Test Time (man-minutes)	Level of Training	Frequency (per day) for a 90-Day Mission	Time Per Subject-Day for a 90-Day Mission (minutes)			Equipment and Instruments			90-Day, 1-Man Supplies and Spares	
						Subject	Observer	Total	Weight (pounds)	Power (watts)	Volume (cubic feet)	Weight (pounds)	Volume (cubic feet)
M43	0.73	Bowel function evaluation and stool characteristics Technique: recording frequency of defecation, quantity and quality; observation of stool, and occult blood (one shot tablet test)	3	A	1	3		3				Included in M6	
M44	0.73	Reflex response and clonus evaluation Technique: Clinical evaluation of deep tendon reflexes	4	P	1/7	2/7	2/7	4/7	Included in M14				
M45	0.73	Urine and fecal nitrogen Coleman automatic analyzer for nitrogen	23	T		Technique not feasible							
M46	0.73	Muscle size Technique: muscle size measurement	14	A	1/7	1	1	2	0.125		0.0012	0.01	0.0001
M47	0.71	Heart sounds Technique: phonocardiography	21	A	1/7	1	2	3	0.5	0.02	0.0058	0.05	0.0006
M48	0.70	Cardiopulmonary symptoms (dyspnea, etc.) Technique: subjective observation of cardiopulmonary symptoms	2	A	1	1	1	2					
M49	0.61	Respiratory rate Technique: pneumotachometry	9	A	2	6	12	18	0.5	1.0	0.0012	0.05	0.0001
M50	0.60	Bleeding time Technique: Ivy Test for bleeding time	14	A	1/7	1	1	2	Included in M21			Included in M1 and M3	
M51	0.56	Voiding evaluation Technique: recording of urine volume, frequency, and complaints	2	A	1	2		2				Included in M6	
M52	0.56	Kidney stone formation (X-ray) Technique: X-ray abdominal film for kidney and bladder stones	17-1/2	P	1/14	1/4	1	1-1/4	Included in M16			Included in M16	
M53	0.55	Visual fields evaluation Technique: evaluation of visual fields	14	A	1/7	1	1	2	2.0		1.0000	0.20	0.1000
M54	0.54	Red blood-cell (RBC) mass Technique: radioisotope study, Cr 51, for RBC mass	90	T	1/60	1/2	1	1-1/2	244.3	40.4	1.8964	Also in M1 24.43	0.1896
M55	0.53	Ocular tonometry Technique: tonometric evaluation of intraocular pressure	14	P		Technique not feasible							
M56	0.50	Capillary fragility Technique: tourniquet test of capillary fragility	14	A	1/7	1	1	2	Included in M1 and M21				
M57	0.50	Eosinophil count Technique: blood smear count of eosinophils	9-1/2	T	1/3	1/6	3	3-1/6	Included in M8			Included in M1 and M6	
M58	0.50	Serum catecholamine Technique: calcul determination of serum catecholamine	9	T	1/7	2/7	1	1-2/7	Included in M1			Included in M3	
M59	0.50	Serum osmolarity Technique: freezing point depression osmometry	21	T	1/7		3	3	Included in M35			Included in M1, M3 and M35	
M60	0.50	Oxygen uptake by red blood cells Technique: electrode analysis for O_2 uptake by RBC	7	T	1/7		1	1	Included in M11			Included in M1	
M61	0.47	Blood-urea nitrogen Technique: calcul determination of blood urea nitrogen	8	T	1/3	2/3	2	2-2/3	Included in M1			Included in M1 and M3	
M62	0.46	Visual illusion evaluation Technique: visual illusion recording	1	A	1	1		1					
M63	0.46	Hearing Technique: audiometric evaluation of hearing	12	A	1/7	5/7	1	1-5/7	3.0	10.0	0.0694	0.30	0.0069
M64	0.46	RBC uptake I_{125} Technique: radioisotope study, T-3, I-125 uptake by RBC	28	T	1/21	1/3	1	1-1/3	Included in M54			Included in M1	
M65	0.44	Joint motion range Technique: kinesthetic determination of joint motion range	14	A	1/7	1	1	2	2.0	1.0	1.0000	0.20	0.1000
M66	0.42	Urinary albumin Technique: calcul determination of urinary albumin	9	T	1/7	2/7	1	1-2/7	Included in M1			Included in M3	
M67	0.42	Fecal flora sampling Technique: bacteria culture (on earth)	5	A	1/90	1/18		1/18	0.03		0.0012	0.01	0.0001

Table 9. Ranked Biomedical Measures and Selected Techniques (Cont)

Rank Order Number	Rank Order Percentage	Basic Biomedical Measures and Selected Techniques	Total Test Time (man-minutes)	Level of Training	Frequency (per day) for a 90-Day Mission	Time Per Subject-Day for a 90-Day Mission (minutes)			Equipment and Instrumentation			90-Day, 1-Man Supplies and Spares	
						Subject	Observer	Total	Weight (pounds)	Power (watts)	Volume (cubic feet)	Weight (pounds)	Volume (cubic feet)
M68	0.41	RBC survival Technique: radioisotope study, Cr-51, for RBC survival	90	T	1/60	1/2	1	1-1/2	Included in M54			Included in M1	
M69	0.41	Clotting time Technique: capillary tube method for clotting time	11	T	1/7	1/7	1-3/7	1-4/7				Included in M1, M3 and M6	
M70	0.41	Serum ATP Technique: calcul determination of serum ATP	8	T	1/7	1/7	1	1-1/7	Included in M1			Included in M1 and M3	
M71	0.41	Retinal examination Technique: opthalmoscopic examination of retina	14	P	1/7	1	1	2	2.0	10.0	0.0521	0.20	0.0052
M72	0.40	Urine catecholamine (24-hour sample) Technique: calcul determination of urine catecholamine	8	T	1/7	1/7	1	1-1/7	Included in M1			Included in M3	
M73	0.40	Serum 17 KG steroid Technique: calcul determination of serum 17-KGS	9	T	1/7	2/7	1	1-2/7	Included in M1			Included in M3	
M74	0.37	Prothrombin time Technique: quick test for prothrombin time	11	A	1/7	1/7	1-3/7	1-4/7				Included in M1 and M3	
M75	0.37	Eating habits evaluation Technique: recording of food intake and evaluation of appetite	2	A	1	2		2					
M76	0.37	Color vision evaluation Technique: optical evaluation of color vision	4	A	1/7	2/7	2/7	4/7	Included in M28				
M77	0.33	Urine 17 KG steroid (24-hour sample) Technique: calcul determination of urine 17-KGS	9	T	1/7	2/7	1	1-2/7	Included in M1			Included in M3	
M78	0.33	Energy requirements Technique: evaluation of energy requirements from food intake, etc.	5	A	1	5		5					
M79	0.33	Heart rate (before and after exercise) Technique: electrocardiography	25	A	1	10	15	25	Included in M15				
M80	0.29	Skin, nailbed, and mucous membrane color Technique: observation of skin, mucous membrane, and nailbed color	5	A	1	2	3	5					
M81	0.25	BSP Technique: microanalytic determination of BSP (bromsulphalein) excretion	15	T	1/7	1/7	2	2-1/7	Included in M1			Included in M1	
M82	0.24	Heart movement (force) Technique: ballistocardiography	28	T	No technique feasible								
M83	0.22	Urine urea Technique: calcul determination of urine urea	8	T	1/7	1/7	1		Included in M1			Included in M3	
M84	0.22	Tremor Technique: electromyographic evaluation for muscle tremor	21	T	1/14	1/2	1	1-1/2	Included in M23				
M85	0.21	Nausea-regurgitation evaluation Technique: subjective evaluation of nausea and observation of emesis	2	A	1	2		2					
M86	0.18	Incidence of aerotitis media Technique: subjective evaluation and otoscopic examination (aerotitis media)	14	P	1/7	1	1	2	Included in M71				
M87	0.17	Serum bilirubin Technique: microanalytic determination of serum bilirubin	15	T	1/7	1/7	2	2-1/7	Included in M1			Included in M1 and M3	
M88	0.17	Sedimentation rate Technique: sedimentation rate determination	No technique feasible										
M89	0.16	Protein assimilation test Technique: microanalytic determination of serum albumin and globulin	23	T	1/7	2/7	3	3-2/7	Included in M1			Included in M3	

Table 9. Ranked Biomedical Measures and Selected Techniques (Cont)

Rank Order Number	Rank Order Percentage	Basic Biomedical Measures and Selected Techniques	Total Test Time (man-minutes)	Level of Training	Frequency (per day) for a 90-Day Mission	Time Per Subject-Day for a 90-Day Mission (minutes)			Equipment and Instruments			90-Day, 1 Man Supplies and Spares	
						Subject	Observer	Total	Weight (pounds)	Power (watts)	Volume (cubic feet)	Weight (pounds)	Volume (cubic feet)
M90	0.16	Mucosal integrity evaluation Technique: visual inspection of oral mucosa	4	A	1/7	2/7	2/7	4/7					
M91	0.14	Breath holding time Technique: manual timing of breath holding time	7	A	1/7	1		1	Included in M21				
M92	0.14	Skin thickness Technique: caliper measure of skin fold, thickness of skin over abdomen, thigh, and upper arm	4	A	1/7	2/7	2/7	4/7	0.250		0.0035	0.03	0.0004
M93	0.12	Venous distention Technique: visual and manual examination for venostasis	3	T	2	2	4	6					
M94	0.12	Liver size Technique: manual percussion and palpation	14	P	1/7	1	1	2					
M95	0.12	Pulse wave velocity Technique: transmission time determination of pulse	21	T	1/7	Technique not feasible							
M96	0.10	Chest circumference Technique: tape measurement of chest circumference	1	A	1/14	1/28	1/28	1/14	Included in M46				
M97	0.06	Gas formation and passage Technique: observation of flatus, etc.	1/2	A	1	1/2		1/2					
		Totals Times, weights, and volumes				131.3	217.3	348.6	645.9		19.70	90.5	2.8147

Other factors influencing the selection of a particular measurement technique are:

Available time for measurements
Space station configuration
Provisions for data storage and transmission
Experimental design
Logistics schedule

Time available within the space mission will be a prime factor in determining measurement techniques. Not only is total time during the mission of significant importance, but also the frequency of measurement, the time allowable per day for measurement, and the distribution of time per day between operator and subject personnel.

The requirement for varying levels of operator skills may present a problem relative to available time and scheduling. Personnel with special biomedical measurement skills (i.e., technician or professional skill levels) may be required to expend a considerably larger percentage of their total time to measurement than companion astronaut personnel in the crew and thus, will be less available for other station operating tasks. The scheduling of measurement tasks of varying frequency, type, and complexity related to operator skill requirements will be specific to a mission and will require detailed advance planning specific to the mission concerned.

An additional problem in scheduling will be the combination of measures and techniques which form a logical procedural sequence so that different measurements possessing similar preparatory or initial procedures, measurements possessing common procedural elements, and measurements that are sequentially related in reference to a logical sequence of procedures are programmed to take advantage of such relationships to effect simplicity of the measurement program and to minimize the time required.

Another factor affecting technique selection is the specific characteristics of the space station configuration. Included in this category are weight, power and volume constraints. An additional constraint arises in the work space arrangement, and the manner in which cabin interior equipments are packaged.

Provisions for data storage and transmission will have a significant effect on the selection of techniques. The measurement techniques discussed

in this report provide a variety of data forms. Equipment readouts, paper records (checklists and medical log), and film recordings represent the three major classes of data forms provide by the measurement techniques. The selection of specific techniques for a given mission should take into consideration the methods, frequency, and channels available for data transmission. Special consideration should be devoted to the data forms required by measurement techniques related to safety measures (crew status).

The experimental design problem is discussed in detail in Section V. The selection of techniques, the programming, and scheduling of measurements will be highly dependent upon the design of the experimental program for a given mission. The experimental design factor is closely related to the problems of crew composition and time available for measurement as discussed previously.

Logistics supply considerations must be carefully analyzed in the selection of suitable measurement techniques in reference to the over-all logistics capability available at the time of the mission, and the requirements placed upon the logistics system by the measurement techniques. On-board preventative and corrective maintenance and repair requirements must be anticipated for a specific mission with definition of on-board spares provisioning for maintenance. Availability of supplies for the accomplishment of measurement techniques must be defined with reserve allowances for normal depletion, accidental loss, and possible extension of on-board supply capability over short periods of time in which normal logistics supply may not be available.

BEHAVIORAL MEASUREMENT TECHNIQUES

As trade-off and confidence data accrued, it became apparent that the primary constraint on selection of behavior measurement techniques was time. Because of multipurpose special equipment, the comprehensive list of 50 performance functions were measurable on-board well within the weight, power, and volume constraints for all projected orbiting stations except the smallest, Apollo Concept I. In addition, there proved to be no requirement for a measurement technician nor a professional psychological examiner to administer the behavioral tests. (A trained behavioral scientist is required for test analysis.)

The problem of reducing time for behavior measurement was a matter of designing measurement techniques rather than selecting alternative techniques for measuring each function.

In general, the time requirements for measuring behavior functions were reduced by two approaches:

1. Wherever possible, tests were so designed that they could be administered by programmed presentation thereby eliminating the need for an observer. In some cases, it was possible to have scoring accomplished automatically and further reduce time by eliminating scoring requirements.

2. Tests were so designed that a stable mean with minimum standard error of the mean could be attained with minimum repetitions. In short, tests were for minimum within subject variability and high sensitivity.

It is to be noted that the program of tailoring some 50 performance tests to fit within allowable time constraints resulted in measurement techniques not available off the shelf. However, the instrumentation and scoring of all tests are within the current state of the measurement art.

In Appendix B, the measurement technique and other information pertinent to each performance function is described in detail.

MEASUREMENT EQUIPMENT

Equipment for the CMS is defined here as all the physical resources required to perform the specified biomedical and behavioral measures. The equipment for each individual measure is listed in Appendixes A and B, biomedical and behavioral areas respectively. Equipment and instruments defined in these tables as those items that will be permanently on board and will be used repeatedly to implement associated measures. The weight, power, and volume of these devices will not change regardless of crew size and mission duration. Supplies and spares (listed in the tables as the requirements for one subject for 90 days) are expendable materials and spare parts for listed equipment and instruments. The weight, power, and volume of supplies and spares are factors that, along with crew size and experimental time, will determine requirements for specific space station missions. Data handling devices are treated as a third and separate type of equipment. It is assumed that written records for both biomedical and behavioral measures will be combined in individual CMS logs. The weight and volume of the logs will vary with CMS package size, length of mission, and crew size. Provisions for magnetic and direct reading tape recorders and data transmission equipment are included but must be correlated with recording and telemetry equipment provisioned for other than CMS purposes in any specified orbital station configuration.

BIOMEDICAL EQUIPMENT

Criteria

The weights, power requirements, and volumes for the medical equipment in Table 9 are based (except as otherwise stated) on the specifications of commercially available instrumentation and supplies. Miniaturized and microminiaturized components are listed only when they have been proven to be reliable, accurate, and suitable for space station use. This is not to say that all specified equipment has been space rated; but, in the judgement of the investigators, all recommended items can be used in space either as is or with minor modification.

Description of Research Method

The equipment listed in Appendix A is the end product of a systematic equipment survey for the associated techniques. The analysis procedure followed to establish equipment parameters for each technique is diagrammed

in Figure 6. The scope varied greatly from technique to technique. For example, little effort was involved in determining the equipment to measure oral temperature; however, studies of such areas as centrifuge and X-ray equipment (Table 9 , measures 4 and 16) were time consuming and complex.

Special Problems

Two general difficulties were encountered throughout the equipment investigation. The first difficulty was to find satisfactory devices that did not require on-board professional medical diagnosis. The second difficulty was to determine techniques and equipment that were feasible for space station application.

Table 9 shows that 13 of the 97 recommended techniques require a physician crew member. These 13 techniques represent 22.6 percent of the 100 percent confidence level based on the 97 measures. It is quite possible that more exhaustive research could determine equipment which, by simplification of data outputs and improved telemetric facilities, would eliminate the requirement for an on-board physician. The time constraint of this short-term study, however, limited the effort on any single technique so that breadth of coverage could be assured.

The second problem of determining the utility of techniques and equipment in space is perplexing but will probably be answered only by study in space. Experiments to evaluate biomedical techniques and equipment (especially those involving liquid transfer and hydraulics) should be programmed for early orbital flights.

Discussion

Research conducted during this study to determine the equipment requirements for biomedical techniques indicates that the prospects for developing satisfactory measurement packages are good. Measurement devices to assure crew safety impose no weight, power, or volume constraint that is incompatible with any space station design. It seems reasonable to assume that continued microminiaturization of biomedical instrumentation and data processing, recording, and transmitting equipment will result in improved measurement capability with greatly reduced weight, power, and volume requirements. The areas in which development is most important are (1) improvement of instrumentation to determine and evaluate cardiac output and (2) better methods to transmit X-ray information for evaluation on earth.

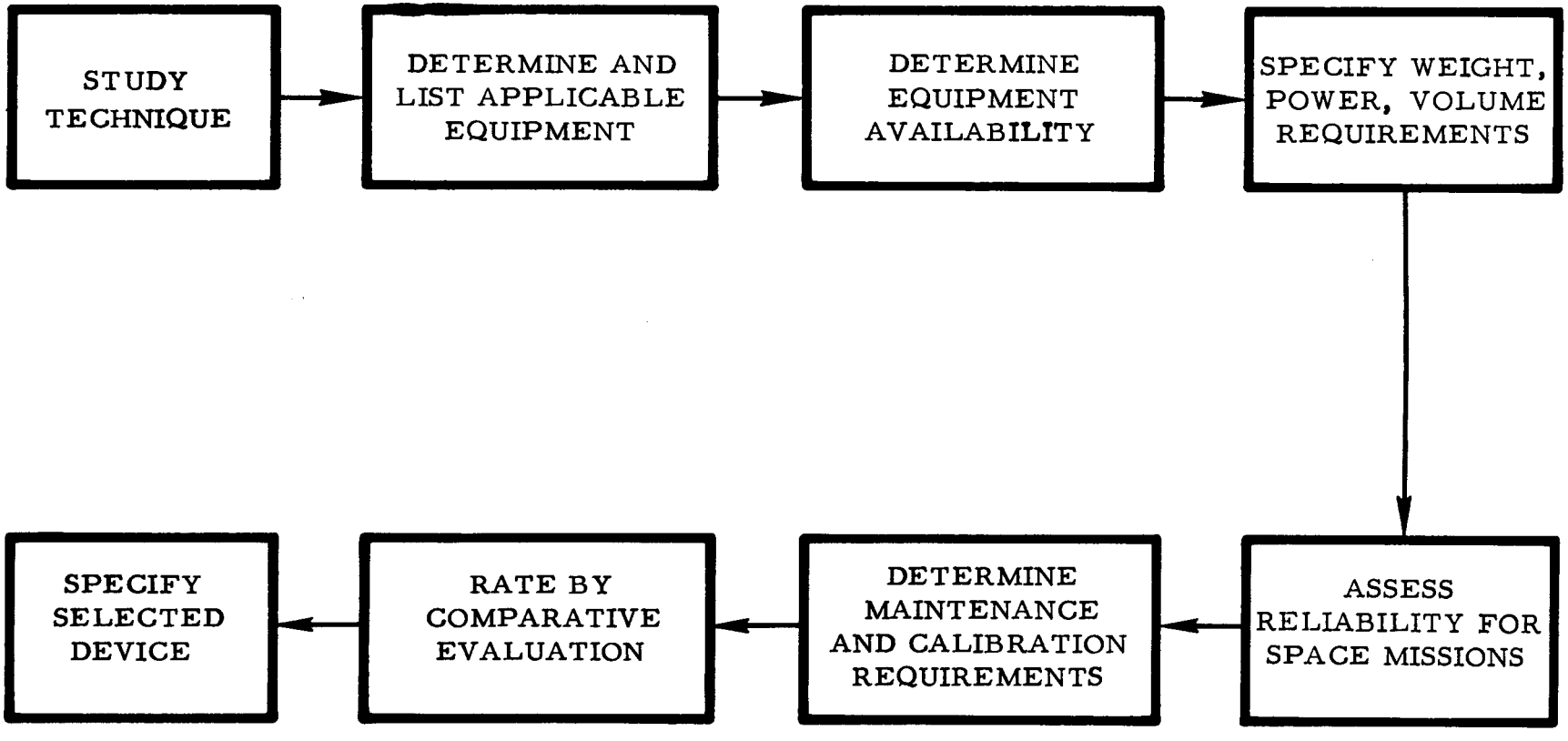


Figure 6. Diagram of Biomedical Equipment Analysis Technique

BEHAVIORAL

The multitude of constraints and special problems associated with an on-board behavior measurement program resulted in a major concern with selection and development of measurement equipment and instruments. Since real mission tasks could provide only limited information about performance status, the development of a real task simulator was a matter of primary emphasis. A simulator of minimum size, weight, and power requirements was designed to measure a number of critical and complex space mission tasks. A definitive description of this simulator for use as a measurement vehicle appears in the appendix of this report as Device "A." In Section III of this report, preliminary design data for such a simulator are presented. There were other constraints and findings that inspired a variety of multipurpose and special measurement devices. Particularly, the problem of time made it necessary to design equipment that could program test stimuli and score automatically and thus eliminate the time required for an observer. Also, for a number of tests, special equipment was necessary to insure that minimum within subject variability and sensitivity could be assured with minimum repetitions. Another unique problem was the inadequacy of most standard measurement equipment for the on-board measurement program. In the first place, standard equipment is not space-rated and required modification or redesign for use in space. Also, except for sensory measurement, most behavior testing materials are designed to provide normative data; and normative data does not meet the requirements of this program where ipsative data is required (that is, data that compares the individual with himself). In short, very little off-the-shelf equipment could satisfy the needs of this program.

Therefore, equipment was tailored to meet the requirements of each individual test and the program as a whole. Equipment that supports more than one test is designated Device "A" or "B," etc., and the design and function of these devices are elaborated in the appendix of this report following the Behavioral Test Data Sheets. Equipment that is used for only one test is briefly described in the Appendix as part of the data for that particular test.

MEASUREMENT REQUIREMENTS

BIOMEDICAL

Biomedical measures were selected initially to determine human status and to diagnose any physiological change that might indicate deteriorization of well being. These measures were rated by several criteria to assess their effectiveness in answering specific questions regarding deviations from normal health and possible effects of weightlessness and other space environmental conditions on physiological status (Table 6). The measures were then listed in rank order (Table 7) and each was analyzed to establish feasible techniques for making the measurement in a space station. Four criteria were considered in connection with each measurement technique.

1. Technical skill to perform the measurement
2. Frequency of measurement required
3. Time necessary to make the measurement
4. Equipment needed

Technical Skills

The skill and knowledge required for each technique were estimated by physicians who were acquainted with the performance and equipment involved. The level of training was stipulated for each technique as (1) astronaut, (2) technician, or (3) professional (Table 6). In designating these levels only minimal training was assumed. The highest required skill or knowledge was designated. For example, a technician can operate X-ray equipment but a physician must evaluate the result, so a physician training level was designated. It was, or course, considered that a physician could perform all techniques and a technician could accomplish all those listed for astronauts. Astronauts could learn to perform most of the techniques designated "technician" and "physician", but this would require special selection and training programs. Some of the complexities of selection and training are discussed in Section V of this report.

To facilitate time estimations, it was necessary to specify the frequency with which a measure should be made to assure confidence of

a continuing state of well being. The frequencies (shown in Section V) are only initial base parameters. For some measures the frequencies would remain the same, but for others the time interval would be lengthened or shortened as data were accumulated regarding measurement efficiency and significance.

Time

The time to accomplish each technique was determined and listed (Appendix A). The time was expressed in man-minutes (the total time for the subject being tested and the observer performing the test). The time was then broken down to show the subject and observer time involved on a minutes-per-day-per-subject basis. These individual time figures are, however, only basic data; they are not additively the time required to accomplish measurements lumped into CMS packages. For example, time would be saved by using single blood and urine samples for several tests, by analyzing numerous samples with one equipment setup, and by performing some measurements while the subject is on watch or engaged in some other activity. An example of some of these time saving techniques is included in Section V.

Equipment

Equipment specifications for biomedical techniques have been discussed. Only a summary of the factors that will determine space station design (weight, power, and volume) will be considered here.

The weight, power, and volume for the equipment required for each technique was determined and recorded (Appendix A). The requirements for equipment, instruments, supplies, and spares and for data processing, recording, and transmitting were all considered in conjunction with each technique. The supplies listed in the Appendix are based on a 90-day, 1-man requirement, and simple conversion to any crew size and mission duration will result in an accurate estimate. The spares weights included in these tables are obviously rough approximations. When actual missions are planned a detailed analysis to establish sparing criteria is recommended.

Trade-Off Considerations

The data on frequency and time (minutes per day), weight, and volume were the subject of a comparative analysis after the development of

the basic CMS package (Section V). Cumulative graphs (Section V) were prepared to illustrate the time, weight, and volume requirements for the basic CMS package. The basic power requirements were accumulated, because they would be meaningful only if all equipment were operated simultaneously. The peak power (550 watts for X-ray operation) is within the capability of any currently conceived space station electrical power supply system.

BEHAVIORAL

Table 10 presents the trade-off considerations—time (Figure 7), frequency, weight (Figure 8), power, and volume (Figure 9) requirements—for the 50 selected measurement techniques. The data are abstracted from the measurement data sheets in the Appendix B.

Table 10. Listing of Behavioral Techniques

Rank Order Number	Listing of Techniques	Total Test Time (minutes)	Level of Training (A-T-P)	Working Frequency (per day) for a 90-Day Mission	Time in Minutes Per Subject-Day for 90-Day Mission			Equipment and Instruments		
					Subject	Observer	Total	Weight in Pounds	Power in Watts	Volume in Cubic Feet
1	Arm/hand/finger/manipulation	25	A	1/7	1.43	2.14	3.57	1	0	0.0116
2	Computation	30	A	1/7	4.28	0	4.28	Device	D	D
3	Docking	50	A	1/7	7.14	0	7.14	Device	A	A
4	Complex pattern discrimination	20	A	1/7	2.86	0	2.86	Device	D	B
5	Handling mass	25	A	1/7	1.43	2.14	3.57	Device D	C	D & G
6	Body positioning	40	A	1/7	2.86	2.86	5.72	Device	D	D
7	Learned procedure	15	A	1/7	0	2.14	2.14	Device	D	D
8	Perceptual (set)	35	A	1/7	5.00	0	5.00	Device	A	A
9	Speaking	15	A	1/7	2.14	0	2.14	Device	C	C
10	Speech perception	15	A	1/7	2.14	0	2.14	Device	C	C
11	Arm/hand/finger control of force	30	A	1/7	3.57	0	4.28	Device	0	H 0.0174
12	Detection/discrimination angular acceleration	35	A	1/7	2.14	2.85	4.99	Device		E
13	Detection/discrimination linear acceleration	35	A	1/7	2.14	2.85	4.99	Device		E
14	Arm/hand/finger control of speed of motion, including reaction time	10	A	1/7	1.42	0	1.42	8.5	100	2.2
15	Detection/discrimination of force against a limb	45	A	1/7	2.86	3.57	6.43	6.2	100	1.2
16	Detection of movement of limb	35	A	1/7	2.14	2.85	4.99	5	10	1
17	Recognition of location of limb	Done Simultaneously With # 16								
18	Leg control of force	15	A	1/7	2.13	0	2.13	Device		H
19	Tracking visual motor	25	A	1/7	3.56	0	3.56	Device		A
20	Visual resolution of detail	25	A	1/7	1.43	2.14	3.57	Device		B
21	Near depth perception	15	A	1/7	0.71	1.42	2.13	4	0	0.1250
22	Peripheral/visual detection/discrimination	25	A	1/7	1.43	2.14	3.57	2	0	1
23	Tone audition	15	A	1/7	2.14	0	2.14	Device		C
24	Stereognosis	35	A	1/7	2.14	2.85	4.99	1	0	0.25
25	Detect/discriminate vibration	15	A	1/7	0.71	1.42	2.13	7	10	0.2
26	Detect/discriminate color	35	A	1/7	4.99	0	4.99	Device		B
27	Deduction	65	A	1/7	4.28	4.99	9.27	Device		A
28	Recording	15	A	1/7	2.14	0	2.14	Device		D
29	Time perception	10	A	1/7	1.43	0	1.43	Device		C
30	Distant static depth perception	20	A	1/7	2.85	0	2.85	Device		A
31	Dynamic depth perception	30	A	1/7	4.28	0	4.28	Device		A
32	Decision making	60	A	1/7	4.28	4.28	8.56	None		

Table 10. Listing of Behavioral Techniques (Cont)

Rank Order Number	Listing of Techniques	Total Test Time (minutes)	Level of Training (A-T-P)	Working Frequency (per day) for a 90-Day Mission	Time in Minutes Per Subject-Day for 90-Day Mission			Equipment and Instruments		
					Subject	Observer	Total	Weight in Pounds	Power in Watts	Volume in Cubic Feet
33	Cue/abstraction	20	A	1/7	2.85	0	2.85	Device		B
34	Problem solving	30	A	1/7	4.28	0	4.28	Device 1	0	D 0.0500
35	Guided performance	14	A	1/7	0	2.0	2.0	Device		D
36	Detection of light touch	35	A	1/7	2.14	2.85	4.99	20	50	1
37	Brightness detection/discrimination	25	A	1/7	3.57	0	3.57	Device		B
38	Association	15	A	1/7	1.43	0	2.14	Device		C
39	Reading	10	A	1/7	1.43	0	1.43	Device		B
40	Writing	25	A	1/7	1.43	2.14	3.57	Device		B
41	Tone pattern discrimination	10	A	1/7	1.42	0	1.42	Device		C
42	Assessment of volume of space	25	A	1/7	1.43	2.14	3.57	Device		G
43	Sound localization	25	A	1/7	1.43	2.14	3.57	Device		F
44	Pain detection	25	A	1/7	1.43	2.14	3.57	2	0	0.4
45	Detection of heat/cold	35	A	1/7	2.14	2.85	4.99	1	0	0.011
46	Texture discrimination	20	A	1/7	1.43	1.43	2.86	0.1	0	0.0093
47	Auditory detection/discrimination of motion	10	A	1/7	0.71	0.71	1.42	Device		F
48	Detection of tone duration	15	A	1/7	2.14	0	2.14	Device		C
49	Olfaction	35	A	1/7	2.13	2.84	4.95	3	0	0.1740
50	Inductive reasoning	60	A	1/90	0.66	0	0.66	None		
	Task Device A to H									
	Device-A simulator							186	445	9.60
	Device-B visual presentation							40	225	2.4
	Device-C recorder/reproducer							20	20	1.0
	Device-D timer with alarm							0.5	0	0.001
	Device-E acceleration chair							20	20	3.0
	Device-F tone generator							0.5	0.2	0.01
	Device-G mass handling							0.5	0	0.1
	Device-H spring-tension/positioning							5	0.5	0.0347
	Estimated volume and weight for answer sheets (for all 50 tasks)									

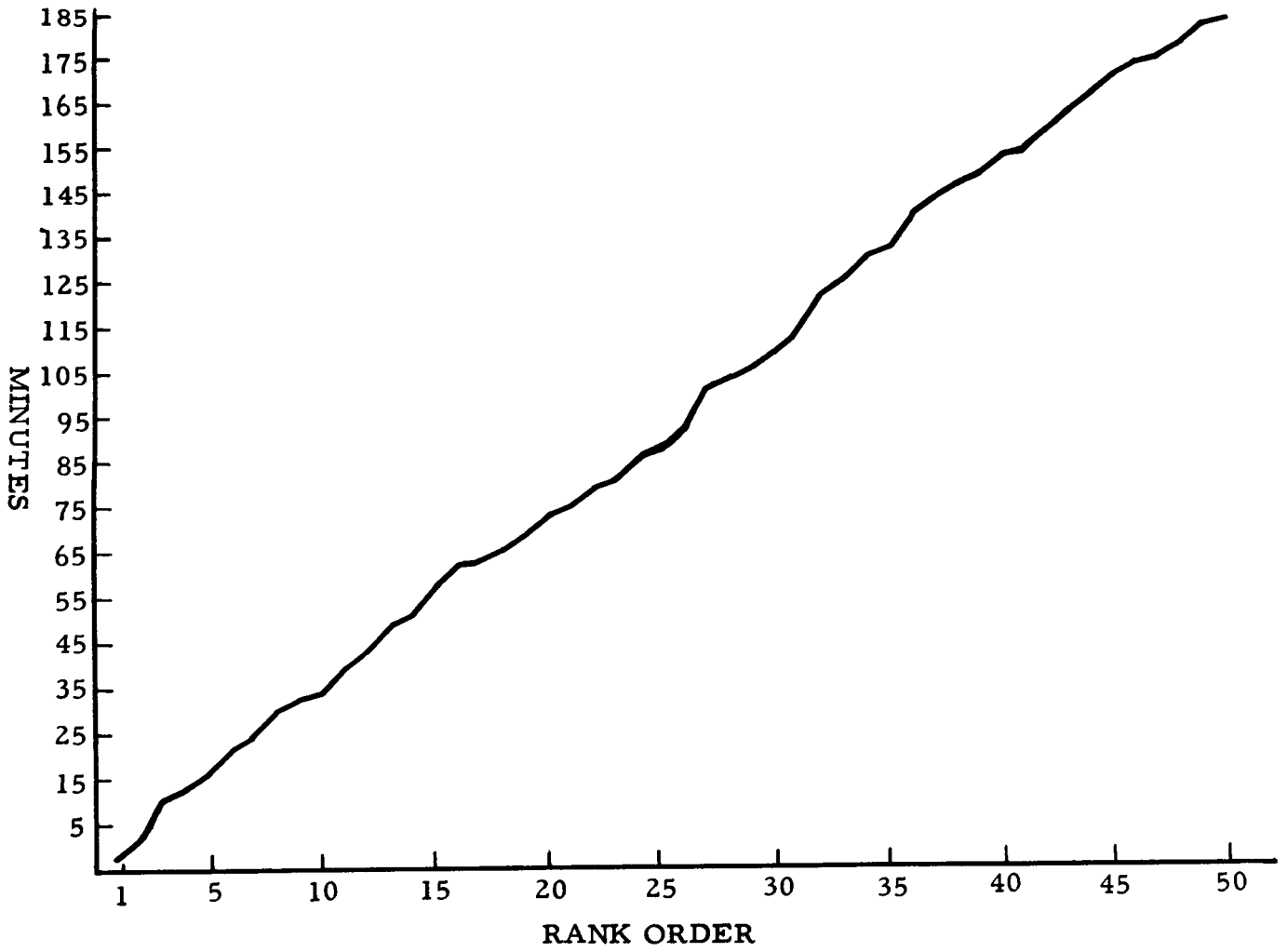


Figure 7. Cumulative Time per Subject Day Behavior Measurements (In Rank Order)

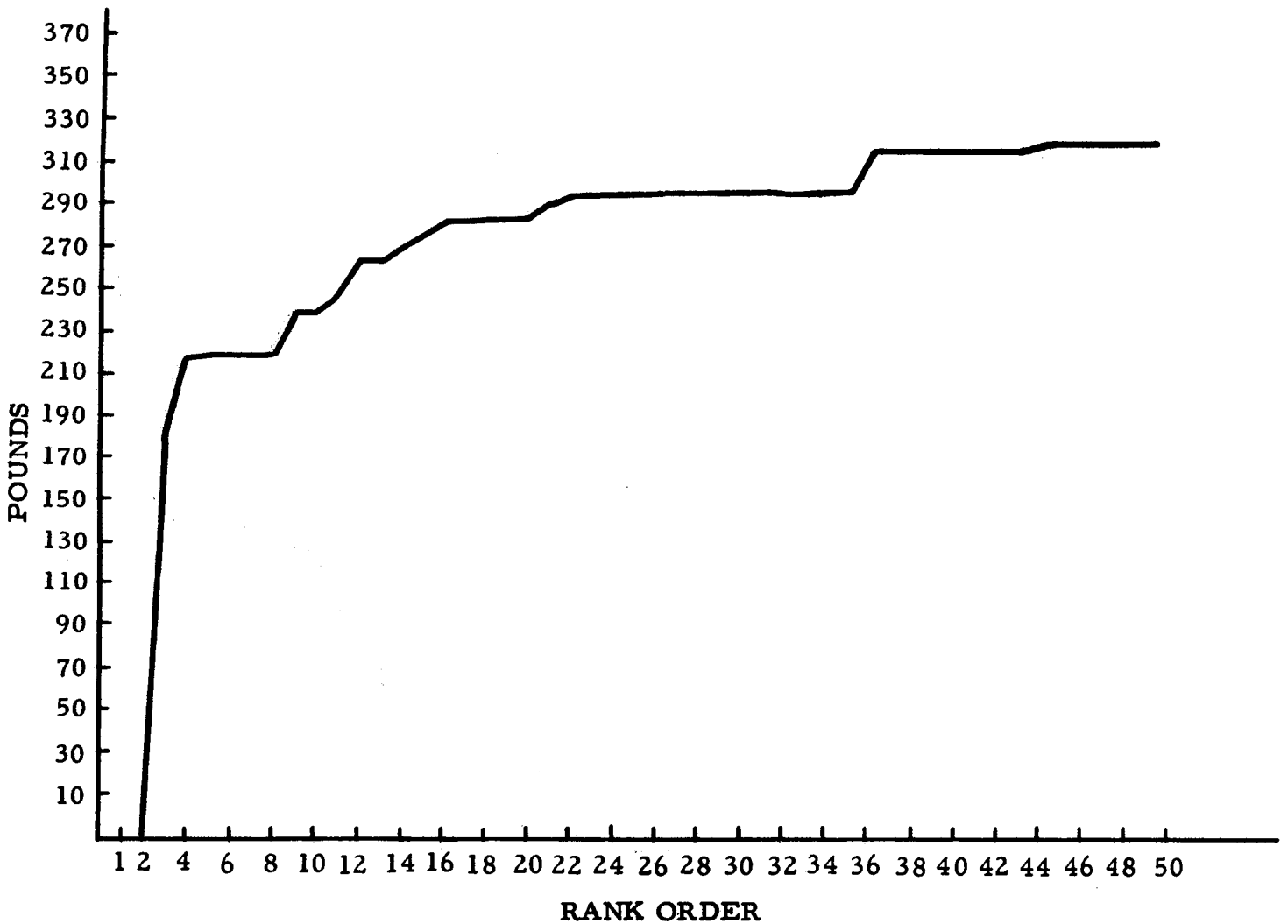


Figure 8. Cumulative Weight Requirements Behavior Measurements (In Rank Order)

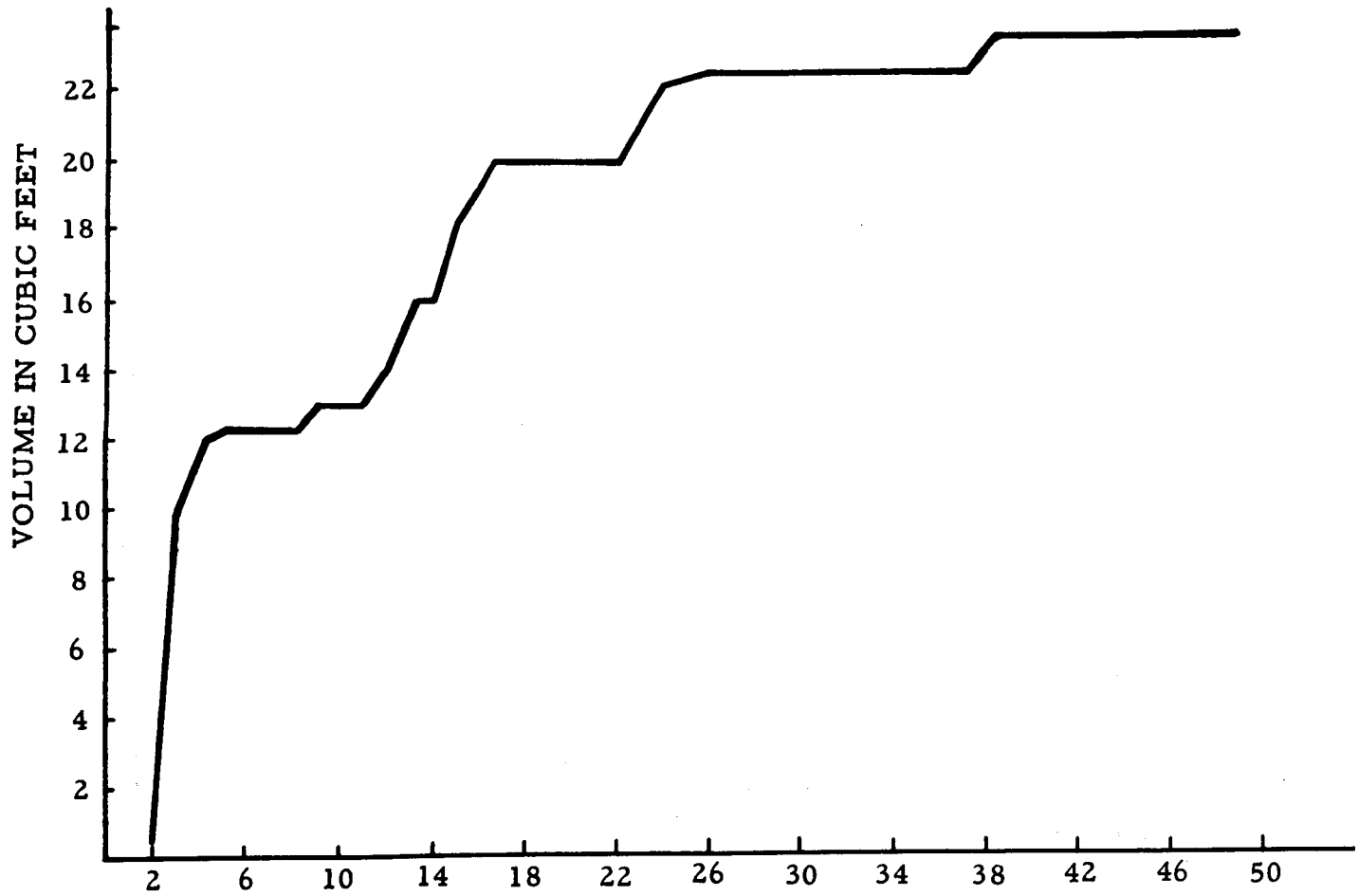


Figure 9. Volumetric Requirements Behavior Measurements (In Rank Order)

SUMMARY

Based upon the analysis of the biomedical and human factors measurement and technique lists, the following principal findings and main constraints are noted.

PRINCIPAL FINDINGS

Biomedical Findings

Accomplishment of the biomedical measurements analyses and the development of final biomedical measures and associated techniques resulted in several findings pertinent to the development of a measurement program including biomedical measures. The resultant findings are considered of sufficient importance to summarize in the following paragraphs.

The problem of the selection of biomedical measures and the problem of the selection of an appropriate technique for measurement of a selected measure must be considered as an integral problem. Whereas the selection of any particular measure in this study was based primarily upon the confidence value of the measure concerning the effect of zero G on man, the final confidence in the measure will be established by the decision of the technique for measurement accomplishment.

The techniques for each biomedical measure, which were presented as selected techniques in this report, were chosen to yield the largest degree of confidence in the results of measurement for the corresponding measure. However, the decision to use one measurement technique as opposed to competing techniques is a function not only of technique value but additional factors as well. These include (1) skill level of the crew; (2) time available for measurement; (3) configurational characteristics (weight, power, volume, workspace design, and packaging of equipment); (4) provisions for data storage and transmission; (5) experimental design of the measurement program; and (6) logistics considerations relative to availability of supplies, crew rotation, etc., and on-board provisions for maintenance, spares, and required supplies.

The list of ranked biomedical measures and associated selected techniques presented in this section was intended to be an ideal measurement package with emphasis on maximization of confidence and was directed to a minimization of requirements (weight, power, volume, and time). However,

the primary objective of the analyses was to develop a measurement package that would serve as a measurement data pool. The Appendix lists the ranked biomedical measures and associated measurement techniques. Alternate techniques are listed in the order of suitability as a measurement instrument for the corresponding measure. This list, then, is intended as the basic measurement data pool. This pool may be referred to as guideline data for selection of individual measures and associated techniques appropriate to a given set of specific mission and system requirements.

Results of the analysis indicated that the specification of a major equipment item for a particular measure may significantly influence the selection of additional measures and techniques. Thus, once a major equipment (i. e., microanalytical technique apparatus) is included in a measurement package, the cost in terms of weight, power, volume, and skill-level requirements for obtaining additional measures requiring similar apparatus (microanalytical procedures) is negligible.

Results of the measurement analyses also indicate that highly skilled personnel will be necessary on the space laboratory if a measurement program yielding high total confidence is to be achieved. In the final list of biomedical measures, the first 15 measures account for approximately 50 of the total confidence value. However, professional and technical skills are required for accomplishment of a large portion of the measurement techniques for the first 15 measures.

Behavioral Findings

The most significant findings pertinent to the development of an onboard behavior measurement program are given in the following paragraphs.

Primary emphasis should be placed on comprehensive coverage; that is, a cross section of all aspects of behavior should be sampled. For purposes of this study, performance tests are classified as sensory, perceptual, medial, motor, and perceptual-motor. The behavioral measurement list comprises 50 tests (Appendix B).

A task analysis of projected space missions identified those tasks that were judged to be most critical and most universal and which could be most reasonably measured as real tasks, simulated tasks, or experimental tests.

It was determined that measurement of real mission tasks would provide only very limited information about the performance status of a subject. Therefore, most behavioral measures were designed to be tested by simulation or by experimental testing. A number of multipurpose measuring instruments were designed and are discussed earlier in this section and in Section III and Appendix B.

It was determined that size, weight, and volume constraints for all configurations considered, except Apollo Concept I, could be met by utilizing all the proposed equipment for the full list of behavioral tests. It should be noted, however, that size, weight, and volume considerations were fundamental to the design of the special measurement equipment.

A system of assigning confidence values to any possible combination of behavior lists was developed.

Since there is so much overlap in the behavior content of complex performance tests, the assignment of an importance value to each test was not tenable. However, the listing of tests by blocks and in rank order within blocks as a basis for allocating available experimental time is a step in that direction. For definitive rank ordering, there should be multiple lists; that is, for any constraint, the rank ordering of behavioral tests will be different.

The combining of biomedical and behavioral measures were derived from an estimate of confidence values superimposed on safety considerations.

PRIMARY CONSTRAINTS

Major constraints to the development of recommended biomedical and behavioral measures and techniques were noted in the course of the measurements analyses.

Biomedical

With the exception of the Apollo Concept I, the primary constraints on development of a biomedical program appeared to be time required for biomedical measurements and complexity or level of skill required for measurement accomplishment.

Availability of time for measurement appears to be a major limiting factor in developing a high-confidence value biomedical measurement program. The total time allowable per day for measurement and the time available per day for participation in measurement by an individual will be factors of considerable import to selection of individual measures and techniques. Appropriate programming and scheduling of testing to take advantage of similar skill requirements, common procedural elements,

and/or logical sequence of individual measurements should aid considerably in reduction of required measurement time.

Complexity of individual measurements is a second major constraint. The presence or absence of an individual in the crew possessing a professional or technical skill level will greatly affect the selection of individual measures in the measurement program. It will also have a very significant effect on the total level of confidence that can be placed upon the data obtained from the measurement program. Measurement analyses results have indicated a stringent requirement for technical skill levels to be present in the space laboratory, with professional skill availability considered to be highly important and desirable.

Behavioral

Except for the Apollo Concept I, the primary constraint on development of a behavioral measurement program was time. Techniques were developed to reduce time of testing by programming and automated scoring and by assuring minimum within subject variability and maximum sensitivity of each test with minimum test trials.

III. SPECIAL EQUIPMENT

SIMULATOR

OBJECTIVES

One of the study ground rules was that operational tasks should be used for measurement purposes to the greatest extent possible. Following this, consideration was to be given to the use of simulation. This necessitated a study of the feasibility of a spaceborne simulator and a preliminary projection of power, weight and volume requirements since operational tasks were not found to provide an adequate base for measurement purposes.

The simulation includes tasks of docking an orbiting space vehicle (with 6 degrees-of-freedom control), navigating a space vehicle with respect to a star field, controlling attitude, monitoring a display, and checking out various systems. The equipment necessary for such a simulation is estimated in this report as the incremental cost in power, weight, and volume for various alternatives of the system complement (Figure 10).

COMPUTER

A general purpose miniaturized digital computer would best fulfill spaceborne simulator requirements. These computers are presently being marketed on a commercial and military basis for various air and spaceborne applications. A computer made by the Autonetics Division of NAA (specified as the Monica J) is representative of the size, weight, and type of computer that would be available and for spaceborne use. The computer would require all the capabilities of performing a real-time simulation of a 6-degree-of-freedom vehicle in space, performing various tasks, and accepting and controlling various input-output devices. It is estimated that the basic computer with a memory of 4096 words will simulate the basic docking task with various initial conditions, will perform depth perception studies, and will sample and store efficiency ratings and times for ultimate transmission. Since the next expansion in memory to the computer is another 4096 words for a total of 8192 words, all other tasks could easily be programmed within this expanded memory. The additional memory would also insure that the basic docking task would have high-accuracy computational capability by allowing double precision operation. The expanded memory computer would be preprogrammed to contain all tasks. Rendezvous

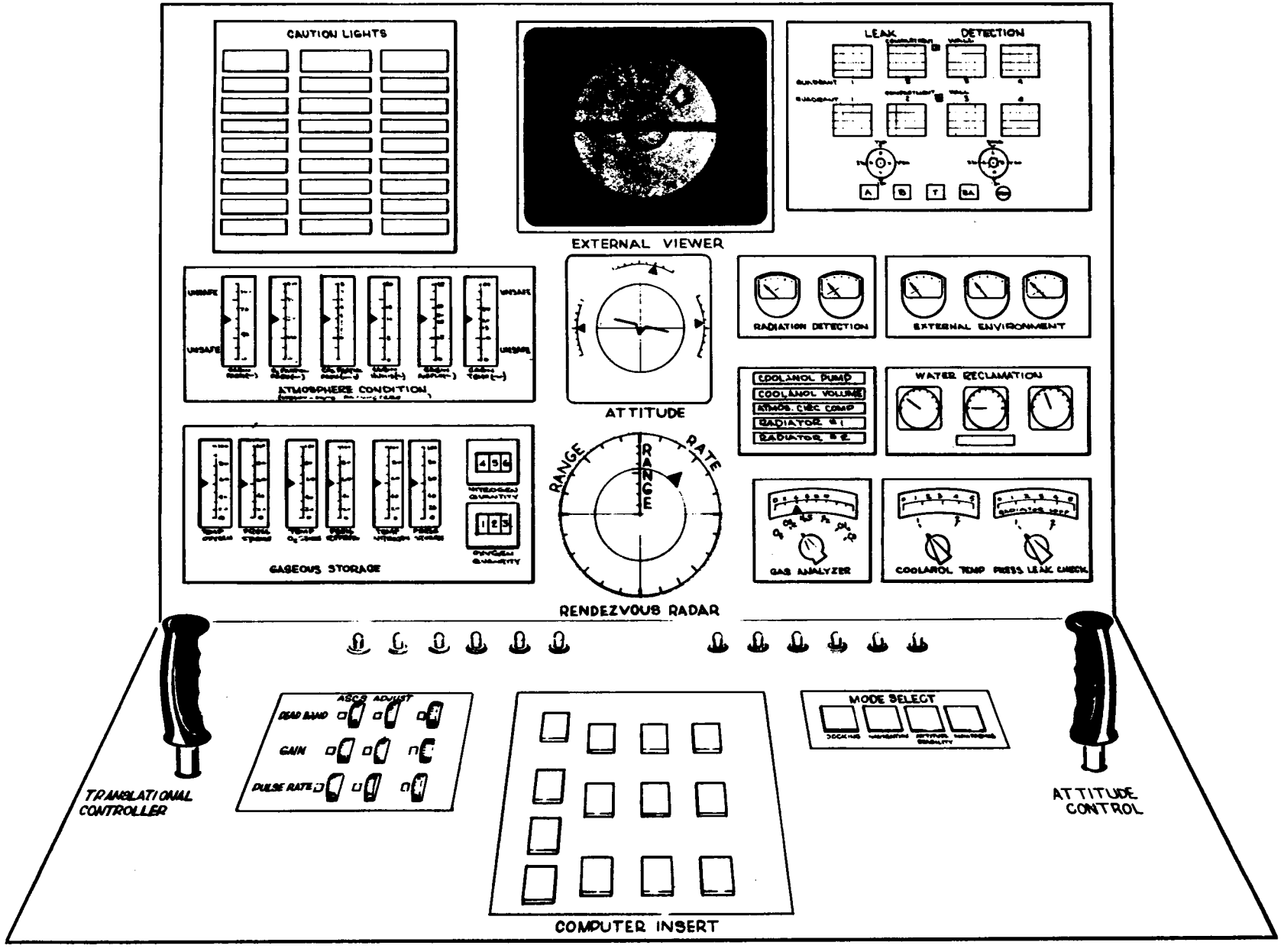


Figure 10. On-Board Simulator Display

and docking problems could be initiated at any simulated distance from the training vehicle (space station) to a simulated space station. A control panel would allow selection of any specific task and any different mode within that task.

The basic and expanded computer and power supply weight, volume, and power requirements are shown in Table 11.

Table 11. Simulator Computer Requirements

Item	Basic Memory (4096)			Expanded Memory (8192)		
	Power (w)	Volume (ft^3)	Weight (lb)	Power (w)	Volume (ft^3)	Weight (lb)
Computer	70	0.25	13.8	85	0.29	16.8
Power Supply	70	0.25	13.0	85	0.29	16.0
Control Unit	20	0.22	10.0	20	0.22	10.0
Totals	160	0.72	36.8	190	0.80	42.8

The Monica J computer is scheduled to be available by January 1964. It should be noted that time is working in favor of reducing the given computer specifications. More demands for these specialized computers and increases in the state of the art will necessarily result in reduced weight, volume, and power requirements and an increase in the capabilities and a wider selection of computers.

DISPLAY

Optical Simulator

The proposed optical system is shown in Figure 11. This system consists basically of four parts:

1. Satellite model
2. Film star field
3. Optical transmission system
4. Servo-drive system

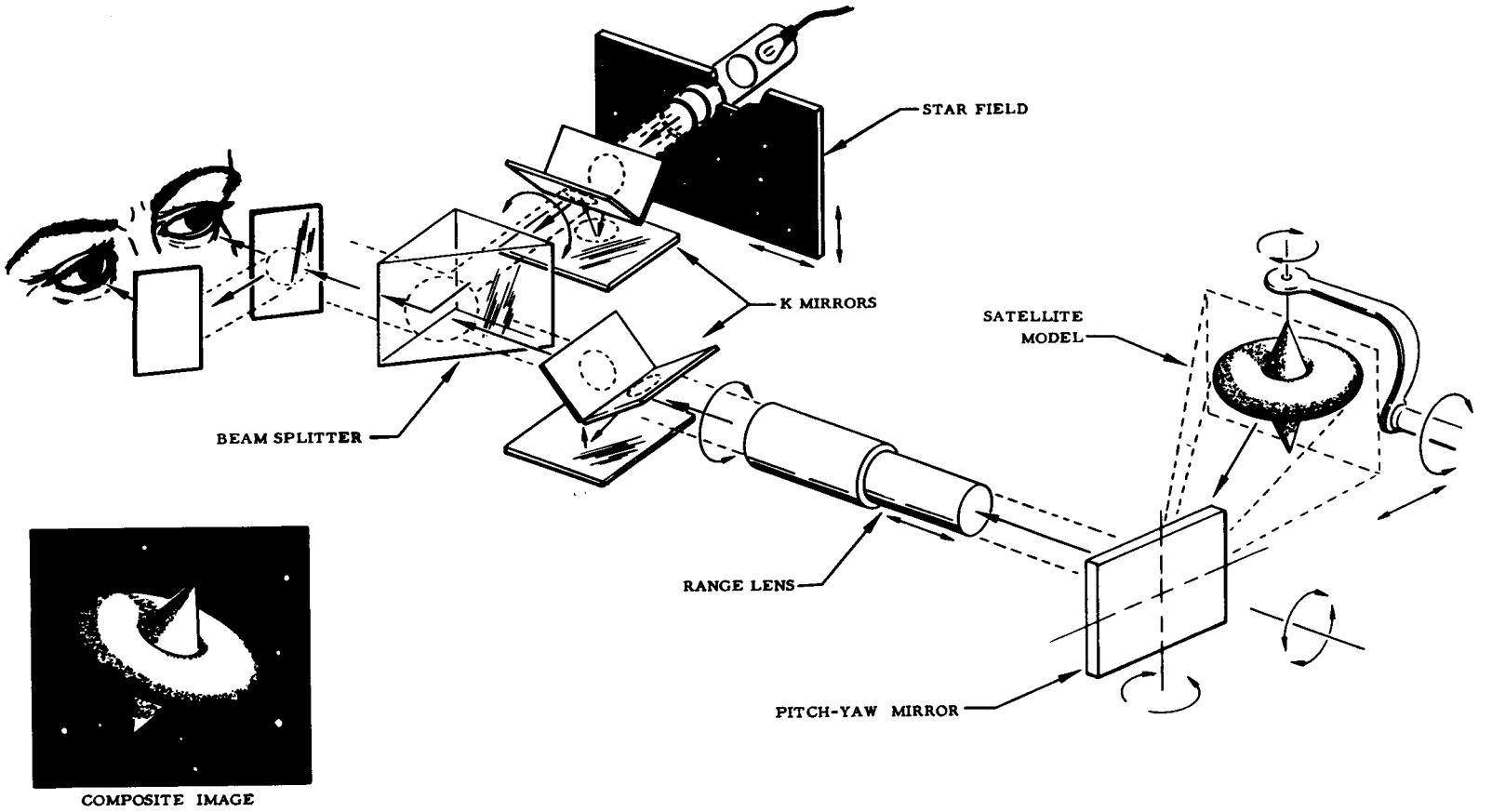


Figure 11. Conceptual - Optical - Satellite Docking Simulator

Satellite Model

The satellite may take on any geometric shape. It is capable of 360 degrees rotation in one axis and approximately 270 degrees in a second axis. The 270 degree limitation would be due to the optical interference of the satellite supporting mechanism as it began to appear in front of the satellite. This should provide no real restriction because there is still an almost infinite number of approach paths possible. The satellite will rotate about two perpendicular axes and will translate to and from the pitch-yaw mirror producing 3 degrees of freedom. The translation will be in combination with the range lens, which will produce the effect of closing between the subject's vehicle and the mother satellite.

Film Star Field

The star field, as the subject will see it, will be superimposed with the image of the satellite by the use of a beam splitter. The stars themselves will be transparencies in a film that is placed within a flat framework. The framework will be servoed in two dimensions that will be able to produce the necessary effects of yaw, pitch, roll and horizontal and vertical translation. A light source will be placed behind the film, and adequate optical focusing lenses will be placed in front to produce the proper images. The limitation of this type of star presentation is that the real world cannot be exactly reproduced. Instead, a random star distribution is presented to produce the necessary cues of motion relative to them.

The Optical Transmission System

The Optical system functions in the following manner: The pitch-yaw mirror mounted in front of the zoom lens produces the appearance of pitching or yawing by rotation about the horizontal and optical axes respectively. The range lens in combination with the satellite model translation produces the effect of closing between the satellite. The K mirrors produce the effect of rolling the subject's vehicle. Two K mirrors are required because of cross coupling between yaw and roll motions of satellite model which must be compensated for. The star field optics consists of adequate lenses to produce the required images on the beam splitter. The beam splitter combines the images of the satellite and star field.

Adequate mirrors and graduated eyepiece assorted half-silvered and fully silvered mirrors will be required to produce the same image for both of the subject's eyes. A graduated eyepiece will be necessary for the subject to determine his distance from the satellite.

Servo System

The servo system will consist of nine servo motors, associated amplifiers, gearheads, and linkages. Information as to the characteristics of the real system and required transfer functions to put these characteristics into the simulator are stored in the computer. With a subject input into the system, the computer senses it, makes the proper transformation to the signal, and sends it to the servo systems. The servo systems, in turn, cause the desired response in the simulator.

Simulation of the 6 Degrees of Freedom

The sensation that the subject is rolling is produced by rolling the two K mirrors interdependently.

Pitch will be produced by the pitch-yaw mirror at the end of the range lens. It will be pitched through a horizontal axis through the optical center of the mirror.

Yaw will be produced by rotating the pitch-yaw mirror about the optical centerline.

Horizontal translation will be produced by rotation of the satellite about a vertical axis through its center, by rotation of the pitch-yaw mirror about its vertical axis, and by synchronized movement of the star field.

Vertical translation will be produced by rotation of the satellite about a horizontal axis that is parallel to the plane in which the vertical motion is to take place. The star field will move in a vertical plane causing formerly hidden stars to appear and others to disappear behind the satellite.

Closing between the two satellites will be produced by a combination of range lens and satellite model approaching or receding from yaw-pitch mirror.

Optical Simulation of Basic Docking

Power requirements for optical simulation of basic docking are as follows:

Nine servo motors and amplifier at 20 watts	180
Lights	25
Associated electronics	50
	255 watts

Weight requirements for optical simulation of basic docking are as follows:

Servomotor and gearing	25
Servo amplifiers	10
Star field film and framework	20
Star field optics	5
Beam splitter and range lens	5
Optical eye pieces and mounting	5
Mounting framework and support	50
Feedback sensors	5
Satellite	1
Control stick	4
Indicators	10
	135 pounds

The optional radar scope simulation requirements are 8 pounds and 20 watts. The volume requirements are 4.5 ft^3 (2-1/2 by 1-1/2 by 1-1/2) for the optical box and 2 ft^3 for the control panel.

Attitude Control, Monitoring, and Checkout System

This system would include the various control and display indicators to simulate the specified tasks. Indicators could be used for dual functions, and the monitoring displays could be used as part of the checkout procedure. All controls and displays would be directly linked to the computer.

The addition of these tasks would add little weight or power to the total simulator but would require panel space dependent on the configuration and design of the display.

Requirements are 0 watts, 3 pounds, and 0.3 ft^3 for the attitude control and 20 watts, 5 pounds, and 2 ft^3 for the monitoring and checkout.

Monitoring System

An alternate monitoring system to replace that of actual hardware, such as instruments and lights, would be a slide projection of a changing instrument panel. This projection system, if used in conjunction with the proposed optical system, could use the same optics as that of the star field projection thereby reducing system weight.

CONCLUSIONS

The requirements of power, weight, and volume for basic docking are as follows:

	Power (watts)	Weight (lb)	Volume (ft^3)
Computer	160	36.8	0.72
Display and Controls	255	135.0	6.5
Total	415	171.8	7.22
Expanded Computer	190	42.8	0.8
Display and Controls	255	135.0	6.5
Total	445	177.8	7.3

Elimination of star field will save 55 watts, 30 pounds, and 1.5 ft^3; and elimination of each degree of freedom will save 20 watts, 10 pounds, and 0 ft^3.

Power, weight, and volume requirements for attitude control are 0 watts, 3 pounds, and 0.3 ft^3; for monitoring and checkout, 20 watts, 5 pounds, and 2 ft^3; and for the total simulator (all tasks), 445 watts, 185.8 pounds, and 9.6 ft^3.

The basic docking task accounts for essentially all the requirements that a total simulation would demand. The addition of attitude control, navigation, monitoring, and checkout tasks entails the need for additional memory locations and necessary potentiometers, switches, and indicators, which add only 50 watts, 8 pounds, and 2.3 ft^3 to the simulator. It must be noted that power ratings are maximum; in actual use the simulator will demand only a percentage of power. Savings can be made by the elimination of the star field or various degrees of freedom of the optical display. However, the cost of realism may be too great. These requirements estimates are for a simulator that could be built presently—with the availability of the Monica J. However, in actual design, it may well be possible to build a simulator with a greater saving of weight and volume, particularly where integration is made with a specific system. Also, without doubt, the size, power, and volume of a comparable simulator will decrease in the future.

DATA MANAGEMENT, SIMULATION, AND COMMUNICATION SYSTEM

The data management, simulation, and communication system for a biomedical and human factors subsystem will present several areas that deviate from similar systems used in an earth environment. A prime consideration is the necessity of operating at zero G and, at times, at or near vacuum pressure (in space). The object of this study is to specify a method of measuring the long-term effects of zero G upon humans, thus the data management system must be designed so as not to inject any perturbations into the test program.

The system as conceived considers all equipment from the point where data is collected to the point where it is delivered to the user. All on-board communication, monitoring, television data handling, processing, display, radio frequency links as well as the associated ground station equipment are included.

During the study of the data management simulation and communication systems, it was necessary to make assumptions so as to derive specific systems. Among the included assumptions were station size, mission objectives; types and layouts of space station laboratories, and crew size. Test criteria that are detailed in other sections of this study report were also considered. These assumptions and criteria were then used for establishing the system requirements to enable the system to be designed.

A prime consideration during the course of the study was the necessity of providing a system flexible enough to allow for growth and change. Whenever possible, a modular approach to system implementation was considered. It is understood that the final size and configuration of an orbiting station has not been determined; therefore, a space station could vary in size from a 2-man modified Apollo-type orbiting station to a station similar to NAA's version of the Manned Orbital Space Station (MOSS), with a 21 to 30 man crew.

To illustrate the ability of the developed system to grow as the need warrants it and to show adaptability to the various space station configurations, three data system configurations will be detailed. The data systems will be for the following space station configurations:

1. 2-man modified Apollo

2. 4-man MORL

3. 21-man MOSS

FUNCTIONAL ORGANIZATION

From the considerations presented in Section II , it is possible to outline the tasks that should be performed by the biomedical data management and communication system. The primary purpose of the data management system is to provide a means of supporting and handling the data taken during zero-G biomedical and psychological testing. This support takes the form of collecting test data and processing it for subsequent transmission.

OPERATIONAL CHARACTERISTICS

As indicated earlier in this study, the biomedical human factors system must be capable of adapting to the space station specified. The system should be developed using modular concepts to allow for growth and modification prior to and subsequent to launch.

A very important feature of the data management and handling system is the ability to display the test data to the on-board operator for analysis. The relative detail of the presented data must be determined as a function of the possible crew make-up. The collected data must also be processed for immediate or subsequent transmission to the ground for more detailed analysis.

Experimental or test data could be recorded by many methods in a variety of forms. The simplest method is, of course, pencil and paper. This technique is quite efficient for very low-rate data from a small number of sensors. However, it must be remembered that it is necessary to provide storage space for the necessary supplies in an area where volume is already critically short, particularly in a small station such as a modified Apollo command module. This and the other considerations, such as the capability to transfer a large amount of data during a very short interval, suggests the use of a magnetic tape storage system.

A complete biomedical and/or psychological test generally is composed of many testing elements. Simulation programs are included to enable subject testing under near-operational conditions. As these tests are quite varied in content and are modified as a function of the input responses, it becomes difficult if not impossible to control the

simulation program manually. An economical solution to this problem employs an on-board data processor that is carried aloft only once, can outperform a hundred test conductors, requires minimal resupply weight, and is able to perform a full spectrum of computations and control functions with ease.

The results of computations performed by the processor would be made available to the ground as a means of checking the test program and the operations of the spaceborne processor.

The equipment required to prepare the data for recording, record it, and play it back will be designated the data handling system. The amount of data to be gathered is such that provision must be made for a wide information band if this data is to be transmitted to the ground. This implies, at the least, VHF carrier frequency.

A study of ground sites has shown that continuous transmission is not feasible. An examination of existing stations has shown that a uniform distribution of data transmission can be obtained with a seven station net. Since the majority of the stations will only be interested in environmental control and similar data, it is possible to simplify the ground station requirements for the biomedical testing. This is accomplished by designating one of the ground stations as the medical receiving station and by transmitting the biomedical and psychological data only when passing over this station. The resultant reduction in both spaceborne communicator capability and in ground-based equipment would compensate for the delay between medical transmissions.

In the ground station study, it was determined that at reasonable orbital altitudes the orbital period would be approximately 90 minutes. At the same time, the satellite would precess in such a manner as to allow any given ground station to be in range for only 8 to 10 minutes. This would seem to indicate the need for a recorder capable of storing 12 hours of data (a station will be in range twice during a 24-hour period) and playing back all of the stored data in 8 minutes or less. A detailed study of the testing requirements, however, has shown that a storage capability of 2 hours is ample (except for the simulation system). This, then, gives a record-to-playback ratio of approximately 1 to 16. If the total amount of data to be stored should exceed a single reel of tape, additional storage units must be added to the system. In this event, it would be necessary to transmit data during two or more consecutive passes over the ground station, transmit simultaneously requiring double the transmission bandwidth, or transmit to two or more ground stations although not necessarily in consecutive order.

Analog recording of signals is possible with presently available equipment; however, attempts to multiplex more than 10 signals prove difficult because of the isolation required between subcarriers. If the incoming information is first digitized, the information becomes independent of the number of sources. No isolation is needed, although it may be provided for by means of interspersed code words.

It is apparent that the recorders and transmitters must be closely related. This is established when it is realized that it is useless to record date at frequencies or data rates in excess of the available transmitter bandwidth.

Consideration must be given to both digital and analog recording requirements. Accuracies of 5 percent are considered sufficient in medical measurements. This may be represented in binary notation by a 6-bit data word. Analog bandwidths of dc 2.5 kc are needed to accurately record voice and special signals (EEG, etc.). If FM carrier techniques are utilized to provide the analog capability, a maximum, digital word rate (digital words) are recorded in parallel or multibrack recording media) of 1875 words per second is possible. The recording bit rate is then approximately 11 kilobits per second (including special coding words such as frame and message identification). The transmission bit rate is accordingly approximately 176 kilobits per second.

State-of-the-art recorders are capable of providing the necessary storage, so it is not considered necessary to embark on an extensive recorder design program. Moreover, if changes in the test program should subsequently require the measurement of long-term, high-rate data, it is possible to use the on-board data processor in conjunction with the data acquisition equipment. The processor can accept the high-rate inputs and by performing a preprocessing function reduce the data to a lower rate output that contains the significant information. The preprocessing technique that could be used includes curve fitting and deviation from norm and, if subsequently proved feasible and desirable, can compare a subject test against a subject profile. The subject profile is defined as the composite results of ground or spaceborne testing taken over a statistical period of time.

From these considerations, a block diagram of the biomedical data management system was derived (Figure 12).

SYSTEM FUNCTIONAL DESCRIPTION

Using the requirements developed in the previous section, it would have been possible to proceed directly to the definition of equipments that

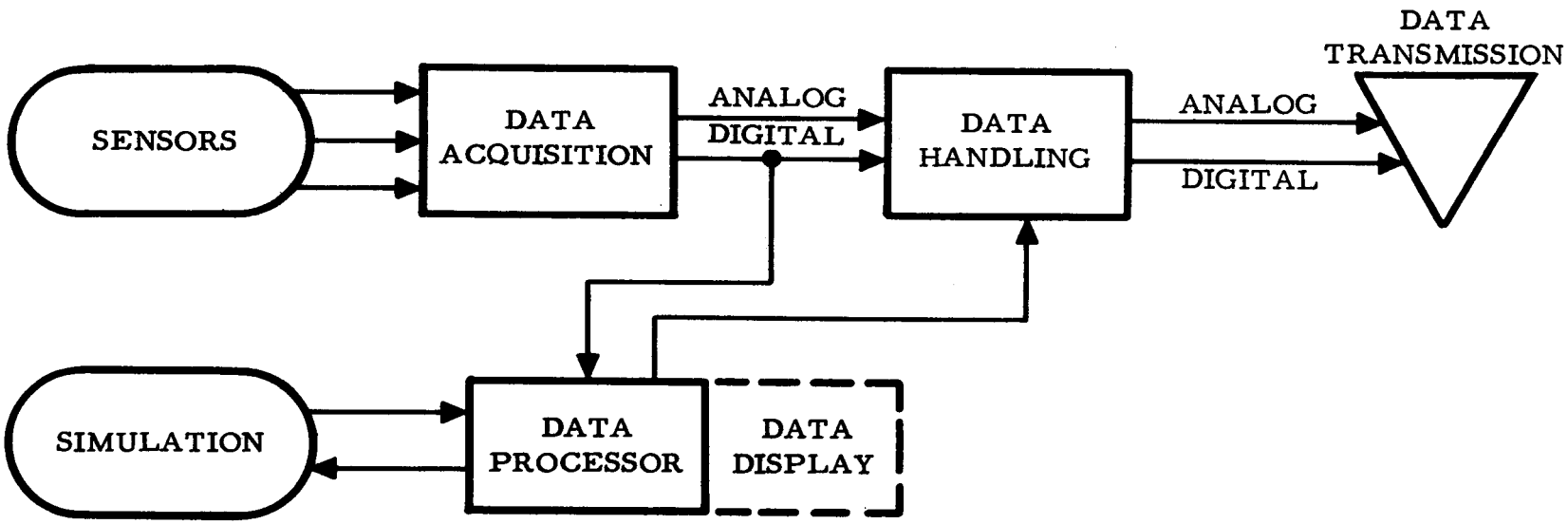


Figure 12. Biomedical Data Management System

would satisfy the test system needs. This procedure would satisfy the immediate need for specific equipment details. This, however, would not have developed a functionally organized system. If this approach is taken, a subsequent change in test function might have required a drastic change in the entire biomedical data management system. A more orderly approach is thus used. The characteristics of each block in Figure 12 will be described before proceeding to a discussion of the hardware required.

During this study, the emphasis is first placed on the spaceborne portion of the biomedical data management system. This is possible since under normal conditions a solution to the total problem is considered satisfactory if the spaceborne equipment is efficient, orderly, and flexible. This is true even if the resulting ground-based equipment is less than optimum.

There are three primary tasks to be performed by the biomedical data management system:

1. Collecting, processing, and transmitting biomedical and psychological data from the station to the ground

2. Providing supporting data for efficient usage of on-board equipment during medical and/or psychological testing

3. Supporting, processing, and modifying simulation functions and displays

Simulation System

The simulation system provides the means by which certain behavioral testing of human subjects can be accomplished under controlled conditions, and consists of equipment necessary for controlling task conditions. The unit is self-contained in that condition, multiplexing (if required), and other data acquisitions and/or data handling functions unique to the simulation requirements are included.

A functional block diagram of the simulation system is presented in Figure 13.

Inputs

The inputs to the simulation system consist of the manual or voice responses to the stimuli presented by the simulation display. In addition to the response inputs, modifying commands to the simulation system may be derived from ground and/or spaceborne data processing systems.

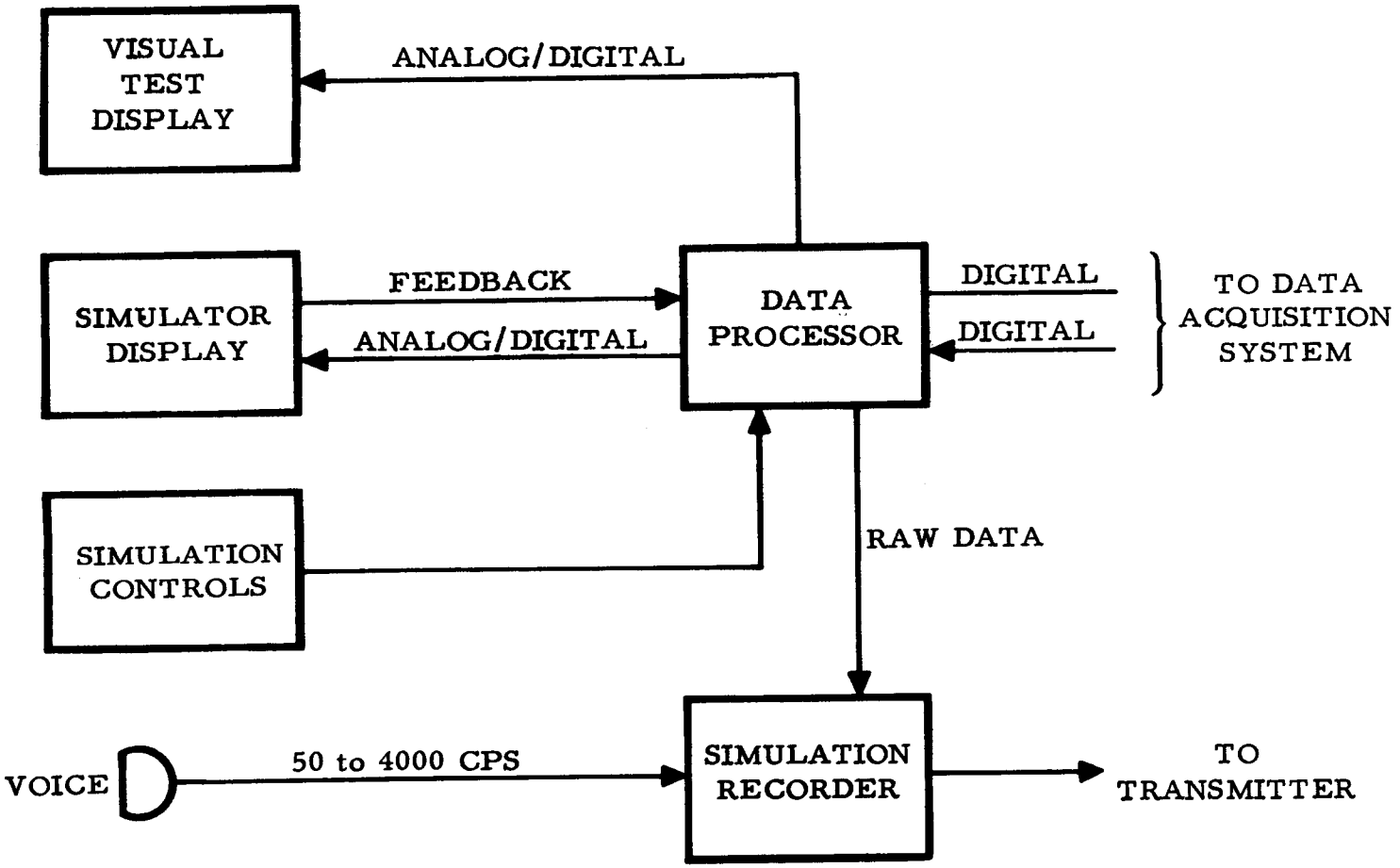


Figure 13. Simulation System

Controls

The control devices used in the simulation system include the various joysticks, switches, volume controls, etc., necessary to properly perform the various tests deemed necessary for evaluation of the subject in performance of related duties. Included in these controls are those for the data processing, recording, and transmission systems.

Displays

The display consists of various meters, lights, and optical subsystems that can simulate docking, navigation, attitude control, monitoring, and checkout of a space vehicle.

Record and Playback

The simulation recording and playback requirements are more stringent than those for the remaining portion of the test package. A typical simulation procedure may run continuously for as long as 2 hours. Obviously, the normal recording system would quickly be saturated after only one simulated operation.

Two solutions are available. The first and perhaps the simplest is to provide a second recording system and transmit either in parallel with or subsequent to the transmission of data in the primary recording system. If time or bandwidth limitations do not permit this procedure, a data processing or reduction function could be performed by the on-board data processing system to extract a data "score" for insertion into the normal record-transmit data path.

Outputs

The output of the simulation system may take the form of an analog signal or voice or raw or processed digital data. In the case of raw data, the output rate will be consistent with the in-range time (8 minutes).

Sensor System

The sensor system consists of the transducers needed to convert various physical factors taken during biomedical and psychological testing to their electrical equivalent. The physical factors include motion, temperature, pressure, etc.

A functional block diagram of various sensors is shown in Figure 14.

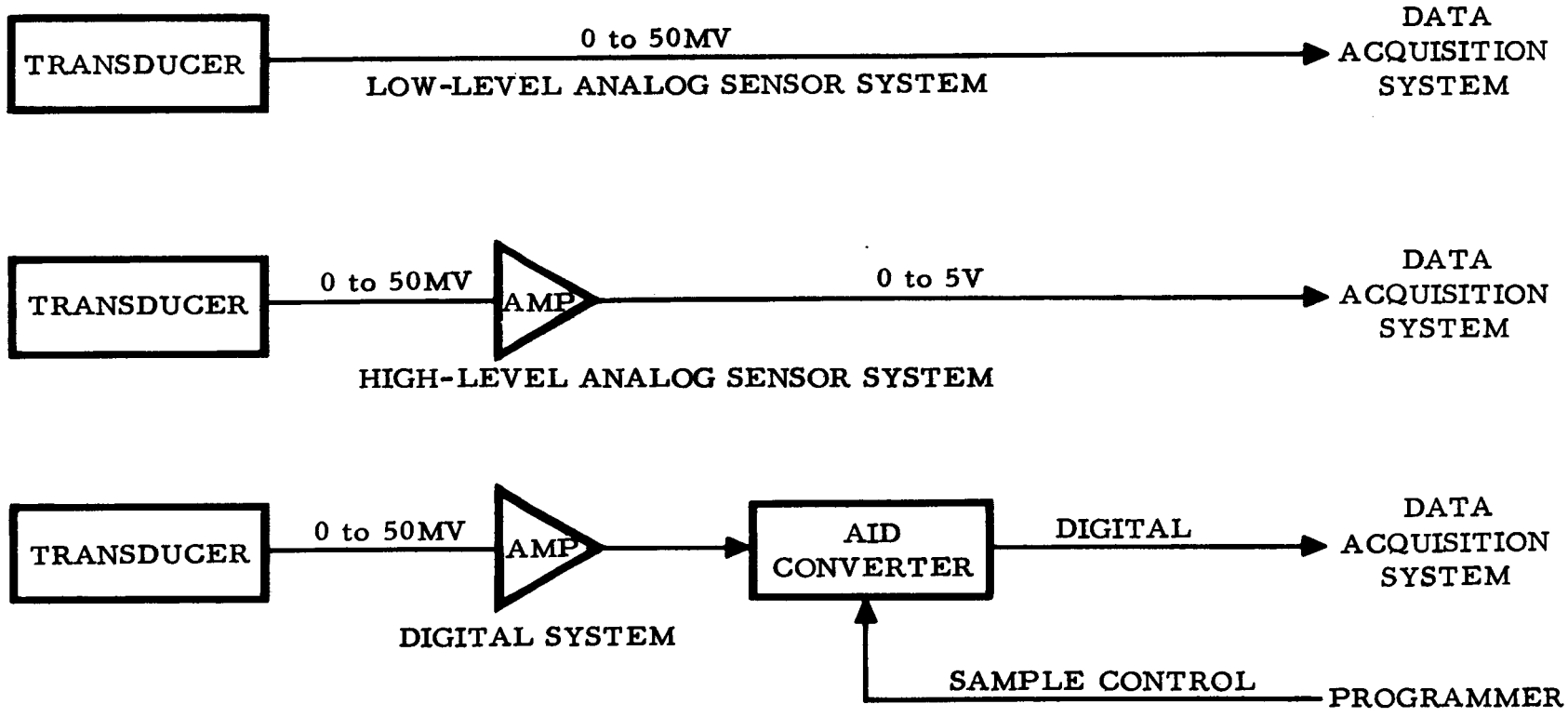


Figure 14. Sensor System

Inputs

The inputs to the sensor system will normally consist of those factors measured during physiological and/or psychological examination. Electroencephalograph (EEG), electrocardiograph (EKG), blood pressure, body temperature etc., are included to represent physiological inputs and body motion, response, etc., as representative of psychological inputs.

Outputs

The outputs of the sensor system may take any one of three forms: (1) unconditioned, low-level analog signals, 0 to 50 millivolts; (2) conditioned, high-level analog signals 0 to 5.0 volts; or (3) conditioned digital outputs. The digital output rates will be tied into the data acquisition system program and, therefore, may be sampled at a rate up to 11 kilobits per second. Any or all of the various output forms may be used by the data acquisition system.

Data Acquisition System

The data acquisition system accepts the data from the various sensors and supplies them in the proper form (digital and analog) to the data processing system, the monitoring system (displays), the data handling system, and the simulation system. The formating consists of signal conditioning, analog multiplexing (if required), analog-to-digital conversion, digital multiplexing, and multiplexor programming.

A functional block diagram of the data acquisition system is presented in Figure 15.

Inputs

The inputs to the data acquisition system will normally consist of three general types. The first is the automatic or continuous type exemplified by environmental inputs (temperature, etc.) and biomedical inputs such as EEG or EKG. The second type of input will be manually entered by a keyboard. The data received in this manner will typically be the result of clinical observations made by an observer during the course of each test procedure. The third input is received from the simulator and consists of response data.

The number of automatically sensed inputs will, or course, depend on the types of experiments and tests that are to be conducted. However, it is expected that the large majority of the input signals will be a type amiable to a sample and digitize technique. Of the few remaining tests,

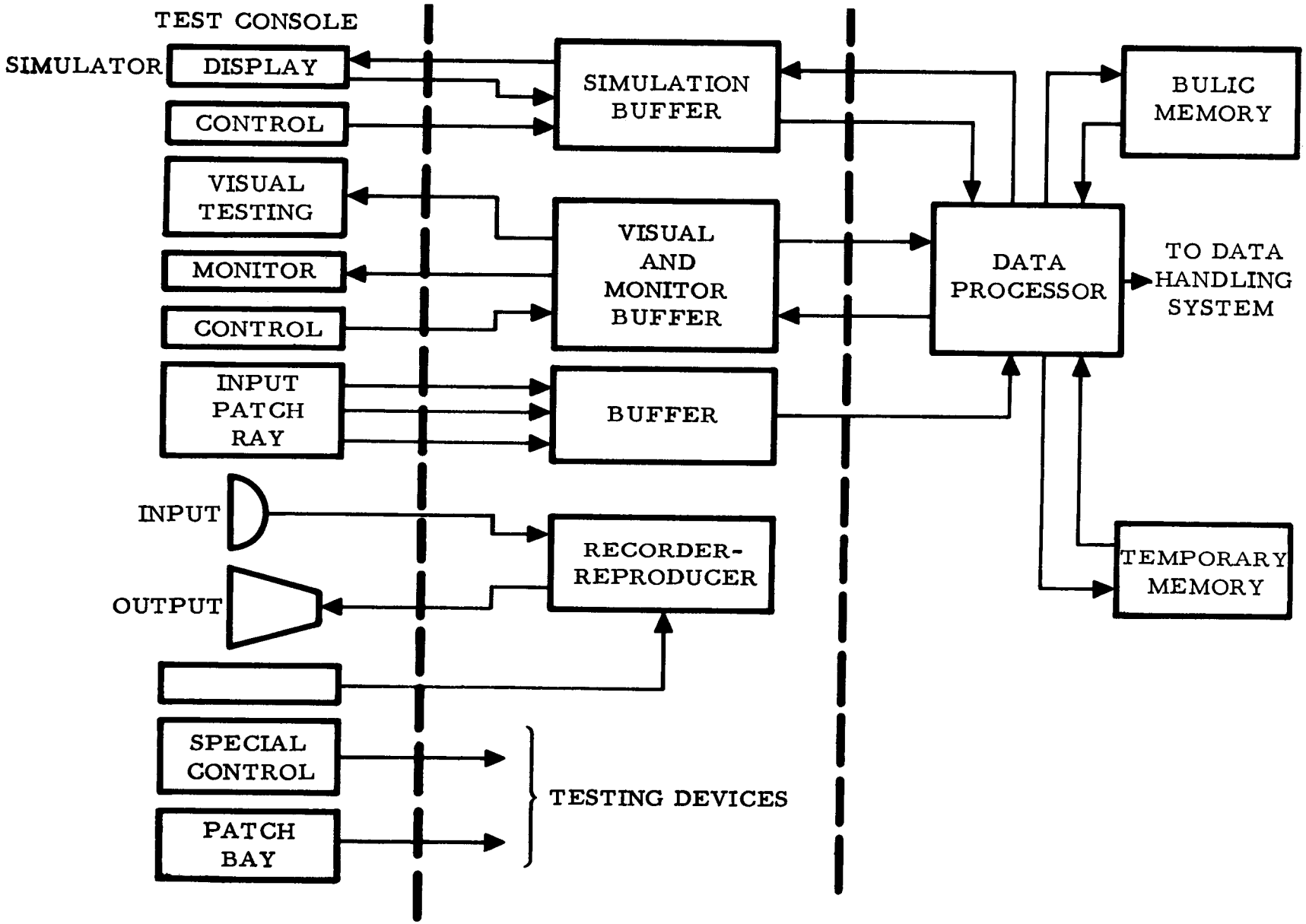


Figure 15. Data Acquisition System

EEG, etc., for which the prevalent viewpoint is to record all frequency components, provision will be made to maintain these signals in either an original or conditioned analog form.

Conditioning

The signal conditioners convert the signals from the sensors into a form suitable for multiplexing and coding or into a form suitable for analog transmission or recording. While signal conditioning is often limited to a sealing operation, signal conditioning could perform other functions as well. If properly used, signal conditioning could reduce the task of the remaining portions of the system. In an ideal system, the conditioned code word output would present an unique amount of information. Although the ideal situation cannot be achieved in a practical system, the signal conditioners can prove of great assistance.

The simplest example of a signal conditioner is a scaling amplifier or divider network. In the case of the amplifier, a 0 to 50 millivolt output may be increased to a 0 to 5 volt output. The inverse operation, a reduction in voltage to a 0 to 5 volt range may be made using a linear divider. A second example is the case in which the sensor output is in the form of sinusoidal signal, the frequency of which is desired. By providing a discriminator and feeding its output, rather than a scaled version of the sine wave, into the system, the subsequent system may be simplified. A third example is the case in which the desired information is contained in the value of a measurement that exceeds a predetermined limit. By proper conditioning, a measurement whose value lies within limits, may be designated by a simplified code word, allowing either a reduction in the number of bits per word or an increase in the accuracy of measurement values outside the designated limits.

For the purpose of this report, it will be assumed that the signal conditioners will consist of several types of amplifiers, filters, and attenuators plus special purpose devices such as discriminators, phase and amplitude detectors, etc.

Sampling

As a significant number of data sources will be sampled and digitized, it is desirable to time-share the data channels to reduce the number of wires needed. The function of time-sharing or sampling data is performed by the multiplexors. Since both analog and digital information may be supplied from the signal conditioner, both analog and digital multiplexers are required. The analog multiplexer precedes the analog-to-digital converter so that it may also be time-shared.

The rate at which individual channels are sampled is determined by the value of the collected data. Consideration must also be given to the allowable error and the manner in which the data is to be subsequently handled. For example, if a continuous waveform is to be reconstructed, by what means is the shape of curve between data values determined? The penalty for sampling faster than required is the loss of system capacity in terms of the number of data sources that may be sampled. This is true because of the maximum bit rate capacity of any system. Conversely, the penalty for sampling too slowly is a loss in accuracy. Great care must, therefore, be taken when selecting a sampling rate.

Any additional possibility that should be considered is the ability to remove redundant data by varying the data rate, dependent upon the behavior of the data, using a computer-controlled programmer.

For this study, a basic analog multiplexor unit will be assumed. The multiplexor will be capable of handling up to 20 different input channels. Since a number of those channels are likely to be from low-level sensors, each input will be capable of being simply switched to receive either high- or low-input signals. This allows the use of one amplifier rather than 20 for these channels. The maximum output word rate is to be 50,000 words per second. This data word rate is well in excess of presently contemplated rate requirements yet allows considerable further expansion without disturbing the existing equipments.

Programming

The programmer provides and controls the sampling sequence of the data channels. As the sampling rates as well as the sampling period may vary from channel to channel, the programmer must be capable of being varied by external means. For this reason, the programmer will be a stored-program type connected in such a fashion as to allow modification by the on-board data processing system. In this manner, the program may be altered by either an on-board command or, if need be, by ground control. Each programmer (if more than one) will be located physically with the multiplexor it controls.

Encoding

The analog-to-digital converters convert the sampled analog signals to their equivalent code in binary notation. The number of bits used for a particular analog channel depends a great deal upon the desired accuracy. That is, it depends upon the quantization increment elected. For the biomedical system, a 0 to 5 volt analog signal plus or minus 5 percent at maximum voltage results in a 0.25 volt quantization. Thus, a 7-bit word is considered sufficient (6-bit message plus a parity or error bit).

For the data collected in this system, a maximum conversion rate of 50 kilobit words per second (parallel) for the analog-to-digital conversion unit is suggested. Although this is far in excess of the presently contemplated system, certain measurements now being transmitted as analog signals may subsequently prove to be subject to digitization and require a higher conversion speed. A compromize may be made by providing a converter capable of two or more conversion speeds. The lower conversion rate allows a decrease in required power.

Outputs

The output of the data acquisition system consists of (1) digitized data for immediate transmission to a ground station, (2) digitized data to be used by the on-board data processing system, (3) digitized data to be recorded or transmitted (delayed) to the ground station. For discussion purposes, the digitized outputs of each group of data acquisition equipment will consist of 7-bit words (including parity). These may be supplied at rates up to 11 kilobits per second. The analog outputs are assumed to be such that a 500 kc bandwidth low-pass filter in the transmission system will not alter them.

System Precision

The accuracy of a data acquisition system depends upon the nature of the input data and upon the characteristics of individual parts of the system. These characteristics include the design and the method and care taken in the construction of the system components.

For convenience, the errors may be divided into two categories, those due to static inputs and those which depend upon the dynamics of the input signals. As most of the errors in a digital system are introduced by the analog conversion equipment, it becomes appropriate to discuss the precision of the data acquisition process.

The principle causes of static inaccuracies are drifts, nonlinearity, interference, and cross talk. These errors may occur in the sensors, the signal conditioning equipment, the multiplexer, or the analog portion of the analog-to-digital converter. An additional error source that may be considered a static error is that contributed by the quantization process. This is due to the use of discrete rather than continuous signal levels.

The dynamic errors in a digital system are due, mainly, to band-limiting in the analog circuits and to the sampling process. Some static errors are not easily categorized. Among these are errors due to common-mode rejection that may appear when testing for static errors

but are actually functions of the dynamics of common-mode signals. Cross-talk errors may also be a function of the dynamics of signals in other channels.

The maximum magnitude of the quantizing error is minus or plus one-half an increment. If the quantizing error is assumed to be equally distributed between its extremes, the RMS error is $\frac{1}{2\sqrt{3}}$ times the quantizing increment. Thus, for an n-bit binary system, the maximum quantizing error (eqn), normalized to full scale is

$$eqn = \pm \frac{1}{2^{n+1}}$$

and the RMS quantizing error (eqr), also normalized to full scale is

$$eqr = \pm \frac{1}{2^{n+1}\sqrt{3}}$$

Thus, for 6 bits, eqn is approximately 0.8 percent; and eqr is approximately 0.5 percent. The magnitude of other static errors that could occur cannot be estimated at this time since they will depend upon the sensors and conditioners used as well as the multiplexor signal level.

The magnitude of dynamic errors will be contingent upon the system design employed. Thus sampling rates required for on-board data processing may be considerably greater than required for ground station interpolation. The efforts of band limitation, if any, could be determined only if the extent to which the space station communication system will be used is known.

Data Handling System

The data handling system is designed to accept data from the data acquisition system and to arrange the data to allow real-time transmission or, if need be, to record the data for later transmission.

A functional block diagram is presented in Figure 16. The system also includes equipment necessary to accept digital data from ground sites and to route these data to the proper equipment on board the space station. The functions performed by the data handling system are format conversion, tape recording, and serial-to-parallel and parallel-to-serial conversion.

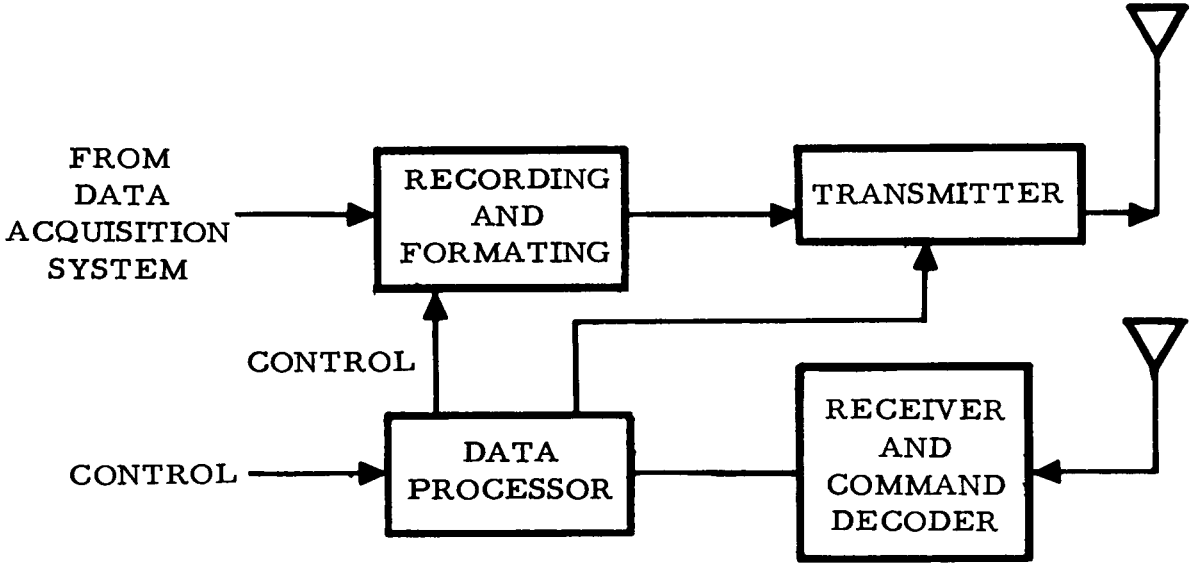


Figure 16. Data Handling System

Inputs

The inputs to the data handling system consist principally of the digital outputs of the data acquisition system. The rate, form (serial or parallel), and number of inputs will depend on the experimental configuration. The inputs from the data processing system will be of several types. When a new program that effects transmission format is read into the programmer of the data acquisition system, it is desirable to read it into the format converter so it can be transmitted to the ground station prior to transmission of data using that format. The capability of supplying output data from the data processing system to the format converter is also required. Similar inputs are provided from the simulator system. Timing information is supplied from a master clock.

Format Generation

The data received by the data handling system may not be in a proper transmission format. The function of the format converter is to arrange the data in a previously defined sequence and to insert signals suitable to identify this sequence at the ground station. The task of assemblying data in a form convenient for subsequent ground processing is simplified by inserting time information into the transmitted message. The time information can then be used by the ground station for subsequent data processing.

The format converter associated with the zero-G data system must select the time slots designated for transmission to the ground; provide a buffer storage capability; insert synchronization, timing, and identification signals; and read out these data at a fixed rate (approximately 11 kilobits per second serial rate) to a tape recorder. The capability of accepting processed computer and/or simulation words is also required.

Sync Generation

For useful information to be extracted from the data received at the ground station, it is necessary that the start of data frames, data words, and data bits be clearly identified. The problem of synchronization in PCM systems has been studied in the past few years and is not considered a serious problem.

Many of the currently operative systems use an NRZ format. Of these, many use a form of word synchronization. This means each word is identified independently of all other words. This method, unfortunately, uses between 10 and 20 percent of the system capacity for the required synchronization. Studies indicate that if the bit rate of the system is

obtained directly from the zero crossing of the data waveforms, insertion of synchronization words once a frame would be sufficient. The percentage of system capacity devoted to synchronization can then be reduced to from 3 to 5 percent.

A problem may occur when using this form of synchronization. To satisfactorily extract bit-rate phasing from zero crossings, it is necessary for the waveform to cross zero (or change bit polarity) in sufficiently short intervals of time. If subsequent information should indicate that excessive gaps exist, either because of continuous zero or full-scale outputs or because of the operating procedure, a clock track may be added to the recorded information to guarantee a crossing at every data word.

Recording

Recording is necessary because of the method of data collection proposed. The biomedical and psychological measurements will normally be obtained over a 24-hour period, while a transmission period may not exceed 8 to 10 minutes. Thus, a means of storing data must be provided.

Because of the clinical nature of the majority of the expected measurements, it is expected that the total biomedical recording time will not exceed 128 minutes during the 24-hour measurement period. The recorder will, therefore, if capable of receiving data at 11 kilobits per second, be required to play back the recorded data at 176 kilobits per second. If the data to be recorded exceeds 128 minutes, it is possible to modify the recording system in two ways: allow the oldest data to be erased and write the new data in the space provided or provide a second recorder with identical specifications. With the second method, an automatic switching technique will cause the second recorder to begin operation at the time first recorder is fully loaded. To maintain the 8-minute transmission period, it will become necessary to transmit the contents of both recorders simultaneously or to use more than one ground station for signal reception.

Parity Checking and Parallel-to-Serial Conversion

As the recorder will provide a parallel output, a device for transforming this output into serial form and for checking parity is required. In addition to checking parity, an indication must be made in the transmitted format if a word is in error when parity is not transmitted. This can be accomplished by replacing the word in error by a special code. One such code consists of a full word of zeros. Prohibiting zero as a level in normal data may be desirable from several other aspects, such as reducing the probability of no zero crossings during a word interval. Parity is used

for checking the tape machines only since the statistics of errors introduced at this point in the system are favorable to detection by parity.

Outputs

The outputs of the data handling system are supplied to the transmission system. The normal output for the zero-G measurements will be in the form of 176 kilobits per second binary nonreturn-to-zero waveform. The number of channels will depend on the experimental configuration.

Data Processing System

Organization

A digital computer is used for data-processing functions. Accordingly, this concept will be considered when determining the type of computer that will be selected. An additional factor considered while determining the data processing system was the fact that although a unique data processor is assumed for the data management simulation and communication system, in practice the data processor will probably be integrated into the space station master data processing system. This was considered if only because of the desire to minimize equipment installed in the space station.

Evaluation Criteria

The basic criterion for selection of a computing or data processing device is performance per unit cost. Performance in this case means actual and not theoretical ability to do the desired job.

In the case of the data management, simulation, and communications system, cost is made up of such things as weight, power, volume, and reliability as well as monetary expense.

In the data management, simulation, and communications system, the computer provides a variety of computing functions including monitor and control and a number of real-time simulation functions. It also provides the communications and control between the spaceborne system and the earth reception stations. Each of these activities will be connected to the computer complex by some form of input-output device, each of which may either be peculiar to the activity or be time-shared by two or more disimilar activities. Input-output devices are defined as equipment external to the arithmetic, processing, and memory portions of the computer; all devices are associated with a specific problem. For example, an input-output device could be a tape unit that has the data for a particular experiment or display device. As is the case in many instances, the cost

of the peripheral equipment could cost more than the computer itself. Thus, a saving in the external equipment is an important saving in computer cost.

It is considered uneconomical to allow the computer to operate on or perform only one function at a time. The computer complex must, therefore, be capable of accepting inputs from various sources and of performing the required operational and control functions on the respective inputs at the proper time.

Alternate Approaches

The computer system to be employed is required to meet a fixed performance level of operation. Unless the job requirements exceed the processing and storage capability of an internally stored memory, the internal memory system will have the lowest cost per operation. This would imply that this form of computer system would be the most economical to use. However, several other considerations favor the use of a system with moderate internal storage capacity and an external bulk storage system controlled by the computer.

A preliminary study has shown that a necessary requirement of the system will be the ability to store many varied physiological and psychological testing programs and control functions. In the case of the simulation program in particular, the complexity of the control program indicates that a relatively large program will be necessary for each of the modes of operation presently contemplated. If this concept of many complicated programs is extended to its possible limit, it becomes apparent that an extremely large memory system would be required. As the cost of internally stored memory computers is very often determined by the size of the memory system selected, an internal memory system is considered uneconomical for use under the specified conditions.

The first advantage of a computer system using an external bulk storage device is the relative case of expanding the total memory capacity from a basic unit as the need arises. A second feature of the form of storage system is the ability, with the addition of a small amount of equipment, to add or delete information contained in the bulk storage during the time the computer is occupied with the processing of a program.

Chosen Method

Because the data management simulation, and transmission system requires a system capable of storing large programs and because the system must be capable of quick expansion or change, the external bulk storage system is proposed.

Figure 17 is a block diagram of a typical computer system using an external bulk memory unit.

Data Processing Methods

With the present capability to miniaturize high-speed, large-capacity, digital computers, the desirability of performing a data processing and data reduction in spaceborne environments is more apparent. Many problems could conceivably arise during the operation of the spaceborne data processing system. These include control and computation of simulation problems and general computation to support other tests such as on-board and space experiments as well as many routine computational problems. The specific task cannot be discussed until the exact problem is specified.

The general approach to be taken assumes the availability of a class of data that will be a function of the independent variable time. The data may be supplied by any of the possible measurement, control, or programming sensors. Typical data processing operations that may use the computation facilities include data validity checking and pretransmission processing.

Data Validity Checking. The validity of the data read into the data processor can be checked by use of various techniques. The most obvious method is by direct comparison when such a comparison is feasible. Usually, however, this approach is not possible. More often, the received data will appear as an episodic variation and will require a statistical comparison to determine validity. Several other techniques based on the general field of information theory may also be used. These include parity checks and dual reading.

Pretransmission. Pretransmission processing (sometimes referred to as data compaction) uses the on-board data processor to perform a reduction in the amount of data that must be transmitted to ground receiver sites. Several techniques may be used to fulfill this function.

1. Fixed tolerance bands - out of tolerance values alone are recognized

2. Variable tolerance bands - allows for several acceptable measurement values

3. Slope-key point - measures slope and starting point

4. Curve patterns - comparison of data curves to reference curves

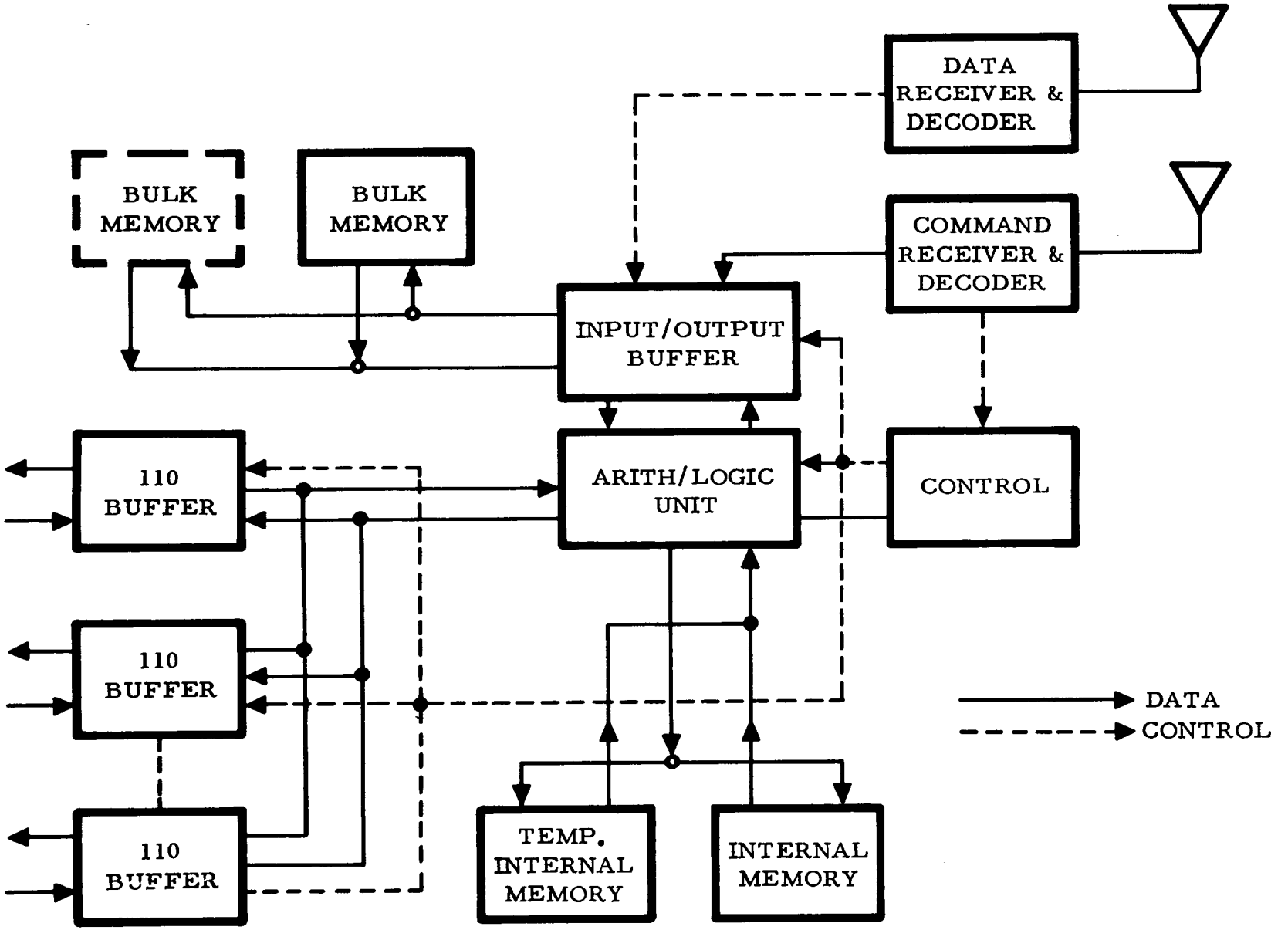


Figure 17. Data Processing System-External Bulk Memory

Curve fitting - determination of equation of data curve

6. Probability analysis - performing an analysis using statistical equations

Communication System

The primary purpose of the RF link is to provide a reliable two-way communications medium between the space station and the ground station. Sufficient information bandwidth should be available to handle the maximum transmission loads of data, television, and voice channels.

Since the selection of equipment, operating frequencies, etc., shall primarily be based on operational requirements, no specific selection of communication equipments will be made in this study. The requirements for the biomedical and psychological package must, however, be considered.

The communication requirements for the biomedical and psychological pacakage are few. The bandwidth requirements are as follows:

Digital Data	- 200 kilobits per second
Analog	- 100 kc
Video	- 2 mc
Voice (Real Time)	- 50 to 4000 cps

Alternate System

The system described to this point assumes that a general purpose, digital computer will be available to perform certain functions within the data system. If such a computer is not available, the data system must undergo some modification. Except where specifically discussed, the sensor, data acquisition, data handling and communication systems will not require any change.

A functional block diagram of the alternate data management system is presented in Figure 18.

Data Acquisition

The system modification capability formally provided by the digital computer may be replaced by a patching system. The function of the

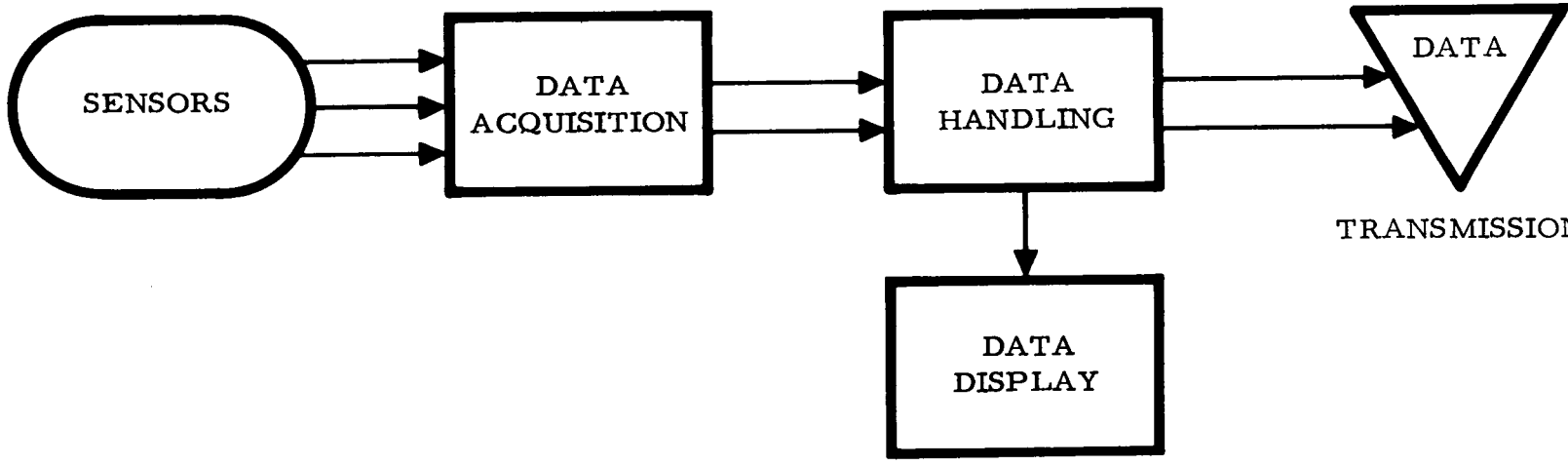


Figure 18. Biomedical Data Management System - Alternate

patch panel will be to allow the changing of sample rates, to perform formating, and to change the amount or type of signal conditioning if required.

Data Handling

The data handling system for the alternate approach will allow direct control of the transfer, recording, and transmission of data by either the space station or ground station operators.

Ground-Based Data Processing and Display

The purpose of the ground-based data processing and display system is to reformat and verify, to compare and analyze, and to display the data received from the space station. Although the amount of processing to be done at the ground station must still be determined by further study, it is possible to establish the minimum capabilities.

Organization

The experimental data is transmitted to the ground station using the on-board RF transmitters. Provisions are made to record the data on magnetic tape as well as transferring the data to the data processing system. The data processing displays may then either present the raw data or the processed and filtered data at the discretion of the operator/analyst.

Alternate Approaches

The simplest approach to ground processing and analysis would be to record all data and to process such data at a later time. However, since it is anticipated that some of the measurements could disclose incipient, catastrophic failure of a nature that could endanger human life, certain measurements should be noted at a minimum and analyzed as soon as recorded. Some of the data may be monitored by visual displays; however, any inputs that may be considered critical should also be monitored by automatic warning subsystems.

In view of the fact that a great deal of data may be received at the medical ground station during a station pass, real-time processing will not be advisable. However, the processing should be completed quickly on critical items and the remaining data should be analyzed at a more reasonable rate.

The method of handling the experimental data is implemented by recording all the postdetection data on magnetic tapes as it is received. Figure 19 shows the information path in the ground station system. When necessary, portions of the data may also be sent to the computer through the decommutator and format converter. The decommutator can be programmed to extract the desired data.

As soon as transmission is complete, the recorded data tapes may be checked to determine validity of the transmitted data. If a portion of the data was found to be invalid for any reason, the ground station may request a retransmittal of the experimental data. After acceptance of the data by the ground station, the space station personnel may then reuse the data tape thereby decreasing the spaceborne storage requirements.

Selected Method

The method selected for processing data at the medical ground station is based on the discussion of the previous section. In the case of experimental data, verification and processing, with the exception of a limited number of critical measurements, need not be done in real time but may be delayed to a more convenient period.

The procedure to be followed with experimental data, then, consists of storing the data on magnetic tapes as received. As soon as possible thereafter, the tapes are read back into the computer to verify the accuracy of the data. If an error is detected, an indication will be printed out. In case of a bit drop out, the computer may attempt to reconstruct as much information as possible by examining other words in the frame to determine if any are acceptable. In most cases, only large error groups, such as caused by fading, would be noted. The acceptable data are then converted to format convenient for subsequent processing and recorded on magnetic tape.

Finally, a sort by experiment is made to separate the various measurements, and all common experimental data recorded on corresponding tapes. Several passes through the original recorded data may be required to store and/or transfer all the data recorded.

Data Handling

It has been assumed that all medical and psychological data will be received at one designated ground station. According, it is desirable that all analysis be performed at the same location. This will minimize the need for shipping, handling, etc. If this is possible, the data handling will consist of transfer of various tapes to the proper tape transport and

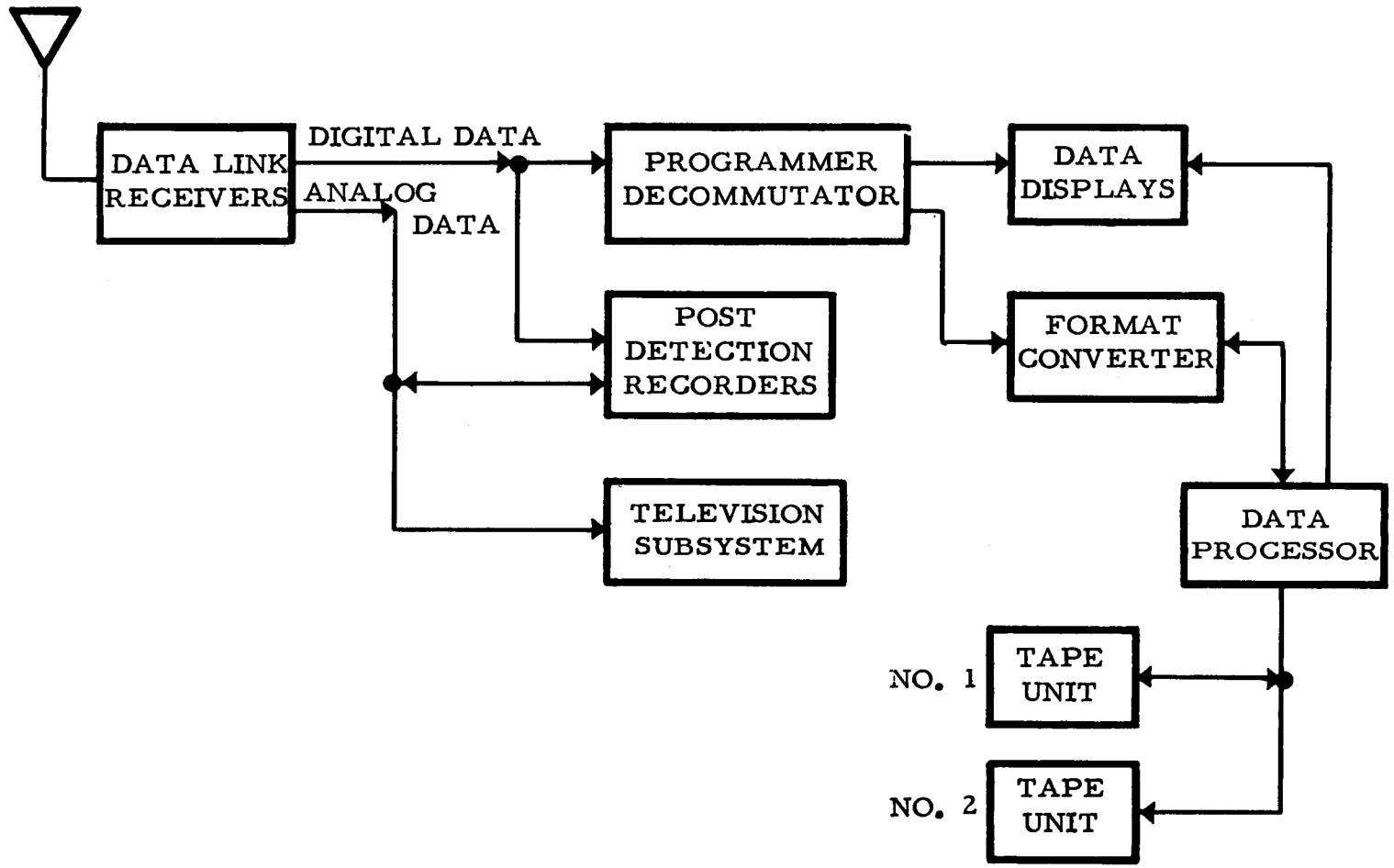


Figure 19. Ground-Based Data Processing System

the conversion, manipulation, and solution of the various statistic and analytical problems needed to extract meaningful medical and psychological information.

The output of the computer used to solve the various problems is then used to activate the various display and recording devices used for data interpretation.

Control and Display

The control and display system will have the ability to provide switching control over both raw and processed data including tape control and computer control as well as direct control of the visual display devices.

The visual devices will consist of television monitors, cathode ray displays of processed computer data, digital readouts, and graphic recorders if needed for subsequent analysis.

DATA PROCESSING SYSTEM

The basic data processing system as outlined in this section is a composite of the state-of-the-art systems as applied to the BAHFR program Signals for amplification and processing, and information for tape or transmission are fed into the data system.

The characteristics of the equipment required for this data system are set forth in Tables 11, 12, 13, and 14. Using the data for the smallest recorder and computer listed, the data processing system has a total weight of 176.8 pounds, power of 413.9 watts, and a volume of 4.71 cubic feet.

Although this is a representative airborne system, these might be reduced in size. Since the data management is essential to any space station, this processing system is considered to be part of the station design and is not included as part of the crew measurement system package.

Table 12. Data Acquisition Equipment

Function	Weight (lb)	Power (watt)	Volume (ft^3)
Signal conditioner	5	1.5	0.14
Multiplexer	2	0.75	0.09
Analog-to-digital converter	4	0.5	0.14
Digital multiplexer	1	0.25	0.03
Programmer	6	0.5	0.26
Totals	18	3.5	0.66

Table 13. Special Equipment

Item	Weight (lb)	Power (watt)	Volume (ft^3)
Micro-film display and decoder	30	100	0.50
Panels			
Computer	3	0.1	0.60
Recorder	2	0.1	0.28
Master power	1	0.1	0.08
Entry keyboard	5	0.1	0.40
Character generator and cathode ray tube	100	200	1.75
Totals	141	300.4	3.61

Table 14. Magnetic Tape Recorders

Manufacturer	Model	Tape Length (ft)	Record Time (min)	Playback Time (min)	Weight (lb)	Power (watt)	Volume (ft^3)
Electronics Division Weber Aircraft Co. Burbank, California	10-110	1200 (1/2 in. wide)	64 (at 3 to 3/4 ips)	4 (at 60 ips)	26	56 at 28 v reg	0.47
	10-126	2400 (1 in. wide)	128 (at 3 to 3/4 ips)	8 (at 60 ips) 4 (at 120 ips)	48	50 to 75 at 28 v reg or 115 v 400 cps 2Ø - (phi) 28 v reg	0.81
Controls Division Leach Corp. Azusa, California	MTR-2100	2100 (1/4 in. wide)	112 (at 3 to 3/4 ips)	7 (at 60 ips)	7.5	10 at 28 v unreg	0.14
	MTR-3100 Serial-to-parallel parallel-to-serial converters)	2400 (1 in. wide)	128 (at 3 to 3/4 ips)	8 (at 60 ips) 4 (at 120 ips)	20.25	25 nom 70 max for 3 sec 115 v 400 cps 3Ø - (phi) 28 v unreg	0.8

Table 15. Computers

Manufacturer	Model	Description	Word Length	Memory Words	Weight (lb)	Power (Watt)	Volume (ft^3)
Autonetics Division North American Aviation, Inc. Anaheim, California	Monica J (Option I)	Stored Programs General Purpose Single Address Parallel Processing Binary 500 kpps	12-16 bits	1,024 4,096 8,192 16,384 Core Random Access	10.3 20.6	100 (with PS) 150 (with PS)	0.3 0.6
Computer Prod. Division Control Data Corp. Minneapolis, Minn.	Prototype	Stored Programs General Purpose 2-4 mc	26 bits	32,000 (13 bits) Random Access Thin Film	48	118	0.5

SPACE STATION CENTRIFUGE

Extended human occupancy of space vehicles operating in weightless conditions dictates a need for some means of artificially inducing gravity to determine man's ability to perform adequately during reentry maneuvers and for use as a conditioning device. Methods of providing the necessary G forces within the constraints of the space system have been examined. A centrifuge device appears to be the best method of providing controlled acceleration and would be adaptable to large or small space stations.

In this study, emphasis has been placed on a centrifuge system installation inside a space capsule in a pressurized compartment, and the problems of such a system are presented. It is recognized that many methods exist whereby centrifugal G forces could be generated by a system external to the space vehicle, but only a brief consideration of such methods are included in this presentation in subsequent paragraphs.

The study has been directed toward arriving at reasonable estimates of requirements imposed by an on-board centrifuge to permit trade-off studies.

In general, it is desirable to reduce the G loads to which the astronaut must be subjected to minimum level that will yield the desired test results. Inasmuch as man does not tolerate head-to-foot gravity forces as well as anterior-posterior forces, it is recommended that the astronaut be oriented with his head toward the axis of rotation and with his body in the plane of rotation. He should be in a crouched position to reduce the volume requirement of the centrifuge couch and to reduce the rpm requirement for a given G load. Since in this position G tolerance is very poor, it would then be necessary to have only centrifuge that would provide acceleration in the 3 to 5 G level rather than the 8 to 10 G otherwise needed.

Installation of a human centrifuge inside a pressurized compartment permits its operation by crewmen in normal clothing. It also permits easier observation of the subject during the test and to render assistance, if necessary. Placing the astronaut's mass center 6 feet from the rotational axis would require a rotational speed of 70 rpm to attain a 10-G force. A clearance volume of 16 feet diameter by 3 feet (600 ft^3) minimum is needed for a subject dressed in light clothing. Wearing a space suit would require a clearance envelope of 17 feet diameter by 3-1/2 feet (800 ft^3). To counteract the gyration that would result from such a system if unbalanced, a

counterweight should be added to enable static and dynamic balancing. To prevent counterrotation (or some other complex resultant movement) of the space station or vehicle, an additional counterrotating assembly would be necessary.

The weight of the space vehicle would have a damping effect on the displacements produced by a moving device in a ratio inversely proportional to the weight ratio between the moving part and the vehicle. A curve is presented, Figure 20, showing the counterrotation of a space station due to an unbalanced weight on a centrifuge arm. This is based on a rigid space station mass, and the displacement is that of the center of gravity of the entire station. Since the actual construction of the space vehicle is of flexible nature, the actual point displacement at the attachment of the unbalanced centrifuge axis to the vehicle structure would depend upon the flexibility of the structure and its inertia relative to the points of application of the disturbing forces from the unbalanced rotating weight. The local structure also would require strengthening to withstand the forces from the centrifuge without producing excessive deflection or leakage throughout the useful life of the centrifuge. considering the fatigue effects of the oscillating loadings. Installation of an unbalanced centrifuge in a structure at a considerable distance from the center of mass and attached to a low-weight outer structure should be avoided, since the local gyrations of the vehicle would be very large and the rotating arm would have to be increased in length or the rpm increased appropriately to attain the design G loadings.

An installation with a counterweight and counterrotating element would reduce the effects of producing wild gyrations as previously noted but would involve providing some protection between the test subject and the counterrotating element. A fairing could be provided as a guard screen for protection against possible accidental physical injury and for aerodynamic streamlining of the crewman enclosure.

Another hazard arises with the internal installation of a centrifuge is the possibility of a structural failure of the centrifuge arm, which would propel the test subject or counterweight against the structure wall of the space station or capsule. The kinetic energy of a capsule or weight of 250 pounds at a 6-foot radius at 70 rpm is 7500 foot pounds and has a momentum of 340 pound seconds. Such a mass to impacting against the inner surface of a pressure capsule would undoubtedly cause structural failure and decompression plus severe disturbance of the remainder of the station.

During the operation of a centrifuge in a space capsule, the rotating mass will act as a gyroscope. Disturbances from the vehicle imposed as a displacement velocity vector on the axis of the centrifuge will induce

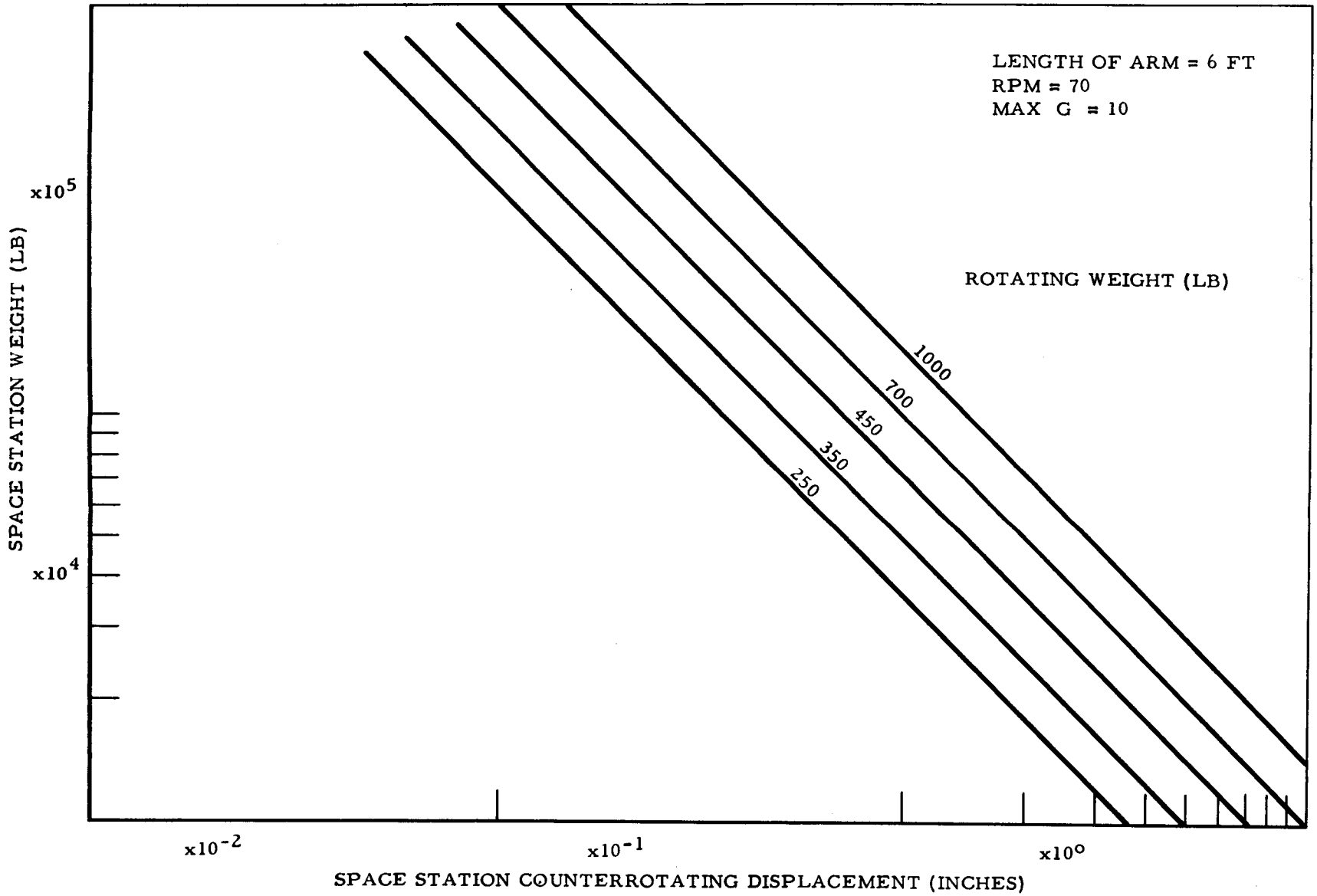


Figure 20. Space Station Counter-Rotation Due to Unbalanced Centrifuge

gyroscopic precession forces at right angles to the applied disturbance. This will act as an additional force couple on the station and produce a disturbing rotation in the plane of this couple. The resulting station movement then acts as an added disturbance to the centrifuge causing additional precession forces which then react back to the station causing more wobble, and so on. If these disturbances are not isolated at the centrifuge itself, an additional load would be imposed on the attitude control system of the vehicle to maintain stability.

Controls for a space capsule centrifuge would include some of the following requirements to enable safe operation of the centrifuge and to minimize the difficulties and dangers involved:

1. Drive motor to have a high-starting torque and rapid acceleration capability, such as a series wound electric motor where dc power can be provided

2. Speed and timing controls required for drive motor

3. Controls in manned capsule for starting and stopping including automatic deceleration actuation if crewman "blacks out"

4. Deceleration device, such as reversing the motor, running the motor as a dynamo with a resistance load, or some other energy absorber (i.e. battery recharging), or using a friction brake to absorb the energy from the two counter rotating masses

5. A locking mechanism integrated with the drive motor control to avoid danger to the crewmen or damage to the station or equipment through premature or accidental starting

6. A restraint harness for the astronaut to hold him in place within the centrifuge capsule

An area requiring special study involves the effects of space station precession brought about by the centrifuge motion and attitude control jets, related displays, control computer design, and control performance of the astronaut. Negative training transfer may result each time the astronaut attempts to correct the attitude of the space vehicle during centrifuge operation in that gyro couples will result in actual motions at right angles to applied corrective forces. This is a 90-degree shift from the normal action of such reaction jets on longitudinal axis of the capsule.

Some of the hazards of a built-in centrifuge may favor an external device with its separate advantages and disadvantages. One such method would be to have a capsule and counterweight provided with reaction jet

acceleration-deceleration power devices and an emergency solid-fuel decelerator. A swivelled tethering line would be necessary to retain an attachment to the vehicle, and a bumper would be needed to prevent impact damage between the device and the station. The centrifuge would require placement and orientation to permit operation without causing a collision between the centrifuge and the space vehicle during the operation of the device. A hazard inherent in this system is that the crewman would have to don a space suit, exit through an air lock, travel to the device, and operate it by himself. If a second man is necessary, an additional hazard is involved. If the crewman must remain in his space suit, the suit must provide bodily restraints that are not incapacitating within the design G-force limits. Automatic "deadman" controls would be required to decelerate the device if the crewman blacks out. Rendering assistance or emergency medical aid is very difficult with an external system; and, if the tethering line should break, there is a danger that the device could drift away from the station.

ANALYSIS

A preliminary trade-off study is presented herein to show the supplied power requirements versus the rate of acceleration and the size of drive motor as a function of centrifuge rpm and rate of acceleration. A thorough analysis of this problem would entail a lengthy study beyond the scope of this investigation. A tentative design point of a 6-foot effective radius centrifuge was arrived at based on the limitations imposed by the size of a man. A 6-foot radius will give a 10-G load at 70 rpm.

Results of the study are shown in Figure 21 based on the following assumptions:

1. A human centrifuge may be installed inside a space vehicle pressurized capsule at 0.5 atmosphere pressure.

2. The test subject may be seated in the device in normal clothing (not in a space suit).

3. The weight of the centrifuge arm, occupant, and counterweight is 500 pounds.

4. A counterrotating rotor would also weigh 500 pounds.

5. A high-starting torque motor is used.

6. Motor efficiency averages 30 percent from no load to full load.

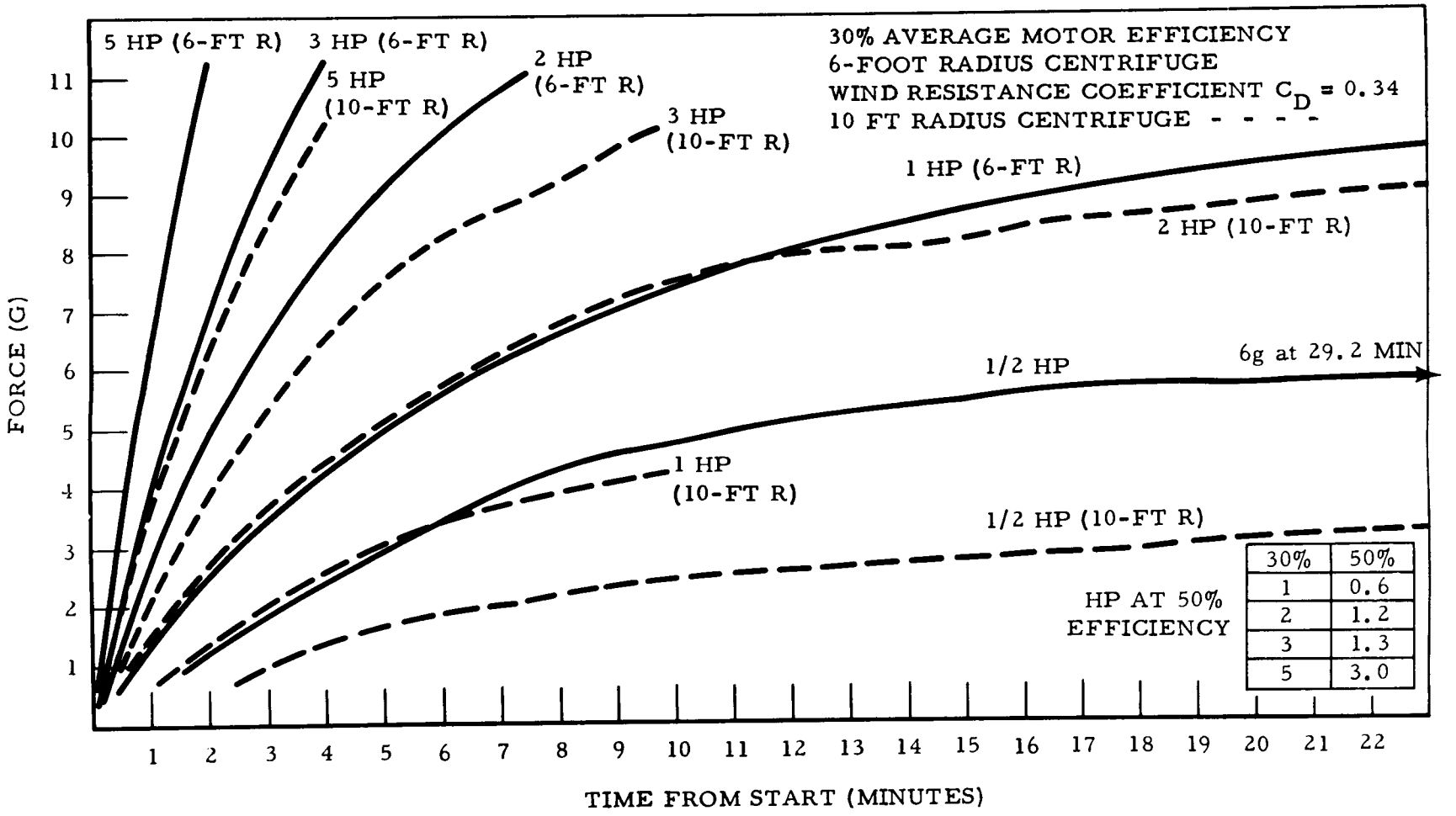


Figure 21. Acceleration Time Versus Power Input to Motor

7. Wind drag coefficient is 0.34 (with some streamlining provision).

8. Acceleration is constant.

9. Bearing and friction losses are 35 percent of inertial horsepower.

To balance input torque and to minimize the gyroscopic reactions due to space vehicle wobble, it is believed that a counterrotating element must be used. It is believed that limiting each rotating element to an effective radius of 6 feet would limit the total weight to 500 pounds making a combined rotating weight of approximately 1000 pounds.

For the motor requirement, series-wound, direct-current motors would probably be most applicable because they provide high torque at low rpm. Since efficiencies vary with motor rpm and size, values probably will vary from close to zero at initial start to a maximum of around seventy percent for small horsepower sizes. Computations for the curves shown in Figure 21 were based on an average efficiency of 30 percent. This average efficiency could possibly be increased to 50 percent. Power input values based on this efficiency are tabulated on Figure 21.

Wind resistance was based on a 0.5 atmosphere pressure density and a drag coefficient of 0.34, which is equivalent to the streamlining of that of a modern automobile. Drag coefficients usually vary from 0.1 to 0.5; 0.1 is applicable to a highly streamlined object, while 0.5 is applicable when there is no streamlining.

The horsepower necessary to overcome inertial forces was calculated assuming constant acceleration from start. Losses due to friction in bearings and speed conversion devices were estimated at about 35 percent of the inertial horsepower based on data obtained from studies of similar centrifuge devices. Smaller losses can only be assumed based on more detailed design of the machine in question.

A study of Figure 21 indicates that to simulate a reentry profile of about 10 G's in 1.7 to 3.2 minutes for a 6-foot-radius centrifuge would require an input to the drive motor of 3 to 5 horsepower. Motor sizes less than these values result in increases in the time to reach an acceleration of 10 G. Dashed lines are given for a centrifuge with an effective radius of 10 feet. The actual radius of the centrifuges would be at least 2 feet larger than these values.

The gyroscopic reaction on the space station from the centrifuge is dependent on the rate of wobble permitted by the attitude control system. As of this date, no known steady-state wobble tolerance has been established.

A preliminary layout, Figure 22, was made to determine some of the physical dimensions for a typical centrifuge installation wherein the effective diameter of the counterrotor is the same as the passenger-carrying rotor. The critical physical dimensions are the axial distances from the bearings to the planes of rotation of the respective rotating masses. The magnitude of reaction on the bearing and thence to the space station varies inversely with the square of these dimensions. Thus, one of the primary aims of design would be to have these dimensions (b_1 and b_2 on Figure 23) for the two rotating elements by nearly equal.

Using the dimensions determined from the configuration of Figure 22) and the same rotor weights as for Figure 21, it was calculated that this configuration would result in a reactive moment of approximately 120 foot-pounds (6-foot radius). The effect of a moment of this magnitude is a function of the size and weight of the station, the location of the centrifuge, and the capacity of the attitude control system.

To reduce this moment, a second configuration was made (Figure 23) in which the difference between b_1 and b_2 was reduced. To accomplish this reduction, the radius of the counterrotating element was also reduced to provide clearance between the two rotating elements as well as to retain the same space for the crewman.

A third configuration (Figure 24) wherein two rotors were put in the same plane, was investigated. It is possible that putting one element inside of the other might impose major structural difficulties and increased weight but would eliminate the gyroscopic reactive moment. A minimum clearance allowances would limit the effective radius of the counterrotating element to approximately 3-3/4 feet to clear the test subject. The drive mechanisms shown in the drawings would probably consist of a rotor attached to the centrifuge arm and the starter attached to the counterrotating weight. This would minimize the force transmitted to the space vehicle.

SUMMARY

A centrifuge with a configuration similar to Figure 22 with both rotors of the same effective radius and rotating at 70 rpm maximum could be developed with a weight of approximately 1000 pounds. This configuration requires a power input of 3 to 5 horsepower at 30 percent efficiency or 1.8 to 3.0 horsepower at 50 percent efficiency to develop the required shaft power. The gyroscopic reaction would be approximately 120 foot-pounds.

To reduce the gyroscopic reaction would cost either an increase in power or weight or combination of both. The optimization of all of these factors would require a very lengthy study to determine the proper trade-offs and design details.

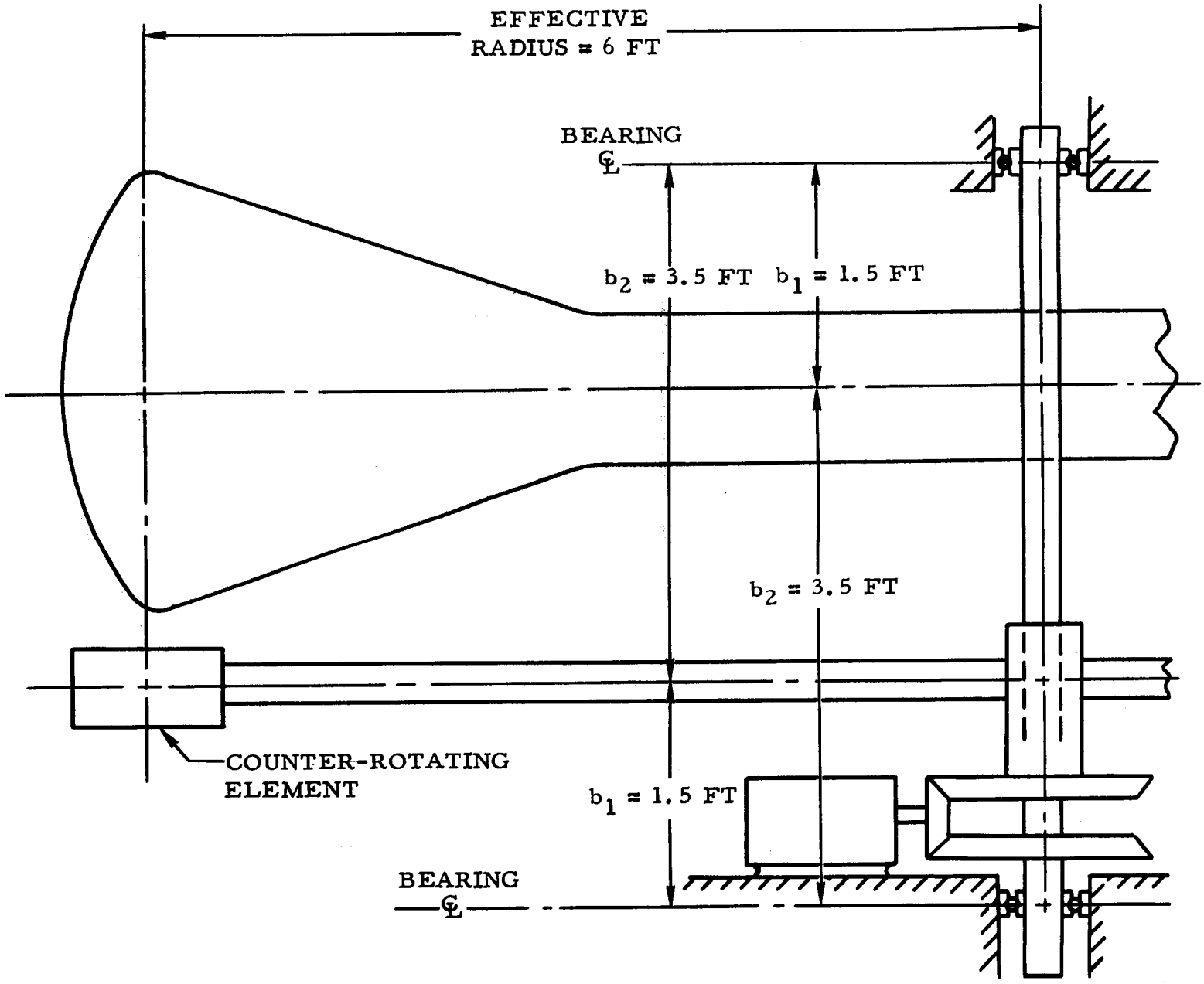


Figure 22. Typical Centrifuge—Preliminary Layout

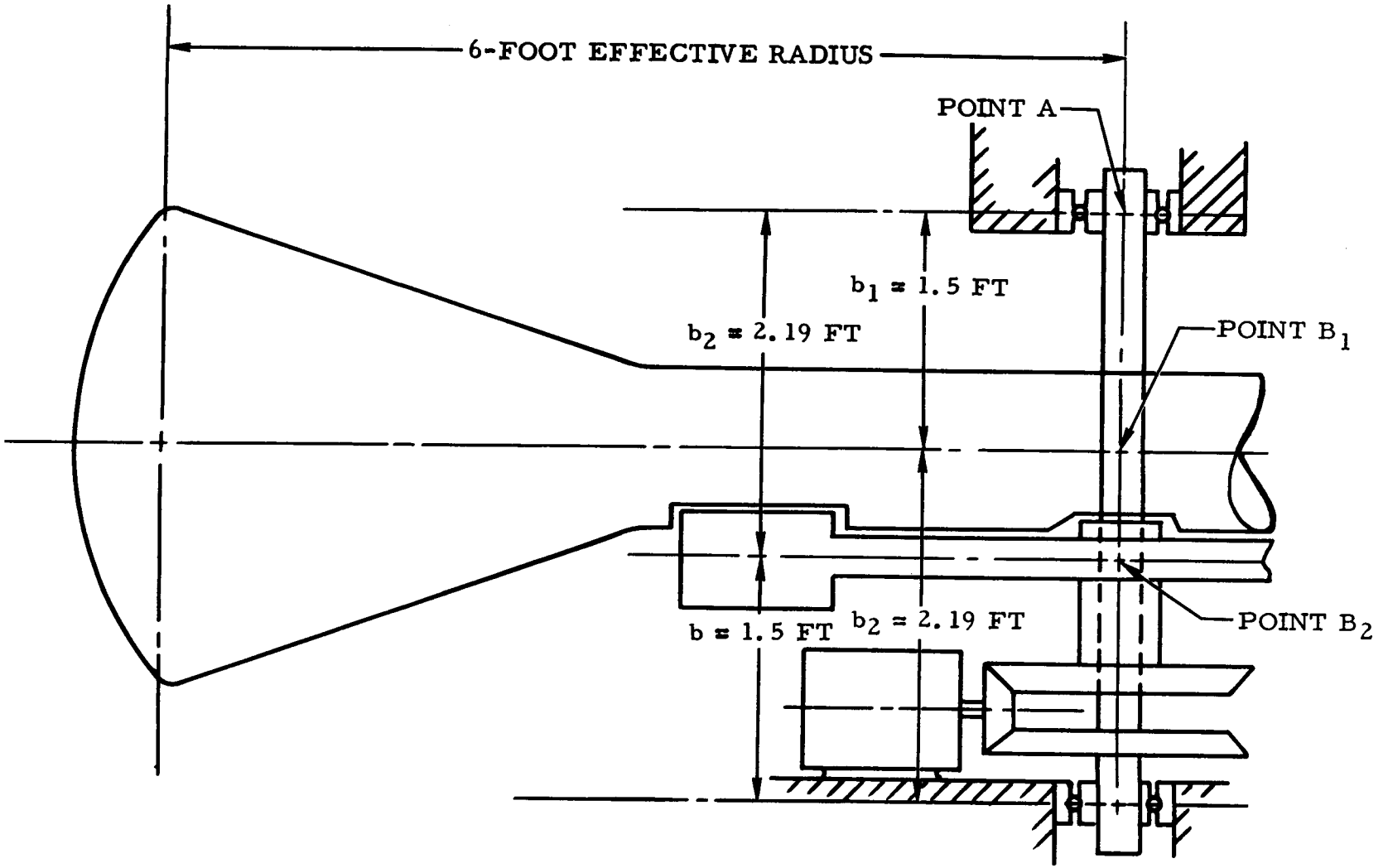
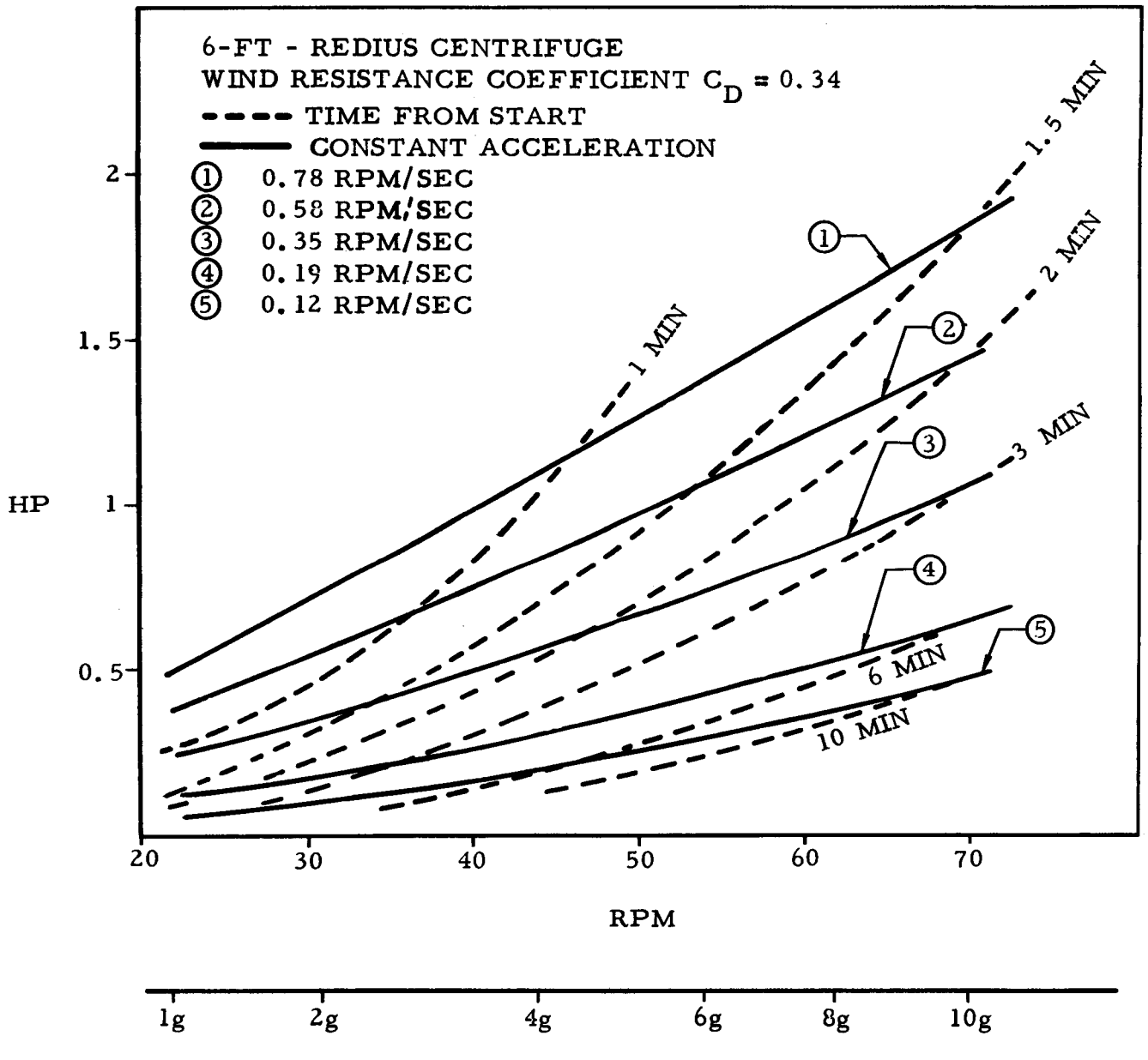


Figure 23. Alternate Centrifuge Configuration


6-FT - REDIUS CENTRIFUGE
WIND RESISTANCE COEFFICIENT C_D = 0.34
TIME FROM START
CONSTANT ACCELERATION
① 0.78 RPM/SEC
② 0.58 RPM/SEC
③ 0.35 RPM/SEC
④ 0.19 RPM/SEC
⑤ 0.12 RPM/SEC
1 MIN
1.5 MIN
2 MIN
3 MIN
6 MIN
10 MIN
HP
2
1.5
1
0.5
20
30
40
50
60
70
RPM
1g
2g
4g
6g
8g
10g

IV. CONFIGURATIONS ANALYSIS

OBJECTIVES

The configurations analysis was performed to provide background data on space station concepts to guide the development of the Crew Measurement Systems. The space station concepts were (1) the extended Apollo Concept I (command module only); (2) the interim stations (extended Apollo Concepts II and III, and MORL); and (3) the large stations (rotating and nonrotating MOSS). Data was derived primarily from S&ID study efforts and briefings by Lockheed Missiles and Space Division on the rotating MOSS, and from Douglas Missile and Space Systems Division on the zero G or nonrotating MOSS. It is noted that study efforts on these space station concepts have continued during the course of this study, and the data presented here may not be entirely consistent with current concepts. However, the data have been used only as general guidelines rather than final and precise limitations.

The primary aim of the analysis was to identify system characteristics that may constrain or limit the crew measurement systems. Station concepts were reviewed with particular emphasis on volume and work space availability, power supply, weights analysis, and crew size. The data resulting from this analysis were used primarily to establish constraints and determine crew performance requirements so that appropriate measurement packages could be developed for the station concepts. In addition, the analysis enabled the rejection of behavioral and biomedical techniques and devices that were not compatible with station concepts and provided background for the development of trade-off curves that reflected station features.

Safety package measurements are given in Table 16; minimum weightlessness measurements are given in Table 17; total measurements are given in Table 18.

Table 16. Safety Package

Identification	Measurement	Device	Weight	Power (watts)	Item	Margin		Workspace	Frequency (No./Wk)	Duration		Time/Week		Total Cumulative
						Storage	Spare			Subject	Observer	Subject	Observer	Cumulative Minimum/Week
			Item		Volume (cubic feet)									
15	Blood pressure	B	1.25	0	0.049	0.067	0.067	(O_{s-1}, S_{s-2})71.0	14	5	5	70	70	140
35	Cardiac activity and state (Electrocardiogram)	C	0.125	0.02	0.0005	0.006	0.0012		14	10	15	140	210	490
143	Venous distention	Checklist	-	-	-	-	-	(O_{s-2})330	14	5	5	70	70	630
63	Pulse rate	Stopwatch	0.022		0.0003	0.001	0.006		7	2	2	14	14	658
125	Food intake (eating habits evaluation)	Checklist	-	-	-	-	-		7	0	0	0	0	
89	Bowel habits (function evaluation and stool)	Checklist	-	-	-	-	-		7	0	0	0	0	
135	Regurgitation and nausea	Checklist	-	-	-	-	-		7	0	0	0	0	
13	Fluid intake and output	Checklist	-	-	-	-	-		7	0	0	0	0	
21	Urinalysis (WBC, RBC, pH, sugar, bacteria, protein, osmolarity)	KQ, R	75.9	175	1.98	2.47	2.60		7/3	0	5	0	12	670
27	Hematocrit and hemoglobin	A, A, E, F, G	16.5	75.0	2.55	3.187	3.250	(O_{s-1})38.0	7/3	5	25	12	55	737
99	Respiratory rate	C	-	-	-	-	-		14	(See No. 35)	0	0	0	
78	Body temperature	U	0.06	-	0.0012	0.0015	0.0005		7	5	0	35	0	772
95	Muscle size	O	0.125	-	0.0012	0.0015	0.0030	(O_{s-1}, S_{s-2})66.0	7/3	5	5	12	12	796
1	Arm-hand manipulation	A, B	1.25	-	0.039	0.049	0.049		7/3	10	15	25	35	856
10	Speech perception	G, H	22.5	2.0	1.03	1.287	1.662		7/3	10	0	21	0	877
3	Computation	B, C, D	0.3	0.2	0.014	0.017	0.049		7/3	20	0	48	0	925
98	Cardiopulmonary symptoms (Dypsnea)	Checklist	- -	- -	- -	- -	- -		7 -	0 0	0 0	0 0	0 0	
101	Voiding evaluation	Checklist	0.2	0	0.001	0.001	0.001		7	2	5	14	305	974
	Total safety package		117.1 total	11.0 Maximum			7.690 total	208 total	Min/man/wk			461	513	974
									Min/man/day			65.9	73.3	139.2
									Hr/man/day			1.09	1.22	2.32

Work space Legend

O_{s-1} - Observer, or S_{s-1} - Subject (standing) - 38 cubic feet
O_{s-2} - Observer, or S_{s-2} - Subject (seated) - 33 cubic feet
S_a - Subject seated in accelerator device - 90 cubic feet

Table 17. Minimum Weightless Package

Identification	Measurement	Device	Weight Item	Power (watts)	Margin			Work Space (ft^3)	Frequency (No./Wk)	Duration		Time/Week		Total Cumulative
					Item	Storage	Spare			Subject	Observer	Subject	Observer	Minimum/Week
L 130	Skin, nailbed and mucous membrane color	Checklist	-	-	-				7	5	5	35	35	70
	Venous pressure and circulation time	H, I	2.5	0	0.045	0.056	0.112		1	5	10	5	10	85
	Circulation time (see above)	I, J	0.112	0	0.001	0.0012	0.0012		1	5	10	5	10	100
106	Capillary fragility tourniquet test	B	-	-	-				1	5	5	5	5	110
23	Venous pH, pCO_2, pO_2	A-1	17.0	20.0	0.40	0.500	0.50		1	0	15	0	15	125
2	Cardiac output	A	-	-	-				1	0	30	0	30	155
10	Total body water	T	244.3	40.4	1.896	2.37	2.5		1/2	30	60	15	30	200
84	Plasma protein	A, E, F, G, I	-	-	-				1	0	20	0	20	220
131	BSP (bromosulfalein)	I, J	-	-	-				1/2	10	30	5	15	240
51	Serum K and Na and	A, E, F, G, I	-	-	-				1	0	20	0	20	260
	Urine K and Na (urine electrolytes)	A, E, F, G, I	-	-	-				1	0	20	0	20	280
11	Respiratory quotient BMR (O_2 uptake and CO_2 production)	D	70.5	310.0	1.92	2.40	2.40	(O_{S-1}) 38.0	1	5	15	5	15	300
21a	Urine osmolarity	K	68.0	150.0	1.375	1.719	1.719		7	0	20	0	140	440
107	Eosinophil count	R, Q	-	-	-	0.350	0.35		7/3	0	15	0	35	475
28	Speaking	G, H	-	-	-				7/3	0	0	0	0	
37	Serum creatinine and urine creatinine	A, E, F, G, I	-	-	-				1	0	30	0	30	505
		A, E, F, G	-	-	-				1	0	30	0	30	535
59	Blood sugar	A, E, F, G	-	-	-				7/3	0	20	0	49	584
17	White blood count and	R, Q	-	-	-				7/3	0	15	0	35	619
	red blood count and	R, Q	-	-	-				7/3	0	15	0	35	654
	white blood cell differential	R, Q	-	-	-				7/3	0	10	0	22	676
	reticulocyte count	Q	-	-	-				7/3	0	15	0	35	711
	platelet estimate	R, Q	-	-	-				7/3	0	0	0	0	
100	Bleeding time	B, Q	-	-	-				1	10	10	10	10	731
110	O_2 uptake in RBC	A-1	-	-	-				1	0	30	0	30	761
109	Serum osmolarity	K	-	-	-				1	0	20	0	20	781
7	Calcium balance study	A, A, E, F, G, I	-	-	-				1/2	0	60	0	30	811
39	Serum Ca and PO_4 and	A, E, F, G, I	-	-	-				1	0	30	0	30	841
	Urine Ca and PO_4	A, E, F, G, I	-	-	-				1	0	30	0		871
91	Reflex response and clunus evaluation	X	0.50	-	0.01	0.013	0.013		1	5	5	5	5	881
61	State of arousal (alert, sleep) (EEG)	Y	0.125	0.02	0.0005	0.0006	0.0008		1	10	15	10	15	906
121	Retinal examination	Z	2.0	10.0	0.052	0.052	0.104		1	10	10	10	10	926
47	Muscle activity and state (electromyogram)	W	0.125	0.054	.0005	0.0007	0.0014		1	10	15	10	15	951
6	Visual acuity	F	40.0	225.0	2.04	3.000	3.375	(O_{S-2}) 33	1	10	10	10	10	971
16	Recognition of location and movement of limbs (proprioception)	P, T	4.0	1.0	0.070	0.0855	0.855		1	5	5	5	5	981
46	Vibration	O	1.5	10.0	0.035	0.044	0.044		1	10	10	10	10	1001
26	Body positioning	A, B	-	-	-				7/2	20	20	70	70	1141
14	Compound pattern discriminating	F	-	-	-				1	10	0	10	0	1151
18	Monitoring	F	-	-	-				7/5	35	0	80	0	1231
4	Respiratory volume (maximum breathing capacity)	D	-	-	-				1	5	10	5	10	1246
45	End expiratory CO_2, O_2		-	-	-				7/3	5	10	12	23	1281
32	Decision making	L	0.25	-	0.029	0.029	0.029		7/10	30	30	21	21	1323
74	Tubular excretion test (PSP)	I, J	-	-	-				1	10	30	10	30	1363
111	Blood urea nitrogen (BUN)	A, E, F, G	-	-	-				7/3	0	20	0	47	1410
29	Sensation (pain threshold	B B	0.5	-	0.003	0.004	0.004		1	5	15	5	5	1420
	detection of heat and cold)	A A	5.0	1	1.0	1.25	1.30		11	10	10	10	10	1440
33	Pulmonary pathology (X-ray	L	84		1.515	1.80	2.0							
	Totals		573.02				22.23	279.0	Min/man/wk			368	1072	1440
									Min/man/day			52.6	153.1	205.7
									Hr/man/day			0.87	2.55	3.43

Work space Legend

O_{s-1} - Observer, or S_{s-1} - Subject (standing) - 38 cubic feet
O_{s-2} - Observer, or S_{s-2} - Subject (seated - 33 cubic feet
S_a - Subject seated in accelerator device - 90 cubic feet

Table 18. Total Measurement Package

Identification	Measurement	Device	Weight Item	Power (Watts)	Item	Margin		Cum. Vol.	Work Space	Freq (No./Week)	Duration (Min)		Time/Week (Min)	
						Storage	Spare				Subject	Observer	Subject	Observer
						Volume (Cubic Feet)								
2	Cardiac output	A	4.50	10.0	0.25	0.312	0.624	0.624		1	0	30	0	30
15	Blood pressure	B	1.25	0	0.0486	0.0607	0.0607	0.628		14	5	5	70	70
1	Arm-hand manipulation	$\overline{A}, \overline{B}$,	1.25	0	0.013	0.016	0.032	0.660		7/3	10	15	23	35
35	Cardiac activity and state (electrocardiogram)	C	0.125	0.02	0.0005	0.0006	0.0012	0.670		14	10	15	140	210
11	Oxygen uptake, CO_2 production	D	70.00	310.0	1.92	2.400	2.400	4.492		7	10	15	70	105
3	Computation	$\overline{B}, \overline{C}, \overline{D}$	0.30	0.2	0.014	0.017	0.049	4.51		7/3	20	0	47	0
27	Hemoglobin and hematocrit	A, A', E, F, G	16.50	75.0	2.55	3.187	3.250	7.583		7/3	5	15	11	35
9	Docking	$\overline{E}$	186.00	445.0	9.600	9.600	10.560	18.143	O_{S-2} 33	7/3	30	0	70	0
31	Exercise test (response to stress)	A-7	10.00	0	2.0	2.50	2.50			1	15	40	15	10
41	Venous pressure	H, I	2.5	0	0.045	0.056	0.112	18.207		1	5	10	5	10
16	Visual acuity	$\overline{F}$	40.0	225.0	2.4	3.000	3.375	21.582	O_{S-2} 33	1	10	10	10	10
See 41	Circulation time	I, J	0.112	-	0.002	0.0025	0.0025	24.583		1	5	10	5	10
7	Calcium balance	A, A', E, F, G, I	-	-	-					1/2	0	60	0	30
8	Peripheral detection	$\overline{M}$	2.0	0	1.0	1.250	1.250	22.933		1	20	25	20	25
80	Serum alkaline phosphates	A, E, F, G, I	-	-	-					1	5	15	5	15
See 11	Respiratory quotient and BMR	D (see 5)	-	-	-					1	5	15	5	15
10	Speech perception	$\overline{C}, \overline{H}$	22.5	20.0	1.03	1.287	1.662	24.495		7/3	10	0	23	0
101	Voiding evaluation	Checklist	-	-	-					7	0	0	0	0
49	Bone (X-rays) density	L	84.00	550.0	1.515	1.893	2.000	28.714	$O_{S-1}S_{S-1}$ 76	7/20	5	15	2	5
12	Static depth perception	$\overline{E}$	-	-	-					1	15	20	15	20
43	Muscle endurance (function)	M, N, O	10.250	-	1.015	1.268	1.3	28.7611		7/3	5	5	12	11
86	Vestibular response and caloric stimulation	$\overline{A}, \overline{A}$	0.5	1.0	1.0	1.25	1.350			1/2	15	20	8	10
14	Compound pattern discrimination	$\overline{F}$	-	-	-					1	10	0	10	0
6	Maximum breathing capacity	D	-	-	-					1	5	10	5	10
	Barium swallow	L	-	-	-					7/20	30	45	10	16
16	Location/movement of limbs	$\overline{J}$	2.0	0.1	1.0	1.250	1.2500	30.011		7/3	10	15	23	35
125	Appetite, eating habits evaluation	Checklist	-	-	-					7	0	2	0	14
13	Fluid intake and output	Checklist	-	-	-					7	0	0	0	0
18	Monitoring	$\overline{F}$	-	-	-					7/3	35	0		0
102	Kidney stone formation (X-ray)	L	-	-	-					1	30	45	30	45
20	Detection discrimination of force on observation	$\overline{V}$	2.0	-	0.12	0.150	0.165			7/3	15	20	35	47
37	Urine creatinine and (serum creatinine)	A, E, F, G A, E, EGI	- -	- -	- -					1 1	0 0	30 30	0 0	30 30
21	Urinalysis (protein, sugar, blood, acetone)	QRK	75.9	175.0	1.98	2.47	2.60			7/3	0	5	0	12
22	Detection of angular acceleration	K	20.0	20.0	3.0	3.75	4.120		S_{S-9}^{0}	7/3	10	15	23	35
See 21	(Urinary albumin)					0.412	0.618			7/3	3	9	7	21
104	RBC mass	T, I	246.3	40.4	1.90	2.37	2.5		O_{S-2} 33	7/60	30	60	3	7
24	Dynamic depth perception	$\overline{E}$	-	-	-					1	30	0	30	0
78	Body temperature	U	0.06	-	0.0012	0.0015	0.0015			7	5	0	35	0
25	Blood volume	T	-	-	-					7/30	30	45	7	10
26	Body positioning	$\overline{A}, \overline{B}$	-	-	-					7/2	20	20		
28	Speaking (see speech perception)	$\overline{C}, \overline{H}$	-	-	-					7/3	0	0	0	0
89	Bowel function evaluation, stool amount	Q, checklist	-	-	-					7	0	0	0	0

Table 18. Total Measurement Package (Cont)

Identification	Measurement	Device	Weight Item	Power (Watts)	Item	Margin		Cum. Vol.	Work Space	Freq. (No. /Week)	Duration (Min)		Time/Week (Min)	
						Storage	Spare				Subject	Observer	Subject	Observer
						Volume (Cubic Feet)								
70	Gastro-intestinal tract mobility bowel mobility	VL, Q	-	-	-				O_{S-2} 33	1	28	49	28	49
30	Learned procedure	(Real Task Measurement)								7	0	20	0	140
135	Incidence of regurgitation and nausea	Checklist	-	-	-					7	0	0	0	0
33	Chest film	L	-	-	-					7/20	5	15	2	5
32	Decision making	$\overline{L}$	2.0	0	0.029	0.036	0.900			7/10	30	30	21	21
47	Electromyogram (muscle activity and state)	W	0.125	0.02	0.0005	0.001	0.003			1	10	15	10	15
91	Deep tendon reflex	X	0.50	-	0.011	0.011	0.011			1	5	5	5	5
34	Tracking	$\overline{E}$	-	-	-					7/3	20	0	47	0
61	State of arousal (alertness, sleep) electroencephalogram	Y	0.125	0.02	0.0005	0.006	0.007			1	10	15	10	15
36	Brightness discrimination	$\overline{F}$	-	-	-					1	20	25	20	25
55	Rheoencephalogram	Y'	8.0	50.0	0.465	0.581	0.639			7	5	10	35	70
107	Eosinophil count	R, Q	-	-	-					7/3	0	15	0	35
38	Color discrimination	$\overline{F}$	-	-	-					7/14	10	15	5	7
19	Total body water	T	-	-	-					1/2	30	60	15	30
53	GI absorption test	E	-	-	-					7/30	15	45	3	10
40	Tone detection discrimination	$\overline{C}$	-	-	-					1	15	0	15	0
99	(Tidal volume), respiration rate	D	-	-	-					14	0	(see EKG)	0	0
61	Minute Volume, inspiration and expiration	D	-	-	-					1	5	10	5	10
42	Stereognosis	$\overline{N}$ Checklist	1.0 -	0 -	0.012 -	0.015	0.015			1 7	10 0	0 0	10 0	0 0
23	Venous pH (pCO_2 and pO_2)	A-1	17.0	20.0	0.40	0.500	0.500			1	0	15	0	15
44	Detection of linear acceleration	F	-	-	-					7/3	10	10	23	23
51	Serum electrolytes (NA, K)	A, E, F, G, I	-	-	-					1	0	20	0	20
46	Detection of vibration	$\overline{O}$	1.5	10.0	0.035	0.044	0.044			1	10	10	10	10
See 51	Urine electrolytes (NA, K) urine pH	A, E, F, G, I	-	-	-					1	0	20	0	20
84	Blood plasma proteins fraction	A, E, F, G, I	-	-	-					1	0	20	0	20
48	Hand manipulation	$\overline{F}, \overline{G}, \overline{E}, \overline{E}, \overline{T}$	7.5	1.0	0.139	0.161	0.161			1	25	30	25	30
109	Serum osmolarity	K	-	-	-					1 7	0 0	20 20	0 0	20 140
97	Heart sounds (phonocardiogram)	A-2	0.5	0.02	0.0058	0.0072	0.0144			1	7	14	7	14
50	Finger manipulation	$\overline{F}, \overline{U}$	2.0	0	0.035	0.044	0.044			1	20	25	20	25
147	Gas formation and passage	Checklist	-	-	-					14	0	2	0	28
52	Association (memory)	$\overline{F}$	-	-	-					7/3	15	0	35	0
140	Mucosal integrity	Checklist	-	-	-					1	2	2	2	2
115	Joint motion (range), bone pain	Checklist	-	-	-					7	0	2	0	14
54	Deductive reasoning	$\overline{E}$	-	-	-					7/14	60	60	30	30
See 61	Alertness, incidence of sleepiness	Y, checklist	-	-	-					7/4	30	40	52	70
142	Skin thickness	Calliper	-	-	-					1	2	2	2	2
56	Recording	$\overline{B}$	-	-	-					7/3	0	30	0	70
111	Blood urea nitrogen (BUN)	A, E, F, G, I	-	-	-					1	0	5	0	5
58	Guided performance	$\overline{B}$	-	-	-					1	0	30	0	30
17	Comp. blood count (RBC, WBC, DIFF, PLATELET EST)	R, Q	-	-	-	0.250	0.250			7/3	0	45	0	105
146	Chest circumference	O	-	-	-					7/14	5	5	2	3
60	Problem solving	$\overline{V}$	-	-	-					7/14	30	0	15	0
141	Breath holding time	N	-	-	-					1	3	0	3	0
62	Handling mass	$\overline{B}$	-	-	-					1	10	15	10	15

Table 18. Total Measurement Package (Cont)

Identification	Measurement	Device	Weight Item	Power (Watts)	Item	Margin		Cum. Vol.	Work Space	Freq. (No. /Week)	Duration (Min)		Time/Week (Min)	
						Storage	Spare				Subject	Observer	Subject	Observer
						Volume (Cubic Feet)								
98	Cardio pulmonary symptoms dyspnea and chest pain	Checklist	-	-	-					7	0	0	0	0
120	Serum ATP	A, E, F, G, I	-	-	-					1	0	15	0	15
64	Reading	$\overline{F}$	-	-	-					7/14	10	0	5	0
100	Bleeding time	B, Q	-	-	-					1	10	10	10	10
144	Liver size	Checklist	-	-	-					1	5	5	5	5
66	Stereopsis	$\overline{F}$	-	-	-					1	5	10	5	10
See 91	Clonus with ATR's	-	-	-	-					1	-	-	-	-
121	Retinal examination	Z	2.0	10.0	0.052	0.060	1.20			1	10	10	10	10
69	Writing	$\overline{V}$	-	-	-					1	5	0	5	0
103	Visual fields evaluation	$\overline{M}$	-	-	-					1	15	15	15	15
71	Leg Manipulation	$\overline{F}, \overline{T}$	-	-	-					1	10	15	10	15
See 16	Proprioception test	$\overline{F}, \overline{T}$	-	-	-					1	5	5	5	5
127	Urinary 17-KGS	A, E, F, G	-	-	-					1	0	20	0	20
73	Inductive reasoning	$\overline{V}$	-	-	-					1	30	0	30	0
108	Serum catecholamine	AERFI	-	-	-					-	-	-	-	-
130	Color skin, nails, mucosm	Checklist	-	-	-					7	5	5	35	35
75	Estimate of volume of space	Checklist	-	-	-					1	10	15	10	15
134	RBC uptake I_{125}	T, I	-	-	-					7/20	10	20	3	7
145	Pulse wave velocity	D	-	-	-					1	10	10	10	10
77	Time perception	$\overline{E}$	-	-	-					1	10	0	10	0
136	Incidence of aerotitis media	Z	-	-	-					1	10	10	10	10
79	Sound localization	$\overline{W}$	0.1	0	0.001	0.001	0.001			1	10	10	10	10
See 17	Reticulocyte count	Q	-	-	-					7/3	0	15	0	35
81	Tone duration	$\overline{C}$	-	-	-					1	15	0	15	0
112	Visual illusion evaluation	Checklist	-	-	-					7	2	0	14	0
83	Cue abstraction (complex stimulation discrimination)	$\overline{F}$	-	-	-					1	15	0	15	0
126	Color vision	X'	0.1	-	0.01	0.012	0.012			1	10	10	10	10
85	Detection of touch	$\overline{K}$	20.0	80.0	1.000	1.250	2.500			1	15	20	15	20
132	Heart movement force (ballistocardiogram)	B, C,	2	10.0	1.0	1.25	1.375			1	10	15	10	15
65	Autonomic hyperactivity (incidence of perspiration)	Checklist	-	-	-					7/3	0	2	0	5
87	Texture discrimination	$\overline{V}$	0.5	0	0.003	0.004	0.004			1	10	10	10	10
See 65	Autonomic hyperactivity (incidence of salivation)	Checklist	-	-	-					7/3	0	2	0	5
88	Tone pattern discrimination	$\overline{C}$	-	-	-					1	10	0	10	0
119	Clotting time	Q	-	-	-					1	10	10	10	10
124	Prothomein time		10.0	10.0	0.25	0.312	0.312			1	10	10	10	10
90	Detection of motion (auditory)	$\overline{W}$	-	-	-					1	5	5	5	5
92	Olfaction	$\overline{Z}$	3.0	0	0.174	0.217	0.217			7/14	15	20	8	10
See 29	Detection of heat and cold	$\overline{AA}$	-	-	-	-	-			1	10	10	10	10
See 29	Detection of pain	$\overline{BB}$	0.5	0	0.003	0.004	0.008			1	5	5	5	5
45	End expiratory CO_2, O_2	Polarographic mass spectrograph								7/3	5	10	12	23

Table 18. Total Measurement Package (Cont)

Identification	Measurement	Device	Weight Item	Power (Watts)	Item	Margin: Storage	Margin: Spare	Cum. Vol.	Work Space	Freq. (No. /Week)	Duration (Min): Subject	Duration (Min): Observer	Time/Week (Min): Subject	Time/Week (Min): Observer
						Volume (Cubic Feet)								
See 21	Urine bacteria	R	-	-	-					7/3	0	0	-	-
See 21	WBC, urine	Q	-	-	-					7/3	0	0	-	-
See 21	RBC, urine	Q	-	-	-					7/3	0	0	-	-
74	PSP	I, J	-	-	-					1	10	30	10	30
110	O_2 uptake in RBC	A-1	-	-	-					1	0	30	0	30
39	Serum (A and PO_4 and urine (A and PO_4)	A, E, F, G, F A, E, F, G, I	- -	- -	- -					1 1	0 0	30 30	0 0	30 30
143	Venous distention	Checklist	-	-	-					14	5	5	70	70
63	Pulse rate	N	-	-	-					7	2	2	14	14
106	Capillary fragility tourniquet test	B	-	-	-					1	5	5	5	5
59	Blood sugar (and urine)	A, E, F, G	-	-	-					7/3	0	20	0	47
131	BSP (see 137) liver function	I, J	-	-	-					1/2	10	30	5	15
137	Serum billirubin	see 131 above								-	-	-	-	-
95	Muscle size	O	-	-	-					1	12	12	12	12
9	(Response to stress) centrifuge test	(No information)								-	-	-	-	-
139	Protein assimilation	A, E, F, G, I	-	-	-					1	2	21	2	21
129	Heart rate (see 132)	B, C	-	-	-					1	1	3	1	3
68	Cortical activity (see 61)	Y	-	-	-					1/2	14	28	7	14
134	Tremor (see 47)	W	-	-	-					1	7	14	7	14
72	Tubular reabsorption test	Q	-	-	-					1/2	2	2	1	1
76	Glomerular filtration test	A, E, F, G, I	-	-	-					1/2	7	14	4	7
82	Expiration inspiration force (flack test)	D	-	-	-					1	4	7	4	7
93	Urine and fecal nitrogen	Probably will not be included												
105	Ocular tonometry	A-4	2.0	1.0	0.3	0.375	0.375			1/3	7	7	2	2
113	Hearing (see 10)	$\overline{G}, \overline{H}$	-	-	-					-	-	-	-	-
117	Fecal floral sampling (see 53)	E	-	-	-					once/3 mo.	5	0	0	0
118	RBC survival	T	-	-	-					once/2 mo.	30	60	1	1
122	Urine catecholamine	A, E, F, G, I	-	-	-					1	0	7	0	7
123	Serum 17, KG, steroid	A, E, F, G, I	-	-	-					1	0	7	0	7
128	Energy requirements	Checklist	-	-	-					7	5	0	35	0
133	Urine urea	A, E, F, G, I	-	-	-					1	0	7	0	7
138	Sedimentation rate	(No technique)												
TOTALS			890.0				50.27						1996	3081

Workspace Legend

O_{S-1} - Observer, or S_{S-1} - Subject (standing) - 38 cubic feet

O_{S-2} - Observer, or S_{S-2} - Subject (seated) - 33 cubic feet

S_a - Subject seated in accelerator device - 90 cubic feet

EXTENDED APOLLO - CONCEPT I

SYSTEM DESCRIPTION

The Apollo currently under development may be modified to provide an extended orbital laboratory mission capability to determine (quickly and at low cost) man's ability to survive extended zero G exposure and to provide behavioral and biomedical experimental capability. This concept consists of a modified Apollo spacecraft to be operational in the 1967 to 1970 time period. The vehicle will be injected into a nearly circular orbit of approximately 200 nautical miles. The laboratory configuration consists of the command module only with the service module being utilized for storage of subsystem equipment and supplies such as metabolic oxygen, nitrogen, fuel, and batteries.

SYSTEM PARAMETERS

The minimum Apollo concept uses a two-man crew and is designed for a one-year mission. Because of the extremely small crew size, both crew members must be capable of piloting the spacecraft. An analysis of crew requirements indicates that approximately three hours per man per day will be necessary to maintain reliable operation of the space vehicle with the remaining time used for experimental duties, sleeping, food preparation and consumption, personal hygiene, and recreation. The amount of time the crew members can devote as subject and/or experimenter/observer will vary upward from five hours per man per day depending on the work/rest schedule employed.

The capability of resupply and crew rotation is included in the system design. The crew rotation schedule is 120 days. The resupply concept is a rendezvous with the resupply spacecraft and a transfer of the crew. The original vehicle will return to earth, and the second vehicle will continue the orbital mission. This method of resupply demands that each vehicle be essentially self-sufficient allowing a convenient method of returning experimental data periodically.

The total pressurized volume in the Apollo command module is 366 cubic feet, but a great deal of this volume is consumed by equipment and crew couches. The current configuration allocates 26 cubic feet for experimental equipment leaving approximately 80 cubic feet for work space.

The Apollo under development includes a pure oxygen atmosphere, but the extended Apollo laboratory mission will use a mixed oxygen/nitrogen atmosphere with an atmospheric level of 7 psia. The CO_2 partial pressure will be maintained at 0.147 psia (7.6 mm Hg) and the O_2 partial pressure at 3.1 psia.

The power system has a power source of solar cells with silver cadmium batteries for power storage. The available power forms will be unregulated dc, regulated dc, and regulated ac with the preferred form being unregulated dc. The power system capacity for launch and ascent is 1692 watts continuous, 2619 watts average, and 4232 watts high. During the orbited phase, the capacity is 679 watts continuous, 1121 watts average, and 2531 watts high. The system was designed to accommodate an average experimental requirement of 8.4 to 9.3 watts average continuous with peaks of 550 watts for 15 minute durations occurring 12 to 15 times monthly. Experimental requirements varying markedly from this (such as 200 watts average continuous) would require redesign of the power system. However, experimental requirements up to 50 to 75 watts average continuous could be accommodated by the present system. Acceptable short term peak loads on regulated dc and regulated ac are limited only by size of the inverters, and unregulated dc is relatively unlimited.

The Apollo laboratory will be launched by a Saturn CIB having a payload of 32,500 pounds. The weight of the initial vehicle as it leaves the booster is 23,691 pounds. The weight of the command module and its contents for both the original vehicle and the resupply vehicles is 10,700 pounds. The limited weight of the command module is approximately 10,000 pounds so that reentry and abort capability is assured. The allocation for experimental equipment is 675 pounds.

The constraints of the extended Apollo systems require that the data system provide capability for ground tracking, voice, television, telemetry data transmission, command-up link, rendezvous radar, displays, data recording, and processing. The data systems summary is included in Table 19. Because there is little difference in the system capabilities for the various concepts of the extended Apollo, the one illustration is used to summarize the system for all concepts.

Two other characteristics of the Apollo laboratory Concept I could impose a constraint on the experimental program. Because of the extremely small volume, it will not be possible to have any isolation of experimental work. This might lead to distraction to the experimental program due to the interference of other on-board activities. In addition, the crew members will be required to perform extra-vehicular maneuvers when transferring from one vehicle to another during the crew rotation/resupply. Further,

Table 19. Extended Apollo Laboratory Data Systems Summary

Earth Orbital				
Channel	Modulation Technique	Frequency (mc)	S/C Antenna	Transmitter Power (watts)
Ground to S/C C-band ranging	PAM	5690	C-band	250 kw
S/C to ground C-band ranging	PAM	5765	C-band	375
Ground to S/C VHF voice	AM	296.8 259.7	VHF scimitar	100
S/C to ground VHF voice	AM	296.8	VHF scimitar	5
S/C to ground T/M 51.2 kbps	PCM/FM	237.8	VHF scimitar	10
S/C to ground TV*	FM	220	VHF scimitar	10
Recovery Communications				
A/C to S/C VHF voice	AM	296.8	VHF recovery	10
S/C to A/C VHF voice	AM	296.8	VHF recovery	5
S/C to A/C VHF beacon	PAM CW	243 243	VHF recovery VHF recovery	100 2
S/C to GOSS HF voice	SSB AM	8 to 16 8 to 16	HF recovery	
Crew - C/M - Laboratory Communications				
S/C to laboratory voice	AM	296.9	VHF scimitar	5
Laboratory to A/C voice	AM	259.7	VHF scimitar	5
S/C to crew voice	AM	296.8	VHF scimitar	5
Crew to S/C voice	AM		VHF scimitar	

*Concepts II and III only

the extremely small volume resulting in decreased crew activity could have physiological effects on the crew members that would be confounded with weightlessness effects. A summary of system parameters of Apollo laboratory Concept I appears in Table 20.

Table 20. Apollo Laboratory Concept I (Summary of System Parameters)

Mission duration	One year
Crew size	Two men
Crew rotation/resupply schedule	120 days
Volume Total pressurized volume Experimental equipment Work space	 366 cubic feet 26 cubic feet 80 cubic feet
Power availability Amount-average, continuous Presently Capacity Amount-peak Presently Capacity Forms Available Preferred	 8.4 to 9.3 watts 50 to 75 watts 550 watts x 15 minute duration x 15/month Relatively unlimited - short term Unregulated dc, regulated dc Regulated ac Unregulated dc
Atmosphere Content Pressure level Partial pressure O_2 CO_2	 Mixed oxygen/nitrogen 7 psia 3.1 psia 0.147 psia (7.6 mm Hg)
Data systems	See Table 20
Special constraints	Only one compartment, extravehicular activity possible confounding of experiments due to crew inactivity

SPECIAL SIGNIFICANCE OF APOLLO I

In the analysis performed on configurations, Apollo Concept I has received considerable attention. There are two reasons for this: because Apollo Concept I represents a minimal volume and crew and can be taken then as a base point for considering minimal packages and because of the findings of the present study with respect to weight, power, and volume constraints. These constraints are such that the restrictions set by basic systems parameters are severe only in Apollo Concept I. For this reason, it becomes important to examine Apollo Concept I for possibilities of achieving not only an optimal system for this station but a realistic one as well.

MEASUREMENT SYSTEM

The extended Apollo I configuration can accommodate equipment to perform the following measurements:

1. Measurements included in the safety package (Table 16)

2. Measurements included in the minimum weightlessness package (Table 17)

3. Measurements that use the same equipments required for the foregoing measurements are as follows:

Identification	Measurement	Time
30	Learned procedures	140
36	Brightness discrimination	45
38	Color discrimination	12
52	Association	35
56	Recording	10
66	Stereopsis	15
76	Glomerular filtration test	21
80	Serum alkaline phosphatates	20
58	Guided performance	30
122	Urine catecholamine	7
123	Serum 17 kilograms steroid	7
133*	Urine urea	7
117	Fecal flora sample	0
108	Serum catecholamine	0
60	Problem solving	15
62	Handling mass	25
120*	Serum ATP	15

Identification	Measurement	Time
127*	Urine 17 kilograms steroid	20
139*	Protein assimilation test	23
64	Reading	5
69	Writing	5
82	Expiratory-inspiratory force	11
145*	Pulse-wave velocity	20
73	Inductive reasoning	30
81	Tone duration	15
72	Tubular readsorption	2
77	Time perception	10
88	Tone pattern discrimination	10

Check list items include the following:

Identification	Measurement	Time
128*	Energy requirements	35
112	Visual illusion evaluation	14
65	Autonomic activity	5
144*	Liver size	10
75	Estimate of volume of space	25
147*	Gas formation and passage	28
140	Mucosal integrity	4
115*	Joint motion range, bone pain	14
142	Skin thickness	4

The total time required to perform the foregoing measurements is 693 minutes per week. By elimination of measurements marked with an asterisk, it is possible to remain within a time limit of 525 minutes per man per week that is available after performance of measurements listed in the safety package and the minimum weightlessness package.

The following criteria apply to selection of measurements for the minimum Apollo Concept I. The space station should not be orbited with human occupants without information provided by the safety package. To serve a useful purpose, the space station measurement system must provide a certain minimum amount of information about the effects of weightlessness over prolonged periods of time.

SPECIAL PROBLEMS

The Concept I Apollo internal space is severely taxed by the equipment required for the safety package and the minimum weightlessness

package, and consideration of additional measures requiring space is not warranted. It is estimated that approximately 250 cubic feet (4 by 9 by 7 feet) of workspace is required to adequately perform the measurement listed in the two packages. Approximately 80 cubic feet (6.5 by 2.5 by 5 feet) is available for this purpose in the minimal Apollo. While it cannot be absolutely stated that it is impossible to perform work requiring 250 cubic feet in a space of 80 cubic feet, such a situation is marginal and not conducive to optimum performance effectiveness. Shortening of the list would not appreciably alleviate the cramped workspace situation because approximately the same amount of freedom of movement is required for a few measurements as is required for a large number of measurements (assuming that the physical size of the equipment is not a factor and that the measurements are performed sequentially by the same number of people).

The time required to perform the measurements listed in the two packages is approximately 2 hours subject time and 3.8 hours observer time per day or 5.8 hours per day per man. When added to the 3 hours per man scheduled for system operation, checking, maintenance, etc., 1.2 hours are allowed for other measurements for which a capability exists.

To accomplish all the measurements for which a capability exists in the Concept I Apollo package requires more time than is available. These measurements must, therefore, be initially selected on a priority basis until such time as it may become apparent that it is not necessary to perform measurements as frequently as originally specified.

Flight Duration

The flight duration of the minimum Apollo mission will have at least three implications for the biomedical and human factors measurement program. These implications refer to the effects of confinement, logistic curtailment of measurement, and limitation on the relevance of measurement results to extended mission.

The effect of confinement for an extended time within the relatively small volume of the command module may have bearing upon the measurement program in two ways: degradation of measurement task performance and confusion of biomedical phenomena with "functional" effects of confinement. There are grounds for suspecting that extended confinement within a small space leads to performance decrement. This performance decrement, with special reference to measurement performance, could prove to be a serious problem in obtaining valid biomedical and human factor experimental data over an Apollo flight of weeks or months. However, even though measurement task performance was not significantly degraded, other physiological and behavioral effects possibly resulting from extended confinement might mask or be confused with the effects of weightlessness.

If the logistics base of the biomedical and human factor measurement program for interim space stations is 90-day resupply and personnel rotation period, the equipment and characteristics of the minimum Apollo program without resupply or crew rotation provisions become different from other space station programs. The equipment constraints associated with supply limitations will have an increasingly curtailing effect upon range and frequency of experiments as flight duration increases. Furthermore, the lack of crew rotation capability precludes the exposure of crew members of the same crew to different periods of zero G.

An anticipated byproduct of the proposed space station crew, biomedical, and performance measurement program is extrapolation of results to long-term missions. If it is to be hypothesized that the effects of long-term exposure to zero G will be qualitatively different from those of short-term exposure, it seems doubtful that the duration of the minimum Apollo flight can be made sufficient to test this hypothesis.

SYSTEM TASK/MEASUREMENT TASK INTERACTION

In the determination of manpower available for measurement activities, it was arbitrarily assumed, for purposes of analysis, that a 24-hour period can be equally divided into three 8-hour blocks: sleeping, assigned duty, and free time. While there is some evidence to indicate that less than the customary 8 hours sleep may be sufficient under conditions of weightlessness, it was decided to follow the conservative approach in arriving at a determination of manpower availability.

The 8-hour block designated free time includes 1 hour for eating, 1 hour for personal hygiene, 2 hours for physical and mental recreation, 4 hours that might be considered as optional. It is felt that the 4 hours set aside for eating, personal hygiene, and recreation must not be encroached upon. However, reported experience in such operations as radar picket ships suggests that some crew members will volunteer more than the required assigned duty time to useful mission activities. It is estimated, therefore, that 50 percent of the optional 4 hours can be counted toward mission activities, and 50 percent can be counted as relaxation or nonproductive time. The bonus 2 hours derived in this manner is considered as time that crew members would be available to act as subjects, which effectively increases the total duty time to 10 hours per day.

Within the third 8-hour block (assigned duties) 5 hours are allocated to measurement duties and 3 hours are allocated to system duties. A breakdown of man-hours in accordance with the foregoing is summarized in Table 21.

Table 21. Man-Hour Breakdown (General)

Activity	Hours/ Man/ Day	Hours/ Man/ Year	Man-Hours/System			
			14-Day Orbit Apollo	100-Day Modified Apollo	MORL	MOSS
Sleep	8	2920	336	1600	11,680	61,320
Eating Breakfast (15 min) Lunch (15 min) Dinner (30 min)	1	365	42	200	1,460	7,665
Personal Hygiene Toilet (10 min) Shaving (15 min) Bathing (10 min) Misc (haircut) (25 min)	1	365	42	200	1,460	7,665
Leisure Time Physical recreation (1 hr) Mental recreation (1 hr)	2	730	84	400	2,920	15,330
Optional Time	4	1460	168	800	5,840	30,660
Mission activities (2 hr)			(84)	(400)	(2,920)	(15,330)
Relaxation (2 hr)			(84)	(400)	(2,920)	(15,330)
Assigned Duties	8	2920	336	1600	11,680	61,320
Measurement activities (5 hr)			(214)	(900)	(7,200)	(40,880)
Systems management (3 hr)			(8)			(2,920)
Communications (3 hr)			(20)			(2,920)
Monitoring (3 hr)			(60)			(8,760)
Maintenance (3 hr)			(30)			(2,920)
Food preparation (3 hr)			0			(2,920)
Totals	24	8760	1008	4800	35,040	183,960

The three hours per day per man required for system duties were arrived at for a three-man crew by tabulating available task analysis data for the Apollo 14-day earth orbit and by computing percentages of time spent in the various activities. Tables 22, 23 and 24 present these data to the extent they were available for system operation tasks, scientific measurement tasks, and personal hygiene and feeding tasks. While the data at this stage of the Apollo development are still incomplete, it was possible to estimate an hours breakdown as shown in parentheses in Table 4-3. Food preparation was assigned 0 hours because for a small space station this will be an individual responsibility and will be buried in the time allotted for eating.

Selected Function	Total No. Times Performed	No. of Task Elements	Percent of Total No. Task Elements (1260)	Estimated Performance Time (sec)	Total Time to Perform (sec)
Monitor Spacecraft System Parameters					
Seat 2	8	54		2	864
Seat 3	73	68		2	9,928
Seat 1	60	2		2	240
Seat 1	22	64		2	2,816
EPS	1	1		2	2
EPS	1	1		2	2
	5	4		2	40
	6	12		2	144
Total	176	206	16		14,036
Perform Maintenance					
Hourly	32	61		2	3,904
6-hour	4	61		2	488
8-hour	3	132		2	792
Scheduled	2	2		2	8
24-hour	1	130		2	260
Total	42	386	31		5,452
Set-up Spacecraft System for Operations					
Set-up for orbit	1	18		2	36
Adjust crew system	1	2		2	4
(seat 1)					
(seat 2)	1	1		2	2
(seat 3)	1	1		2	2
Total	4	22	1.7		44
Communicate to GOSS	34	2			
Total	34	2	0.2		

Table 23. 14-Day Earth Orbit-Task Analysis Data: Scientific Measurements Tasks

Selected Function	Total No. Times Performed	No. of Task Elements	Percent of Total (1260) No. Task Elements
Perform medical monitoring	22	3	
Subject for medical monitoring	22	1	
Disconnect biomedical hookup	10	5	
Connect biomedical hookup	10	2	
Perform scientific observation	-	-	
Perform scientific observation	1	22	
Perform observations	1	1	
Perform scientific observation	2	2	
Perform scientific observation	1	1	
Perform scientific observation	1	1	
Total	71	39	3.0

Table 24. Apollo 14-Day Earth Orbit Task Analysis Data - Personal Hygiene and Feeding Tasks

Selected Function	Total No. Times Performed	No. of Task Elements	Percent of Total (1260) No. Task Elements
Doff spacesuit	12	15	
Assist doff spacesuit	12	1	
Don spacesuit	12	18	
Assist don spacesuit	12	1	
Obtain and prepare food	16	9	
Food intake	26	10	
Perform personal hygiene	23	9	
Exercise	7	1	
Total	120	64	5

Estimate of hours breakdown for a large space station represented by the MOSS and computed on the basis of a 21-man crew were based on prior S&ID advanced system studies of large orbiting space stations. Previous studies indicate that a six-man crew would be adequate to operate and maintain a large space station. Estimates shown in parentheses (Table 17) are for a seven-man crew consisting of a space station manager, a communications specialist, three systems specialists to provide a capability for continuous systems monitoring, a maintenance specialist, and a food and sanitation specialist. These seven crew members would have no other duty than their assigned specialties. Figure 25 shows that there is a gain in efficiency of crew utilization, from the standpoint of a greater percentage of hours available for measurement activities, for a large crew assigned on a basis of job specialization over a small crew which must share equally in all duties. Figure 26 shows that from the over-all 24-hour cycle, the percentage of time required for system activities for a small station does not vary by more than 0.5 percent from that of a large station. Since these estimates were derived from independent sources, it is felt that this tends to substantiate their validity.

Transcriptions of MA-6 flight communications have been analyzed in an attempt to determine the amount of time Mercury astronauts were involved in various activities. For over half the time of his three-orbit flight, John Glenn was either talking or listening to ground stations. On only two occasions did more than one minute lapse without some form of communication: once between 4 hours and 7 minutes and 4 hours and 13 minutes when radio contact was apparently lost and a second time between 4 hours and 15 minutes and 4 hours and 18 minutes when Glenn was maneuvering into retro attitude. While it was intended for this particular flight that a considerable amount of information be reported verbally, it appears that the burden of system duties was not such to prevent the astronaut from accomplishing this aspect of the mission with a high degree of success. Time thus occupied on the Mercury flight can be assumed to be available to devote to the measurement package on the space station insofar as communications with ground stations will be much more limited.

Various methods of scheduling hours allotted in accordance with Table 7 were studied in an attempt to maximize availability of crewman to attend to measurement duties. Figure 27 depicts four alternative concepts of work-rest cycles for a two-man crew. Concept I provides for the greatest amount of flexibility in arranging crew duty and recreation hours to maximize observer-subject interaction. However, this concept was rejected because it would result in the system going unattended for as much as 8 hours. The greatest constraint to arranging work-rest cycles is a requirement for periodic system monitoring and/or checks. Two ways to provide a capability for frequent system checks are to stagger sleep periods as shown in Concept II or to break sleep cycles into shorter periods as

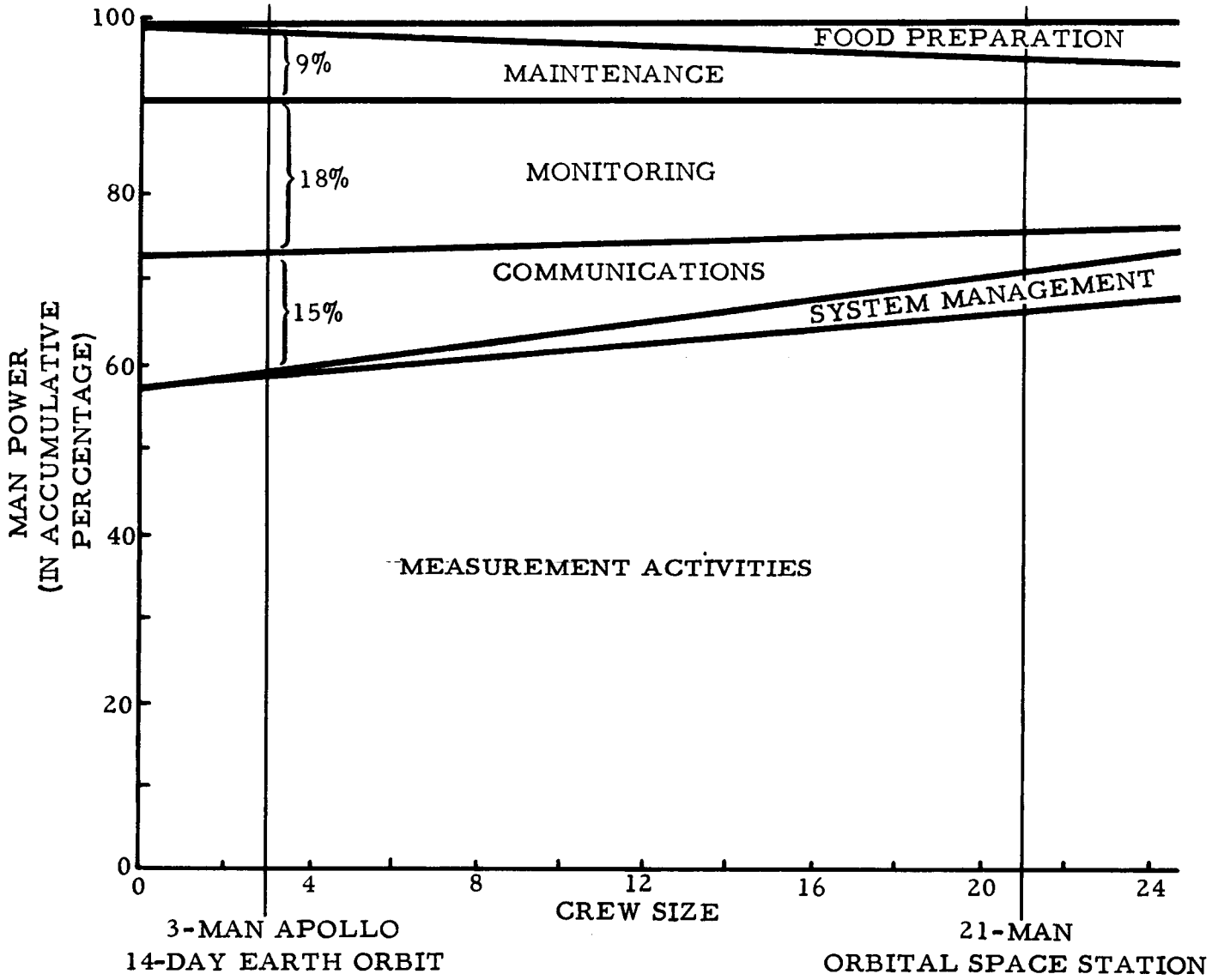


Figure 25. Manpower Requirements as a Function of Activity Versus Crew Size. (On-Duty Time Only)

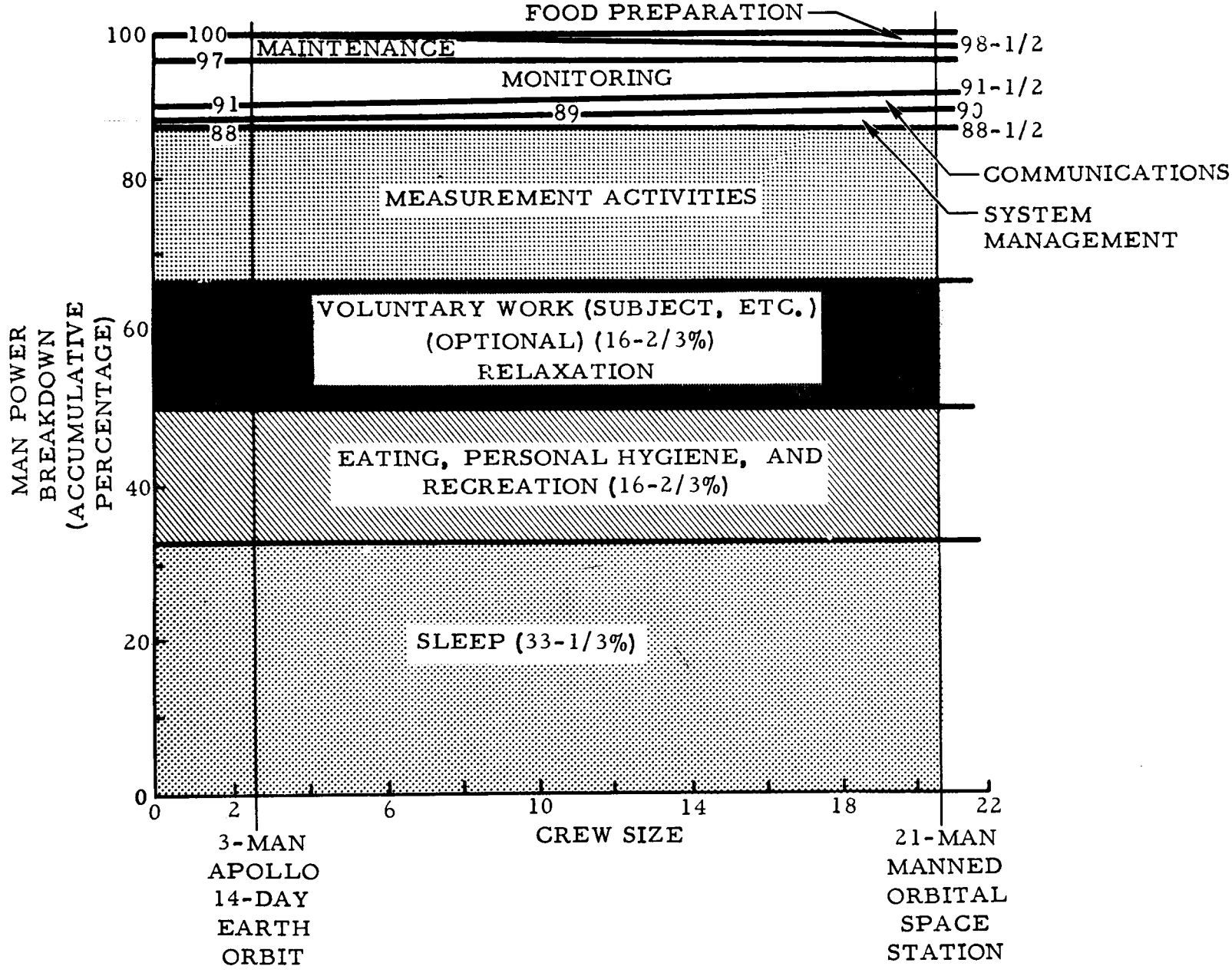


Figure 26. Percentage Breakdown of Man-Hour Allocations to

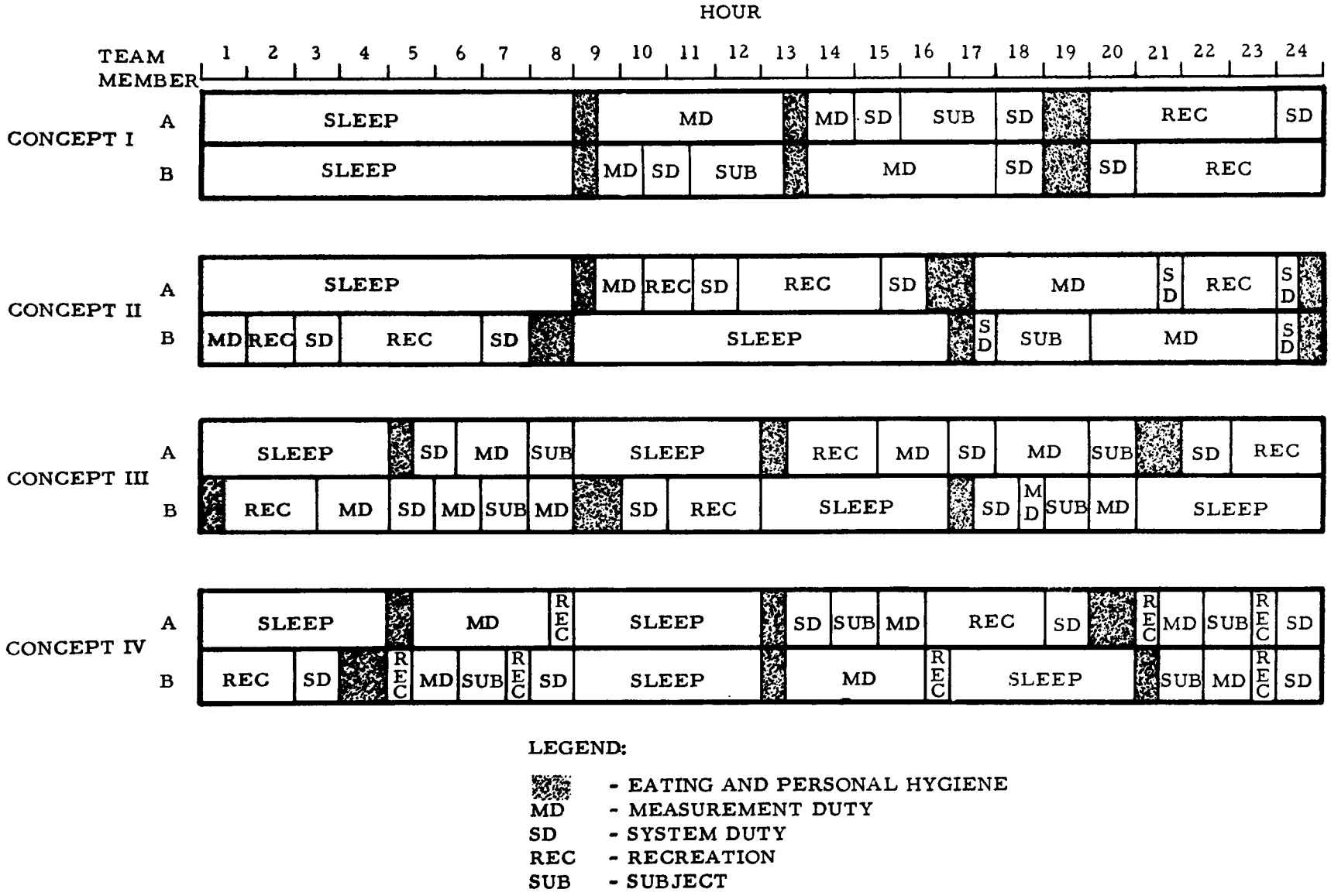


Figure 27. Alternative Work-Rest Cycles for 2-Man Crew

shown in Concepts III and IV. The staggered sleep periods restrict the freedom of matching team members in terms of availability of subject and observer and recreation time. It was therefore decided to adopt a compromise schedule (Concept IV) that maximizes the advantages offered by the two alternatives. Table 25 summarizes the comparative advantage of the alternative concepts.

Table 25. Comparison of Alternative Concepts for 2-Man Crew Work-Rest Cycles

Item	Hours Per Concept			
	I	II	III	IV*
Team measurements	6	5-1/2	5-1/2	6
Team system checkout	1	1/2	1	1
Task measurement	2	1	1	1-1/2
Individual measurement	0	2	3	0
System unattended**	8	3-1/2	6	4-1/2
Shared off-duty time	5	1	0	2-1/2

*Recommended concept
**Elapsed time between system checks

Figure 28 depicts work-rest cycles for 3-, 4-, and 6-man crews.

INTERFACES

Table 26 summarizes the interacting relationships of the various areas of consideration applicable to the minimum extended Apollo as a space station for the biomedical and human factors crew measurement program. The areas of consideration whose interfaces are summarized include measurement systems, power, weight, item volume, crew characteristics, time (measurement time), workspace, flight duration, and certain special considerations. Each area of consideration is examined with respect to how it may influence and how it may be influenced by every other area. Where, in the matrix of Table 26, an area of consideration coincides with itself, a statement of pertinent facts (e.g., weight, 1,000 pounds capability), is given for that area.

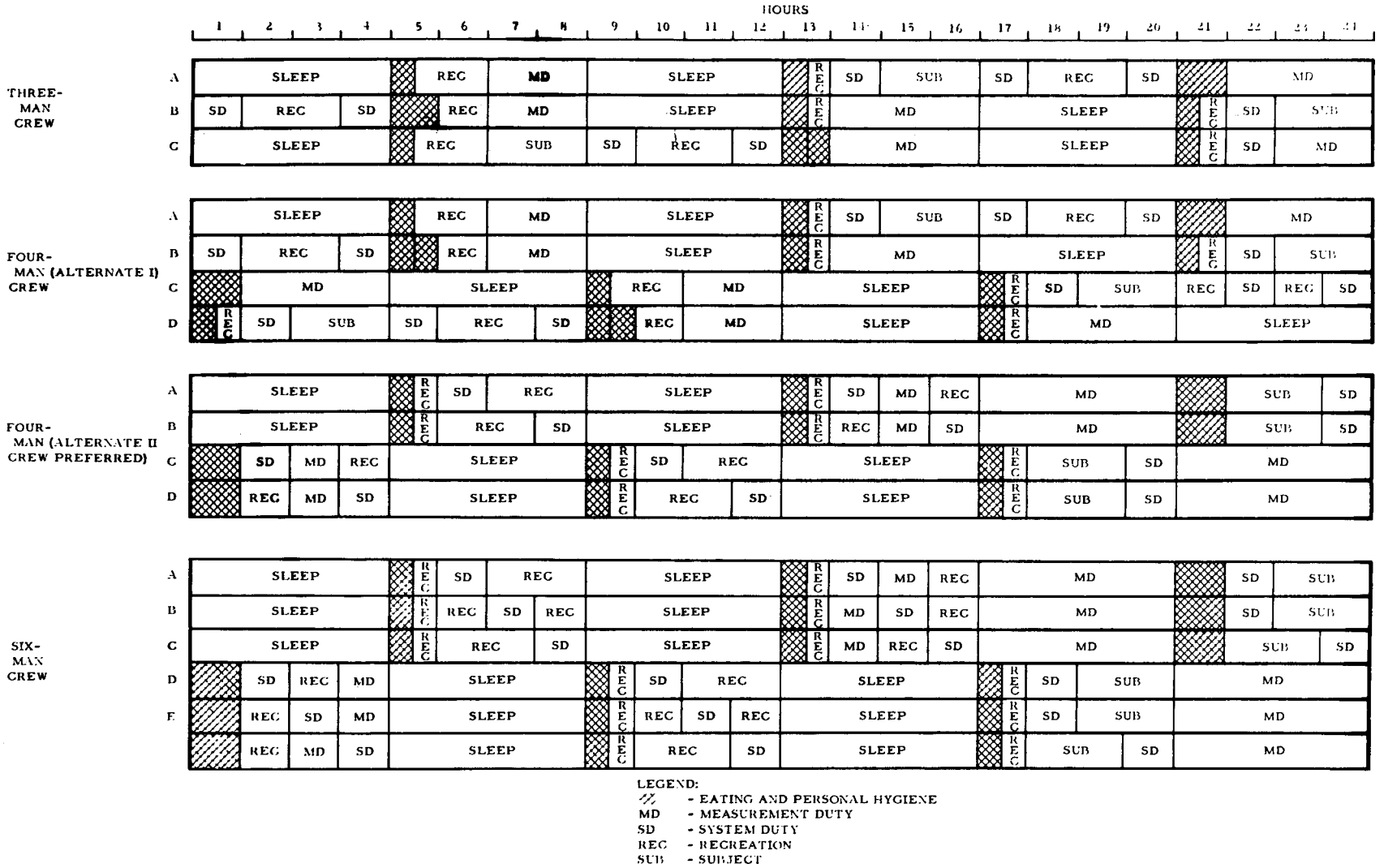


Figure 28. Work-Rest Cycles for 3-, 4-, and 6-Man Crews

Table 26. Interface Summary Extended Apollo I

Areas of Consideration	Measurement Systems	Power	Weight	Item Volume	Crew Characteristics	Time	Workspace	Flight Duration
Measurement system	Priority SP MWP Other	Utilizes over and above operational system requirements	Contributes to over and above operational system requirements	Dictates need of space, equipment use, and storage	Influences selection and training	Utilizes over and above all scheduled crew requirements	Utilizes for measurement task performance	Dictates minimum useful flight duration
Power	May influence Maximum item power Maximum item combination	550 watts maximum, 15 minutes, 15 times/month	Power requirements greater for heavier items	Power requirements greater for larger items	No significant interface	May limit concurrent item use	No significant interface	Limits flight duration if power unit replacement required
Weight	Limits Maximum item Number items	Heavier items require more power	1000-lb capability available	Heavier items larger	May impose requirement for handling training (mass)	No significant interface	No significant interface	May limit flight duration if influences orbit
Item volume	Dimensions of item, plus spares, plus storage for item and spares	Larger items require more power	Larger items heavier, storage volume a weight factor	26 cu ft available for measurement equipment	May impose requirement for storage access training	No significant interface	Portable items may affect utilization of workspace	No significant interface
Crew characteristics	Determine and determined by	No significant interaction	Should be a design factor in weight (mass) characteristics	Should be a design factor in volume characteristics	Two men representative of space craft crew population	Trained for efficiency in utilization of available measurement time	Severe anthropometric and measurement task performance constraints	May impose limits on confinement time feasible
Time	Limits cumulative measurement times and measurement schedule	Distribution of item power utilization in measurement schedule	No significant interface	No significant interface	Imposes requirement for measurement duty efficiency	Maximum 7 hours man/day measurement time	Time-sharing with other activities	No significant interaction
Workspace	Severe constraints of utilization of measurement items	No significant interface	No significant interface	Severe limitation on number of items in concurrent use	Imposes anthropometric and measurement task performance constraints	Severe constraints on space sharing in time	80 cu ft available for measurement tasks	Confinement effects may limit flight duration
Flight duration	Affects amount of data from measurement systems	May be limited by power unit replacement requirements	May be limited by weight influences or orbit	No significant interface	May generate confinement effects	No significant interaction	May generate confinement effects	Open
Special constraints	Confinement effects may confound results						Operational tasks may interfere with measurement tasks	

INTERIM STATIONS

The interim stations include a group of space station systems, such as the extended Apollo Concepts II and III and MORL, that have a similar capability. These stations are designed to have a minimum life of 1 year, and their crew sizes vary from three to six men. Although primarily zero-G concepts, the feasibility of providing artificial gravity backup is being investigated. They do not differ markedly from extended Apollo Concept I in weight or power allocations for the experimental program but do provide a substantially larger volume for experimental equipment and workspace.

SYSTEMS DESCRIPTIONS

Extended Apollo Laboratory - Concept II

This concept of the extended Apollo consists of a modified Apollo spacecraft docked with a laboratory module. The laboratory module is housed in the lunar excursion module interstage and is to be supported entirely by the Apollo spacecraft. The laboratory module contains three compartments: a recreation area, a laboratory area, and a storage area. The total pressurized volume of the laboratory module is 5620 cubic feet with an additional 366 cubic feet available in the command module. The major command-control center is located in the Apollo spacecraft. The sleeping provisions are also in the command module. This concept is designed to support a crew of three men and includes capability for crew rotation and resupply. Resupply and crew rotation are carried out by a second Apollo vehicle docking to a second docking port with the original modified Apollo returning to earth. Extravehicular activity will be required of the crew when transferring from the command module to the laboratory module. Although the modified Apollo spacecraft will be recoverable, the laboratory module will not. The system will be launched by a Saturn IB into a nearly circular orbit of approximately 200 nautical miles. The spacecraft will be operational in the 1967 to 1970 time period.

Extended Apollo Laboratory - Concept III

This concept is similar to Concept II with the exception that the laboratory is self-supporting. The three compartments in the laboratory module house a laboratory area, a command and control center, and a recreation area. As in Concept II, the sleeping quarters are in the command module. In Concepts II and III, the radiation shielded area, or storm cellar, is located in the command module.

Studies are being directed toward providing the extended Apollo laboratory with artificial gravity. The feasibility of rotating the configurations about some self-contained axis is being considered as is the possibility of connecting two Apollo spacecraft and spinning them about an axis centered between the two vehicles. In addition, a number of internal devices, such as a centrifuge or a linear accelerometer, are being studied for application to the Apollo laboratory system.

Manned Orbiting Research Laboratory (MORL)

MORL is designed to be launched into a 200- to 300-nautical-mile circular orbit by the Saturn I or IB and must be compatible with the dimensions of the launch vehicle. The MORL has been assumed to provide an internal living volume of 1500 to 2000 cubic feet depending upon the configuration. The configuration used in this analysis has a living volume of 2000 cubic feet. The system would be designed to support a crew of 4 to 6 men and to have a minimum lifetime of 1 year. The system design includes crew rotation and resupply. The feasibility of providing internal and/or external means of artificial gravity is being studied. Various radiation protection devices are also being studied including the storm shelter concept in which radiation shielding is provided for the section of the vehicle that contains the command center and the crew sleeping quarters (Figure 29).

SYSTEM PARAMETERS

Since small crews will be used in the interim space stations, a great deal of cross training will be required because all men must be capable of operating the vehicle and performing experimental functions. Analysis of the system requirements indicate that approximately seven hours per man per day will be available for measurement activities. If an odd number of crew men are used, there will be some difficulty scheduling the experimental work.

The capability of resupply and crew rotation is included in the systems designs, and the schedules have been established at 90 days for MORL and 120 days for both Apollo concepts. In all systems, the resupply/crew rotation process requires that the crew members make extravehicular maneuvers to get from the ferry vehicle into the laboratory systems.

The total pressurized volume assumed in the three systems emphasized ranges from approximately 2000 cubic feet (MORL) to 5620 cubic feet (Apollo concepts II and III). The volume available for experimental equipment and workspace in these configurations is considerably more than in the Apollo Concept I and can be anticipated to be an absolute minimum of 500 cubic feet. In addition, all of these systems are compartmentalized to offer some seclusion if desired for the experimental work.

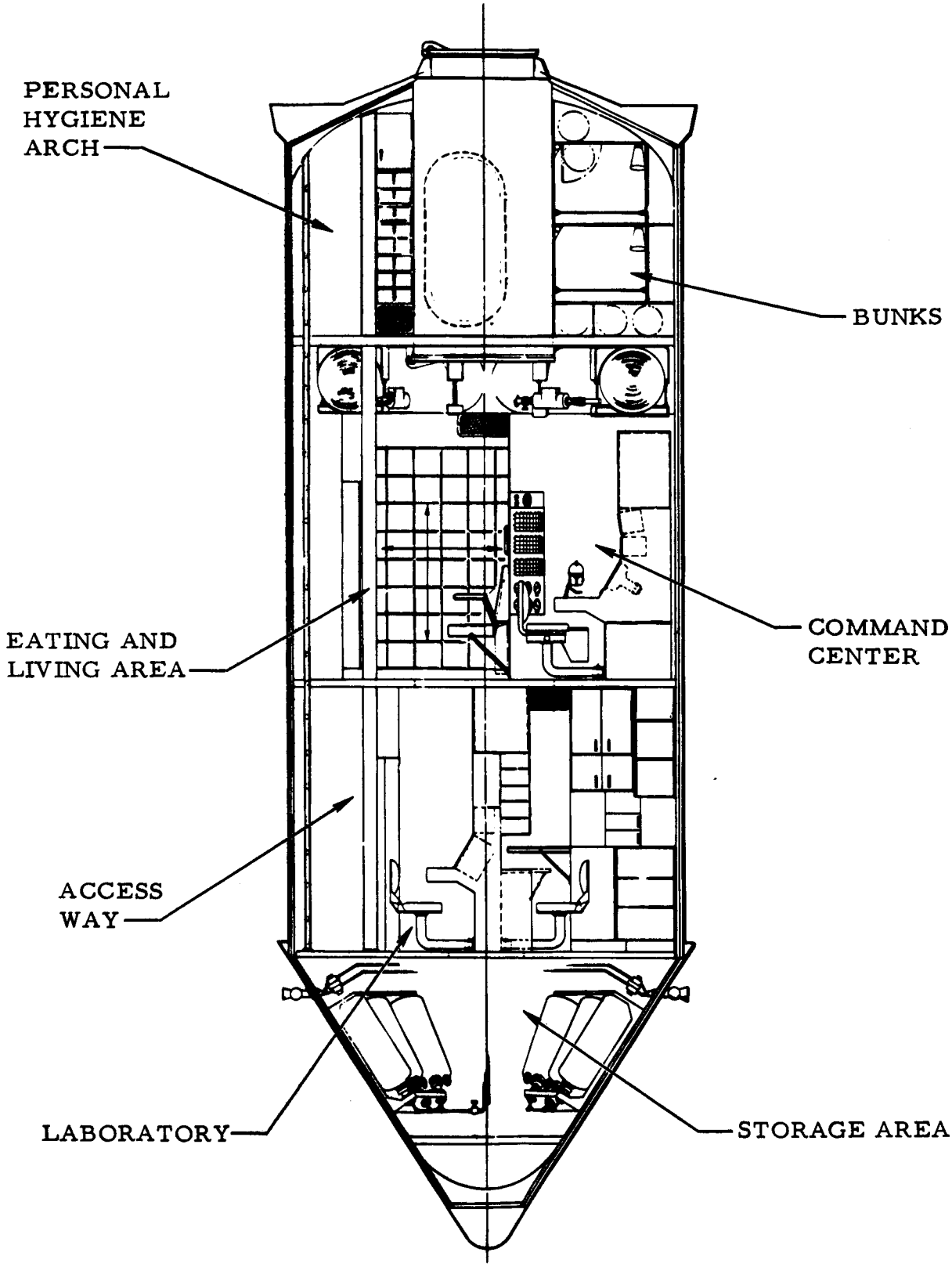


Figure 29. MORL Interior

The atmospheric composition and pressure levels for Apollo Concepts II and III will be the same as for Apollo Concept I, i.e., mixed gas (oxygen-nitrogen), 7 psia with pO_2 of 3.1 psia and pCO_2 of 0.147 psia (7.6 mm Hg). Although no current data regarding the atmospheric parameters for MORL have been available, it is anticipated that a mixed gas (oxygen-nitrogen) atmosphere will be used with a pressure level of approximately 10.0 psia and pO_2 of 160 to 190 mm Hg.

The power system to be used in the two Apollo concepts consists of solar panels as the power source and silver cadmium batteries for power storage. The power forms available will be unregulated dc, regulated dc, and regulated ac, with the preferred form being unregulated dc. In extended Apollo Concept II, the power system capacity during the orbital phase is 694 watts continuous, 1184 watts average, and 2456 watts high. For Concept III the capacity in the orbital phase is 968 watts continuous, 1539 watts average, and 3415 watts high. As in the extended Apollo Concept I, the systems were designed to accommodate an average experimental requirement of 8.4 to 9.3 watts continuous with peaks of 550 watts for 15-minute durations occurring 12 to 15 times monthly. Experimental requirements varying markedly from this (such as 200 watts average continuous) would require redesign of the power system; however average experimental requirements up to 50 to 75 watts continuous could be accommodated by the present system. Acceptable short-term peak loads on regulated dc and regulated ac are limited only by the size of the inverters, and unregulated dc is relatively unlimited.

It has been assumed on the basis of the available study data that the MORL power system will also consist of solar cells as the power sources with silver cadmium batteries for power storage. Again, the available power forms will be unregulated dc, regulated dc, and regulated ac, with the preferred form being unregulated dc. Although no firm data are available on the capacity of the MORL power system, it can be safely estimated that up to 500 watts continuous can be made available for experimental purposes if required. The acceptable short-term peak capacity can be expected to be similar to those of the extended Apollo concepts.

In the extended Apollo laboratories Concepts II and III, 811 pounds has been allocated for all experimental equipment. In the case of Concept II, this allocation could be increased since the total weight of the initial vehicle at launch is less than the booster capacity. The difference between the initial vehicle weight and the booster capacity is almost 1000 pounds; therefore this allocation could be increased considerably if this were indicated to be desirable. In the case of Concept III, the weight of the initial vehicle is already critical in view of the boosters capacity, and it cannot be anticipated that the experimental weight allocation can be increased. However,

the resupply vehicle weight is considerably less than the booster payload; therefore, a great deal of additional experimental equipment can be carried to the laboratory on resupply runs providing the volumetric requirements of the laboratory system allow this. The weight of the resupply vehicle in extended Apollo Concept II also allows the experimental equipment to be increased during resupply runs if desirable. No current data are available on the weights analysis of the MORL system. Since the Saturn IB launch vehicle is the same as that for the extended Apollo concepts and since the capacity of the two systems are similar, it can be estimated that the experimental allocation in weight would resemble that of the two larger extended Apollo concepts.

The constraints of the extended Apollo laboratory Concepts II and III require that the data system for these vehicles provide capability for ground tracking, voice, television and telemetry data transmission, command up-link, rendezvous radar, displays, and data recording and processing. The data systems summary is included in Table 19 in the discussion regarding the data systems for extended Apollo Concept I. Since there is little difference in the system capabilities for the various concepts of the extended Apollo, the one illustration has been used to summarize the system for all concepts. Again, there are no current data regarding the communications and data systems for the MORL. Since the MORL system is similar in capacity to the extended Apollo laboratories and since the requirements on the data system will be similar, it can be estimated that the data systems for the MORL will closely resemble those of the extended Apollo Concepts II and III.

A somewhat special constraint in the interim stations is that of the radiation storm shelter concept. This calls for a design that provides a storm shelter housing with at least the minimum requirements for command-control facilities, bunks, and emergency supplies for crew safety in the event of a major solar flare. In the case of two Apollo concepts, this is located in the command module. In the MORL, no constraint has been made on the location of the storm shelter; however, the design must also be such that this concept can be removed from the system later in its development if research proves radiation to be of little danger. This constrains the interior arrangement of the MORL in that the command center and the bunks must be located in proximity. In all cases this is a constraint in that it is a potential distraction or interference to the experimental program.

System parameters for interim stations are listed in Table 27.

Table 27. Summary of System Parameters for Interim Stations

Parameter	Measurement
Mission duration	1 Year
Crew size	3 to 6 men
Crew rotation-resupply schedule	90 to 120 days
Volume	
Total pressurized volume	2000 to 5620 cubic feet
Experimental equipment	500 cubic feet or greater
Work space	500 cubic feet or greater
Power availability	
Amount-average, continuous	50 to 75 watts (possible up to 500 watts)
Amount-peak	Relatively unlimited - short term
Forms available	Unregulated dc, regulated dc, regulated ac
Preferred form	Unregulated dc
Atmosphere	
Content	Mixed oxygen-nitrogen
Pressure level	7 to 10 psia
Data systems (See Table 19)	
Special constraint	Radiation storm shelter, housing, command facilities, bunks, and emergency supply

MEASUREMENT SYSTEM

The interim stations, MORL and Concepts II and III of the extended Apollo, are capable of accommodating all the measurements insofar as weight, power, and volume are concerned (with the possible exception of the centrifuge facility discussed in another section of the report).

Time is the only constraint insofar as accomplishment of all desired measurements. Based on the initial frequencies for performing

measurements, which will be modified as data is obtained and indicates that it is desirable to do so, it is possible to accomplish measurements as follows:

1. Measurements listed in the safety package (Table 16).

2. Measurements listed in the minimum weightlessness package (Table 17).

3. Measurements that can be performed within the time limitation of 525 minutes per man per week, which include the following:

Identification	Measurement	Time
5	Docking	70
8	Peripheral detection	45
12	Static depth detection	35
117	Fecal floral sampling	0
108	Serum catecholamine	0
118	RBC survival	2
129	Heart rate	4
105	Ocular tonometry	5
72	Tubular readsorption test	2
65	Autonomic hyperactivity	5
64	Reading	5
69	Writing	5
49	Bone density	7
33	Pulmonary pathology (heart size)	7
42	Stereognosis	10
38	Color discrimination	12
77	Time perception	10
53	GI absorption test	13
40	Tone detection and discrimination	15
25	Plasma volume	17
31	Exercise test	20
24	Dynamic depth perception	30
88	Tone pattern discrimination	10
90	Detection of motion	10
82	Expiratory-inspiratory force	11
60	Problem solving	15
66	Stereopsis	15
43	Muscle function	24
104	RBC mass	10
81	Tone duration	15
83	Que abstraction	15

Identification	Measurement	Time
79	Sound localization	20
80	Serum alkaline phosphatase	21
68	Cortical activity	21
114	RBC uptake I_{125}	10
144	Liver size	10

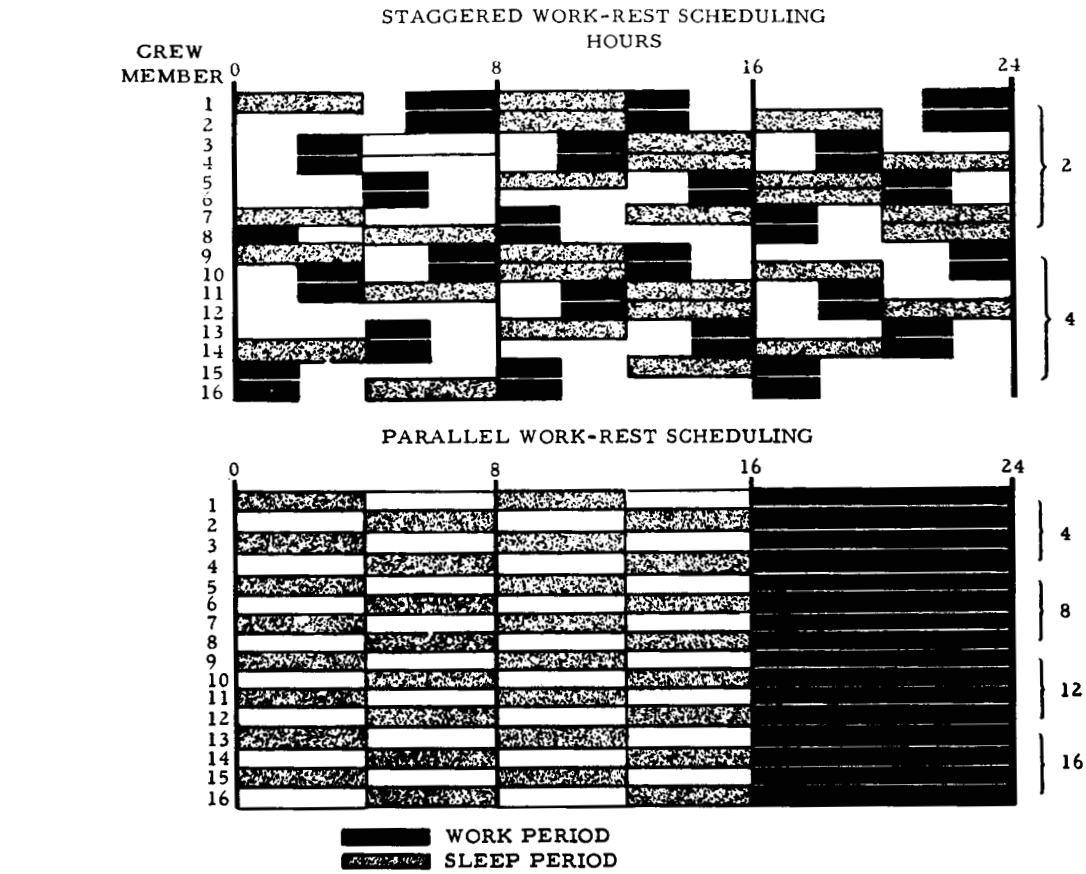
SPECIAL PROBLEMS

MORL and Concepts II and III of the extended Apollo are representative of an intermediate or medium-sized space station. Concepts II and III of the extended Apollo provide for approximately 750 cubic feet of workspace in the laboratory area. MORL affords nearly an equivalent amount of space for laboratory purposes.

The entire measurement package requires from 400 to 500 cubic feet of workspace for satisfactory performance by a crew of two men working together. A larger crew requires a greater amount of space because of the need to time-share facilities and workspace. Figure 30 depicts the amount of laboratory workspace required as a function of crew size for two concepts of work/rest scheduling. The two concepts represent two extremes: staggered scheduling, whereby available space is utilized to greatest possible advantage, and parallel scheduling in which available manpower can be utilized advantageously in terms of flexibility and efficiency in scheduling of measurements but at considerable cost in terms of workspace. The increase in workspace with the number of men simultaneously occupying the same area is based on an estimate of a 50 percent increase rather than a straight 100 percent increase each time the laboratory crew size is doubled. If it were possible to compute an accurate curve, it would probably be found to appear more like the dotted line increasing rapidly at first and tending to level off as the crew becomes larger.

The entire measurement package (not including a centrifuge discussed in Section III) involves a total equipment volume of 56.04 cubic feet. This, as in the case of work space volume, does not present a problem for the intermediate-sized space station configurations. The major problem for the intermediate (3 to 6 man) space station concerns time to perform the measurements.

The biomedical and behavioral measurement time requirements were integrated into daily crew workrest cycles covering two works for each crew member for a two-, three-, four-, and six-man crew and for a crew of a large orbital station, e.g., a twenty-man crew. The measurements



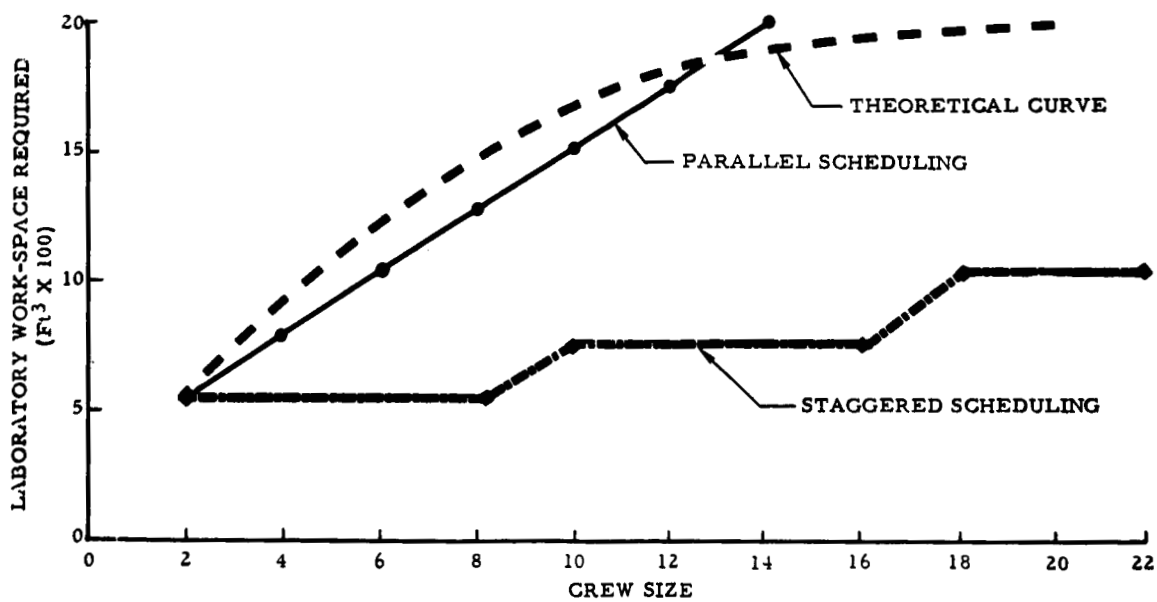


Figure 30. Laboratory Workspace Required as a Function of Crew Size Based on Two Extremes of Work-Rest Scheduling

to be taken each day per man are shown in Tables 28 through 34. The schedules of measurement times per man are shown in Figures 31 through 33 for two types of maximum measurement load days. The measurements considered were those comprising the safety package (SP) and the minimum weightlessness package (MWP). Time remaining for measurement duty after the inclusion of SP and MWP into the daily schedule was considered available for additional measurements subject to weight, power, volume, and scheduling considerations. The measurement schedules shown in Tables 28 through 34 and Figures 31 through 34 are initial schedules, i.e., it was not considered feasible to illustrate measurement deletions, additions, and frequency modifications that may be expected to occur over the duration of the orbital station experimental program.

In integrating the measurement times of SP and MWP into the daily work-rest cycles, the following ground rules were observed:

1. Each crew member was to be subject to all measurements.

2. Each crew member was to be capable of carrying out all measurements.

3. Measurement times could be combined but not fractionated, e.g., two measurement times of 20 minutes and 40 minutes could be considered as a block of 60 minutes but not as three blocks of 20 minutes each.

4. The quantitative relationship between subject time and corresponding observer time must be retained in scheduling, e.g., an accumulation of 20 minutes of subject time and 30 minutes of associated observer time must be so shown. This ground rule was occasionally ignored for small blocks of scheduled measurement time.

5. Where observer time exceeded associated subject time, the excess was scheduled after the termination of subject time.

6. No crew member was available for more than one measurement duty at any one time, e.g., he could not be a subject while being an observer.

While every effort was made to equalize the measurement workload across days in Tables 28 through 34, this equalization was not achieved. The principle single complication in measurement workload equalization derived from blood sample analysis constraints. The blood samples in SP were taken every three days; therefore, to use this blood sample for all

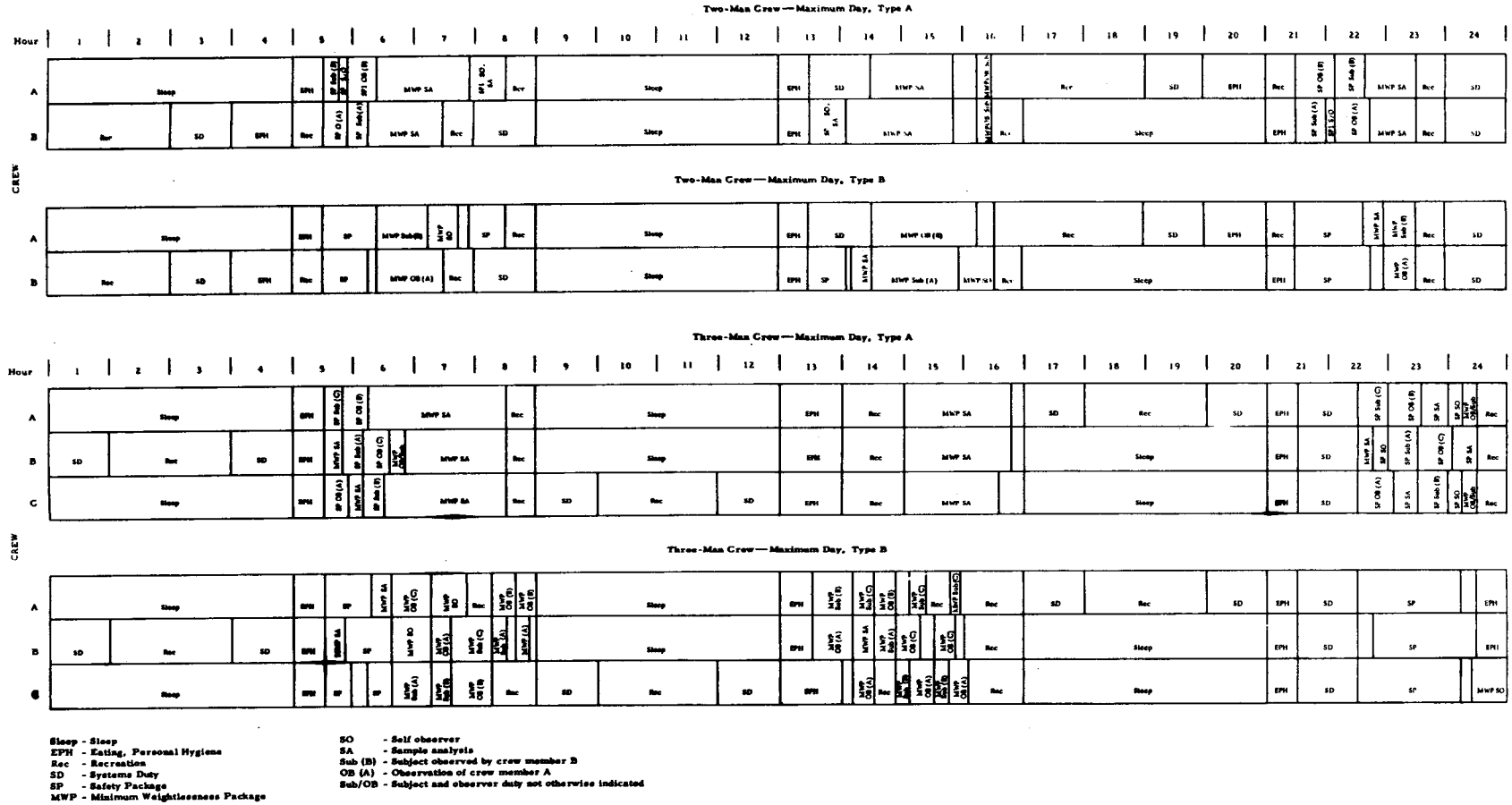


Figure 31. Two- and Three-Man Crew Work-Rest Cycles

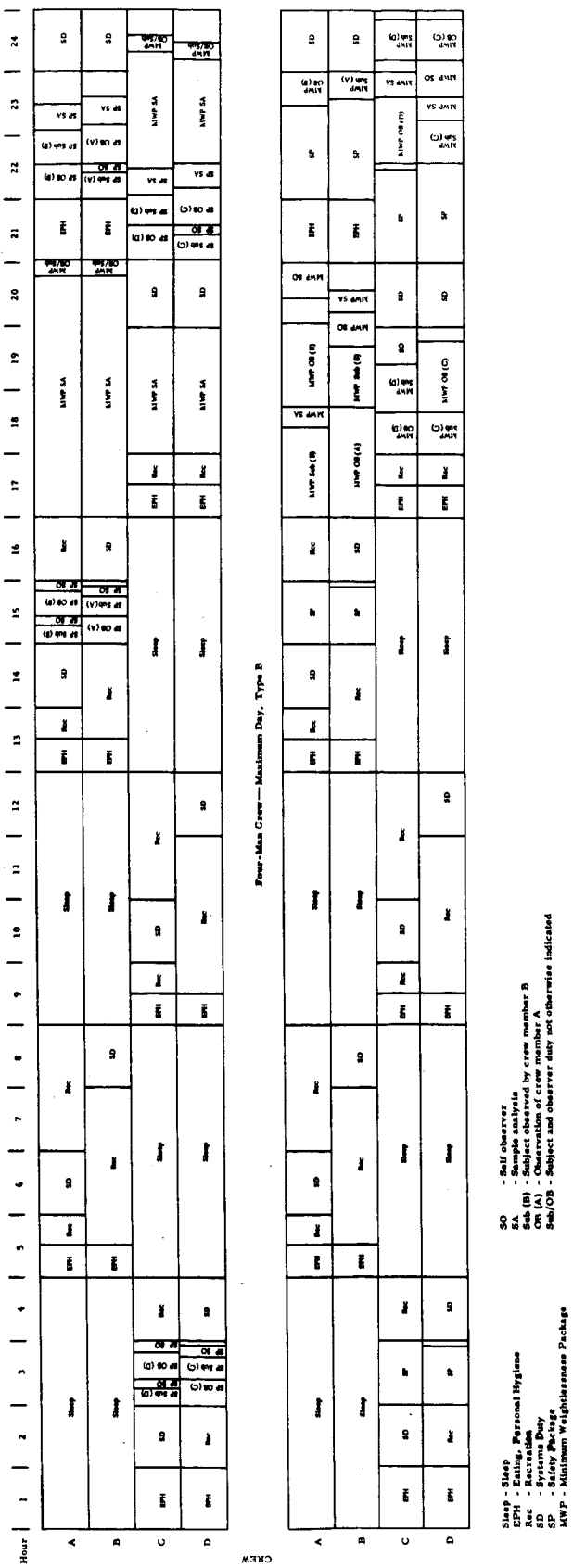
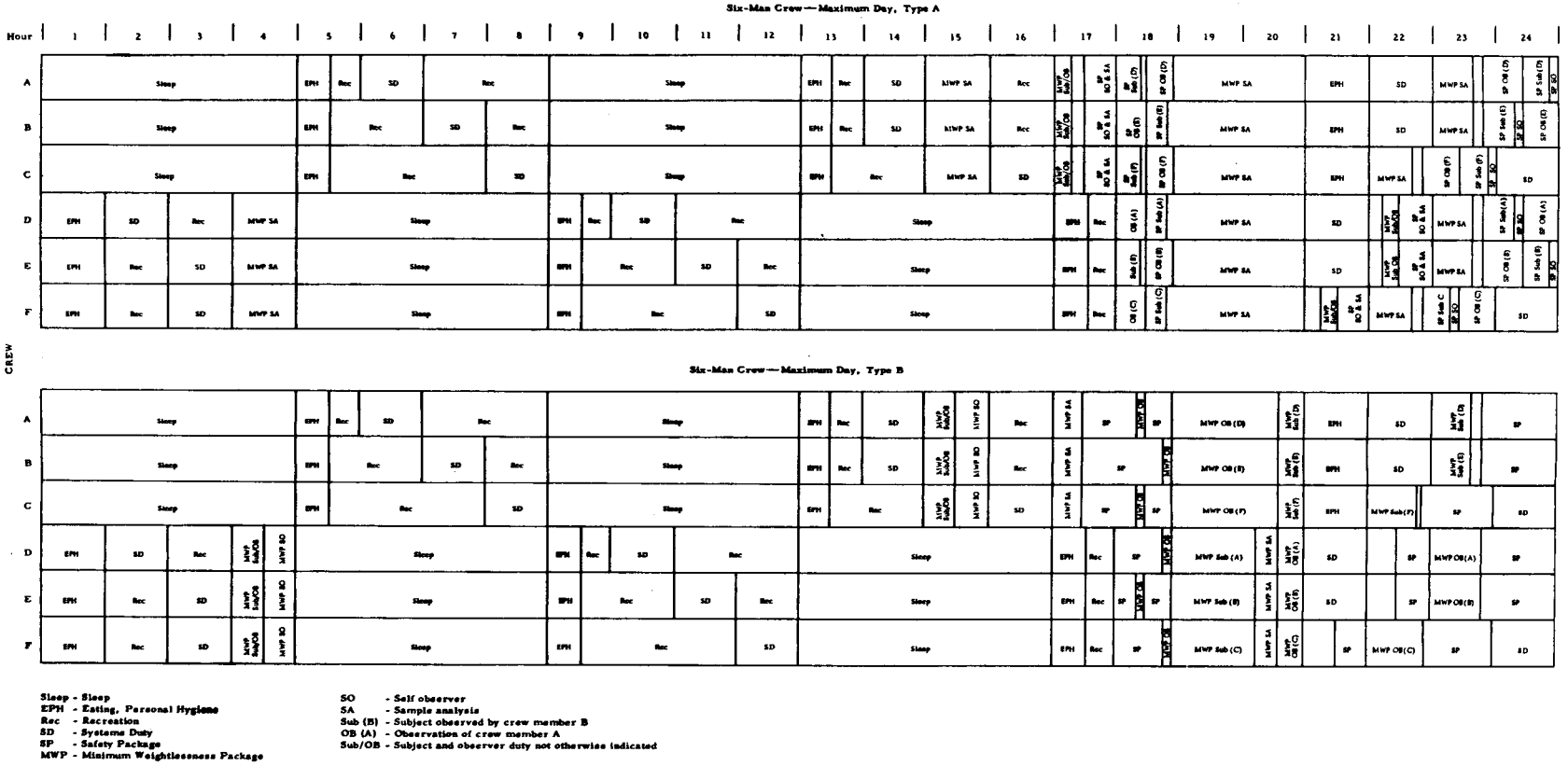


Figure 32. Four-Man Crew Work-Rest Cycle



Sleep - Sleep
EPH - Eating, Personal Hygiene
Rec - Recreation
SD - Systems Duty
SP - Safety Package
MWP - Minimum Weightlessness Package

SO - Self observer
SA - Sample analysis
Sub (B) - Subject observed by crew member B
OB (A) - Observation of crew member A
Sub/OB - Subject and observer duty not otherwise indicated

Figure 33. Six-Man Crew Work-Rest Cycle

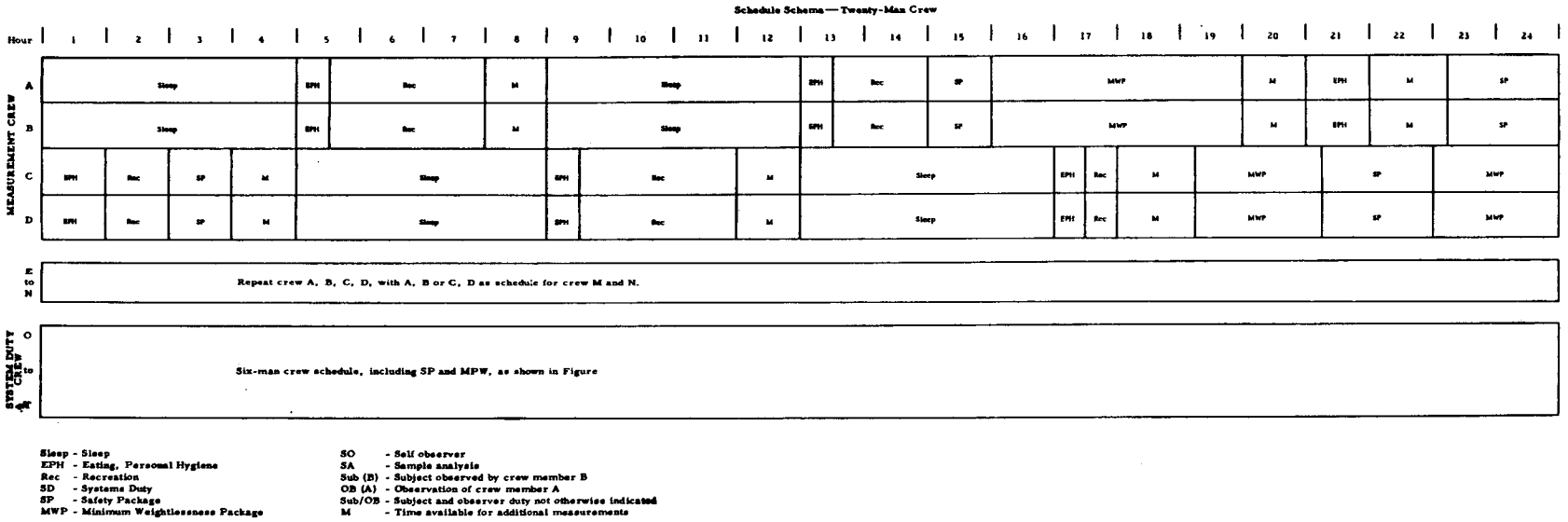


Figure 34. Twenty-Man Crew Work-Rest Cycle

Table 28. Measurements on Days 1 and 2

Day 1 (Time in minutes)					Day 2 (Time in minutes)				
M	S	O	S/O	SA	M	S	O	S/O	SA
15	5	5			15	5	5		
15	5	5			15	5	5		
35	10	15			35	10	15		
35	10	15			35	10	15		
143	5	5			143	5	5		
143	5	5			143	5	5		
63	2	2			63	2	2		
125	NC				125	NC			
89	NC				89	NC			
135	NC				135	NC			
13	NC				13	NC			
21				5	27	5			25
1	10	15			10			10	
99	NC				99	NC			
78			5		78			5	
98	NC				98	NC			
101	2	5			101	2	5		
Total SP:									
	54	72	5	5		49	57	15	25
21				20	17				55
18			35		111				20
45	5	10			107				15
130	5	10			59				20
19*	30	60			2				30
					84				20
					57				20
					37				30
					21				20
					130	5	10		
Total MWP:									
	40	80	35	20		5	10		230
Total: 311					391				

*Once in two weeks

Table 29. Measurements on Days 3 and 4

Day 3 (Time in minutes)					Day 4 (Time in minutes)				
M	S	O	S/O	SA	M	S	O	S/O	SA
15	5	5			15	5	5		
15	5	5			15	5	5		
35	10	15			35	10	15		
35	10	15			35	10	15		
143	5	5			143	5	5		
143	5	5			143	5	5		
63	2	2			63	2	2		
125	NC				125	NC			
89	NC				89	NC			
135	NC				135	NC			
13	NC				13	NC			
95	5	5			21				5
3			20		1	10	15		
99	NC				99	NC			
99	NC				99	NC			
78			5		78			5	
98	NC				98	NC			
101	2	5			101	2	5		
Total SP:									
	49	62	25			54	72	5	5
51				20	21				20
37				30	18				35
21				20	45	5	10		
91	5	5			130	5	10		
61	10	15			131*	10	30		
121	10	10			74	10	30		
47	10	15							
130	5	10							
26	20	20							
Total MWP:									
	55	55		70 (180)		30	80		55
Total:		296					301		

*Once in two weeks

Table 30. Measurements on Days 5 and 6

Day 5 (Time in minutes)					Day 6 (Time in minutes)				
M	S	O	S/O	SA	M	S	O	S/O	SA
15	5	5			15	5	5		
15	5	5			15	5	5		
35	10	15			35	10	15		
35	10	15			35	10	15		
143	5	5			143	5	5		
143	5	5			143	5	5		
63	2	2			63	2	2		
125	NC				125	NC			
89	NC				89	NC			
135	NC				135	NC			
13	NC				13	NC			
27	5			25	95	5	5		
10			10		3			20	
99	NC				99	NC			
99	NC				99	NC			
78			5		78			5	
98	NC				98	NC			
101	2	5			101	2	5		
Total SP:									
	49	57	15	25		49	62	25	
17				55	39				30
111				20	21				20
107				15	14			10	
59				20	6	10	10		
23				15	16	5	5		
109				20	46	10	10		
110				30	4	5	10		
39				30	41	5	10		
21				20	130	5	10		
130	5	10			26	20	20		
Total MWP:									
	5	10		225		60	75	10	50
Total:		386					296		

Table 31. Measurements on Days 7 and 8

Day 7 (Time in minutes)					Day 8 (Time in minutes)				
M	S	O	S/O	SA	M	S	O	S/O	SA
15	5	5			15	5	5		
15	5	5			15	5	5		
35	10	15			35	10	15		
35	10	15			35	10	15		
143	5	5			143	5	5		
143	5	5			143	5	5		
63	2	2			63	2	2		
125	NC				125	NC			
89	NC				89	NC			
135	NC				135	NC			
13	NC				13	NC			
21				5	99	NC			
1	10	15			99	NC			
99	NC				78			5	
99	NC				98	NC			
78			5		101	2	5		
98	NC				27	5			25
101	2	5			10			10	
Total SP:									
	54	72	5	5		49	57	15	25
21				20	17				55
18			35		111				20
29	5	5			107				15
29	10	10			59				20
56	5	5			2				30
11	5	15			84				20
100	10	10			57				20
45	5	10			37				30
130	5	10			21				30
26	20	20			130	5	10		
32*	20	20							
Total MWP:									
	85	105	35	20 (245)		5	10		230
Total:		381					391		
*Once in 10 days									

Table 32. Measurements on Days 9 and 10

Day 9 (Time in minutes)					Day 10 (Time in minutes)				
M	S	O	S/O	SA	M	S	O	S/O	SA
15	5	5			15	5	5		
15	5	5			15	5	5		
35	10	15			35	10	15		
35	10	15			35	10	15		
143	5	5			143	5	5		
143	5	5			143	5	5		
63	2	2			63	2	2		
125	NC				125	NC			
89	NC				89	NC			
135	NC				135	NC			
13	NC				13	NC			
99	NC				21				5
99	NC				1	10	15		
78			5		99	NC			
98	NC				99	NC			
101	2	5			78			5	
95	5	5			98	NC			
3			20		101	2	5		
Total SP:									
	49	62	25			54	72	5	5
					18			35	
21				20	51				30
7				60	37				30
130	5	10			21				20
	10	30			91	5	5		
					61	10	15		
					14	10	10		
					47	10	15		
					45	5	10		
					130	5	10		
Total MWP:									
	15	40		80		45	65	35	80
Total:		271					361		

Table 33. Measurements on Days 11 and 12

Day 11 (Time in minutes)					Day 12 (Time in minutes)				
M	S	O	S/O	SA	M	S	O	S/O	SA
15	5	5			15	5	5		
15	5	5			15	5	5		
35	10	15			35	10	15		
35	10	15			35	10	15		
143	5	5			143	5	5		
143	5	5			143	5	5		
63	2	2			63	2	2		
125	NC				125	NC			
89	NC				89	NC			
135	NC				135	NC			
13	NC				13	NC			
99	NC				99	NC			
99	NC				99	NC			
78			5		78			5	
98	NC				98	NC			
101	2	5			101	2	5		
27	5			25	95	5	5		
10			10		3			20	
Total SP:									
	49	57	15	25		49	62	25	
17				55	21				20
111				20	16	10	10		
107				15	16	5	5		
59				20	46	10	10		
23				15	4	5	10		
109				20	41	5	10		
110				30	130	5	10		
39				30	26	20	20		
21				20					
130	5	10							
Total MWP:									
	5	10		225		60	75		20
Total:		386					301		

Table 34. Measurements on Days 13 and 14

Day 13 (Time in minutes)					Day 14 (Time in minutes)				
M	S	O	S/O	SA	M	S	O	S/O	SA
15	5	5			15	5	5		
15	5	5			15	5	5		
35	10	15			35	10	15		
35	10	15			35	10	15		
143	5	5			143	5	5		
143	5	5			143	5	5		
63	2	2			63	2	2		
125	NC				125	NC			
89	NC				89	NC			
135	NC				135	NC			
13	NC				13	NC			
21				5	99	NC			
1	10	15			99	NC			
99	NC				78			5	
99	NC				98	NC			
78			5		101	2	5		
98	NC				27	5			25
101	2	5			10			10	
Total SP:									
	54	72	5	5		49	57	15	25
39				30	17				55
21				20	111				20
18				35	107				15
14			10		59				20
15	5	10			21				20
130	5	10			29	5	5		
					29	10	10		
					56	5	5		
					11	5	15		
					100	10	10		
					130	5	10		
					26	20	20		
Total MWP:									
	10	20	10	85		60	75		130
Total:		261					411		

other blood sample analysis measurements in SP and MWP, it was necessary to schedule these measurements on one or all (depending on frequency of analysis) of these above mentioned three days. This constraint not only complicated the equal interval scheduling of other measurements, with unequalizing results on daily workload but also resulted in days predominately devoted to blood sample analysis (type A days) and days predominately devoted to other types of measurements, mainly those involving subject-observer associations (type B days). It should be noted that inequalities of daily measurement workload are mainly ascribable to the MWP.

In Tables 28 through 34, each measurement is identified by number (M). The measurement times in minutes are listed as subject (S) and associated observer (O) times, self-observer (S/O) times, and sample analysis (SA) times. Certain measurements are noted as NC; these measurements result from other measurements and involve no additional time charge. Total times are shown for SP and MWP.

Figures 32 through 35 show the integration of the measurement schedules into the work-rest cycles for each crew member for a maximum measurement load type A and type B day. The maximum type A (blood sample analysis) day is Day 2 from Table 38; the maximum type B day is MWP portion Day 7 from Table 31 added to the SP portion of Day 2. (Day 14 is somewhat heavier than Day 7 but is not typical of either type A or B.) Each "block" in Figures 31 through 34 is identified with appropriate indication of the measurement activity involved.

In general, each day has 270 minutes per man available after the inclusion of SP; however, this is almost completely used by MWP. The most complicated scheduling problems arose with respect to subject-observer measurements. For subject-observer measurements, the most complicated scheduling problem was with respect to the three-man crew. The scheduling complication for the three-man crew arises from the requirement that each man share his subject and observer availability with two other men. This constraint tended to result in blocks of time in which one of three men had no one available for association with him in measurement duties. It is anticipated that this problem would be encountered with any odd-numbered crew. The four-man crew was treated as two 2-man crews. The six-man crew was treated mainly as three 2-man crews; although some measurements had to be scheduled on a three-man basis to accommodate other work-rest cycle requirements.

Since SP and MWP used practically all the maximum day measurement time, further measurement time can only come from two sources: (1) use of time otherwise devoted to other activities, especially recreation, and (2) freeing certain crew members from system duty responsibilities.

The release of crew members from system duty responsibilities would be an attractive asset of a large space station. If a large enough crew could be accommodated so that a number of men could take full responsibility for system duty, the remaining crew members would be available for further measurement duty beyond the safety package schedule. A possible arrangement of this nature is shown in Figure 34, which illustrates a 20-man crew with 6 men assigned to system duty and the remaining 14 specializing in measurement duty.

While the individual duty schedules have been referred to herein as "crew members", it should be noted that these schedules are not bound to actual persons. This means that individual crew members can be periodically rotated among schedules and thus periodically associate different subjects with different observers. This rotation of subject-observer association has experimental design implications with respect to the detection and evaluation of systematic observer and subject deviations.

Crew Rotation

Special problems associated with crew rotation will involve scheduling measurements, evaluation of the long term effects of zero G, and the effect of weightlessness sophistication upon the measurement program. Basically, these problems stem from the fact that, after the first rotation, the crew is no longer a homogenous sample with respect to space station tenure.

If it is assumed that for reasons of crew safety or experimental design the measurement package for the initial and early portions of each crew member's space station duty period will differ from the measurement package for later portions, the space station crew will not all be scheduled for the same measurements or for the same frequency of measurement after the first crew rotation. It has been shown in other sections of this report that the scheduling of measurements, particularly for odd numbered crews, presents difficulties even when the crew is homogenous as to measurement package. It is reasonable to anticipate that dissimilarity of measurement program among crew members will produce further scheduling difficulties. Paralleling the time problems associated with intracrew differences in the measurement program may pose equipment problems reflecting, for example, the unfeasibility of phasing certain equipment items wholly or partially out of the program or, even, an increase in demand for certain items.

From an experimental design standpoint, a crew rotation schedule has the advantages of varying length of exposure to weightlessness and offering scheduled opportunities for ground debriefing of crew members. However, these advantages are accompanied by the liability of a decrease

in sample size as the period of exposure to weightlessness increases. The biomedical and human factor data reflecting the longest weightlessness exposure (i. e., those data that may be of most pertinance to extended interplanetary missions) will be derived from the smallest sample.

It is highly probable that no amount of ground or other pre-space station training will bring about the sophistication of performance under weightlessness that long-term space station experience will achieve. One aspect of this performance sophistication will be increasing efficiency in measurement technique under zero G. The rotation schedule will tend to disrupt, or at least dilute, this efficiency by introducing a relatively inexperienced observer and subject into the experimental program periodically. However, this introduction of new personnel will be of some benefit in applying a check on experimental procedures to ensure that the adaptation of technique to weightlessness has not resulted in serious departures from approved experimental design.

Station Rotation

Station rotation to produce artificial G may be expected to pose problems in carrying out the measurement program. These problems may be expected to include measurement scheduling, equipment design and utilization, personnel adaptation, and complicating experimental design considerations.

Even if no rotation is contemplated, the scheduling of measurements must be integrated with assigned periods for sleep, system duty, recreation, eating, and personal hygiene. To these requirements the rotation of the space station adds the integration of measurement scheduling with rotation periods. Furthermore, if two distinct, though interrelated, experimental programs are put into effect (i. e., one for weightlessness and one for artificial G), these will pose scheduling problems over time associated with two differing systems of measurements, measurement times, and measurement frequencies.

Potential problems of equipment design and utilization arise from the differing operational environments associated with weightlessness and tangenital rotation-induced G. Some of these problems may be encountered in equipment design to meet the requirements of two different gravity situations. Other equipment problems may reflect different utilization procedural requirements under rotational G as compared with weightlessness. A special case of procedural problems might be the requirement for recalibration or other equipment adjustment after the initiation of either gravity state.

From currently available evidence, it may be anticipated that crew members may require a certain exposure time to adapt to either

weightlessness or rotation after the initiation of, or return to, either state. If this period of adaptation is of significant duration, the measurement performance of the crew may be significantly, though temporarily, degraded. It is possible that this performance degradation may occur at a time when the most precise measurements are desired to evaluate the biomedical and human factors effects to gravity transition.

The anticipated use life of interim stations may place constraints on the experimental design of evaluation of rotation effects. If, for example, it were desired to evaluate the variables of length of weightlessness, length of rotation, speed of rotation, and scheduling of rotation, the required time for an adequate experimental design might well exceed the design life span of the space station. Another special experimental program complication might be in the interaction of station rotation with crew rotation. If it were considered desirable for newly arriving personnel or departing personnel to be exposed to either gravity state for a certain period after arrival or before departure, these requirements would place constraints on rotation versus non-rotation periods.

INTERFACES

Table 35 summarized the interacting relationships of the various areas of consideration applicable to the interim stations as space stations for the biomedical and human factors crew measurement program. The areas of consideration, whose interfaces are summarized, include measurement systems, weight, item volume, crew characteristics, time (measurement time), work space, flight duration, crew rotation (and resupply), and artificial G (station rotation). Each area of consideration is examined with respect to how it may influence and how it may be influenced by every other area. Where, in the matrix of Table 35, an area of consideration coincides with itself, a statement of pertinent facts, e.g., weight in excess of 1500 pounds capability, are given for that area.

Table 35. Interface Summary - Interim Stations

Areas of Consideration	Measurement Systems	Weight	Item Volume	Crew Characteristics	Time	Work Space	Flight Duration	Crew Rotation (and re-supply)	Artificial G (Station Rotation)
Measurement Systems	Priority: SP MWP Other	Utilizes over and above operational system requirements	Concerned with equipment use and storage	Influences selection and training	Utilizes over and above all scheduled crew requirements	Special work space and work space shared with other activities	Influenced by experimental design	Influenced by experimental design	Influenced by experimental design
Weight	No constraint on foreseen items	In excess of 1500-lb capability available	Heavier items larger	May impose requirement for handling training (mass)	No significant interface	No significant interface	No significant interface	May influence resupply schedule	Items variably affected by artificial G
Item Volume	Dimensions of items, plus storage, plus spaces	Larger items heavier	500 plus cuff available for equipment	May impose requirement for storage access training	No significant interface	Must be compatible with layout of use areas	No significant interface	Spare part logistics	Volume may be affected by design for artificial G
Crew Characteristics	Determine and determined by	No significant interface	May need special storage access training	3, 4, or 6 man astronaut, professional technical qualification	Trained for efficient utilization of measurement time	Dynamic anthropometry compatible with work spaces	No significant interface	Imposes some of crew rotation requirements	Must adapt to varied G status
Time	Limits cumulative measurement time and measurement	No significant interface	No significant interface	Imposes requirement for measurement duty efficiency	7 hours man-day measurement time. Scheduling problem for odd number crew	May be some need for time sharing of work space	Over-all measurement schedule may be affected by flight duration	Schedule may be disrupted by crew rotation	Scheduling problem for experimental design
Work Space	Preallocated and ad hoc work space utilization	No significant interface	Designed to accommodate item volume characteristics	Designed for compatibility with crew anthropometry	May put some constraint on scheduled space utilization	500-plus cu ft	No significant interface	No significant interface	Designed for utilization under artificial G
Flight Duration	May be constraint on over-all experimental design	No significant interface	No significant interface	No significant interface	May constrain over-all measurement schedule	No significant interface	1 year or more	Will influence schedules	Will influence G schedules
Crew Rotation (and re-supply)	1. Subject factor in experimental design 2. Logistics support	Resupply schedule by influenced weight requirements	Spare part logistics	Rotation schedule influenced by crew requirements	May disrupt measurement schedule	No significant interface	Influences flight duration	Every 90 days	Should be integrated with
Artificial G	An important experimental design factor	Will produce item weight variation	Effect on item and storage design	Imposes adaptive requirements	Scheduling problem	Work space design factor	Rotation scheduling influenced by	Should be integrated with	Rotation parameters

LARGE STATIONS

The large stations include a group of space-station systems, both rotating and nonrotating that vary in volume upward from 25,000 cubic feet and can support a crew of more than 21 men. These stations will be launched by a Saturn V, S-1C, and S-II stages only, into a low circular earth orbit (200 to 300 nautical miles). The stations will be designed to be pre-assembled, not to be recoverable, and provisions will be made for rendezvous and docking, cargo transfer, and emergency crew evacuation. The life time of the vehicles will be one year with no orbital maintenance provisions and as much as 5 years with orbital maintenance provisions. Some of these systems are designed to be rotated to provide an artificial gravity for the crew members; others are designed to be nonrotating zero-G facilities.

SYSTEM DESCRIPTIONS

Rotating Systems

Some of the rotating space stations that have been proposed are the hexagonal configuration, and the toroidal configuration, and the radial element. The radial element or "Y" configuration will be detailed in this analysis (Figure 33). This configuration consists of three cylindrical modules extending from a central zero-G docking hub. It has a total volume greater than 30,000 cubic feet. The station is rotated about an axis located through the center of the docking hub. The hub is counter-rotated to maintain its zero-G state. Each spoke or module has been assumed to contain seven levels or compartments; each compartment having a different gravity level due to the differing distances from the central zero-G hub. Experimentation is therefore possible at differing gravitational levels. The four outer compartments of each module can be used for living and working areas and the three inner compartments can be used for storage of supplies and equipment. The station can support a crew of more than 20 men. Figure 35 shows a detailed design drawing of a radial configuration.

Nonrotating Systems

The configuration of a large nonrotating space station used in this analysis is of a large single cylinder, 33 feet in diameter and 61 feet in length. At the end of the cylinder is a compartment with a 15-foot diameter that tapers to 11 feet. In addition, there is a docking hub which is 15 feet

in diameter and 10 feet in length. The total volume of the configuration is approximately 65,000 cubic feet, considerably more than the rotating stations. Although a 21-man crew has been assumed for this configuration, the volume is sufficient to accommodate a larger crew if the experimental program indicates this to be desirable. Figure 36 shows the zero-G configuration used in this analysis.

SYSTEM PARAMETERS

The volumetric availability of the larger space stations is considerably greater than that of the interim stations or the extended Apollo Concept I. The rotating radial configuration has a total volume of approximately 28,000 cubic feet in addition to the central hub that is 3,200 cubic feet. The total volume of the large nonrotating configuration is approximately 65,000 cubic feet. It can be safely estimated that a volume of at least 1500 to 2000 cubic feet will be available for laboratory equipment and workspace.

Although preliminary estimates for crew size now range from 21 to 36 men, the zero-G station is capable of supporting a larger crew. With crews of 21 men or greater, it can be safely anticipated that some specialization of tasks will be utilized. Here the possibility of using specialists as crew members is feasible. Although a substantial portion of the crew will be required to pilot the escape vehicles, it is possible that some of the crew members will need only back-up and emergency training on these spacecraft. In addition, it is likely that some of the crew members will be devoting the majority of their time to command and system operations functions, while others will be primarily responsible for the conduction of experiments. Even with a specialization of tasks within the crew, it would be possible, and probably desirable, to have all crew members available to serve as subjects for some portion of their working day. The large crews and crew rotation capability of these stations allow that scientific specialists may be brought up to the station for a scheduled period of time. This will augment the experimental program by allowing a great number of specialists to be utilized.

Crew rotation and resupply capability is designed into all of the large systems. Although no firm resupply crew/crew rotation schedule has been set, this would probably be scheduled at a minimum of 90-day intervals. The systems provide rendezvous, docking, cargo and crew transfer without requiring the crew members to perform extra-vehicular activity. The docking hub is designed in such a way that cargo and crew can be transferred directly from the ferry or logistics vehicle into the hub of the space station.

A weights analysis for the rotating configurations has disclosed approximately 21,000 pounds allocated for experimental equipment. Since

the launch payload for the rotating station and the zero-G station are identical, the two types of stations can probably support a similar scientific payload. There is considerably less surface area on the zero-G stations; therefore, structures weight requirements are likely to be smaller; however, the increased pressurized volume will necessitate more gas supplies for repressurization.

Available sources indicate that a solar cell system will provide on-board power for the rotating configurations and a solar dynamic system will generate on-board power for the nonrotating configuration. The available power for experimentation in recreational activities has been designated as between 1 and 2 kw continously for the rotating system and greater than 2 kw for the nonrotating. In both systems the power forms available are unregulated dc, regulated dc and regulated ac. The preferred power form for the rotating systems is unregulated dc and for nonrotating systems is regulated ac.

The data management and communication system proposed for the rotating station include provisions for on-board communications, monitoring and warning, television, data handling, processing, display, radio-frequency links, and the associated ground station equipment.

The television system consists of nine portable cameras and eight portable monitors, all designed for use at any location inside the space station. The radio-frequency links are summarized in Figure 37. Since no data are available on the data system in the zero-G station, it is assumed that these will be at least similar to those for the nonrotating systems.

The atmospheric conditions selected for the design point of the environmental control system of the larger stations are content-oxygen/nitrogen; dry bulb temperature, 75 F; total pressure, 10 psia; oxygen partial pressure, 4 psia; relative humidity, 50 percent; and CO_2 partial pressure, maximum, 7.6 mm Hg.

The rotating stations will provide an artificial gravity level of at least 0.25 G. In addition, the docking hub provides a zero-G laboratory for weightlessness experimentation. The nonrotating configurations are primarily zero-G; however, the available volume certainly permits inclusion of a centrifuge or linear accelerometer if it is desired to condition the crew for reentry or for the experimental program. A summary of these parameters is presented in Table 36.

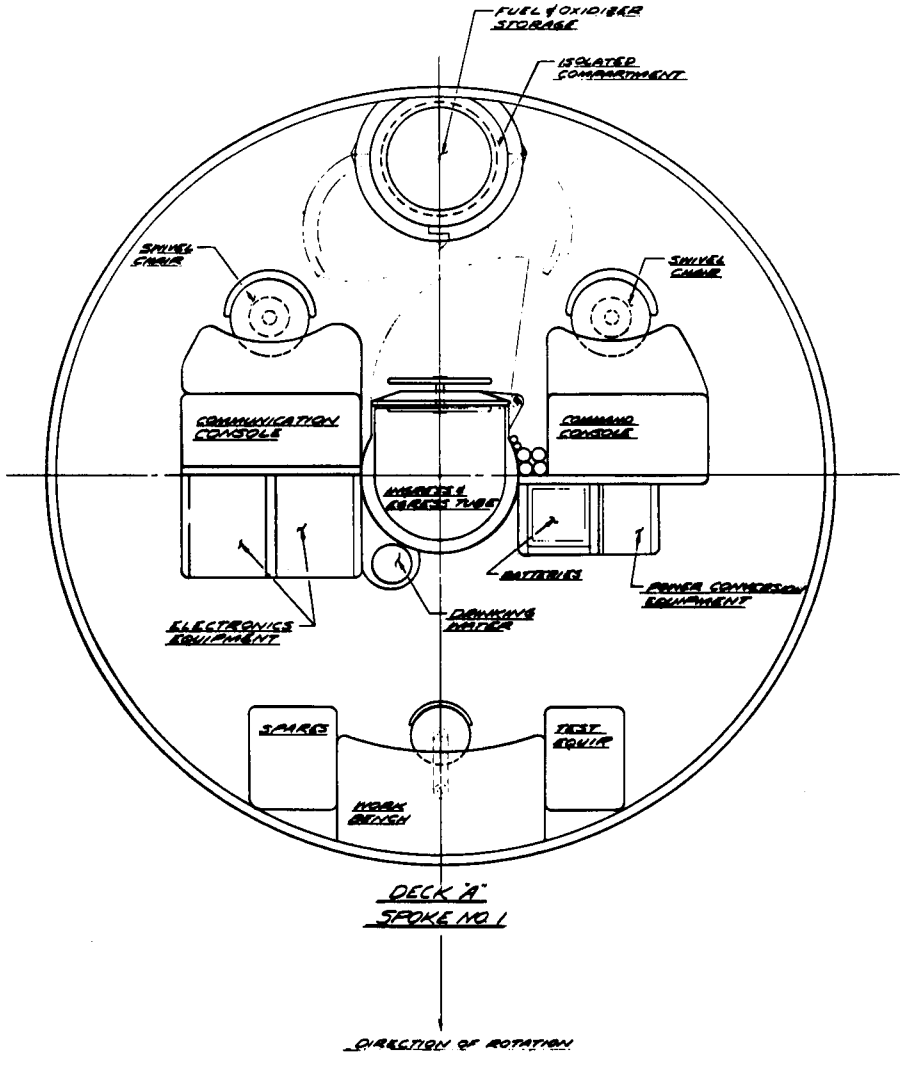


Figure 35. Self-Deploying Space Station "Y" Configuration (Sheet 1 of 7)

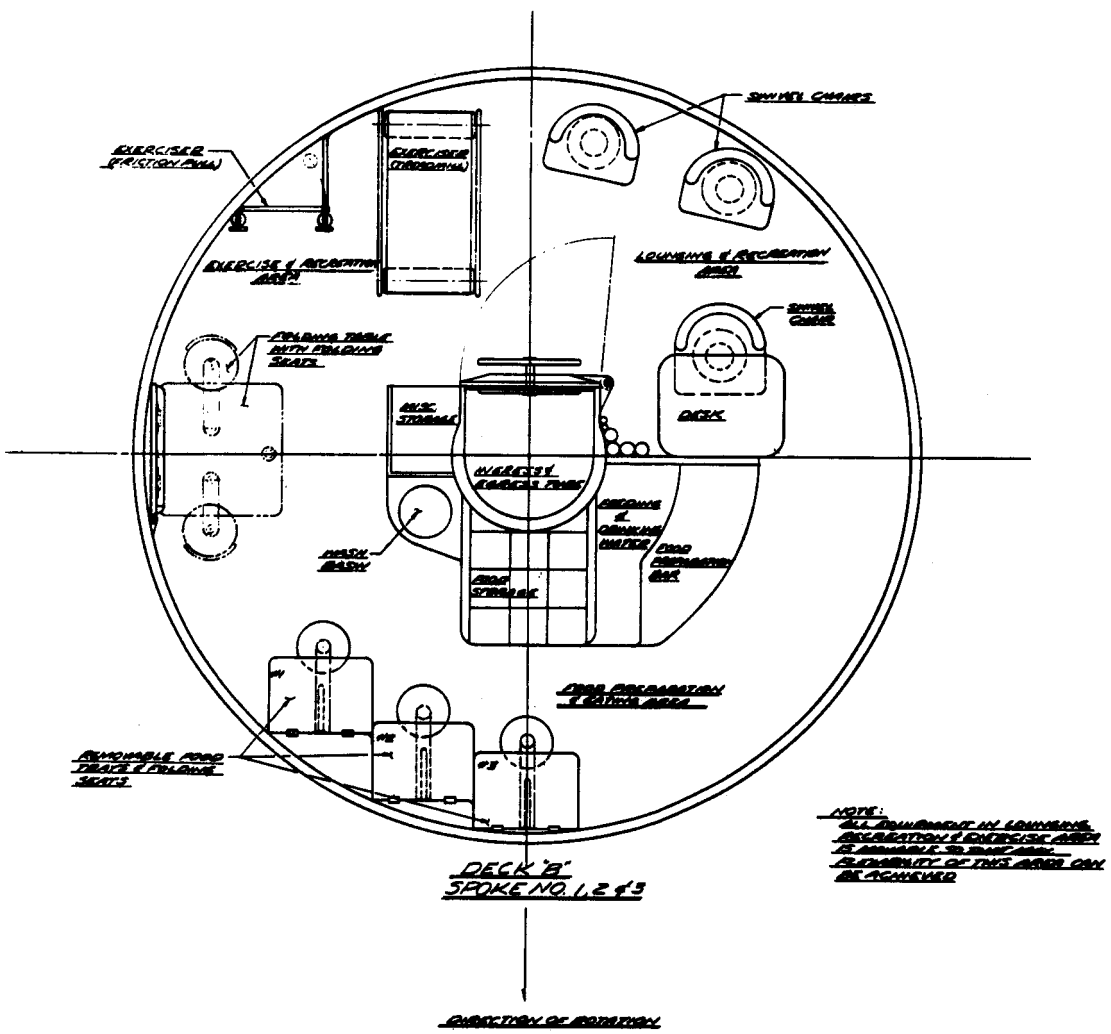


Figure 35. Self-Deploying Space Space Station "Y" Configuration
(Sheet 2 of 7)

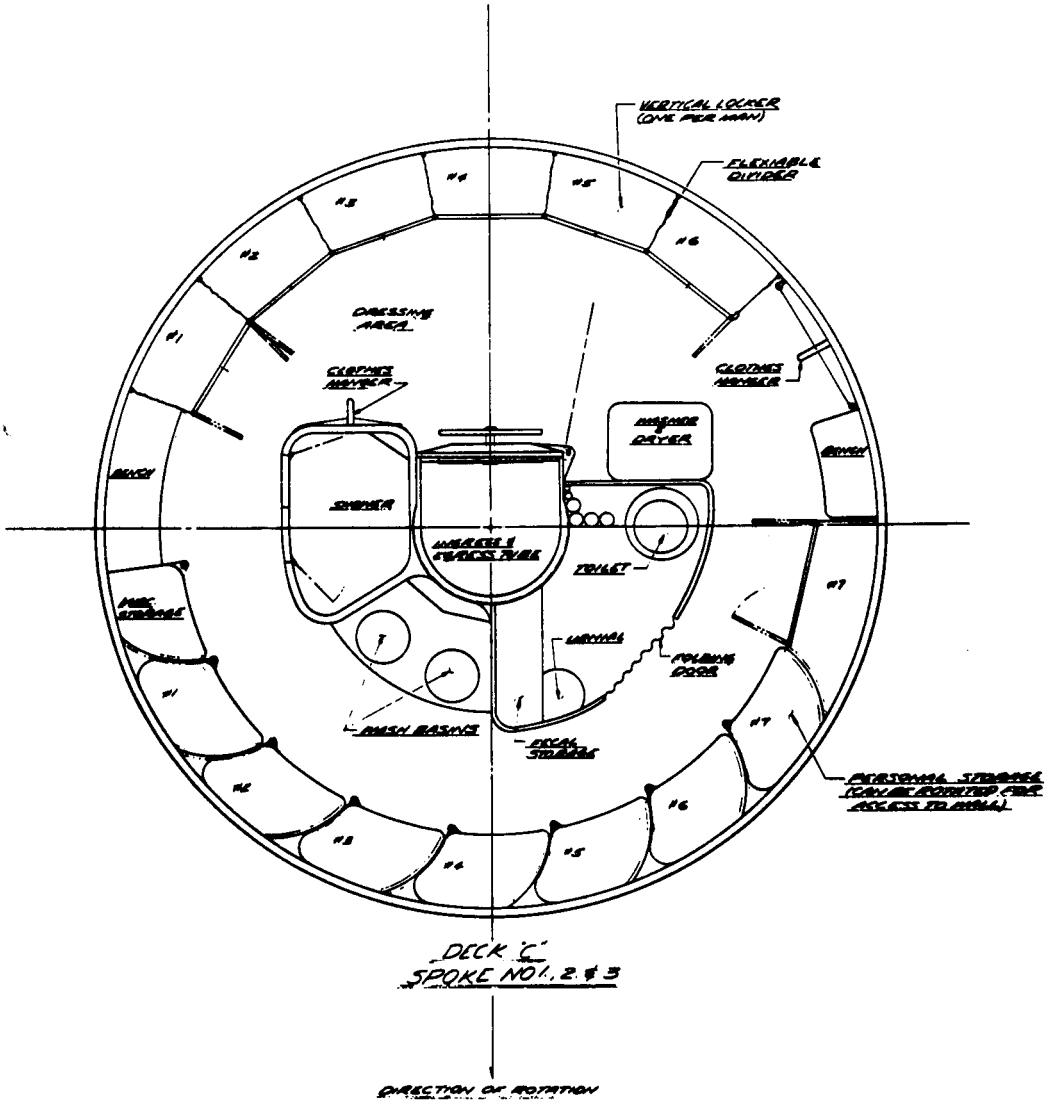


Figure 35. Self-Deploying Space Station "Y" Configuration (Sheet 3 of 7)

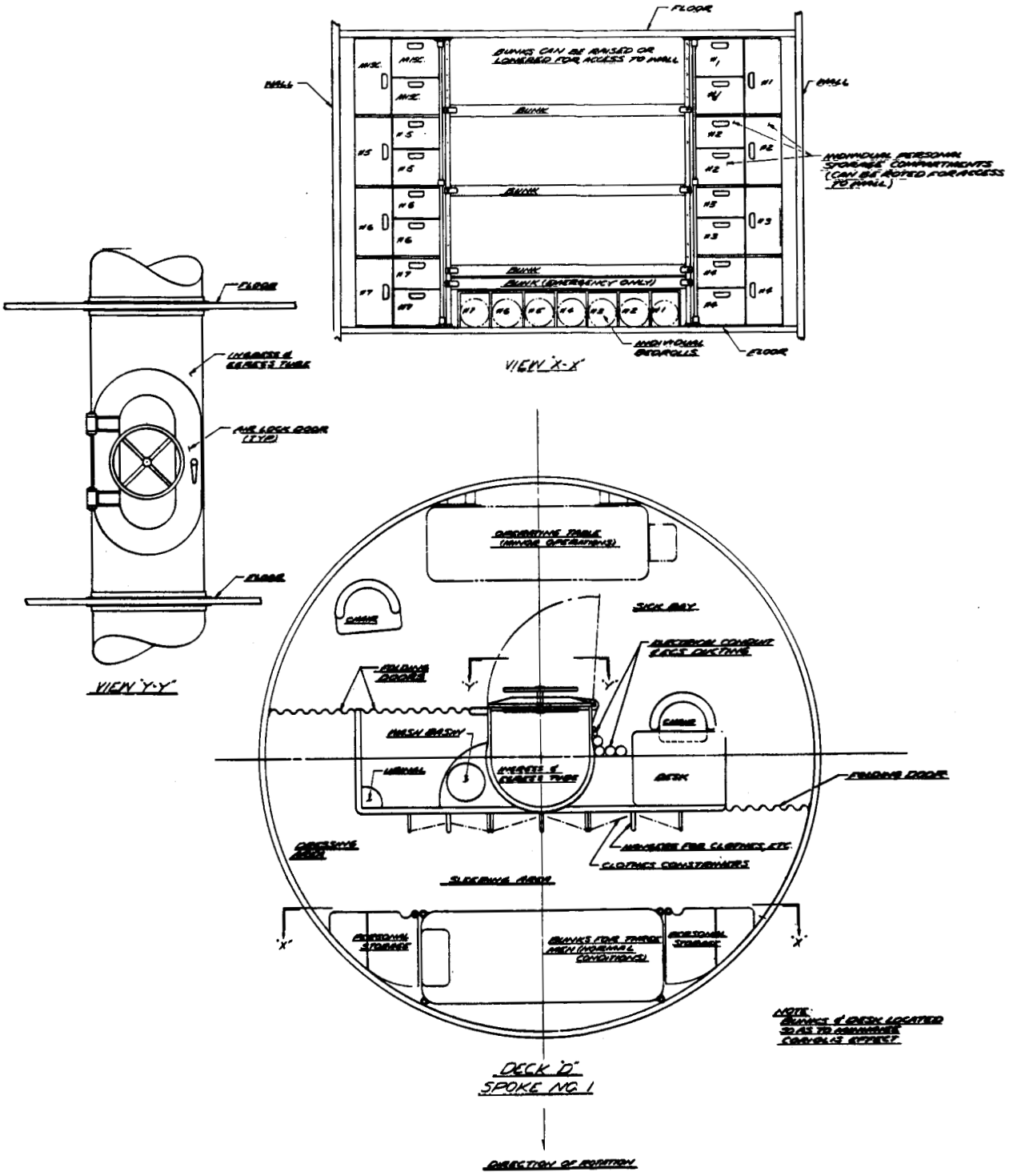


Figure 35. Self-Deploying Space Station "Y" Configuration
(Sheet 4 of 7)

ARRANGEMENT

SPOKE NO.	DECK	FUNCTION
1	A	COMMAND & COMMUNICATION
1-2-3	B	FOOD PREPARATION, EXERCISE & RECREATION
1-2-3	C	PERSONAL HYGIENE
1	D	SLEEPING & SICK BAY
1-2-3	E	STORAGE
1-2-3	F	STORAGE
1-2-3	G	STORAGE
2-3	A	LABORATORY
2-3	D	SLEEPING & LOUNGE

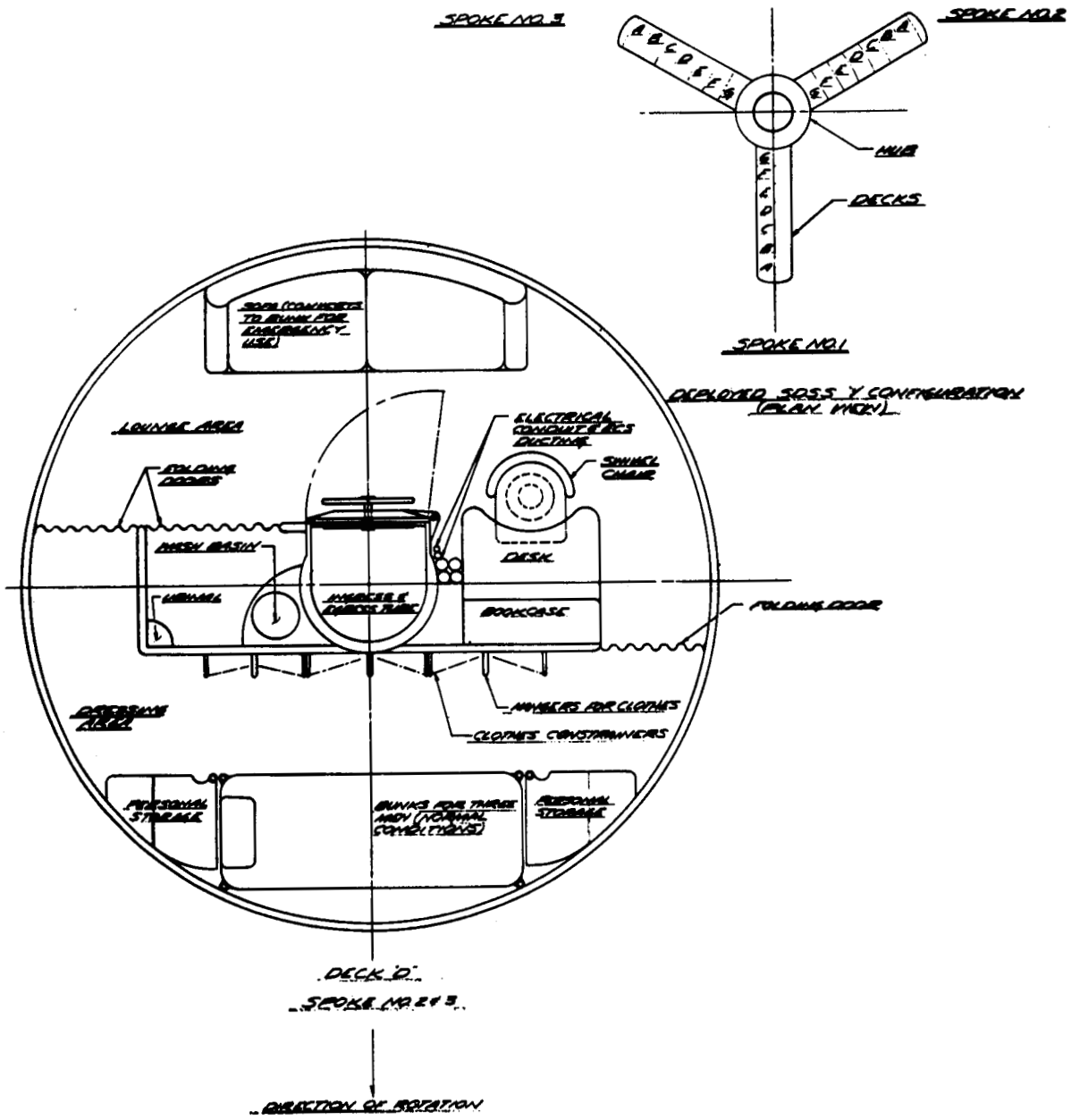


Figure 35. Self-Deploying Space Station "Y" Configuration
(Sheet 5 of 7)

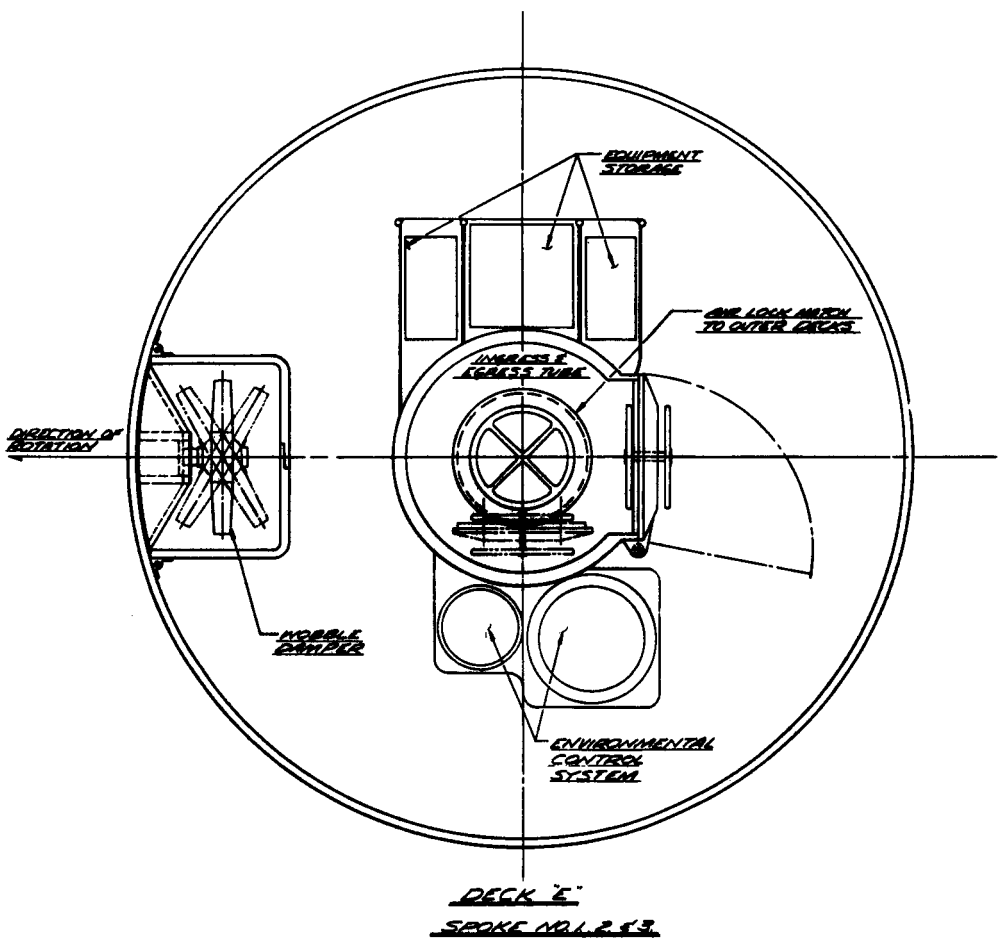


Figure 35. Self-Deploying Space Station "Y" Configuration
(Sheet 6 of 7)

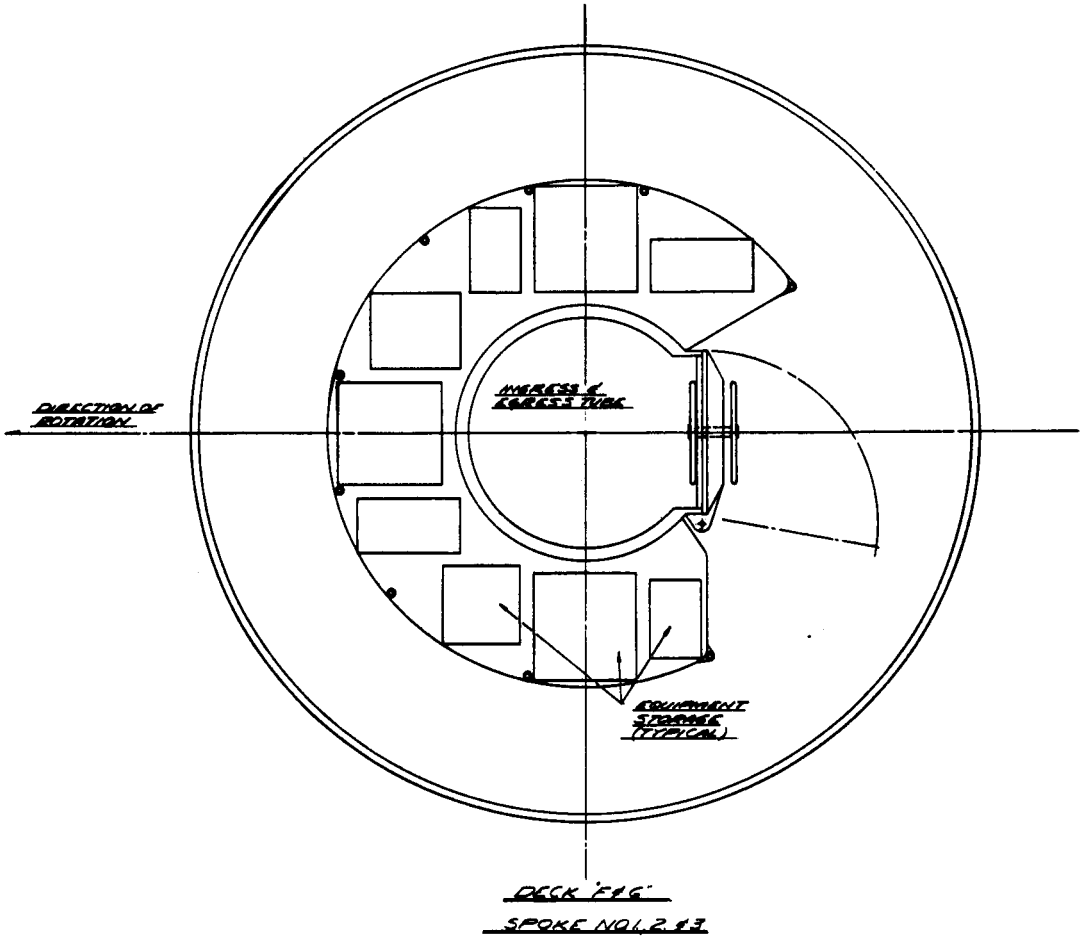


Figure 35. Self-Deploying Space Station "Y" Configuration (Sheet 7 of 7)

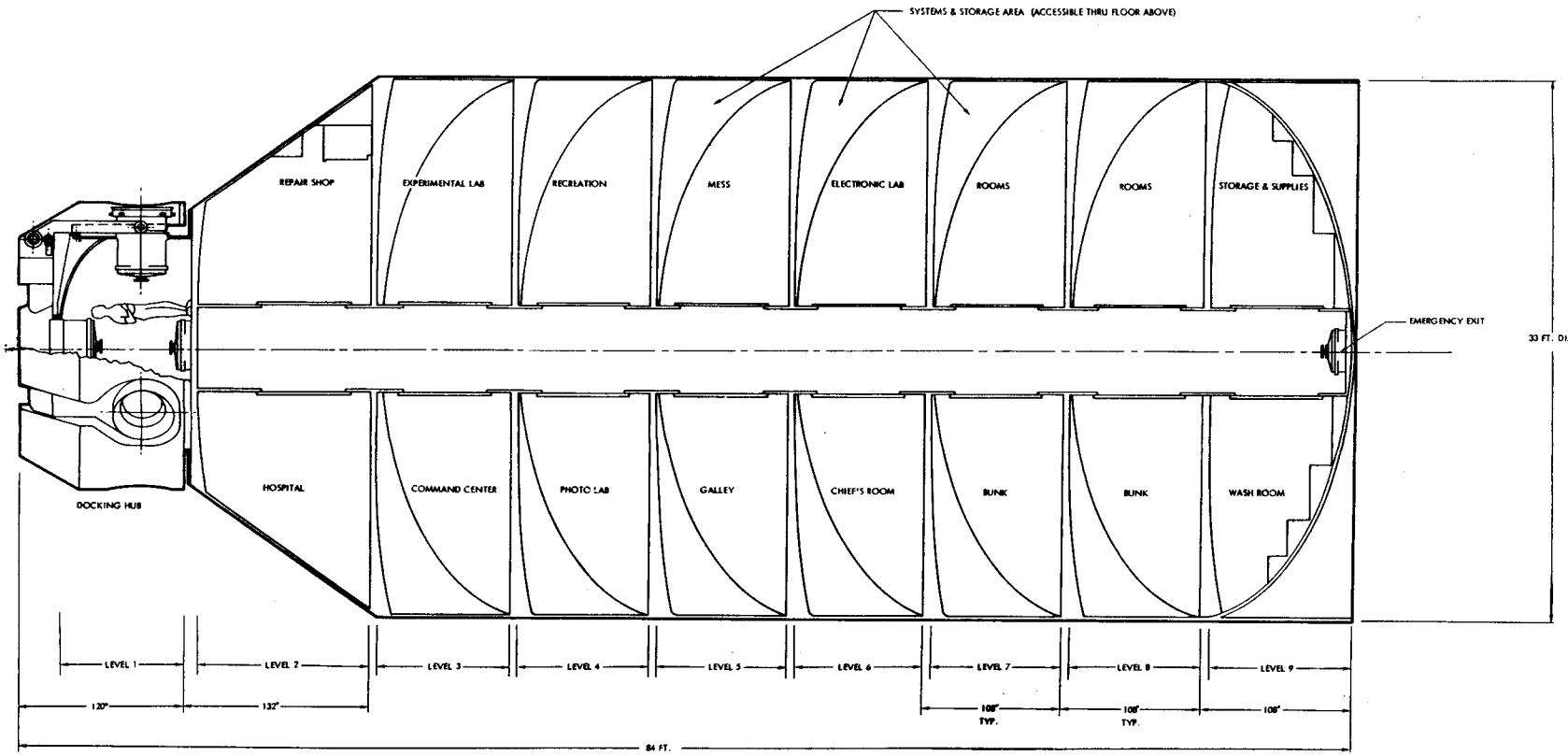


Figure 36. Zero-Gravity Configuration of Space Station, Internal Arrangement

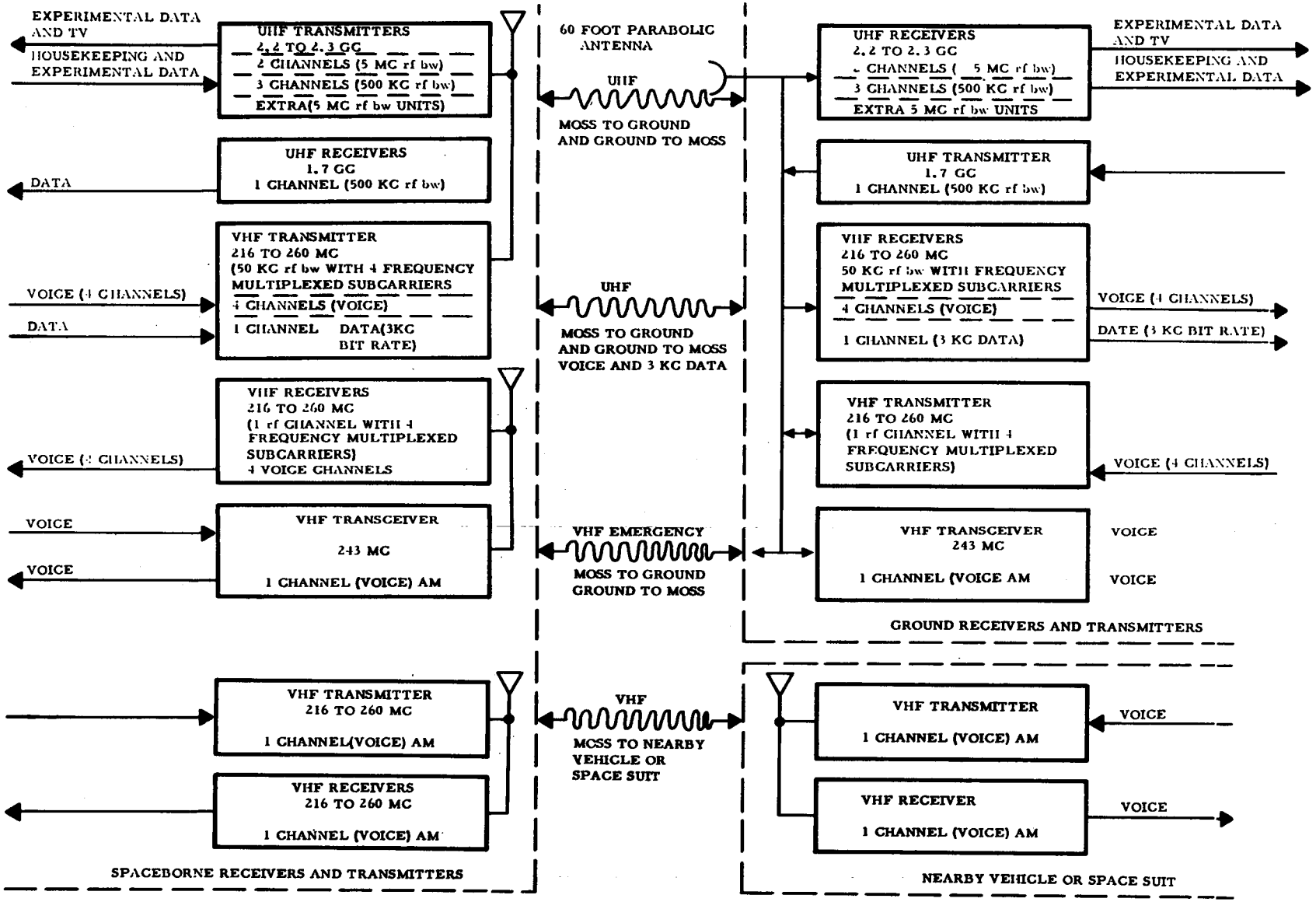


Figure 37. Summary of Radio-Frequency Links

Table 36. Summary of System Parameters

Large Stations	System Parameters
Mission duration	5 years
Crew size	21 or more men
Crew rotation resupply schedule	Minimum of 90-day intervals
Volume	
Total pressurized volume	25,000 to 65,000 cubic feet
Experimental equipment and workspace	1500 to 2000 cubic feet minimum
Power availability	
Amount	Minimum of 1 to 2 KW continuous
Forms available	Unregulated dc, regulated dc, and regulated ac
Preferred forms	Unregulated dc, (rotating systems) Regulated ac (nonrotating systems)
Atmosphere	
Dry bulb temperature	75 F
Content	Mixed gas-oxygen-nitrogen
Pressure level	10 psia
Oxygen partial pressure	4 psia
Relative humidity	50 percent
CO_2 partial pressure maximum	7.6 mm Hg
Data systems	See Table 19
Special constraints	In rotating stations, it is possible to study the effects of reduced gravitational levels and rotation.

MEASUREMENT SYSTEMS

The large space stations, which include the zero G MOSS and the rotating radial configuration, present no constraints with respect to power, weight, and volume. Time to perform all measurements, however, remains somewhat of a problem. On the basis of 8 hours per man per day for measurement duty time and an additional 2 hours per man per day to act as subjects, it would be possible to include in the initial schedule all measurements with the exception of the following:

Recording

Heart movement

Learned procedure

Incidence of aerotitus media*

Skin thickness

Cerebral blood flow

Energy requirements

Kidney stone formation*

Protein assimilation test

Pulse-wave velocity

*Since these are vital diagnostic measures when symptoms are present, they would be evaluated when indicated.

The foregoing measurements are eliminated from the initial listing because of the amount of information they provide for what it costs to obtain them in terms of time. These measurements will be considered for selection in the order in which they are listed and as is indicated by results of other measurement data that certain of the foregoing measurements should be taken or other specified frequencies can be relaxed. It should also be noted that the centrifuge test is considered as a special item in the study, and time to perform the test was not included in these estimates. If a capability exists to perform a centrifuge test, it would take precedence over most of the other measurements; and time could be made available by subtracting measurements from the bottom of the list (Table 18) in such a manner as to retain those measurements which would contribute most to a high level of confidence.

The measurements designated would, if deleted, degrade confidence of the behavioral measurement package by 1.6 percentage points and the biomedical package by 2.8 percentage points.

COMPARISON OF STATION MEASUREMENT SYSTEMS

APPROACH

Data have been analyzed and presented in such a manner as to enable comparison of measurement system capabilities for the selected space station configurations or for any other configurations that may be proposed.

The initial step in the analysis of station measurements systems comparisons consisted of tabulating measurement data as shown in Tables 16, 17, and 18. Tabulation of data in this manner enabled the determination of total weight, power, volume, subject time, and observer time for the safety package, the minimum weightlessness package, and the entire list of measurements for comparison against the constraints of a given station configuration. Initial examination of the data resulted in the determination that weight and power did not present a problem; volume presented a problem only insofar as the Apollo Concept I is concerned; and time to perform measurements was a problem for all configurations. On the basis of this information, measurement procedures and techniques were carefully reviewed for determination of means whereby savings could be realized in terms of time and volume. It should be noted that data once entered for a measurement device were not entered for subsequent measurements using the same device.

Data were revised accordingly and were analyzed in the form of a nomograph that permitted comparisons of costs (time and volume) against estimated measurement information value. Estimates were made of the relative information value and cost (in volume) for various combinations of measurements. The information estimates were made in terms of initial rankings of biomedical and behavioral measures, which were converted to percentile ranks, p, (with the convention that the first percentile rank was taken as 2) and then transformed by use of the formula $i = 50 (\log_{10} p)$. This procedure permitted initiation of the configuration analysis at the earliest possible date so that data from the configurational analysis could provide guidance of final efforts in the measurement analysis effort.

A similar analysis was made of cost in terms of time. From this analysis, it was possible to estimate maximum information as defined obtainable within any given time constraint. It was also possible to list all the measurements in order of their worth in terms of those measurements that will buy the most information at least cost with respect to time. Such a list is shown in Table 37 and provided a basis for selection of combinations

of measurements which yield higher levels of information within available time for performance of measurements.

INTERIM VERSUS LARGE STATION

The primary advantage of a large station over an interim station is that it can accommodate a larger crew. The additional space provided by a large station is not of importance insofar as weight, power, and volume requirements imposed by the experimental equipment are concerned since an interim station is adequate for this purpose (with the possible exception of a centrifuge). The larger crew, however, is of importance from the following standpoints.

1. Larger Sample Size - More subjects ensure a higher confidence level as well as reducing the measurement load per man by easing up on frequency requirements. It may be possible to overcome this advantage with a smaller station by placing several such stations into orbit. However, it is beyond the scope of this study to evaluate the costs of several small stations against a large one.

2. Specialization - A large crew permits specialization of station operating personnel as well as scientific personnel, which permits the scientific crew members to devote more time to measurement duties because it relieves them from system duties. Specialization increases efficiency in other ways, such as making it possible to handle a greater number of urine and blood samples per unit time.

3. Scheduling of Measurements - A large crew permits a greater amount of flexibility in scheduling of measurements because work-rest cycles can be programmed to greatest advantage and there are more individuals available for matching of subjects and observers.

Factors such as the foregoing make it possible to schedule a greater number of measurements and be assured of a higher level of confidence. Other benefits to be derived from a larger station involve such things as better control of extraneous variables including isolation of laboratory facilities from working and living areas, habitability factors that should contribute to a high level of morale, and a greater capability to vary the experimental program in the event of unexpected developments. The capability to provide artificial gravity in a large rotating station could prove to be a very considerable advantage. It is not the purpose of this study to resolve whether or not rotation is required; this is to be answered by the space station facility.

Table 37. An Ordered Listing of Measurements Based on an Estimate of Worth in Terms of Information Provided for Their Cost in Time

Identification	Safety Package or Min. Weightlessness Package	Measurements	Time (min)
13	SP	Blood pressure	0
89	SP	Bowel function evaluation and stool	0
98	SP	Dyspnea, etc.	0
108		Serum catecholamine	0
117		Fecal flora sampling	0
125	SP	Eating habits evaluation	0
135	SP	Nausea - regurgitation - evaluation	0
137		Serum bilirubin	0
4	0	Respiratory volumes	15
*6 & 57	0	Visual acuity	20
2	0	Cardiac output	30
72		Tubular readsorption test	2
14	0	Compound pattern recognition	10
16	0	Recognition of location and movement of limb	10
3	SP	Computation	48
1	SP	Arm, hand manipulation	60
10	SP	Speech perception	21
7	0	Calcium balance study	30
11	0	Oxygen uptake and CO_2 production	20
33		Pulmonary pathology (X-ray)	7
21	SP	Urinalyses	12
64		Reading	5
65		Autonomic hyperactivity	5
69		Writing	5
118		RBC survival	2
49		Bone density	7
23	0	Venous pCO_2 pO_2 pH	15
8		Peripheral detection	45
5		Docking	70
38		Color discrimination	12
25		Plasma volume	17
42		Stereognosis	10
12		Static depth perception	35
106	0	Capillary fragility	10
105		Ocular tonometry	5

Table 37. An Ordered Listing of Measurements Based on an Estimate of Worth in Terms of Information Provided for Their Cost in Time (Cont)

Identification	Safety Package or Min. Weightlessness Package	Measurements	Time (min)
28	0	Speaking	21
40		Tone detection and discrimination	13
31		Exercise test	20
53		GI absorption test	15
129		Heart rate	4
77		Time perception	10
24		Dynamic depth perception	30
60		Problem solving	15
88		Tone pattern discrimination	10
90		Detect of motion	10
91	0	Reflex response and clonus evaluation	10
82		Expiration-inspiratory force	11
46	0	Detection of vibration	20
29	0	Sensation	30
66		Stereopsis	15
19	0	Total body water	45
122		Urine catecholamine	7
43		Muscle function	23
123		Serum 17 kg steroid	7
47	0	Muscle activity and state	25
104		RBC mass	10
81		Tone duration	15
83		Cue abstraction	15
39	0	Serum, urine and fecal Ca and PO_4	30
114		RBC uptake I_{125}	10
41		Venous pressure and circulation time	30
68		Cortical activity	21
32	0	Decision making	42
79		Sound localization	20
22		Detection of angular acceleration	58
76		Glomerular filtration test	21
61	0	State of arousal	25
80		Serum alkaline phosphatates	20
58		Guided performance	30
62		Handling mass	25
86		Vestibular reaction	18

Table 37. An Ordered Listing of Measurements Based on an Estimate of Worth in Terms of Information Provided for Their Cost in Time (Cont)

Identification	Safety Package or Min. Weightlessness Package	Measurements	Time (min)
133		Urine urea	7
18	0	Monitoring	80
45	0	End expiratory pCO_2, pO_2	35
34		Tracking	47
84		Blood plasma protein fractionation	20
36		Brightness discrimination	45
63	SP	Pulse rate	28
71		Leg manipulation	25
52		Association	35
112		Visual illusion evaluation	14
87		Texture discrimination	20
75		Estimation of volume of space	25
20		Detection and discrimination of force	82
92		Olfaction	20
97		Heart sounds	21
115		Joint motion range	14
51		Serum and urine potassium and sodium	40
27	SP	Hemoglobin and hematocrit	68
73		Inductive reasoning	30
44		Detection of linear acceleration	46
15	SP	Blood pressure	140
50		Finger manipulation	45
100	0	Bleeding time	20
120	0	Serum ATP	15
109	0	Serum osmolarity	20
78	SP	Body temperature	35
95	SP	Detection of heat and cold	24
59	0	Blood sugar	47
17	0	Complete blood cell count	127
37	0	Urine creatinine	60
48		Hand manipulation	55
74	0	Tubular excretion test	40
85		Detection of touch	35
121	0	Retinal examination	20
124		Prothromein time	21
126		Color vision evaluation	20
127		Urine 17 KG steroid	20
54		Deductive reasoning	60

Table 37. An Ordered Listing of Measurements Based on an Estimate of Worth in Terms of Information Provided for Their Cost in Time (Cont)

Identification	Safety Package or Min. Weightlessness Package	Measurements	Time (min)
103		Visual fields evaluation	30
131	0	BSP	20
140		Mucosal integrity evaluation	4
141		Breath-holding time	3
21-A	0	Urine osmolarity	140
110	0	O_2 uptake by RBC	30
116		Urinary albumin (1517)	28
56		Recording	70
132		Heart movement	25
134		Tremor	21
26	0	Body positioning	140
107	0	Eosinophil count	35
30		Learned procedure	140
70		Gastro-intestinal tract motility	77
136		Incidence of derotitis media	20
142		Skin thickness	5
55		Cerebral blood flow	105
101	SP	Voiding evaluation	49
111	0	Blood-urea nitrogen	47
*35	SP	Activity and state	350
128		Energy requirements	35
102		Kidney stone formation	75
139		Protein assimilation test	23
130	0	Skin, nailbed and mucous membrane color	70
*99	SP	Respiratory rate	
144		Liver size	10
146		Chest circumference	6
145		Pulse-wave velocity	20
147		Gas formation and passage	28
143	SP	Venous distention	140

INTERIM VERSUS APOLLO I

While the interim stations have certain disadvantages as compared to the large stations, they compare very favorably with the Apollo Concept I. As has already been indicated, the Apollo Concept I is severely limited for workspace to perform measurements and utilize equipment that can be carried on board. Accuracy and validity of measurements would probably suffer from the standpoint of inability to perform techniques properly and poor morale of the crew due to inadequate habitability features. An example of inadequate equipment utilization is the taking of X-ray pictures. Although there is sufficient space to store an X-ray camera on board the Apollo Concept I, it is highly doubtful if interpretable X-ray pictures can be produced within its confines.

The limitation on measurement equipment that can be carried on board the Apollo Concept I does not permit any appreciable variation of the measurement program as may be desired to follow-up leads that appear promising. The interim station is not constrained in this respect because it can accommodate all required equipment. Although the crew of an interim station will be short of time to perform measurements with stipulated frequencies, they will be under no physical limitation with respect to varying the measurement program if it appears desirable to do so to thoroughly investigate unexpected developments or trends.

GENERAL CONCLUSIONS AND RECOMMENDATIONS

As might be expected, a large station compares most favorably with regard to satisfying the requirements for a measurement system intended to evaluate effects of prolonged weightlessness. On the other extreme, the Apollo Concept I can only be regarded as being marginal with respect to satisfying the requirements for a measurement system. It is marginal from the standpoint of the quality of work it would be possible to perform on board and the extent of information that could be obtained.

The difference between an interim station and the minimal station is quantitative as well as qualitative. It is quantitative in that it is possible to accomplish much more in terms of the number and type of measurements that can be obtained. It is qualitative in that conditions for performing measurements will be more nearly ideal to ensure higher validity of results. On the other hand, it appears that the differences between the large station and interim station are not nearly so great. The difference here being essentially qualitative in that a larger number of subjects ensures high confidence in results. If the cost of a large station over an interim station is proportional to that of an interim station over a small station, it would not appear to be worth the difference.

On the basis of the foregoing comparison between the interim stations and the Apollo I station and between the interim stations and the large stations, it is concluded that

1. The storage space, weight, and power capabilities of the currently conceived Apollo I are compatible with the requirements of the minimum measurement program herein described.

2. The workspace and habitability constraints of the Apollo I are, at best, marginally compatible with the requirements of the minimum measurement program herein described.

3. The interim space stations meet the weight, power, and volume requirements for a total measurement program. This program goes considerably beyond that of the minimum presented herein.

4. The work space and habitability features of the interim station are compatible with the requirements of the measurement program, although considerable care must be exercised in designing such a station to ensure compatibility of duties involving crew measurement and other activities.

5. Subject to the solution of scheduling problems, the interim station provides measurement time per man for the requirements of a measurement program somewhat beyond that of the minimum acceptable program; but more importantly, it provides a capability to vary the program as required to investigate all measurements of interest.

6. The large space stations, as compared with the interim stations, offer benefits for the measurement program in terms of larger sample size, capability for a more extended measurement spectrum, and greater crew capability for taking measurements and an enhanced working environment.

7. The larger space stations do not offer significant advantages over the interim stations in terms of weight, power, and equipment volume capability.

On the basis of the foregoing conclusions and preceding discussion, it is recommended that

1. The Apollo I space station be considered as a measurement facility only for a more limited program than recommended for thorough weightlessness investigation.

2. The measurement program herein described should be considered as compatible with the capabilities of the interim stations.

3. The advantages of larger space stations should be seriously considered as enhancing the growth potential of the measurement program described in this report.

V. CREW MEASUREMENT SYSTEM

SYSTEM PARAMETERS

The techniques of preparing crew measurement system (CMS) packages for various space station configurations has been discussed in section

A CMS package must be designed in one of two ways: (1) a model CMS can be developed and a space station then designed to accommodate it, or (2) a CMS can be designed to fit a given space-station configuration.

One of the objectives of this study has been to develop a basic CMS package to serve as a data source. The basic packages for biomedical and behavioral measurements discussed in the following pages can be adapted by mathematical processes for any specific space-station configuration and mission.

BASIC BIOMEDICAL CMS

Table 9 is a rank order listing of the biomedical measures and the associated selected techniques. (For details regarding techniques selection and associated equipment, see the Appendix.)

The Rank Order Percentage column indicates the relative importance of the listed measures taken here as a confidence rating. The sum of the rank order percentages for any given CMS package drawn from the basic package will equal a percentage of coverage based on the confidence rating assigned to the measures listed in Table 9 . For example, using all possible measures from the basic package would be only 98. 2 percent effective since there are no currently feasible techniques for measures 45, 55, 82, 88, and 95.

The Total Test Time column lists the number of man-minutes estimated to perform the measurement by the selected technique listed.

The Level Of Training column indicates those techniques which can be applied by an astronaut (indicated as A), a medical technician (indicated as T), and a physician (indicated as P). This ranking assumes only rudimentary medical training for astronauts, that a technician can perform all techniques indicated A and T, and that a physician can accomplish all listed feasible techniques. This column is not totaled since the sum would be of no use without consideration of frequency.

The Frequency column lists the number of times it is recommended that each measure should be performed each day. A frequency of one or more times per day is recommended for only a few measures so most of the entries in this column are fractions such as 1/7 = once every 7 days. It should be repeated that the listed frequencies are arbitrary and would be altered in an operational situation as indicated by test results. They are, however, a realistic estimate for initial manning requirements.

The Subject, Observer and Total columns under Time In Minutes Per Subject Day list the minutes per day required for each measure. The Total is the product of Total Test Time and Frequency. The subject and observer times indicate the minutes required to test the subject and the time required for the observer to set up, test, analyze samples when applicable, and process any resulting data. These columns are totaled but the results (as explained in the following pages) are not indicative of actual time requirements.

The weight, power, and volume data listed under equipment and instruments are for those items which would be required to perform the listed techniques. These weights would not change regardless of crew size or mission length.

The weight and volume data under 90-day, 1-man supplies and spares includes figures for those material and hardware requirements which would vary in proportion to mission duration and crew size. The spare weight and volume were arbitrarily designated as 10 percent of the associated equipment figures. There were no forecasted power requirements for items in this category.

BASIC BIOMEDICAL CMS TIME CONSIDERATIONS

The sum of the times for individual measures compiled in Table 9 is as follows:

Subject minutes per day	131.3
Observer minutes per day	217.3
Total man-minutes per day	348.6

Several things need to be clarified regarding these figures. First, the ratio between subject and observer time can be disregarded. The observer time is longer because test setup times and all analyses and data processing times were included in the observer time. For time analyses the subject and observer involvement can be assumed as equal, which means that only total times need be considered. Second, some techniques are used for more than one measure and time can be saved by eliminating equipment

setup and subject preparation times. For example, it is estimated that 25 minutes can be saved by using a single electrocardiographic examination for measure M17 and M79. A third consideration is that many of the tests can be conducted while subjects are on duty, especially during monitoring activities. (For example, taking blood pressure, temperature, and pulse rate). Fourth, single blood and urine samples can be used for numerous measures and time is saved because an allowance was included for each separate technique.

The four factors mentioned above result in a net man-minutes per subject day of:

Total from Table 9	348.6	
Time saved by:		
Test combinations		27.6
Subject on duty		43.5
		71.1
Net time	277.5	

Another very important consideration is that subsequent measurement times will be substantially reduced. This is because the analysis of two or more samples of blood or urine require only short additional times due to equipment setup time saved. Analysis of the basic package in Table 9 indicates that 55.9 man-minutes would be saved on subsequent subjects. Thus, the man-minutes per additional subject would be 221.6.

The times discussed above have been referred to as times per subject day. However, they actually represent the total time for each member of the experimental team since subject-observer teams would be formed when feasible, and the schedule of the complete space-station work load would assign duties based on individual capabilities and equitable individual work loads. The average time required per crew member for any CSM package would be

$$T = \frac{Mi + Ms(C-1)}{C}$$

in which

T = Average time per crew member

Mi = Time for initial measures

Ms = Time for subsequent measures

and

C = Number of crew members

Substituting for the values obtained from Table 9, the times required for this package would be:

Number of Crew Members	Average Minutes Per-Day Per Crew Member
2	249.6
3	240.2
4	235.5
5	232.8
6	230.9

The relation of time requirements to the rank order measurement list is illustrated in Figure 38.

WEIGHT DATA FOR THE BASIC BIOMEDICAL CMS

The two weight factors shown in Table 9 are graphed by Figure 39 showing the cumulative weight requirements in relation to the basic rank ordered biomedical measures. The weights for both equipment-instrumentation and supplies-spares are shown. The requirements for any mission can be calculated

$$\frac{W_T = W_E + C\, W_S\, M_T}{90}$$

in which

W_T = Total weight

W_E = Equipment-instrument weight

C = Number of crew members

W_S = Supplies-spares weight

M_T = Length of mission in days

POWER DATA FOR THE BASIC BIOMEDICAL CMS

The additive value of power requirements is not needed since all the equipment would not be operated at the same time. The peak power requirement is 550 watts for the X-ray used in measures 16, 24, 34, and 52.

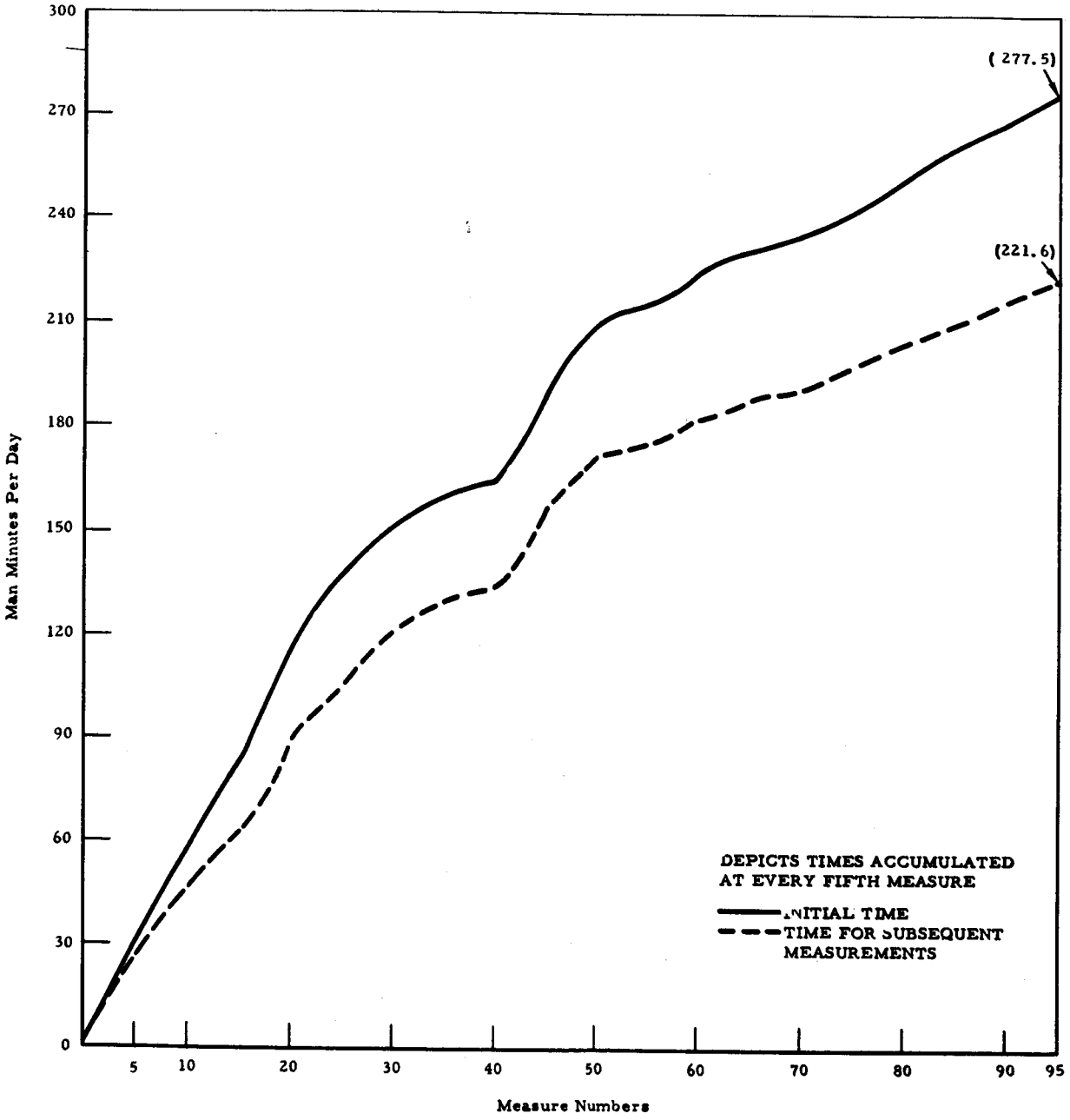


Figure 38. Relation of Time Requirements to the Rank Order Measurement List

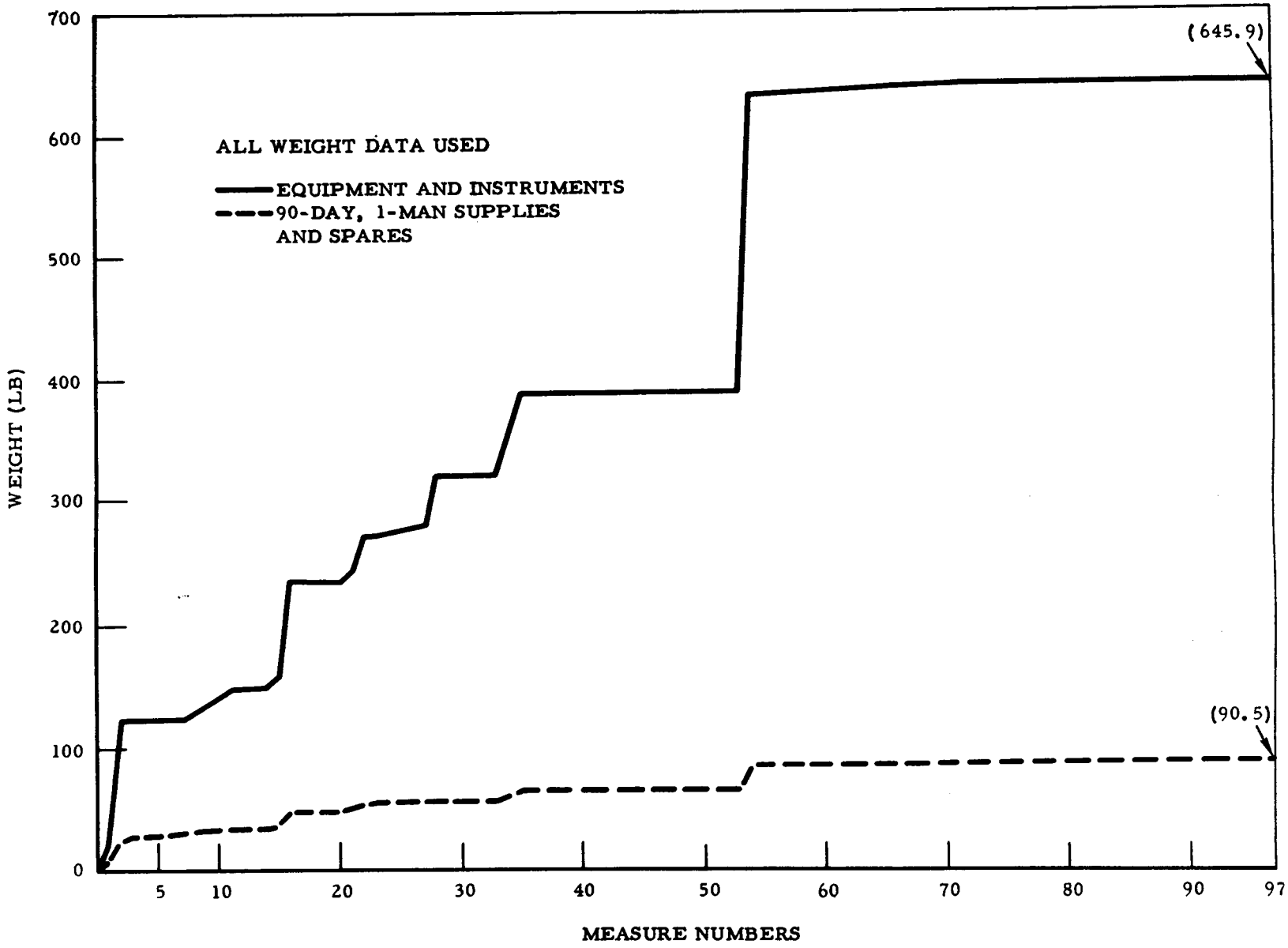


Figure 39. Accumulated Weight for Biomedical Measures

VOLUMETRIC DATA FOR THE BASIC BIOMEDICAL CMS

The cumulative volumes required for equipment-instrumentation and supplies-spares are graphed in Figure 40. The formula shown for determining weights can be used for volume also by substituting volume (V) for weight (W).

ADDITIONAL WEIGHT, POWER, AND VOLUME CONSIDERATIONS

The weight, power, and volume requirements for the data management and centrifuge equipment discussed in Section III are not included in Figures 39 and 40. It is assumed that the requirements for this equipment will receive separate consideration. It must be noted that adequate provisions must be made for both biomedical and behavioral data processing, recording, and transmission.

It is suggested, where written records of biomedical and behavioral measurement are required, that appropriate forms be incorporated in individual crew member logs. There should be no consequential increase in either weight or volume if carefully thought-out forms for measurement data are incorporated in log books.

BEHAVIORAL

(Refer to Sections II and III and Appendix B.)

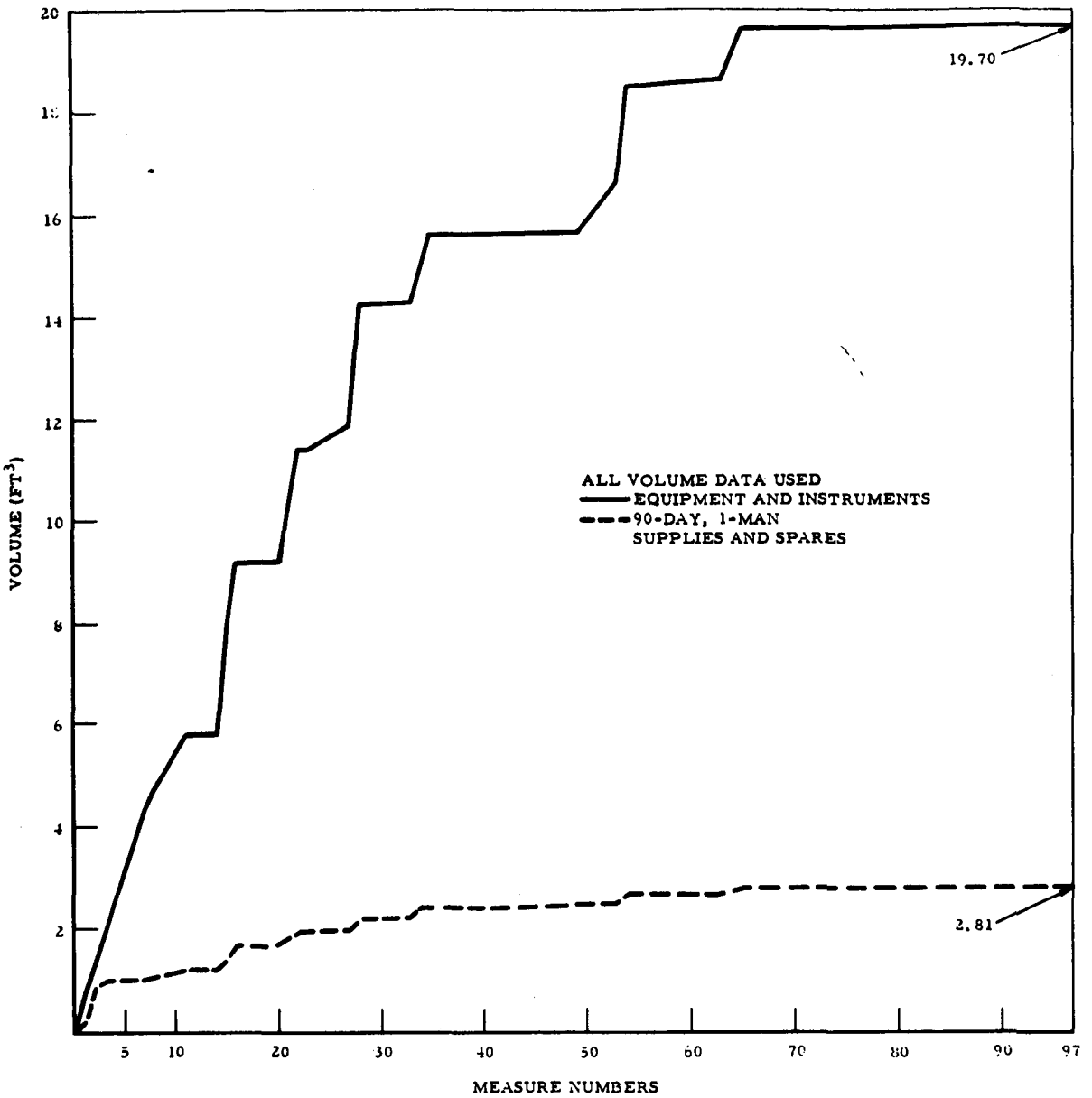


Figure 40. Accumulative Equipment and Instrument Volumes and 90-Day, 1-Man Supplies and Spares for Basic Biomedical Measurement Package

CONFIGURATION

The present study has included definition of equipment components which could be logically grouped and made readily accessible by installing or mounting them in specially designed panels or cabinets. Design concepts of individual panels, consoles, work counters, and cabinets, were then fabricated into plywood mock-ups in such a manner that they could be arranged to outline a laboratory area.

Workspace layout and working area were then evaluated by simulating measurement procedures in various arrangements of the mock-up components. Table 38 shows a listing of the major work areas that were evaluated and indicates the workspace in square feet of floor space that was found to be adequate for performance of the required procedures. Figures 41 through 50 depict subject and/or observer performing the operation indicated for the respective work areas. It should be pointed out that 56 square feet (Table 38) represents area required for floor space and consequently does not include workspace over counter surfaces or access to equipment components for such operations as calibration and maintenance.

It was calculated that a total floor area of 90 square feet is required for the crew measurement laboratory. This includes approximately 35 square feet occupied by built-in components. A laboratory of this size is compatible with the space available in one level of a MORL, or Concepts II and III Apollo-type space station.

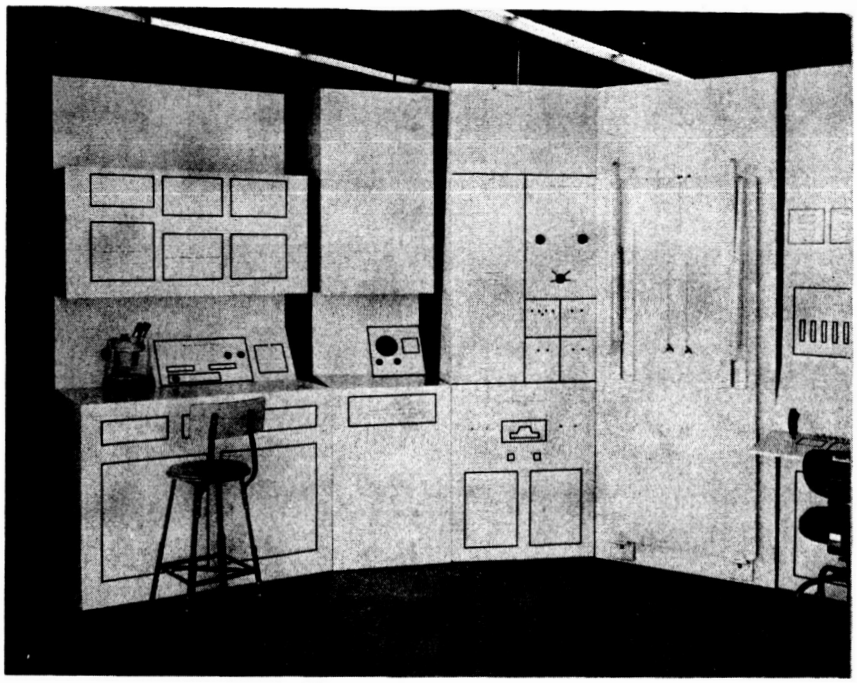


Figure 41. Over-All View of Biomedical Measurements Area

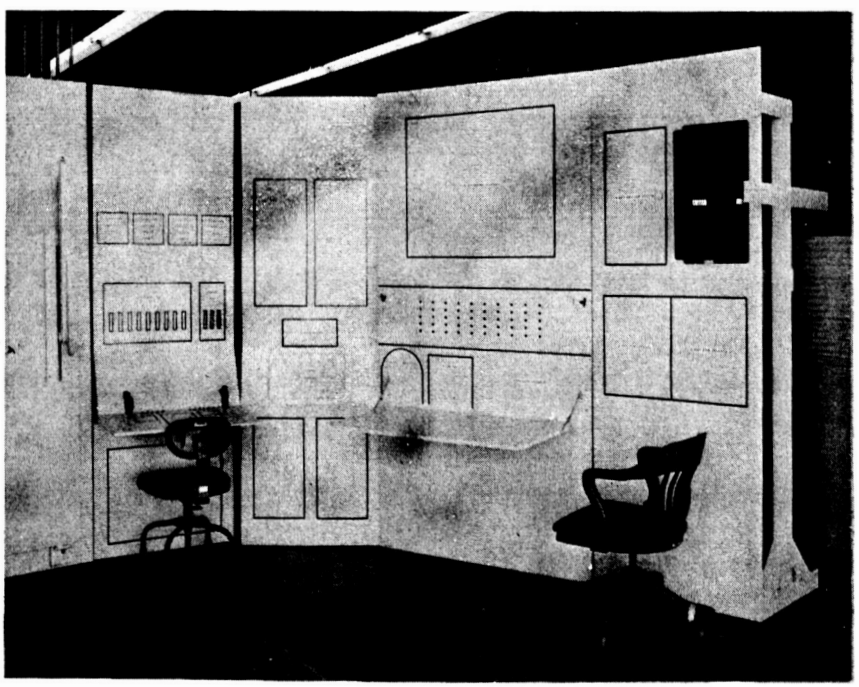


Figure 42. Over-All View of Behavioral Measurements Area

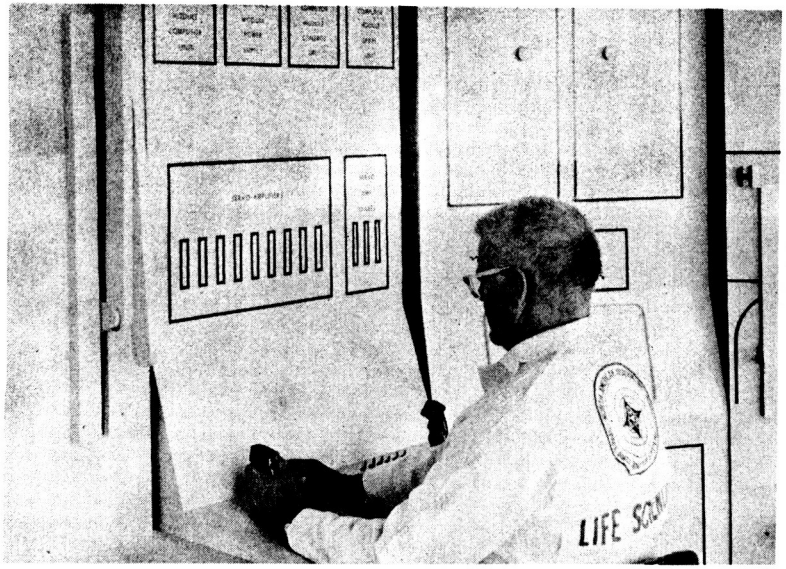


Figure 43. Simulator Measurements

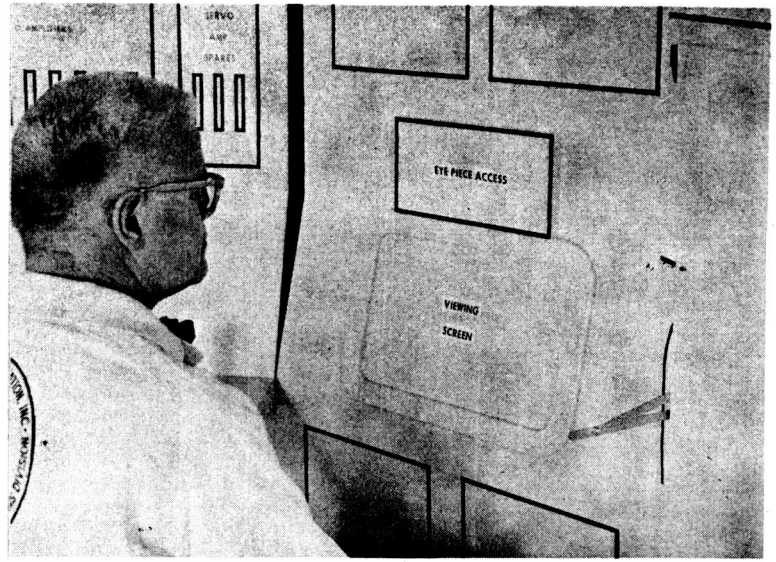


Figure 44. Visual Measurements

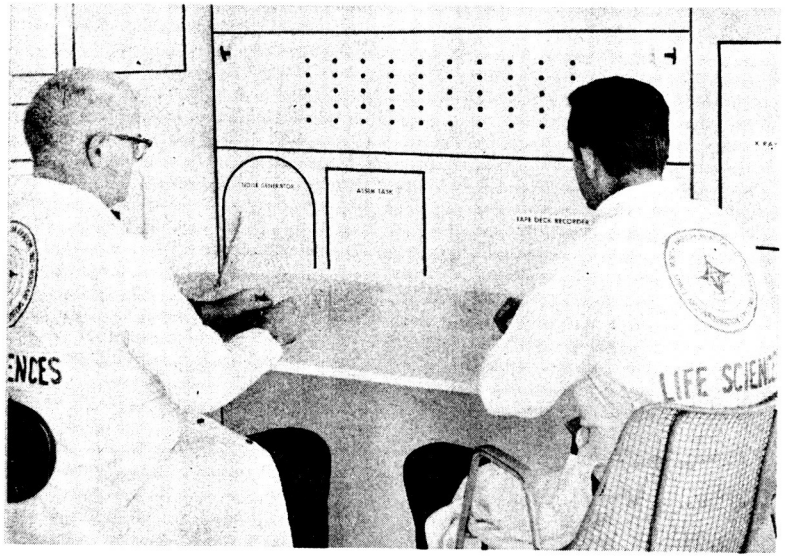


Figure 45. Manipulation, Auditory and Speaking Measurements

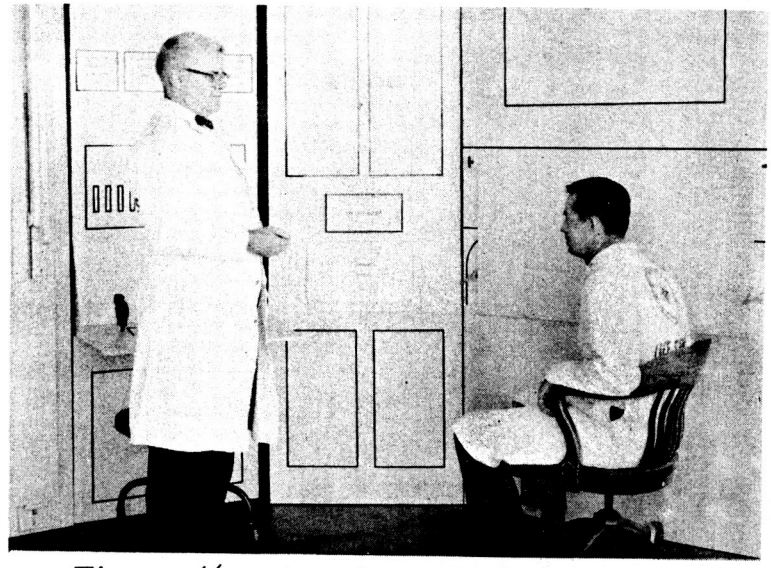


Figure 46. Acceleration Measurement

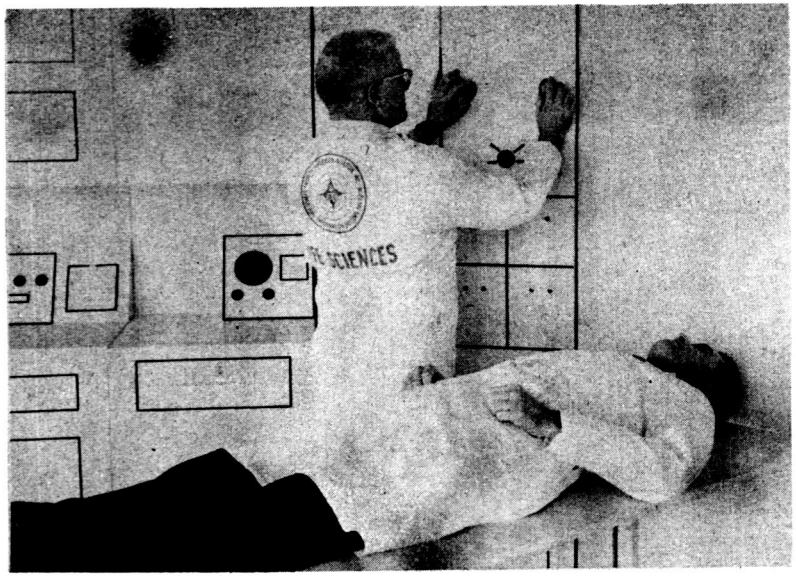


Figure 47. Electronic Analysis

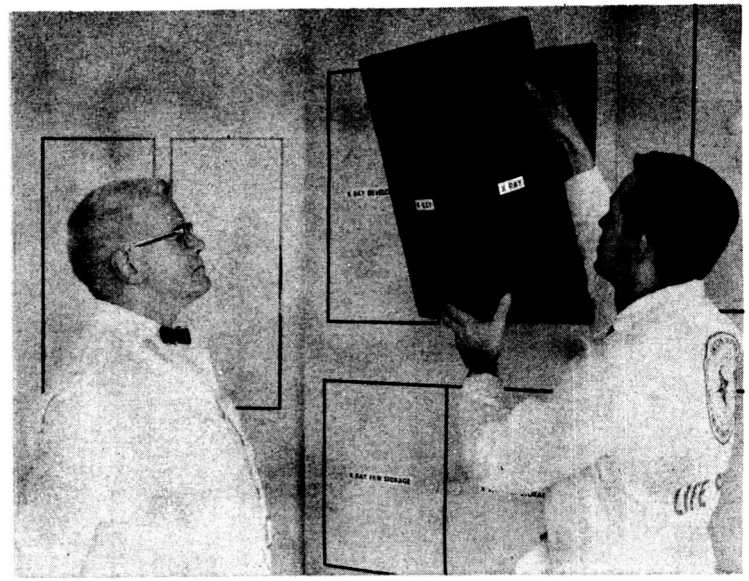


Figure 48. X-Ray

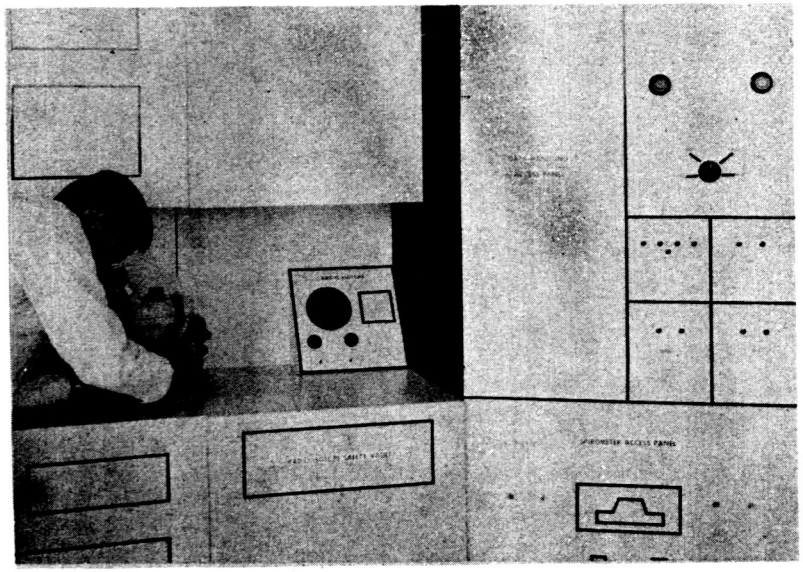


Figure 49. Microanalytic

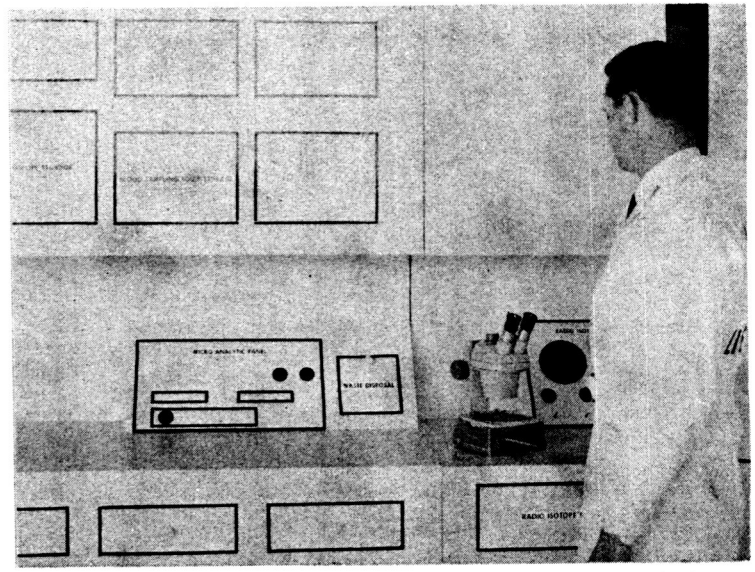


Figure 50. Spirometer and Radioisotope

Table 38. Workspace Requirements

Illustration	Work Area	Floor-Space Dimensions (inches)		Work Space (square feet)
		Built-Ins	Working	
3	Simulation tests	30 x 18	30 x 32	7
4	Visual tests	30 x 12	Included in simulation test	
5	Manipulation, auditory and speaking	48 x 12	48 x 32	10
6	Acceleration test	24 x 24	6 x 48 included in manipulation, auditory and speaking	2
7	Electronic analysis			
8	X-ray, subject preparation, blood sampling	36 x 12	84 x 36	21
9	Spirometry, exercise	30 x 24	All but 30 x 36 included in X-ray	9
10	Micro analytic	48 x 24	All but 48 x 12 included in X-ray	4
9	Radio-isotope	24 x 24	All but 36 x 12 included in X-ray	3
7	Exercise area	12 x 12	Included in X-ray area	
			Total	56

EXPERIMENTAL PROGRAMS

OBJECTIVES

"What are the effects of weightlessness upon man's performance and well-being?" The study effort is directed to this question. However, in order to develop a specific experimental program it is necessary to have a concise statement of the objective. The specific questions posed for the purpose of developing an experimental design were the ones listed below. Each of these questions is to be interpreted as a two-part question; one part being directed toward man's well-being, the other part being directed toward his behavior.

Will there be changes due to weightlessness? (attention first to those functions that are important for space mission success and man's survival)

After long term exposure to weightlessness, can man survive and perform during reentry and upon return to normal gravity conditions?

For those functions affected by weightlessness, what will be the course of change over the period of a Mars mission (three years)?

For those changes due to weightlessness, how do the responses of individuals in the astronaut population of the future differ?

If there are effects due to weightlessness, what is the specific mechanism affected and what is the nature of the effect?

While these are taken as specific questions to guide the development of the experimental program, it is understood that the program of investigation under weightlessness probably will eventually evolve into a program of testing solutions to weightlessness problems if weightlessness effects are found. However, consideration of questions about specific solutions to weightlessness problems is considered to be beyond the scope of the experimental program under consideration here. Realization that the long-range objective is to solve weightlessness problems if any are found, does serve as a reminder that the program has a practical cast. That is, it serves as a reminder with the first objective to find out whether or not there are weightlessness problems so that effort can be directed toward a fix of any

that are found; only secondarily is the program one of pure scientific investigation of the effects of weightlessness. The design of experiments to determine cause of the effects of any weightlessness effects found is therefore required primarily as a means for gathering information necessary for the design of solutions to weightlessness problems. Thus there is an order of importance to the questions listed above. This order of importance is reflected in the order of listing. Since the detection of all effects due to weightlessness is of primary importance, no experimental design which gives answers to questions 2, 3 and 4 before obtaining a complete answer to question 1 is to be considered of highest quality.

In order to answer the questions listed above, it is obviously necessary to conduct a large number of experiments under weightlessness. The experiments to be performed, however, will all be executed with the same crew, in the same vehicle, and over the same experimental test period. Therefore, the separate experiments require an over-all framework so that they will properly fit together to form a package of experimentation that can be conducted judiciously with efficiency. One of the requirements for an experimental design is thus an over-all plan of experimentation to set the basic framework within which each individual experiment can be designed. A second requirement is, of course, a complete design for each individual experiment. Let us consider the over-all plan first.

OVER-ALL FRAMEWORK FOR EXPERIMENTATION

The basic plan of experimentation within which all individual experiments for the program must fit is summarized by the chart below. Basically the over-all plan permits using each subject as his own control and comparison of any experimental subject with a matched control. The plan provides for measurement prior to the introduction of the experimental variable of weightlessness, measurement under weightlessness, and measurement upon return to normal gravity.

Experimental Group	I Training for roles as subjects and observers	II Measurement under simulated conditions on the ground for h days	III Measurement in orbit for h days	IV Post-orbit measurement
Control Group (matched subjects)	I Same	II Same	III Measurement on the ground under simulated conditions for h days	(used as experimental subjects, Phase III for 2 h days

This plan requires extensive measurement on the ground under conditions which faithfully simulate those that will prevail in orbit (Condition II for the Experimental Group and conditions II and III for the Control Group). This extensive ground program is not one that will be accepted easily. However, from the design point of view it is required for two reasons:

1. It is required to obtain a before measure for all tests where this is possible so that the efficient before-after analysis using the subject as his own control can be employed. Without the efficiency of the before-after analysis, a more costly program of in orbit measurement would be required to obtain equally good results;

2. In order to separate the effects due to weightlessness from effects which should properly be attributed to other factors such as confinement, it is necessary to replicate the measurement program using a control group that does not undergo weightlessness. Clearly it is important to separate out effects which are not due to weightlessness because further experimental investigation of such effects can be carried on more cheaply on the ground.

The plan calls for an extensive measurement program upon return of the experimental subjects to normal gravity. This measurement program on the ground is not suggested simply to take advantage of extensive ground-based facilities. Rather, it is required to obtain measurements relevant to Question 2 "Can man survive and perform upon return to normal gravity conditions?" The experimental designs developed for individual tests are based upon the expectation that information about survival under one "G" can best be obtained under normal gravity conditions and therefore do not call for measurements relevant to this guestion in orbit. To insure that no subject will be kept under a weightless condition so long that he cannot survive to return to normal gravity, the over-all plan for experimentation assumes a replication of the plan shown above with increasing periods of time, h, from replication to replication. The specific time periods assumed for each replication are discussed below. It should be sufficient here to note that the plan calls for obtaining data under "return to normal gravity conditions" at several intervals of time in order to obtain an answer to the Question can man survive and perform during reentry and return to earth.

To answer the questions about predictability to future missions, control over the number of measurements performed and the number of subjects employed is required rather than control of over-all design. Control over these factors will also be discussed below. The over-all plan of experimentation is important however with respect to the question "What are the specific mechanisms affected by weightlessness?"

In order to answer this question there must be a logic built into the inter-relationships among the tests included in the program so that one can trouble shoot the information obtained to arrive at an identification of the specific function involved in an observed degradation. No simple plan can be given for implementing this logic. The need for it will be familiar to anyone who has conducted a series of related experimental investigations, however. It is enough to say here that the need for establishing deliberate relationships among tests so that it will be possible to draw inferences from the measurement obtained for different tests was recognized in selecting the biomedical and behavioral tests listed. Indeed, part of the problem of selecting a subset of all the listed tests is that of preserving as much of the logical interrelationships among the tests as possible.

DESIGN OF INDIVIDUAL EXPERIMENTS

The design of the experiment utilizing each test is given for each of the behavioral tests on the data sheets in Appendix B. Wherever possible the design built around each behavioral test utilizes a subject as his own control. However, in many cases it is not possible to repeat the same test upon a given subject and in these cases the design calls for a matched control. Each of the designs may be inferred to follow the over-all plan described above. In the case of the biomedical tests, the design for each test calls for the use of a subject as his own control.

The design of an individual experiment calls for more than notation of what will be compared with what. The design also requires attention to the measurement schedule. That is, for each design one must identify the period of time over which measurement will be made and the number of measurements will be made and the number of measurements to be made in that period. The attempt to do this for each of the individual experiments in the biomedical and behavioral list forced consideration to be given to a number of related factors before a solution could be found to this question of measurement schedule.

THE DEVELOPMENT AT A MEASUREMENT SCHEDULE FOR EACH EXPERIMENT

To begin our analysis of the problem, we will suppose that for a given test and for a given subject the degradation can be described by a simple functional relationship. For many of the tests an exponential decay seems realistic, but for simplicity we will use a linear model. (That frequency which is high enough to detect an important difference under linearity assumptions will be approximately the same as that necessary to detect the same difference under an exponential model.) The assumption of

linearity at this point in the analysis will not prohibit the actual functional form from being studied during the mission.

Suppose that one testing relative to the j^{th} measure consists of r_j duplicate measurements of the response (e.g., blood pressure, pattern recognition, hand manipulation, pulse), and that the entire testing is repeated n_j times throughout the mission. Let the error variance of duplicate measurements within a test be $\sigma^2_{w,j}$ and the error variance between tests be $\sigma^2_{B_j}$. For the present it is assumed that there is no serial correlation between successive complete testings. There will be sufficient opportunity to determine the actual covariance structure of the various measurements and to obtain good estimates of the variance components during preliminary informal study and the formal pretest. The primary statistical questions are to determine the measurement schedule (select values of r_j and n_j) which meet the objective of extrapolation to longer test missions. The frequencies necessary to meet the objective of short-range prediction for safety reasons can presumably be set by clinical considerations.

As a model for the results of a given test on a given subject over time we will choose the following:

$$Y_{k\ell} = \mu + \alpha_k + \beta x_k + e_{k\ell}$$

where $Y_{k\ell}$ is the response or ℓ-th duplicate of the k-th repetition of the test, μ is a grand mean, α_k is the between test effect which is normally distributed with mean 0 and variance σ_B^2, β is the slope of the assumed linear degradation, x_k is the time of the k-th repetition of the test, and $e_{k\ell}$ is the experimental error of the ℓ-th repetition of the k-th test and is normally distributed with mean 0 and variance σ_w^2. (Reference to the subscript j has been dropped.) Assuming that the tests are done at equally-spaced intervals and scaling the time interval so that the mission begins at time 0 and ends at time 1, the variance of a predicted value at time x is given by

$$\left[12(x-1/2)^2 + 1\right]\left[\sigma^2_w + r\sigma^2_B\right]/nr$$

For most of the tests the quality function can be taken to be $1/(1+S/d)$, where S is the standard deviation of a predicted value at time x and d is the smallest difference which must be detected. After more experience is obtained (in particular after a ground-based pretest) it may be possible to use more sophisticated quality functions.

For measures associated with well-known tests the value of r, the number of duplicate measurements of which a "test" consists, may be a traditional value. For other tests, there will be more freedom in choosing a value, and for these tests it is possible to make an optimum choice.

The time, S_j, it takes to do the j-th test is partly setup time spent in getting ready for the test. If the test consists of r duplicates, it seems reasonable to express the total time spent in the form t_0+rt where t_0 is set-up time and t is the time to take one measurement. For any fixed total testing time it is easy to derive a cubic equation which r must satisfy so that the variance of predicted values is minimized. When r has been chosen the value of t_0+rt becomes S_j, the time for one testing. For each contemplated test the expression above can be used to screen the tests before the over-all optimization is done. Given a degradation of d units to be detected, it is an easy task to solve for that value of n such that the $_y$ confidence interval on a predicted value is less than d at time x.

It can be seen that in order to arrive at a prescribed frequency of measurement for a test, we must know the length of time over which measurement can be accomplished in orbit and the number of measurements required to detect a difference, d. Further, in order to determine the number of measurements we need to be able to identify the smallest difference, d, that we wish to be able to detect, and the within-subject variances. We must, of course, state the level of confidence that we wish to achieve in detecting a difference of the size, d. Let us therefore consider these factors.

LENGTH OF THE EXPERIMENTAL PERIOD OVER WHICH MEASUREMENTS CAN BE OBTAINED

We consider three factors as bearing upon the determination of the length of the experimental period.

1. Logistic support requirements

2. Safety of the crew in orbit

3. Safety of the crew upon return to normal gravity

For any vehicle which incorporates a reasonable portion of behavioral and biomedical measurement list of instrumentation, there is little reason to consider safety of the crew in orbit as a limiting factor. Thus it appears that the weight, power and volume allowances for any station that is likely to be used will be liberal enough to incorporate all measurements required to obtain knowledge of crew safety. It will not be necessary to return crews to the ground so that extensive measurement can be made to evaluate their capability to continue under zero G. Logistics support schedules for a given vehicle must be considered in determining the length of stay, however. For vehicles of the Extended Apollo and MORL type, current evidence is that the logistic supply schedule will be once every 90 days. For an MOSS type of vehicle the supply schedule is estimated at once every six weeks. Let

us then take 90 days as the maximum period over which measurement will be made without opportunity for the scheduled rotation of crews. Let us now ask whether the requirement for insuring safety under normal gravity conditions upon return is compatible with a 90-day period of measurement. (It must be kept in mind that we have proposed to base our information about performance upon return to normal gravity upon measurements obtained after the return of crews to the ground.) Let us assume that prior to the first launching of an experimental station that we will have data after return to one G for crews exposed to weightlessness for a period of up to 15 days. The question now becomes by what factor are we willing to extend the data based on 15 days of weightlessness in order to determine the safe length for the first measurement period. Realizing that flights for crew rotation and logistics support add considerably to the cost of station operation, it is certainly desirable to minimize the number of such flights, which means maximizing the factor by which one is willing to extend the first period of measurement beyond the initial 15-day data point. For safety, a factor of two is suggested. Using a factor of two, initial data for 15 days, and a maximum interval between flights of 90 days, we arrive at the following schedule for a 300-day period.

Cumulative Days in Orbit at Time of Support Flight	Days Since Last Support Flight
30	30
60	30
120	60
210	90
300	90

THE SMALLEST DIFFERENCE OF INTEREST

It has been shown that in order to determine the number of measurements required we must identify the size of difference we wish to check at a given confidence level. Let us choose that confidence level to be the 95-percent level. For the biomedical tests, the smallest difference that we wish to be able to detect can be set for most tests on the basis of what we already know about the amount of degradation of physiological function that can be tolerated with safety. However, in the case of the behavioral tests, the determination of d cannot be made against a background of information about the amount of degradation to be expected in job performance as related to changes in test performance. However, in the case of the behavioral tests we can reason in the following manner. On a mission such as a Mars mission, present limits of hardware reliability make it

necessary to utilize crew performance to achieve high probability of mission success. Therefore, for a Mars mission we are just as interested in very small degradations in the reliability in crew performance as we are in very small degradations in the reliability of hardware components. It follows then that in behavioral testing we are not merely searching for degradations so large as to be obvious, but rather we are searching for degradations which may be quite small and difficult to detect. We are interested in being able to predict small changes in the reliability in which crews perform various assigned tasks on a Mars mission. With this rationale in mind, the difference of interest in the case of behavioral tests may be said in general to be the smallest difference that we can detect at reasonable cost. Even this rationale does not get us out of the woods with respect to behavioral testing and prior to the final selection of behavioral tests for an experimental program to investigate weightlessness, it is strongly recommended that ground experimentation be performed to determine the size of the difference that each behavioral test should be designed to detect. Such an experimental program will of course involve determining the relationship between changes in test performance and changes in the reliability of job performance.

In the discussions that follow, a maximum factor for extrapolating from data obtained after return to the ground is two, and the maximum period between scheduled crew rotations is 90 days. Further, it is assumed that the first period of measurement will be 30 days in length.

WITHIN- AND BETWEEN-SUBJECT VARIANCES

There are two possible solutions to the problem of within-subject variance. The first is to conduct ground experimentation to obtain estimates of σ_W^2 and σ_B^2 for both biomedical and behavioral tests. Given an empirical basis for within-subject variance, we can proceed to calculate the number of measurements required to detect a given "d" for one subject. This calculation will determine the frequency of measurement required in a 30-day period. This frequency will be appropriate to answer the principal question, "Will there be change due to weightlessness for each subject?" Should the number of measurements required be excessively high for any test, we can pursue a second course of action, which is to refine testing procedures in order to improve the quality of the test by manipulating within-subject variance.

It is clear that if one is seriously concerned with achieving high confidence in the detection of zero-G effects, there must be a preliminary study program to obtain estimates of σ_W^2 and σ_B^2. Without such estimates, there is a real danger that the programmed frequency of measurement for the biomedical and behavioral tests would be too low to permit the detection of degradations with confidence This is especially true because of the apparent time constraint on the measurement program.

THE EFFECT OF FREQUENCY OF MEASUREMENT UPON EXPERIMENTAL DESIGN FOR THE TOTAL PROGRAM

If, "best estimate" values for within-subject variance are used for the purpose of calculating the number of measurements to be programmed in a 30-day test period for selected biomedical and behavioral tests, it becomes apparent that the frequency of measurement required to achieve confidence in the effect of degradation for each test may become so high that there will be a serious time-for-measurement problem for the total measurement package. Thus, estimates of frequency of measurement based upon the considerations given above tend to be higher than the working frequencies employed for the purpose of calculating time cost of measurement packages. This creates an experimental design problem, not at the level of the individual experiment, but at the level of the total package. Clearly if time for measurement remains a constraint upon the measurement package even after weight, power, and volume considerations are no longer constraining, then deliberate effort must be directed toward a solution of the time-for-measurement problem for the entire measurement package. The following section discusses a proposed solution to this problem.

A PROCEDURE FOR DETERMINING THE OPTIMUM CREW-MEASUREMENT SCHEDULE

The requirements of a crew measurement system requires some sort of systematic approach for the optimum selection of tests to be made. This selection must be consistent with the over-all objectives of the program and with the limitations imposed by the time that is available for testing. In the following analysis, it will be assumed that weight, power, and volume constraints are not significant or at least are sufficiently less important than the time constraint. The basic approach follows.

We consider a collection of biomedical and behavioral procedures which have been collected as candidates for inclusion in the crew-measurement system. Each of these will be referred to as a measure; the number of potential measures at the moment is roughly 150. Although preliminary considerations indicate that the instrumentation and supporting equipment required for these 150 measures can be stored on all but the smallest planned earth-orbiting station, there simply is not sufficient time to perform all of these tests at satisfactory sampling frequencies. By a test we shall mean that collection of activity required to evaluate the measure at a certain point in time. For example, for a blood pressure measure a test would include the entire procedure of obtaining a blood pressure measurement including rapidly repeated consecutive measures, if this is the usual procedure. Tests are separated by longer periods of time, and when we speak of test frequency it is this separation which is implied.

Broadly speaking, the fundamental objective of the experimental program is to first detect, and then describe quantitatively, degradation in behavioral and biomedical attributes as a result of zero-G conditions. Although this basic purpose motivates the analysis to follow, there are several peripheral requirements which must also be taken into consideration. For example, a certain specified subset of the approximate 150 measures must be included as part of the crew-measurement system (CMS) for safety reasons, and although the test frequency for these measures may be adjusted periodically, some information concerning these measures must always be obtained. Prediction of the degradation due to effects is to be made over long periods of time, up to 36 months. However, the manned-flight test program, during which information will be generated for making such predictions, may be of a shorter duration, such as 10 to 12 months. Thus, the sampling procedures to be established must be particularly suitable for extrapolational purposes. It is now necessary to find the optimum subset of the measures to be used during a given interval of time, and it is also necessary to determine explicit sampling procedures for the tests relative to each measure. Precisely, this means establishing test frequency for each measure and establishing explicitly which crew members are to be involved in specified tests on specified days. Consequently, the optimization must assume explicit experimental designs for a test program related to each measure. These individual experimental designs will take into consideration all the special features of the particular measure, and will not only provide appropriate evaluation of degradations for a given astronaut but also provide a basis for establishing variations in degradations between astronauts if such degradations are of importance.

It is important to point out that the test program for all astronauts need not be identical. It may be sufficient, for example, for some measures to establish the shape of the degradation curve for one particular astronaut with great statistical reliability. If it can then be assumed that the basic curve type is appropriate for all astronauts, a relatively smaller number of tests may be sufficient to establish the explicit degradation curve for each additional subject.

For purposes of the over-all optimization, each experimental design will provide a precise measure of the quality of the planned test program as a function of such variables as sampling frequency and the number of astronauts involved. This quality function will be discussed in more detail below; for the present it can be thought of as the reciprocal variance of prediction of the degradation effects being studied. (We assume that all statistical estimation procedures will be unbiased.) In the sections that follow, we will present the system model which provides the basis for the selection of the optimum CMS.

The System Model

Definition of Variables

In order to formulate the system model, we require the following definitions:

N = number of astronauts in the station

T = number of hours per day per astronaut available for human factors studies

D = total number of days of mission

M = total number of behavioral and biomedical measures, each of which is designated by a particular value of the index j, $j = 1, 2, \ldots, M$

Q_j = quality function for the test program relative to the j-th measure ($o \geqq Q_j \geqq 1$)

Q_j, min = minimum acceptable quality of results from tests on j-th measure ($o \geqq Q_j$ min $\leqq 1$)

s_j = number of hours required for the subject during a single test of the j-th measure

o_j = number of hours required for the observer during a single test of the j-th measure

α_j^s = 0 if a test on the j-th measure does not actually require a subject to take time away from regular responsibilities, and = 1 if the subject must actually take time for the test

α_j^o = 0 if no observer is actually required for a test on the j-th measure, and = 1 if an observer is required (It is assumed that no test on any measure requires more than one observer.)

f_j, min = minimum frequency of tests acceptable for the j-th measure from the viewpoint of either behavioral or biomedical considerations

f_j, max = maximum frequency of tests acceptable for the j-th measure from the viewpoint of either behavioral or biomedical considerations

μ_j = importance weights, for the j-th measure, $0 < \mu_j \leq 1$.

Apart from the quality functions and the importance weights, all these given or specified variables are self-explanatory. Quality functions and importance weights will be discussed in more detail below.

Our goal is to select a CMS which maximizes the over-all quality of the measurement schedule. The variables to be specified by this optimization are as follows:

m = number of measures **actually** to be evaluated **during the** program ($m \leq M$)

$N^s_{i,j}$ = number of tests for the i-th astronaut as subject, relative to the j-th measure

$N^o_{i,j}$ = number of tests for the i-th astronaut as observer, relative to the j-th measure

$F^s_{i,j} = N^s_{i,j}/D$ = test frequency for the i-th astronaut as subject for the j-th measure

$F^o_{i,j} = N^o_{i,j}/D$ = test frequency for the i-th astronaut as observer for the j-th measure

$T^s_{i,j}$ = actual time spent per day as subject for the i-th astronaut participating in the test program for the j-th measure

$T^o_{i,j}$ = actual time spent per day as observer for the i-th astronaut participating in the test program for the j-th measure

We will suppose that the measures are listed in such an order that the first ℓ measures correspond to those required for safety considerations; that is, for $j = 1, 2, \ldots, \ell$, at least a minimal test program must be included. It is for these values of j that the minimal quality levels, $Q_{j,\min}$ will most likely be specified, although they can also be specified for other measures if desired. These minimum quality levels may be established by specifying the smallest degradation that is to be detectable at a given confidence level, or by specifying directly the maximum allowable variance of prediction.

The Model

In the simplest case, when the test programs for each measure are independent, the j-th quality function, Q_j, can be written in the form

$$Q_j = Q_j(N^s_{i,j}, N^s_{i,j}, N^s_{2,j}, \ldots, N^s_{,j}, N^o_{,j}, N, T, \ldots, \text{other specified variables}),$$ in which $0 \leq Q_j \leq 1$.

In the most general situation, the quality of the test program relative to the j-th measure depends on the tests conducted for other measures as well. In other words, there may be measures which bear generally on several others. Indeed, this correlation is very important and useful in making more effective use of the limited time available to obtain some information concerning as many measures as possible. Thus, in the most general case, we have

$$Q_j = Q_j(N^s_{1,1}, N^o_{1,1}, N^s_{1,2}, \ldots, N^s_{1,m}, N^o_{1,m}, N^s_{2,1}, \ldots, N^s_{,m}, N^o_{\ m}, N, T, \ldots, \text{other specified variables})$$

It is desirable initially to ignore this interdependence of the quality functions in order to simplify the model, and instead adjust the optimization for such effects by using the "importance weights" μ_j. That is, if a particular measure j_0 sheds light on a great many other measures, then μ_{j_0} would be set equal to 1 or very nearly 1. For another measure j_1, which is entirely independent of all other measures, μ_{j_1} would be made very small. The importance weights must also serve another purpose, however. Some of the measures (even those entirely independent of other measures) are important for a wide variety of biomedical and behavioral reasons. In fact, it will be possible to rank all M measures according to their importance in the human factors program. The μ_j will then reflect not only the interdependent structure of the measures but also this ranking. Suppose a particular measure, for example, is uncorrelated with all other measures and hence would be assigned a low correlational weight. The final importance factor μ_j might still be large, however, since, in this case, a test program relative to the j-th measure is the only way of getting any information concerning this measure. In subsequent optimizations it will be desirable to take care of the interdependence of the measures explicitly with the quality functions. In this case, the μ_j will only reflect the ranking of the measures.

For practical considerations, it is not reasonable that every astronaut be trained as an observer relative to every measure. Consequently, it is necessary to place restrictions in the model on each astronaut. Suppose that the i-th astronaut can act as observer for a collection, J_i ($i = 1, \ldots, N$)

of measures. For example, the first astronaut may only be capable of acting as observer on measures corresponding to j = 3, 6, 27. In this case $J_1 = \{3, 6, 27\}$. We will represent the general restraints of this type by

$$T_{i, J_i} = 0; \; i = 1, \ldots, N$$

In addition, we have the following restraints implicit in our formulation of the problem

$$\Sigma_j \, (T^o_{i,j} + T^s_{i,j}) \leq T$$

$$f_{j,\max} \geq F^s_{i,j} \geq f_{j,\min}, \text{ for all } F^s_{i,j} \neq 0$$

$F^s_{i,j} > 0$ for j = 1, ... , ℓ , and all i (This restraint provides that each astronaut be exposed to all the safety measures.)

The second restraint indicates that if a specified astronaut is to be involved in the test program for the j-th measure, then has test frequency must be (either for medical or behavioral reasons) at least $f_{j,\min}$ and not more than $f_{j,\max}$. If for a specified measure it is known in advance that there are not significant variations between responses of different astronauts, then in certain cases the term $F^s_{i,j}$ in this restraint will be replaced by $\sum_i F^s_{i,j}$. Finally the time and frequency variables are related by the obvious equations

$$F^s_{i,j} \cdot s_j \cdot \alpha^s_j = T_{i,j}; \quad F^o_{i,j} \cdot o_j \cdot \alpha^o_j = T^o_{i,j}$$

The problem for optimization may now be formulated precisely. Given particular values of the variables N, M, T, $f_{j,\min}$, $f_{j,\max}$, $Q_{j,\min}$, D, s_j, o_j, α^s_j, α^o_j, μ_j, and the quality functions Q_j, we seek values of the variables $m > 0$, $N^o_{i,j} \geq 0$, $N^s_{i,j} \geq 0$ which satisfy the restraints of the preceding equations and which maximize the weighted over-all quality.

$$Q = \frac{1}{M} \sum_{j=1}^{m} \mu_j Q_j$$

Here we have normalized by dividing by M so that the maximum average quality can approach unity only if the optimum m turns out to be M. The optimum average quality so determined will be called the confidence of the CMS and will be denoted by C. Note that $0 \leq C \leq 1$.

The model has the form of a nonlinear programming problem, nonlinear because in the objective form the quality functions Q_j depend non-linearly on the unknown variables $N^s_{i,j}$, $N^o_{i,j}$. Consequently, special mathematical methods will be required for the solution, depending on the explicit nature of the quality functions obtained as a result of detailed experimental designs of the test programs for each measure.

Although this model includes a great many aspects of the real situation, it is important to point out some important factors that have not been treated. First, it has been assumed that all tests relative to a given measure are to be conducted at equally spaced intervals of time (e.g., $F^s_{i,j}$ and $N^s_{i,j}$ are related only by the constant D). Although this may be a suitable assumption for many of the test programs, there may be situations in which nonconstant test frequencies are suitable. For example, in estimating the degradation of a response which follows an exponential decay law, it is more efficient for the statistical estimation of the parameters involved to space the observations at logarithmic intervals, more tests being made during the early stages of the degradation. The above model could be generalized to include such test spacing if it appears necessary.

Secondly, we have ignored the question of daily scheduling of the tests. Some consideration of the precise order of tests relative to different measures on any given day would of course have to be made in the detail specification of the CMS. However, such matters should have little influence on the selection of the over-all optimum sampling plan.

Thirdly, and most importantly, it should be pointed out that strictly speaking, our model is static. That is, we have not included formally any time dependence in the given or specified variables (e.g., N, T, μ_j), and, consequently, the computed optimum sampling variables m, $N^s_{i,j}$, $N^o_{i,j}$ are time independent. In many situations this limitation is untenable. However, at least a quasi-dynamic aspect may be gained by reapplying the optimization procedure sufficiently frequently during the course of the mission. That is, every week or two during the flight, a reappraisal of the specified model parameters, particularly the μ_j, T, and perhaps even the quality functions Q_j, will be made. This reevaluation will be performed on the basis of preliminary evaluation of the data already collected, such as rescheduling requirements and mission-plan changes. It may be found, for example, during the first few weeks of flight that degradation effects relative to an arbitrary j_0-th measure seem to be nonexistent. If $j_0 > \ell$ (i.e., if this measure is not part of the safety package), then it may be advisable to reduce μ_{j_0}, or reevaluate Q_{j_0}, or both, depending on the nature of the problem. When the reoptimization is subsequently performed, emphasis on the j_0-th measure may be reduced and one or more other measures given more intensive evaluation.

Reoptimization can also be performed when the possibility arises of returning astronauts or acquiring additional personnel during flight. Suppose, for example, that N = 16 initially, and after eight weeks a decision must be made concerning how many of these men should be returned to ground and how many replacements should be added. At this time, all the specified variables could be reevaluated and a series of optimizations performed with N equal to such values as 6, 5, and 4. The CMS confidences C(N) corres-

ponding to these crew sizes could then be compared, and from the point of view of the optimum CMS a best choice made of N for that time.

Once the algorithmic procedure for finding the optimum quality C is programmed for computer solution, a great many parameter variation studies can be conducted. For example, the explicit nature of the dependence of C on N can be determined over a wide range of N values. Knowledge of this function C(N) will be useful for establishing future mission size requirements.

Finally, we note that, should space and weight requirements become crucial in the selection of the optimum CMS, it would be a relatively easy matter to include such restraints in the model. One would simply note the volume and/or weight required for the instrumentation for each measure and restrain the space and weight totals for the m measures b. these values.

RECOMMENDED METHOD FOR SCHEDULING MEASUREMENT TIME FOR THE TOTAL PACKAGE

In view of the fact that time rather than weight, power, or volume is seen as the primary constraint upon the achievement of confidence in the detection of zero-G effects, it is recommended that a nonlinear program of the type described above be developed and that the program be employed to optimize the use of measurement time by sequentially applying the program during operation of the orbiting station. Thus, by using ground-base data, an initial measurement schedule which will make the best use of time during the first period of station operation can be developed through the use of the program. During the initial period of operation the data gathered can be used to develop a new measurement schedule for the second period of operation utilizing the same program, and likewise for subsequent periods of operation. This sequential determination of the over-all design will permit optimum utilization of time and will permit the accumulation of basic information for virtually every test that can be included within weight problems and volume constraints. The program will permit basic information, that is the determination of whether or not there is degradation, for every test because it will permit, at the very least, measurement at the end of the measurement period for functions not measured throughout the period. Measurement at the end of a period is most sensitive to degradation. Measurement over the course of a measurement period provides information not only about degradation but also about the course which degradation follows. Prediction to a longer period of time is thus permitted. The program will maximize the achievement of confidence in the detection of degradation before it develops data relevant to the course of degradation at the cost of confidence in detection.

Thus, through the use of the dynamic design permitted by the program, optimum use will be made of measurement time.

CREW MEASUREMENT SYSTEM DESIGN

GUIDELINES FOR COMBINED BIOMEDICAL AND BEHAVIORAL LIST

In establishing a Crew Measurement System (CMS) applicable to a particular space station configuration, certain considerations must be established as guidelines so that the design represents the most efficient use of the data pool presented in this report. It is obvious that any particular space station represents unique constraints to be placed upon the use of this data pool. The guidelines presented here provide one approach to a crew-measurement system design that may be used for specific applications. Combining the biomedical and behavioral measurements is really in an appropriate concept as the two sets of measures are relatively independent; an attempt to give some equal value on a numerical scale is therefore unrealistic. The combination of measures that has been shown in this study is a combination based on weight, power, volume, and time constraints rather than on any particular value of the measure involved.

Safety

In designing the CMS, the first consideration must be safety. Safety is here identified as that of the flight surgeon; that is, the means by which crew status (survival or health and welfare) is evaluated on a day-to-day or periodic basis. A safety package can therefore be defined as being primarily a group of biomedical measures for crew-status evaluation with a small number of behavioral measures to assess the ability of the crewman to perform essential tasks. These measures were chosen by the biomedical and behavioral team of the project as the minimal number of measures that would allow the decision to be made that this particular crewman is healthy and may remain in zero-G or that he must be brought back immediately. The list of the safety package is presented in Table 16. In any space station design this safety package must be first considered for inclusion in the CMS.

Minimal Weightlessness

It is next essential to establish some minimal number of measures that would be considered necessary in order to study weightlessness with a minimal but acceptable degree of confidence. The biomedical and behavioral team selected a series of measures that they considered should be included in such a package of data. This minimal weightlessness package, as opposed to the safety package, is more concerned with prediction than with immediate

crew status. Table 17 is a listing of this group. It is essential, therefore, that this minimal weightlessness package be included in any CMS design if reasonable expectation of evaluation of zero G is to be obtained.

Confidence

The development of a CMS must be accomplished first on the basis of confidence as determined in the sections on measures evaluation. If there were no other constraints placed upon the measurement program, measures would then be included in the CMS on the basis of confidence, the first, or most important measure, being included first. The confidence lists presented in the previous sections could be used as lists of rank order for this purpose. In any consideration, where no other constraint forces a compromise, confidence must take precedence.

Other Constraints

Since this program is mainly concerned with the design for a zero-G station, the typical engineering constraints of weight, power, and volume must be considered. Another constraint, and the one that is probably the most limiting factor, is that of time provided to make the measure. These constraints may be handled independently by eliminating measures on the basis of confidence. For example, if weight is the limiting factor, then starting with the least important measure and working toward the most important measure, weight may be reduced by simple trade-offs between the values of the measures and the weight of the equipment necessary to make the measure. Confidence would be least affected by this elimination.

The consideration of time as a constraint is evaluated more thoroughly in the experimental discussion preceding this section. Although initial set frequencies are established as data are returned from the orbiting station, frequencies of measurements should be changed, based on the analyses of these data, so that optimal use of measurement time may be made. By this method, if the techniques are available on board the station, any series of measurements may be made.

The number of subjects present on a station is a critical factor in both the time-use problem and the frequency of measurement required to return statistically significant data. Since it is assumed that the subjects are thoroughly evaluated before the mission, and that they represent a fairly homogeneous population, less between-subject variation will be expected than with the general population. Thus, probably a lower number of subjects will be needed than if the subjects were unknown. However, since the effects of zero G are not known, one cannot be certain that the response between

subjects will be similar to what is known under the G condition. Therefore, more subjects will provide better prediction capabilities but not necessarily better sensitivity of measurement. Optimal numbers of subjects have been discussed in the preceding sections on the experimental program.

LEVEL OF TRAINING REQUIRED

The level of training required to perform the particular techniques involved in making the separate measurements are listed under headings: astronaut, technician, or physician. These headings mean the following:

> Astronaut - no cross training in measurement techniques or a level of cross training represented by about an hour a day for several months.
>
> Technician - skill level of a typical clinical laboratory technician representing approximately a full year of training and several years experience in the field.
>
> Physician - a licensed physician with several years experience in the field or clinical or aerospace medical research.

Obviously, if an astronaut has the training level of a technician, he is here considered a technician. A well-trained technician can be expected to make all the observations necessary as indicated in Table 6 as well as those indicated for the astronaut level of training. A physician with research experience is considered to have the necessary background to perform all of the techniques listed. In those cases where it is indicated that a physician is needed, the requirement is either for his professional ability to ensure the well-being of the subjects because of the particular kind of measurement made, such as the stress tests; or for his ability for on-board evaluation of crew status measures, such as, X-ray analysis. It is interesting to note that, for example, if a physician is not included in the crew, only about 30 percent of the confidence can be obtained relative to the cardiovascular system as opposed to 100 percent obtainable when one is included. It is not the purpose, here, to determine the particular levels of training for crew selection; however, it seems reasonable to suppose that a space station experimental program of the magnitude of such national importance and expense necessary to study zero G, would include those crew skills most important to the experimental design. Thus, where needed, professionally trained personnel; i.e., research physicians or flight surgeons should be considered necessary crew complement and cross-trained for other scientific or operational functions as necessary. It is probably that physicians could be cross-trained for essential tasks with relative ease. If a physician or

even a technician were not included, it is a simple matter of summing the confidence values of the measures indicated under astronaut category to determine the probable loss of confidence that would follow by such omission.

CREW MEASUREMENT SYSTEM DESIGN

The Optimal Package

The total of measures that have been listed in both behavioral and biomedical obviously does not represent all the measures that could be made, but represents only those measurements that were considered germane to the evaluation of zero-G effects. The optimal package, then, will have an upper limit that includes all the measures listed. The lower limit of this optimal package is represented by those measures included in the minimal weightlessness package group. Weight, power, and volume constraints do not appear to be the limiting factors, except for certain minimal station configurations, such as the Apollo Concept I alone. It is reasonable to expect that provisions will be supplied to make all the measures indicated. The selection of frequency of measures will then be made on the basis of time and periodic analyses of data returned from the orbiting station. In this way, maximum confidence can be ensured while allowing for the maximum variety of measurements. Where certain techniques are not feasible, the confidence and the data is decreased somewhat; however, as has been demonstrated in the section on Measurements Analysis, this amounts to only a small percentage of the total confidence.

THE MINIMAL WEIGHTLESSNESS PACKAGE

Based on the considerations discussed under Minimum Weightlessness, the minimum package, as shown in Table 17, is considered to be the least number of measures, both biomedical and behavioral, that should be included in any system for a reasonable degree of confidence to determine the effects of zero G upon man. It is assumed that unless engineering constraints are so severe to preclude the use of this package that it will be included as a basic measurement group.

MINIMAL SYSTEMS

It may become necessary at some period in space station design to consider systems which cannot include at least the minimal weightlessness package. If this is the case, it is assumed that the CMS will be chosen on the basis of confidence by serially eliminating, starting with the least valuable, those measures that best allow the CMS to fit within the constraint imposed. By the same token, the value of the package should be increased

where possible above the minimal weightlessness package in the same fashion. Again, it must be emphasized that it is the opinion of the biomedical and behavioral personnel of the project that a CMS reduced below the minimal weightlessness package will give questionable data about the effects of zero G upon man, especially the ability to predict for a longer duration than the period of measurement.

Another method of approach that has been recommended for such minimal systems is to make shorter duration and more numerous flights evaluating the man primarily before and after. The problems with this approach are the expense of the numerous missions and the fact that severe G and one G is imposed upon the crewman before he is reevaluated on earth.

THE SAFETY PACKAGE

As previously discussed, the safety package outlined in Table 16 must be the first group of measures provided in the CMS.

Where constraints are so severe that the safety package is restricted, one cannot in conscience ensure the safety of the crew. It must be noted here that safety package measurements must have a fixed frequency if they are to be of value for crew-status determinations.

USE OF THE BASIC GUIDELINES - AN EXAMPLE SYSTEM

In the configuration analysis, a procedure for combining measures into packages was employed and is described in Section IV. This procedure was based on the initial rankings of the biomedical and behavioral measurement lists. The first steps may be considered to have involved the establishment of the safety and minimal weightlessness packages whose constitution reflected professional judgment. Following this, measures were added to the over-all package according to the relative rank of the measure and the requirement in terms of weight, power, volume, or time. The information value of the measures were estimated by a logrithmic conversion of percentile ranks, this being done separately for each list. When the safety and minimal weightlessness packages had been chosen, this left two pools of measurement items with estimated information value and requirements, such as time. Measures were drawn from those pools to establish additions to the basic packages with three criteria:

The amount of information was maintained relatively equal for both biomedical and behavioral lists.

Measures were chosen to maximize increments in information.

The cost of the measure, such as the cost in time, was minimized.

This procedure has well recognized limitations. First, the estimated values of the individual measures are a function of the total number of measures, being smaller when the total number in the list is larger. The two lists that were used had unequal numbers of items. Second, the items ranked should be, as nearly possible, along the same dimension. This is a difficult criterion to meet in the case of ranks since if a dimension existed, there would be no necessity for ranking. In the present case, it was assumed that the number of items reflected a nearly complete set for each list and that increasing or decreasing the number would not affect the individual values. With respect to unidimensionability, the procedure that was used always involved immediate knowledge of any items or combination of items selected so that the summing of values could be directly monitored to insure the results would be reasonable. Within the limitations noted, this technique has the advantage that it will indicate selection of items in terms of a confidence based upon the rank assigned by a group of experts and the cost of the item in terms of constraining parameters.

This procedure can be applied to the data pool which has resulted from the study, using the confidence data provided. The data can be set up for computer use, the criteria to be used defined (e. g. the levels of confidence to be obtained for the behavioral and biomedical components) and various packages established for professional consideration.

Applying this approach to the most important measurement packages under consideration provides an estimate of the value of these crew-measurement system designs. These basic packages are: the safety package, the minimal weightlessness package, Concept I Apollo, the interim stations (Concepts II and III Apollo and MORL), and the large stations (MOSS) The method, outlined above in the preceding paragraph, was used for combining these packages. Examples of these various crew-measurement system designs have been shown in Section IV. The confidence data, the totals of which are shown here for the various configurations, are those derived in the sections under Biomedical Measurements Evaluation and Behavioral Measurements Evaluation. Table 39 shows the individual biomedical and behavioral confidence levels attached to these CMS packages. One thing important to note here is that these values represent an estimation of confidence that would be expected if the measures were done under optimal conditions. It is expected that such conditions will be provided in the designs of the interim and large stations. Concept I Apollo, on the other hand, not only does not appear to provide the habitable features required for long-duration laboratory operation, but in the opinion of the BAHFR biomedical and behavioral specialists, also will not provide the workspace necessary to perform all the measures listed for Concept I without serious degradation in confidence. There is further some question as to whether all those

measurements listed could be made within the free volume that Concept I Apollo allows. The volume constraints for the measurements chosen for these configurations were based primarily upon the volumes of the techniques, equipments and supplies. One of the most important problem areas identified by the BAHFR study exposes the need for empirical evaluation of experimental measurement techniques within space-cabin limitations.

Table 39. CMS Packages Confidence Levels

CMS	Biomedical (percent)	Behavioral (percent)
Safety Package (SP1)	17	19
Minimum weightlessness Package (SP2)	52	37
Concept I Apollo	75	56
Interim stations (MORL, Concepts II and III Apollo)	85	69
Large stations (MOSS)	97	95

The interpretation that is made about these data is obvious. The safety package only provides a gross evaluation of survivability and the information obtained about zero G effects is small. The minimum weightlessness package evaluates especially the biomedical and physiological aspects of zero G status with a basic group of behavioral measures added. The information as obtained from Concept I Apollo indicates increasing emphasis upon behavior measures; and, within the interim and large stations the behavioral measurement's confidence level approaches the biomedical, because here the survival aspects are less emphasized and total zero-G evaluation is paramount.

CREW REQUIREMENTS

The major aspects of crew requirements for manned orbital space systems that incorporate crew measurement as a major function of the mission are the training of the crew for space station operations, the tasks involved in implementing the measurement program and in operating the systems, the skills and knowledge required by the tasks, and the selection of a suitable crew for performing them. Table 40 indicates the relationship between these tasks, skills, and requirements of knowledge as well as between selection and training requirements.

The tasks involved in effecting an orbital space station crew measurement mission include the scientific tasks comprising the crew operation of the measurement program, those tasks necessary to the operation and maintenance of the space station, logistic support, personal requirements, and those tasks connected with the crew safety. The measurement tasks include those of observer, subject, self-observation, sample analysis, scientific instrument maintenance, and research program modification. The observer tasks are involved in making observations on another crew member as a subject. The subject tasks involved cooperating in the subject-observer procedure. Self-observation tasks involve the crew member performing measurement tasks upon himself as a source of data. Sample analysis tasks are those involved in the analysis of blood, urine, and feces specimens which constitute a major source of the biomedical data. The maintenance of scientific instruments will be critical to the continuity of the measurement program. The tasks involved in this maintenance may be either a simple part replacement for small or interim space stations or an extensive bench maintenance for the largest systems. Research program modification tasks will become involved as programmed or contingency changes in the measurement program occur. Requirements for contingency modifications might arise quite suddenly and much of the value of the measurement mission might be dependent upon the crew's capability in initiating these modifications.

The skills and knowledge requirements for the measurement tasks include those which must be met on a technical, or even professional, level in medicine and psychology. Professional ability and knowledge may be particularly important in emergency modification of the experimental program if valuable data are not to be lost or confounded. The skills and knowledge required by the operation and logistics support of the space station as well as the tasks involved in crew safety and personal duties relate largely, though not entirely, to the utilization of on-board operational equipment.

Table 40. Crew Requirements Summary

Tasks	Skills and Knowledge	Selection Criteria	Training Specifications
Measurement			
Observer	Utilization of measurement equipment and procedures Analysis of such samples as blood, urine, and feces Methodical observation and recording of observational data		Intensive instruction in professional areas peculiar to spacecraft conditions
	Facility in data recording, conversion, and transmission	Professional status in relevant disciplines such as medical, physiological and psychological Technician level experience in relevent areas	Technician level instruction and practice in relevant areas Practice in application of measurement and observer techniques under space-station conditions
Subject	Facility in cooperation with observer in experimental tasks	Representative of space crew population Tolerance for requirements of experimental program Previous subject experience	Establish base lines for comparison with space-station data Instruction and practice in serving as subject under space-station conditions
Self observation	Facility in application and data pick-off from all self applied instrumentation. Utilization of all check lists and record forms	Previous experience in self-data reporting Familiarity with instruments and measurement techniques	See "subject" above, instruction and practice in self-observation techniques
Sample analysis	Facility in utilization of standard and unique sample analysis techniques Organization of analysis procedure for most intensive use of samples	Laboratory technical training and experience Tolerance for requirements of sample analysis	Instruction in sample analysis under space-station conditions

Table 40. Crew Requirements Summary (Cont)

Tasks	Skills and Knowledge	Selection Criteria	Training Specification
Scientific instrument maintenance	Capability of scheduled and unscheduled maintenance of scientific instruments Familiarity with de-activation and storage requirements of scientific instruments	Scientific instrument experience, especially electronic, at laboratory technician level	Instruction and practice in maintenance of space-station scientific equipment under space-station conditions
Research program modification	Knowledge of effect on data and results of experimental design modification Versatility in adaptation of experimental parameters to changing conditions	Professional training and experience in design and conduct of biomedical and behavioral research	Familiarization with all interacting aspects of research program Graduate student level instruction in experimental design
Operational			
Systems management, monitoring, checkout	Familiarity with specific systems characteristics Knowledge of tolerance limits Monitoring alertness Knowledge of system interaction Familiarity with checkout schedule Familiarity with system status indicators	Background in areas of knowledge relevant to systems Retention of perceptual alertness under stress	Refresher in relevant knowledge areas, specific to systems involved
Maintenance			
Scheduled Unscheduled	Familiarity with systems characteristics Familiarity with maintenance schedule Trouble shooting Part replacement techniques Dexterity and mobility under zero-G and variable-G Tool use Bench maintenance	Background in areas of knowledge relevant to systems Trouble shooting and tool use experience Manipulative dexterity and agility Deductive and inductive reasoning ability Efficiency under emergency stress	Refresher in relevant knowledge areas Specific to systems involved Tool and part replacement techniques under zero-G Confined and awkward space operations Pressure suit operations Scheduled and unscheduled maintenance drill

Table 40. Crew Requirements Summary (Cont)

Tasks	Skills and Knowledge	Selection Criteria	Training Specifications
Attitude Control	Perceptual-motor coordination	Astronaut or pilot experience Tracking proficiency	Simulator drill, including centrifuge Orbital training flight(s)
Communication	Communication code familiarity Speech perception Speech clairty Immediate memory	Auditory activity Speech quality Immediate memory	Communication drill Special communications code training
Contingency decision and action	Systems status Ground support status Program status Alternatives available Resources available	Inductive and deductive reasoning General scope of training and experience Emotional stability	Contingency drill
Logistic			
Inventory control	Record keeping Familiarity with characteristics and uses of inventory items Ability to adapt items to unforeseen requirements	Attention to detail Supply or quartermaster type experience	Familiarization with space inventory item use and characteristics Inventory control and adaptation problems
Crew and supply transfer	Mobility in confined spaces in pressurized suit Controlled mobility in space Distance, velocity, and acceleration judgement	Gross manipulative dexterity Mobility control Experience in pressure suit type operations	Mobility and mass handling under zero-G and artificial-G conditions Pressure suit techniques
Reentry and landing	Pilot capability under variable G-load	Physiological and perceptual capability to tolerate G-loads Astronaut status	Orbital training flights Simulator drill, including centrifuge Study of reentry vehicle to be used

Table 40. Crew Requirements Summary (Cont)

Tasks	Skills and Knowledge	Selection Criteria	Training Specifications
Rendezvous and docking on-board controlled	Perceptual motor coordination Position, velocity, acceleration, rate-of-closure judgement System status evaluation Contingency decision and action	Astronaut status In-flight refueling experience	Rendezvous and docking Simulator drill Contingency drill
Crew Safety			
Hazard control	Familiarity with nature and probable location of potential hazards Familiarity with location and utilization of hazard control equipment Ingenuity in improvising hazard control measures	Experience and training in hazard control programs Emotional stability and action effectiveness in emergencies	Familiarization with space-station hazard control equipment Hazard control drill under space-station conditions
Interpersonal observation	Ability to detect evidence of physiological and behavioral decrement from routine observation	Experience in observation and interpretation of behavior characteristics	Familiarization with observable indications of personal decrement
Medical care	Application of emergency and scheduled medical measures	Physician, preferable flight surgeon Training and experience of medical corpsman or first-aid level	Instruction and practice in medical care techniques peculiar to space-stations

Table 40. Crew Requirements Summary (Cont)

Tasks	Skills and Knowledge	Selection Criteria	Training Specifications
Personal Duties			
Sleep	Ability to adapt to required work-rest cycles	Experience in work-rest cycles similar to those prevailing in space-station Adaptability to ad hoc sleeping periods	Adaptation to sleep cycles
Personal hygiene	Capability of carrying out personal hygiene activities, especially defecation and urination under space-station conditions	Experience with personel hygiene under unusual conditions Conscientiousness in personal hygiene combined with tolerance for unavoidable lapses	Instruction and practice in personal hygiene under space-station conditions
Eating	Selection, preparation, and consumption of food under space-station conditions	Experience with food preparation and consumption under unusual conditions Appetitive and digestive tolerance for unusual eating conditions	Instruction and practice in food preparation and consumption under space-station conditions Adaptation to space-station dietary spectrum
Recreation	Capability of a wide range of solitary and group recreation activities	History of a wide range of recreational interests, with appropriate capabilities for solitary recreation	Acquisition of recreational skills compatible with space-station equipment and opportunities
Mobility	Capability of moving from place to place within the space-station without hazard to personnel or equipment	Anthopometric dimensions compatible with space-station volumetric constraints Evidence of capability of mobility in confined spaces	Instruction and practice in mobility under space-station conditions

Table 40. Crew Requirements Summary (Cont)

Tasks	Skills and Knowledge	Selection Criteria	Training Specifications
Mental hygiene	Capability of functioning as a compatible member of a group under confinement and other stresses peculiar to space-stations	Such measures and indicators of emotional tolerance, intergroup relationships and personal resources as may be applicable History of successful functioning as member of small, isolated groups Compatibility with make-up of space-station crew	Group confinement experience Instruction in elements of mental hygiene at undergraduate college level

Selection criteria must be adequate for obtaining suitable crew material and reducing training requirements, but it must not be so rigorous as to unduly constrict the size of the pool of space station crew candidates. Obviously, space station operational requirements dictate a crew background in engineering. There also will be a requirement for as many astronauts as are needed to insure crew safety. Certain other selection criteria may represent desirabilities rather than necessities. However, selection criteria associated with measurement tasks, as well as with crew safety, must necessarily be heavily loaded with considerations of professional competance in medicine, physiology, and psychology. These criteria will be difficult to fulfill in combination with the requirement for astronaut status. One solution could be an astronaut-flight surgeon with additional training in other measurement specialties, assisted by as many trained technicians as the size of the crew dictates.

Unlike selection criteria, all of the training requirements are probably critical since training provisions must compensate for the limitations of selection criteria application. Whereas such basic crew requirements as pilot experience and engineering training may be met by selection, including the qualification of astronauts, with additional training for specialized space station conditions, a major training requirement will exist for establishing competence in measurement techniques. Measurement training will be critical for both small and large crews. With small crews all men should be able to make all measures and perform all laboratory work. With large crews the available professional personnel will still be dependent upon technician assistance to accomplish all the measurements on a relatively large sample. Therefore, in view of this importance of the technician in any crew size, the measurement training should be effected on at least the college level. Training in experimental design, for example, will greatly increase validity of data by enabling the crew to cope with unexpected measurement contingencies which may not be referrable to ground support for decision due to time or communications constraint. Another critical training area will be the establishment of baselines for comparison of ground based performance with space station results. Not only is the accumulation of subject data critical for this purpose, but it will also be essential for training to ensure detailed comparability of space-station measurement procedure with ground-based procedure.

For smaller stations (10 men or less) the number of personnel in training at any one time, as shown in Table 41, should satisfy three quantitative requirements:

1. The number of crew members in the space station

Table 41. Quantitative Personnel Training Requirements

Size Station	Number in Station Crew	Number in Station Crew Backup*	Number in Ground Control Crew	Number in Ground Control Backup	Total in Training
2 man	2	3	2	2	9
4 man	4	4	4	4	16
6 man	6	6	6	6	24
10 man	10	10	10	10	40
20 man	20	15	20	10	65
30 man	30	20	30	15	95

*Assumes the rotating crews will provide their own piloting capability for launch and reentry.

2. The same number of crew members for ground-based experimental control

3. At least double the number of crew members in the space station to allow for drop-outs in meeting requirements 1 and 2 above and to provide for crew rotation requirements

For large space stations the backup requirements could probably be proportionately somewhat lower, as illustrated in Table 41, partly at least, as a result of flexibility in experimental design considerations gained by a larger crew. For purposes of experimental control the rotation crews should be probably drawn from the station crew backup.

In actuality, the number of personnel required for the various space stations is not a direct function of station and crew size. In the case of larger stations, it is reasonable to assume that personnel transport type logistics vehicles will become available, either initially or during the station operations. Under such circumstances the range of selection for personnel would be extended. In all likelihood, the operations of a large station would follow the pattern of the antarctic stations. NASA would provide operational personnel including ground crews and astronauts for station and ferry operations. Civilian scientists and engineers from industry and universities would be qualified by NASA medical personnel for flight duty, and selected on background data and requirements for participation in research programs. Under this approach a number of research scientists would participate in the station program for as few as one duty tour. Over a period of station operation several hundred personnel might be considered eligible for station duty.

Existing and anticipated facilities for astronaut training should provide an adequate basis for crew capability in operating the space station and providing crew rotation and logistic support transport. However, attention should be given to developing training and simulation facilities for ensuring crew competence in measurement activities. It is tentatively suggested that currently existing colleges and universities (including service schools) might provide an economical basis for such training developments.

LOGISTICS AND GROUND SUPPORT

CREW ROTATION SCHEDULES

Although crew rotation is extremely important to the experimental design of the research program, there are other factors that become involved in the selection of a crew rotation schedule, such as the training requirements and cost, the operational philosophy with respect to maximum duty tours, and the flight training of crews for future missions. However, this study is concerned mainly with requirements evolving from the experimental program. It is extremely important to analyze the over-all measurement system and the gross criteria of the experimental program to derive a rationale for the selection of crew rotation schedules. The determinants of crew rotation schedules are discussed in Section IV.

RESUPPLY

The logistics support requirements of an earth orbiting laboratory will be primarily determined by the requirements of the space vehicle and its subsystems. The resupply requirements for experimental equipment and supplies are minimal. (See Measurement Equipment in this section.) and the data transmission requirements. (See Data Management - Section III.) can easily be accommodated by the communications and data systems of the various spacecraft.

GROUND ACTIVITIES

The test direction and over-all data analysis will be performed on the ground. It will be required that the test director carry on a two-way voice communication with the crew daily, although this perogative might not be exercised daily. Ground analysis of the data will be twofold; that is, the data will be analyzed daily for determination of astronaut status and safety and the data will be analyzed over longer time periods for over-all trends and differences within the group.

CONDITIONING PROGRAMS

The reactions of man to prolonged zero-G exposure have been the subject of much previous speculation and some simulated experimental investigation. Investigations, necessarily limited in realism, have demonstrated, among other changes, loss of muscular strength, cardiovascular alterations, respiratory and metabolic disturbances, and impaired general fitness.

It is generally accepted that exercise regimes will be required to offset the deleterious effects of prolonged exposure to the weightless environment. A series of investigations has demonstrated the efficacy of isometric and isotonic exercises as maintainers of muscle tonus and strength in circumstances which normally have as their end product loss of strength, calcium mobilization and circulatory response reflex impairment. It has been suggested that daily sessions of such exercise, programmed to involve the major muscle groups of the body, be employed in such fashion that muscle strength and tonus will be maintained. At present there exists some experimental evidence that single training sessions daily will be sufficient. In a recently completed, but as yet unpublished study, the effectiveness of isometric exercises as maintainers of the circulatory response reflexes was investigated. It was determined that isometric exercises would satisfactorily maintain these reflexes. Still to be determined is the amount of exercise required to achieve a satisfactory maintenance level.

One major question which remains unanswered is whether isometric exercise regimes will prevent calcium mobilization. In accordance with Wolff's Law the structural integrity of a bone will be maintained as a function of the load which is placed upon it. No investigations have satisfactorily demonstrated the validity of exercise techniques as stressors over extended periods for maintaining bone integrity.

An on-board program of exercises involving isometric and isotonic contractions for all the major muscle groups of the body has been studied. These exercise regimes can be accomplished in less than 10 minutes per day, can be accomplished within the space allocated for exercise, and may be accomplished on an operator's couch. Most importantly the exercises are so designed that they can be utilized selectively for extensor and flexor activity of major muscle groups. Thus it will be possible to tailor an exercise regime to counteract observed differential degradation of muscle functions.

It is recommended that exercise programs be utilized differentially and experimentally in the early stages of orbital flight to determine definitively the effectiveness of exercise in counteracting some of the expected deleterious effects of prolonged exposure to weightlessness.

In addition to the proposed program of isometric and isotonic exercises there will be a bicycle ergometer on board. This device will serve two purposes. For those biomedical measurements that will observe the effects and rates of recovery from controlled amounts of exercise, the bicycle ergometer will be the exercise vehicle. Also, the bicycle may be utilized for physical conditioning and recreation.

A complete discussion of the centrifuge as a test and conditioning device has been presented in Section III. It is only necessary to note, here, that if a centrifuge is provided on board the station, it may be used for a conditioning device should the biomedical measurements indicate this requirement. In this event the decision must be made whether to continue and accept the influence of G conditioning upon the zero G experimental results or to rotate the crew to earth and study a second group in the station.

VI. SUMMARY AND CONCLUSIONS

The study reported here has presented a measurement data pool for the determination of biomedical and behavioral effects of long-term exposure to weightlessness. This includes measures, techniques, equipments, and requirements in terms of weight, power, volume, time, crew activities, subsystem interfaces and experimental programs and designs, and confidence ratings for their effectiveness for determining weightlessness effects.

The measurement data pool resulted from the following:

1. Space station system constraints analysis

2. Measurement requirements and rationale analysis

3. Orbital station and planetary vehicle systems functions and tasks analyses

4. Trade-off studies including alternate measurement techniques and equipment and confidence versus significant systems parameters

5. Evaluation of specimen measurement systems for selected configurations

6. Development and evaluation of a crew measurement system

Among the more significant conclusions of the study were the following:

1. Crew measurement systems of relatively high confidence levels are feasible for a wide range of space station configurations where evaluated in terms of power, weight, volume, and time. The minimal configuration evaluated, Apollo Concept I, was found to present constraints in terms of workspace volume.

2. The principal constraint imposed upon crew measurement systems is time required for measurement activities.

3. The indicated experimental program is a sequential one with the set of measures employed changing as data on significant trends accumulate.

4. Experimental design requirements, such as number of subjects and frequency of measurements, are significant determinants for system parameters.

5. The use of medically qualified personnel can contribute significantly to the confidence attainable with crew measurement systems.

APPENDIX A

BIOMEDICAL MEASURE, TECHNIQUE,

EQUIPMENT AND SPARES DATA

INTRODUCTION

Appendix A represents the data pool developed during the BAHFR project for the biomedical measurements analysis. This consists of some 97 biomedical measures with the alternate techniques required for each measure and the equipments and supplies necessary for those techniques.

A discussion of each Measurement is made including a description of the measure, the question or hypothesis for which the measurement is made, and results to be expected. The number of the measure refers to the rank order of the measure.

A discussion of each alternate technique that may be used for the measurement to which it applies follows the measurement. Contained therein is a description and evaluation of the technique, training level required, frequency and time to make the technique, an equipment list, and a list of supplies required for the technique. Alternate techniques are listed one after the other under the measurement to which they apply. Each technique is completely discussed before the next technique is begun. The "letter" of the technique refers to the order in which the technique is recommended for inclusion in the Crew Measurement System. The first technique listed (letter "a") is the recommended technique. Reasons are given for the choice of this technique and the elimination of the others. The format for the appendix is set forth below.

MEASURE -- RANK NUMBER AND NAME OF MEASURE

Question or Hypothesis

Description of Measure

Results

TECHNIQUE (a) Name of Technique (First Choice Technique)

Description

Evaluation

Equipment and Instruments

Supplies and Spares

TECHNIQUE (b) Name of Technique (Second Choice Technique)

MEASURE 1. CARDIAC OUTPUT

Question or Hypothesis

Because of the loss of gravitational forces on the cardiovascular system, loss of muscle tone, and reduced metabolic requirements, cardiac output may decrease in the weightless state. The most important factor contributing to decreased cardiovascular function may be the decreased ability of the cardiovascular reflexes to adapt to sudden demands producing a subnormal increase in cardiac output under conditions of stress.

Description of Measure

Cardiac output is a measure of the volume of blood pumped by the heart per minute. It is the most significant index of cardiovascular status.

Results

If cardiovascular deconditioning occurs it would cause a decrease in cardiac output at rest, however the most significant functional impairment would be noted when the subject is stressed with exercise or centrifugation when a much greater decrease in cardiac output from the normal would be noted.

TECHNIQUE (a) Dye Dilution T-1824

Description

A known amount of dye is rapidly injected intravenously, and serial arterial blood samples are obtained over a 30 to 60 second period. The amount of the dye is determined colorimetrically.

Evaluation

This is an accurate measure of cardiac output and is the most feasible for space station application. It is a routine clinical test and will provide reliable data to answer the hypothesis. This technique is recommended for inclusion in the CMS.

(Training Level - Physician)

Total man-minutes	42
Frequency	1/7
Minutes per day	
Subject	2
Observer	4
Total	6

Equipment And Instruments

Microanalytic Package: (Beckman Instruments, Palo Alto, Calif - Model 150)

1a-Spectrocolorimeter Photocolorimeter for analyzing micro blood samples.

Weight	4.5000	lbs.
Power	10	watts
Volume	.2488	cubic feet

1b-Microcentrifuge; High rotation rate centrifuge for micro blood sample analysis

Weight	11.0	lbs.
Power	70	watts
Volume	.2556	cubic feet

1c-Micromixer; Device for mixing several micro blood samples simultaneously

Weight	2.5	lbs.
Power	5	watts
Volume	.3040	cubic feet

Supplies and Spares

1. Syringe Package:

1a - Syringes and needles (disposable) (quantity - 100)

Weight	2.0	lbs.
Volume	.0218	cubic feet

1b - Injectable dyes:

T-1824 (qty - 18)
BSP (qty - 6)
PSP (qty - 12)

Weight	.1120	lbs.
Volume	.0018	cubic feet

1c - Injectables - other

Decholin (qty - 12)
Urea (qty - 12)

Weight	.0560	lbs.
Volume	.0009	cubic feet

1d - Lancets (qty - 50)

Weight	.0280	lbs.
Volume	.0003	cubic feet

1e - Alcohol (8 oz.)

Weight	.5230	lbs.
Volume	.0084	cubic feet

1f - QAA (Antiseptic) (8 oz.)

Weight	.5230	lbs.
Volume	.0084	cubic feet

1g - ABD (antiseptic soap solution) (8 oz.)

Weight	.5230	lbs.
Volume	.0084	cubic feet

1h - Cotton Sterile balls

Weight	1.000	lbs.
Volume	.0413	cubic feet

1i - Gloves, disposable (4 doz.)

Weight	2.2300	lbs.
Volume	.0520	cubic feet

Totals for Syringe Package	6.9950	lbs.	.1433 cubic feet

TECHNIQUE (b) Exercise Tolerance

Description

Subject exercises to the point of maximal physical exertion (heart rate of 180 beats per minute) and maximum oxygen consumption measured. Baseline blood hemoglobin concentration also required.

Studies have shown that, at maximum oxygen consumption, the oxygen content of the mixed venous return in the right atrium is approximately 5.0 cc. If the blood hemoglobin content and maximum oxygen consumption are also known, it is possible to calculate both cardiac output and stroke volume.

Evaluation

This technique is an indirect measure valuable for measuring cardiac output during exercise but is not as simple of accurate as the dye dillution technique. And is, therefore, only recommended as a back-up technique for use during the exercise tests.

(Training Level - Physician)

Total man-minutes	84
Frequency	1/7
Minutes per day	
Subject	4
Observer	8
Total	12

Equipment and Instruments

1 - Exercise Apparatus

Double bicycle ergometer for use of arms and legs simultaneously

Weight	10.0	lbs.
Volume	2.00	cubic feet

2 - Hemoglobinometer (American Optical Co, Spencer Div)

AO Spencer Hemoglobinometer for rapid determination

Weight	.5	lbs.
Power	5	watts
Volume	.0579	cubic feet

3 - Sphygmomanometer Including Acclusive Cuff

Aneroid Manometer for measuring blood pressure
(Tycos, Taylor Inst Co, Rochester, N. Y.)

Weight	1	lbs.
Volume	.0463	cubic feet

4 - Stethoscope
(Littman Stethoscope, Cardiosonics, Belmont, Mass.)

Weight	.25	lbs.
Volume	.0023	cubic feet

TECHNIQUE (c) Electrode Gas Analysis of Venous Blood Sample

Description

Venous blood sample analyzed for pO_2, pCO_2 and pH using a direct reading electrode gas analyzer.

Evaluation

Blood gas analysis is not an adequate technique for the measurement of cardiac output since it gives only generalized data pertinent to the measure.

(Training Level - Physician)

Total man-minutes	28
Frequency	1/7
Minutes per day	
Subject	1
Observer	3
Total	4

Equipment and Instruments

1 - Electrode Blood Gas Analyzer; Direct reading electronic gas analyzer (Beckman Inst - Model 160)

Weight	20.0	lbs.
Power	140.0	watts.
Volume	.8640	cubic feet

TECHNIQUE (d) Cardiac Catherization

Description: (Brief explanation of what the technique is)

Blood is sampled from the left side of the heart at the outlet to the aorta by an arterial catheter from the left arm. A similar sample of blood from the right side of the heart is taken by a venous catheter from the right arm. This is a serious surgical procedure which could have severe consequences.

Evaluation

Cardiac Catherization would accurately measure cardiac output but is a surgical procedure which would require precautions and equipment not feasible for a space station.

MEASURE 2. RESPIRATORY VOLUMES

Question or Hypothesis

Decreased metabolic activity expected with zero-g would cause decreased oxygen demand with subsequent decrease in respiratory rate. Cosmonauts were noted to have decreased rate during orbital flight.

Decreased demand respiratory system could cause reduction in response to severe demands. The probable use of other than normal earth atmosphere requires constant monitoring of pulmonary function.

Description of Measure

Measurement of respiratory volumes should be made at rest and after programmed exercise. Time required is one-half hour per trial. The measure is made by having subject breathe into spirometer in a set-pattern of maneuvers.

Results

Impairment of function would be reflected in decreased volumes and decreased flow (prolonged expiratory and inspiratory times).

TECHNIQUE (a) Servo-Spirometric Determination of Respiratory Volumes

Description:

Use of servo-spirometer as discussed above necessary to make maximum number of measures, i.e. total volume, minute volume, maximum breathing capacity, inspiratory and expiratory end volumes, and inspiratory and expiratory reserves. A routine pattern of testing (pulmonary function test) is followed.*

Evaluation

This is a highly accurate direct technique for measuring respiratory volumes that is comparable to other spirometric techniques. Unlike the others however, the servo-spirometer is ideally suited to zero-g use. It is sturdy and gives digital readout. This the technique recommended for inclusion in the CMS.

Training Level - Physician

Total man-minutes	35
Frequency	1/7
Minutes per day	
Subject	1
Observer	4
Total	5

*Subject breathes into mouthpiece of hose to spirometer and is tested during rest and programmed exercise.

Data Form

Digital readout of volume and flow simultaneously

Volume: 0-215V as 1, 2, 5, 10 liters

Flow: 0-17.5V as 1 to 35 liters/sec

Equipment and Instruments

1 - Servospirometer Package

This package includes: Servo spirometer
Thermal conductivity analyzer
Closed circuit hardware
CO_2 absorbant (2.43 lbs.)
Oxygen (2 lbs. from system)

Total package values*

Weight	108.5	lbs.
Power	320	watts
Volume	3.8291	cubic feet

2 - Servo spirometer (ref M-2-a-1)
(Medscience Electronics, St. Louis, Mo. - Model 350)

Weight	70.5	lbs.
Power	310	watts
Volume	1.9271	cubic feet

(Included in M-2-a-1 total)

3 - Thermal Conductivity analyzer (ref M-2-a-1)
(Godart Pulmoanalyzer, Instrumentation Assoc, Inc, N. Y., N. Y.)

Weight	25.0	lbs.
Power	10	watts
Volume	1.1120	cubic feet

(Included in M-2-a-1 total)

4 - Closed Circuit Hardware (ref M-2-a-1)

Weight	10.0	lbs.
Volume	.5000	cubic feet

(Included in M-2-a-1 total)

S1 - (M2-a-1) CO_2 absorbant (2.43 lbs.)

Weight	3.0	lbs.
Volume	.2900	cubic feet

(Included in M-2-a-1 total)

S2 - (M2-a-1) Oxygen (2 lbs. - from system)

(Included in M-2-a-1 total)

TECHNIQUE (b) Spirometric Determination of Respiratory Volumes

Description

Directly measures lung volumes by displacement of spirometer bell and also measures oxygen uptake. Rest same as Servo-Spirometer.

Evaluation

The standard and highly accurate direct technique for measuring respiratory volumes because most spirometers are water-sealed and are gravity dependent redesign is necessary. For this reason, and also because of the fragility of the device, the technique is second choice.

Training Level - Technician

Total man-minutes	42
Frequency	1/7
Minutes per day	
Subject	2
Observer	4
Total	6

Data Form

Direct readout on graph paper to storage.

Equipment and Instruments

1 - Spirometer Package

Spirometer

Thermal Conductivity Analyzer

Closed Circuitry Hardware

CO_2 Absorbant (2.43 lbs.)

Oxygen (2 lbs. - from system)

Total Package Values *

(See References)

Weight	108.0	lbs.
Power	110	watts
Volume	10.3470	cubic feet

2 - Spirometer (ref M-2-b-1)
(Godart Pulmonet - Inst Assoc, Inc, N. Y., N. Y.)

Weight	70.0	lbs.
Power	100	watts
Volume	8.4750	cubic feet

(Included in M-2-b-1 total)

3 - Thermal Conductivity Analyzer (ref M-2-b-1)

Weight	25.0	lbs.
Power	10	watts
Volume	1.1120	cubic feet

(Included in M-2-b-1 total)

4 - Closed Circuit Hardware (ref M-2-b-1)

Weight	10.0	lbs.
Volume	0.5000	cubic feet

(Included in M-2-b-1 total)

S1 - CO_2 Absorbant (M-2-b-1) (2.43 lbs.)

Weight	3.0 lbs.
Volume	0.2600 cubic feet

(Included in M-2-b-1 total)

S2 - Oxygen (2 lbs. - from system) (M-2-b-1)

(Included in M-2-b-1 total)

TECHNIQUE (c) Mass Flow - Flowmeter Determination of Respiratory Volumes

Description

Sensing flow of respired air through flowmeter device as a measure of volume changes of lungs with respiration.

Evaluation

This technique is simple and requires small equipment. It does not measure volume change directly as does the Spirometer. The technique is not well validated or correlated with Spirometric data although claims are generous. It would be a valuable technique for small space cabins or where Spirometry is not otherwise feasible.

(Training Level - Astronaut)

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Data Form

Digital form to data processing

Volume:

Flow: 0-5V ASO-500 liters/min

Equipment and Instruments

1 - Strain gauge mass flow transducer (face mask - pneumotachometer)
(Glennite MF401, Gulton Industries Inc, Metuchen, N. J.)

Weight	.5	lbs.
Power	1	watt
Volume	.0012	cubic feet

TECHNIQUE (e) Impedance Pneumographic Determination of Respiratory Volumes

Description

Impedance changes across thorax reflects respiratory rates and volumes measured electronically.

By means of transthoracic electrodes, a high frequency carrier signal (20 - 60 KC) is passed through body and impedance changes due to respiration rates and volumes sensed, amplified and recorded. To be used for weekly respiratory volumes measured at rest and during programmed exercise.

Evaluation

New technique. Advantages: simple, small, light, reliable, minimal subject attachment, little training required, same electrodes for EKG. Disadvantages: needs calibration each time, baseline shifts with electrode placements, movement artifact. It has not been validated to date.

(Training Level - Astronaut)

Total man-minutes

Freq [illegible]y

Minutes per day

Subject

Observer

Total

Equipment and Instruments

1 - Mass Flowmeter (Space Labs, Van Nuys, Calif)

Weight	1.5	lbs.
Power	N.A.	
Volume	.0145	cubic feet
Total		

TECHNIQUE (d) Mass Flow - Strain Gauge Determination of Respiratory Volumes

Description

Senses flow of respired air through a face mask strain gauge transducer. Face mask is worn during periods of exercise and/or stress testing once per week.

Evaluation

This is also a simple technique but works upon strain gauge sensing of air in movement similar to flowmeter, although it is less accurate. It also would be valuable for minimal situations.

(Training Level - Astronaut)

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	5

Data Form

Flow: 0 to 5V - 2.5 to 250 liters per minute.

Data Form

Digital record to data processing

Rate: 8 to 40 breaths/min

Flow: 1/2 to 4 liters/breath.

Equipment and Instruments

1 - Impedance Pneumograph (Space Labs, Van Nuys, Calif or 6570 Aerospace Med Gp, WPAFB)

Weight	N.A.
Power	N.A.
Volume	N.A.
Total	

TECHNIQUE (f) Strain Gauge Determination of Respiratory Volumes

Description

Strain gauge transducer attached to chest band and respiratory volumes measured as movement of chest cage.

Evaluation

Volume changes sensed indirectly from chest movement with inherent inaccuracy. It is, thus, the last choice although it requires simplest and smallest equipment and does not encumber subject.

(Training Level - Astronaut)

Total man-minutes

Frequency

Minutes per day

Subject

Observer

Total

Data Form

Digital record to data processing.

Flow: 0. to 5V - 0 to 250 liters/min

Equipment and Instruments

1 - Chest Strain gauge transducer
(Glennite MF402, Gulton Ind Inc, Metuchen, N. J.)

Weight	.375	lbs.
Power	1	watt
Volume	.0006	cubic feet

MEASURE 3. CALCIUM BALANCE STUDY

Question or Hypothesis

Under zero "g" muscle atrophy due to loss of gravitation stress may ultimately also be reflected as a decreased stress on the skeletal system, which in turn will respond by a degree of demineralization. Calcium balance studies will document the turnover of body calcium.

Some evidence already exists relating exposure to weightlessness to a condition which occurs with prolonged restriction in muscular activity. Calcium deposits in the body are observed to free much of this element. Higher calcium levels are noted in the serum and urine. Feces calcium should be correlated with calcium content of the foods, as a greater percentage of nutrient calcium may be excreted if such a condition exists. In addition to possible degradation of bone tissue, calcium loss involves excessive reduction in inorganic phosphate. Phosphates constitute the prime buffer system for the body fluids. Marked utilization of this ion could radically affect blood and urine.

Description of Measure

Measurements would be made periodically until a stable baseline is reached. A diet of known calcium content will be employed. Serum urine, and fecal calcium will be determined on a programmed schedule over a 3-day period.

Results

Demineralization of bone would result in increased blood and urine levels of calcium during the study. Malabsorption would cause increase in fecal calcium.

TECHNIQUE (a) Microanalytic determination of calcium balance - programed determination of serum and urine calcium and phosphate

Description

Biochemical determination of calcium and phosphate using the Microanalytic System.

A discussion of the biochemical systems recommended for inclusion in the CMS follows this technique section.

Evaluations

Excellent method for biochemical determinations. Longer and more involved then the Calsul technique, however the Calsul technique cannot be used for calcium and phosphate determinations. Part of the microanalytic system is also required for the Calsul technique.

(Training Level - Technician)

Total man-minutes	63
Frequency	1/14
Subject	1/2
Observer	4
Total	4-1/2

Data Form - Direct readout of colorimeter as mg of calcium, etc. Recorded on paper.

Equipment and Instruments

1 - Chemical package - This package includes the supplies listed below (M-3-a-1-(S1-S6)

Total Package Value*		
Weight	4.96	lbs
Power		
Volume	0.1651	cubic feet

2 - Microanalytic Package (Ref: M-1-a)

S1- M-3-a-1. Calsuls (reagent tests, qty-112)
(Calif Corp for Brochem Research, Los Angeles, Calif)

Weight	.25	lbs.
Volume	.0040	cubic feet

(Included in M-3-a-1 total)

S2 —M-3-a-1 Micropack (reagent tests, qty-100)

Weight	.28	lbs.
Volume	.0250	cubic feet

(Included in M-3-a-1 total)

S3 —M-3-a-1 Capillary tubes (qty - 50)

Weight	.68	lbs
Volume	.0058	cubic feet

(Included in M-3-a-1 total)

S4 — M-3-a-1 Miscellaneous items

Weight	1.00	lbs
Volume	.0100	cubic feet

(Included in M-3-a-1 total)

S5 – M-3-a-1 Edible dyes: Charcoal (qty - 6) sugar (qty - 6)

Weight	.55	lbs
Volume	.0850	cubic feet

(Included in M-3-a-1 total)

S6 – M-3-a-1 Dilution water

Weight	2.20	lbs
Volume	.0353	cubic feet

(Included in M-3-a-1 total)

Analytical Methods for Biochemical Constituents

No completely automatic methods for the analysis of biochemical constituents exist at the present time. Some degree of technical competence will therefore be required in proper preparation of the samples and performance of the analyses.

The methods specified are based mainly on the use of three commercial systems. All may be employed by relatively unskilled personnel and still provide highly accurate experimental results. The first of these methods employs "Calsuls," products of the California Corporation for Biochemical Research, 3625 Medford Street, Los Angeles. Each "Calsul" consists of a pre-measured, individually packaged analytical system. All that need be done by the operator is the dissolution of the contents in a measured volume of water, the addition of sample and the recording of two meter readings, before and after a predetermined time interval, usually 10 minutes. The reagents are specific for the particular determination, but all are based on a DPN- or TPN-linked reaction and may therefore be traced by taking readings at only one wave length, 340 mu. The use of only one wave length setting eliminates errors due to improper absorption peak readings. The universal nature of the DPN- or TPN-linked reaction also makes the "Calsul" principle amenable to a large number of other biochemical assays in addition to those commercially available. It is recommended that every effort be made to foster the further development of this analytical system. Its inherent simplicity, speed and accuracy makes it the method of choice for space applications.

The second commercially available system to be considered is the Ultra-micro Analytical System, Model 150, produced by the Spinco Division of Beckman Instruments, Inc., Stanford Industrial Park, Palo Alto, California. Four special pieces of equipment comprise this system: a

spectro-colorimeter, micro-centrifuge, microtitrator and mixer. These units permit complete colormetric determination of many biochemical constituents. All tests are accomplished on a micro basis, so that a battery of determinations may be accurately performed on a few drops of sample material. The system employs no glassware, since all reagents are stored in polyethylene pipette bottles. The sample tubes are disposable, eliminating the cleaning and washing of analytical equipment. Specifications for the units in the commercially available system are as follows:

Spectrocolorimeter, Model 151

Function: Measurement of colorimetric absorption in the 400 - 650 mu range
Size: 10-3/4" L x 8" D x 5"H, Weight: 14 pounds,
Power required: 23 watts

Micro-centrifuge, Model 152

Function: rapid separation of solids in liquid suspension
Size: 11" L x 3-1/2" D x 5" H, Weight: 11 pounds
Power required: 70 watts

Microtitrator, Model 153 (Not needed for the CMS)

Function: titrates ultramicro samples in analytical techniques requiring volumetric analysis.
Size: 7" L x 7" D x 9" H, Weight: 5 pounds, Power required: 6 watts

Mixer, Model 154

Function: insures adequate mixing of micro samples by subjecting them to controlled vibration
Size: 5-3/4" L x 3-1/4" D x 3" H, Weight: 3-1/2 pounds,
Power required: 8 watts

The third analytical system involves the use of direct indicator tablets, powders, sticks and papers, of the type commercially distributed by the Ames Company, Inc. These devices offer probably the quickest, most compact and simplest test methods available at the present time. They are, however, limited in scope and can only be considered semi-quantitative tests under usual conditions. Maximum utilization of these techniques is recommended in the determination of constituents which are valuable diagnostics on a qualitative, or "yes - no," basis.

The recommended analytical procedures for each biochemical measurement previously justified are listed in the table on the next page.

Measurement	Calsul Method: Available now	Calsul Method: Not available, but feasible	Calsul Method: Method Available	Beckman Microanalytical System: No. of Reagents required	Beckman Microanalytical System: Run many samples concurrently	Beckman Microanalytical System: Time per run (min.)	Beckman Microanalytical System: Comment	Direct indicator, paper, stick or tablet	Other Methods Required
I. Total nitrogen									Kjeldahl or Coleman automatic analyzer
II. Urea		X	X	3	yes	5(A) 60(P)	Reagents need refrigeration		
III. Creatinine		X	X	5	yes	10(A) 10(P)			
IV. Albumin		X	X	3	yes			X	
V. Hemoglobin			X	1	yes	5(A)		X	
VI. Ketone bodies								X	
VII. Calcium			X	4	yes	15(A) 45(P)	precipitation required		
VIII. Catecholamines		X							Elaborate extraction procedure followed by fluorometric determination.
IX. Steroids		X							Elaborate extraction procedure followed by colorimetric determination.
X. Sodium									Flame photometry or precipitate zinc uranyl acetate salt
Potassium			X	4	yes	15(A) 15(P)	measure turbidity of tetraphenylboron salt		Flame photometry.
XI. Alkaline phosphatose	X								
XII. Plasma proteins			X	3	yes	5(A) 15(P)	indicate total protein, albumin and albumin/globulin ratio		Separate by paper electrophoresis; clute & measure colorimetrically
XIII. Blood ureau nitrogen		X	X	3	yes	5(A) 60(P)			
XIV. A. T. P.	X								

(A) = active time
(P) = passive time - allowing precipitation to occur, color to develop, etc. other operations may be accomplished during this time.

Further changes in the Beckman Ultramicro Analytical System are possible in order to make it more amicable to space cabin conditions. For example, the centrifuge may be replaced by a hand operated unit, thereby saving the power required while providing an extra exercise unit for the crew. In addition, none of the procedures required for the determinations mentioned in the table involve titrimetric methods, thereby eliminating the need for the microtitrator, and, besides, standard titrators are gravity dependent. The spectro-colorimeter should be modified to permit the reading of samples analyzed by the Calsul technique. This would necessitate a change in the light source and optics to permit transmission of the 340 mu band. It is understood that the Beckman Company has proposed modification of the ultramicro system to NASA for more efficient space applications. The modifications suggested by Beckman significantly reduce the weight and power requirements for the units comprising the system. The following were indicated by Beckman as design criteria for this modification:

Spectro-colorimeter	- reduced to 4.5 pounds, drawing 10 watts.
Micro-centrifuge	- replaced by hand operated model, weighing about 4 pounds.
Micro-mixer	- reduced to 2.5 pounds, drawing 5 watts.

Reagents for each determination are stored in individual plastic containers, which also serve as delivery devices. 2-ounce containers of each reagent would provide sufficient material for approximately 1,000 determinations. Some reagents and all calsuls would have to be stored at refrigerator temperature (4 - 10°C).

MEASURE 4. CENTRIFUGE TEST

Question or Hypothesis

If cardiovascular deconditioning occurs it could cause severe decrease in tolerance to g- stress and seriously effect the astronauts ability to withstand reentry-g.

Description of Measure

Crewmen will be centrifuged periodically to test the cardio-pulmonary response to g-stress. The head to foot position is the least tolerable and would require much lower g for the test. Heart rate, respiration rate, and as many other cardio-pulmonary and behavioral measures as can be made before during and after centrifuging should be used.

Results

Deconditioning will result in decreased tolerance to g-stress resulting in decrease behavioral function, and rapid outlet of loss of vision and black-out.

TECHNIQUE (a) Centrifuge Test

Description

Crewman will be centrifuged periodically and cardiopulmonary response observed.

Evaluation

This provides the only actual test of g-tolerance and thus a direct measure of reentry response. Exercise stresses the cardiovascular system also but there is no data available to indicate correlation between g response and exercise response.

(Training Level - Physician)

Total Man-minutes	84
Frequency	1/7
Minutes per day	
Subject	4
Observer	8
Total	12

Data Form

Recorded on paper

Equipment and Instruments

Centrifuge Test

1 - Servo Spirometer Package (ref. M-2-a)

2 - Syringe Package (ref. M-1-a)

3 - Microanalytical Package (ref. M-1-a

4 - Electrocardiogram (Biometrics Inst Corp, Dallas, Texas - Model 2033)

Weight	.125 lbs.
Power	.02 watts
Volume	.0005 Cubic feet

5 - Sphygmomanometer (ref. M-1-b)

6 - Stethescope (ref. M-1-b)

7 - Hemoglobinometer (ref. M-1-b)

8 - Centrufuge Apparatus (See Centrifuge section in report.)

MEASURE 5. OXYGEN UPTAKE AND CARBON DIOXIDE PRODUCTION (INCLUDES BMR AND RQ)

Question or Hypothesis

Oxygen uptake measurement offers the best indication of metabolic activity. This measure is also important for evaluating cardiac status, especially cardiac output. Decreased metabolic activity expected during long duration exposure to zero "g" will be primarily due to decreased work requirements. Some postulate, however, that zero "g" may also effect the basal requirements due to decreased activity of various body systems. Measurements of the basal metabolic rate will reflect any such changes. Some further speculate that there may be change in the utilization of food-stuffs associated with zero "g" state. The respiratory quotient provides a measure of this food utilization.

There is also some evidence to suggest that activity in the weightless state may be accompanied by greater than normal energy usage.

Description of Measure

The measure should be made at rest and with programmed activity. Measurement requires monitoring of oxygen inspired and carbon dioxide expired, either using a mask or the suit circuit. The measurement requires about 15 minutes with a one-half hour preliminary test period.. The resting level should be obtained after a 12 hour fasting period.

The BMR and respiratory quotient can be determined during oxygen and carbon dioxide measurements. Urinary nitrogen should be additionally determined or estimated to establish the complete quotient which includes protein metabolism.

Results

Decreased metabolic rate would be seen as decreased resting oxygen consumption. A change in respiratory quotient could indicate a variation in food utilization. A decrease or increase in metabolism with programmed exercise would indicate the energy levels associated.

TECHNIQUE (a) Servo-Spirometric Determination of Oxygen Consumption and Thermal Conductivity Analysis for Carbon Dioxide

Description

Oxygen consumed during use of servo-spirometer by measurement of volume displacement of spirometer. Analysis of expired gases for carbon dioxide by thermal conductivity method (which technique also determines volume by closed circuit helium method).

$$\text{BMR} = O_2 \text{ consumed}$$

$$\text{RQ} = \frac{\text{Vol } CO_2 \text{ produced}}{\text{Vol Oxygen consumed}}$$

Evaluation

Using the closed circuit technique, oxygen consumption can be easily and accurately determined with the servospirometer. Carbon dioxide consumption is determined for an expired air sample with about a 20 second lag. Average CO_2 values would be obtained. This technique would probably be suitable for CO_2.

(Training Level – Technician)

Data Form

Digital readout

Time Requirements

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1 Servo-Spirometer Package (Ref. M-2-a)

TECHNIQUE (b) Servo-Spriometric Determination of Oxygen Consumption
Mass Spectrographic Analysis Carbon Dioxide Consumption

Description

Same as preceeding technique except mass spectrograph used for CO_2 production.

Evaluation

This is a highly accurate determination of CO_2 but gives a breath by analysis of CO_2 at end of expiration.

(Training Level –

Data Form

Ditigal readout

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1 Polaragraphic Oxygen Sensor (Beckman Inst)

Weight	.1563 lbs
Power	supplied from M-5-b-2
Volume	.0012 cubic feet

2 High Impedance Amplifier (Beckman Inst)

Weight	1.1250 lbs
Power	2 watts
Volume	.0174 cubic feet

3 Mass Spectographic Gas Analyzer (AiResearch Corp, LA, Cal)

Weight	25.000 lbs
Power	50 watts
Volume	1.1574 cubic feet

MEASURE 6. FLUID INTAKE AND OUTPUT ELEVATION

Question or Hypothesis

Decreased metabolic requirements should be reflected in decreased fluid intake and output. Activity and thermal levels most significantly determine fluid use. Fluid shifts within the body will be determined by other techniques. In a zero "g" environment, the desire to void may be deminished because of a lack of sensation of bladder fullness due to weight alone; zero "g" may also alter the normal desire for adequate fluid intake.

Description of Measure

Fluid intake will be recorded daily. Urine volume and fecal weight will be recorded daily. From known food analyses and the biochemical measures, the total turnover can be computed.

Results

Inadequate fluid intake and dehydration will result in decreased urine output. Decrease metabolic requirements will be reflected in decreased intake, as well.

TECHNIQUE (a) Record of Fluid Intake and Output

Description

Water and food intake, urine and fecal water output determined, and perspiration estimated, and all recorded daily on checklist. Water intake and output calculated daily.

Evaluation

Provides good estimation of fluid turnover. Limiting factor is sensible perspiration which can only be estimated.

(Training Level – Astronaut)

Data Form

Checklist

Time Requirements

Total man-minutes	3
Frequency	1
Minutes per day	
Subject	3
Observer	-
Total	3

Equipment and Instruments

1 Checklist of fluid intake and output – medical log

2 Color Indicator Package (graduated container for measuring urine volume); package includes the following listed supplies* (References: M-6-a-2(S1-S8)

*Total Package Value

Weight	2.905 lbs
Power	-
Volume	0.0392 cubic feet

Supplies and Spares

2 Color Indicator Package:

S1 Filter paper (qty-50)

Weight	0.028 lbs
Volume	0.004 cubic feet

(Included in M-6-a Total)

S2 Slides (qty-50)

Weight	0.224 lbs
Volume	0.0035 cubic feet

(Included in M-6-a Total)

S3 Counting chambers (qty-5)

Weight	0.448 lbs
Volume	0.0069 cubic feet

(Included in M-6-a Total)

S4 Diluents (qty-4 two oz)

Weight	0.523 lbs
Volume	0.0084 cubic feet

(Included in M-6-a Total)

S5 Stains, Blood (qty-4 two oz)

Weight	0.523 lbs
Volume	0.0084 cubic feet

(Included in M-6-a Total)

S6 **Combihematest** (qty-100) (Ames Co Inc, Elkhart, Ind)

Weight	0.131 lbs
Volume	0.0014 cubic feet

(Included in M-6-a Total)

S7 Acetest (qty-100 tests) (Ames Co Inc)

Weight	0.028 lbs
Volume	0.0002 cubic feet

(Included in M-6-a Total)

S8 Miscellaneous Items

Weight	1.000 lbs
Volume	0.0100 cubic feet

(Included in M-6-a Total)

MEASURE 7. BLOOD PRESSURE (BEFORE AND AFTER EXERCISE)

Question or Hypothesis

Due to disuse under weightlessness, there may be a loss in muscle tone resulting in blood pooling, a decreased venous return to the heart and consequently a decrease in blood pressure. The loss of cardiovascular adaptability because of disuse of compensatory reflex circulatory mechanisms (deconditioning) may be an even greater factor in producing an decrease in blood pressure.

Description of Measure

Blood pressure measured in upper extremity using standard technique. Measurement made periodically by astronauts on each other. External blood pressure measure gives peak and trough of pressure pulse, not a continuous pulse measure.

Results

Decreased activity results in decreased resting blood pressure. Deconditioning results in poor response to stress with possible low blood pressure episodes if significant venous pooling should occur.

TECHNIQUE (a) Auscultatory Determination of Blood Pressure

Description

Standard blood determination using an aneroid type of occulusive arm cuff. Standard stethoscope used to monitor Korothoff sounds.

Evaluation

Valid routine b.p. measure; if environmental atmospheric pressure differs from 14.7 psi, the instrument would require minor modification (recalibration). Because it is an indirect measure and uses auscultation, it is somewhate inaccurate. A definite conclusion as to blood pressure change may be predicted, but only contributory non-conclusive evidence may be obtained regarding the mechanism of the effect. This method can be readily adapted to weightless conditions.

(Training Level -- Astronaut)

Data Form

Direct to paper record.

Time Requirements

Total man-minutes	6
Frequency	2
Minutes per day	
Subject	4
Observer	8
Total	12

Equipment and Instruments

1 Sphygmomanometer (Ref. M-1-h)

2 Stethescope (Ref. M-1-b)

MEASURE 8. COMPLETE BLOOD CELL COUNT (RED AND WHITE RETICULOCYTE AND DIFFERENTIAL)

Question or Hypothesis

Zero "g" may alter hematopoiesis and be reflected as an alteration in the peripheral blood composition. In addition, the wbc is an index of systemic infection, the red count and reticulocyte count an index of anemia, and the platelet count an index of blood clotting mechanism intactness.

Description of Measure

Measurement made on blood sample either from venipuncture or finger stick. Smears made on slides for differential, reticulocyte and platelet counts and dilutions made for WBC, and RBC.

Measurement would be performed periodically and require approximately 20 to 30 minutes. Data will be recorded and analyzed as numerical counts.

The wbc and differential count give useful clinical data regarding systemic infection.

Together with the other red blood cell measures (hemoglobin, hematocrit, reticulocyte count), the rbc count allows calculation of the rbc indicies and quantification of anemia. The platelet count also reflects bone marrow activity and intactness of the blood clotting mechanism. If abnormal cell types develop, their nature can also be described as part of the blood smear evaluation.

The eosinophil count can be used to provide a gross estimate of adrenal cortical activity and function.

TECHNIQUE (a) Optical Count for Complete Blood Count

Description

A small quantity of blood will be obtained from an ear lobe or finger prick and used to prepare a standard blood smear, a wbc, a rbc, and a smear for reticulocyte count.

This is a standard clinical procedure, however, some modification of staining procedure, such as immersion of slide in a "closed" container, will be required since the routine method of pouring the liquid over the slide cannot be used in zero "g".

Evaluation

A standard clinical test providing reliable data when performed by trained personnel.

(Training Level -- Technician)

Data Form

Paper record

Time Requirements

Total man-minutes	33
Frequency	1/3
Minutes per day	
Subject	1
Observer	10
Total	11

Equipment and Instruments

1. Color indicator package (Ref M-6-a)
2. Syringe package (Ref M-1-a)
3. Microscope

Weight	5.0 lbs
Power	10 watts
Volume	.5700 cubic feet

MEASURE 9. TOTAL BODY WATER

Question or Hypothesis

Under the influence of zero gravity normal cardiovascular mechanism may be altered resulting in blood pooling and subsequent redistribution of fluid in the body fluid compartments.

Description of Measure

The radioactive tracer method requires ingestion of tritium (H-3). The dilution method requires injection of urea. A measured quantity is taken of a substance that is known to distribute evenly in the body water. At a later time blood samples are measured for dilution of the injected substance. Total body water can be calculated from the ratio of dilution.

TECHNIQUE (a) Urea Dilution Determination of Total Body Water

Description

A known quantity of urea is injected intravenously, allowed to equilibrate (for 10 to 20 minutes) and then a determination of the serum concentration of urea is made. By comparing the serum level of urea before and after the urea injection, the total body water causing the dilution can be calculated.

Evaluation

This is only a moderately accurate technique (some urea is metabolized or excreted into the urine) but should provide clinically useful data. The same comments apply to the antipyrine method. Since the technique requires no additional equipment and is highly feasible, it is the technique of choice.

(Training level -- technician)

Data Form

Paper record

Time Requirements

Total man-minutes	30
Frequency	1/14
Minutes per day	
Subject	1/7
Observer	2
Total	2-1/7

Equipment and Instruments

1. Microanalytic Package (Ref. M1-a)
2. Chemical Package (Ref. M3-a)
3. Syringe Package (Ref. M1-a)

TECHNIQUE (b) Radioisotope Study, H-3 Determination of Total Body Water

Description

Tritium (H-3) is taken orally and the H-3 level in the blood is determined determined 4 hours later. A basic radioisotope tracer laboratory would permit the determination of a number of biochemical measure in addition to the determination of total body water. Inclusion of such a laboratory appears realistic in terms of existing hardware. A description of the technique follows.

Evaluation

This technique is accurate but its use in a closed ecological system where urine was purified for drinking water would not be advisable. The radioactive water given to test subjects would eventually be distributed among all crew members. While this would not be harmful, it would make continued accurate measurement impractical.

(Training level -- technician)

Time Requirements

Total man-minutes	58
Frequency	1/4
Minutes per day	
Subject	1/7
Observer	4
Total	4-1/7

Equipment and Instruments

1. Syringe Package (Ref. M1-a)

2. Radioisotope Package (Nuclear-Chicago Corp, Chicago, Ill)

   a. High Voltage Power Supply (Model 40-8B)

Weight	4.0 lbs
Power	8.0 watts
Volume	(Included in d.)

   b. Amplifier Analyzer (Model 33-13)

Weight	5.0 lbs
Power	5.4 watts
Volume	(Included in d.)

   c. Pre-Set Count Scaler & Timer (Models 49-26 & 54-7)

Weight	3.3 lbs
Power	9.0 watts
Volume	(Included in d.)

   d. Case and Power Supply (B+) (Model 29-1)

Weight	35.0 lbs
Power	18.0 watts
Volume	1.4912 cubic feet

   e. Shielded Well Detector (Model DS-202)

Weight	145.0 lbs
Power	-
Volume	.3320 cubic feet

f. Shielded Isotope Container with Isotopes

Weight	52.0 lbs
Power	-
Volume	0.0732

TOTALS FOR RADIOISOTOPE PACKAGE:

Weight	244.3 lbs
Power	40.0 watts
Volume	1.8964 cubic feet

3. H-3 Supplementary Radioisotope Package (Needed only for H-3 technique and not included for other radioisotope measures).

a. Beta Spectrometer and Power Supply (Model 2C088A)

Weight	52.0 lbs.
Power	-
Volume	1.045 cubic feet

b. Chroma/Cell Unit (No Model No.)

Weight	165 lbs
Power	-
Volume	(Included in a.)

TOTALS FOR H-3 SUPPLEMENTARY RADIOISOTOPE PACKAGE

Weight	217 lbs
Power	-
Volume	1.045 cubic feet

Measurement Technique

Radioisotope Tracer Laboratory

Measures: Red Blood Cell Mass

Red Blood Cell Survival Time

(Plasma Volume)

Red Blood Cell T3 Uptake

Total Body Water

Technique: Radioisotope tracer methods

Summary Description of Techniques:

A basic radioisotope tracer laboratory capability would permit the determination of a number of fundamental biochemical measures. Inclusion of such a capability appears realistic in terms of existing hardware. The determinations noted above require the provision of gamma and beta radiation detection systems.

The required isotopes for these studies are:

Measure	Isotope	Half-Life
Red Blood Cell Mass	Cr-51	27.8 days
Red Blood Cell Survival Time	Cr-51	27.8 days
Red Blood Cell Uptake of T3	I125	62 days
Total Body Water	H^3	12.26 years

(Plasma volume can be computed from the red blood cell mass and the venous (average) hematocrit.)

Shielding requirements:

Cr-51	6-8 cm of lead
I_{125}	2-3 mm of lead
H^3	essen. none (container provides adequate attenuation)

Adequate shielding for all three isotopes can therefore be provided by a small lead safe, est. weight 50 lbs.

1. Red Cell Mass

   Red Blood Cell Survival

   Requirements:

   25 microcuries of sodium radiochromate

   10 ml. strumia solution

   30 ml. subject's venous blood

   100 mgr stenle ascorbic acid

   10 cc 0.97 sodium chloride

   100 cc water

   RBC survival requires only the additional withdrawal of 10 ml. blood samples twice weekly for two weeks.

RBC mass test requires approximately one hour for completion; RBC survival requires about 1/2 hour per determination. A fairly accurate weighing must be done in the current procedure; obviously this will not be possible in zero "g" - future investigations should provide alternative techniques.

Plasma volume can be calculated from the hematocrit and red blood cell mass.

2. RBC T_3 Uptake (Thyroid Function Test - in vitro)

   Requirements:

   0.2 ml I_{125} labeled T_3

   10 cc whole blood

   100 cc normal saline

3. Total Body Water

   Requirements:

   2 millicuries H^3O (given orally)

   urine sample at 4 hours

MEASURE 10. URINALYSIS (WBC, RBC, pH, SUGAR, PROTEIN, OSMOLARITY)

Question or Hypothesis

The effects of zero gravity on the urinary system are uncertain; it does not appear that there will be any direct effects. However, because of the general importance of the urinary system in body chemistry, including the fact that it reflects abnormalities in other body systems, it is important to monitor urinary functioning by routine clinical methods.

Description of Measure

Urine will be collected every three days for routine analysis including microscopic study, hemoglobin and chemical determinations.

Result

Ketone bodies will appear in the urine as a result of any condition which accompanies incomplete oxidation of carbohydrate or fatty acid nutrients. Ketone bodies are normally found in the urine (about 20 mg/day, expressed as acetone). Higher levels may result in acidosis and consequent increase in urinary ammonia. This reaction will, therefore, provide an indication of uniform carbohydrate metabolism during an orbiting period. Hemoglobin is observed in the blood as a result of conditions which bring about abnormal hemolysis of erythrocytes. It will be an early indication of changes in serum osmolarity, oxygen-transport capacity and infection.

TECHNIQUE (a). Microscopic and Color Test Urinalysis

Description

A microscope, centrifuge, and color indicators are required. A urine sample is centrifuged for five minutes and the resulting sediment observed by microscope for cells, bacteria, particulate matter, etc. Color indicators (Henia-combistix) are dipped in urine for indications of pH, sugar, protein, and blood. A drop of urine is placed on an acetest table for color indication of acetone. Specific gravity will be determined as urine osmolarity using the freezing point depression technique (see serum osmolarity, measure 59).

Evaluation

This is a standard laboratory technique of proven reliability.

(Training level -- technician)

Data Form

Paper record

Time Requirements

Total man-minutes	12
Frequency	1/3
Minutes per day	
Subject	1
Observor	3
Total	4

Equipment and Instruments

1. Microscope (Ref. M8-a)
2. Microanalytic Package (Ref. M1-a)
3. Color Indicator Package (Ref. M6-a)

MEASURE 11. VENOUS pCO_2, pO_2, AND pH.

Question or Hypothesis

Existing evidence from United States and Russian orbital flights and hypodynamic studies indicates that weightlessness may result in a reduction of cardiovascular reflex adaptability. The cardiac work load may also be lighter effecting a reduction in cardiac output with venostasis changes resulting in variations of pH, pCO_2, and pO_2.

Description of Measure

Venipuncture to obtain a blood sample for analysis to determine pCO_2, pO_2, and pH.

Results

Venostasis would cause increased pCO_2, and decreased pO_2 and pH.

TECHNIQUE (a). Electrode Gas Analysis of Venous Blood Sample

Description

See technique M1-c.

Evaluation

See technique M1-c.

(Training level -- technician)

Data Form

Digital to data processing

Time Requirements

Total man-minutes	28
Frequency	1/7
Minutes per day	
Subject	1
Observer	3
Total	4

Equipment and Instruments

1. Syringe Package (Ref. M1-a)
2. Electrode Blood Gas Analyzer (Ref. M1-c)

MEASURE 12. PLASMA (BLOOD) VOLUME

Question or Hypothesis

Under the influence of zero "g", cardiovascular mechanisms may be altered causing shifts in body fluid; also, inappropriate urine output has been noted in at least one flight.

With the loss of gravitational forces on the cardiovascular system and the possible reduction in muscle tone, blood pooling may occur together with a redistribution of fluid among the body fluid compartments.

Description of Measure

A given amount of substance known to be taken up by the blood plasma is given and later the amount determined in a blood sample. From the dilution of the sample the plasma volume can be determined.

Result

Measure is a standard clinical test and would allow a direct evaluation of the hypothesis.

TECHNIQUE (a) Dye Dilution, T 1824, for Plasma Volume

Description

A known quantity of the dye is injected introvenously. Approximately 10 minutes later, a blood sample is drawn and the blood concentration of the dye determined. The measured dilution occurring in the blood allows the calculation of plasma volume. From this and the hematocrit, the blood volume can be calculated.

Evaluation

The Evans Blue dilution method is less accurate, however, it can be repeated more often and is fairly innocuous.

Because of the simplicity of the technique and the fact that all equipment is already on board it is the recommended technique.

(Training level -- physician)

Data Form

Paper record

Time Requirements

Total man-minutes	84
Frequency	1/14
Minutes per day	
Subject	2
Observer	4
Total	6

Equipment and Instruments

1. Syringe Package
   (Ref. M-1-a)

2. Micro analytic Package
   (Ref. M-1-a)

TECHNIQUE (b) Radioisotopic test (RBC Mass and Venous Hematocrit)

Description

From the RBC mass and the hematocrit the plasma volume can be determined.

Evaluation

RBC mass cannot be determined more often than once a month because of persistance of tagged RBC and thus the biweekly determination of blood volume could not be performed. The method is quite accurate. It is not recommended for use since the dye dilution test is less complex and requires much less time.

(Training level -- technician)

Time Requirements

Total man-minutes	90
Frequency	1/60
Minutes per day	

Subject	1/2
Observer	1
Total	1-1/2

Equipment and Instruments

1. Radioisotope Package (Ref. M-9-b)

2. Syringe Package (Ref. M-1-a)

TECHNIQUE (c) Radioisotopic Total Body Water Determination for Estimation of Plasma Volume

Description

Plasma volume can be estimated from total body water. (see technique M-9-b)

Evaluation

This technique is not recommended because water used would be contaminated with H_3 leading to inaccuracies. Weight of required equipment and time required to perform the test excessive for space station application.

(Training level -- physician)

Time Requirements

Total man-minutes	58
Frequency	1/14
Minutes per day	
Subject	1/7
Observer	4
Total	4-1/7

Equipment and Instruments

1. Radioisotope Package
   (Ref. M-9-b)

2. Syringe Package
   (Ref. M-1-a)

MEASUREMENT 13. HEMOGLOBIN AND HEMATOCRIT

Question or Hypothesis

Hematopoietic activity and/or red blood cell destruction may be altered in zero gravity and, thus, alter hemoglobin. Long term exposure to zero gravity may also alter hematopoesis and/or body fluid balance and distribution resulting in hematocrit changes.

Description of Measure

The hemoglobin determination indicates the concentration of hemoglobin in red cells in gm/100cc. The hemoglobin concentration can be readily measured to clinical accuracy. Together with the hemotocrit and RCB count, these data will allow the computation of the RBC indicies (mean corpuscular values). The hematocrit provides a clinically useful index of anemia by measuring the volume of packed red blood cells. On a long term basis the hermatocrit also will reflect changes in body fluid balance (i.e., hemoconcentration in dehydration). Taken together with the RBC count and hemoglobin concentration, it is possible to calculate mean corpuscular values.

Results

Alteration of hematopoietic activity or fluid balance will be seen as corresponding changes in hemoglobin or hematocrit. Long exposure to low Oxygen levels produces marked increases in both measures.

TECHNIQUE (a). Cyanmethemoglobin and Capillary Tube Methods

Description

A venous blood sample is used for spectrocolorimetric determination of hemoglobin concentration. Hematocrit is determined by centrifuging a blood sample and then noting the percentage of red blood cells.

Evaluation

Although this technique requires more time than the hemoglobinometer technique, its accuracy and sensitivity are much greater. The equipment required is provided for techniques used for other measurements.

(Training level -- technician)

Data Form

Paper record

Time Requirements

Total man-minutes	16
Frequency	1/3
Minutes per day	
Subject	1/3
Observer	5
Total	5-1/3

Equipment and Instruments

1. Chemical Package (Ref. M3-a)
2. Microanalytic Package (Ref. M1-a)
3. Syringe Package (Ref. M1-a)
4. Color Indicator Package (Ref. M6-a)

TECHNIQUE (b). Hemaglobinometer and Capillary Tube Method

Description

A finger tip (or ear lobe) puncture wound is made to obtain a drop of blood which is then placed on the slide of a Spencer hemoglobinometer. Hemoglobin concentration is read directly in grams/100cc. The hematocrit technique is the same as described for M13-a.

Evaluation

This is a rapid technique, excellent for screening determinations, but is not considered accurate enough for controlled space station studies.

(Training level -- astronaut)

Time Requirements

Total man-minutes	2
Frequency	1/3
Minutes per day	
Subject	1/3
Observer	1/3
Total	2/3

Equipment and Instruments

1. Color Indicator Package (Ref. M6-a)
2. Hemoglobinometer (Ref. M1-b)
3. Microanalytic Package (Ref. M1-a)
4. Syringe Package (Ref. M1-a)

MEASURE 14. SENSATION, (SUPERFICIAL) (PAIN, TEMP., PRESS, TOUCH)

Question or Hypothesis

No hypothesis for significant alterations in these sensory modalities due to weightlessness can be offered. It seems unlikely that the reduction in sensory stimulation due to the loss of gravitational effects would be sufficient to cause a decrement in these modalities.

Description of Measure

The superficial sensation of pain, temperature, pressure and touch is evaluated clinically. Measurements would be in the form of subjective ratings on a 1 to 4 scale and would be compared with pre-flight responses.

TECHNIQUE (a) Clinical Neurological Examination of Superficial Sensation

Description

Clinical evaluation of these senses made, such as, response to pin prick, cotton wisp, etc.

Evaluation

The techniques employed are standard clinical tests, and provide only a gross evaluation. A physician should perform the tests because of his experience in rating this response. No special equipment is required, a tuning fork, pin, cold object, and strand of cotton; can all be provided by a combined neurological tool (hammer).

(Training level -- physician)

Data Form

Paper record

Time Requirements

Total man-minutes	12
Frequency	1/7
Minutes per day	
Subject	5/7
Observer	1
Total	1-5/7

Equipment and Instruments

1. Neurological tool (Medics Inc, Hamilton Bell Co, Patterson, N. J.)

Weight	0.5 lbs
Power	-
Volume	0.0116 cubic feet

MEASURE 15. EXERCISE TEST

Question or Hypothesis

Same as M-1

Description of Measure

Subject exercises to the point of maximal physical exertion (heart rate of 180 beats per minute) and maximum oxygen consumption measured. Baseline blood hemoglobin concentration also required.

Measure involves a number of basic assumptions which should be easy to evaluate on the prospective astronauts. Accuracy is only fair, but method has the advantage of requiring a minimum amount of instrumentation.

Results

Cardiovascular deconditioning, pulmonary and muscle function impairment seen as decreased ability to perform exercises, low maximum heart rate, etc.

TECHNIQUE (a) Exercise Test

Description

Same as exercise test M-1-b. Exercise device is a bicycle ergometer allowing exercise arms and legs simultaneously.

Technique Evaluation

Technique provides an indication of maximum exertion capability or the subject as well as his maximum cardiac output. The instrumentation required is fairly simple and the accuracy fair. Because of the moderately severe stress imposed by this test, it should be conducted by a physician.

(Training level -- physician)

Data Form

Paper record

Time Requirements

Total man-minutes	84
Frequency	1/7
Minutes per day	

Subject	4
Observer	8
Total	12

Equipment and Instruments

1. Servo Spirometer Package (Ref. M-2-a)
2. Syringe Package (Ref. M-1-a)
3. Microanalytical Package (Ref. M-1-a)
4. Electrocardiogram (Ref. M-4-a)
5. Sphygmomanometer (Ref. M-1-b)
6. Stethoscope (Ref. M-1-b)
7. Hemoglobinometer (Ref.M-1-b)
8. Exercise Apparatus (Ref. M-1-b)

MEASURE 16. PULMONARY PATHOLOGY (HEART SIZE)

Question or Hypothesis

There is no special justification for expecting zero gravity to produce heart or lung damage. Cardiovascular deconditioning over a long period might produce reduction of heart size. Long term exposure to unnatural atmospheres could result in pulmonary damage such as atalectosis (Small area of lung collapse). The value of this measure is primarily one of crew safety determination.

Description of Measure

Determination could be made by chest x-ray or clinical evaluation.

Result

See Question or Hypothesis above.

TECHNIQUE (a) X-Ray of Chest

Description

Clinical x-rays taken with light-weight, low-power x-ray equipment on Polaroid film. There are available Polaroid x-ray components (see Equipment and Instruments) which make this technique feasible.

Evaluation

This is the most accurate means of determining heart size and other aspects of pulmonary pathology. It is the recommended technique primarily because of its value as a crew safety measure. A number of additional vital questions concerning the effects of zero gravity can be answered by x-ray diagnosis. Films of the long bones (see measure 24) can be used to discover and document loss of bone calcium. Chest x-rays will reveal any atelectasis of the lungs. X-ray and standard barium meal techniques will verify correct functioning of the gastro-intestinal (G-I) tract (see measure 34), and the formation of kidney or bladder calculi (measure 51) can also be detected by films of the abdomen.

(A technician can operate the x-ray equipment but a physician will be required to diagnose the films.)

Data Form

X-ray film.

Time Requirements

Total man-minutes	17 1/2
Frequency	1/14
Minutes per day	

Subject	1/4
Observer	1
Total	1-1/4

Equipment and Instruments

1. X-Ray Package

a. Basic x-ray unit (camera) (Fexitron Model 845, Field Emission Corp, McMinnville, Ore.)

Weight	50 lbs
Power	550 watts (Note: This is the peak power requirement)
Volume	.7674 cubic feet

b. Cassette (Device to hold film for exposure and development) (Polaroid Cassetie, Picker X-Ray Corp, White Plains, N. Y.)

Weight	6.0 lbs
Power	-
Volume	(fits into processing unit -c-)

c. Poloroid Processing unit (for film development) (3000x Radiographic Packet Polaroid Corp, Needham Heights, Mass.)

Weight	20.0 lbs.
Power	(hand operated)
Volume	.5398 cubic feet

TOTAL REQUIREMENTS FOR X-RAY PACKAGE
(Including package of 48 films -- see SUPPLIES AND SPARES)

Weight	84.0 lbs.
Power	550 watts
Volume	1.5155 cubic feet

Supplies and Spares

1. X-ray film (package of 48)

Weight	8.0 lbs
Volume	0.2083 cubic feet

TECHNIQUE (b) Clinical Evaluation of Heart Size.

Description

Gross evaluations can be made with percussion (sounding) and auscultation (stethoscopic examination).

Evaluation

This is basic clinical technique but would need x-ray confirmation for any tentative diagnosis.

(A physician would be required.)

Time Requirements

Total man-minutes	2
Frequency	1/14
Minutes per day	
Subject	1/14
Observer	1/14
Total	1/7

Equipment and Instruments

1. Stethoscope (Ref. M1-b)
2. Heart size checklist.

MEASURE 17. CARDIAC ELECTRICAL ACTIVITY AND STATE (BEFORE AND AFTER EXERCISE)

Question or Hypothesis

Weightlessness may result in loss of myocardial tone, decrease in myocardial oxygenation, change in cardiac irritability, loss of cardiovascular adaptability, decrease in heart rate, and loss of inorganic salts, all of which may be reflected in EKG recordings. Existing evidence from hypodynamic studies U.S. & Russian orbital flights demands further evaluation of EKG.

Description of Measure

Electrocardiographic recordings from chest (transthoracic) and precordial (movable) leads. Cardiac rate rhythum, and myocardial oxygenation state as well as serum salt concentrations (such as Ca^{++} and K^{+}) are reflected in the EKG. This measure can contribute evidence for a conclusion regarding the hypothesis, but is not conclusive in itself for demonstrating the mechanism causing the EKG changes. This method can readily be adapted to weightless conditions. Measure would be made at rest, during centrifuge and exercise tests, and during critical flight phases.

TECHNIQUE (a) Electrocardiography

Description

A high-gain differential amplifier is used for recording heart potentials (EKG). A switching device would be provided to allow recording of a standard 12 lead cardiogram. Standard EKG electrodes, posts, and leads would be used to couple to the preamplifier. A standard EKG will be obtained (12 lead). A switching circuit will have to be provided to allow for the 12 lead recording using the single preamplifier; also some form of automatic lead identifying system would have to be provided to identify the data on the magnetic recording. A 15 second recording of each lead will be obtained.

Evaluation

Technique is essentially the same as used for clinical EKG recording.

(Training Level - Astronaut)

Data Form

Digital to data processing

Time Requirements

Total man-minutes	25
Frequency	1
Minutes per day	
Subject	10
Observer	15
Total	25

Equipment and Instruments

1. Electrocardiogram (Ref. M-4-a)

MEASURE 18. SERUM AND URINE CREATININE

Question or Hypothesis

The "cocatinine coefficient", the daily excretion of creatinine in mg per kg. of body weight, is known to increase with increased tissue catabolism. Decreased creatinine is also significant, as this occurrence is observed in disorders associated with muscular atrosphy and general muscle weakness. It is anticipated that there may be some reduction in muscle strength after long periods of exposure to weightlessness. Levels of this material in the blood may also be of similar significance.

Description of Measure

Serum (blood) and urine creatinine determined biochemically.

TECHNIQUE (a) Calsul Determination of Serum and Urine Creatinine

Description

See calsul technique discussed under measure 3.

Evaluation

Where the calsul reagent can be used it is the most rapid, practical and feasible technique.

(Training Level - Technician)

Data Form

Paper record

Time Requirements

Total man-minutes	9
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	1
Total	1 2/7

Equipment and Instruments

1. Chemical package (Ref. M-3-a)
2. Microanalytical Package (Ref. M-1-a)

TECHNIQUE (b) Microanalytical Determination of Urine and Serum Creatinine

Description

See microanalytic technique under measure 3.

Evaluation

Same accuracy as calsul reagent technique but requires more time and more involved procedures selection and training requirements.

(Training Level - Physician)

Time Requirements

Total man-minutes	23
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	3
Total	3 1/7

Equipment and Instruments

1. Microanalytical Package (Ref. M-1-a)

2. Chemical Package (Ref. M-3-a)

MEASURE 19. SERUM, URINE AND FECAL CA AND PO

Question or Hypothesis

See measure M-3.

Description of Measure

This is a routine evaluation not a programmed study; otherwise, it is the same as measure M-3.

TECHNIQUE (a) **Microanalytic Determination of Serum and Urine Calcium and Phosphates.**

Description

Same as technique for M-3.

Evaluation

Same as technique for M-3.

(Training Level - Technician)

Data Form

Paper record

Time Requirements

Total man-minutes	29
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	4
Total	4 1/7

Equipment and Instruments

1. Chemical Package (Ref. M-3-a)
2. Microanalytical Package (Ref. M-1-a)

MEASURE 20. VENOUS PRESSURE AND CIRCULATION TIME

Question or Hypothesis

Weightlessness may result in the loss of cardiovascular adaptability and loss of muscle tone resulting in venous pooling and an increase in venous pressure and may cause an alteration in the distribution of blood flow resulting in an increase of circulation time. Existing evidence from hypodynamic studies and U.S. and Russian orbital flights indicate the need for this measurement.

Description of Measure

Venous pressure will be measured directly from a needle in an anteculital (elbow joint) vein and circulative measure by injection of a substance that stimulates the subjects taste via the tongue circulation.

Results

With the absence of hydrostatic pressure effects and loss of muscle tone under weightlessness, there is an increased tendency to peripheral pooling of blood and a consequent increase in venous pressure. If venous return is decreased and the distribution of blood flow is altered, arm to tongue circulation time may be predicted to be increased.

TECHNIQUE (a) Manometric Determination and Decholin Test using Venipuncture

Description

A physican will introduce an 18 gauge needle connected to stopcock, syringe and aneroid manometer into the antecubital vein of each astronaut. The venous pressure reading obtained will then be recorded. Next, 5 ml of a 20% solution of decholin will be injected through an antecubital vein with a syringe needle and the time until the bitter taste is noted and recorded.

Data Form

Paper record

Evaluation

This is the simplest, quickest method for venous pressure recording and as it is as accurate as the others it is recommended for the CMS.

(A physican will be required)

Time Requirements

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1. Syringe Package (Ref. M-1-a)

2. Manometer (Aneroid)

Weight	.5 lbs.
Power	
Volume	.0231 cubic feet

TECHNIQUE (b) Strain Gauge Determination and Decholin Test using Venipuncture

Description

Subject will have routine venipuncture done in antecubital vein with needle having a strain gauge attached. The strain gauge will be activated by a transistorized carrier amplifier and standardized with an aneroid pressure gauge. Circulation time as before.

Data Form

Digital readout

Evaluation

Since this technique requires more time for set-up and standardization with an aneroid gauge it is a second choice.

(An astronaut could use this technique)

Time Requirements

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1. Syringe Package
   (Ref. M-1-a)

2. Venous Pressure Strain Gauge Transducer (Model P-23 Statham Transducers, Inc. or Type 268 Sanborn Co.)

Weight	.375 lbs
Power	1 watt
Volume	.0006 cubic feet

TECHNIQUE (c) Opthalmoscopic Examination for Venostasis

Description

Venoustasis can be observed by examination of the retinal veins for increased size.

Evaluation

This is a subjective evaluation and not quantitative.

(Training Level - physician)

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment and Instruments

1. Opthalmoscope, Otoscope combined instrument. (Welch-Alyn, American Optical, or Bausch and Lomb)

Weight	2.0 lbs.
Power	10 watts
Volume	.0521 cubic feet

TECHNIQUE (d) Differential Pressure Transducer and Decholin Test using Venipuncture

Description

After standardization of pressure the transducer with an aneroid pressure indicator, venipuncture will be done with attached transducer. Subject will be in supine position.

Data Form

Paper record

Evaluation

Same as for strain gauge (M20-b)

(Training Level - astronaut)

Time Requirements

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1. Syringe Package (Ref. M-1-a)

2. Differential Pressure Transducer

Weight	1.0 lbs
Power	1 watt
Volume	.0023 cubic feet

MEASUREMENT 21. MUSCLE FUNCTION (FORCE, POWER, ENDURANCE)

Question or Hypothesis

The reduction of muscle strength during hypodynamic states may also be evidenced in the weightless state. Aspects of this reduction may be measured as changes in muscle force, muscle power, muscle endurance.

Description of Measure

The amount of resistance that a muscle can overcome measured in pounds exerted against a spring indicates muscle force. Tests should be made for flexion and extension of the forearm, thigh, and lower leg; abduction and adduction of the supper arm at the shoulder and for grip forces. Power may be defined as force/unit time. The maximum power that may be exerted by each of the movements listed in "Force measures" would be determined. The force moved during a maximum power output would not necessarily correspond with the maximum force. The units would be in lbs./sec. A resistance somewhat less than the maximum that

can be overcome by a maximum exertion of force will be selected for determination of muscle endurance. The resistance will be repeatedly overcome until the muscle fatigues to a point where it can no longer overcome it.

Results

Any deterioration in the muscle due to hypodynamic conditions should be reflected in these measurements.

TECHNIQUE (a) Resistive Test with Spring for Muscle Function

Description

The test of muscle function is a resistive test utilizing a spring device. The subject can administer the test to himself, but it would take somewhat longer. Gross muscle force, muscle power and muscle endurance will be taken simultaneously. They should be measured for each subject in the same period of his sleep/rest cycle. They will be taken in a specially designed area.

Data Form

Paper record

(Training Level - Astronaut)

Time Requirements

Total man-minutes	36
Frequency	1/3
Minutes per day	
Subject	12
Observer	-
Total	12

Equipment and Instruments

1. Spring Scale

Weight	.125 lbs.
Power	-
Volume	.0003 cubic feet

2. Stop Watch (Ref 3.1.a.1.)

MEASUREMENT 22. END EXPIRATORY PCO_2 AND PO_2

Question or Hypothesis

Prolonged weightlessness may cause a reduction in pulmonary ventilation, alter blood flow to the lungs, or cause anemia. This measure will reflect all of the above conditions.

Description of Measure

End expiratory pCO_2 and pO_2 is one of the vital measures of pulmonary function as it provides a primary indication of blood-lung (alveolar) gas exchange. Expired air evaluation for pCO_2 and pO_2.

Results

Inadequate pulmonary function due to the effects of zero "g" (not at this time expected) or due to atmosphere effects could show increased pCO_2 and decreased pO_2. End expiratory pCO_2 and pO_2 is a standard clinical measure of good accuracy.

TECHNIQUE (a) Mass Spectrographic Analysis for End Expiratory pO_2 and pCO_2

Description

Subject breathes into a mouth piece connected to a mass spectrograph. A breath by breath analysis of pCO_2 and pO_2 is provided in analog form by the spectrograph.

Data Form

Analog readout

Evaluation

This technique is a research instrument of high accuracy and moderate reliability and is recommended for inclusion in the Crew Measurement System.

(Training level - astronaut)

Time Requirements

Total man-minutes	42
Frequency	1/3
Minutes per day	
Subject	2
Observer	3
Total	5

Equipment and Instruments

1. Polaragraphic Half Cell (Ref. M5-b)
2. High Impedance Amplifier (Ref. M5-b)
3. Mass Spectograph (Ref. M-5-b)

MEASURE 23. MUSCLE ACTIVITY AND STATE

Question or Hypothesis

Prolonged weightlessness may result in a decrease in muscle tone due to reduced myotatic stimulation (gravity stimulation).

Description of Measure

Muscle activity evaluated by associated electrical activity of resting and active muscles using the electromyograph. This measure reflects the level of muscle activity (muscle unit discharge) to determine the effects of

weightlessness on muscle tone status. The measure should be taken in conjunction with measurements of muscle force, power and endurance. (Reference Measure 21.)

Results

A reduction in muscle activity and state may be interpreted as indicative of a decrease in muscle functional capability (atrophy).

TECHNIQUE (a) Electromyographic Evaluation of Muscle Activity

Description

Electrodes are attached in sequence to the antagonistic (opposing) groups of the anti-gravity muscles in the upper and lower extremities (i.e., biceps-triceps, quadriceps, hamstrings) with the muscle at rest (tonus) and during exertion of a given force against a dynamometer. A gross index of muscle activity (muscle unit discharge) can be obtained by subsequent analysis of recordings (integration, frequency, spectrum analysis.

Data Form

Analogue readout

Evaluation

This technique is accurate relative to actual contractions, both isotonic and isometric. However there is some question if the EMG can reflect the desired subtlety of changes in muscle tone. This technique is recommended for inclusion in the Crew Measurement System.

(Training level - technician)

Time Requirements

Total man-minutes	21
Frequency	1/14
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1. Electromyograph: Surface electrodes and a high gain pre-amplifier. (Biometrics Model 2033 - Ref 4a4)

Weight	.125 lbs.
Power	.02 watts
Volume	.0005 cubic feet

MEASURE 24. BONE DENSITY

Question or Hypothesis

Prolonged weightlessness may result in a loss of calcium from the bones due to a decreased stress on the skeletal system.

Description of Measure

This measure (bone X-ray) reflects changes in bone density which may be used to document loss of calcium from the bones.

Results

A significant reduction in bone density may be interpreted as indicative of bone calcium demineralization.

TECHNIQUE (a) X-Ray of Long Bones

Description

(Refer to M-16-a). This technique involves a clinical X-ray of the long bones taken with a light weight low power X-ray device using Poloroid X-ray film. Films of the long bones are used to demonstrate changes in bone density and can be used to document loss of calcium from the bones.

Data Form

Film

Evaluation

Useful for detection of bone calcium demineralization and supplements findings of calcium balance studies through demonstration of bone changes. Reliability of technique is high but requires professional interpretation for accuracy. This technique is recommended for inclusion in the CMS.

(Training level - physician)

Time Requirements

Total man-minutes	21
Frequency	1/21
Minutes per day	
Subject	1/3
Observer	2/3
Total	1

Equipment and Instruments

1. X-Ray Package (Ref. M-16-a)

MEASURE 25. SERUM AND URINE POTASSIUM AND SODIUM

Question or Hypothesis

Long term weightlessness may result in a high rate of tissue destruction or cellular turnover. This measure provides an indication of the rate of tissue destruction or cellular turnover.

Description of Measurement

Serum and Urine sodium and potassium are determined biochemically. Sodium and potassium ions are mainly responsible for maintaining body fluid osmotic pressure. They are always present in serum and urine in a fairly well maintained ratio.

Results

The body tissues cannot deposit potassium, so a change in the Sodium/Potassium ratio favoring potassium indicates a higher rate of tissue destruction or cellular turnover.

TECHNIQUE (a) Microanalytic Determination of Serum and Urine Potassium and Sodium

Description

(Refer to Measure M-3 for Description of Technique) This technique involves the utilization of microanalytic methods for analysis of biochemical constituents and is similar to the technique described in M-3.

Data Form

Paper record

Evaluation

Preferred technique and recommended for inclusion in the CMS. Calsul reagent not feasible for determining sodium and potassium.

(Training level - technician)

Time Requirements

Total man-minutes	22
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	3
Total	4 1/7

Equipment and Instruments

1. Microanalytic Package (Ref. M1-a)

2. Chemical Package
(Ref. M-3-a-1)

3. Syringe Package
(Ref. M1-a)

MEASURE 26. G. I. ABSORPTION TEST

Question or Hypothesis

Zero-g may alter gastro-intestinal motility and/or basic cellular metabolism and thereby alter absorption of carbohydrate from the intestine. This measure reflects the level of gastro intestinal absorption of carbohydrate.

Description of Measure

Absorption of given quantity of glucose determined by blood (or urine) levels at timed intervals. The measure is a standard clinical test for gastrointestinal absorption of carbohydrate. However only gross alterations would be reflected by the test.

TECHNIQUE (a) D-Xylose Test of G. I. Absorption

Description

Subject is fed a standard quantity of a sugar (D-Xylose). He is then required to fast for the duration of the test, approximately four hours with samples of urine collected over the four hour period. The number of grams of Pentose excreted in the urine over the four hour period serves as an indication of G. I. absorption ability.

Data Form

Paper record

Evaluation

This technique is considered as the best technique for indicating general intestinal ability to absorb foods. It is recommended for inclusion in the CMS.

(Training level - technician)

Time Requirements

Total man-minutes	56
Frequency	1/14
Minutes per day	
Subject	1
Observer	3
Total	4

Equipment and Instruments

1. Chemical Package
   (Ref. M-3-a)

2. Microanalytic Package
   (Ref. M-1-a)

TECHNIQUE (b) Glucose Test of G. I. Tract Absorption

Description

Subject is required to fast during the test approximately four hours in duration. Blood samples are taken during this period at 1/2, 1, 2, and 3 hours. The unit of measurement is the milligrams of glucose in the blood.

Data Form

Paper record

Evaluation

This technique is generally considered less accurate than the D-Xylose technique.

(Training level - technician)

Time Requirements

Total man-minutes	56
Frequency	1/14
Minutes per day	
Subject	1
Observer	3
Total	4

Equipment and Instruments

1. Chemical Package (Ref. M-3-a)
2. Microanalytic Package (Ref. M-1-a)

MEASURE 27. CEREBRAL BLOOD FLOW

Question or Hypothesis

Same as for measure M-1. Reduction in cardiac output would cause decreased cerebral flow.

Description of Measure

Cerebral flow determined indirectly by impedance changes.

TECHNIQUE (a) Rheocenphalography

Description

Impedance change under an active electrode reflects fluid changes under electrode. Changes can be interpreted as cerebral flow.

Data Form

Analog readout

Evaluation

A reliable instrument is available but because little validation has been accomplished to date interpretation of the recording is not possible at this time. The technique need not be included unless recording for future reduction is desired.

(Training level - astronaut)

Time Requirements

Total man-minute	42
Frequency	1/7
Minutes per day	
Subject	2
Observer	4
Total	6

Equipment and Instruments

1. Rheocenphalograph (Physical Instruments Inc., Coral Gables, Fla., Monopolar Model)

Weight	8.0 lbs.
Power	50 watts
Volume	.4630 Cubic feet

MEASURE 28 VISUAL ACUITY, DEPTH PERCEPTION AND ACCOMMODATION

Question or Hypothesis

Will weightlessness affect visual acuity, depth perception, and accommodation? No changes in basic visual functions are hypothesized, however, the criticality of this function demands accurate serial evaluation to detect potential decrements.

Description of Measure

These visual measurements will be accomplished by standard optical testing methods.

Results

See Question or Hypothesis

TECHNIQUE (a). Optical Evaluation of Visual Acuity, Depth Perception and Accommodation

Description

Visual acuity, depth perception, and accommodation will be evaluated with an optical testing device. The commercially available Orthorater could serve as a prototype but, because of high power requirements and large size, a special model should be constructed for space application.

Data Form

Paper record

Evaluation

This is an excellent technique within the equipment limitations noted.

(Training level - astronaut)

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	3

Equipment and Instruments

1. Visual Presentation Device

Weight	40 lbs.
Power	225 watts
Volume	2.4000 cubic feet

MEASURE 29. BLOOD (AND URINE) SUGAR

Question or Hypothesis

Although no specific hypothesis can be constructed from current data to predict significant problems, a routine check every three days is warranted to detect unsuspected alterations.

Description of Measure

Blood and urine sugar can be determined biochemically or by microanalysis. These techniques reflect pancreatic functions as well as renal (kidney) transport mechanisms (tubular reabsorption).

Results

See Description of Measure

TECHNIQUE (a). Calsul Determination of Blood and Urine Sugar

Description

See Calsul Technique under Measure 3.

Data Form

Paper record

Evaluation

This is the technique of choice

(Training level - technician)

Time Requirements

Total man-minutes	7	
Frequency		1/3
Minutes per day		
Subject		1/3
Observer	2	
Total	2	1/3

Equipment and Instruments

1. Chemical Package
   (Ref. M3-a)

2. Microanalytic Package
   (Ref. M1-a)

3. Syringe Package
   (Ref. M1-a)

TECHNIQUE (b). Microanalytic Determination of Blood and Urine Sugar

Description

See Microanalytic Technique under Measure 3.

Data Form

Paper record

Evaluation

This technique is second choice. (See Measure 3.)

(Training level - technician)

Time Requirements

Total man-minutes	22
Frequency	1/3
Minutes per day	
Subject	1/3
Observer	7
Total	7 1/3

Equipment and Instruments

1. Chemical Package
   (Ref. M3-a)

2. Microanalytic Package
(Ref. Ml-a)

3. Syringe Package
(Ref. Ml-a)

MEASURE 30. STATE OF AROUSAL (ALERTNESS, SLEEP DEPTH AND CYCLES)

Question or Hypothesis

The state of alertness, equated with cortical arousal or desynchronization is due to impulses from the reticular formation of the brainstem. The reticular formation is, in turn, activated by all incoming sensory impulses. A reduction of these (such as proprioceptive and certain extraneous touch and pressure activities) will occur when the gravity stimulus is absent and may cause a decreased alertness. Reports from immersion studies indicate that subjects have significantly reduced their sleep time, but retained a subjective sensation of being rested. The depth of sleep observed during these studies did not seem to be as great as normal.

Description of Measure

Observation, subjective reports and certain performance tests could reveal changes in alertness and sleep cycles. A more quantitative method would be the measurement of the EEG during various portions of the daily cycle: at rest, monitoring, control situations, sleep, etc.

Results

Subjective and objective checklists and recorded brain wave patterns (possibly reducible to cycles per second).

TECHNIQUE (a). Subjective Evaluation and Observation of State of Arousal

Description

Subjective observation and recording of alertness reciprocally between crew members. Records of sleeping habits should also be kept.

Data Form

Check list

Evaluation

Subjective observation has the advantage of being, hypothetically, continuous as opposed to occasional EEG recordings. For this reason and because little time is required, it is the recommended technique.

(Training level - astronaut)

Time Requirements

Total man-minutes	6
Frequency	1/7
Minutes per day	
Subject	3/7
Observer	3/7
Total	6/7

Equipment and Instruments

1. Arousal State Checklist

TECHNIQUE (b). Electroencephalographic Examination of State of Arousal

Description

A high gain differential amplifier is used for each channel of EEG. Two channels are the minimum required for bilateral simultaneous recording. A subject is connected to the EEG preamplifiers by standard EEG disc electrodes and leads. Recording is usually made during sleep and results are in brain waves, possibly reducible to cycles per second. In experimental situations EEG is normally utilized as the device of choice for establishing a level of consciousness. EEG has been used in most experimental sleep studies.

Data Form

Analog readout

Evaluation

Subjective observation is more desirable for this measure.

(Training level - technician)

Time Requirements

Total man-minutes	10
Frequency	2
Minutes per day	
Subject	10
Observer	10
Total	20

Equipment and Instruments

1. Electroencephalograph (Biometrics Model 2033, Ref 4a4)

Weight	.123 lbs.
Power	.02 watts
Volume	.0005 cubic feet

MEASURE 31. PULSE RATE

Question or Hypothesis

Weightlessness may decrease the work load on the heart and result in a decreased pulse rate. Existing evidence from hypodynamic studies and United States and Russian orbital flights is inconclusive. Since pulse rate is a vital sign and easily measured, it is recommended on a regularly scheduled basis.

Description of Measure

Pulse rate counted manually or with a transducer device.

Results

Decreased pulse rate is to be expected with decrease work load. Increased rate could be due to anxiety, exercise, and stresses such as low oxygen pressure.

TECHNIQUE (a). Manual Counting of Pulse Rate

Description

Radial (wrist) pulse determined by manual counting for a period of from 30 seconds to a minute timed with a stopwatch.

Data Form

Paper record

Evaluation

This is a simple, accurate technique and is recommended as a first choice.

(Training level - astronaut)

Time Requirements

Total man-minutes	2
Frequency	2
Minutes per day	
Subject	2
Observer	2
Total	4

Equipment and Instruments

1. Stopwatch

Weight	.125 lbs
Volume	.0001 cu ft

TECHNIQUE (b). Pulse Tachometry

Description

Pulse measuring and recording with a pulse transducer (Cardiotachometer)

Data Form

Digital readout

Evaluation

This is an unnecessary technique because of the EKG measurement (measure 17).

(Training level - astronaut)

Time Requirements

Total man-minutes	7
Frequency	2
Minutes per day	
Subject	4
Observer	10
Total	14

Equipment and Instruments

1. Cardiotachometer (Ref 4.a.4)

Weight	.125 lbs.
Power	.02 watts
Volume	.0005 cubic feet

MEASURE 32. AUTONOMIC HYPERACTIVITY

Question or Hypothesis

Prolonged weightlessness will result in changes in stimulation of the vestibular apparatus which may produce autonomic effects such as nausea, sleepiness, changes in salivation or changes in perspiration.

Description of Measure

This measure is intended to provide a continuous recording of noted effects (nausea, sleepiness, sweating of palms, loss of appetite, etc.) for detection of autonomic hyperactivity.

Results

Abnormal stimulation of the vestibular system (equilibrium centers) can produce autonomic overactivity. Anxiety can also cause this effect.

TECHNIQUE (a). Subjective and Objective Evaluation of Autonomic Hyperactivity

Description

Simple observation by crew personnel of symptoms when they occur and recording of the absence or presence of the symptoms daily on a checklist which will form a part of the medical log.

Data Form

Paper record

Evaluation

This simple subjective technique, used as a gross indication of well being, is recommended for inclusion in the CMS.

(Training level - astronaut)

Time Requirements

Total man-minutes	2
Frequency	1
Minutes per day	
Subject	2
Observer	0
Total	2

Equipment and Instruments

1. Hyperactivity Checklist
   A simple checklist format in which subjects records yes or no to the occurrence of symptoms. Space should be included for descriptions when applicable.

MEASURE 33. CORTICAL ACTIVITY

Question or Hypothesis

Prolonged weightlessness may result in a reduced level of cortical activity due to the continued absence of gravity produced proprioceptive cues and certain extraneous touch and pressure cue alterations.

Description of Measure

The electrical activity of the brain is measured with the electroencephalograph. This measure is intended to provide an index of cortical acitivity as an indication of level of consciousness or alertness (see also description of M-30).

Results

See description above.

TECHNIQUE (a) Electroencephalographic Evaluation of Cortical Activity

Description

See M-30-b.

Evaluation

See M-30-b.

(Training Level - Astronaut)

Data Form

Analog voltage - 0.5 to 1 volt.

Time Requirements

Total man-minutes	42
Frequency	1/14
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1. Electroencephalograph (Ref M-30-b)

MEASURE 34. GASTRO-INTESTINAL TRACT MOTILITY

Question or Hypothesis

Long term exposure to zero "g" may alter the normal peristaltic activity of the gastro-intestinal tract such that the transit time of food may

be altered, probably prolonged, and rever eristalsis and esophogeal reflux may occur. This measure is inte to provide an indication of the general level of gastro-intestinal perista ic activity.

Description of Measures

The activity of the digestive tract is evaluated either by measuring transit time, observing activity by x-ray methods, measuring pressure changes within the tract, or listening to bowel sounds.

Results

See description above.

Technique (a) X-Ray G. I. Series

Description

Subject is required to swallow a barium meal and is x-rayed at 1-2 hours intervals for six hours. Radio-translucent clothing is worn during the x-ray procedure (see also M-16-a).

Evaluation

An excellent means of determining gastro-intestinal status. Should be accomplished infrequently, however, due to radiation exposure and barium meal.

(Training Level -- Physician)

Data Form

Polaroid Film

Time Requirements

Total man-minutes	90
Frequency	1/60

Minutes per day	
Subject	1/2
Observer	1
Total	1 1/2

Equipment and Instruments

1 X-Ray Package (Ref M-16-a)

2 Chemical Package (Ref M-3-a)

TECHNIQUE (b) Dye Markers in Food

Description

This technique consists of the oral ingestion of a harmless dye marker material (methylene blue, charcoal) by the subject and the measurement of the time interval between the ingestion and the time of passage of the dye colored feces. Normally this occurs in 24-36 hours.

Evaluation

A simple inexpensive (WPV) technique. The information obtained is almost as valuable as a single abdominal film although not nearly as good as a G. I. series (series of G. I. tract x-rays). Should be used in between G. I. series measurements.

(Training Level – Astronaut)

Data Form

Checklist

Time Requirements

Total man-minutes	7
Frequency	1/7
Minutes per day	
Subject	2
Observer	-
Total	1

Equipment and Instruments

1 Color Indicator Package

2 Clock (in station clock)

3 Dye Markers in Food Checklist; checklist form with provision for notation of time of ingestion and time of passage of dye colored feces

TECHNIQUE (c) Endoradiosonde Technique

Description

An ingestible, pressure sensitive, pill sized transponder (endoradiosonde) is swallowed by the subject. At hourly intervals, the subject is required to lie down on a couch and the antenna of the associated transceiver is applied to the abdomen for a tape recording (1-3 minutes) of data received from the pill as it passes along the gastro-intestinal tract. Recordings alone are taken over a 6 to 12 hour period and consist of pressure and temperature recording. Data analysis, at present, is limited to eyeballing techniques noting characteristic patterns and amplitudes of pressure variation. The pill is later recovered from the stool, sterilized and re-used.

Evaluation

This technique is only in the experimental stage and requires equipment of weight and volume that can be best used elsewhere.

(Training Level – Technician)

Data Form

Analog voltage – 0.5 to 1 volt range

Time Requirements

Total man-minutes	70
Frequency	1/14
Minutes per day	
Subject	2
Observer	3
Total	5

Equipment and Instruments

1 Endoradiosonde Package; equipment consists of an ingestible pressure sensitive transponder (endoradiosonde) pill, a transceiver and antenna. (Airborne Instruments Lab, Deer Park, Long Island, NY).

Weight	30 lbs
Power	100 watts
Volume	1.5000 cubic feet

TECHNIQUE (d) Stethoscopic Examination for Abdominal Sound

Description

Gastro-intestinal peristaltic activity normally produces abdominal sounds which reflect qualitatively the intensity and frequency of smooth muscle contraction and propulsion of intestinal contents. This technique consists of observation of various abdominal sounds by using a stethoscope. Gross alterations in the normal sound pattern may be interpreted as an alteration in normal peristaltic activity either characteristic of hyperactivity or hypoactivity of the intestinal tract.

Evaluation

Gross indication of gastro-intestinal activity. Reliability of observation directly related to adequacy of training of observer.

(Training Level -- Technician)

Data Form

Subjective Recording

Time Requirements

Total man-minutes	3
Frequency	1/17
Minutes per day	
Subject	1/17
Observer	2/7
Total	3/7

Equipment and Instruments

1 Stethoscope (Ref M-1-b)

MEASURE 35. TUBULAR REABSORPTION TEST

Question or Hypothesis

There is no current data to suggest that tubular reabsorption will be impaired by zero "g". However, the function is an important indicator of normal kidney function and as such should be observed. This measure is a valid clinical measure of moderate sensitivity.

Description of Measure

This measure provides an index of the ability of the renal tubes to excrete a concentrated urine in the face of water deprivation. The subject is allowed no fluid intake for 12 hours. Urine osmolarity (specific gravity) is determined on two urine samples. A low specific gravity in indicative of improper kidney function.

Results

Renal dysfunction of kidney tubules causes inability to concentrate urine.

TECHNIQUE (a) Fishberg Concentration Test

Description

Subject is deprived of water for 12 hours. The osmolarity (specific gravity) of two urine samples is determined with a freezing point osmometer.

Evaluation

Valid clinical measure of moderate sensitivity.

(Training Level – Astronaut)

Data Form

Observation to Paper Record.

Time Requirements

Total man-minutes	4
Frequency	1/14
Minutes per day	
Subject	1/7
Observer	1/7
Total	2/7

Equipment and Instruments

1 Freezing Point Depression Osmometer
(Model CY-2, Industrial Instruments Inc)

Weight	68.0 lbs
Power	150 watts
Volume	1.3750 cubic feet

MEASURE 36. TUBULAR EXCRETION TEST

Question or Hypothesis

No definite hypothesis can be generated from current data for deleterious effects of prolonged zero "g" on renal tubule function with the possible exception of tubular damage secondary to calcium deposition.

Description of Measure

This measure is included as a means for evaluating and monitoring one of the basic functions of the renal tubules. The measure consists of observation of a test dye (PSP) concentration in subject urine.

Results

Renal dysfunction (kidney tubules) results in poor excretion of dye.

TECHNIQUE (a) PSP Test

Description

PSP dye is injected intravenously into a dehydrated subject and urine samples are collected at 15, 30 and 60 minutes. Determination of PSP dye

concentration in the urine would be performed by a colorimeter and relayed to earth for serial analysis and comparison with pre-flight norms.

Evaluation

Standard clinical test, however sensitivity is moderate to low.

(Training Level -- Technician)

Data Form

Numerical percentage of dye concentration.

Time Requirements

Total man-minutes	9
Frequency	1/14
Minutes per day	
Subject	1/7
Observer	1/2
Total	9/14

Equipment and Instruments

1 Chemical Package (Ref M-3-a)

2 Syringe Package (Ref M-1-a)

3 Microanalytical Package (Ref M-1-a)

MEASURE 37. GLOMERULAR FILTRATION TEST

Question or Hypothesis

No hypothesis for an impairment of glomerular filtration can be based upon current data; however, this is a critical renal function which should be serially observed for possible degradation.

Description of Measure

This measure provides for an indication of glomerular filtration capability and hence kidney function by providing an index of the ratio of blood

urea/urine urea level. The ratio of blood urea/urine urea concentrations would be expected to rise with restricted glomerular filtration capability.

This measure is a useful method for evaluating glomerular function. It is only moderately sensitive.

Results

Renal dysfunction (glomerular damage) results in increased serum/urine urea ratio.

TECHNIQUE (a) Urea Clearance Test -- Calsul Method

Description

Subject provides two urine and venous blood samples over a two hour period. Urine volume during this time period as well as urea concentrations in the blood and urine are determined by the Calsul method and the ratio of blood urea/urine urea is calculated.

Evaluation

Acceptable clinical technique -- moderate sensitivity.

(Training Level -- Technician)

Data Form

Results of analysis to paper record.

Time Requirements

Total man-minutes	21
Frequency	1/14
Minutes per day	
Subject	1/2
Observer	1
Total	1 1/2

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytic Package (Ref. M-1-a)

TECHNIQUE (b) Urea Clearance Test -- Microanalytic Method

Description

Subject provides two urine and venous blood samples over a two hour period. Urine volume during this time period as well as urea concentrations in the blood and urea are determined by the microanalytical method and the ratio of blood urea/urine urea is calculated.

Evaluation

Acceptable clinical technique -- moderately sensitive.

(Training Level -- Technician)

Data Form

Results of analysis to paper record.

Time Requirements

Total man-minutes	35
Frequency	1/14
Minutes per day	
Subject	1/2
Observer	2
Total	2 1/2

Equipment and Instruments

1 Microanalytic Package (Ref. M-1-a)

2 Chemical Package (Ref. M-3-a)

3 Syringe Package (Ref. M-1-a)

MEASURE 38. BODY TEMPERATURE

1. The zero "g" environment may produce a decrease in metabolic rate because of loss of resistance of gravity. There is some evidence, however, that zero "g" work may severely increase muscular activity because of tractiarless environment.

2. Zero "g" may influence diurnal cycling of metabolic activity.

Description of Measure

Body temperature as determined by a thermometer reflects both metabolic rate and the ability of the body to maintain homeostasis.

Results

Decreased metabolic rate causes decreased body temperature. Increased activity, high environmental temperature, and fever cause increased body temperature.

TECHNIQUE (a) Thermometry

Description

Axillary and oral temperature recording.

Evaluation

Routine clinical measure.

(Training Level -- Astronaut)

Data Form

Paper record.

Time Requirements

Total man-minutes	12
Frequency	4
Minutes per day	
Subject	3
Observer	-
Total	3

Equipment and Instruments

1 Bimetallic Thermometer (Cary Thermometer Co, NY, NY)

Weight	.0625 lbs
Power	-
Volume	.0012 cubic feet

MEASURE 39. SERUM ALKALINE PHOSPHATASE

Question or Hypothesis

Prolonged weightlessness may result in bone disorders and liver disorders which can be detected by analysis of enzyme activity.

Description of Measure

This measure provides one source of assessment of bone and liver normal function by providing an index of enzyme activity present in blood and urine serum.

The enzyme alkaline phosphatase is noted to increase in adults upon the occurrence of bone disorders involving increased osteoblastic activity. Enzyme activity also increases with liver disorders, particularly in cases of obstructive jaundice. Enzyme determination may thus serve as a useful indicator of the relative health of both organ systems.

Results

See description above.

TECHNIQUE (a) Calsul Determination of Serum Alkaline Phosphatase

Description

See Calsul Technique under Measure M-3.

Evaluation

See M-3.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	8
Frequency	1/7

Minutes per day

Subject	1/7
Observer	1
Total	1 1/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytical Package (Ref. M-1-a)

3 Syringe Package (Ref. M-1-a)

MEASURE 40. EXPIRATORY--INSPIRATORY FORCE (FLACK TEST)

Question or Hypothesis

Reduced activity and metabolic demands of zero "g" conditions could cause decrease in respiratory force. Zero "g" may alter the functioning of the respiration system due to alterations in the strength of the respiratory muscles, altered gas dynamics, and impaired handling of secretions, as well as altering cardiovascular reflexes.

Description of Measure

This measure provides an indication of lung work capacity by assessing sustained inspiration and expiration pressures. Maximum positive and negative pressures are recorded.

The measure is a clinically accepted test used to define the integrity of the reflex control of the circulatory system as well as to identify cardiac arrythmias which occasionally occur during the test. Respiration function is also indirectly evaluated.

Results

Decreased work capacity of lung measured as decreased inspiratory--expiratory force.

TECHNIQUE (a) Flack Test of Expiratory--Inspiratory Force

Description

Subject exerts a maximum effort expiratory and then inspiratory force to an aneroid pressure gauge through a standard rubber mouthpiece. Maximum positive and negative pressures in lbs/in^2 or mm of mercury are recorded.

Evaluation

Technique is used as a measure of cardiovascular reflex integrity but also is a fairly good index of subject motivation.

(Training Level -- Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	10 1/2
Frequency	1/7
Minutes per day	
Subject	1/2
Observer	1
Total	1 1/2

Equipment and Instruments

1 Aneroid Pressure Gauge with Mouthpiece; aneroid pressure gauge with rubber mouthpiece -- readings of gauge in lbs/in^2 or mm of mercury (Taylor Instruments, Rochester, NY)

Weight	1.0 lbs
Power	-
Volume	.0116 cubic feet

MEASURE 41. BLOOD PLASMA PROTEIN FRACTIONATION

Question or Hypothesis

No specific hypothesis exists regarding the effects of zero "g" on the concentration and relative distribution of blood plasma proteins.

Description of Measure

The plasma proteins serve a number of functions, ranging from speci-physiological rates, immunological reactions, physio-chemical properties and nutrients. The concentration of relative distribution of blood plasma proteins provides an overall indice for assessing the health of an individual.

Results

See description above.

TECHNIQUE (a) Microanalytic Determination of Blood Proteins with Paper Electrophoresis

Description

See Microanalytic Technique under Measure M-3.

Evaluation

See M-3.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	21
Frequency	1
Minutes per day	
Subject	-
Observer	21
Total	21

Equipment and Instruments

1 Microanalytic Package (Ref. M-1-a)

2 Chemical Package (Ref. M-3-a)

3 Syringe Package (Ref. M-1-a)

MEASURE 42. VESTIBULAR REACTION

Question or Hypothesis

Weightlessness may affect vestibular (equilibrium) response.

Description of Measure

This measure provides for an index of vestibular response through caloric stimulation. The effect of caloric stimulation on the vestibular apparatus is due to the convection currents set up by changes in specific gravity during cooling or heating.

Results

See description above.

TECHNIQUE (a) Caloric Stimulation Test for Vestibular Response

Description

A stream of cold air is applied to the external ear canal with a small flexible catheter. The subject is then tested for disorientation.

Evaluation

This is an acceptable clinical technique and yields reliable data.

(Training Level -- Technician)

Data Form

Paper record

Time Requirements

Total man-minutes	35
Frequency	1/14
Minutes per day	
Subject	1
Observer	1 1/2
Total	2 1/2

Equipment and Instruments

1 Caloric Stimulator (Cold Air Duct or Syringe)

Weight	.125 lbs
Power	-
Volume	.0058 cubic feet

MEASURE 43. BOWEL FUNCTION EVALUATION AND STOOL CHARACTERISTICS

Question or Hypothesis

Weightlessness may have an effect on bowel function and stool characteristics due to changes in normal peristaltic activity, or the particular diet used and the possible alteration of gastro-intestinal tract bacterial flora.

Description of Measure

This measure provides for the observation of frequency of defecation and stool character for detection of change in gastro-intestinal tract function. The measure is gross and subjective but would suffice for clinical purposes.

Results

See description above.

TECHNIQUE (a) Recording Frequency of Defecation, Quantity and Quality; Observation of Stool, and Occult Blood (One Shot Tablet Test)

Description

Checklist recording of frequency of defecation quantity and quality and consistency of stool.

Occult Blood (One Shot Tablet Test) consists of a color reagent applied to a fecal sample.

Evaluation

The Checklist method is gross subjective observation but acceptable for clinical. Occult Blood Test is clinically simple and reliable.

(Training Level – Astronaut)

Data Form

Paper record.

Time Requirements

Total man-minutes	3
Frequency	1
Minutes per day	
Subject	3
Observer	-
Total	3

Equipment and Instruments

1 Color Indicator Package (Ref. M-6-a)

2 Stool-Occult Blood Checklist

MEASURE 44. REFLEX RESPONSE AND CLONUS EVALUATION

Question or Hypothesis

The prolonged lack of gravity force on mystatic receptors may influence the role that these receptors play in tendon reflexes. If muscle tone is reduced, the reflex may be altered in either magnitude or briskness. It may also be hypothesized that lack of gravity will effect not only the tone of the antigravity muscles but also the tone of the antagonist muscles but also the tone of the antogonist muscles by means of a reduction on reflex inhibition. The altered tone possibly being reflected in variations in brainstem facilitation and inhibition will result in clonus (sustained series of rhythmic jerks).

Description of Measure

This measure consists of an observer initiating and judging deep tendon reflexes of the Pattelar tendon, Achilles tendon and the biceps and triceps of the arms. Clonus evaluation consists of observation of presence of same during reflex testing.

Results

Decreased tone would result in decreased reflexes.

TECHNIQUE (a) Clinical Evaluation of Deep Tendon Reflexes

Description

The tendons of the large voluntary muscle groups, biceps, triceps, quadriceps, and hemstrings are tapped with a reflex hammer and reflex response noted. A quick passive jerk of the relaxed foot is done to test for clonus

Evaluation

This is a standard clinical examination of the reflexes and the results are only as good as the experience of the testor.

(Training Level -- Physician)

Data Form

Direct evaluation to paper

Time Requirements

Total man-minutes	4
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	2/7
Total	4/7

Equipment and Instruments

1 Neurological Tool (Reflex Hammer) (Ref. M-14-a)

MEASURE 45. URINE AND FECAL NITROGEN

Question or Hypothesis

A major question to be resolved in long term exposure to weightlessness will be the adequacy of nutritional factors to fulfill the needs of the human body. If changes in digestion, absorption or utilization of foods occur, drastic alteration in nutrition may become necessary.

Description of Measure

Analytical procedures are recommended to determine if the crew is utilizing the protein and other nitrogen-containing matter present in their food in the usual manner, or if they are excreting more nitrogenous matter than they normally would. A comparison with ground controls is important, as is determination of nitrogen content of all food ingested.

Results

Changes in urine and fecal nitrogen reflect changes in body use of same.

TECHNIQUE (a) Coleman Automatic Analyzer for Nitrogen (Coleman Instruments, Maywood, Ill.)

Weight	50.0 lb
Power	750.0 w
Volume	3.4 cu ft

Description

Urine and fecal samples are assayed for nitrogen with the Coleman Automatic Analyzer.

Evaluation

This is a complex electronic biochemical assay technique. The weight, power, and volume required for this apparatus make it prohibitive for general space station use. Nitrogen will be estimated from urea determinations.

(Training Level -- The technique is not recommended)

Data Form

Direct readout to paper.

Time Requirements

Total man-minutes	23
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	3
Total	3 2/7

TECHNIQUE (b) Kjeldahl Chemical Determination of Nitrogen

Description

This is the basic biochemical technique for nitrogen determination. It is a very long and involved procedure which requires a separate laboratory set-up.

Evaluation

The procedure and equipment required make this procedure not feasible for general station use.

(Training Level -- The technique is not recommended)

Data Form

Direct to paper.

Time Requirements

Total man-minutes	184
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	26
Total	26 2/7

MEASURE 46. MUSCLE SIZE

Question or Hypothesis

Muscle atrophy may result from long term exposure to weightlessness. Bedrest, confinement, and immersion have reduced muscle strength and caused some atrophy.

Description of Measure

Periodic measurements and appropriate records will provide data to determine if muscles are deteriorating and to indicate requirements for remedial exercises. This simple test will provide positive information relative to the question of the affect of zero gravity on muscle status.

Results

Atrophy causes reduction in muscle size (mass).

TECHNIQUE (a) Muscle Size Measurement

Description

The technique recommended to determine changes in muscle size is measurement of calf, upper thigh, forearm, biceps and chest circumferences once a week. Measurements made at precisely located anatomical points with a good quality tape measure (to nearest 1/16 inch). Measurements should be made once a week and careful records kept in individual medical logs.

Evaluation

This technique will give early warning of muscle atrophy.

(Training Level -- Astronaut)

Data Form

Medical log.

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment and Instruments

1 Tape measure (American Hospital Supply Corp, Evanston, Ill, Model 37580)

Weight	.125 lbs
Power	-
Volume	.0012 cubic feet

MEASURE 47. HEART SOUNDS

Question or Hypothesis

Evidence from orbital flights indicates some changes in cardiac activity due to reduced work load on the heart. This raises the question as to whether prolonged weightlessness will reduce the heart workload and alter its spatial orientation within the thoracic cavity in a manner which can be detected by stethoscopic or phonocardiographic evaluation of heart sounds.

Description of Measure

This measure is not recommended as definitive but will furnish contributory data to detect changes in cardiac workload and will provide ancillary information on valve closure times and murmurs. The measure involves evaluating the heart sounds either electronically or by ausculation (listening).

TECHNIQUE (a) Phonocardiography

Description

A recording of vibrations transmitted from a chest contact microphone through a high-gain preamplifier and a buffer amplifier to a magnetic tape recorder. Three 15-second tests are recommended (subject at rest lying and standing, and following 30 seconds of strenuous exercise).

Evaluation

This technique is recommended because accurate recordings can be made by minimally trained personnel, telemetered to earth and diagnosed by qualified physicians. Re-recorded tapes on earth should be saved for comparative evaluation.

(Training Level -- Astronaut)

Data Form

Analog readout

Time Requirements

Total man-minutes	21
Frequency	1/7

Minutes per day

Subject	1
Observer	2
Total	3

Equipment and Instruments

1 Phonocardiograph (Biometrics Inc. Model 2033, RE 4. a. 4)

Weight	. 5 lbs
Power	. 02 watts
Volume	. 0058 cubic feet

TECHNIQUE (b) Stethoscopic Examination for Heart Sounds

Description

Stethoscopic evaluation of heart sounds by a qualified medical doctor is as accurate as a phonocardiographic diagnosis but cannot be as accurately recorded for comparison of tests taken over a period of time.

Evaluation

In the absence of phonocardiographic equipment, a stethoscopic examination of heart sounds should be made weekly, but is a secondary choice.

(Training Level -- Physician)

Data Form

Direct readout to paper.

Time Requirements

Total man-machine	6
Frequency	1/7
Minutes per day	

Subject	2/7
Observer	4/7
Total	6/7

Equipment and Instruments

1 Stethoscope (Ref. M-1b)

MEASURE 48. CARDIOPULMONARY SYMPTOMS (DYSPNEA, ETC.)

Question or Hypothesis

Cardiovascular changes of a severe nature can produce chest pain or shortness of breath (dyspnea), however, there is no reason to suspect such change. Zero "g" may affect the normal lung mechanisms for removal of secretions which could result in stasis and infection, although this is not expected. Low pressure atmospheres may produce areas of lung collapse (atalectasis) upon long exposure.

Description of Measure

Requires reporting and recording cardiopulmonary symptoms especially chest pain and dyspnea.

Results

Positive complaints might mean cardiopulmonary pathology and require further diagnostic procedures.

TECHNIQUE (a) Subjective Observation of Cardiopulmonary Symptoms

Description

Requires recording and reporting of dysphea and chest pain.

Evaluation

These symptoms are good clinical indicators of cardiopulmonary difficulties. Positive complaints require further diagnostic procedure.

(Training Level -- Astronaut)

Data Form

Checklist

Time Requirements

Total man-minutes	2
Frequency	1

Equipment and Instruments

1 Cardiopulmonary Symptoms Checklist

MEASURE 49. RESPIRATORY RATE

Question or Hypothesis

Decreased metabolic activity expected with zero "g" would cause decreased oxygen demand with subsequent decrease in respiratory rate. Cosmonauts were noted to have decreased rate during orbital flight. This is a standard vital sign and as such is one important status indication. It is also one of the measures needed to get total evaluation of cardiopulmonary response to zero "g".

Description of Measure

Rate of respiration measured as breaths per minute either manually or electronically.

Results

Decreased metabolism will be reflected by decreased respiration rate. Decreased oxygen pressure, increased carbon dioxide content and other atmosphere problems cause increased rate.

TECHNIQUE (a) Pneumotachometry

Description

See technique (d) measure M-2. All respiratory volumes techniques provide respiration rate also. Respiration rate can also be sensed from the electrocardiograph.

Evaluation

All techniques except the manual count are equally valuable. This requires little encumbering equipment.

(Training Level -- Astronaut)

Data Form

Digital readout

Time Requirements

Total man-minutes	9
Frequency	2
Minutes per day	
Subject	6
Observer	12
Total	18

Equipment and Instruments

1 Straingauge transducer Pneumotachometer (face mounted) (Ref. M-2-d)

TECHNIQUE (b) Strain Gauge Determination of Respiration Rate

Description

See technique (f) measure M-2.

Evaluation

Same as previous technique (M-49-a)

(Training Level -- Astronaut)

Data Form

Digital readout

Time Requirements

Total man-minutes	9
Frequency	2
Minutes per day	
Subject	6
Observer	12
Total	18

Equipment and Instruments

1 Chest Straingauge Transducer (Ref. M-2-f)

TECHNIQUE (c) Impedance Pneumographic Determination of Respiration Rate

Description

See technique (e) Measure M-2.

Evaluation

See M-49-a.

(Training Level -- Astronaut)

Data Form

Analog readout

Time Requirements

Total man-minutes	9
Frequency	2
Minutes per day	

Subject	6
Observer	12
Total	18

Equipment and Instruments

1 Impedance Pheumograph (Ref. M-2-e)

TECHNIQUE (d) Manual Counting of Respiratory Rate

Description

Manual counting of respiration rate.

Evaluation

Adequate technique for resting rate but not practical to determine with stress tests.

(Training Level -- Astronaut)

Data Form

Direct to paper

Time Requirements

Total man-minutes	2
Frequency	2
Minutes per day	
Subject	2
Observer	2
Total	4

Equipment and Instruments

1 Stopwatch (Ref. M-21-a)

MEASURE 50. BLEEDING TIME

Question or Hypothesis

There is no data at present to indicate that zero "g" will alter bleeding time directly. Possible increases in venous pressure might be reflected by this measure.

Description of Measure

The length of bleeding time until cessation of flow is measure. Skin bleeding time is a clinical measure useful primarily to indicate the presence of systemic vascular diseases and thrombocytopenia. Clot strength, as well as hemic clotting factors are reflected by this measure.

Results

The measure gives no specific data as to the cause of a prolonged bleeding time. The various factors affecting the bleeding time could be only inferentially evaluated as to their contribution to an observed prolongation.

TECHNIQUE (a) Ivy Test for Bleeding Time

Description

Blood Pressure Cuff is placed around the arm below the elbow, inflated to 40 mm Hg, and a 4 mm stab wound made in the skin of the forearm, length of time for bleeding to cease noted.

Evaluation

Routine clinical test of only moderate accuracy and reproducibility.

Data Form

Direct to paper.

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	

Subject	1
Observer	1
Total	2

Equipment and Instruments

1 Syringe Package (Ref. M-1-a)

2 Chemical Package (Ref. M-3-a)

3 Stopwatch (Ref. M-21-a)

MEASURE 51. VOIDING EVALUATION

Question or Hypothesis

Urinary problems and associated disorders are frequently accompanied by increased output, increased frequency, and discomfort upon voiding. Dehydration and and endocrine problems have associated volume of voiding changes. This is primarily an indicator of crew status.

Description of Measure

Daily checklist measures of volume frequency and complaints should be made. Urine will also be collected for biochemical measures and urinalyses when scheduled.

Results

Kidney stones cause severe pain.

Infection causes frequency and pain.

Dehydration causes decreased volume.

TECHNIQUE (a) Recording of Urine Volume, Frequency, and Complaints

Description

Checklist required for volume, frequency, and complaints.

Evaluation

Adequate for measure.

(Training Level -- Astronaut)

Data Form

Direct to paper.

Time Requirements

Total man-minutes	2
Frequency	1
Minutes per day	
Subject	2
Observer	-
Total	2

Equipment and Instruments

1 Fluid Intake-Output Checklist (Ref. M-6-a)

2 Color Indicator Package (Ref. M-6-a)

MEASURE 52. KIDNEY STONE FORMATION (X-RAY)

Question or Hypothesis

Bone demineralization and/or increased serum levels of calcium could cause kidney or bladder stone formation. See measure M-3.

Description of Measure

Analysis is made of x-ray film of abdomen for presence of stones. Continued high levels of serum calcium would be sufficient cause for a conditioning program or return to earth. All precautions should be taken to prevent development of stones.

Results

X-ray changes indicative of stones.

TECHNIQUE (a) X-Ray Abdominal Film for Kidney and Bladder Stones

Description

See technique of Measure M-16 (X-Ray).

Evaluation

(Training Level -- Physician)

Data Form

Photorecord to storage.

Time Requirements

Total man-minutes	17 1/2
Frequency	1/4
Minutes per day	
Subject	1/4
Observer	1
Total	1 1/4

Equipment and Instruments

1 X-Ray Package (Ref. M-16-a)

MEASURE 53. VISUAL FIELDS EVALUATION

Question or Hypothesis

There is no reason to suspect change in visual fields due to zero "g". Low oxygen pressure can cause reduction in visual fields.

Description of Measure

Peripheral field of vision mapped on paper.

Results

No change expected.

TECHNIQUE (a) Evaluation of Visual Fields

Description

Peripheral field of vision tested. Points of first sensing object moving into field of vision noted and a map of this made. This can be accurately done by using a perimeter which has set distance of object and accurate measure of point of sensing. This can also be done grossly.

Evaluation

Adequate for measure.

(Training Level -- Astronaut)

Data Form

Direct to paper.

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment Instruments

1 Perimeter (Lafayette Inst Co. Model 1223)

Weight	2.0 lbs
Power	
Volume	1.0000 cubic feet

MEASURE 54. RED BLOOD CELL MASS

Question or Hypothesis

Under the influence of zero "g", the cardiovascular and hematopoietic systems may be altered so that rbc time and mass survival are changed.

Description of Method

Mass of red blood cells in micrograms per ce of blood is determined radioisotopically.

TECHNIQUE (a) Radioisotope Study, Cr 51, for RBC Mass

Description

See technique (b) measure M-9.

Evaluation

Method is quite accurate and provides quantitative data. Increased or decreased rbc survival and mass (turn over) are accurately measured. This single procedure allow determination of RBC survival also.

(Training Level -- Technician)

Data Form

Direct to paper.

Time Requirements

Total man-minutes	90
Frequency	1/60
Minutes per day	1/2
Subject	1/2
Observer	1
Total	1 1/2

Equipment and Instruments

1 Radioisotope Package (Ref. M-9-b)

2 Syringe Package (Ref. M-1-a)

MEASURE 55. OCULAR TONOMETRY

Question or Hypothesis

Shifts in body fluid may occur as a result of alterations in venous pressure, blood pressure, and muscle tone which ultimately may affect the intraocular pressure.

Description of Measure

Intraocular pressure (pressure inside the eyeball) is determined by pressure or force sensing device. The measure is used clinically to detect glaucoma (increased intraocular pressure); however, the alterations postulated to occur in zero "g" can be more easily and directly measured by other means.

Results

Increased intraocular pressure caused by venous stasis.

TECHNIQUE (a) Tonometric Evaluation of Intraocular Pressure

Description

Intraocular pressure determined by measuring resistance of eyeball to pressure. A weight or probe is used.

Evaluation

The only commercially available instrument is the Schiotz tonometer. This is a gravity operation instrument in its present design and would not be suitable for zero "g" use. A strain gauge type of probe has been developed which is not gravity dependent. However, since both of these techniques involve the placing of a foreign body against the cornea, this is a potentially dangerous measurement except in competent medical hands with suitable treatment facilities should a corneal abrasion occur. It is not recommended for inclusion in CMS.

(Training Level -- Physician)

Data Form

Time Requirements

Total man-minutes	14
Frequency	1/21
Minutes per day	
Subject	1/3
Observer	1/3
Total	2/3

Equipment and Instruments

1 Schiotz Tonometer (American Hospital Supply, Evanston, Ill., Model 24564)

Weight	.375 lbs
Power	-
Volume	.0087 cubic feet

MEASURE 56. CAPILLARY FRAGILITY

Question or Hypothesis

Although evidences of capillary oosing in the legs has been noted upon return to earth in one astronaut, there is no reason to expect increased capillary fragility on zero "g". This functional test is included, however, to monitor the possible development of this state.

Description of Measure

Integrity of blood vessel capillaries over forearm determined by observing for small hemorrhages (petechiae) following release of sustained cuff pressure above.

The measure is a very crude one subject to many variables; only gross changes in capillary integrity can be estimated.

Results

See description above.

TECHNIQUE (a) Tourniquet Test of Capillary Fragility

Description

Blood pressure cuff is placed about the upper arm and inflated to a point half way between diastolic and systolic blood pressure and maintained for 10 minutes. The appearance of petechiae following release of the cuff is noted together with their relative number.

Evaluation

There is not standardized, well-defined normal value for this test, it provides only a gross estimate of marked changes in capillary state.

(Training Level -- Astronaut)

Data Form

Direct to paper.

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment and Instruments

1 Sphygmonanometer (including occlusive cuff) (Ref. M-1-b)

2 Stopwatch (Ref. M-20-a)

MEASURE 57. EOSINOPHIL COUNT

Question or Hypothesis

Weightlessness may precipitate stress response and result in adrenal hyperactivity.

Description of Measure

Increased liberation of cortisone from the adrenal cortex or adrenalin from the adrenal medulla are normal response to stress. Eosinophil blood cells are known to increase during stressful states and the amount of increase is well correlated to cortisone and adrenalin production. Thus, the eosinophil level provides an index of stress response.

Results

Increased eosinophil levels are indicative of stress response.

TECHNIQUE (a) Blood Smear Count of Eosinophils

Description

A smear of blood is stained and eosinophils are counted under a microscope.

Evaluation

Fair technique for evaluation of stress response although not as accurate or as specific as catecholamine or 17 KGS levels.

(Training Level -- Technician)

Data Form

Direct to paper record.

Time Requirements

Total man-minutes	9 1/2
Frequency	3
Minutes per day	
Subject	1/6
Observer	3
Total	3 1/6

Equipment and Instruments

1 Color Indicator Package (Ref. M-6-a)

2 Microscope (Ref. M-8-a)

3 Syringe Package (Ref. M-1-a)

MEASURE 58. SERUM CATECHOLAMINE

Question or Hypothesis

Weightlessness may precipitate stress response and result in adrenal hyperactivity. Catecholamine have also been employed as indicators of excessive muscular activity.

Description of Measure

Increased liberation of cortisone from the adrenal cortex or adrenalin from the adrenal medulla are normal response to stress. Eosinophil blood cells are known to increase during stressful states and the amount of increase is well correllated to cortisone and adrenalin production. Thus, the eosinophil level provides an index of stress response. Catecholamine level represents the assay product of adrenalin. Serum catecholamine gives instantaneous values rather than average values for a given time period and is more indicative of immediate response.

Results

Increased stress and autonomic response cause an elevation of catecholamine.

TECHNIQUE (a) Calsul Determination of Serum Catecholamine

Description

See Calsul Technique under Measure M-3.

Evaluation

The Calsul is the only feasible space station technique for catecholamine determination.

(Training Level -- Technician)

Data Form

Direct readout to paper record.

Time Requirements

Total man-minutes	9
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	1
Total	1 2/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytical Package (Ref. M-1-a)

TECHNIQUE (b) Determination of Serum Catecholamine by Extraction and Flourometry

Description

Elaborite biochemical flourimetric assay requiring unique laboratory equipments.

Evaluation

The technique is impractical for typical space station use.

(Training Level -- Technician)

Data Form

Direct to paper.

Time Requirements

Total man-minutes	30
Frequency	1/7

Minutes per day

Subject	2/7
Observer	4
Total	4 2/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Flourimetric Package

Weight	100.0 lbs
Power	75 watts
Volume	5.0 cubic feet

MEASURE 59. SERUM OSMOLARITY

Question or Hypothesis

Weightlessness may result in a decrease in serum osmolarity. Existing evidence from some studies indicates that osmetic pressure of colloid solutions increases with increasing "g" load. If the curve is extrapolated backwards, one may hypothesize a decrease in osmotic pressure with a reduction on gravitational force (weightlessness).

Description of Measure

This measure is intended to provide an indication of the osmotic pressure of the blood and hence an index of the distribution of body fluids.

Results

Changes from normal osmotic pressure will result in abnormal distribution of body fluids.

TECHNIQUE (a) Freezing Point Despression Osmometry

Description

Blood specimens are drawn once a week and serum osmolarity determined utilizing a freezing point depression osmometer.

Venous blood samples will be drawn once a week. The samples will be analyzed with the osmometer by a technician to determine serum osmolarity.

Evaluation

Excellent technique.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	-
Observer	3
Total	3

Equipment and Instruments

1 Syringe Package (Ref. M-1-a)

2 Chemical Package (Ref. M-3-a)

3 Freezing Point Depression Osmometer (Ref. M-35-a)

MEASURE 60. OXYGEN UPTAKE BY RED BLOOD CELLS

Question or Hypothesis

Prolonged weightlessness may affect cellular metabolic and enzymatic activities and be reflected as a decrease in O_2 uptake by RBC. However, no data appears available to support this hypothesis.

Description of Measure

This measure provides a direct evaluation of the oxygen carrying capacity of the blood.

Results

Impaired cellular metabolic and enzymatic activities would be reflected in decreased O_2 uptake by RBC.

TECHNIQUE (a) Electrode Analysis for O_2 Uptake by RBC

Description

A venous blood sample is equilibrated with 100% O_2 and then the pO_2 of the sample then measure with a microelectrode.

Evaluation

An accurate clinical technique.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	7
Frequency	1/7
Minutes per day	
Subject	-
Observer	1
Total	1

Equipment and Instruments

1 Electrode Blood Gas Analyzer (Ref. M-1-c)

2 Syringe Package (Ref. M-1-a)

MEASURE 61. BLOOD-UREA NITROGEN

Question or Hypothesis

Increased blood urea is observed in conditions associated with damaged renal function. In view of the increase excretory function of the kidneys expected during weightlessness, a further check on kidney function at the blood serum level is indicated.

Description of Measure

This measure provides an indication of renal function by providing data on blood serum urea nitrogen content levels.

Results

High levels of blood urea nitrogen are indicative of kidney damage and occasionally liver malfunction.

TECHNIQUE (a) Calsul Determination of Blood Urea Nitrogen

Description

A blood sample is obtained from the subject and analyzed by the calsul analytic method. (See Calsul Technique description under Measure 3.)

Evaluation

See Calsul Technique description under Measure 3.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	8
Frequency	1/3
Minutes per day	

Subject	2/3
Observer	2
Total	2 2/3

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytical Package (Ref. M-1-a)

3 Syringe Package (Ref. M-1-a)

TECHNIQUE (b) Microanalytic Determination of Blood-Urea Nitrogen

Description

Blood sample is obtained from the subject and sample is analyzed by the microanalytic method for determination of blood-urea nitrogen.

Evaluation

See Microanalytic Technique under Measure 3

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	23
Frequency	1/3
Minutes per day	
Subject	2/3
Observer	7
Total	7 2/3

Equipment and Instruments

1 Microanalytic Package (Ref. M-1-a)

2 Chemical Package (Ref. M-3-a)

3 Syringe Package (Ref. M-1-a)

MEASURE 62. VISUAL ILLUSION EVALUATION

Question or Hypothesis

The oculoagravic illusion has been described by Graybiel. Also some oculogyral illusions may occur due to the possibly enhanced semicircular stimulation in the absence of gravity damping and otolithic "silence". The observation of relatively minute detail on the earth's surface while in orbit by one astronaut has raised some degree of controversy and deserves investigation.

Description of Measure

This measure permits the revealing of any visual illusions which may occur either during ordinary activities or as may be revealed during scheduled tests of visual capabilities.

Results

Revealed illusions indicate merely their occurrence and not the underlying mechanisms. Therefore this measure would be followed by more specific measures serving a diagnostic function.

TECHNIQUE (a) Visual Illusion Recording

Description

Checklist of occurrence and description of nature of illusions which may occur in ordinary daily activities or as revealed by vision testing.

Evaluation

Gross subjective measure serving as a possible entrance to more detailed diagnostic measures.

(Training Level -- Astronaut)

Data Form

Paper record.

Time Requirements

Total man-minutes	1
Frequency	1
Minutes per day	
Subject	1
Observer	-
Total	1

Equipment and Instruments

1 Visual Illusions Checklist

MEASURE 63. HEARING

Question or Hypothesis

There are no current data to suggest hearing loss due to weightlessness alone. However, an evaluation of hearing is recommended as an assessment of one of the sensory systems of moderate importance.

Description of Measure

This measure provides an estimation of hearing loss (monaural and biaural) in decibels for various frequencies.

Results

Results will indicate normal hearing or extent of impairment in hearing for specified frequencies. Measure is fairly accurate, sensitive and relatively simple to administer.

TECHNIQUE (a) Audiometric Evaluation of Hearing

Description

Subject will be tested by standard audiometry techniques. Standard clinical procedure.

Evaluation

High reliability; should provide valid interpretation.

(Training Level -- Astronaut)

Data Form

Paper record.

Time Requirements

Total man-minutes	12
Frequency	1/7
Minutes per day	
Subject	5/7
Observer	1
Total	1 5/7

Equipment and Instruments

1 Audiometer (Aloe Scientific, St Louis, Mo, Model A18A)

Weight	3.0 lbs
Power	10 watts
Volume	10694 cubic feet

MEASURE 64. RBC UPTAKE I_{125}

Question or Hypothesis

The removal of the normal stress of one "g" may effect a reduction in the metabolic processes which will be reflected as a reduction in thyroid function.

Description of Measure

This measure provides an index of thyroid activity by measurement of the ability of the red cells to take up I-125. Red cell uptake of I-125 is well correlated with thyroid function.

Results

Decreased metabolism and/or thyroid function will be indicated by reduction in uptake of I-125 by red cells.

TECHNIQUE (a) Radioisotope Study, T-3, I-125 Uptake by RBC

Description

Refer to Measure 9, technique (b) (Radioisotope technique description)

Evaluation

Refer to Measure 9, technique (b) (Radioisotope technique description)

(Training Level --)

Data Form

Paper record.

Time Requirements

Total man-minutes	28
Frequency	1/21
Minutes per day	
Subject	1/3
Observer	1
Total	1 1/3

Equipment and Instruments

1 Radioisotope Package (Ref. M-9-b)

2 Syringe Package (Ref. M-1-a)

MEASURE 65. JOINT MOTION RANGE

Question or Hypothesis

Zero "g" may affect the tone of both the agonists and antagonists (opposing muscle groups) acting on a joint. If this occurs the ability to move the joint during the phasic contraction of a set of muscles may be changed.

Description of Measure

This measure provides for kinesthetic measurements and subjective assessment of joint motion range.

Results

If there is impairment in the tone of the agonists and antagonists, joint motion range will be degraded.

TECHNIQUE (a) Kinesthetic Determination of Joint Motion Range

Description

Objective assessment of subject ability for motion range. Subject moves arms or legs and maximum range is noted and plotted.

Evaluation

Gross indication but clinically acceptable technique.

(Training Level -- Astronaut - no special training)

Data Form

Paper record.

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment and Instruments

1 Grid Screen

Weight	2.0 lbs
Power	1 watt
Volume	0.10 cubic feet

2 Joint Motion Range Checklists; Checklist for recording of joint motion range maximum values

MEASURE 66. URINARY ALBUMIN

Question or Hypothesis

Analysis of urinary albumin level in the weightless state will provide some idea of pressure changes arising from existence in zero "g" habitat. Ordinarily no albumin urea would be anticipated in the weightless state.

Description of Measure

Orthostatic albumin urea is a unique condition which is observed after periods of standing in an upright position. Urine formed while in this position often contains protein while urine formed when lying down is free of protein. This condition is apparently related to posture and may be due to lumbar pressure on the renal blood vessels. This measure is intended to provide an indication of renal function by detection of albumin which would not be expected to be present in excessive amounts in urine in the weightless state.

Results

Presence of excessive levels of urinary albumin may indicate impairment of renal function.

TECHNIQUE (a) Calsul Determination of Urinary Albumin

Description

Urine samples analyzed by Calsul method.

Evaluation

See Calsul Technique under Measure 3.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	9
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	1
Total	1 2/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a-1)

2 Microanalytical Package (Ref. M-1-a-2)

TECHNIQUE (b) Microanalytical Determination of Urinary Albumin

Description

See Microanalytic Technique under Measure 3.

Evaluation

See Microanalytic Technique under Measure 3.

(Training Level --)

Data Form

Paper record.

Time Requirements

Total Man-minutes	23
Frequency	1/7

Minutes per day

Subject	2/7
Observer	3
Total	3 2/7

Equipment and Instruments

1 Microanalytic Package (Ref. M-1-a)

2 Chemical Package (Ref. M-3-a)

MEASURE 67. FECAL FLORA SAMPLING

Question or Hypothesis

Long term weightlessness, subsistence on somewhat artificial diet, and exposure to cosmic radiation may produce a net alteration in gastro-intestinal tract function with subsequent alteration in normal fecal character.

Description of Measure

Samples of feces are obtained for analysis for bacterial flora content and changes. Samples obtained just prior to a resupply or crew rotation and sent to earth for evaluation. The same method is practicable for urine bacterial analysis.

Results

See description above.

TECHNIQUE (a) Bacteria Culture (on earth)

Description

The effects of zero "g" per se on bacteria is not known. There has been some speculation that basic cellular mechanisms may be affected and thereby produce cell death or mutation. Some investigators have attempted to extrapolate data obtained from experiments on plant seed germination in zero "g" to bacteria. Such seeds have shown a shortened time of germination.

In order to do meaningful studies to determine the effects of zero "g" on the human bacterial flora, it would be necessary to be able to detect rather subtle changes. A fairly complete microbacteriology facility would be needed to conduct these studies. In addition to a wide variety of culture media, glassware, temperature controlled ovens, special stains, other techniques such as phage typing would also be required. Some method of disposing of the cultures of bacteria would also be required to prevent the contamination of the space vehicle by a possibly pathogenic mutant strain of bacteria. Moreover, the effect of zero "g" on the culturing and sub-culturing of the bacteria and on the phages used for typing is an unknown variable at this time. Finally, the weight and volume requirements imposed by providing glassware, culture media, ovens, autoclaves, etc. for several bacterial studies for up to six months on a number of individuals becomes overwhelming.

Storage of samples for subsequent return to earth also has several difficulties. Refrigeration, preservatives, and packaging require space and power. In addition, the storage of biological material for extended periods of time (six months) will possibly produce alterations comparable or greater than that caused by zero "g" alone.

Since the changes, if any, in the bacterial flora are assumed to be gradual and of a subtle nature, it is felt that the collection of bacterial samples should be done from crewmen immediately upon their return to earth. The samples can then be analyzed by a variety of techniques not practical for space station use. Samples could also be taken immediately before the arrival of a supply vehicle on those crewmen remaining on the station on extended period of time, and then be returned to earth on the supply vehicle.

Evaluation

See description above.

(Training Level -- Astronaut)

Data Form

Paper record.

Time Requirements

Total man-minutes	5
Frequency	1/90

Minutes per day

Subject	1/18
Observer	
Total	1/18

Equipment and Instruments

1 Sample Containers (Fecal); 2-03 Neoprene Containers

Weight	1/2 oz
Volume	2 cubic inches

MEASURE 68. RED BLOOD CELL SURVIVAL

Question or Hypothesis

See Measure 54.

Description of Measure

RBC survival is a measure of life span of red blood cells. It is determined radioisotopically with RBC mass.

Results

Suppression of hematopoetic function results in decreased survival time.

TECHNIQUE (a) Radioisotope Study, Cr-51, for RBC Survival

Description

See technique (b), Measure 9.

Evaluation

See technique (b), Measure 9.

(Training Level -- Technician)

Data Form

Digital readout to data processing

Time Requirements

Total man-minutes	90
Frequency	1/60
Minutes per day	
Subject	1/2
Observer	1
Total	1 1/2

Equipment and Instruments

1 Radioisotope Package (Ref. M-9-b)

2 Syringe Package (Ref. M-1-a)

MEASURE 69. CLOTTING TIME

Question or Hypothesis

Zero "g" may alter the normal blood clotting mechanism. However, there are no experimental data or hypothesis to support this supposition.

Description of Measure

A sample of blood is obtained and drawn into capillary glass tubes which are subsequently broken and time of appearance of first fibrin strands (clot strands) are noted. The coagulation time is affected by a wide range of clotting factors as well as the exposure of the blood sample itself to air, contact with glass and mechanical agitation. The large number of variables involved limits the usefulness of this measure.

Results

Prolonged clotting times may be indicative of decreased clotting capability probably due to destruction of or decreased production of clotting factors.

TECHNIQUE (a) Capillary Tube Method for **Clotting Time**

Description

Blood is obtained from a skin puncture wound and drawn into several glass capillary tubes. Tubes are broken at 30 second intervals and time of appearance of first fibrin strands noted.

Evaluation

Standard clinical test of moderate accuracy. Prolongation of clotting time should be further investigated for diagnostic purposes.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	11
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	1 3/7
Total	1 4/7

Equipment and Instruments

1 Syringe Package (Ref. M-1-a-1)

2 Color Indicator Package (Ref. M-6-a-2)

3 Chemical Package (Ref. M-3-a-1)

MEASURE 70 SERUM ATP

Question or Hypothesis

ATP is known to be the major carrier of phosphate necessary for energy production in the aerobic degradation (oxidation cycle) of carbohydrate.

Exposure to weightlessness is expected to bring about changes in muscular function. ATP analysis will determine if this change occurs on a cellular level or if the effect is mainly due to less muscular activity in the weightless environment.

Description of Measure

Analyses of serum for presence and levels of ATP adinosine triphosphate.

Results

Presence of ATP and levels of ATP concentration in serum will permit determination of changes in muscular function as occurring at a cellular level or due to less muscular activity.

TECHNIQUE (a) Calsul Determination of Serum ATP

Description

See Calsul Technique under Measure 3.

Evaluation

See Calsul Technique under Measure 3.

(Training Level --)

Data Form

Paper record.

Time Requirements

Total man-minutes	8
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	1
Total	1 1/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Syringe Package (Ref. M-1-a)

3 Microanalytical Package (Ref. M-1-a)

MEASURE 71. RETINAL EXAMINATION

Question or Hypothesis

Zero "g" may alter the shape of the globe or produce venous stasis due to increased venous pressure. The possible redistribution of blood volume due to a loss of muscle tone and a loss of hydrostatic differences in the blood column may change the amount of blood sent to the brain. This could be reflected in the vessels of the eye grounds.

Description of Measure

This measure provides for a visual examination of the retina as to condition of retinal veins, changes in shape of optic disc or shape of orbit.

Results

Observation of changes such as changes in the shape of the retinal globe or venostasis would indicate increased venous pressure.

TECHNIQUE (a) Opthalmoscopic Examination of Retina

Description

Standard opthalmoscope examination by medically trained personnel (standard funduscopic examination).

Evaluation

Highly reliable in hands of trained personnel.

(Training Level -- Physician)

Data Form

Paper record.

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment and Instruments

1 Opthalmoscope - Otoscope Combined Instrument (Ref. M-20-c)

MEASURE 72. URINE CATECHOLAMINE

Question or Hypothesis

See Measure 58.

Description of Measure

See Measure 57 and 58. Urine catecholamine provide average values for given time period.

Results

See Measure 58.

TECHNIQUE (a) Calsul Determination of Urine Catechalamine

Description

See Calsul Technique under Measure 3.

Evaluation

This is the only practical feasible technique.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	8
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	1
Total	1 1/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytical Package (Ref. M-1-a)

TECHNIQUE (b) Determination of Urine Catecholamine by Extraction and Flourometry

Description

Same as Measure 58.

Evaluation

Same as Measure 58.

(Training Level -- Technician)

Data Form

Direct to paper.

Time Requirements

Total man-minutes	29
Frequency	1/7

Minutes per day

Subject	1/7
Observer	4
Total	4 1/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Flourimetric Package (Ref. M-58-b)

MEASURE 73. SERUM 17 KG STEROID

Question or Hypothesis

Weightlessness may result in an experience of increased stress to the organism. Increased stress levels may be detected by presence of serum 17-ketogenic steroid (17KGS) levels.

Description of Measure

17 KGS is the urine metabolite (breakdown product) of the cortisone fraction of the adrenal gland. It is elevated in states of stress. This measure consists of the analysis of serum to determine the presence and level of 17 KGS content in serum.

Results

High levels of steroids are indicative of organism reaction to physical stress.

TECHNIQUE (a) Calsul Determination of Serum 17-KGS

Description

See Calsul Technique under Measure 3.

Evaluation

See Calsul Technique under Measure 3.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	9
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	1
Total	1 2/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytic Package (Ref. M-1-a)

TECHNIQUE (b) Microanalytic Determination of Serum 17-KGS

Description

See Microanalytic Technique under Measure 3.

Evaluation

See Microanalytic Technique under Measure 3.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	16
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	2
Total	2 2/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytic Package (Ref. M-1-a)

Equipment and Instruments

1 Chemical Package (Ref. M-3-a-1)

2 Syringe Package (Ref. M-1-a-1)

TECHNIQUE (b) Prothrometer Determination of Prothrombin Time

Description

Determination of prothrombin time made on drop of fingertip blood by using electronically operated prothrometer.

Evaluation

Excellent technique but requires extra equipment for single low confidence measure that can be determined by "Quick Test".

(Training Level --

Data Form

Paper record - Direct readout

Time Requirements

Total man-minutes	3 1/2
Frequency	1/7
Minutes per day	
Subject	
Observer	1/2
Total	1/2

Equipment and Instruments

1 Prothrometer (Oxford Laboratories Inc, San Mateo, Calif)

Weight	5.50 lb.
Power	15 watts
Volume	0.129 cubic feet

MEASURE 74. PROTHROMBIN TIME

Question or Hypothesis

No hypothesis can be constructed to relate alterations in prothrombin time under weightlessness. However prothrombin time is an vital function in clotting time and also serves to evaluate liver function and hence should be evaluated.

Description of Measure

Prothrombin is one of the major blood clotting factors and is formed in the liver. Prothrombin time is a measure of the amount of prothrombin carried in the blood and is determined by time of clotting of prepared blood samples.

Results

Liver dysfunction and blood clotting impairment may cause decreased prothrombin clotting time.

TECHNIQUE (a) Quick Test for Prothrombin Time

Description

This is a biomedical assay for prothrombin activity in the blood.

Evaluation

Evaluates both clotting factor and liver function. Good accuracy. First choice because the technique utilizes existing equipment.

(Training Level --)

Data Form

Direct to paper record.

Time Requirements

Total man-minutes	11
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	1 3/7
Total	1 4/7

MEASURE 75. EATING HABITS EVALUATION

Question or Hypothesis

Related hypothesis under zero "g" body metabolic needs may be so altered due to lack of the normal stress provided by one "g" that food intake is curtailed on an ad lib diet. Exposure to the psychophysiological stresses of prolonged weightlessness in a space station may alter the normal eating habits of astronauts.

Description of Measure

Observation of food intake, and attitude toward eating, i.e., notation of hunger, appetite, aversions, preferences, etc.

Results

Measure permits conclusions regarding specific individuals for particular diet and environment in addition to clinically useful index of total caloric intake. Results may be recorded with other measurements.

TECHNIQUE (a) Recording of Food Intake and Evaluation of Appetite

Description

Each crewman will record his intake of food in terms of portions of pre-measured food on the same ad lib diet. The method would be a simple observation of food intake, hunger, and appetite by the astronauts. This would be recorded on some rating scale, say 0 to 4+ on a daily basis until a plateau is reached.

Evaluation

Subjective, simple but useful method.

(Training Level -- Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	2
Frequency	1
Minutes per day	
Subject	2
Observer	
Total	2

Equipment and Instruments

1 Food Intake Checklist; Provision for recording of food, caloric intake remarks concerning appetite hunger aversions and preferences.

MEASURE 76. COLOR VISION EVALUATION

Question or Hypothesis

No hypothesis regarding color vision exists, but the function should be evaluated because of the importance of color vision to performance.

Description of Measure

Detection of color vision deficiencies by visual presentation device incorporating visual charts or presentation of visual charts without device.

Results

Evaluation permits detection of changes in color vision function.

TECHNIQUE (a) Optical Evaluation of Color Vision

Description

Color vision charts presented on visual presentation device. Individual is requested to note pattern imbedded in various color forms. Response of normal individual differs from affected individuals.

Evaluation

Simple common clinical measurement - preferred to simple color charts.

(Training Level -- Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	4
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	2/7
Total	4/7

Equipment and Instruments

1 Visual Presentation Device (Ref. M-28-a)

TECHNIQUE (b) Evaluation of Color Vision with Color Charts

Description

Color vision cards similar to Ishihara Charts. Response of normal individual differs from affected individuals to color patterns imbedded in background color forms.

Evaluation

Simple clinical technique - not as good as visual presentation device evaluation.

(Training Level -- Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	4
Frequency	1/7

Minutes per day

Subject	2/7
Observer	2/7
Total	4/7

Equipment and Instruments

1 Color Vision Charts

Weight	.375 lbs.
Volume	.0081 cubic feet

MEASURE 77. URINE 17 KG STEROID

Question or Hypothesis

Same as Measure 73 except that Urine 17 KG Steroid is measured by amount excreted over a period of time whereas Serum 17-KG Steroid is an instantaneous measure.

Description

Same Description as Measure 73 (Serum 17 KG Steroid) with exception that Urine 17 KG Steroid is measured by amount excreted over a period of time whereas Serum 17 KG Steroid is an instantaneous measure.

Results

See Description above.

TECHNIQUE (a) Calsul Determination of Urine 17-KGS

Description

See Calsul Technique under Measure 3.

Evaluation

See Calsul Technique under Measure 3.

(Training Level -)

Data Form

Paper record

Time Requirements

Total man-minutes	9
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	1
Total	1-2/7

Equipment and Instruments

1 Chemical Package (Ref M-3-a)

2 Microanalytic Package (Ref M-1-a)

TECHNIQUE (b) Microanalytic Determination of Urine 17-KGS

Description

See Microanalytic technique under Measure 3.

Evaluation

See Microanalytic evaluation under Measure 3.

(Training Level - Technician)

Data Form

Paper Record

Time Requirements

Total man-minutes	16
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	2
Total	2-2/7

Equipment and Instruments

1 Chemical Package (Ref M-3-a)

2 Microanalytic Package (Ref M-1-a)

MEASURE 78. ENERGY REQUIREMENTS

Question or Hypothesis

Altered metabolism which may occur in the zero "g" environment would cause energy requirements to change. This alteration could be due to decreased demand or due to changes in enzyme activity. Work in the frictionless state has been postulated to cause increase activity.

Description of Measure

Energy requirements determined from tabulation of food and water intake and urine and fecal output.

Results

Increased energy consumption reflects increased metabolic rate or activity levels.

TECHNIQUE (a) Evaluation of Energy Requirements from Food Intake, Etc.

Description

This involves a checklist recording of intake and output, and a computation of energy requirements from this data.

Evaluation

It is a gross indication of energy exchange but it can be calculated after the mission from the astronaut logs as long as input-output is recorded.

(Training Level - Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	5
Frequency	1
Minutes per day	
Subject	5
Observer	
Total	5

Equipment and Instruments

1 Energy Requirements Checklist

MEASURE 79. HEART RATE (BEFORE AND AFTER EXERCISE)

Question or Hypothesis

Weightlessness will decrease the work load on the heart thereby resulting in a decrease in heart rate or in an alteration in heart rhythm response to stress (exercise).

Description of Measure

Determination of heart rate before and after exercise and notation of extent of change and direction of change.

Results

Decreased heart rate. The decreased metabolic activity due to weightlessness. Increased heart rate can be caused by activity, fever, autonomic hyperactivity (anxiety), decreased O_2 supply, etc. If noted, further diagnostic measures should be taken.

TECHNIQUE (a) Electrocardiography

Description

The heart rate will be determined from the EKG.

Evaluation

This technique is most accurate for pulse rate and should be used when equipment is on board. It is most valuable for active subjects.

(Training Level - Astronaut - training in operation of electrocardiograph)

Data Form

To equipment readout

Time Requirements

Total man-minutes	25
Frequency	1
Minutes per day	
Subject	10
Observer	15
Total	25

Equipment and Instruments

1 Electrocardiogram (Ref M-4-a)

TECHNIQUE (b) Stethoscopic Examination for Heart Sounds

Description

Counting of rate while listening with a stethoscope applied to the chest over the apex of the heart.

Evaluation

This technique not as accurate as EKG method. It is especially difficult to get heart rate by this technique when subject is active.

(Training Level - Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	4
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	3/7
Total	4/7

Equipment and Instruments

1 Stethoscope (Ref M-1-b)

MEASURE 80. SKIN, NAILBED, AND MUCOUS MEMBRANE COLOR

Question or Hypothesis

Weightlessness will result in the loss of cardiovascular adaptability resulting in blood pooling in the periphery and consequent cyanosis in the color of skin, nailbed and mucous membranes. Long term exposure to zero "g" and 100% O_2 atmosphere may produce a depression of bone marrow hematopoietic activity. The resulting anemia could be subjectively evaluated in terms of a loss of normal color of the skin, etc.

Description of Measure

Visual observation of skin, nailbed and mucous membrane for color changes.

Results

Lightening (anemia) would be indicative of hematopoetic impairment and cyanosis (blush color of integument) would be indicative of lowered blood levels of oxygen.

TECHNIQUE (a) Observation of Skin, Mucous Membrane, and Nailbed Color

Description

A physician will visually inspect the color of skin, nailbed and mucous membranes of each astronaut. Visual inspection of the skin, nailbed, and mucous membranes will be performed under the same given light conditions three times a day by a physician or well trained individual on each astronaut.

Evaluation

Fair reliability, subject to moderate error, depending upon experience of observer.

(Training Level - Astronaut - trained in assessment technique)

Data Form

To paper record

Time Requirements

Total man-minutes	5
Frequency	1
Minutes per day	
Subject	2
Observer	3
Total	5

Equipment and Instruments

1 Skin, Mucous Membrane and Nailbed Color Checklist - Checklist including provision for notation of presence of anemia or cyanosis and description thereof.

MEASURE 81. BSP (BROMSULPHALEIN)

Question or Hypothesis

No hypothesis can be generated on currently available data. However, because of the importance of liver function, this test is included to document any decrement.

Description of Measure

Excretion of Bromsulphalein (BSP) is a basic measure of liver function because BSP is removed from the blood almost exclusively by the liver.

Results

Prolonged excretion time is indicative of hepatic disfunction.

TECHNIQUE (a) Microanalytic Determination of BSP (Bromsulphalein) Excretion

Description

Five mg of BSP dye per kg body weight is injected intravenously and the serum concentration 45 minutes later is determined on another blood sample. See Microanalytic Technique under M-3.

Evaluation

A valid clinical test of liver excretory function of moderate sensitivity.

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	15
Frequency	1/7
Minutes per day	

Subject	1/7
Observer	2
Total	2 1/7

Equipment and Instruments

1 Microanalytic Package (Ref. M-1-a)

2 Syringe Package (Ref. M-1-a)

MEASURE 82. HEART MOVEMENT (FORCE)

Question or Hypothesis

Weightlessness may reduce venous return to the heart due to peripheral stasis, and cardiac output may be reduced. The heart movement (force) will reflect this reduction.

Description of Measure

Evaluation of heart movement (force) involves the measurement in a frictionless or near frictionless state body motion resulting from heart movement. This is considered to be correlated with cardiac output, and cardiac function.

Results

Heart movement (force) as a measure has not been validated to date.

TECHNIQUE (a) Ballistocardiography or vibrocardiography

Description

Utilization of a device that provides frictionless or near-frictionless support and sensors which detect heart movement or body movement.

Evaluation

Not validated -- lack of standardized data.

(Training Level -- Technician)

Data Form

Readout equipment.

Time Requirements

Total man-minutes	28
Frequency	1/7
Minutes per day	
Subject	2
Observer	2
Total	4

Equipment and Instruments

1 Ballistocardiogram; no well validated commercial equipment.
2 Vibrocardiogram; no well validated commercial equipment.

MEASURE 83. URINE UREA

Question or Hypothesis

There is no reason to suppose that nitrogen metabolism will be effected by zero "g". However, as an index of nitrogen, metabolic activity urea should be determined.

Description of Measure

Urea is the principal end product of protein metabolism, accounting for 80 - 90% of the theoretical nitrogen content in normal human urine (about 30 Gm/day). Urea should be separately determined, in addition to its determination as part of the total nitrogen content, to indicate if nitrogen metabolism is proceeding normally, or if nitrogen loss via another compound (such as ammonia) is responsible for maintaining the nitrogen balance. As nitrogen will not be otherwise determined because of the unfeasible technique, urea determination should be used as an index of nitrogen metabolism.

Results

Shift from usual urea levels would be indicative of liver malfunction, since the liver alone is responsible for the formation of urea.

TECHNIQUE (a) Calsul Determination of Urine Urea

Description

See Calsul Technique under M-3.

Evaluation

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	8
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	1
Total	1 1/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytical Package (Ref. M-1-a)

TECHNIQUE (b) Microanalytic Determination of Urine Urea

Description

See Microanalytical Technical under M-3.

Evaluation

(Training Level -- Technician)

Data Form

Paper record.

Time Requirements

Total man-minutes	22
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	3
Total	3 1/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Microanalytic Package (Ref. M-1-a)

MEASURE 84. TREMOR

Question or Hypotheses

See M-44.

Description of Measure

See M-44. Tremor may be due to its nervous system malfunction or due to muscle denervation. Neither is expected in the zero "g" condition.

Results

See description above.

TECHNIQUE (a) Electromyographic Evaluation for Muscle Tremor

Description

See M-23.

Evaluation

EMG gives more accurate determination of tremor, and can be recorded by astronaut. This is technique of choice.

(Training Level -- Technician)

Data Form

Analog record

Time Requirements

Total man-minutes	21
Frequency	1/14
Minutes per day	
Subject	1/2
Observer	1
Total	1 1/2

Equipment and Instruments

1 Electromyogram (Ref. M-23-a-1)

TECHNIQUE (b) Clinical Examination for Muscle Tremor

Description

Evaluated by physician for tremor during neurological examination.

Evaluation

Will be evaluated as part of routine examination of physician on board, but is only gross difficult evaluation even for a physician.

(Training Level -- Physician)

Data Form

Time Requirements

Total man-minutes	10
Frequency	1/7
Minutes per day	

Subject	3/7
Observer	1
Total	1 3/7

Equipment and Instruments

1 Muscle Tremor Checklist

MEASURE 85, NAUSEA-REGURGITATION EVALUATION

Question or Hypothesis

Weightlessness may alter the normal peristaltic activity of the gastro-intestinal tract such that foods and liquids may remain longer than normal in the stomach. This in turn may cause reflux esophogitis with or without gross regurgitation and emesis.

Description of Measure

Subjective observation of occurrence of nausea-regurgitation.

Results

Occurrence may be due to changes in G.I. motility secondary to absorption changes, disturbances in equilibrium or autonomic activity due to anxiety.

TECHNIQUE (a) Subjective Evaluation of Nausea and Observation of Emesis

Description

Astronaut completion of subjective observation of esophogitis (heart burn), nausea, and emesis. A note would be made of circumstances attending such occurrences, i.e., relationship to eating, sleeping, body position, activity, etc..

Evaluation

Simple subjective assessment.

(Training Level -- Astronaut)

Data Form

Paper record.

Time Requirements

Total man-minutes	2
Frequency	1
Minutes per day	
Subject	2
Observer	-
Total	2

Equipment and Instruments

1 Nausea Evaluation Checklist; checklist form of occurrence and provision for description and correlation with attendant events, i.e., eating, sleeping, body position, etc..

MEASURE 86. INCIDENCE OF AEROTITIS MEDIA

Question or Hypothesis

Zero "g" may result in impairment of drainage of normal secretions from the Eustachian tube with subsequent accumulation and stasis and infection in the middle ear. Pure oxygen atmosphere because of absorption oxygen in middle ear frequently causes severe pain and irritation.

Description of Measure

Subjective complaints of earache which can best be evaluated by examining the ear drums.

Results

Earaches in the zero "g" environment or in a pure 0_2 atmosphere frequently represent aerotitis media and further diagnostic action is necessary.

TECHNIQUE (a) Subjective Evaluation and Otoscopic Examination (Aerotitis Media)

Description

Complaints of earache, plugging, etc. noted. Examination of ear canals and ear drums with otoscope by physician essential.

Evaluation

This is a clinical evaluation and is primarily a crew status measure.

(Training Level -- Physician)

Data Form

Direct to paper record.

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment and Instruments

1 Opthalomoscope, Otoscope Combined Instrument (Ref. M-20-c)

2 Otoscopic Checklist

MEASURE 87. SERUM BILIRUBIN

Question or Hypothesis

No hypothesis can be offered for expecting zero "g" effects upon liver function, but, because of the importance of liver function, it is felt appropriate that some biochemical index of its status be included.

Description of Measure

Hemoglobin liberated during red blood cell destruction is broken down by the liver to bilirubin. The level of bilirubin in the serum is a useful index of liver function.

Results

Markedly elevated bilirubins levels indicates liver dysfunction

TECHNIQUE (a) Microanalytic Determination of Serum Bilirubin

Description

(See Microanalytic Technique under Measure M-3)

Evaluation

(Training Level -- Technician)

Data Form

Direct to paper record

Time Requirements

Total man-minutes	15
Frequency	1/7
Minutes per day	
Subject	1/7
Observer	2
Total	2 1/7

Equipment and Instruments

1 Chemical Package (Ref. M-3-a)

2 Syringe Package (Ref. M-1-a)

3 Microanalytic Package (Ref. M-1-a)

MEASURE 88. SEDIMENTATION RATE

Description of Measure

This is not a feasible measure for zero "g". It requires lg for evaluation. It is a measure of the rate of settling of red blood cells.

TECHNIQUE Sedimentation Rate Determination

Description

Red cells in blood sample measured for rate of settling.

Evaluation

The determination of sedimentation rate not only requires one "g" but depends upon uniform settling so that centrifugation is worthless and the measure not feasible in zero "g".

Equipment and Instruments

Time Requirements

Total man-minutes

Frequency

Minutes per day

Subject

Observer

Total

MEASURE 89. PROTEIN ASSIMILATION TEST

Question or Hypothesis

No reasonable hypothesis has been established for expecting interference with protein assimilation in the zero "g" state. An evaluation is necessary for complete evaluation.

Description of Measure

Determination of serum albumin and globulin gives an evaluation of the bodies ability to assimilate protein.

TECHNIQUE (a) Microanalytic Determination of Serum Albumin and Globulin

Description

See Microanalytic Technique under Measure 3

Data Form

Paper record

Time Requirements

Total man-minutes	23
Frequency	1/2
Minutes per day	
Subject	2/7
Observer	3
Total	3 2/7

Equipment and Instruments

1 Microanalytic Package (Ref. M-1-a)

2 Chemical Package (Ref. M-3-a)

MEASURE 90. MUCOSAL INTEGRITY EVALUATION

Question or Hypothesis

Weightlessness may result in a decrease in epithelial cell reproduction, therefore resulting in a breakdown in mucosal integrity.

Description of Measure

Determination of the cohesiveness of superficial mucosa layers in the interior of the mouth.

Results

Disfunction of epithelial cell production will result in peeling of oval mucosa when pressure is applied.

TECHNIQUE (a) Visual Inspection of Oral Mucosa

Description

Application of pressure to the interior of the mouth and notation of peeling of the mucosa as a result of the pressure.

Evaluation

Indirect method of determining epithelial cell reproduction

(Training Level -- Astronaut)

Training in this specific technique

Data Form

Paper recorded

Time Requirements

Total man-minutes	4
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	2/7
Total	4/7

Equipment and Instruments

Oral Mucosa Inspection Checklist

1. Checklist including provision for an occurrence of peeling and description thereof.

MEASURE 91. BREATH HOLDING TIME

Question or Hypothesis

Breath holding time primarily reflects oxygen levels in blood. Rate decreases with decreased oxygen demand. Rate increases during periods of work and anxiety as well as with decreased oxygen supply.

Description of Measure

Manual timing of breath holding capacity.

TECHNIQUE (a) Manual Timing of **Breath** Holding Time

Description

Breath holding ability timed manually.

Evaluation

Excellent. No other techniques need be considered.

(Training Level -- Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	7
Frequency	1/7
Minutes per day	
Subject	1
Observer	
Total	1

Equipment and Instruments

1. Stop watch (Ref. M-21-a)

MEASURE 92. SKIN THICKNESS

Question or Hypothesis

Under zero "g" conditions body metabolism may be altered so as to produce shifts in lean body mass and body fat. Skin fold thickness is an index of subcutaneous fat.

Description of Measure

Index of the amount of subcutaneous (fat) tissue present.

Results

Increased skin thickness would reflect accumulation of skin fat.

TECHNIQUE (a) Caliper Measure of Skin Fold, Thickness of Skin over Abdomen, Thigh, and Upper Arm

Description

Calibrated caliper measurement of skin fold, skin thickness over abdomen, thigh, and upper arm.

Evaluation

Rough, indirect estimate

(Training Level -- Astronaut)

Familiarity with calipers

Data Form

Paper record

Time Requirements

Total man-minutes	4
Frequency	1/7
Minutes per day	
Subject	2/7
Observer	2/7
Total	4/7

Equipment and Instruments

1. Caliper (Cenco Instruments, Chicago, Ill, Model 72610)

Weight	.250 lbs.
Volume	.0035 cubic feet

2. Skin Thickness Checklist

Checklist for recording of obtained measurement values

MEASURE 93. VENOUS DISTENTION

Question or Hypothesis

Weightlessness may result in the loss of cardiovascular adaptability and loss of muscle tone resulting in venous distention and pooling. With the absence of hydrostatic pressure effects under weightlessness, there may be a loss of cardiovascular adaptability and an increased tendency to peripheral pooling of blood causing venous distention.

Description of Measure

Evaluation of distention of veins of arms, neck, and legs for signs of distention, i.e., pooling of blood.

Results

Distention of veins is indicative of blood pooling.

TECHNIQUE (a) Visual and Manual Examination for Venostasis

Description

The veins on the neck, arms, and legs shall be visually inspected and manually examined by each astronaut on one another. Twice a day each astronaut will make the evaluation described.

Evaluation

This technique provides only a qualitative indication of venous stasis. Fair reliability; a subjective type of observation.

(Training Level -- Technician)

Data Form

Paper record

Time Requirements

Total man-minutes	3
Frequency	2
Minutes per day	
Subject	2
Observer	4
Total	6

Equipment and Instruments

1. Venostasis

Check list providing notation and description of veins on neck, arm and legs relative to venoustasis.

TECHNIQUE (b) Opthalmoscopic Examination for Venostasis

Evaluation

This technique does not give an indication of generalized stasis especially in the extremities. It cannot be done by an astronaut.

Data Form

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Instruments and Equipment

1. Opthalmoscope - Otoscope Combined Instrument (Ref. M-20-c)

MEASURE 94. LIVER SIZE

Question or Hypothesis

Weightlessness may result in the loss of cardiovascular adaptability resulting in blood pooling in the liver with consequent increase in liver size.

Description of Measure

Evaluation of liver size by percussion and palpation of abdomen over the liver area.

Results

Liver size may be predicted to increase in size as a result of venous congestion

TECHNIQUE (a) Manual Percussion and Palpation

Description

A physician or other similarly trained person will manually percuss and palpate the chest and abdomen above each astronaut's liver.

Each astronaut shall have his liver percussed and palpated manually through his chest and abdomen once daily by a physician who will mark the positions of the superior and inferior borders.

Evaluation

Fair reliability, subject to major error.

(Training Level -- Physician)

Data Form

Paper record

Time Requirements

Total man-minutes	14
Frequency	1/7
Minutes per day	
Subject	1
Observer	1
Total	2

Equipment and Instruments

1. Liver Size Checklist

   Checklist including provision for notation and description of changes in liver size.

MEASURE 95. PULSE WAVE VELOCITY

Question or Hypothesis

Zero "g" may alter the elasticity of the arterial system due to changes in skeletal muscle tone and venous pressure.

Description of Measure

Velocity pulse in large vessels measured.

TECHNIQUE (a) Transmission Time Determination of Pulse

Description

Time between heart beat and arrival of peripheral pulse is times.

There is little standarized equipment or clinical data on PWV. Enthusiastic claims have been made for it; however, comparatively little has been reported in the literature. It is an experimental research tool at present, and its inclusion in a flight package can be justified only for purposes of validating the techniques rather than for obtaining data on zero "g".

(Training Level -- Astronaut)

Data Form

Analog output to data processing

Time Requirements

Total man-minutes	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1. Pulse Pressure Transducer (Type 1) Space Labs, Van Nuys, Cal)

   In development stage - not available

TECHNIQUE (b) Transmission Time Determination of Externally Induced Pulsation

Description

Wave propagation time is measured in a peripheral vessel when a pulse is introduced through the vessel wall.

Evaluation

This technique requires more equipment than the other. Both have not been validated as yet.

(Training Levels --

Data Form

Analog output to data processing

Time Requirements

Total man-minute	21
Frequency	1/7
Minutes per day	
Subject	1
Observer	2
Total	3

Equipment and Instruments

1. Pulse Pressure Transducer (Type 2) (Airborne Instruments, L. I., N. Y.)
   In-development stage - not available

MEASURE 96. CHEST CIRCUMFERENCE

Question or Hypothesis

An indication of tissue mass of thorax and expansion requirements of lungs. Decreased respiratory activity could cause slight decrease in circumference.

Description of Measure

Manual measurement of chest circumference is made.

Results

Decreased size consonant with decreased respiratory function could cause decrease in size.

TECHNIQUE (a) Tape Measurement of Chest Circumference

Description

Circumference of chest measured with tape measure.

Evaluation

Excellent. No other technique need be considered.

Evaluation

It is a subjective evaluation, but, if, positive findings occur further diagnosis is warranted.

(Training Level -- Technician)

Data Form

Paper record

Time Requirements

Total man-minutes	1
Frequency	1/2
Minutes per day	
Subject	1/2
Observer	
Total	1/2

Equipment and Instruments

1. Flatus checklist

BODY ELECTRODES FOR ALL INSTRUMENTATION

There are numerous body surface electrodes currently on the market, for example:

Epsco, Inc. Biodes - small round plate of German Silver.

Electronic Medical Systems, Inc. Electrode - small round plate of brass, chrome finish, with belt.

Telemedics, Inc. Telectrode - wire mesh with adhesive backing.

All electrodes need electrode paste for best contact. It appears from many observations of numerous investigations that the wire mesh with adhesive provides best contact for longer time period.

(Training Level -- Astronaut)

Data Form

Paper record

Time Requirements

Total man-minutes	1
Frequency	1/14
Minutes per day	
Subject	1/28
Observer	1/28
Total	1/14

Equipment and Instruments

1. Tape Measure (Ref. M-46-a)

MEASURE 97. GAS FORMATION AND PASSAGE

Question or Hypothesis

Bowel motility and/or poor nitrogen absorption can cause abnormal gas formation and flatus of flatus passage.

Description of Measure

Subjective evaluation of flatus passage discomfort, etc.

Results

Increased flatus observed and noted.

TECHNIQUE (a) Observation of Flatus, etc.

Description

A check list recording of positive findings is kept.

APPENDIX B

BEHAVIORAL

INTRODUCTION

The description and information concerning each behavior test discussed in this appendix is presented in conformity with the following format:

Function: This is the name of the behavior function to be tested, not the name of the test.

Definition: This is the definition of the function to be tested. It is to be noted that no mention is made in this definition of the nature of the test or device for testing the function. The definition is tailored to be useful to this measurement program; it may not always be a dictionary definition.

Questions: These questions are the ones expected to be answered by whatever technique is used for testing the function under consideration.

Selected Measure: This is a statement of the unit of the number that will constitute the score for evaluating the function. Included in this explanation will be an estimate of the probability that the selected measure will reflect a change in the function tested.

Task Selection: This will be a statement of whether the function will be tested as a mission task, a simulated task, or an experimental test.

Technique: This is the nomenclature of the test that will be used to evaluate the function under consideration. All discussions under technique have reference to this test.

Task: This is a description of what the subject does.

Data Form: This is a brief description of the form in which scores are recorded.

Experimental Method and Analysis: This will usually explain the procedure and requirements for establishing a stable baseline score on the ground for the test under discussion and will briefly describe onboard testing and how test scores will be treated.

Technique Evaluation: This discussion will estimate the quality of the test as a means of obtaining measurements that reflect "true" values for the selected measure. This section will also include the tabular presentation of confidence data for the principle question toward which the test is directed and for those related questions that are partially answered by the test under consideration.

Equipment and Costs

Time per testing: This will list time required in the following form:
This will list time required in the following form:

Set up _____ (time) _____

Subject _____ (time for test) _____

Observer _____ (time for test) _____

Total _____ (time) _____

(The time allowance given assumes the proper number of replications per testing)

Personnel

Subject: This will be a brief statement of the training requirements for the subject to perform the test.

Observer: This will be a brief statement of training requirements for the observer to set up, administer, and score the test.

Equipment: This will be a statement of weight, power, and volume costs associated with the test including task equipment and measurement equipment.

Note:

1. Where one piece of equipment serves as the task device for more than one test, this device will be referenced as "Device A, or B, or C," etc.

The size, weight, and volume costs of these special devices are presented at the end of the tabular behavioral test information in the appendix.

2. Costs for spares and maintenance are also presented as a cumulative figure for all behavior tests at the end of the tabular information in Section II.

FUNCTION 1. ARM/HAND/FINGER MANIPULATION

Definition

This function involves the fine control of integrated arm, hand, and finger action to achieve some desired manipulation of objects in the real world. Fine control of force application, direction of movement, speed and timing of movement are involved. This function also involves the coordinated use of digits in manipulation of objects.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Total time required to complete a manipulation task is selected as the measure to reflect performance. This measure is expected to be sensitive to changes in all aspects of manipulative performance. The probability that this measure will reflect any sort of change in manipulative performance is high (.90), although the measure will not permit diagnosis of the reason for change. To enable diagnosis, if it is required, a descriptive record of performance difficulties seen by an observer is selected as an ancillary measure.

Task Selection

Manipulative tasks required for routine station operation will not be sensitive to small changes in manipulative performance. Therefore a specially devised assembly task whose difficulty can be controlled is selected as the task for obtaining measurements of performance.

TECHNIQUE 1. Arm/hand/finger manipulation test

Task

S assembles a "puzzle" (which may be a real mechanical component) and is timed by an observer who also keeps a running account of performance.

Data Form

Time to assemble puzzle manually recorded on prepared score sheets and detailed observer description of performance to be saved for later analysis, if necessary.

Experimental Design and Analysis

S is trained on the ground to assemble puzzles A and B. Training is carried beyond asymptotic performance (in terms of time to assemble). Baseline mean time score is obtained after performance becomes asymptotic. In orbit Form A is administered frequently. Form B is administered infrequently. Form B is to detect degradation which may be masked by compensatory learning in the case of Form "A" which is administered frequently. Basic analysis is to compare S's performance in orbit with ground baseline and to plot change over time in orbit.

Evaluation

Quality of this test as a technique for obtaining an indication of change by means of time score is estimated to be 95%. Quality is high because sensitivity and error can be controlled to a large extent by careful development of the assembly task.

Arm/hand/manipulation test - Time to assemble - q = .95

Function	p	Q	pQ	w
Arm/hand/finger manipulation	.90	.95	.86	.0172
Proprioception	.70	.50	.35	.0070
Learned procedure	.80	.30	.24	.0048
Association	.60	.30	.18	.0036
Visual acuity	.60	.30	.18	.0036
Complex pattern	.50	.50	.25	.0050
Near depth	.80	.70	.56	.0112
Stereognosis	.60	.30	.18	.0036
Tracking (eye-hand)	.70	.50	.35	.0070
Control of force-hand	.50	.50	.25	.0050
Damp tracking	.50	.50	.25	.0050
Control of speed	.50	.50	.25	.0050

Equipment and Costs

Time Per Testing

Set-up	5
Subject	10
Observer	10
TOTAL	25

Personnel

Subject: Selected for satisfactory manipulative ability and trained to baseline performance in the assembly test (forms A and B).

Observer: Trained to set-up time, record scores and observe ancillary behavior of subject for forms A and B of assembly test.

Equipment	weight/lb	power/watts	volume/cu ft
Assembly task (puzzle) Forms A and B	1.0	---	0.0116
3 dimensional assembly tasks selected for desired σ^2 and mean time to assemble			

Device D

FUNCTION 2. MEDIAL FUNCTIONS

Definition

The medial functions selected for measurement in this program are separately defined under appropriate headings. The best evidence available indicates that performance of these medial functions is highly correlated. Thus the quality of decision-making performance, for example, can be expected to be correlated with the quality of problem solving performance. Certainly it is difficult to separate the medial functions by unique definitions. Beacuse of the difficulty in definition, the high correlations expected among performance scores for medial functions, and the probability that the list of medial functions is not optimum, it is desirable to insert a task which is deliberately constructed to involve a variety of medial functions and which is constructed for convenience of testing. We are concerned here, therefore, with the performance of medial functions as a class rather than any specific function. By medial functioning we mean complex information processing at the level of central nervous system. In testing for medial performance, we must be able to assume that the information input is not degraded and that output channels operate without degradation. That is, to test for medial functioning we must set up a task which we can reasonably say does not tax sensory processes and which does not tax effector processes.

Questions

1. Will change in medial performance occure under weightlessness?

Selected Measure

Proportion of correct responses of a sample of medial performance is chosen as the measure. Alternatively, time to carry out performance might be selected as a measure but it is expected that time scores for the task chosen in this case would be associated with large variance making it difficult to analyze results.

Task Selection

In order to test for medial performance as a class, careful control must be exercised in the selection of the task to insure that a number of types of medial performance is included and to insure that sensory and effector channels are not taxed. No regularly scheduled on-board task is seen as being appropriate. Therefore, a specially devised task must be constructed for the purpose.

TECHNIQUE 2. Computation

Task

The subject is given a sample of "real world" problems such as navigation problems which can be solved by the use of trigonometric functions. The subject's task is to set up a mathematical statement which corresponds to given real world situation and which can be solved to obtain a numerical answer to the real world problem. Subject then solves the mathematical statement using his knowledge of algebra and trigonometry and tables of trigonometric functions.

Data Form

Problem answers manually recorded on work sheets.

Experimental Design and Analysis

The subject is given refresher training on the ground to insure he has adequate capability in algebra and trigonometry. Adequate capability is demonstrated when the subject's capability to solve typical problems appears to be stable. In orbit the subject solves a sample of several problems at each testing. The proportion of problems solved correctly is compared with a score of a matched subject who performs under comparable circumstances on the ground. Analysis is for the purpose of detecting a reliable difference

between matched experimental and control subjects. Subjects are matched on the basis of performance prior to initiation of the experimental phase.

Evaluation

The quality of this test as a technique for obtaining an indication of change and medial performance capability is fair. However, a test score is relatively easily obtained. It is most reasonable to evaluate the quality of the test for each of the types of medial performance that it is designed to effect rather than as a whole. Quality evaluation are shown below.

Computation - time to complete a problem

Function	p	Q	pQ	w
Learned procedure	.90	.50	.45	.0090
Decision	.80	.30	.24	.0048
Association	.80	.50	.40	.0080
Deduction	.80	.50	.40	.0080
Recording	.80	.30	.24	.0048
Problem solving	.80	.50	.40	.0080
Guided performance	.90	.50	.45	.0090
Reading	.50	.50	.25	.0050
Set	.50	.50	.25	.0050

Equipment and Costs

Time Per Testing

Set-up	0
Subject	30
Observer	0
TOTAL	30

Personnel

Subject: Trained on the ground to perform trigonometric computations.

Observer: None required.

Equipment

Device D

FUNCTION 3. DAMPED TRACKING - VISUAL

Definition

A damped tracking task is a tracking performance which comes to an end-point according to an inherent task criterion. Thus, a damped tracking task requires tracking for the purpose of achieving a goal. When the goal is achieved, the tracking test is over. In the achievement of the goal of a damped tracking task the allowable error becomes smaller and smaller as the goal is approached. Here we are concerned with damped tracking where the information input is visual.

Questions

1. Will change in performance occur under weightlessness:
2. If there is a change, what will be the course of change over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

The measure selected is the total amount of motion required to achieve the goal of the tracking task given a fixed starting point. In this sort of tracking task, the subject continuously replots the path to the goal from moment to moment. If the optimum path which is plotted at the beginning of the task is followed without error, the motion required to achieve the goal will be minimum. Any deviation from this path requires the plot of a new optimum path. The probability that this measure will reflect change in performance is very high.

Task Selection

In good part this function is recommended for investigation because there is a mission task, docking, which requires damped tracking. To utilize the real docking situation for measurement purposes would be probibitively expensive. A simulated docking task is therefore selected.

TECHNIQUE 3. Docking

Task

By means of a simulator a subject is presented with a docking task in which the subject is on-board the maneuverable vehicle and must approach and dock with a satellite presented by means of the simulator. The simulator provides the subject with the appropriate displays and controls and the subject performs the tracking task until he has achieved a dock. The computer associated with the simulator records the total amount of fuel used in the simulated

dock as a measure of total motion required to achieve the dock.

Data Form

Amount of fuel used to perform docking (in lbs) automatically recorded by simulator.

Experimental Design and Analysis

Subject is trained on the ground to perform the docking test with the simulator that will be used in orbit. Training is carried well past asymptotic performance and baseline time scores are then obtained. In orbit, scores are compared with base line scores using the subject as his own control. Performance in orbit is plotted over time in orbit.

Evaluation

The quality of this test as a technique for obtaining the required measure is high due in part to the control that can be exercised in test development. Questions to which this test is related and associated weights are listed below.

Docking Test - total motion - q = .90

Function	p	Q	pQ	w
Damped tracking	.99	.90	.89	.0178
Arm/hand/finger manip.	.90	.50	.45	.0090
Arm/hand/finger control of force	.90	.70	.63	.0126
Arm/hand/finger control of speed	.90	.70	.63	.0126
Learned procedure	.75	.50	.38	.0076
Decision	.50	.50	.25	.0050
Visual acuity	.50	.80	.40	.0080
Peripheral detection	.30	.60	.18	.0036
Static depth	.50	.70	.35	.0070
Dynamic depth	.70	.70	.49	.0098
Compound pattern	.50	.70	.35	.0070
Brightness	.50	.60	.30	.0060
Color	.50	.50	.35	.0050
Time	.70	.70	.49	.0098
Tracking	.80	.80	.64	.0128
Set	.80	.50	.40	.0080

Equipment and Costs

Time Per Testing

Set-up	5
Subject	45
Observer	0
TOTAL	50

Personnel

Subject: Trained to perform task on the ground

Observer: None required

Equipment

Docking mode Device A

FUNCTION 4. COMPLEX PATTERN DISCRIMINATION

Definition

As used here, complex pattern discrimination refers to the identification of complex visual patterns after familiarization training. By complex pattern is meant a visual stimulus object which presents a double criterion task to the learner prior to familiarization. We are thus concerned here with the question of whether or not complex visual percepts which have been learned continue to be aroused as effective percepts under zero G.

Questions

1. Will change in performance occur under weightlessness?
2. If there is a change, what will be the course of change over time?
3. If there is a change, how will individual be affected differentially?

Selected Measure

The measure selected to reflect performance is the minimum presentation time required for reliable identification of the complex stimulus object for which a percept has been established. This measure has been used experito demonstrate the course of perceptual learning and is a sensitive indicator of visual perceptual performance. Probability that this measure will reflect change is very high.

Task Selection

The control required in developing stimulus materials to measure this function are so exacting that the use of job stimuli for the test is precluded. Laboratory type experimentation is required if measurement is to be carried out with sensitivity and mimimum time investment.

TECHNIQUE 4. Complex Pattern Discrimination

Task

Subject views complex visual patterns which he has previously learned to identify at a rate of presentation which has been shown on the ground to be just above threshold for identification. After each tachistoscopic presentation of a stimulus compound (such as a star pattern whose relevant cues may be position and brightness), subject identifies the star pattern he has seen by selecting it from among other star patterns on a prepared score sheet.

Dat Form

Subject judgments of "same" and "different" marked on prepared score sheet.

Experimental Design and Analysis

Subject is trained on the ground by a familiarization procedure until his tachistoscopic threshold for recognition (idenfification) has become asymptotic for all patterns to be used in the test. The speed of presentation at which performance is 80% correct is determined. This presentation speed is used for testing in orbit and it is determined whether or not subject's capability to identify becomes reliably less than 80% under weightlessness. Performance is plotted over time. Each subject is used as his own control by selecting his tachistoscopic presentation rate on the basis of subject's own performance on the ground. If there is change over time, a new speed of presentation must be selected in orbit when the subject's performance drops below 40% at his baseline speed.

Evaluation

The quality of this test is very high because sensitivity and error can be controlled by careful development of the stimulus materials. Questions to which this test is related and the associated weights are listed below.

Compound pattern discrimination - threshold speed - q = .95

Function	p	Q	pQ	w
Compound pattern	.90	.95	.86	.0172
Visual acuity	.70	.60	.42	.0084
Peripheral detection	.60	.40	.24	.0048
Brightness discrimination	.75	.60	.45	.0090
Cue abstraction	.85	.80	.68	.0136

Equipment and Costs

Time Per Testing

Set-up	5
Subject	15
Observer	0
TOTAL	20

Personnel

Subject: Pre-trained on the ground to recognize test patterns.

Observer: None required.

Equipment

Tachistoscopic mode	Device B

FUNCTION 5. CONTROL OF MASS IN MOTION - LOOP BEHAVIOR

Definition

The handling of mass under weightlessness involves the acceleration, direction control, deceleration, and positioning of objects whose mass is not detectable with accuracy from cues employed under gravity.

Questions

1. Will S be able to function as a mass handler in zero gravity as he did at 1 G?
2. Will S's be able to learn to respond to the appropriate mass cues in zero gravity; how rapidly will he learn this new skill?

3. If S's are not able to function as mass handlers in zero gravity as well as they did in 1 G, how will subjects differ from each other in response to weightlessness?

Selected Measure

The main measure is the total time required to move objects of different mass from one position to another. Supplementing information will be provided by O's comments as to the manner in which the S performs. This time score is the best single score of cumulative movement error in handling mass. This measure will predict changes in mass-handling capability 90% of the time, but because of the many factors involved - vision, deep touch sensitivity, proprioception, dexterity, etc., by this measure alone, it will not be possible to diagnose which factors contribute to any measured performance degradation.

Task Selection

Since mass handling in zero gravity is a newly-learned, space-peculiar skill which interferes with previous mass-handling skills, it is necessary to continue introducing to the S objects of unpredictable mass, that is, to minimize the S's experience with objects of known mass so that his skill in handling mass is more directly measurable. Therefore it will be necessary to control (systematically vary) the mass of familiar-appearing objects. Further, since this loop behavior is a cascading function, most of the required sensory inputs would be acquired during initial acceleration, thus obscuring the performance capabilities in object control, deceleration, and positioning which may be more critical since most acceleration movements will be at minimum velocity. Therefore, all initial accelerations will be controlled as to amount of force required. While it is possible to use onboard items as both containers and as items for altering mass, it is necessary to be able to vary the mass of test objects so that the S cannot use previous visual experience to prejudge their mass.

TECHNIQUE 5. Mass Handling

Task

S uses considerable force to pull objects of different mass from a spring-loaded clip, corrects trajectory forward a frame, and positions objects in the frame.

Data Form

Total time required in whole movement and O's remarks manually recorded on prepared score sheet.

Experimental Design and Analysis

S's are trained on Earth on the general procedure and their mean time scores are recorded. These scores serve as reference standards but failure of the space crew as a group to eventually regain their previous speed levels cannot be considered degradation. Comparison is both individual and within-group.

Evaluation

The quality of this test to detect changes in mass-handling skill is estimated at 90%. It would be higher except for the many sources of variance.

Handling mass - time - q = .90

Function	p	Q	pQ	w
Handling mass	.90	.90	.81	.0162
a/h/f manipulation	.60	.60	.36	.0072
a/h/f control of force	.80	.40	.32	.0064
a/h/f control of speed	.80	.50	.40	.0080
Force on observer	.80	.50	.40	.0080
Proprioception	.75	.50	.38	.0076
Body positioning	.80	.30	.24	.0048

Equipment and Costs

Time Per Testing

Set-up	5
Subject	10
Observer	10
TOTAL	25

Personnel

Subject: No unusual capabilities required.

Observer: Trained to record manner in which S attempted to handle unexpected mass.

Equipment	Weight/lb	Power/watts	Volume/cu ft
Spring clip and box for items used to build up mass	0.5	—	0.5

FUNCTION 6. BODY POSITIONING

Definition

As used here, body positioning refers to setting up the body as a work platform in a coordinated fashion. The function includes neuro-muscular facilitation, muscular strength, and proprioception.

Questions

1. Will weightlessness change positioning performance?
2. If there is change, what will be the course of change over time?
3. How will subjects differ in response to weightlessness?

Selected Measure

The main measure is total time for S to assume several different positions, accomplish several different movements, and successfully accomplish the total task. Additional information is provided by O's detailed comments about the performance. The probability that this measure will reflect changes in S's capability in body positioning is estimated at 90%.

Task Selection

Body positioning is critical for rapid and accurate performance of many critical tasks and is especially sensitive to the effects of weightlessness. On board job performance requiring body positioning may provide the basis for an adequately sensitive test.

TECHNIQUE 6. Don/doff Space Suit

Task

S dons and doffs his pressure suit.

Data Form

Time scores manually recorded on prepared score sheets.

Experimental Design and Analysis

S's are trained on the ground until time to don and doff pressure suit is stabilized. Subject will serve as his own control as well as being compared to the scores of his space crewmates.

Evaluation

The quality of the test is estimated at 90%.

Body positioning - time to perform - q = .90

Function	p	Q	pQ	w
Body positioning	.90	.90	.81	.0062
Arm/hand/finger manip.	.80	.60	.48	.0096
Arm/hand/finger control of force	.75	.60	.45	.0090
Arm/hand/finger control of speed	.80	.60	.48	.0096
Leg control of force	.70	.50	.35	.0070
Learned procedure	.70	.40	.28	.0056
Stereognosis	.80	.35	.28	.0056
Texture	.70	.35	.24	.0048
Proprioception	.80	.60	.48	.0096

Equipment and Costs

Time for Testing

Set-up	0
Subject	20
Observer	20
TOTAL	40

Personnel

Subject: No unusual capabilities required.

Observer: Trained to make detailed analysis of behavior.

Equipment

Pressure suit	(On board item)
timer	Device D

FUNCTION 7. LEARNED PROCEDURE

Definition

A learned procedure is defined here as the performance of a sequence of simple stimulus - response steps in a given order. The fixed order may be determined arbitrarily, or may reflect the fact that the stimulus for each successive step may be obtained only by performing the prior step properly. The task must be carried out without a performance guide and there must be feed-back with respect to adequacy of performance for each step. The criterion for performance of a learned procedure may involve a time limit, but the limit must not be so severe that an integrated motor response must be learned.

Questions

1. Will change in the performance of learned procedure occur under weightlessness?
2. If there is a change in performance, what will be the course of change over time?
3. If there is a change, how will individuals be affected differentially?

Selected Measure

The total number of errors of commission and omission (including corrected errors) during the performance of a learned procedure is selected as the measure to reflect performance. The probability that this measure will reflect any change in the performance of learned procedures is reasonably high, but the measure will not permit diagnosis if change is detected. To enable diagnosis, an observer will make record of performance difficulties as a supplementary measure.

Task Selection

It is anticipated that the operation of any manned space station will require the performance of learned procedures on a scheduled basis. A daily checkout is an example. If possible, in order to conserve time such a regularly scheduled task should be selected for the purpose of measuring the performance of learned procedure. Should it become apparent that no requlary scheduled task will be sensitive to degradation, it will be necessary to develop a simulated learned procedural task for the purpose of measurement.

TECHNIQUE 7. Learned Procedure

Task

Subject carries out previously learned lengthy procedural task on a

scheduled basis. An observer using a prepared score sheet keeps a running account of performance for later analysis and keeps a step by step record of errors for immediate analysis.

Data Form

Errors per testing, by work step, manually recorded on prepared score sheets.

Experimental Design and Analysis

Subject is trained on the ground to perform a selected procedural task. The training is carried well past asymptotic performance. After performance becomes asymptotic a baseline percent correct score is obtained. In orbit, percent of steps correct per trial is measured frequently. The basic analysis is a comparison of percent of steps correct in orbit with a ground baseline score. In orbit scores are plotted over time in orbit to reflect the course of change if any is detected.

Evaluation

The quality of this test is a technique for obtaining a change in procedural performance and is estimated to be 70%. Quality is relatively poor because sensitivity will be low.

Questions to which this test is related and the associated weights of the measure for each question are listed below.

Learned procedure - % errors/trial - q = .70

Function	p	Q	pQ	w
Learned procedure	.90	.70	.63	.0126
Assn (memory)	.85	.60	.51	.0102
Guided perf.	.85	.20	.17	.0035
Arm/hand/finger manip.	.60	.60	.36	.0072
Arm/hand/finger control of force	.50	.30	.15	.0030
Arm/hand/finger control of speed	.60	.40	.24	.0048
Visual acuity	.60	.30	.18	.0036
Compound pattern	.60	.40	.24	.0048
Reading	.70	.40	.28	.0056
Cue abstraction	.65	.30	.21	.0042
Speech perception	.50	.30	.15	.0030
Time	.40	.30	.12	.0024
Monitoring (set)	.70	.50	.35	.0070

Equipment and Costs

Time Per Testing

Set-up	0
Subject	0
Observer	15
TOTAL	15

Personnel

Subject: Trained on ground to perform procedure.

Observer: Trained to record observations of performance for the specific procedure.

Equipment

None

FUNCTION 8. PERCEPTUAL SET

Definition

Set is involved in perceptions in which the stimulus is learned, response is learned, the preparedness or set to respond is learned, and association is learned. Perception involves the organization of sensory inputs so as to be a stimulus event, including preparedness or set as part of the sensory input. That is, the input complex consists of sensory data against a background of alertness or preparedness or motivation or set. When subjects are proficient the sensory modality and set comprise a stimulus combination that leads to detection of a signal and appropriate action.

Questions

1. Will change in perceptual set occur under weightlessness?
2. If a change does occur, what will the cause of change be over time?
3. If there is a change, how will individuals be affected differentially?

Selected Measure

Number of errors of omission and number of errors of commission per unit of task time is selected as the measure to reflect perceptual set. This measure is expected to be sensitive to alteration in perceptual set and alertness

in general. The probability that this measure will reflect any change in performance that involves set is high (.99), although the measure will not permit diagnosis of the reason for change.

Task Selection

Real station operation tasks that involve perceptual set are usually of a watchkeeping nature and involve vigilance and monitoring. Real task measurement is not feasible since detection of signals can be assured by sound human engineering that will supplement signals with buzzers or flashing lights. Also, the mechanics of recording watchkeeping performance in real operations would require a significant amount of complex wiring and instrumentation that would complicate control panel design and would reduce operational reliability. Most importantly, real task watchkeeping tasks would not reflect small changes in perceptual set.

Therefore a specially designed watchkeeping task on a simulated panel is selected as the task for measuring perceptual set. There are 5 possible measures of watchkeeping proficiency: errors of omission, errors of commission, response latency changes in threshold sensitivities and changes in observing responses. The most straightforward measure is the number of errors of omission and the number of errors of commission in a given time.

TECHNIQUE 8. Monitoring

Task

S maintains a 30 minute monitoring task at a simulated control panel. Subject is required to detect visual signals occurring at irregular intervals programmed to simulate signals from the environmental control system, the power system, leak detection matrix, a master control panel and a timing display.

Data Form

Number of signals omitted and number of responses committed without signal, over 30 minutes in 5 minutes intervals. Recorded automatically by simulator.

Experimental Design and Analysis

S is trained and tested on the ground until a stable performance curve for a 30 minute monitoring task is achieved. This curve for errors of omission and commission will be baseline performance. In orbit subject will be tested at regular intervals and scores plotted. Curves will be compared with baseline and previous in-orbit curves. A curve of change over time will also be plotted.

Evaluation

The quality of this test as a technique for obtaining an indication of change in capability to sustain perceptual set is estimated to be 80%. This figure is based on the idea that this measure is only a true measure of set in a monitoring situation involving visual signals. For other monitoring tasks and for alertness in general, this test cannot be assumed to provide full coverage.

This test is intended to be relatively unrelated to any other behavior measures.

Monitoring (set) - minutes to k degradation - q = .80

Function	p	Q	pQ	w
Monitoring (set)	.99	.80	.79	.0158

Equipment and Costs

Time Per Testing

Set-Up	5
Subjece	30
Observer	0
TOTAL	35

Personnel

Subject: Selected for adequate monitoring capability (perceptual set) and trained to stable baseline monitoring performance in 30 minute watch-keeping task.

Equipment

Monitoring Task Device A

FUNCTION 9. SPEAKING

Definition

Speaking is the transmission of information by voice by means of language.

Questions

1. Will changes in speech occur under weightlessness?
2. If change does occur, what will the course of change be over time?

Selected Measure

Proportions of information successfully transmitted by speech, given a known information transmission requirement. The probability that this score will reflect any change in the intelligibility of speech is high (.99).

Task Selection

This measure will be an experimental task. Careful control of input information is required.

TECHNIQUE 9. Speaking Test

Task

S records ad lib description of test picture with known information content. Description is limited by timer.

Data Form

Voice recording on tape, gross analysis on board; fine grain analysis on ground.

Experimental Design and Analysis

Subject is tested on ground to establish baseline. Voice recording generated in orbit will be compared with baseline. Crude on board judgment of "same" or "changed." Analysis on ground will be by trained experts.

Evaluation

The quality of this test as a technique for obtaining an indication of change in use of speech to transmit information is estimated to be low (70%).

Speaking - scaled value - q = .99

Function	p	Q	pQ	w
Speaking	.99	.70	.70	.0140
Writing	.70	.50	.35	.0070
Association	.80	.70	.56	.0112

Equipment And Costs

Time For Testing

Set-up	5
Subject	10
Observer	0
TOTAL	15

Personnel

Subject: - pre-tested on ground.

Observer: none required for testing, but a crew members must be trained to make gross analysis of speech performance on board.

Equipment

Device C

Device D

FUNCTION 10. SPEECH PERCEPTION

Definition

For purposes of this study, speech perception is the capability of the subject to derive information from speech.

Questions

1. Will change in speech perception occur under weightlessness?
2. If a change does occur, what will the course of change be over time?

Selected Measure

Percentage of words in paragraphs of approximately 100 words that can be perceived when speech is impoverished to a given point was selected as the measure of choice. The use of percentage of sentences or the use of

a score for % of impoverishment that was threshold for a subject or any day were discarded. Both of these measures imposed too great a burden on paragraph preparation. The probability that this measure will reflect any change in performance that involves perception of speech is high (.90).

Task Selection

Measurement of this function requires an experimental test, although it closely resembles the problems of garbled radio communication.

TECHNIQUE 10. Perception of impoverished speech

Task

Taped paragraphs of approximately 100 words will be impoverished by electronic clipping to a % of impoverishment that is threshold for the subject. Sentences that comprise the paragraph will be well within the range of the demonstration assimilation span of the subject and will be adjusted to reduce within subject variability to a minimum. Threshold will be at that level of impoverishment where the subject is able to repeat only 80% of the words. The subject in the test is required to repeat as many words as possible at the end of each unit of presentation.

Data Form

Voice recording on tape in response to instructions.

Experimental Design and Analysis

Subject is tested until threshold for perception of impoverished speech is stable. Tapes are then prepared at this level of impoverishment. These tapes are the subject's baseline at which he can perceive 80% of the words. Subject is tested in orbit at regularly recurring intervals. In orbit performance is compared with baseline and a curve of performance over time will be plotted.

Evaluation

The quality of this test as a technique for obtaining an indication of change in capability to perceive impoverished speech is estimated to be 80%. This figure is based on the idea that impoverishment of speech by clipping and compression is slightly different than garbled radio communication. Also the audibility of words must necessarily vary in ease of perception. That is, one paragraph may be more or less difficult than another.

Speech perception - % words/sample correctly identified - q = .80

Function	p	Q	pQ	w
Speech perception	0.90	0.80	0.72	0.0144
Tone thresholds	0.80	0.50	0.40	0.0080
Tone duration	0.50	0.40	0.20	0.0040
Tone pattern	0.60	0.50	0.30	0.0060
Reading	0.70	0.50	0.35	0.0070
Association	0.90	0.80	.70	.0140

Equipment And Costs

Time Per Testing

Set-up	5
Subject	10
Observer	0
TOTAL	15

Personnel

Subject: Selected for adequate speech perception and trained to stable baseline; that is threshold for perception of impoverished speech is determined. Also trained to administer test to himself and record responses.

Observer: None required.

Equipment

Device C

FUNCTION 11. ARM/HAND/FINGER CONTROL OF FORCE

Definition

Both reactive control of force and positioning against no counter force are included in this function. By control is meant adjusting an exerted force to some desired criterion either for a brief instant or over a short span of time.

Questions

1. Will weightlessness increase or decrease his ability to control exertion of force?

2. If there is a change in performance, what will be the change over time?

3. Will subjects differ in response to weightlessness?

Selected Measure

Total error score in total pounds of pressure difference about a standard over a given time period. The probability that this measure will reflect changes in S's ability to control force is very high.

Task Selection

Control of force is crucial for most control task, and is amenable to testing in a relatively isolated manner. To achieve this isolation of capability it is necessary to construct 2 laboratory types of task.

TECHNIQUE 11. Control of force and positioning

Task

S attempts to reach and to maintain a specified amount of force against a spring for a 10 second interval. Control of position is measured for several test amounts. To test positioning, S maintains a position on an indicator when there is no reactive force. Arm control will be measured separately from hand control. For both arm and hand, one test amount will be selected to test for maximum force.

Data Form

Error in control of force over 10 second period, automatically integrated by computer.

Equipment	Weight/lbs.	Power/watts	Volume/cu. ft.
		--	60 cu. in.
	Device H		
Dynamometer	1	--	0.018

Experimental Design and Analysis

S will be his own control. Mean integrated error per test on ground will be compared with in-orbit scores.

Evaluation

The quality of the test is estimated at 90% since many repetitions of the test should provide sufficient sensitivity.

Arm/hand/finger control of force - error in lbs/t - q = .90

Function	p	Q	pQ	w
Arm/hand/finger control of force	0.99	0.90	0.89	0.0178
Arm/hand/finger manipulation	0.30	0.70	0.21	0.0042
Force on observer	0.80	0.70	0.56	0.0112
Proprioception	0.70	0.40	0.28	0.0056
Handling mass	0.70	0.80	0.56	0.0112
Damped tracking	0.80	0.50	0.40	0.0080
Tracking	0.70	0.60	0.42	0.0084
Body positioning	0.60	0.50	0.30	0.0060

Equipment And Costs

Time Per Testing

Set-up	5
Subject	25
Observer	0
TOTAL	30

Personnel

Subject: No unusual capabilities

Observer: None

FUNCTION 12. DETECTION/DISCRIMINATION OF ANGULAR ACCELERATION

Definition

By detection of angular acceleration is meant the detection of rotation of the whole body.

Questions

1. Will change in performance occur under weightlessness?

2. If change does occur, what will the course of change be over time?

Selected Measure

The measure of choice is time from onset of rotation to detection of motion. Alternatively, degrees of rotation before detection could be used. The probability that this measure will reflect a change in sensitivity is high (.90).

Task Selection

The measurement of ability to detect angular acceleration necessarily requires special apparatus and a laboratory type test.

TECHNIQUE 12. Detection of angular acceleration

Task

Subject is blindfolded and set in acceleration chair with his head lightly supported. The chair is accelerated at a low rate of acceleration. Subject indicates when he detects motion. Score will be time from onset of rotation to detection of motion.

Data Form

Time to detect motion; manually recorded on prepared form.

Experimental Design and Analysis

Subject is tested on the ground until a stable threshold for detection of angular acceleration is established. Subject will be tested in orbit and score will be compared with baseline to determine change in threshold. Curve of scores will be plotted over time to reflect any trend.

Evaluation

The quality of this test as a technique for obtaining an indication of change in threshold for detection of angular acceleration is estimated to be 90%.

Detect angular acceleration - time to threshold - q = .90

Function	p	Q	pQ	w
Angular accel.	0.90	0.90	0.80	0.0162
Linear acceleration	0.70	0.40	0.28	0.0056
Body positioning	0.70	0.50	0.35	0.0070

Equipment And Costs

Time Per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: Tested for baseline threshold for detection of angular acceleration on ground.

Observer: Trained to setup apparatus, control the acceleration chair and record scores.

Equipment

Device E

FUNCTION 13. DETECTION/DISCRIMINATION OF LINEAR ACCELERATION

Definition

By detection of linear acceleration is meant the detection of acceleration of the whole body along a linear path using all normal cues except vision.

Questions

1. Will the threshold of detection of linear acceleration be changed by weightlessness?

2. If change does occur, what will the course of change be over time?

Selected Measure

The measure of choice is the time from onset of motion to detection of motion. Distance traveled is necessarily a function of time. The probability that this measure will reflect a change in threshold for detection of change in rate of motion is high (.90).

Task Selection

The measurement of ability to detect linear acceleration necessarily requires special apparatus and a laboratory type test.

TECHNIQUE 13. Detection of linear acceleration.

Task

Subject is blindfolded and seated in an acceleration chair with his head lightly supported. The chair is accelerated along tracks by a motor that produces acceleration. Subject indicates when he detects motion. Score will be time from onset of motion to detection of motion.

Data Form

Time to detect motion manually recorded on prepared form.

Experimental Design and Analysis

Subject is tested on ground until a stable threshold for detection of linear acceleration is established. Subject will be tested at regularly recurring intervals in orbit and score will be compared with baseline. Curve of scores will be plotted over time to reflect any trend.

Evaluation

The quality of this test as a technique for obtaining an indication of change in threshold for detection of linear acceleration is estimated to be 90%. This figure is based on the idea that the rate of movement and acceleration of the chair can be adjusted to establish a highly consistent threshold and that this threshold will change with small changes in sensitivity of the motion detecting senses.

Linear acceleration - time to threshold - q = .90

Functions	p	Q	pQ	w
Linear acceleration	0.90	0.90	0.81	0.0162
Angular acceleration	0.70	0.40	0.28	0.0056
Body positioning	0.70	0.30	0.21	0.0042

Equipment and Costs

Time Per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: Trained to baseline threshold for detection of linear acceleration on ground.

Observer: Trained to setup apparatus, control the acceleration chair and record scores.

Equipment

Device E

FUNCTION 14. ARM/HAND/FINGER CONTROL OF SPEED OF MOTION INCLUDING REACTION TIME

Definition

Arm, hand, and finger control of speed of motion is the ability to control constancy and change of speed of motion.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Cumulative error in repeating the speed of a basic motion for a given period of time is selected as the measure. Probability of measure reflecting changes in ability is estimated at 99%.

Task Selection

A laboratory test is required to obtain sensitivity.

TECHNIQUE 14. Arm/hand/finger control of speed and reaction time

Task

S listens to a signal which repeats at a steady rate. This signal is a standard for speed of movement. When the signals stop, S moves a stylus back and forth through a given arc at the specified rate for a given period of time. Separate measurement of reaction time is taken as part of this test.

Data Form

Total cumulative time error scores and reaction time in seconds automatically scored by computer.

Experimental Design and Analysis

S's will be trained on the ground to minimum error criterion and then will serve as their own controls.

Evaluation

The quality of the test is estimated at 90%.

Arm/hand/finger control of speed of motion - q = 90 - error in msec

Function	p	Q	pQ	w
Arm/hand/finger control of speed	0.99	0.90	0.90	0.0180
Arm/hand/finger manip.	0.70	0.60	0.42	0.0084
Arm/hand/finger control of force	0.60	0.40	0.24	0.0048
Proprioception	0.50	0.30	0.15	0.0030
Time	0.50	0.50	0.25	0.0050
Tracking	0.70	0.60	0.42	0.0084
Damped tracking	0.80	0.50	0.40	0.0080

Equipment And Costs

Time Per Testing

Set-up	2
Subject	8
TOTAL	10

Personnel

Subject: No unusual capabilities.

Observer: (none required).

FUNCTION 15. DETECTION/DISCRIMINATION OF FORCE AGAINST LIMB

Definition

This is the function of sensing relative amounts of force and changes in force acting against an extremity.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course be over time?
3. If there is change, how will individuals be affected differentially?

Equipment	Weight/lbs.	Power/watts	Volume/cu ft.
Measurement Device (Plate with two contact surfaces and stylus. Contact between stylus and plate provides signal to computer)	1	10	0.023

Selected Measure

The size of JND's in terms of pounds of pressure required by the S's to reach threshold discrimination of change of amount of reactive pressure was selected as the best means of measurement. The probability that this measure will reflect changes in S's capability to detect changes of force is estimated at 99%.

Task Selection

It is not feasible to build force varying capabilities into on-board devices. A separate laboratory type of test is required.

TECHNIQUE 15. Detection/Discrimination of Force Against Arm & Hand

Task

Restrained, seated S is required to maintain pressure on a spring-mounted lever and, while the spring resistance is altered, by 0 and report detection of change in force required to maintain his position. S also reports the direction of the change detected.

Data Form

Data manually recorded on prepared score sheets.

Experimental Design and Analysis

The S's are tested to establish size of JND on the ground. S is tested in orbit for change of JND about several selected standards.

Evaluation

The quality of the test is estimated at 99% since the increments of change can be highly controlled.

Detect force or observer - b^2 in force est. - q = .90

Function	p	Q	pQ	w
Force or observer	0.90	0.90	0.81	0.0162
Control of force	0.80	0.90	0.72	0.0144
Proprioception	0.80	0.60	0.48	0.0096
Handling mass	0.70	0.50	0.35	0.0070

Equipment And Costs

Time Per Testing

Set-up	5
Subject	20
Observer	20
Total	45

Personnel

Subject: No unusual capabilities.

Observer: Trained in determination of JND.

Equipment	Weight/lbs.	Power/watts	Volume/cu. ft.
Force Detection Device	6	100	1.2

FUNCTION 16. DETECTION/DISCRIMINATION OF MOVEMENT OF LIMB

Definition

It is a measure of an individual's ability to detect motion imparted to his limb.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

The angle through which a limb is moved before detection of a change is selected as the measure to reflect sensory degradation. The probability that this measure will reflect a change in ability is high (.90). If a change

is indicated, other measures; sensory and biomedical, will have to be sought for a causal analysis as this measure is only an indicator of change.

Task Selection

A laboratory task must be selected as on board functions do not lend themselves to sufficiently precise measurement.

TECHNIQUE 16. Detection of movement of limb.

Task

Seated subject has forearm lightly strapped on a support movable about a ball joint under the elbow. The arm (from elbow down) is caused to move by a motor which moves the support at a slow constant rate. S reports when he detects change and the direction of change.

Data Form

Threshold in degrees manually recorded on prepared score sheets.

Experimental Design and Analysis

On board performance compared to on ground performance using S as his own control.

Evaluation

It is estimated that the quality of this test as a technique for obtaining an indication of change in the ability is 80%. Control of subject variance is possible through manipulation of the speed, time, distance parameters of the system, e.g., we can set the motor so that S will respond within 2 seconds.

Movement of limb/degrees at threshold - q = .80

Function	p	Q	pQ	w
Movement of limb	0.90	0.80	0.72	0.0144
Arm/hand/finger manipulation	0.40	0.30	0.12	0.0024
Arm/hand/finger control of force	0.80	0.50	0.40	0.0080
Arm/hand/finger control of speed	0.80	0.50	0.40	0.0080
Body positioning	0.70	0.60	0.42	0.0084

Equipment And Costs

Time Per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: No unusual requirements.

Observer: Trained to operate and maintain equipment, administer test, and records subjects responses.

Equipment	Weight/lbs.	Power/watts	Volume/cu. ft.
Motor Driven Arm Rest	5	10	1

Support holds upper arm in a fixed position, forearm, hand and fingers. Strapped in a cushioned rest. Motor capable of moving from below threshold speed and upward at a constant rate.

FUNCTION 17. RECOGNITION OF LOCATION OF LIMB

Definition

As we define this function it is the ability of an individual to identify the location of one of his extremities without visual cues.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

Variance in detection of location of the limb is selected as the measure to reflect sensory degradation of this ability. The probability that this measure will reflect change in ability is high (.90).

Task Selection

An artificial task must be selected as actual on board tasks do not lend themselves to measurement.

TECHNIQUE 17. Test for location of limb.

Task

Observer places subject's arm or leg and asks for a report of its position. S who is blindfolded uses a previously learned reference system to report his estimate of position.

Data Form

Error in degrees from actual position manually recorded on prepared score sheet.

Experimental Design and Analysis

S is used as his own control, in-orbit variance being compared with ground baseline variance.

Evaluation

It is estimated that the quality of this test as a technique for obtaining an indication of change in ability is 60%. Large experimental error is a factor in the relatively low quality of the measure.

Recognition of Location of Limb/b^2 in degrees - q = .60

Function	p	Q	pQ	w
Proprioception	0.90	0.60	0.54	0.0108
Tracking	0.60	0.50	0.30	0.0060
Handling mass	0.80	0.50	0.40	0.0080
Body positioning	0.90	0.50	0.45	0.0090

Equipment and Costs

Time Per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: Tested on ground.

Observer: Trained to set up test and to conduct test.

Equipment

None

FUNCTION 18. LEG CONTROL OF FORCE.

Definition

This is the function of transmitting information by means of control over the force exerted by the leg. It is intended to include positioning in which the reactive force is zero and a test of control near maximum strength.

Questions

1. Will change in performance occur under weightlessness?

2. If there is a change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

The total error in control over force exerted by leg over a unit of time will be taken as the measure to indicate change in ability. The probability that this measure will reflect a change in leg control is high (.99).

Task Selection

A laboratory task must be used for this function as there is no real task available in this setting which is applicable to measurement.

TECHNIQUE 18. Leg control of force.

Task

S exerts a force to bring a spring to a given position and hold it there for a designated length of time. S monitors a meter while he exerts the force. Three forces levels are tested. In a second part of the task, S moves the device to a given position with no force against him and holds the device for a period of time (positioning).

Data Form

Positioning errors over test time period integrated by computer.

Experimental Design and Analysis

Subject used as own control. Base line scores obtained on ground. Summation of errors per time unit used as basic measure. On-board errors compared to on-ground data.

Evaluation

The quality of this task as a technique for obtaining an indication of change in ability is estimated to be 90%.

Leg control test - Error -lb - q = .90

Function	p	Q	pQ	w
Leg Control	0.99	0.90	0.89	0.0178
a/h/f control of force	0.60	0.10	0.06	0.0012
Force on observer	0.70	0.30	0.21	0.0042
Proprioception	0.70	0.60	0.42	0.0084
Body positioning	0.50	0.30	0.15	0.0030

Equipment And Costs

Time Per Testing

Set-up	5
Subject	10
Observer	0
TOTAL	15

Personnel

Subject: Trained to run equipment and administer test to himself.

Observer: None

Equipment

FUNCTION 19. TRACKING, VISUAL-MOTOR

Definition

This is the function of visual-motor loop behavior in which control action is carried out to keep a visually detectable error in control action at a minimum.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

Measure is an integrated error score for a specified time period. The probability that this measure will reflect changes in S's ability to perform tracking tasks is estimated at 90%.

Task Selection

It is necessary to use a special simulator since the tracking test must be more difficult than any job task.

TECHNIQUE 19. Compensatory tracking

Task

S attends to attitude control portion of the simulator and is instructed to use his control to maintain a steady attitude. The target has 3-axes cross-coupling with programed drift.

Data Form

Integrated position error scores automatically recorded by simulator.

Experimental Design and Analysis

S's are trained on the ground to achieve minimum error scores. Each S is his own control.

Evaluation

Since variance can be controlled it is estimated that the quality of this test is 95%.

Tracking test - error/t - q = .95

Function	p	Ω	pΩ	w
Tracking	0.90	0.95	0.86	0.0172
Arm/hand/finger manip.	0.85	0.70	0.60	0.0120
Arm/hand/finger control of force	0.85	0.70	0.60	0.0120
Arm/hand/finger control of speed	0.85	0.70	0.60	0.0120
Visual acuity	0.75	0.70	0.53	0.0106
Peripheral detection	0.60	0.50	0.30	0.0060
Compound pattern	0.75	0.50	0.38	0.0076
Force on observer	0.10	0.10	0.01	0.0002
Proprioception	0.50	0.30	0.15	0.0030
Damped tracking	0.80	0.50	0.40	0.0080
Handling mass	0.50	0.30	0.15	0.0030
Body positioning	0.30	0.30	0.09	0.0018
Set	0.30	0.50	0.15	0.0030

Equipment And Costs

Time Per Testing

Set-up	5
Subject	20
Observer	0
TOTAL	25

Personnel

Subject: No unusual capabilities

Observer: None required

Equipment

Device A

FUNCTION 20 VISUAL RESOLUTION OF DETAIL

Definition

Visual acuity is the ability of the eye to sense information by means of discrimination of fine details. Functionally it is the capacity of the retina to make fine discriminations in the image.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is a change, how will individuals be affected differentially?

Selected Measure

The measure for this function will be the smallest standard Landholt ring reliably discriminated at 16 inches and at 20 feet. This measure has a very high probability (.99) of reflecting any change.

Task Selection

To obtain sensitive measurement, a laboratory type of task is required.

TECHNIQUE 20. Visual acuity test

Task

S views sets of Landholt rings of decreasing size per set above and below his threshold. S marks the position of each C on a prepared score sheet. The procedure is repeated for 16 inches and 20 feet.

Data Form

Record of performance on prepared score sheet.

Experimental Design and Analysis

S will be his own control. Visual acuity scores on ground provide a baseline. Scores on board will be based on enough testings to ensure reliability. Scores will be plotted to reflect any trend in visual acuity over time.

Evaluation

This is a perfectly clear-cut measure of visual acuity that can be made on board and should reflect significant changes in visual performance. The quality of the test as a technique is 99%. The high quality is due to the amount of control over the stimulus variables.

Visual acuity test - Landholt C at threshold - q = .99

Function	p	Q	pQ	w
Visual acuity	.99	.99	.99	.0198

Equipment And Costs

Time Per Testing

Set-up	5
Subject	10

Observer 0

TOTAL 15

Personnel

Subject: Normal vision at selection. S tested on ground until average acuity score is stable at reading distance and for far vision.

Observer: None required.

Equipment

Visual Presentation
Device B

FUNCTION 21. NEAR DEPTH PERCEPTION

Definition

This function is the perception of distance relationships among objects in space where convergence is an important cue.

Questions

1. Will change in performance occur under weightlessness?

2. If there is a change, what will the course of change be over time?

3. If there is a change, how will individuals be affected differentially?

Selected Measure

The variance of the errors in judging equidistance will be the measure to indicate near depth perception. The probability that this measure will reflect a change in this perceptual ability is high (.99). Even with this high probability, the function will not yield information about cause; information of this type will have to be obtained with more specific measures.

Task Selection

It is necessary to use laboratory materials so that the subjects cannot learn the distance relationship between on board objects and use this knowledge in making judgments.

TECHNIQUE 21. Near depth perception with stereopsis

Task

S determines which object in a test field of similar objects is equidistant to a standard object in a similar field. Both fields will be equidistant from the subject and a short distance from each other. Two observation distances will be used: one at arm length; and one at cabin length distance.

Data Form

Identification of selected objects (equidistant objects) on prepared score sheet.

Experimental Design and Analysis

S used as his own control. On ground measures given repeatedly to obtain a distribution of base line errors. On board measurement follows same procedure as on ground. At least two testings per observation distance should be possible for each session. Variance on board will be compared with variance on ground. Variances will be taken about true values.

Evaluation

The quality of this test has been estimated to be 90%. The quality can be made this high by careful construction of the test device to increase task difficulty.

Stereopsis Test	σ^2 of equal distance - q = .90			
Function	p	Q	pQ	w
Stereopsis	.99	.90	.89	.0178
Visual acuity	.90	.80	.72	.0144

Equipment And Costs

Time Per Testing

Set-up	5
Subject	5

Observer 5

TOTAL 15

Personnel

Subject: Normal vision at selection. No special training required of S.

Observer: Trained to set up the equipment and administer the test in predetermined fashion.

Equipment	weight/lbs.	power/watts	volume/cu. ft.
Two 6" x 8" stimulus boards, each with interchangeable stimuli	2	0	0.15

FUNCTION 22. PERIPHERAL VISUAL DETECTION/DISCRIMINATION

Definition

Peripheral visual detection involves the perception of objects or their movement in that part of the visual field outside of the fovea.

Questions

1. Will change in performance occur under weightlessness?
2. If there is a change, what will the course of change be over time?
3. If there is a change, how will individuals be affected differentially?

Selected Measure

For this function the selected measure will be the size of arc measured from a fixation point through which moving objects can be detected. The measure can be predicted to indicate change in ability with a high degree of accuracy (.95).

Task Selection

It is necessary to use laboratory control.

TECHNIQUE 22. Peripheral visual detection.

Task

S wears a mask device similar to a catchers mask across which the visual stimulus is presented. The test patch is moved along scaled arcs on the mask through the visual field of S. S reports when the patch moves out of sight. One eye is tested at a time, and a visual field map is made for each eye.

Data Form

Manually recorded on prepared score sheets.

Experimental Design and Analysis

On ground maps are constructed for S. On board tests are compared with the on ground base line values.

Evaluation

The quality of this measure as a technique for obtaining an indication of change in effective field if vision is 99%. Its high quality is due to the degree of control over the experimental variables.

Peripheral detection/visual - inches from fixation · q = .99

Function	p	Q	pQ	w
Peripheral detection	.95	.99	.95	.0190

Equipment And Costs

Time Per Testing

Set-up	5
Subject	10
Observer	10
TOTAL	25

Personnel

Subject: Normal vision at selection.

Observer: Trained to administer test and record data.

Equipment	Weight/lbs.	Power/watts	Volume/cu. ft
Face Mask	2	0	1

Specially constructed face mask to present visual stimuli in arcs through visual field.

FUNCTION 23. TONE AUDITION

Definition

This is the function of obtaining information through the auditory channel by the detection of intensity and frequency of the stimulus. Speech is excluded as a stimulus.

Questions

1. Will change in performance occur under weightlessness?

2. If there is a change, what will the course of change be over time?

3. If there is a change, how will individuals be differentially affected?

Selected Measure

Intensity of the stimulus at threshold for all frequencies is selected to indicate change in performance. This measure is expected to reflect change in ability at a high level (.90).

Task Selection

A sensitive measure of degradation in auditory ability is needed. This requires a laboratory rather than a job task.

TECHNIQUE 23. Tone Detection/Discrimination-Non Speech

Task

S listens to prerecorded tapes of a random sampling of tones at various frequencies and intensities within the hearing envelope. S responds to any perceived tones by pressing a key which records a signal on the test tape whenever a tone is heard. An absence of a response indicates the tone was below threshold and was not heard.

Data Form

Responses recorded on test tape.

Experimental Design and Analysis

Subject as his own control. On ground testing provides a stable measure of thresholds at a sample of frequencies. On board data is compared to on-ground information for indication of any significant changes in thresholds.

Evaluation

The quality of this measure to indicate changes in auditory ability is estimated to be 90%.

Tone detection/discrimination - intensity at threshold - q = .90

Function	p	Q	pQ	w
Tone threshold	.90	.90	.81	.0162
Speech perception	.70	.50	.35	.0070
Tone duration	.60	.40	.24	.0048
Tone pattern	.60	.60	.36	.0072

Equipment And Costs

Time Per Testing

Set-up	5
Subject	10

Observer 0

TOTAL 15

Personnel

Subject: Normal hearing at selection. Trained to operate equipment. Subjects tape recorded response rules out the need for an observer.

Equipment

Tape Recorder Task Device C

FUNCTION 24. STEREOGNOSIS

Definition

Stereognosis is the capability of perceiving and understanding the form and distinctive characteristics of objects by touch sensors only.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Total number of errors in discriminating between objects whose surface characteristics vary. Probability of measuring change is estimated at 99%.

Task Selection

To provide a range of objects which are only slightly different from each other it is necessary to use laboratory control in selection.

TECHNIQUE 24. Stereognosis

Task

S is blindfolded and instructed to rank a number of objects in order of increasing number of flat surfaces.

Data Form

Total number of ranking errors.

Experimental Design and Analysis

S's are tested on the ground to criterion of minimum error and this serves as baseline score.

Evaluation

It is estimated that test quality is 90% because the size of increments can be controlled for maximum sensitivity.

Stereognosis Test # Improper Ranks - q = .90

Function	p	Q	pQ	w
Stereognosis	.99	.90	.90	.0180
Light touch	.85	.70	.60	.0120
Texture	.80	.70	.56	.0112

Equipment And Costs

Time Per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: No unusual capability.

Observer: Trained to score performance.

Equipment	Weight/Lbs	Power/watts	Volume/cu.ft
12 plastic blocks	1 lb	---	.25 cu. ft

FUNCTION 25. DETECT/DISCRIMINATE VIBRATION

Definition

The lower threshold for the detection of the sensation of vibration occurs at that frequency of touches at which touches cease to be sensed as discrete events and melt into a smooth sense of vibration.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

Threshold frequency in terms of cycles/sec is the selected measure. The probability of this measure reflecting changes in the threshold detection of vibration is estimated at 90%.

Task Selection

It is necessary to use laboratory equipment to control changes in touch frequency.

TECHNIQUE 25. Detection of vibration.

Task

S inserts his fingers in a rigid ringer form (so that uniform muscle tonus is maintained) and a vibrator is attached to his palm. O uses method of limits to determine threshold.

Data Form

Threshold in terms of cycles/sec.

Experimental Design and Analysis

S's are tested on the ground to determine their mean threshold values and this is used as baseline reference.

Evaluation

The quality of this test is estimated at 90%.

Vibration - cps at Threshold - q = .90

Function	p	Q	pQ	w
Vibration	.90	.90	.81	.0162
Proprioception	.60	.90	.54	.0108

Equipment And Costs

Time Per Testing

Set-up	5
Subject	5
Observer	5
TOTAL	15

Personnel

Subject: No unusual capability.

Observer: Trained to gradually administer test and record values.

Equipment	Weight/Lbs	Power/watts	Volume/cu. ft.
Variable frequency vibrator	1/2	10	0.1
Rigid finger form	1/8	---	0.1

FUNCTION 26. DETECT/DISCRIMINATE COLOR

Definition

Color has three psychological components: hue, saturation and brightness. Hue is related to the color name and is closely related to wavelength of light. Saturation is the degree to which a hue differs from a gray of the same brightness. Brightness is related to the amount of luminous flux reach-

ing the eye. Color detection/discrimination is the ability to perceive differences in one or more of these factors.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially.

Selected Measure

The response measure to be used for this task will be size of the just-noticeable differences about several selected standards.

Task Selection

Because no on board task will permit sensitive measurement, a laboratory mode of testing must be used.

TECHNIQUE 26. Color discrimination test

Task

S scans a set of stimulus pairs to find the pair which is just noticeably different and records the number of the pair. Sets of stimuli differ in that each set tests for the size of the JND about a different standard. Some sets test for hue, some for saturation. Within sets, pairs of stimuli differ by larger and larger steps from pair to pair.

Data Form

Manual record of judgments, easily transformed to a number score for each trial.

Experimental Design and Analysis

S is used as his own control. Size of JND determinations are made on the ground using the same stimulus materials as those used in orbit.

Evaluation

This task can be designed for any required degree of quality.

Color discrimination - # steps in jnd - q = .95

Function	p	Q	pQ	w
Color	.99	.95	.95	.0190

Equipment And Costs

Time Per Testing

Set-up	5
Subject	30
Observer	0
TOTAL	35

Personnel

Subject: Normal color vision.

Observer: None.

Equipment

Task device B.

FUNCTION 27. DEDUCTION

Definition

Deduction is required when a subject is presented with familiar items of information and must apply general principles and rules of inference to process the input information and arrive at a specific conclusion relative to the input information. In uncontaminated deductive performance, not only is the input information familiar, but the response required is also one that is in the repertoire. That is, deductive performance does not involve stimulus or response problems.

Questions

1. Will change in performance occur under weightlessness?

2. If there is a change, will individuals be affected differentially?

In view of the state-of-the-art of measurement, it is probably unreasonable to ask about the course of change over time.

Selected Measure

Percent correct of a sample of problems is selected as a measure to measure performance. The probability that this measure will reflect change is high although the measure will not permit diagnosis of the reason for change. To enable diagnosis, a descriptive record of the steps in performance should be recorded by a trained observer.

Task Selection

Deductive reasoning which taxes a performers capability is not required on a regularly scheduled basis as part of any on board performance. Therefore, a simulated or laboratory type of task must be used for measurement.

TECHNIQUE 27. 1st Phase Troubleshooting Test

Task

The subject performs the first phase of complex trouble shooting tasks, carrying his trouble shooting only so far as the formulation of the first hypothesis about the location of the trouble within the equipment. The on board simulator is selected as the equipment upon which performance will be carried out because the simulator is not involved in critical station operations. The simulator must be equipped so that a large number of simulated malfunctions can be inserted and must be provided with 10 or 12 readouts which will enable the subject to gather enough information to formulate an hypothesis about the trouble. Diagrams of the simulator must be provided to the subject as required to support his performance. The simulated trouble is inserted by an observer who keeps a running account of the subject's performance and who scores his hypothesis as correct or incorrect.

Data Form

Correct/incorrect score for each problem for immediate analysis and description of behavioral steps for delayed processing - manually recorded on prepared score sheets.

Experimental Design and Analysis

Subject is trained on the ground to use basic trouble shooting and strategy and is familiarized with trouble shooting of the simulator. In orbit, the subject attempts 5 or 6 problems at each testing. The proportion of success is compared with the success achieved by matched subjects who perform the same problems under comparable conditions on the ground.

Evaluation

Quality of this test is only relatively high, .80. Questions to which this test is related and the associated weights are listed below.

Deduction - % correct - q = .80

Function	p	Q	pQ	w
Deduction	.90	.80	.72	.0144
Learned procedure	.70	.60	.42	.0084
Decision	.50	.40	.20	.0040
Association	.70	.80	.56	.0112
Problem solving	.60	.20	.12	.0024
Induction	.60	.10	.06	.0012

Equipment And Costs

Time Per Testing

Set-up	5
Subject	30
Observer	30
TOTAL	65

Personnel

Subject: Trained on ground in troubleshooting strategy and in troubleshooting of specific equipment to be used in the test.

Observer: Trained to make record of troubleshooting behavior.

Equipment

Device A

FUNCTION 28. RECORDING

Definition

The taking of shorthand notes is an example of recording performance. As defined here, recording performance is the translation of familiar stimulus materials by means of learned rules into unique responses. In recording performance, the elements of the responses required are well learned, but the integration of the elements may be unique for each of the stimulus items to be translated.

Questions

1. Will change in performance occur under weightlessness?

2. If there is a change, what will the course of change be over time?

3. If there is a change, how will individuals be affected differentially?

Selected Measure

Percent of a sample of material correctly recorded is selected as the measure to reflect performance. The probability that this measure will reflect any change in recording performance is very high.

Task Selection

To control for sensitivity and to achieve optimum use of time, a specially devised recording task is suggested rather than the selection of an element of job performance.

TECHNIQUE 28. Data Transformation Test

Task

The subject is given a work sheet with a large number of stimulus items printed at the left of the page. The subject must use previously learned rules of translation to write the translation of each stimulus item in the space provided beside it. The subject must work within a time

limit but the time limit is set to be much longer than the time required to perform the task on the ground, the only purpose of the time limit being to avoid a completely open-ended test. It is suggested that a simple rule for coding verbal material be employed.

Data Form

Work sheets from which percent correct score may be readily obtained for each testing.

Experimental Design and Analysis

The subject is trained on the ground to use the code rules. Training is carried well past the achievement of asymptotic performance. Baseline scores are obtained. Basic analysis is to compare the subject's performance in orbit with his ground baseline and to plot his in orbit scores over time in orbit.

Evaluation

The quality of this test as a technique is high because sensitivity and error can be controlled by selection of the proper coding rules and by test development.

Recording - % Correct q = .90

Functions	p	Q	pQ	w
Recording	.95	.90	.86	.0172
Association	.80	.70	.56	.0112
Set	.80	.50	.40	.0080

Equipment And Costs

Time Per Testing

Set-up	0
Subject	15
Observer	0
TOTAL	15

Personnel

Subject: Trained on ground to use transformation rule accurately.

Observer: None required.

Equipment

Device D

FUNCTION 29. TIME PERCEPTION

Definition

Perception of the passage of time is a complex capability as it involves many internal factors such as motivation and fatigue as well as environmental factors such as recurrent sounds, activities, and other familiar and regular changes in the environment.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

Variance in attempt to match a time sample is the measure chosen. The probability of this measure reflecting changes in time duration perception is estimated at 90%.

Task Selection

It is necessary to use laboratory equipment to present signals that can be systematically controlled as to intervals, that are not related to operational tasks, and to provide a means of recording the response.

TECHNIQUE 29. Perception of Time Duration

Task

Two tones will be presented to the S which will mark an interval of time. The subject's task is to reproduce this interval by pressing a key at an interval after the second tone which is the same as the signal interval

between the two tones.

Data Form

Time estimate recorded on test tape by S.

Experimental Design and Analysis

S's are trained to minimum error criterion and serve as their own control. Scores of flight personnel will also be compared to those of matched control group.

Evaluation

The quality of this test is estimated at 90% because of the fairly high number of possible error sources.

Test Time Perception - σ^2 time - q = .90

Function	p	Q	pQ	w
Time	.90	.90	.81	.0162
Set	.70	.40	.28	.0056

Equipment And Costs

Time Per Testing

Set-up	0
Subject	10
Observer	0
TOTAL	10

Personnel

Subject: No unusual capabilities.

Observer: None required.

Equipment

Device D

FUNCTION 30. DISTANT STATIC DEPTH PERCEPTION

Definition

Static depth perception is the ability of S's to distinguish distance relationships of objects in space. Objects are at a distance greater than 20 feet, thus eliminating cues of convergence. Perception of object relationships (distance from each other and arrangement) is dependent upon factors such as shading, familiarity with the objects size, and interposition.

Questions

1. Will changes in depth perceptions occur under weightlessness?

2. If a change does occur, what will the course of change be?

3. If there is a change, how will individuals be affected differentially?

Selected Measure

The measure which will reflect the accuracy of depth perception for a subject will be error in perceived distance. This measure is expected to be sensistive to changes in the ability to perceive spacial relationships. The probability that the measure will reflect changes is high (.90). If change does occur, the measure will not indicate the source of the error. A more diagnostic measure would have to follow up an indicated change to get at the source. The measure here will merely be an indicator of change.

Task Selection

Since it is necessary to present controlled test material at distances beyond the poi nt of convergence, laboratory equipment is required.

TECHNIQUE 30. Static Depth Perception

Task

S views space vehicle models with apparent distances of over 20 feet. S judges which of 5 spacecraft is the same distance away from him as a comparison spacecraft.

Data Form

Error in distance units. Response entered directly into simulator.

Experimental Design and Analysis

S familiarized and trained with task until learning effects have reached asymtote. A stable measure of base line variance is obtained from cumulative error scores of subject (own control).

Order of stimulus presentation, that is, relative positions of 5 test stimuli, is randomized. On board testing follows on ground procedure with at least 12 trials per session. On board variance compared to on ground variance about true value.

Evaluation

The quality of this test to obtain an indication of change in dynamic depth perception using error in distance is 90%. Quality will be assured if the visual cues are good. The lighting and background cues of the simulator will have to be kept constant.

Test Static Depth Perception - σ^2 of est. - q = .90

Function	p	Q	pQ	w
Static depth	.90	.90	.81	.0162
Visual acuity	.80	.70	.56	.0112
Compound patterns	.60	.80	.48	.0096
Brightness	.40	.50	.20	.0040
Color	.30	.30	.09	.0018
Dynamic depth	.80	.60	.48	.0096

Equipment And Costs

Time Per Testing

Set-up	5
Subject	15
Ob server	0
TOTAL	20

Personnel

Subject: Selected with normal vision and tested to obtain a stable measure of base line variance.

Observer: None required.

Equipment

Simulator, Static depth mode	Device A

FUNCTION 31. DYNAMIC DEPTH PERCEPTION

Definition

This function provides information about the movementof bodies in the environment. The ability to perceive and follow bodies in actual motion involves a complex combination of cues and eye movements. The eye keeps the object in focus on the retina by means of pursuit movements involving corrective saccadic movements. Depth perception of a moving body is also dependent upon cues of object size such as shading and lighting and knowledge or familiarity with the object.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

Proportion of correct judgments in a standard test of capability to predict the path of moving bodies is selected as the measure of dynamic depth perception. The probability that this measure will reflect change in depth perception is high (.90).

Task Selection

Due to the distances involved in dynamic depth perception, actual situations cannot be reproduced within the station. Therefore, a simulator must be used to permit testing beyond 20 feet.

TECHNIQUE 31. Dynamic Depth Perception

Task

The subject's task is to determine whether a moving object will collide with his static position in space. A space-borne simulator will be used in conjunction with a preprogrammed computer. The programming will determine the paths followed by the object (a model of a spacecraft). On each stimulus presentation S must respond with a "hit" or "miss" decision within a certain time as the object moves toward him.

Data Form

Automatically recorded by simulator.

Experimental Design and Analysis

S used as his own control. Training trials given on ground to determine baseline proportion of errors per session. On board scores compared with on ground baseline determine whether there has been a significant change in judgment.

Evaluation

The quality of this test as a technique for obtaining an indication of change in ability to perceive and follow a moving body in space is estimated to be 90%. This stems from the fact that the within variance can be controlled through manipulation of the difficulty of the tast.

Dynamic Depth - % of collision course - q = .90

Functions	p	Q	pQ	w
Dynamic depth	.90	.90	.81	.0162
Visual acuity	.80	.70	.56	.0112
Peripheral detection	.85	.80	.68	.0136
Static depth	.85	.80	.68	.0136
Compound pattern	.90	.70	.63	.0126
Brightness	.80	.50	.40	.0080
Color	.70	.50	.35	.0070
Time	.70	.50	.35	.0070

Equipment And Costs

Time Per Testing

Set-up	5
Subject	25
Observer	0
TOTAL	30

Personnel

Subject: Normal vision at selection. Trained to use simulator.

Observer: None.

Equipment

Task Device A

FUNCTION 32. DECISION MAKING

Definition

This function requires the processing of familiar information inputs to arrive at a selected course of action that is predicted to lead to optimum solution of a given problem. In general, decision-making performance begins with the presentation of a problem requiring action and a small amount of basic information about the problem situation. When the subject recognizes that there are several possible alternative courses of action which may lead to problem solution, he has entered the decision-making process. Typically he then identifies all likely good courses of action and proceeds to gather more information about the problem situation until he is able by rules of deduction to identify the course of action which is best. Having identified that course of action he has completed his decision-making process. At the completion of the process, however, the subject has no feedback which enables him to test the adequacy of his selected solution.

Questions

1. Will change in performance occur under weightlessness?

Selected Measure

In view of the fact that the outcome of a decesion-making performance is typically characterized by lack of any basis for objective determination of the goodness of the solution as compared with all possible solutions, expert judgment of responses has been selected as the method of measurement. Thus, a description of the decision-making steps undertaken by the subject and his solution will be presented to a panel of experts who will judge the quality of this performance and assign a scale value to each performance. The probability that all changes in decision-making behavior will be reflected by this sort of measure is relatively low.

Task Selection

In order to enable judgment of performance, it will be necessary to use rather carefully developed problem situations in testing. Decision-making performance on the job will vary too greatly from task to task to permit the required control of difficulty of test situation.

TECHNIQUE 32. Decision Making

Task

Using a data book which contains all of the necessary information for the test, the observer presents a decision-making situation to the subject along with a minimum of basic data about the situation. On the basis of the initially presented information the subject decides what additional information he requires and asks the observer for each element of information as he needs it. The observer provides information from the data book as it is asked for. The subject processes the information and selects his solution. The observer records the order in which information is requested by the subject and also records the list of alternative solutions considered by the subject. Finally the observer records the selected solution. Suggested decision-making task are: (1)Simulated change of mission objectives situations apropos satellite operation, (2)Simulated combat decision situations.

Data Form

Manually recorded record of observable aspects of decision making behavior.

Experimental Design and Analysis

The subject is trained on the ground to use a basic decision-making procedure. Scores obtained in orbit are compared with scores of matched

subjects who perform under comparable conditions on the ground. Analysis is simply for the purpose of detecting degradation of experimental subjects as compared with controlled subjects. No attempt will be made to determine amount of change.

Evaluation

In view of the difficulty in constructing decision-making problems of controlled difficulty and of the large variance expected, quality of this technique is estimated to be low.

Decision making - Scale value - q = .70

Functions	p	Q	pQ	w
Decision	.70	.70	.49	.0098
Speaking	.60	.40	.24	.0048
Writing	.40	.30	.12	.0024
Learned procedure	.80	.60	.48	.0096
Association	.80	.55	.44	.0088
Deduction	.70	.40	.28	.0056
Problem solving	.50	.20	.10	.0020
Induction	.50	.20	.10	.0020
Reading	.50	.30	.15	.0030
Speech perception	.60	.40	.24	.0048
Monitoring (Set)	.30	.20	.05	.0010

Equipment and Costs

Time For Testing

Set-up	0
Subject	30
Observer	30
TOTAL	60

Personnel

Subject: Trained in basic decision making procedure.

Observer: Trained to act as data source during testing and to record behavior.

Equipment

None

FUNCTION 33. COMPLEX VISUAL GENERALIZATION/DISCRIMINATION

Definition

This is the function of discrimination at the visual-perceptual level. That is, it is the function of generalizing to complex visual stimuli within prescribed limits. It is the performance, not the learning, of generalization and discrimination that is under consideration.

Questions

1. Will change in performance occur under weightlessness?
2. If there is a change, what will be the course of change over time?
3. If there is a change, how will individuals be affected differentially?

Selected Measure

The minimum speed of exposure at which correct discrimination or generalization can be performed reliably is selected as the measure for detecting change in performance. It is expected that this measure will reflect change in performance with high reliability.

Task Selection

This type of performance is commonly required as a component of complex task performance but is so imbedded in job task performance that a laboratory type of task is required for measurement.

TECHNIQUE 33. Cue Abstration

Task

The subject views complex visual forms tachistoscopically, and identifies them as "same" or "different" on a prepared score sheet which presents a form for comparison.

Data Form

Prepared score sheets marked with judgements of "same" or "different" by subject. Easily reduced to % correct per test.

Experimental Design and Analysis

The subject is trained on the ground to generalize (discriminate) complex visual forms within predetermined limits. Training is carried well beyond asymptote to assure that performance is highly reliable and the

tachistoscopic threshold for the subject is determined. The subject's in orbit scores at just above threshold are compared with his own baseline scores.

Evaluation

The quality of the technique is judged to be high if the sample of stimuli is broad and if proper care is taken in test development.

Cue abstraction - speed - q = .95

Function	p	Q	pQ	w
Cue abstraction	.95	.95	.90	.0180
Compound pattern	.80	.80	.64	.0128
Visual acuity	.70	.80	.56	.0112
Peripheral detection	.80	.60	.48	.0096
Brightness discrim	.50	.40	.20	.0040

Equipment and Costs

Time per Testing

Set-up	5
Subject	15
Observer	0
TOTAL	20

Personnel

Subject: Trained to identify test stimuli.

Observer: None required.

Equipment

Device B

FUNCTION 34. PROBLEM SOLVING (INVENTION)

Definition

This function requires the processing of familiar information inputs to achieve a solution to a problem not previously encountered. Performance begins with the presentation of the problem and ends with a demonstration that a satisfactory solution has been obtained. During the course of problem solving, the subject acquires information as he requires it and uses any and all information and technique at his command to arrive at his solution. As it is used here, problem-solving implies invention rather than problem solution in the mathematical sense. That is, it implies performance for which there is no previously determined rule for solution.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

Selected Measure

Proportion of a sample of problems correctly solved is chosen as the measure to reflect performance. The probability that this measure will reflect any sort of change for problem solving behavior is reasonably good but not high.

Task Selection

As in the case of most medial functions, to obtain reasonable quality of testing it is necessary to use carefully constructed test items rather than real job performance to obtain measurement of behavior.

TECHNIQUE 34. Problem Solving (invention) Test

Task

By means of a problem booklet the subject is presented with a number of problems at each testing. To preclude the expenditure of too much time at a testing, the subject sets a timer with an alarm at the beginning of each problem and must complete his solution before the timer tells him to proceed to the next problem. The time allowance should be so generous however that the subject seldom fails to finish within the time limit.

Data Form

Percent of problems solved correctly.

Experimental Design and Analysis

The subject's performance is compared with his own performance baseline obtained on the ground and with the performance with a matched control. It is suggested that common games such as checkers, chess and bridge provide the basis for the problems presented in the booklet. The use of games will preclude the need for a great deal of background training of factual material and will provide an element of interest to an otherwise tedious task.

Evaluation

The quality of the sort of test recommended is moderately good but is not high both because of the large variance expected and because of the caution that should be exercised in generalizing to types of problem solving situations other than those used in the test.

Problem solving - % correct - q = .80

Function	p	Q	pQ	w
Problem solving	.80	.80	.64	.0128
Assn.	.80	.20	.16	.0032
Deduction	.10	.20	.02	.0004
Induction	.80	.70	.56	.0112
Set	.30	.10	.03	.0006

Time per Testing

Set-up	0
Subject	30
Observer	0
TOTAL	30

Personnel

Subject: Throughly familiarized with games used in test.

Observer: None required.

Equipment

Device D

FUNCTION 35. GUIDED PERFORMANCE

Definition

In guided performance, organized stimulus materials are employed to guide the subjects through the steps of a task which he has never performed previously. However, the stimulus materials employed and the basic units of response rquired for the task must all be familiar to the subject.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will be the course of change over time?

3. If there is change, how eill individuals be affected differentially?

Selected Measure

Time to complete a test task is selected as a measure to reflect guided performance. This measure is expected to be sensitive to any change in performance capability.

Task Selection

Task carried out under guidance during normal operations will ordinarily be so well human engineered that there will be little opportunity to observe small degradation under weightlessness. However, the time cost of using simulated tasks for testing is probably larger than can be justified. Therefore it is recommended that when the specific job tasks to be assigned to crew members for the specific station to be are known, guided tasks which are not time critical and which permit error so lon as error is corrected be selected for testing. In order to obtain regularly scheduled test results, scheduled maintenance tasks are principal candidates.

TECHNIQUE 35. Scheduled Maintenance Test

Task

The subject carries out a complex scheduled maintenance task which he has never before performed following a prepared guide. Calibration tasks and adjustment tasks which require breakdown and reassembly of equipment may be at the appropriate level of difficulty.

Data Form

Time score manually recorded by observer.

Experimental Design and Analysis

No pre-training on the ground is required. The subject's time scores in orbit are compared with time scores of control subjects who perform the same tasks under comparable conditions on the ground.

Evaluation

The quality of the test can be quite high, if freedom is allowed in constructing guidance sheets so that difficulty of task can be controlled to introduce sensitivity, and if test task can be selected out of a large number on the basis of variance estimates.

Guided performance - Time to Complete - 2 = .90

Function	Q	Q	pQ	w
Guided performance	.90	.90	.81	.0162
Learned procedure	.90	.30	.27	.0054
Association	.40	.20	.08	.0016
Arm/hand/finger manip.	.50	.60	.30	.0060
Arm/hand/finger control of force	.40	.30	.12	.0024
Arm/hand/finger control of speed	.40	.60	.24	.0048

Equipment and Costs

Time per Testing

Set-up	0
Subject	0
Observer	15
TOTAL	15

Personnel

Subject: No unusual requirements.

Observer: None required.

Equipment

Device D

FUNCTION 36. DETECTION OF LIGHT TOUCH

Definition

The detection of touch occurs when there is an inward or outward force of pressure upon the skin. When the rate of pressure ceases or becomes stable, the sensation of touch "adapts," i.e., ceases.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Amount of force in grams at threshold is the selected measure. The probability of this measure to reflect changes in light touch sensitivity is estimated at 90%.

Task Selection

A special laboratory device is required to test touch sensitivity due to the requirements of controlling both pressure and area stimulated.

TECHNIQUE 36. Detection of Light Touch

Task

An electromagnetic aestheseometer which applies a known force to a hair pressed against the skin at a constant rate. S reports when he senses touch or the cessation of touch.

Data Form

Threshold data manually recorded on prepared score sheets.

Experimental Design and Analysis

S's are tested with the device on the ground and their thresholds are determined. They serve as their own controls.

Evaluation

Test quality is estimated at 90%.

Test - Light Touch - grams - q = .90

Function	p	Q	pQ	w
Light touch	.90	.90	.81	.0162
Stereognosis	.60	.20	.12	.0024
Texture	.80	.30	.24	.0048

Equipment and Costs

Time per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: No unusual capabilities

Observer: Trained in method of limits testing.

Equipment

	Weight/lbs.	Power/watts	volume/cu. ft
Aestheseometer	20	50w	1

(Adaption of Research Instruments Laboratory model)

FUNCTION 37. BRIGHTNESS DETECTION/DISCRIMINATION

Definition

Brightness discrimination is the ability to detect differences between two levels of illumination.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Change in JND will be the measure to indicate change in brightness discrimination. The probability that this measure will reflect any sort of change in brightness detection is very high (. 99).

Task Selection

The task selection will have to be of a laboratory nature as performance measures of actual on-board functions will not permit sensitive testing.

TECHNIQUE 37. Brightness detection/discrimination

Task

S views a set of paired stimuli, so arranged that the pairs differ in brightness and so that one member increases in brightness from pair to

pair by very small steps. S determines which pair is just noticeably different and tells the direction of the difference. The test is repeated with differing sets.

Data Form

Manually recorded on prepared score sheets.

Experimental Design and Analysis

S used as his own control. On ground base line measurements obtained for all test sets. On board thresholds compared with base line data.

Evaluation

The quality of this test as a technique for obtaining an indication of change using a paired comparison method is estimated to be 95%. Quality is high because the spread of the responses about thresholds can be controlled by the degree of differences between stimuli.

Brightness discrimination - jnd in m/lamberts - q = .95

Function	p	Q	pQ	w
Brightness	.99	.95	.95	.0190

Equipment and Costs

Time per Testing

Set-up	5
Subject	20
Observer	0
TOTAL	25

Personnel

Subject: Normal vision at selection. Trained to make discriminations in a paired comparison situation.

Observer: None.

Equipment

Visual presentation device-
Brightness mode Device B

FUNCTION 38. ASSOCIATION (SHORT AND LONG TERM MEMORY)

Definition

As used here the term association implies performance, not learning. It refers to the exercise of a previously established stimulus - response pair. That is, it refers to the performance of a previously established response when the stimulus to which it was trained is presented.

Questions:

1. Will change in performance appear under weightlessness?

2. If there is a change, what will be the course of change over time?

3. If there is a change, how will individuals be affected differentially?

Selected Measure

Proportion of correct responses in a sample of items which test capability to recall previously learned responses upon presentation of the adequate stimulus is selected as the measure to reflect association performance. It is expected that this measure will reflect virtually any change in performance.

Task Selection

Associated performance is a component of many job tasks, but it is commonly buried within the task in a way which makes specific testing of association difficult. Therefore in order to obtain specific testing of associative performance it is recommended that a laboratory type of test be employed.

TECHNIQUE 38. Association (Short and Long Term Memory)

Task

(a) Short term memory

The subject listens to a taped program of paired-associate materials which may be presented in meaningful context or as straightforward paired-associates. Immediately after listening to the programmed materials the subject is presented with selected stimuli from the program and is required to give the correct response, recording his response directly on the test tape.

(b) Long term memory

By means of a prepared tape the subject is presented with stimuli to which he has previously over-learned associative responses. The subject demonstrates capability to recall by recording the correct response for each stimulus directly on the test tape.

Data Form

Simple verbal responses recorded on test tape.

Experimental Design and Analysis

For the long term memory portion of the task the subject is over trained on the ground to respond reliably to the test stimuli. The extinction curve is compared with the extinction curve of a matched control subject who performs on the ground under comparable conditions. The short term memory analysis employs the subject's own baseline scores for comparison as well as comparison with a control subject on the ground.

Evaluation

Quality of this test as a technique for obtaining an indication of change is estimated to be high. This estimate assumes careful testing development to insure test of appropriate difficulty and tests which yield optimum variance.

Association (short term)a - % correct recall - q = .90
(long term)b

Function	p	Q	pQ	w
Association (memory)	.95	.90	.86	.0172

Equipment and Costs

Time per Testing

Set-up	5
Subject	10
Observer	0
TOTAL	15

Personnel

Subject: Trained with paired-associates on the ground.

Observer: None required.

Equipment

Device C

FUNCTION 39. READING

Definition

Reading as we define it for this function is the ability to comprehend information presented by means of printed words.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Total correct responses to questions covering material read is selected as the measure to reflect comprehension. This measure is expected to be sensitive to changes in all aspects of reading performance. The probability that this measure will reflect a change is .90.

Task Selection

A need for rather close control over variables affecting reading comprehension necessitates a laboratory test for the measurement of change in ability. The task will be kept simple; speed and memory will not be factors in the measure.

TECHNIQUE 39. Reading

Task

This is a reading comprehension test in which speed and memory are reduced in importance. Presentation of reading material will be one paragraph at a time followed by questions pertaining to that paragraph. S controls the presentation, but cannot return to the completed paragraph once he has started the questions.

Data Form

Proportion of errors per test session.

Experimental Design and Analysis

S tested on ground to establish stable reading comprehension score for material of given difficulty level. Test materials will be tailored to the capability of the individual so as to insure a stable mean and minimum within subject variability. On board testing will take place at regular intervals, S scores will be compare to base line data. Session to session results can be plotted to reflect trends.

Evaluation

The quality of this test as a method for obtaining an indication of change through use of response scores is estimate to be 70%.

Reading - % inf items correct - q = .70

Function	p	Q	pQ	w
Reading	.90	.70	.63	.0126
Compound pattern	.40	.20	.08	.0016
Speech perception	.30	.20	.06	.0012

Equipment and Costs

Time Per Testing

Set-up	0
Subject	10
Observer	0
TOTAL	10

Personnel

Subject: No unusual requirements. Trained to operate equipment and administer test.

Observer: None.

Equipment

Visual presentation device - Reading mode Task Device B

FUNCTION 40. WRITING

Definition

By writing is meant the ability to transmit information by means of written responses.

Questions

1. Will change in performance occur under weightlessness?
2. If change does occur, what will be the course of change over time?

Selected Measure

Writing performance will be measured by a count of the information content of the test written message. The probability that this measure will reflect change in writing quality is very high (.99).

Task Selection

In order to tape the ability to compose written responses under controlled conditions an experimental type of test is required.

TECHNIQUE 40 WRITING-COMPOSING A WRITTEN SUMMARY

Task

Subject is required to write a summary of prepared expository information.

Data Form

Sample of writing on prepared form. Comparison by observer and experts on ground.

Experimental Design and Analysis

Subject is pretrained and tested on ground until his written summaries of prepared expository information results in stable scores. This represents his baseline writing performance. Subject is tested in orbit at regularly recurring intervals and his scores are compared with baseline. A curve is plotted to reflect writing performance over time. Writing records are transmitted to ground for detailed analysis by experts.

Evaluation

The quality of the technique for obtaining an indicative of ability to compose written summaries is estimated to be 80%. This figure is based on the idea that the evaluation of written summaries is highly subjective and the difficulty and content of prepared expository information may vary in difficulty for a subject.

Test Writing - % info content - q = .80

Function	p	Q	pQ	w
Writing	.99	.80	.79	.0156
Speaking	.80	.40	.32	.0064
a/h/f manip.	.70	.60	.42	.0084
Assn. (memory	.90	.70	.63	.0126

Equipment and Costs

Time per Testing

Set-up	5
Subject	10
Oberver	0
TOTAL	15

Personnel

Subject: Subject trained to baseline standard on ground.

Observer: None required

Equipment

None

FUNCTION 41. TONE PATTERN DISCRIMINATION.

Definition

This is the function of discriminating confusable tone patterns.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is a change, how will individuals be affected differentially?

Selected Measure

The selected measure to indicate change in ability to detect tone pattern change is change in proportion of correct responses to standard test stimuli. The probability that this measure will reflect a change in high (.90).

Task Selection

The task selected for this function is an experimental test rather than on the job performance task.

TECHNIQUE 41. Tone pattern discrimination.

Task

Prerecorded tapes will be used to present tone patterns. Patterns will be three tones presented simultaneously followed by three more simultaneous tones which will be the same or slightly different. S will respons with "same" or "different" by using a key to mark the test tape.

Data Form

Recorded on test tape.

Experimental Design and Analysis

S as own control. Base line data obtained after several test sessions. On board testing yields a measure of correct responses during each session. Compared to on ground data to see if a significant change in number of correct responses has taken place.

Evaluation

Quality of this measure as a technique for obtaining an indication of change in performance is estimated to be 80%.

Test - Tone pattern discrim. - % correct - q = .80

Function	p	Q	pQ	w
Tone pattern	.90	.80	.72	.0144
Speech percept.	.60	.30	.18	.0036
Tone Thresholds	.80	.20	.16	.0032

Equipment and Costs

Time Per Testing

Set-up	5
Subject	5
Observer	0
TOTAL	10

Personnel

Subject: Normal hearing at selection. Trained to administer the test to himself and record his own answers.

Observer: None.

Equipment

Tape Recorder Task Device C

FUNCTION 42. ASSESSMENT OF VOLUME OF SPACE

Definition

The determination of the volume of space implies the estimation of the volumetric relationship of objects and spaces.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Proportion of correct judgements of volumetric relationships in a standard test is the selected measure. Probability that this measure will reflect changes in the assessment of volume of space is estimated to be 90%.

Task Selection

It is necessary to use laboratory equipment as the measurement standard but the test objects can be on-board items.

TECHNIQUE 42. Assessment of Volume of Space

Task

S is given several on-board items (square or rectangular) and required to estimate whether or not the object will fit in a space bounded by an adjustable frame set by O for each trial at a different size.

Data Form

Manually recorded on prepared score sheet.

Experimental Design and Analysis

Proportion of correct judgments on the ground is compared with subjects in-orbit score.

Evaluation

Quality of test is estimated at 90%.

Test Volume of Space - % correct - q = .90

Function	p	Q	pQ	w
Volume of space	.90	.90	.81	.0162
Comp pattern	.60	.40	.24	.0048
Static depth	.40	.50	.20	.0040

Equipment and Costs

Time Per Testing

Set-up	5
Subject	10
Observer	10
TOTAL	25

Personnel

Subject: No unusual capabilities

Observer: No unusual requirements

Equipment

Task Device G

FUNCTION 43. SOUND LOCALIZATION

Definition

Localization of sound for individuals with normal hearing involves two input channels and is termed as dichotic. The ability is dependent upon several rather sensitive cues. The cue called the "binaural distance difference" is a strong one and stems from the fact that a sound emitted from any source other than median plane will have to follow different paths to reach the two separate input channels. This distance difference results in phase and intensity differences in the sound as received by the two ears. Very slight differences can provide very effective cues for sound localization. Sounds emitted in the median plane lack these cues and ability to localize sound becomes unreliable.

Questions

1. Will change in performance occur under weightlessness?

2. If there is a change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

Amount of error in degrees in localizing the source of sound will be the measure used. This measure is expected to be an indication of change in ability a high probability (.90).

Task Selection

The task selected for testing this function is a pure laboratory test.

TECHNIQUE 43. Sound localization

Task

The blindfolded S responds to a tone presentation by stating where it is in terms of a previously learned location scheme. 0 places the tone following a predetermined order about S.

Data Form

Manually recorded on prepared scope sheets.

Experimental Design and Analysis

S as own control. After several on ground test sessions a stable measure of response variance about the true mean is obtained to be used as baseline. On board variance will be compared to on ground variance for any significant change using at test.

Evaluation

The quality of this test as a technique for obtaining an indication of change by means of localization error is estimated to be 80%.

Test Sound Localization - σ^2 - q = .80

Function	p	Q	pQ	w
sound loc.	.90	.80	.72	.0144
sound move-ment	.80	.40	.32	.0064

Equipment and Costs

Time Per Testing

Set-up	5
Subject	10
Observer	10
TOTAL	25

Personnel

Subject: Normal hearing at selection.

Observer: Trained to present stimuli and record scores.

Equipment

Tone generator Task Device F

FUNCTION 44. PAIN DETECTION

Definition

This function involves the detection of deep and superficial pain.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, how will individuals be affected differentially?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Force in grams/mm^2 at the lower thresholds for the reporting of the sensation of pain is the selected measure. The probability that this measure will reflect change is predicted to be 90%.

Task Selection

It is necessary to use laboratory control for location and amount of pressure exerted.

TECHNIQUE 44. Pain detection

Task

Pressure devices are attached to back of the hand and calf of the leg, methods of limits for deep and superficial pain is used.

Data Form

Manually recorded on prepared score sheets.

Experimental Design and Analysis

S's tested on ground to determine lower limits for deep and superficial pain. Each S serves as his own control.

Evaluation

Quality of test is estimated at 90%. This high a confidence is possible only by assuming a very high level of crew motivation and their maintenance of a detached point of view toward pain.

Test Pain Thresholds - Force oms/mm^2 - q = .90

Function	p	Q	pQ	w
Pain	.90	.90	.81	.0162

Equipment and Costs

Time Per Testing

Set-up	5
Subject	10
Observer	10
TOTAL	25

Personnel

Subject: No unusual capabilities

Observer: No unusual requirements

Equipment

	Weight/lbs.	power/watts	volume/cu.ft.
Algesiometer-Spring type	2	0	.4

FUNCTIONS 45. DETECTION OF HEAT/COLD

Definition

Thermal sensation is aroused by raising or lowering the temperature of the skin.

Questions

1. Will change in performance occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

The thresholds for detection of heat and cold are selected. Probability of reflecting change is estimated at 90%.

Task Selection

A special laboratory device must be used to control temperature.

TECHNIQUE 45. Detection of heat/cold

Task

Observer stimulates S on hand by means of device which permits control of temperature. Thresholds are determined for heat and cold.

Data Form

Threshold data manually recorded on prepared score sheets.

Experimental Design and Analysis

S's tested on ground to determine thresholds. Each S serves as his own control.

Evaluation

Quality is estimated at 90%.

Test Thermal detection - degrees F - q = .90

Function	p	Q	pQ	w
Thermal	.90	.90	.81	.0162

Equipment and Costs

Time Per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: No unusual capabilities

Observer: No unusual capabilities

Equipment

	Weight/lbs.	power/watts	volume/cu.ft.
Temperature Simulator	1	none	0.01

FUNCTION 46. TEXTURE DISCRIMINATION

Definition

This is the function of discriminating objects solely on the basis of surface fixture cues.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Number of rank-order errors is the selected measure. Probability of reflecting change is estimated at 90%.

Task Selection

Laboratory materials are required to provide sensitivity.

TECHNIQUE 46. Texture discrimination.

Task

Ten squares of sandpaper of graded fineness are randomly arranged in a cardboard frame. The blindfolded S rolls the balls of his fingers on each card, and arranges the cards in order of roughness.

Data Form

Errors in ranking manually recorded on prepared score sheet.

Experimental Design and Analysis

S's are tested on ground to obtain baseline score. Each S will serve as his own control.

Evaluation

Quality of test is estimated at 90% since the increment size can be carefully controlled.

Test Texture discrimination - rank error - q = .90

Function	p	Q	pQ	w
Texture	.90	.90	.81	.0162
Light touch	.80	.30	.24	.0048

Equipment and Costs

Time Per Testing

Set-up	5
Subject	10
Observer	0
TOTAL	15

Personnel

Subject: No unusual capabilities

Observer: None required

Equipment

	Weight/lbs.	power/watts	volume/cu.ft.
Texture Discrim. kit	1	-	0.0093

FUNCTION 47. AUDITORY DETECTION/DISCRIMINATION OF MOTION

Definition

Detection of the motion of an auditory stimulus is a function of the same cues as detection of the location of a static sound source. The difference in the task is the continual change of the source of the cues. In sound localization where hearing is dichotic, the dominant factor is the difference in the paths sound must follow to reach the two separate ears. This difference provides the all important phase and intensity differences. The detection of these cue differences is very sensitive. When a sound source is moved, the complexity of relationship of cues becomes compounded. With a static sound source (other than median planes) the time difference of the arrival of the sound waves produces phase differences; with a moving source this phase difference is under continual change. From this complexity, the auditory system is able to detect movement and direction of sound.

Questions

1. Will change in performance occur under weightlessness?

2. If there is a change, what will the course of change be over time?

3. If there is a change, how will individuals be affected differentially?

Selected Measure

Amount of error in estimation of direction of sound movement is selected as the measure to reflect any change in ability to discriminate motion of sound. The probability that this measure will reflect a change in performance is .90.

Task Selection

Due to the complexity of the function an on-board, on job situation would not provide a measure of degradation. A laboratory test is necessary to assess change in this ability.

TECHNIQUE 47. Auditory detection/discrimination of motion

Task

S reports the direction of sound movement by marking the direction on a prepared grid sheet. O moves the sound source in a predetermined path and attempts to keep the speed of sound motion constant each time. Sound presentation will always take place behind S.

Data Form

Degrees of error in direction of sound movement manually recorded on prepared score sheet.

Experimental Design and Analysis

S used as own control. Subject variance about true mean obtained on ground after learning effects have been minimized. As accuracy of sound localization is also a function of frequency the most optimal frequencies are chosen (between 3,000 to 10,000 cps.). On board variance compared to on ground variance using a "t" test of significance of difference.

Evaluation

The quality of this measure as a technique for detecting change in ability is rather low. It is estimated to be 70%. This is reflected in the winthin subject variance which, is hard to control.

Test Detection of motion/auditory - σ^2 - q = .90

Function	p	Q	pQ	w
Sound movement	.90	.70	.63	.0126
Sound localization	.80	.60	.48	.0096
Tone thresholds	.60	.10	.06	.0012

Equipment and Costs

Time Per Testing

Set-up	0
Subject	5
Observer	5
TOTAL	10

Personnel

Subject: Normal hearing at selection. No unusual requirements.

Observer: Trained to administer test - must be consistent.

Equipment

Tone generator Task Device F

FUNCTION 48. DETECTION OF TONE DURATION

Definition

This is the function of detecting a tone throughout the entire period of its presentation.

Questions

1. Will change in performance occur under weightlessness?
2. If there is change, what will the course of change be over time?
3. If there is change, how will individuals be affected differentially?

Selected Measure

Total error time in detecting tone duration at threshold is selected as the measure to reflect performance change. The probability that this measure will reflect a change in detection of tone duration is high (.99).

Equipment and Costs

Time Per Testing

Set-up	5
Subject	10
Observer	0
TOTAL	15

Personnel

Subject: Normal hearing at selection. Trained to adjust recorder to his threshold level and administer the test to himself.

Observer: None

Equipment

Task Device C

FUNCTION 49. OLFACTION

Definition

Experimental investigations of olfaction have provided no definative information as to the bases of classification or rank ordering. It has been demonstrated that organic sensors are considerably more sensitive than mechanical ones and that olfactory sensitivity can be a major safety device. Here we are concerned with gross capability to detect odors.

Questions

1. Will change in ability occur under weightlessness?

2. If there is change, what will the course of change be over time?

3. If there is change, how will individuals be affected differentially?

Selected Measure

Number of correct identifications at supra threshold is the selected measure. Probability of test reflecting change is estimated at 99%.

Task Selection

Actual on board auditory stimulation (speech) is not amenable to use as a measuring device of the restricted level required here. For this reason, a laboratory test will be used.

TECHNIQUE 48. Detection of tone duration

Task

In this self administered test, S adjusts tone level of tape recording to threshold. After level has been adjusted to just above threshold for intensity, S proceeds with actual test section of tape. When he hears a tone S presses a key, recording his response on the test tape. S continues to hold the key down so long as he hears the tone.

Data Form

Recorded on the test tape.

Experimental Design and Analysis

S own control. On ground base line obtained after S has become familiar with the task. A stable measure of on ground variance obtained. On board variance for each session compared to on ground variance using a "t" test.

Evaluation

The quality of this task as a technique for obtaining an indication of change by means of error in detection of tone duration at threshold is estimated to be 90%. This stems from the operational control over the stimuli.

Tone duration test - σ^2 - q = .90

Function	p	Q	pQ	w
Tone duration	.99	.90	.89	.0178
Tone thresholds	.70	.70	.49	.0098

Task Selection

While the stimuli are similar to on board objects, it is necessary to use laboratory control of their properties.

TECHNIQUE 49. Olfaction

Task

S is presented known concentrations of a selected sample odors at supra threshold values, and is required to identify them.

Data Form

Number of identification errors.

Experimental Design and Analysis

S's lower threshold for discrimination of specific odors is determined on the ground and for each subject the concentration is increased 1 standard deviation for testing in space.

Evaluation

Quality of test is estimated at 90%.

Olfaction Test - % correct - q = .90

Function	p	Q	pQ	w
Olfaction	.99	.90	.89	.0178

Equipment and Costs

Time Per Testing

Set-up	5
Subject	15
Observer	15
TOTAL	35

Personnel

Subject: No unusual capabilities

Observer: No unusual capabilities.

Equipment

	weight/lbs.	power/watts	volume/cu.ft.
Olfactometer	3	none	0.18

FUNCTION 50. INDUCTION

Definition

Induction refers here to performance in which the subject derives a general rule from consideration of basic data such that the general rule is descriptive of the data as a whole and permits extrapolation. Induction is associated with scientific endeavor; it is seldom a component of station keeping tasks.

Questions

1. Will change in performance occur under weightlessness?

Selected Measure

Percentile ranking of performance in comparison to astronaut population values is selected to reflect inductive performance. The probability that this measure will reflect small changes in performance is rather low.

Task Selection

Analysis of the tasks likely to be performed on-board the station yielded no inductive reasoning performance. Therefore, performance of a laboratory type of task will be used for measurement.

TECHNIQUE 50. Induction

Task

The subject performs without time limit using a test such as the Inductive Reasoning Test, 1946, Educational Test Bureau. This test is available in only one form and does not permit repeated measures. However, tests of the general type are easily prepared in several forms. The test presents a portion of a number series and requires the subject to induce the rule for the series. The subject demonstrates his induction by giving the next number in the series.

Data Form

Marked prepared answer sheet.

Experimental Design and Analysis

Baseline measurement is obtained on the ground, measurement being in terms of the subject's percentile rank for an astronaut population. Measurement in orbit is accomplished by alternate forms and again comparison is with astronaut population. This comparison precludes the need to develop alternate forms of equal difficulty.

Evaluation

Considering the poor sampling of inductive performance which the test permits, quality is quite low.

Inductive reasoning - percentile - q = .50

Function				
Induction	.70	.50	.35	.0070
Association	.70	.10	.07	.0014
Problem solving	.90	.20	.18	.0036

Equipment and Costs

Time Per Testing

Set-up	0
Subject	60
Observer	0
TOTAL	60

Personnel

Subject: No requirements

Observer: None required

Equipment

None

SUPPLEMENT TO APPENDIX B.
MULTI-PURPOSE DEVICES USED FOR BEHAVIORAL MEASUREMENT

DEVICE A. MULTI-PURPOSE SIMULATOR FOR BEHAVIORAL MEASUREMENT

Related Tests

This simulator will be used for obtaining measurements relevant to the following tests:

Docking
Monitoring
Dynamic depth perception
Static depth perception
Tracking
Deduction

General

Six separate modes of operation will be required to enable the use of the simulator for these tests. As it is presently conceived, the simulator will be computer controlled and scoring will be automatic in all modes of operation except that for deductive reasoning. The simulator will enable the simulated presentation of visual objects more than 20 feet distant from the subject. Although the simulator requires development and has a relatively high cost in terms of weight, power, and volume, no alternative to the simulator is seen if it is desired to investigate visual perceptual performance involving motion beyond 20 feet—that is, beyond the point at which convergence cues operate. If a basic simulator is justified on these grounds, then at slight additional cost the basic simulator can be modified to provide for the testing of all of the functions listed above. The tracking, monitoring, and deduction tests are tied to the simulator only because it is convenient to do so. These tests could alternatively be accomplished by the use of less costly equipment if desired. However, in view of the importance of dynamic depth perception as a component of rendezvous and docking, if is considered important to include a test of this critical function. Thus, it is recognized that a very small degradation in the reliability of docking performance could seriously endanger mission success where docking is required as a part of the mission.

Modes of Operation

Mode 1 — Docking

To enable a test of docking performance, simulation of distance from 20 feet to several hundred feet is required. The simulator should enable the subject to "pretend" that his vehicle is docking with a three dimensional model of a satellite presented by the simulator. Thus, it should provide appropriate controls for the subject. The simulator should enable the subject to see the effects of his control actions during his attempt to dock, with the satellite displayed by the simulator. That is, the subject should be provided with the appropriate panel displays and with an appropriately changing visual presentation of the satellite. All normally available cues should be presented including a background starfield. Ideally, 6 degrees of freedom should be provided.

Mode 2 — Dynamic Depth Perception

In this mode the subject is provided with no controls. The simulator should enable the subject to view a satellite in motion for a brief period of time so that he can make a judgment of whether or not the satellite is on a collision course with himself or with another target. To enable frequent testing, it must be possible to present a large number of different test patterns. For this test the subject is assumed to be static, but 3 degrees of freedom are required in the motion of the satellite presented by the simulator.

Mode 3 — Static Depth Perception

This mode utilizes the optics required for docking and dynamic depth perception to present depth perception problems at a simulated distance greater than 20 feet. No controls are required for the operator. The simulator must be capable of providing a large variety of depth perception problems, the subject's task being to identify a test object from one cluster that is at an equal distance from S as a standard object from another cluster.

Mode 4 — Tracking

This mode utilizes the controls and the panel displays used in docking. Therefore, the only additional functional capability required in this mode is a program to simulate station movement. In this mode, the simulator must provide a second-order compensatory tracking task to the subject. The task suggested is manual attitude control.

Mode 5 — Monitoring

This mode employs the panel displays provided for docking simulation, plus additional displays as required to create a significantly difficult monitoring task. The subject need be provided only with a key which enables him to signal to the scoring mechanism of the simulator that he has made a detection during a monitoring watch. The simulator must enable pre-programmed stimuli to be presented to the subject by means of the panel displays over a 30-minute test watch.

Mode 6 — Deductive Reasoning

Phase I troubleshooting is recommended as the test of deductive reasoning. Troubleshooting of the simulator is recommended because the simulator is not critical to station operation. To enable a test of troubleshooting performance, the simulator must be fitted with a bank of switches which permit the insertion of simulated malfunctions. The simulator must also be fitted with sufficient readouts to enable the subject to gather troubleshooting information during testing without using special test equipment.

Overall Maintenance Requirements

Normal scheduled and nonscheduled maintenance of the optics, servos, and computer.

Costs Simulator		Maintenance	
Weight	186 lb	Weight	18.6 lb
Power	445 watts	Volume	0.5 cu ft
Volume	9.6 cu ft		

DEVICE B. VISUAL PRESENTATION DEVICE

Related Tests

This device will be used for obtaining measurements relevant to the following tests:

Visual Acuity
Compound Pattern Discrimination
Brightness Discrimination

Color Discrimination

Reading

Complex Discrimination — Generalization

General

This specially designed device will enable almost all visual testing to be accomplished by a single instrument. To achieve this objective the device must be capable of several methods of operation and it must be possible for the user to insert cartridges of test slides which differ from test to test. The basic methods of operation are a tachistoscopic method, a manual control method, and a method in which rate of presentation from slide to slide is automatically controlled. Given these three basic methods, it is possible by using different cartridges of stimulus materials to accomplish all six of the above tests by means of the device.

Modes of Operation

Mode 1 — Visual Acuity

In this mode the subject inserts a cartridge of slides containing Landolt rings and selects slides by manual operation. Visual acuity is to be tested at 16 inches and 20 feet, and the subject must therefore be provided with a range selection switch. In this mode, the subject's operation of the device is controlled by means of instructions on prepared score sheets and his responses are manually recorded on the same sheets.

Mode 2 — Brightness Discrimination

The subject must insert the appropriate cartridge of slides. The subject operates the device manually, turning from slide to slide until he identifies the slide upon which he can just detect difference in brightness. Responses are manually recorded on prepared score sheets which also instruct the subject in a selection of the appropriate cartridges and in the operation of the device.

Mode 3 — Color Discrimination

Operation is essentially the same as for brightness discrimination. The slides contain color patches differing slightly in hue and saturation and are arranged in a sequence that enables the subject to identify the slide at which difference in hue or difference in saturation is just detectable. Prepared score sheets are used for marking responses and for controling the use of the device.

Mode 4 — Reading

In this mode the operator inserts the cartridge containing reading material and sets the device to the reading mode. In this mode a "page" of reading material is presented for a period of time that is controlled by the device. The subject responds by answering questions on prepared score sheets that are keyed to the cartridges inserted in the device.

Modes 5 and 6 — Complex Pattern Discrimination and Complex Visual Generalization/Discrimination

The appropriate cartridge of stimulus materials is inserted by the operator. When he is ready for a stimulus presentation, the operator punches a key which presents the stimulus at a controlled exposure rate (tachistoscopically). A control for selecting the rate of presentation must be provided for the operator. Responses are marked on prepared score sheets keyed to the cartridges.

Overall Maintenance Requirements

Spare projector bulbs and spare control mechanism to back up unscheduled maintenance.

Costs

Device	
Weight	40 lb
Power	225 watts
Volume	2.4 cu ft
Maintenance	
Weight	4 lb
Volume	.2 cu ft
Supplies	
Slide Cartridges	4 lb
	.04 cu ft

DEVICE C. RECORDER-REPRODUCER WITH HEAD SET

Related Tests

This device will be used for obtaining measurements relevant to the following tests:

Speech
Perception
Speaking
Tone Detection/Discrimination
Association
Tone Duration
Tone Pattern Recognition

General

An off-the-shelf tape device which permits easy insertion and removal of tape cartridges and which is capable of high fidelity recording and reproduction can be used as a basic mechanism for the tests listed above. All of these tests require the presentation of auditory stimuli or the recording of speech as part of the test. From test to test, the use of the machine will differ principally in the way in which the stimulus material is programmed on the tape. For the tests of tone detection, tone duration, and tone pattern, high fidelity reproduction is required, and ambient noise must be reduced to a minimum by the use of a properly constructed headset. For all tests, reliable control of tape movement by the subject is required. Programmed stops will be useful for some of the tests. Recording reasonably high in fidelity is required for the speaking tests, but the ambient noise control provided by a directional microphone will probably be sufficient.

Modes of Operation

Mode 1 — Speech Perception

The subject inserts a cartridge which contains speech material that has been compressed by electronically removing very short segments of sound until the material has been clipped to the point at which interpretation of the message is less than perfect. Programmed stop at the end of a test message is desirable. The subject records his reconstruction on the tape following each test sequence.

Mode 2 — Speaking

This mode requires only a directional microphone and control by the subject over tape movement.

Mode 3—Tone Detection/Discrimination

This mode requires a specially prepared tape of stimulus materials and a key which enables the subject to mark the tape at the onset of a tone signal. Test tones are thus presented in a programmed manner and scoring is accomplished directly on the test tape.

Mode 4—Association

The subject uses a specially prepared tape of stimulus materials which tests short-term and long-term memory. His responses are spoken into the microphone and recorded on the test tape. Programmed stops are desirable.

Mode 5—Tone Duration

A specially prepared tape of tone signals is required. The subject must be able to set the gain according to special instructions at the beginning of the test session. The device must be capable of maintaining intensity of sound at the set level. The subject responds by means of a key which marks his judgment of termination of the tone directly on the test tape.

Mode 6—Tone Pattern Discrimination

The subject inserts the specially prepared cartridge of test patterns. His responses are judgments of "same" or "different." They are recorded directly on the test tape by means of a microphone.

Overall Maintenance Requirements

Normal requirements for scheduled and unscheduled maintenance of tape recorder-reproducer.

Costs

Device

Weight	20 lb
Power	20 watts
Volume	1 cu ft

Maintenance

Weight	2 lb
Volume	0.1 cu ft

Supplies

Tape	6 lb
	0.3 cu ft

DEVICE D. TIMER

Related Tests

The timer is used for many tests. (See data sheets for behavioral measurement in Appendix B.)

General

The timer must be capable of recording increments of time in milliseconds and must be capable of accumulating time up to 30 minutes. The timer must be simple to operate. It should be provided with an alarm which can be set to operate to the nearest 10 seconds.

Overall Maintenance Requirements

At least one spare timer. Additional spares according to the reliability of the device selected.

Costs

Weight	0.5 lb
Volume	0.001 cu ft

Maintenance

Spare one timer

DEVICE E. ACCELERATION CHAIR

Related Tests

This device will be used for obtaining measurements relevant to angular acceleration and linear acceleration.

General

The device must provide a means of placing the subject in the seated position with light support for arms and legs. An adjustable frame which holds the head in a fixed position is also necessary. Since the chair need not support the weight of the subject, it can be light in construction as compared with similar chairs used for acceleration testing on the ground. Basically, the purpose of the chair is to provide a way to place the subject's body and extremities in a fixed position. For the angular acceleration test, the chair must be capable of being rotated about an axis through the subject's spine in a controlled manner. To accomplish control of acceleration, an electric motor is suggested. Angular acceleration at one rate is required. Similarly, linear acceleration along a track is also required at one rate and should be accomplished by means of a motor to obtain control of rate. The chair should be provided with scales to enable accurate measurement of linear displacement and rotational displacement during testing.

Overall Maintenance Requirements

Spare motor. This motor should be the same model as the one used in the test of movement of limb.

Costs

Weight	20 lb
Power	20 watts
Volume	3 cu ft

Maintenance

Weight	2 lb
Volume	0.3 cu ft

DEVICE F. TONE GENERATOR

Related Tests

This device will be used to measurement of auditory localization and auditory detection of motion. It can also be used as a backup device for other auditory testing.

General

The tone generator should be capable of producing pure tone with a means of controlling intensity. A wide range of frequencies is not necessary,

but the device should produce tones within the 3,000- to 10,000-cps range. The device should include a small speaker and should be capable of being held in the hand.

Overall Maintenance Requirements

Little or no maintenance should be needed.

Costs

Weight	0.5 lb
Power	0.2 watts
Volume	0.01 cu ft

DEVICE G. ADJUSTABLE FRAME

Related Tests

This device will be used for obtaining measurements relevant to the control of mass in motion and the visual perception of volume of space.

General

This device consists of four strips of metal that can be adjusted to form the four sides of a container of any desired length and width. For the measurement of the handling of mass, the strips will be adjustable to a good fit for the object being handled. For the measurement of visual perception of volume, the subject can adjust the frame according to lies estimate of the size of the object.

Overall Maintenance Requirements

There should be no maintenance required for this device.

Costs

Weight	0.5 lb
Power	—
Volume	0.15 cu ft

DEVICE H. FORCE CONTROL DEVICE

Related Tests

This device will be used for obtaining measures relevant to arm-hand control of force and leg control of force.

General

The device must provide tension which S works to overcome and control. For arm-hand control the device will have a grip handle attached to a spring. The spring will be in line with and under the arm of S, attached at a point on the chair behind S. The spring will have a variable resistor in series with it, as the spring is stretched the contact point with the resistor will change. Information about spring position will be displayed to S on a meter and will be simultaneously fed into the computer. S will stretch the spring to a given value on the meter and attempt to hold it there. For positioning tasks, the spring tension will be disengaged and the subject's task will be to bring the device to a meter position and hold. The device will be used in a similar fashion for leg manipulation.

Overall Maintenance Requirements

There should be little if any maintenance for this device.

Costs

Weight	5 lb
Power	0.5 watt
Volume	0.0347 cu ft