NASA SP-86

Medical Aspects of an Orbiting Research Laboratory

SPACE MEDICINE ADVISORY GROUP STUDY
JANUARY TO AUGUST, 1964

S. P. VINOGRAD

Scientific and Technical Information Division 1966
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Foreword

THE PRESENT VOLUME DESCRIBES how the scientific community within the United States carried out the first systematic investigation of the medical aspects of an orbiting research laboratory in space.

It was a challenging project. Under Dr. Sherman P. Vinograd's guidance, the National Aeronautics and Space Administration brought together a group of leading medical scientists of the nation. These leaders applied their varied specialized competence toward solving the potential problems that man would face as he left his earth bound environment and moved into space, bringing their interdisciplinary and their interdepartmental viewpoints together to develop a research and development program that could point the way toward man's ultimate conquest of the space environment.

The Office of Space Medicine within NASA, and indeed the entire scientific community concerned with the medical behavioral sciences, is indebted to Dr. Vinograd and to the group of scientists who gave so willingly of their time and effort toward furthering the national goal of space exploration.

JACK BOLLERUD
Brigadier General, USAF, MC
Acting Director, Space Medicine
Manned Space Flight

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Preface

THE SPACE MEDICINE ADVISORY GROUP (SPAMAG) is a group of consultants representing varied disciplines in the life sciences who met eight times to be briefed on the current status of the space program and to consider the various aspects of a proposed biomedical program of an orbiting research laboratory. This group was asked to consider the support recommendations under three broad categories: (1) life support, those environmental factors which are to be controlled or considered to be constant; (2) experiments in which environmental factors might be varied in a significant way in order to test the response in the space environment; and (3) research laboratory decision items which are related to the requirements for its design.

The initial challenge to the Group is part of this report and lists the variety of environmental factors and ORL decisions which were discussed. In each of these areas, the Group was furnished a format as guidance in life support or experiment decisions. Additionally, the Space Medicine Advisory Group was divided into task groups so that they might address themselves to the specific areas in which they had competence. These task groups are listed in the separate sections of the report.

Priority assignment, in the context of this report, is an evaluation by the group for administrative purposes. The priority assessment is given on the basis of the degree to which consideration of the experiment was necessary in design of the research laboratory and the degree to which the experiment required preliminary ground-based experimentation. Leadtime in terms of experiment design as well as the personnel involved is also a factor. In this respect it will be clear that the Group felt that all of the experiments were in a high priority category; that is, the experiments were necessary for consideration in design requirements as well as experimental planning at this time. A priority related to importance of the problem must be made at a later date.

The report is given in three phases. Phase I on life support recommendations covers six categories: (1) hazards, (2) atmosphere, (3) living conditions, (4) metabolic factors, (5) group integrity, and (6) medical considerations. Under each of these categories the groups made recommendations concerning the spacecraft, research and development necessary for design of the spacecraft, ground-based experiments which were necessary for the design requirements, and, in some cases, experiments which should be accomplished in space flight preceding the orbiting research laboratory.

The hazards section considers the toxicological and general housekeeping problems in the spacecraft. The atmosphere section prescribes the ideal atmosphere for a research laboratory and indicates the necessity for being able to change the atmosphere for experimental purposes. The living conditions section deals with general body functions and hygiene, decor, illumination and work schedules as well as volume requirements in the spacecraft. The metabolic requirements section sets forth the present day estimate of the food, water, and waste requirements. The group integrity section discusses those factors which are involved in efficient and harmonious group functioning; however, it does not consider in detail the previously well-studied topic of individual performance. The section on medical considerations addresses itself to recommendations concerning flight crew medical selection and considerations of illness and injury among the crew as well as recommendations for medical safety monitoring.

These 6 sections represent a grouping of the some 15 items which were presented for discussion and considered individually.

Phase II is concerned with the experiments. These experiments fall into three major categories; the first of which are those related to general medical and physiological measurements. Although a number of specific experiments are designed to test the characteristics of physiological and psychological systems, certain observations are recommended on a continuous daily basis to provide data which may be used in a number of data acquisition and reduction procedures. These also will serve for the general medical monitoring in the spacecraft.

Physiological tests cover experiments which are designed to test the characteristics of the cardiovascular system and the respiratory system. Additional experiments are designed to test and give indications of functions of overall metabolism, metabolism of bone and muscle and metabolism as related to hematology. A group of experiments which assess the neurologic function and miscellaneous experiments on the cellular level are also included. Although several stress factors were listed by the group for consideration, the experiments given are directed toward weightlessness and total combined flight stress. This does not negate the importance of the interaction of these factors, but it emphasizes the unique factor of weightlessness.

Psychological experiments are devised to test the emotions, performance, reaction to frustration, and spontaneous activities.

For Phase III on the design and operational recommendations, the ORL requirements were gathered from a free discussion by the Group and relate to specific spacecraft requirements, requirements for personnel in the spacecraft, and requirements for specific equipment in laboratory facilities on the spacecraft.

The factors presented under the three phases of this report represent the present best opinion of the group with respect to the decisions and areas of emphasis for orbiting research laboratory considerations and give a general presentation which should be continuously reevaluated and revised.

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Contents

PAGE

PAGE

PHASE III: DESIGN AND OPERATIONAL RECOMMENDATIONS

Introduction

EARLY IN THE YEAR 1963, NASA began serious consideration of the potential of an Orbiting Research Laboratory. Investigations into both scientific and design requirements were launched by various cognizant groups throughout NASA. Studies of the medical aspects of the Orbiting Research Laboratory concept were initiated within NASA, and were supplemented a short time later by contracted industrial participation. As the feasibility of an Orbiting Research Laboratory grew apparent, so grew the opportunity to tap one of our richest national resources, the scientific community. These representatives of American medicine were invited to participate not only to provide maximal expertise in the structuring of a specific national space effort of the future, but also because it was recognized that in doing so they would at the same time be contributing strongly to the direction of space medical investigation as a whole.

This participation was realized with the formation of the Space Medicine Advisory Group, a group of 20 distinguished consultants representing some 16 specialties and subspecialties in medical and medically related fields. The group was organized and its methodology established in accordance with certain objectives, predetermined in order to enhance the effectiveness of its work. Foremost among these objectives were:.

(1) The establishment of SPAMAG as a working group rather than a reviewing committee to enable recommendations to be made on the basis of "shirt-sleeve" familiarity with the conditions of manned space flight and with the several disciplines both within and without the broad field of medicine which are necessarily involved in these recommendations.

(2) The composition of a group of a majority of members who had not been previously active in the space program together with a strong minority of those who had. This made it possible to obtain a fresh evaluation while preserving the continuity of familiarity with manned space flight, all by highly competent scientific authority.

(3) The clear statement of methods, goals, and anticipated end products of the work of SPAMAG from the outset of its activity was regarded important for obvious reasons. While the goals and end products were set forth with some degree of rigidity, the methodology was only offered. However, it too was accepted with small modification after minimal discussion.

(4) The establishment of a program of orientation to space flight and its technology to take place throughout the series of meetings. This was deemed necessary if recommendations were to be made on a realistic and current basis.

(5) Provision for frequent updating of the original report in the light of new research and technology, and even of "second thoughts" or future SPAMAG meetings. This principle of a dynamically oriented effort was served, at least in part, by the initial presentation of this report in loose leaf form.

IN DECEMBER, 1963, after the first meeting had already been scheduled for January 1964, the Manned Orbiting Laboratory (MOL) study program was assigned to the U.S. Air Force. Consistent with the NASA/DOD policy of close coordination, the Air Force, through General Benjamin A. Strickland, was then invited to participate with NASA in this endeavor. In response, the Air Force assigned a co-chairman, Colonel Andres I. Karstens, and two observers to the SPAMAG meetings.

The Group met on two consecutive days each month for a total of eight meetings. The first morning of each two-day session was devoted to briefings on various developmental and operational aspects of space flight given chiefly by NASA personnel. Additional indoctrination was provided by convening two of these meetings at operational centers, Cape Kennedy and the Manned Spacecraft Center at Houston. Both of these were three-day sessions, the third day of which was devoted to a tour and discussions of facilities at each of these two sites. The remaining meetings were held in Washington, D.C. The Group was in every sense of the word a working group; through diligent effort and by means of strict adherence to a very tight schedule, it managed to complete the very large task undertaken within the given time schedule.

Prior to the first meeting in January, 1964, a 14-page general format was devised, which the Group agreed to adopt with minor revisions at the time of the first meeting. The full format, included in this report as Tables I through XII, specifies the aims and methods of the work of SPAMAG.

The total study of the ORL concept from the medical standpoint was seen as consisting of three major phases or tasks. These are shown in Table I.

The first task was to make recommendations concerning specifications for the environmental factors which are to be supplied the flight crew. Although the format shows this section (Phase I, "Life Support") as consisting of nine subtask areas, evaluations and recommendations were made by five panels, one of which submitted two reports, namely "Living Conditions and Standards", and "Medical Safety Monitoring." Consequently, Phase I consists of six panel reports.

The second task or phase was to define the medical experiments and measurements to be performed aboard the ORL. These were devised on the basis of need rather than available space, and needs were determined by means of carefully examining the interfaces between single and combined environmental factors on the one hand, and bodily functions on the other. In order to accomplish this, the Group as a whole first generated a list of potential single and multiple stress factors (Tables II and III), then reviewed and revised a comprehensive outline of body functions (Table IV). They then separated into three panels which examined the interfaces relevant to their assigned areas of body function, and devised experiments and measurements in accordance with the method and outlines shown in Tables V and VI. The reporting of SPAMAG experiments, measurements, and recommendations was done according to the outlines shown in Tables VIII, IX, and X. Upon closer scrutiny, it may be recognized that these are, in reality, check lists of information required.

It was thought logical that only after thorough consideration had been given the first two phases could reasonable recommendations be made concerning the third phase, that of general ORL recommendations. The questions to which these recommendations were addressed are shown under column III, "ORL Recommendations" (Table I), more particularly those listed under point 5. It can be seen that this phase is, in effect, an operational and engineering translation of the first two phases, and, as such, can provide the most direct guidance to designers and engineers. Phase III was discussed and recommendations were made by the Group meeting in general session.

Finally, the anticipated end products of this entire effort, as shown in Table XII, have, in fact, been accomplished. Among these products, the areas of prerequisite space flight experiments, prerequisite ground-based experiments, and prerequisite research and development warrant particular mention since these comprise the skeletal structure of an overall integrated program of space flight medical investigation.

Since publication of this report follows its completion by more than 18 months, a few of the concepts presented may now be considered dated in light of more recent findings. Yet these instances are surprisingly few. This report is presented primarily for those who have a scientific interest in the field. At the same time, those who are interested in programmed research, or in the historical or administrative aspects of the field may also find it of some value.

The Space Medicine Advisory Group met this heavy challenge with diligence, enthusiasm and skill. Their generous and able participation is most sincerely appreciated not only by those of us whose privilege it was to work with them but by all who are concerned with national progress in space medicine.

S. P. Vinograd, M.D.
Director Medical Science and Technology,
Space Medicine Division
Office of Manned Space Flight

*Table I.—ORL Support Recommendations**

Life Support
I

(Controlled environmental factors)
(Constants)

***1. Atmosphere (Gas pressure, temperature, humidity, total quantity required, circulation, atmospheric toxins)
2. Suits
   a. Intravehicular
   b. Extravehicular
      (1) Maneuvering unit
      (2) Communications
      (3) Portable life support system
      (4) Hazard protection (see below)
3. Food and electrolytes
4. Water
5. Waste
6. Living conditions and standards
   a. Body functions and hygiene
   b. Laundry
   c. Exercise
   d. Decor
   e. General conveniences
   f. Schedules
   g. Diversions
   h. Volume
   i. Noise
   j. Vibration
7. Group integrity (selection and training)
   a. Social compatibility
   b. Mutual confidence
   c. Individual emotional stability
   d. Individual physical ability
   e. Individual mental ability
   f. Individual professional ability
8. Hazard protection
   a. Toxic substances
   b. Particulate contamination of atmosphere
   c. Fire
   d. Ionizing radiation
      (1) Selection of orbit
      (2) Dosimetry
      (3) Protection of subjects by
         (a) Shielding
         (b) Prophylaxis (drugs)
         (c) Therapy
   e. Radio frequencies

Experiments**
II

(Uncontrolled environmental factors)
(Variables)

List of experiments and experimental requirements to be formulated according to the following schema:

Environmental factors → Effects on bodily functions
↓
Experiments + measurements

ORL Recommendations
III

1. ORL experiments
2. Prerequisite ground experiments
3. Prerequisite space flight experiments
4. R&D areas to be explored
5. General ORL decisions to be made
   a. Best and cheapest overall approach
      (1) Method
      (2) Vehicle
      (3) Duration
      (4) Type of reentry vehicle
      (5) Suggested cost effectiveness parameters
   b. Orbit
   c. Onboard centrifuge specs.?
   d. Rotation for artificial G?
   e. Size requirements
   f. Weight reqts. (total for medical experiments)
   g. Power reqts. (total for medical experiments)
   h. Number of personnel
   i. Types of personnel
      (1) Selection reqts.
      (2) Training reqts.
      (3) M.D. included?
   j. Animals?
      (1) Number
      (2) Types
      (3) Special provisions
   k. Cycling of personnel and animals
   l. Onboard laboratory requirements
   m. Storage reqts. (volume and type)
      (1) For medical lab. supplies
      (2) For food, H_2O, waste
      (3) For laboratory specimens
   n. Supporting logistics
   o. Bioinstrumentation requirements
   p. Communications (methods and equip.)
      (1) Telemetry
      (2) Onboard recording
      (3) Reqts. for extravehicular activities
      (4) Voice communication schedule
   q. Ground support
      (1) Personnel
      (2) Equipment and communication
      (3) Distribution and schedules

Table I.—Continued

Life Support I	Experiments** II	ORL Recommendations III
f. Micrometeoroids g. Loss of pressure h. Illness i. Behavior of drugs in space j. Accidental injury k. Extravehicular hazards 9. Safety monitoring (medical) a. Bioinstrumentation b. Communications c. Ground support		(4) Recovery plan r. Necessity for total ground simulation prior to flight s. Requirements for postlanding medical examinations t. Double-ended trampoline onboard ORL u. Criteria for abort

*Each item in I and II to be examined from standpoint of prerequisite ground and space flight experiments, indicated R&D, (for techniques, instrumentation and engineering), and ORL Experiment (with priority evaluation for each investigation).
**Any of the items listed under "Life Support" may be changed to an experimental variable if deemed indicated.
***Atmosphere decision of primary importance.

Table II.—Environmental Factors (Stress) of Space Flight

Single Environmental Factors (Stresses) (Prolonged)	Combined Stresses (Double)	Combined Stresses (Triple)
1. Weightlessness	1. Weightlessness + radiation	1. Weightlessness + social restriction + confinement
2. Radiation	2. Weightlessness + confinement	2. Weightlessness + threat of danger + particulate matter
3. Confinement	3. Weightlessness + social restriction	3. Weightlessness + artificial atmosphere + particulate matter
4. Social restriction	4. Weightlessness + monotony	4. Weightlessness + toxic substances + particulate matter
5. Monotony	5. Weightlessness + threat of danger	5. Weightlessness + microorganisms + particulate matter
6. Threat of danger	6. Weightlessness + artificial atmosphere	6. Weightlessness + thermal stress + particulate matter
7. Artificial atmosphere	7. Weightlessness + toxic substances	
8. Toxic substances	8. Weightlessness + particulate matter	
9. Particulate matter	9. Weightlessness + microorganisms	
10. Microorganisms	10. Weightlessness + circadian rhythm changes	
11. Change in circadian rhythms	11. Weightlessness + UV exposure	
12. Ultraviolet exposure	12. Weightlessness + IR exposure	
13. Infrared exposure	13. Weightlessness + noise	
14. Noise	14. Weightlessness + thermal stress	
15. Thermal stress		

Table III.—Determination of Combined Stress Requirements

	WEIGHTLESSNESS	RADIATION	CONFINEMENT	SOCIAL RESTRICTION	MONOTONY	THREAT OF DANGER	ARTIFICIAL ATMOSPHERE	TOXIC SUBSTANCES	PARTICULATE MATTER	MICROORGANISMS	CHANGE IN CIRCADIAN RHYTHMS	ULTRAVIOLET EXPOSURE	INFRARED EXPOSURE	NOISE	THERMAL STRESS
WEIGHTLESSNESS															
RADIATION	S														
CONFINEMENT	S	ND ∅													
SOCIAL RESTRICTION	S	ND ∅	SPACE G WTL												
MONOTONY	S	ND ∅	G	G											
THREAT OF DANGER	S	ND ∅	G	G	G										
ARTIFICIAL ATMOSPHERE	S	A G	G	ND ∅	ND ∅	G									
TOXIC SUBSTANCES	S	A G	G	ND ∅	ND ∅	G	G								
PARTICULATE MATTER	S	G	ND ∅	ND ∅	ND ∅	SPACE G WTL	SPACE G WTL	SPACE G WTL							
MICROORGANISMS	S	G	G	G	ND ∅	ND ∅	G	G	SPACE G WTL						
CHANGE IN CIRCADIAN RHYTHM	S	ND ∅	G	G	G	G	G	ND ∅	ND ∅	ND ∅					
ULTRAVIOLET EXPOSURE	S	ND ∅	ND ∅	ND ∅	ND ∅	ND ∅	ND ∅	G	ND ∅	G	ND ∅				
INFRARED EXPOSURE	S	A G	ND ∅	ND ∅	ND ∅	ND ∅	G	G	ND ∅	G	ND ∅	ND ∅			
NOISE	S	ND ∅	G	G	G	G	G	ND ∅	ND ∅	ND ∅	G	ND ∅	ND ∅		
THERMAL STRESS	S	A G	G	G	G	G	G	G	SPACE G WTL	G	G	ND ∅	ND ∅	G	

LEGEND

A G = TO BE DONE WITH ANIMALS ONLY - GROUND-BASED

S = ORL STRESS - CAN ONLY BE DONE IN SPACE

ND ∅ = GROUND-BASED EXPERIMENT - WILL DETERMINE, BUT NOT DEMANDED

G = GROUND-BASED EXPERIMENT - WILL DETERMINE AND IS RE - QUIRED

SPACE G WTL = TRIPLE COMBINED STRESS WITH WEIGHTLESS - CAN ONLY BE DONE IN SPACE

Table IV.—Body Functions

1. Neurological function
   a. Central nervous system
      (1) States of consciousness
         (a) Sleep
         (b) Alertness
      (2) Speech functions
      (3) Adaptability
      (4) Emotional reactivity
   b. Special senses
      (1) Vision
      (2) Auditory
      (3) Smell
      (4) Taste
      (5) Vestibular
   c. Peripheral nervous system
      (1) Somatic
      (2) Autonomic
2. Psychological performance
   a. Sensation
   b. Psychomotor
   c. Perception
   d. Higher mental processes
3. Circulation
   a. Pump
   b. Blood volume control
   c. Vasomotor control
4. Respiration
   a. Lung
   b. Blood
   c. Tissue
5. Digestion
6. Metabolism
7. Endocrine balance
8. Thermoregulatory and integumentary
9. Neuromuscular
10. Skeletal
11. Fluid and electrolyte balance, renal and urinary tract functions
12. Reproduction
13. Hematological response
14. Immunological response

Table V.—Sample Evaluation of Environmental Factors Format

Weightlessness and Radiation

Body functions list

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____

____

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____

____

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Evaluate each as potential problem area, assign priority, and devise experiments and/or measurements in experimental design format.

Table VI.—Guidelines

1. Experiments and measures are to be designed to:
    a. Establish effects both qualitatively and quantitatively with time relationship
    b. Determine mechanisms
    c. Establish predictive means both qualitatively and quantitatively
    d. Determine most effective countermeasures
2. Consider effects of orbital environmental factors (stresses) both intrinsically and in terms of postorbital environmental requirements. (See Table VII)
3. Assign priorities to all ORL experiments and measures, all prerequisite experiments, and recommended R&D.
4. Attempt to build flexibility into ORL experimental protocol and equipment. Provide redundancy where possible.
5. In terms of personnel, time, equipment size, weight and power, etc., ORL experiments are to require the least to provide valid and reliable results. Suggested alternative experiments or additional measurements beyond minimal should be categorized as "minimal," "desirable—1," "desirable—2," etc.
6. Consider all stresses, functions, measurements, procedures, life suppport requirements, equipment function, storage, animal housing, etc. in terms of behavior in weightlessness.
7. Consider the basic question to be the means by which prolonged manned interplanetary and orbital missions can be achieved in terms of the well-being of man. Therefore, in general, MOL environmental conditions may be set up paralleling those anticipated onboard an interplanetary or orbital vehicle rather than Earth.
8. Adopted the general philosophy that man is to be supported in the best manner possible by life support systems. "Best manner" means preservation of psychophysiological integrity.
9. Keep in mind throughout this exercise the possible uses of space for studying and perhaps treating various pathological states.
10. Bear in mind MOL (two-man) constraints.

Table VII.—Environmental Factors (Stresses) of Medical Importance for ORL Planning

(Ref.—Table VI, Item 2)

1. Orbital
    a. Variables
    b. Constants
2. Post orbital
    a. Reentry (Constant)
        (1) Acceleration, impact, possible oscillation and vibration
        (2) Change of atmosphere provided by ECS
        (3) Danger
        (4) Need for alertness
        (5) Need for precise coordination
        (6) Need for short reaction times
    b. Terrestrial (constant)
        (1) Constant 1 G
        (2) Change to normal atmosphere
        (3) Organic and functional integrity to resume all normal earth activities

Table VIII.—Format for Life Support Recommendations

1. Recommendations (specify allowable limits—quantitative and qualitative)
2. Rationale
3. References, briefly annotated

Consider interactions of systems with other systems, with spaceflight stresses, and with followup postorbital environmental factors to formulate the following:

4. Prerequisite ground experiments
5. Prerequisite spaceflight experiments
6. Recommendations for research and development
7. ORL medical experiments
8. Special comments

Table IX.—Experimental Design Format

(For ORL experiments, ORL measurements, and for prerequisite spaceflight experiments)

1. Name of Experiment
2. Estimated Priority (priority 1, 2, or 3)
3. Purpose
4. Justification
5. Experiment (experimental design in detail)
6. Experimental Controls
7. Summary of Number and Types of Space Station Personnel (level of training required, i.e., physician, lab tech, trained astronaut, etc.)
8. Summary of Onboard Experimental Equipment Required (latest state-of-the-art equipment, size, weight, and power requirements, as nearly as known)
   a. Fixed equipment
   b. Consumable equipment
9. Summary of Animals, if needed (number, type, and alternative types in order of preference)
10. Summary of Other Living Forms, if needed (number, type, and alternative types in order of preference)
11. Summary of Onboard Laboratory Determinations (type, frequency, time consumed for each)
12. Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination (type, number, and timing of specimens, how stored aboard, and types of determination)
13. Proposed Rendezvous Schedule for Rotation of Crew
14. Telemetry versus Onboard Recording Requirements
15. Prerequisite Ground Based Experiments
16. Prerequisite Space Flight Experiments
17. Prerequisite Research and Development
18. Onboard Gaseous Atmosphere Desired
19. Requirement for Rotation for Artificial G (if any)
20. Comments re Form of Data and Interpretation of Data
21. Special Comments
22. Postflight Evaluation of the Crew
23. References (briefly annotated)

Table X.—Format for "Prerequisite Ground Experiments" and "Recommended Research and Development"

1. Title and basic format reference (A, B, or C and No., if any)
2. Priority
3. Purpose and description
4. Bibliographical reference (if any), briefly annotated
5. Special comments and recommendations

Table XI.—General Agenda

1. Review entire format for overall approach and completeness—comment and amend.
2. Review list of single stresses.
3. Create list of combined stresses (double, triple, etc.)
   a. Star those to be included as experimental variables for addition to list of ORL experimental stresses
   b. Note with circle those *requiring* prerequisite ground-based or spaceflight experiments but not ORL experiments (start lists of these for specific recommendations for each in format later on).
4. Review list of body functions—comment and amend.
5. Review list of guidelines—comment and amend.
6. Review formats for experiments (2)—comment and amend.
7. Review list of anticipated results of SPAMAG effort and comment.
8. Define "priority."
9. Expose each stress (including combinations) to list of body functions, utilizing guidelines, determine ORL experiments, additional measurements, and prerequisite ground-based and spaceflight experiments, and R&D. Write up in appropriate formats placing byproducts (philosophies, general ORL decision recommendations, etc.) in appropriate categories according to list of "anticipated end products of SPAMAG effort."
10. Review items in 3b. Make recommendations in format. Again categorize byproduct recommendations.
11. Study "life support" items. Make recommendations in format. Categorize byproduct recommendations.
12. Review total, make recommendations listed in Phase III, "general ORL decisions," and complete "anticipated end products."

Table XII.—Anticipated End Products of Space Medicine Consultant Advisory Group Effort

1. Group of ORL medical experiments in format.
2. Group of additional ORL medical measurements in format.
3. Group of life support recommendations in format.
4. Group of prerequisite ground-based experiments.
5. Group of prerequisite spaceflight experiments.
6. Group of recommendations for research and development.
7. General philosophy and recommendations for ORL experimental approach.
8. Recommendations for general ORL decisions.
9. Tentative flight plan.
10. Reviews of work of four study contracts and ORL Biomedical Experiments Working Group.
11. Summary of possible uses of space environment for study and therapy of pathological states.
12. Recommendations for future study effort.

phase I

LIFE SUPPORT RECOMMENDATIONS

Atmosphere and Suits

Dr. Carlson
Dr. Forster
Dr. Wood
Dr. Swisher

Food, Water, and Waste

L/Col. Knoblock
Dr. Gordon
Dr. Pollack
Dr. Whedon

Group Integrity

Dr. Kubis
Dr. Reitan
Dr. Townsend

Living Conditions and Standards and Safety Monitoring

Dr. Graybiel
Dr. McFarland
Dr. Warren

Hazard Protection

Dr. Baldwin
Dr. Buesseler
Dr. Grahn
Dr. Natelson

Life Support Recommendations

THESE RECOMMENDATIONS are based upon the concept that the unique property of the near-Earth orbital flight environment which cannot be duplicated on Earth is weightlessness. The physiological and behavioral effects of this variable should then be studied under conditions that simulate Earth as closely as possible. Where interactions between weightlessness and other variables are suspected to exist, these variables should be controlled in the experimental sense, if possible; if the interacting variable is not controllable, it should be monitored precisely to provide a full description of the experimental conditions. Engineering exigencies should not dictate the environment—the environment must be supplied to provide the best medium for the experimental effort.

ATMOSPHERE RECOMMENDATIONS

Life Support Factors

Atmosphere

1. Ideally the atmosphere should be identical in pressure and composition to Earth's atmosphere between sea level and not greater than 5000 ft altitude.

The altitude of 5000 ft is arbitrarily chosen. The consensus is that short- or long-term residence at this altitude does not constitute a practical significant physiological stress. Atmospheric pressure and composition may ultimately be considered as experimental variables.

If this ideal cannot be met, the atmosphere should be a mixture of O_2, N_2, and rare gases; the rare gases should be present in the same molecular ratios relative to N_2 found in the atmosphere of Earth at sea level.

Until experiments prove otherwise, it must be assumed that the remaining gaseous constituents of the atmosphere are necessary. A chemically inert gas is not necessarily physiologically unimportant.

If the ideal atmosphere cannot be provided, the requirements for preflight ground-based experiments will be greatly increased and the entire program may be slowed.

The oxygen partial pressure should be within the range of 150 mm of Hg (2.9 psi) to about 185 mm of Hg (3.6 psi).

The minimum value of 7 psi is the nearest approach to normal which may carry an acceptable degree of risk against (1) occurrence of bends on rapid decompression to suit pressure, assumed to be 3½ psi (additional ground-based experiments are required to determine the actual risk); (2) fire hazard (additional experiments are mandatory to be certain of the acceptability of the fire hazard risk associated with this atmosphere); (3) hazard of pulmonary atelectasis (additional experiments are mandatory to define the degree of this risk); and (4) the risk of hematological disorders, e.g., possible hemolytic anemia (this risk also requires further investigation).

The total pressure should be between 360 mm of Hg (7.0 psi) and the ideal 760 mm Hg (14.7 psi). This requires that the partial pressure of N_2 be approximately 180 mm Hg (3.5 psi) to 610 mm Hg (11.8 psi) if the ideal (Earth) atmosphere is selected.

2. The maximum partial pressure of carbon dioxide (CO_2) should be 8 mm Hg with less than this value desirable.

This recommendation is based on the work of Schaefer (ref. 21) in which older work is summarized which indicates that above 3% CO_2 there is a deterioration in performance. Above 1.5% CO_2 there may be difficulty with small adaptive processes. The permissible level of 0.5% to 0.8% CO_2 suggested is the general equivalent of 8 mm Hg.

3. Carbon monoxide (CO) concentration should be below 0.001%. This concentration of CO is that which would be in equilibrium with the normal carboxy hemoglobin content of the blood of a nonsmoker. There is evidence of change in visual threshold at blood concentrations of 3 to 5% carboxy hemoglobin,

which is equivalent to CO concentrations of about 0.0126 to 0.021 mm Hg in inspired air.

4. Rigorous control of all gaseous and particulate contaminants of the system must be established. Particular attention must be directed to removal of ozone and prevention of atmospheric contamination by organic compounds which may be in the environment. The chronic toxicology of such compounds must be investigated.

The standards for maximum accumulated concentration of substances in the atmosphere should be expressed in absolute terms. Preliminary working standards should be obtained from the current toxicology literature.

5. Relative humidity should be in accordance with the ASHVE standards for comfort at 1 atmosphere.

These values should be confirmed by simulation of the atmospheric conditions, including ventilation, composition, and pressure which are finally selected.

6. Temperature should be adjusted to the thermal comfort zone determined by studies with simulation of the chosen atmosphere. Some range of adjustment of temperature should be under the control of the crew.

7. Air processing rate must be adequate to maintain the specified atmospheric composition. The distribution of air flow throughout the environment must be such as to assure bodily comfort.

Space Suits

1. From the point of view of the primary function of the ORL, suits should be considered only as emergency devices. A "shirtsleeve" environment is considered essential for the performance of the primary mission.

2. Suit requirements which are laid down by other operational aspects of the ORL program, e.g., reentry or extravehicular maneuvering, should be made compatible, if possible, with the secondary use of the suit to meet emergency conditions.

Ground-Based Experiments Prior to Launching the ORL

Pulmonary Atelectasis Problem

It has been demonstrated by Rahn and others that the susceptibility to pulmonary atelectasis is increased when pure or practically pure oxygen is breathed. Apparently this susceptibility increases in inverse proportion to the atmospheric pressure and in direct proportion to the metabolic rate. For instance, it is estimated that lung collapse would occur in approximately 70 seconds if a man with a normal metabolic rate breathing oxygen at a total atmospheric pressure of 3 psi were to hold his breath for 90 seconds. If his metabolic rate were greatly increased by strenuous effort, such a phenomenon could occur inadvertently if the individual closed his glottis during a period of maximal muscular effort lasting less than 30 seconds.

Furthermore, evidence from centrifuge studies indicates that atelectasis occurs during exposure to levels of acceleration encountered in the launch and reentry phases of space flight. Theoretically, it would be expected that susceptibility to atelectasis would be increased when oxygen was breathed simultaneously, particularly under reduced pressure. It is a matter of record that atelectasis has been demonstrated roentgenographically after exposures to acceleration while breathing O_2 both in aircraft and in the centrifuge (refs. 11, 23). The incidence and degree of atelectasis detected after such exposure was increased when antiblackout suits were used. (ref. 11)

Proposal

Experiments designed to elucidate the mechanism of this occurrence of atelectasis and the associated pulmonary arterial venous shunts (ref. 23) during exposure to acceleration should be carried out and the relationship of the susceptibility to these pulmonary derangements to the pressure and composition of the gas mixture being breathed should be delineated.

Oxidative Hemolysis

Certain data suggest that shortened red cell life span may be induced by chronic exposure of man to oxygen tensions above normal. To date, there have been no experiments directed specifically toward elucidation of this phenomenon. What is known suggests that the hemolytic process is mild, self-limited and achieves a steady state within 7-14 days. Strong analogies exist with G6PD deficient red cell hemolysis in these and other respects.

It is recommended that this phenomenon be investigated in ground-based experiments to (1) determine the time-concentration relationships which may effect red cell life span shortening, (2) insofar as possible, determine individual differences in susceptibility, and (3) develop an in vitro predictive test of this susceptibility.

These studies should be carefully controlled for blood loss, blood sampling, and change in red cell mass, blood volume, and red cell life span. Studies of pigment metabolism, erythropoietic response and iron metabolism are of secondary, but substantial, interest. If possible, experiments should be run long enough to involve a complete turnover of the red cell mass.

It is probable that the hemolytic state which may accompany high oxygen tensions is not a serious environmental hazard. Nevertheless, elucidation of this phenomenon is deemed important in order to be sure of its magnitude as a hazard and as a basis for interpretation of other experiments on board an ORL which might be affected by the occurrence of hemolysis.

Effect of Atmosphere Composition on Hazards of Dysbarism

Essential to the establishment of firm life support criteria for atmosphere selection are further ground-based studies to clarify the potential incidence of dysbarism following either premeditated operational or emergency decompressions to the 3.5 psi (absolute) pressure suit atmosphere. Most critically needed are experiments on men decompressed to the 3.5-psi atmosphere following varying periods of equilibration to approximately a 7½-psi atmosphere, 40% O_2 and 60% N_2. The goal is to develop the relation of incidence of dysbarism vs time of equilibration at operationally important atmospheres and to determine what equilibration time is needed to reduce essentially to zero the probability of a dysbaric event.

Secondly, when dysbarism occurs under these experimental circumstances, the efficacy of simple recompression to the original intravehicular atmosphere should be evaluated as a countermeasure.

In addition, once the detailed atmosphere pressure and composition history of any mission is determined, consideration should be given to experiments tailored to the specific mission in order to establish firmly the dysbarism hazard for that mission.

Research and Development Prior to Launching the ORL

Flammability in Various Atmospheres

Atmospheres which support life may introduce a fire hazard. Research is necessary to determine the extent of risk with various combinations of inert gas with oxygen in the pressure range of 3.5 psi to 14.7 psi. Since gravity dependent factors are involved in fire, the critical tests will necessarily require validation in the weightless state.

These are engineering tests rather than biomedical, but they are essential for certain decisions concerning atmosphere. Further studies of materials with primary interest in vapors and flammability are important.

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METABOLIC FACTORS RECOMMENDATIONS

Food, Water, and Waste

1. The diet should be as simple as possible with emphasis on maximum use of natural foods which will provide balanced nutritional components, and which is either in a liquid formula form or one which can be readily reconstituted into a semiliquid or a liquid form to be consumed in space.

   A formula diet is required for accurate estimation of intake and to provide adequate measurements for any balance studies. Natural foods will assure balance of amino acid components and micronutrients.

2. For purposes of planning a schedule of activity for a 24-hour day is suggested as follows:

Activity	*hours*
Sleep	8
Eating	2
Exercise	2
Rest and Relaxation	4
Work Program	8

   This is an estimated schedule to evaluate activity for purposes of calculation of energy requirements and to maintain physical fitness.

3. In a shirtsleeve environment for a 150-pound man, the following caloric requirements are thought reasonable:

Sleeping	70 cal/hr or 280 Btu/hr
Eating	1.5 × basal or 420 Btu/hr
Exercise	2.5 × basal or 700 Btu/hr
Rest and Relaxation	1.5 × basal or 420 Btu/hr
Work Program:	
Flight Control	2 × basal or 560 Btu/hr
Reconnaisance	2–2.5 × basal or 560–700 Btu/hr
Scientific Observation	1.5–2.5 × basal or 420–700 Btu/hr
Repair	2.0–4.0 × basal or 560–1120 Btu/hr

   In a suited environment add increased factors as follows:

Activity	%
Sleep	10
Eating	50
Exercise	50
R&R	50
Work	50

For extravehicular work, a mean rate of 2000 Btu/hr may be required. This level of expenditure is possible for only limited periods of time. These figures presented for panel reference are the best available.

4. The dietary component should consist of natural foods of low fiber and low laxative nature. No adjustment of bacterial flora should be attempted.
   This recommendation is aimed at minimizing bowel activity and to avoid alterations in micronutrient production by normal bacterial flora.
5. The administration of diet should be by liquid or liquid reconstitution with coded cubes which are preweighed to facilitate adequate recording of food intake for purposes of balance studies.
6. An oral exercise medium such as a gum or other suitable device should be provided for oral hygiene purposes. This is especially necessary if liquid formula diets are to be used.
7. Composition of the diet should be as follows:

	%
High quality protein	12.5
Carbohydrate	52.5 to 57.5
Fat	35

   This ratio will be used to provide 2700–3200 cal/day (10,800–12,800 Btu/day) with an RQ at 0.8 to maintain a $CO_2 \div O_2$ ratio which would spare the CO_2 scrubbing requirements of the environmental control system.
8. The ratio of polyunsaturated to saturated fat in the diet will be dependent upon the conditions of preservation of diet during the flight program and the method chosen for reconstitution of the diet for feeding in space.
   Because of their lower melting point, polyunsaturated fats lend themselves to easy reconstitution for use in space.
9. Recommendations concerning mineral and vitamin requirements are as follows:
   - Calcium—0.8 gram/day
   - Phosphate—1.2 to 1.5 grams/day
   - Sodium as NaCl for individuals who are acclimatized to the environment—4.5 to 5 grams/day
   - For those not acclimatized, add 1 gram of sodium as NaCl for each liter of water consumed per day over 4 liters. This figure is tentative, and the suggestion is made that in view of the possibility of adrenal stress, the potential use of 10–15 grams of sodium chloride per day be considered; a corresponding reduction of potassium to approximately 1 gram/day might serve as a protective device for the adrenal glands. Accordingly, the water intake may need to be increased to 4 liters or more per day. This would also be useful for maintenance of heat balance.
   - Vitamin D—1000 units/day
   - Other vitamins—In flights of under 2 weeks there should be no vitamin problem, but for extended flights the use of a standard minimum daily requirement type of polyvitamin preparation in no greater quantity than the minimum daily requirement as recommended by the NAS–NRC (Nat. Acad. of Science—Nat. Research Council) is advocated. The one exception to the above is ascorbic acid with consideration for use of as much as 150 mg/day to compensate for the stress of flight.
   - Minerals—Trace mineral supplements are strongly advocated if food used is processed by chelation. This is one of the strong reasons for the recommendation for the maximum use of natural foods.
   - Water—2.5 liters/day (1 cc/calorie of food). Water intake should be sufficient to maintain the urine at a specific gravity of 1.015 or less or a volume of at least 1 to 1.5 liters/day to avoid the development of urinary gravel. Water should be consumed in definite quantities on a programmed schedule. Daily measurements of body mass should be used to adjust water intake.

   These estimates are based upon the best available information regarding nutritional requirements.
10. Because of power, weight, and volume requirements, recycling of water is not considered practical for flights of less than 30-day duration, but it should be considered for flights in excess of that period of time. Water sources for reclaiming include metabolic water and that produced by the fuel cells. The recycling of urine is considered to be costly in both energy and volume-weight requirements. Ion-exchange or millipore filters appear to be simple devices for re-

claiming metabolic and fuel cell water and converting them to a potable supply. Metabolic water can be reclaimed easily for hygienic use.

This recommendation is based upon presently available engineering estimates.

11. On each voiding, the total volume of urine must be accurately recorded and an aliquot separated for study. Aliquots according to aeromedical requirements can probably be stored in the walls of the cabin to provide additional radiation shielding until they are returned for analysis. Cryogenic preservation is recommended.

    Any meaningful study of metabolic activity is dependent on accurate measurements of urine components. Adequate preservation is required to prevent loss of labile chemical constituents.

12. To reduce the quantity of fecal material, a low residue diet is recommended. Samples should be collected, adequately identified, and stored in sealed containers for analysis (as with the urine). Desiccation and cryogenic storage, utilizing the conditions of space, might well be employed to facilitate this program. It should be borne in mind with reference to the storage of feces that drying without either freezing or sterilization may well introduce the danger of bacterial contamination of the atmosphere.

13. From the standpoint of metabolic considerations, medical selection for the ORL program should attempt to rule out those who have a tendency toward nephrolithiasis. It is also important to record any food intolerances and idiosyncrasies of flight crew candidates.

    To minimize medical problems of space flight, all factors which would predispose a medical problem should be screened carefully.

Research and Development Prior to Launching the ORL

1. A study of nutritional acceptability and palatability for extended periods of such potential foods as algae, reconstituted liquid or semiliquid diets of natural products should be made. It is recommended that an investigation be made as to the possibility of extending a natural diet by means of a concentrated, high-density, synthetic diet which can be consumed periodically during the flight program.

   As it may be necessary in extended flights to use high caloric density foods, preliminary data are required to assess the potential use of such food sources.

2. Continued work in the field of food packaging to enable the accurate measurement of intake of food constituents is important.

   Any metabolic experiment depends on accurate measurement of food components consumed in the daily diet.

3. Continued development of improved urine and fecal collection devices to improve both metabolic balance studies as well as improving sanitation for the pilot is necessary.

4. Further research and development on the recycling of water, with purification to acceptable standards of potability for human use, should be made.

   For extended space flight the conservation of any water supply may be essential.

Ground-Based Experiments and Flight Crew Training Prior to Launching the ORL

1. The study of calcium metabolism at various phases of training under various conditions during preflight to establish baseline levels for each potential astronaut is recommended. Each man must serve as his own control in addition to furnishing data for statistical evaluation of space flight.

2. Extensive training in the handling of special foods, containers and reconstitution techniques during the flight training program as well as familiarization with the taste and digestive problems associated with special foods should be provided.

   Preflight orientation will minimize inflight problems.

3. A study of the effects of centrifuge simulation of the flight launch profile on the antidiuretic hormone activity and other urinary secretion control factors to provide parameters for comparison with both 1 G and zero G observation should be made.

   Adequate ground based experiments are required to assess the effects of gravity on urinary secretion mechanisms.

4. The preconditioning of the ORL crew members to a low caloric intake is recommended, and body fat stores should be normalized prior to flight. Metabolic studies to determine the caloric cost of activity should also be done.

In the event there is a space and weight limitation on the food available, conditioning programs are necessary.

Space Flight Experiments Prior to Launching the ORL

1. To fly an animal metabolic cage to determine the effect of weightlessness on metabolism (by means of oxygen consumption and carbon dioxide output determination), on H_2O balance, and calcium balance. The effects of weightlessness on peristalsis and muscle deterioration are also in need of exploration by means of animal flights.

   This is an endorsement of the Biostat program to encourage updating as soon as possible.

2. The determination of ADH activity during manned space flights by means of urinary assays. This determination relates not only to fluid requirements, per se, under weightless conditions, but also to blood volume and cardiovascular effects of weightless flight.

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LIVING CONDITIONS RECOMMENDATIONS

The following recommendations are given on the basis of clinical judgment and experience.

Life Support Factors

Body Functions and Hygiene

1. A high standard of personal appearance, dress, and tidiness of the cabin must be maintained.
2. A means of nonaqueous body hygiene should be available. The use of an oil for cleansing the skin may be desirable. Droplet contamination of the atmosphere by the cleansing material is to be carefully avoided.
3. The control of body odors is imperative.
4. Shaving should be by mechanical razor (spring-wound or turbo-driven). An electric razor should be used if the atmosphere provided does not impose the danger of spark-induced fire.
5. Haircutting and nail paring should be done by methods which avoid particulate contamination of the atmosphere.
6. A laundry facility or substitute, such as an adequate supply of disposable clothing, must be provided. This area is in need of investigation.

Decor and Illumination

1. The decor and illumination should be chosen not only for its present effect but should be such as to provide visual orientation as well. In the case of a rotating spacecraft (for artificial G) this should include indication of the direction of the centripetal force and direction of rotation of the spacecraft.
2. Recommendations for the illumination of wall surfaces, colors, and design of lighting are offered in references Morgan, C. T., 1963, Meaker, P., 1955, and General Electric Company, 1960.
3. Recommendations for the illumination of displays are offered in Morgan, C. T., 1963, pages 78 to 122. Here it must be borne in mind that the contrast between display light and background light is important. Special cases meriting consideration are the following: (1) the light required for a visual warning, (2) moving types of displays, and (3) visual displays requiring dark adaptation, i.e., radar displays, etc.

General Conveniences and Diversions

1. Ground-based radio and TV should provide the crew with periodic (daily) broadcasts of news and special events as well as personal messages.
2. Facilities for diversion should be available. These might include a small microfilm library, a TV or radio for use when orbital position permits, and a source of music such as a tape recorder. Personal earphones will permit the use of these without disturbance of other crew members.

3. Each crew member might be given a certain weight and volume allowance for recreational materials such as playing cards and other games. Game equipment will have to be designed for the gravity-free state. Early ground experience with flight crews working together would lead to joint selection of these materials.

Schedules (Work-Rest-Sleep Cycles)

1. A work-rest-sleep (W–R–S) cycle of 24-hour duration is the most suitable schedule. An 8-hour on and 16-hour off schedule is recommended. If the crew is large enough, the possibility of setting up two teams operating twelve hours out of cycle may provide a regular individual schedule yet round-the-clock hours for crew duties and maximum utilization of the facilities.

Man is fairly well accustomed to a sleep-wakefulness cycle of 24-hour duration. He has diurnal variations in both performance and physiological functioning which are adapted to this rhythm. When an atypical cycle is imposed, his physiological rhythms may be expected to show some adaptation to the non-24-hour periodicity, but the adaptation is not likely to be complete nor to be equal for all individuals.

2. Should limitations on crew size and operational constraints require the imposition of a non-24-hour work-rest-sleep cycle, the consistent day-to-day adherence to a *stable* W–R–S cycle is recommended.

The maintenance of a stable W–R–S cycle (as indicated by a superimposable body temperature curve peaking during wakefulness, and dropping during sleep) serves a dual purpose: (1) it makes for alertness and efficiency during working hours and (2) it insures an easy onset of sleep.

3. A review of existing literature seems to indicate that where "watches" are required, individuals adjust more favorably in groups where a 4-hour on and 4-hour off schedule is used than those where other schedules are used.

Work-rest-sleep cycle total durations based on 12-hour (Mills, 1950; Mills and Stanbury, 1951), 8-hour (Steinkamp, et al, 1959), and 6-hour (Adams, et al, 1961) time periods have all been studied extensively. These studies favor the above statement.

The most common division of standing watch, used in the United States submarine fleet, is the 4-hour on and 8-hour off schedule, which is in operation on an artificial 12-hour cycle. Reports in the literature indicate that while the duties of a submariner may be satisfactorily carried out on such a schedule, efforts to establish a 12-hour physiological rhythm in man have been uniformly unsuccessful on subjective, biochemical, and hematological bases. (refs. 9, 10, 5)

4. Thought should be given to the type of duty scheduled during the wakefulness period regardless of the W–R–S cycle used.

Kleitman (1962) has reported that efficiency of performance during a normal 24-hour cycle varies rhythmically throughout the course of the day. Efficiency was low upon arising, showed an initial ascent phase, a plateau in the middle of the day, and a terminal descent phase. Viaud (1945, 1947) has noted that performance immediately upon getting up from a period of sleep was often poorer than it was just before retiring. Kleitman, in tests with very small numbers of subjects on a 4-hour on, 4-hour off schedule, reported a "very low" capacity for work during the 4-hour interval separating the two sleep periods. Husband (1935) has reported similar findings using a 3-hour sleep, 3-hour awake cycle.

5. If an atypical schedule is to be used, it is recommended that preflight presynchronization periods be employed to provide for crew adaptation.

6. Preflight presynchronization should be accomplished in accordance with the ability of each individual member of the crew to adapt (those who adapt least well should be kept close to their typical schedule).

7. Where synchronization is found to be difficult, sedative and stimulant drugs may be used as an aid. Since this method is generally considered undesirable, it should be used only if the rapid adaptation of a particular individual is highly important and very difficult.

8. Local adaptation to an atypical cycle can be accomplished by new crew members as they arrive aboard the ORL if they are not required to go on duty immediately upon arrival.

Volume (Space) Requirements

1. As a minimal requirement for a 3-month mission there should be sufficient space for arms outstretched plus 1 foot, and the "ceiling" should be 1 foot higher than the astronaut's head.

2. Insofar as space is available, areas for on-duty activities and relaxation should be separate. An area of privacy away from the others must be provided individual crew members.

3. As space available is increased, assuming a stepwise approach to progressively larger orbiting laboratories, more normal room proportions should be achieved and space provided for exercise and group activities such as a "ward room."

Research and Development Prior to Launching the ORL

1. The development of techniques and materials for the accomplishment of body cleansing in space.
2. The development of technique and equipment for shaving, haircutting, and nail paring in space.
3. The development of techniques and equipment for the laundering of clothes in space.
4. The investigation of optimal clothing fabrics for space existence considering weight, skin tolerance, ease of laundering, ease of storing, and/or disposal (in lieu of laundering).
5. Investigation of the effects of angular acceleration on visual acuity.

Ground-Based Experiments Prior to Launching the ORL

1. Trial and long-term occupation of fixed-based simulators employing variations in lighting and color. Note effects on crew well-being and performance and interactions with other variables.
2. Preflight trial of displays in simulator.
3. Simulation of rendezvous maneuver.
4. Attempts at recognition of lunar and Earth landmarks by the use of charts and photographs.

Space Flight Experiments Prior to Launching the ORL

1. Experimental extravehicular recognition.
2. Practice rendezvous and docking.
3. Measurement of flux of light energy at various wave lengths.
4. Measurement of atttenuation of light achieved by the use of shielding materials.
5. The determination of the interaction between vision and weightlessness.
6. Experimentation with various combinations of non-24-hour W–R–S cycles in the weightless environment.

ORL Experiments

1. Recognition of extravehicular objects.
2. Interaction between visual characteristics and weightlessness.

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GROUP INTEGRITY RECOMMENDATIONS

Life Support Factors

Group integrity implies efficient and harmonious group functioning. In the context of space exploration it implies two or more astronauts working together, living together, and depending on each other for the efficient execution of the space mission. Although group integrity presupposes individual integrity, especially in those activities involving all members of the group, competent and well-motivated individuals do not always form a cohesive, harmonious, and efficient group. Further, initially well-organized groups can deteriorate with time, as continued stresses lower the anxiety and frustration tolerance levels of the weakest members. This report, then, will consider the problems and methods involved in obtaining and maintaining group integrity. It will also concern itself with the factors related to individual integrity and efficiency insofar as these are related to harmonious group functioning. However, it must be borne in mind that many considerations of individual functional integrity remain. These problems have been well-studied in the past and are documented in available sources. These considerations are not dealt with in detail in the text, but references are appended.

With the forthcoming multicrewmen program, new problems emerge which were not present or planned for in the one-man missions. Group interactions, involving added adjustments and integration of effort, create new situations needing evaluation as to their effect upon the success of the mission. An additional vector, one which may well compound the problems involved in group interaction, is the extended time required for the completion of the mission. These factors, extended time and group interaction, pose questions quite different in character from those encountered in the one-man, short-duration flight. The effects of these two new variables upon the selection, training, and in-flight aspects of the program must be considered.

Selection

Any negative effects of group interaction probably will not play a significant role in the currently planned two-week duration missions. In the first place, considerable attention has been paid to the emotional stability and adjustment capability of the candidates in the current selection process. Secondly, the excellent motivation and morale of the astronauts would minimize any tendencies toward group disintegration on a short mission. Finally, the mission will include relatively intense activity schedules wherein the crewmen will be involved primarily in task-oriented, rather than interpersonal-oriented behavior. This report, therefore, is directed toward extended mission requirements such as are pertinent to the ORL or lunar-based missions.

Recommendations

1. Expand the present psychological selection test battery to include tests and techniques which will evaluate candidate potential for positive group interaction. Areas of interest and need include:

a. group efficiency measured both in terms of group output and each individual's contribution to the team effort,

b. adaptation of the individual to group stresses,

c. flexibility of adjustment of an individual to different groups,

d. adaptation of the group, as a group, to the stresses of confinement, environmental and social monotony, and basic anxiety and frustration over an extended time period,

e. deterioration of morale and group efficiency over time under the continued stresses of extended space flight, and

f. leadership potential and decision making ability.

The additional dimension of group interaction over extended time periods under confining and frustrating conditions introduces additional complexities which may contribute directly to mission success. As a specific instance, locomotion and control of intracapsule objects under conditions of weightlessness will involve a learning experience which cannot be simulated or practiced to any extended degree before the mission and thus may engender a degree of annoyance and hostility, especially in the early mission phases.

2. Introduce into the selection battery a series of psychological measures which have been demonstrated to be sensitive to temporary or long-standing impairment of cerebral functions. During the last 20 years a considerable number of tests have shown excellent validity for this purpose. Specifically, the Category Test and Tactual Performance Test (Halstead), (refs. 2, 3, 5, 8, 10, 15, 16, 17, 22), various tests of rhythm and sound discrimination and the Wisconsin Card Sorting Test (Milner), (refs. 11–14), the Continuous Performance Test (Rosvold), (ref. 23), the Psychomet apparatus (Birren), (ref. 1), and the Trail-Making Test and the Picture Arrangement, Block Design, and Digit Symbol tests of the Wechsler Scale (Reitan), (refs. 1, 4, 6, 7, 9, 18, 19, 20, 21), should be studied with regard to their contributions to a core-battery.

The inclusion of the evaluation of "those abilities which are specifically related to cerebral functions which are particularly susceptible to variations" will provide for the systematic collection of data which may prove highly significant in (a) the assignment of crewmen to future missions and (b) the selection of future astronauts. The selection data collection plan should include consideration of the ability to conduct in-flight evaluations which will yield data directly comparable with preflight information. The purpose of this recommendation is to complete a systematically designed matrix of information on cerebral functions.

Findings to date suggest that the higher mental functions (excluding primary sensory and motor functions) group themselves into the areas of: (1) concept formation or abstraction abilities, (2) visuo-spatial and temporal patterns of organization, and (3) language and related symbolic representations for communications purposes. The corresponding regional areas of the cerebral hemispheres, in which intactness of function appears necessary for maintenance of the above abilities are, respectively: (a) one or both frontal lobes, (b) the right temporo-parieto-occipital area, and (c) the left temporo-parieto-occipital area (and probably including the posterior-inferior left frontal area). Other aspects of higher mental functions (4) perceptual awareness and (5) the ability to sustain high levels of vigilance over fairly extended time periods appear to be related morphologically to (d) overall, general cerebral functioning rather than to specific areas of the brain. Classification of the tests into the above psychological functions (1 through 5) and the corresponding regional or general areas of cerebral functions (a through d) would best be stated in a preliminary fashion as follows: Function 1—Halstead Category Test, Trail-Making Test, and Wisconsin Card Sorting Test; Function 2—Milner's tests of rhythm and sound discrimination as perceived through the left ear, the Picture Arrangement and Block Design subtests from the Wechsler Scale, the Tactual Performance Test score with the left hand, and comparatively poor performance on Part A as compared with Part B of the Trail-Making Test; Function 3—Milner's tests of rhythm and sound discrimination as perceived through the right ear, comparatively poor performance on Part B as compared with Part A of the Trail-Making Test, and possible analysis of the inflight verbal communications of the astronauts for indications of deterioration of language functions; and Functions 4 and 5—Rosvold's Continuous Performance Test, the Psychomet apparatus, and the Digit Symbol Test of the Wechsler Scale.

Although real-time data are not currently envisioned as necessary, provision for telemetering of data should be included to avoid loss of inflight data points in the event of landing malfunction.

Training

As a general principle, the training of astronauts should provide an opportunity for extending and supplementing the selection procedure. This is an endorsement of the current concept that the training program is actually a "selection-in-depth" process.

In particular, when group interactions within the crews during the latter phases of the training become well enough established, the data could be very useful in the final selection of compatible and efficient crews for a particular mission.

In addition to the training required to prepare for and complete a successful mission, training tasks should include a number of basic psychophysiological activities which would sample sensory, perceptual, sensory-motor, learning, and thought and decision processes which underlie ordinary human behavior. These data would provide essential baselines for the evaluation of in-flight performance and for the analysis of possible change due to extended flight experience.

Recommendations

1. a. During the training procedures, special attention should be directed to identify those individuals whose behavior and performance reduce group efficiency. Specific interactions between two or more members bringing about deterioration of group performance should also provide criteria for proper assignment of crew members. The above recommendations could be more easily implemented if "good" and "poor" crews, representing the extremes of efficiency, were subjected to careful psychological analysis.

b. The crews in training should be systematically reconstituted in order to (1) test hypotheses regarding crew efficiency, (2) promote flexibility and adaptability in group interactions, and (3) meet the possible contingency of a last-minute replacement of a crew member for an actual flight.

With the anticipation of multiman crews numbering four or more members, it will be virtually impossible to "scrub" an entire crew in the event that one member is unable to participate in the flight mission. It therefore becomes important to determine the effect of crewman substitution on the morale and efficiency of the basic crew. This recommendation is applicable to prerequisite R&D work and ground-based experimentation (discussed under those sections) and also to the systematic manipulation of astronaut crew members into different groups during their training experiences.

2. Ideally an actual mission should be preceded by a simulated flight of intense realism and of equal duration with astronauts as crew members.

This procedure would serve as an analogue of the "shakedown" cruise and would provide a realistic basis for developing appropriate countermeasures for possible failures in equipment or crew integrity. It is recognized that the practicality of this recommendation is problematical, also the predictive values of simulated missions are yet to be established. Meanwhile, this recommendation will serve to (1) provide the most adequate substitute for the in-flight situation, and (2) provide the basis for validating the simulation by means of the in-flight mission itself. If the ideal situation is impossible, it is recommended that the simulation be completed with as many mission similarities as are practical.

The use of astronauts in the simulated mission would make possible direct inferences to the astronaut population. Beneficial but less valuable results would be obtained from "astronaut-like" crew members. The value and pertinence of data from simulations with non-astronaut-like crew members, e.g., college students, etc., are highly questionable. The same type of thinking applies to simulation itself. The more realistic the simulation, the greater is the applicability of the data to the space flight situation.

3. At selected intervals during the training period, sensory and perceptual functions, sensory-motor and learning activities, and higher thought and decision processes should be tested to provide individual baselines of performance for each astronaut.

More specifically there should be tests of visual and auditory acuity, near and far depth perception, motor coordination, speed and dexterity (gross and fine), visual form and motion discrimination, temporal orientation and discrimination, kinesthesis and appreciation of body/limb positioning and interaction, vigilance, span of attention, continuous digit span, speech production and perception, problem solving (numerical and verbal), and logical analysis. In large part, the functions measured by these tests are related to the problems of maneuvering in a weightless environment and to the problems of "docking" and so have a decidedly practical orientation. Many of the tests involve standard test equipment (of the Republic and North American Aviation reports, 24–25); others need no special equipment, as in the case of evaluating speed of "suiting," quality of writing, and intelligibility of speech. The apparatus tests should be packaged into a Behavior Reaction Panel to conserve space and permit automatic recording.

Since these functions will be utilized in space, both within the capsule environment and outside the capsule, they need to be evaluated periodically throughout an extended space mission. Theoretical and practical considerations demand such a program. From a theoretical viewpoint it would be extremely important to know whether weightlessness has an effect on any of these functions. (Simulation would control for confinement, monotony, and group interaction effects on those functions). Practical considerations require that these functions be under continuous surveillance to assure integrity during the course of the mission. Post-testing on these same functions would provide an overall estimate of the changes induced by the entire mission. Retesting at intervals during the training period not only provides a more stable baseline but yields an estimate of expected variability within each function.

Research and Development Prior to Launching the ORL

Much information concerning the influence of variables encountered in space can be determined by performing ground-based experiments. With the exception of the effects of weightlessness and the actual psychological stress of space flight, both as single and as interacting variables, all of the known pertinent variables of immediate concern can be investigated as to their effects on the astronaut. Particularly, it would appear that most of the variables of interest in the selection process associated with preserving group integrity under a variety of exposures to both physical and psychological space factors are amenable to ground-based experimentation and identification. Once these variables have been identified, then appropriate tests can be either selected or developed to identify the desirable and undesirable factors in the astronauts and selection made accordingly.

1. Expand psychological test battery to include tests and techniques which will evaluate candidate potential for positive group interaction. Develop procedures (tests, ratings, etc.) to evaluate:
   a. group efficiency,
   b. adaptation to group stresses,
   c. flexibility to adjustment within different groups,
   d. deterioration of morale and group efficiency over time, and
   e. leadership potential and decision making ability.

No tests or valid measures of the variables of interest here have been standardized. Test construction and validation is time consuming and must be started without delay. Without such tests, no measurement in the areas of interest will be available, and then not only the selection process but the comparison methods of training will be handicapped.

2. Introduce into the selection battery psychological measures which have been demonstrated to be sensitive to temporary or long-standing impairment of cerebral functioning. Develop instruments and/or test procedures to make in-flight measurements of cerebral deficit or deterioration which are directly comparable to ground-based measurements.

Category Test and Tactual Performance Test, Wisconsin Card Sorting Test, Continuous Performance Test, Psychomet apparatus, Trail-Making Test, and Picture Arrangement, Block Design and Digit Symbol subtests of the Wechsler scale, miniaturized EEG and Critical Flicker Frequency (CFF) equipment are recommended for initial consideration.

3. During training procedures, special attention should be directed to identify those individuals whose behavior and performance reduce group efficiency. Develop a program to identify which specific crew characteristics serve as criteria for "good"

and "poor" crews (the extremes of efficiency in performance).

4. At selected intervals during the training period, sensory and perceptual functions, sensory-motor and learning activities, and higher thought and decision processes should be tested to provide individual baselines of performance for each astronaut. Many of the tests for the various sensory, perceptual, and higher thought processes are described in the North American and the Republic Aviation reports. These should be evaluated for reliability and repeatability and, where necessary, revised for adequacy and feasibility.

Many psychomotor tests and most tests of higher mental ability which are presently available are not designed for repeated valid administration. The need for repetition of the tests over an extended time period will be necessary in the in-flight evaluation of astronaut performance. In addition, preflight and postflight performances will need evaluation. This problem (repeated measurement) requires research for the development of appropriate tests, multiform if necessary.

Ground-Based Experiments Prior to Launching the ORL

1. Selected tests to measure cerebral functioning.

a. Conduct an evaluation program on tests or techniques which will detect even a slight trend toward cerebral impairment as a result of psychological concomitants of confinement as well as physiological changes, which is designed to:

(1) establish sensitivity of tests to space capsule conditions, and

(2) collect normative data under these conditions.

With the systematic variation of such conditions as (1) confinement and monotony, (2) time, (3) atmosphere composition, (4) atmospheric pressure, (5) contaminant level, and (6) other variables representing a threat to crew and individual integrity, these objectives can be met.

Such tests will aid in the selection of crews with high tolerance for changes in environmental space variables and will, under repeated administration, permit in-flight evaluation of changes in the astronauts' physiological and psychological integrity.

The test developed in response to the above recommendations must be capable of repeated valid administration. Further, the data yielded by the tests must be capable of immediate evaluation so that their usefulness in early detection will permit immediate remedial measures to be initiated.

b. Utilize any space and time facilities in other earlier manned experiments.

c. Develop flight-type instrumentation with which to make in-flight measurements directly comparable to measurements secured during ground-based experiments.

Through such measurements, it will be possible to compare the astronaut in flight with his baseline as secured on earth. Further, experiments performed on earth will have the potential of transposability and generalization of results to the in-flight situation.

2. Conduct simulations of specified missions manned with astronauts or astronaut-like crew members for durations equal to mission time. Measurements related to human reliability regarding flight control and allied mission tasks should be made. Also of prime importance are measurements regarding the nature of group dynamics and the effects which may be generated as a result of these interactions. In addition, the tests of the sensory, perceptual, and high mental processes should be conducted as they would on an extended space mission.

Such simulated missions will provide full rather than part task training. The confinement variable plus the problems associated with group interaction can only be discovered prior to actual flight in such real, time-full task simulation.

3. Perform a habitability experiment which will answer the qeustions:

a. What are the psychological effects of prolonged spatial confinement with its concomitant social restriction?

b. What are the psychological effects of restricted exercise?

c. What are the psychological effects of crowding?

All of the variables can be investigated in an experiment where exercise, spatial confinement, and number of individuals confined in a given-sized volume are the independent variables and performance on a battery of psychomotor tasks (as measured by a performance panel), critical flicker fusion, a form of the Categories Test, performance of operational procedures, and measures of group and individual interaction are measured as dependent variables.

As space flights continue, the time spent in such flights will increase. Because of engineering limitations, the space travelers will be faced with confinement to small spaces, restricted socially, crowded by other crew members, faced with a monotonous existence for long periods of time, and have reduced possibility for normal exercise. The effects of these variables on astronaut performance need to be understood.

Space Flight Experiments Prior to Launching the ORL

1. The currently scheduled Gemini and Apollo missions provide the opportunity to study (in retrospect) the group interactions which may occur dur-

ing space flight. It is recommended that an appropriate debriefing form be constructed to elicit this information once the astronauts have completed their missions. The purpose of such a study would be to note:

a. any atypical interpersonal behavior and to evaluate its effects on group efficiency (positive or negative)

b. any deviations in group efficiency and to determine if any atypical interpersonal behavior accompanied such changes.

A distinct advantage of this procedure is that data from an actual flight mission will be available for evaluation.

2. Every opportunity should be exploited to utilize as many behavioral procedures as feasible during the Apollo flights. These need not be complex; for example, simple motor dexterity (e.g., tapping) need take little time and can be correlated with other simultaneously monitored physiological indices (e.g., breathing, pulse rate, etc.) to study mobilization of effort under conditions of weightlessness.

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HAZARD RECOMMENDATIONS

Life Support Factors

Radiation (Electromagnetic Spectrum)

In order to consider exposure limits to ionizing radiation, several assumptions must be made regarding the flight profile. It is assumed for the present that the Orbiting Research Laboratory will be at an altitude of about 200 to 300 nautical miles at a 30° inclination from the equator. This flight trajectory will be protected from solar flare events since it is within the confines of the earth's geomagnetic force field and avoids exposure at the polar region. The primary radiation hazard, therefore, will be principally the electrons of nuclear fission origin that are encouraged at these flight altitudes. Traverse of the South Atlantic geomagnetic anomaly will cause several small radiation pulses to occur each day. A secondary radiation hazard will be the primary cosmic radiations. Though dose rates from the latter will probably not exceed 0.5 rad/week, this cannot be easily modified and will contain a significant portion of extremely high LET radiations. Since the biological effectiveness of these radiations is not thoroughly understood, continual surveillance for early damage to the eye and brain, for example, should be maintained.

Extremely eccentric orbits that might cause brief traverse of high-energy proton fluxes probably will not occur. It has been indicated that an associated drop in perigee altitude would induce atmospheric drag to foreshorten the useful life time of the mission.

It is additionally assumed that no effective means of prophylaxis and/or treatment of ionizing radiation injury will be available to the flight crew.

Two exposure limits are given:

(1) an allowable upper limit for prompt or brief exposures selected to avoid injury manifestations

(2) an allowable accumulated dose for a 1-year flight mission assuming a nearly constant, low, daily dose rate.

It is extremely unlikely that the suggested exposure limits will be reached since the flight profile does not cause potentially hazardous ionizing radiation parameters to be presented. Should they be reached, however, recovery of the crew can probably be accomplished within 24 hours. The expected time to recovery must be considered due to the varying latent periods for the diverse clinical manifestations of radiation injury. When time to recovery may be days to weeks, then the allowable exposure limits should be lowered.

Eye

1. *Ionizing radiation:* Upper limit dosage of 200 rad for a single exposure; 300 to 350 rad for accumulated exposure in a 1-year mission.

These doses are based on present clinical experience and Group judgment relative to lens opacities. These are minimum cataractogenic doses (refs. 5, 11, 17).

2. *Ultraviolet radiation spectrum* (14 to 400 milimicron): All wave lengths below 400 millimicrons should be screened out. (1×10^5 ergs/cm^2/24 hr

or 0.0024 cal/cm²/24 hr maximum tolerable for wavelengths of 220 to 320 millimicrons).

These doses are based on present clinical and animal research experience and Group judgment relative to harmful photobiologic effects to the eye (refs. 6, 11, 19).

3. *Visible radiation spectrum* (400 to 780 millimicron): The range of 0.2 to 2.0 cal/cm²/sec should be considered the maximum.

Retinal damage is unrelated, either quantitatively or qualitatively, to any particular portion of the visible light wavelength band, but it depends merely on the concentration of energy incident in this region of the eye. The 0.2 to 2.0 cal/cm²/sec limitation as the maximum allowable concentration of visible spectrum radiation on the retina is also based on present clinical and research experience and Group judgment.

4. *Infrared radiation spectrum* (0.78 to 6 micron): The maximum allowable concentration should be 0.2 to 2.0 cal/cm²/sec.

At 0.8 micron, 78% of incident energy reaches the retina. At 1.5 micron, 20% of incident energy reaches the lens and 3% reaches the retina. At 3 micron and above, essentially all of the incident energy is absorbed by the cornea. However, the band of greatest biological damage is from 0.8 to 1.2 microns. Because tissue damage is dependent on the concentration of energy absorbed by the portions of the eye upon which the infrared radiation is incident, criteria for maximum tolerable exposure of the retina should be essentially the same as that determined for the visible spectrum. In the absence of determinations for tolerable maximums of absorbed infrared radiation for the cornea, lens, and vitreous, it is recommended on the basis of Group judgment that the same limitation be used for these tissues as defined for the visible spectrum incident on the retina, 0.2 to 2.0 cal/cm²/sec (refs. 11, 16).

5. *Radiofrequency radiation:* The maximum allowable exposure should be determined according to the following conditions which will modify significantly the effects of microwave radiation:

a. the frequency or wavelength of the generating equipment
b. the period of time of exposure in hours, minutes, or seconds
c. the irradiation cycle rate, referring to the individual ON-OFF periods during a unit time interval (1 min), when total time of irradiation per minute is kept constant
d. air currents
e. environmental temperature
f. body weight, type, or mass and covering in relation to the exposed area
g. orientation or position of an individual influencing resonant conditions and standing waves
h. differences in sensitivity of organs and tissues
i. effect of reflections (ref. 9)

An exposure of 10 milliwatts/cm² may produce dangerous thermal effects under certain conditions (ref. 23). There is some evidence that microwave radiation is capable of inducing nonthermal effects as well (refs. 4, 15, 20).

Skin

1. *Ionizing radiation:* As a general consideration, set the 1-year accumulated dose to the skin below 1000 rad at energies less than 100 keV.

This dosage is selected on the basis of clinical experience for a single dose in radiation therapy (refs. 7, 25):

- Erythema (first-degree burn)
  - 200 rad at energies less than 100 keV
  - 400 rad at energies greater than 200 keV
- Blistering (second-degree burn)
  - 500 rad at energies less than 100 keV
  - Limit for higher energies automatically set by bone marrow exposure limits.

2. *Ultraviolet radiation:* Wavelengths below 365 millimicrons (refs. 11, 24) should be screened out.

Erythemal effect is produced by the wave band from 180 to 315 millimicrons with peak action in the region of 240 and 297 millimicrons. Tanning effect is produced by the wave band from 315 to 400 millimicrons. Antibacterial effect is produced by the wave band from 180 to 280 millimicrons with peak action at approximately 265 millimicrons. Antirachitic effect is produced by the wave band from 180 to 315 millimicrons by the production of Vitamin D in the skin; however, the minimum daily requirement is approximately one-tenth the erythemal threshold.

3. *Visible radiation spectrum:*

Essentially unexplored except in cases of photo-allergy; other effects are not known. Therefore, in the opinion of the Group, no limitation criteria can be given.

4. *Infrared radiation:* The range from 0.2 to 2.0 cal/cm²/sec should be the limit.

The band from 0.8 to 1.5 microns can penetrate to a depth of 3 cm if sufficient energy is involved. Penetration of radiation with a wavelength above 6 microns is virtually nil. In the absence of determinations for tolerable maximums of absorbed infrared radiation for the skin, it is recommended on Group judgment that the same limitations be used for this tissue as defined for the cornea, 0.2 to 2.0 cal/cm²/sec (refs. 11, 24).

5. *Radiofrequency radiation:* Observe the same recommendations as those given for the eye.

Bone Marrow

The ionizing radiation limits should be 150 rad as single exposure maximum and 300 rad as accu-

mulated exposure maximum in a 1-year time period.
This dosage is selected on the basis of present human experience (refs. 7, 25, 27).

Testes

The maximum tolerable limits for ionizing radiation are automatically set by those listed for skin and bone marrow.

Gastrointestinal Tract

The upper-limit for a single dose of ionizing radiation at the midline should be no greater than 100 rad.

Any dose above 400 rad to the midline of the body is associated with a high probability of inducing nausea, vomiting, and diarrhea with onset occurring within 4 hours of exposure.

It is extremely difficult to establish a fixed limit below which the probability of gastrointestinal symptomatology will be nil since these manifestations of radiation injury are susceptible to individual variation, psychogenic factors, combined stresses, and radiation dose and dose rate.

The exposure is set on the basis of present human experience (refs. 7, 25, 27).

Ears

The maximum noise level at the auricle should not exceed 85 decibels total average for all three bands of 300 to 600, 600 to 1200, and 1200 to 2400 cycles per second. Above this decibel level, ear noise guards should be worn (ref. 3).

In the judgment of the Group, maximum prolonged noise level at the auricle within the spacecraft should not exceed 55 decibels because of associated hindrance to speed communication.

Atmospheric Contaminants

Particulate Contamination

1. *Size:* It is recommended that no spicules larger than 50 microns in their longest diameter be allowed to remain in capsular atmosphere.

This opinion is based on the clinical experience and judgment of the Group members.

2. *Quantity:* In the absence of determination for tolerance maximums, it is the opinion of the Panel that the number of particulates per cubic meter should not exceed that which will induce ocular surface discomfort or pulmonary ciliary overload. An effort should be made to establish tolerance maximums for particles reasonably expected to become airborne in the spacecraft.

3. *Quality:* In the clinical judgment of the Group, the particles should be physiologically inert.

The possibility of an "inert" particle absorbing or adsorbing a gas or vapor in concentrations sufficient to induce a toxic reaction should be evaluated.

4. *General recommendations:* Lint-free fabrics, nonflaking interior surface of capsule, scuff-proof shoe soles, and particle-retaining floor material should be used.

If the proper precautions are taken before the flight, it probably would not be necessary to monitor *continuously* the number and size of particles in the atmosphere.

Gaseous Contamination

Maximum acceptable or time-weighted mean concentrations of exogenous toxic elements and compounds in the air for continuous (24 hours per day) exposure are not available for most toxic agents. Therefore, an effort should be made to establish such concentrations of the toxic agents most likely to be encountered in the atmosphere of the spacecraft.

Threshold limit values of some elements and compounds most likely to be present and to be possible sources of difficulty within the spacecraft environment are: antimony, 0.5 mg/cu m; arsenic, 0.5 mg/cu m; beryllium, 0.002 mg/cu m; cadmium (as oxide fume), 0.1 mg/cu m; chromium (as CrO_3), 0.1 mg/cu m; copper (as fume), 0.1 mg/cu m; copper (as dust or mist), 1.0 mg/cu m; lead, 0.2 mg/cu m; mercury (inorganic), 0.1 mg/cu m; mercury (organic), 0.01 mg/cu m; phosphorus (yellow), 0.1 mg/cu m; phosphorus (compounds), 1 to 3 mg/cu m; zinc (oxide fume), 5 mg/cu m; carbon monoxide, 100 ppm; chlorine, 1 ppm; cyanide, 5 ppm; fluorine, 0.1 ppm; ozone, 0.1 ppm. Limits for other toxic agents which might be present in the atmosphere of the spacecraft also should be considered. Special consideration should be given to the fact that exposures will be to mixtures of several substances. Freon contamination should be completely avoided (refs. 10, 14, 21, 26).

In the opinion of the Group, all materials used in the capsule should be tested under simulated flight conditions for the presence of and the kinds of trapped gases and volatile materials as well as volatile deterioration products which may be physiologically active. Abnormal atmospheric conditions should be created with the compounds detected and tested for physiological effect. Additive or possibly synergistic activity of mixtures of compounds should be tested. Testing time for these contaminants should extend over a time period at least equal to that of the flight duration.

2. *Aerosols and vapors:* Based on its professional judgment, the Group recommends that, wherever practicable, no highly volatile chemical reagents or materials should be carried which could contaminate the atmosphere, e.g.: ammonia, HCl, alcohol, etc.

3. *Flatus:* A diet should be selected that will produce little or no gas.

The volume of flatus reportedly varies from 500 ($\pm 50\%$) to 5000 ($\pm 50\%$) milliliters per 24 hours. The lower volume is associated with a milk diet and the higher volume associated with a legume diet. The composition varies and generally consists of:

Gas	%
CO_2	8 to 34
Methane	0 to 56 (combustibles other than hydrogen)
Hydrogen	
Nitrogen	10 to 64

The higher percentage of combustible gases is associated with a legume diet (refs. 1, 2, 8, 13, 22).

4. *General recommendations:* The diet should be such that a minimum volume of flatus is produced from its ingestion. The atmospheric filtration system should be such that atmospheric contaminants are prevented from accumulating in the capsular atmosphere.

Nutritional Contaminants

Water

1. *Insoluble contaminants:* In the opinion of the Group, all abrasive contaminant materials such as particles (e.g. fiberglass) from the storage containers or container wall degradation should be avoided.
2. *Soluble contaminants:* Based on its professional judgment, the Group recommends that ammonium, sodium chloride, potassium, and calcium salt concentration combined should not exceed 100 parts per million.
3. *Heavy metals, etc.:* The maximum permissible concentration of various elements for potable water should be taken from U.S. Code, Title 42—Public Health, if listed therein (ref. 28).

Examples of maximum recommended concentrations of materials which might contaminate potable water in the spacecraft are: arsenic, 0.05 mg/1.; cadmium, 0.01 mg/1.; lead, 0.05 mg/1.; and fluoride, 1 mg/1. The limits for soluble salts of other metals such as antimony, beryllium, bismuth, mercury, and thallium should be in the order of 1 mg/1. (expressed as metal). Maximum values for other chemicals potentially present should be established.

4. *Odoriferous contaminants:* The concentration of such odoriferous materials as H_2S or SO_2 should not exceed 10 ppm (ref. 10).
5. *General recommendations:* Supply anion-cation ion-exchange filter and activated charcoal filter for emergency use in case the water supply becomes contaminated so that condensate water may be used. A conductivity meter should be available for metering the drinking water. Carboxylic acid soaps should be used for hygiene purposes to facilitate removal in the recycling process. Sulfonated detergents should be avoided.

Food

Food to be used in the capsule should not contain insecticides, other toxic elements, or microorganisms in excess of levels which are considered safe by the Food and Drug Administration (refs. 12, 18). Certain contaminants such as antimony, arsenic, beryllium, cadmium, cyanide, fluoride, lead, mercury, and thallium should be mentioned as potentially harmful in the spacecraft. A few milligrams of some of these agents ingested in a single dose or ingested repeatedly could cause toxic effects. It is extremely difficult to establish a safe maximum daily intake (expressed as mg/24 hrs) for these elements because the toxicity of each can vary many fold depending on the salt or compound ingested.

Prevention and Control of Fire

1. Nonexplosive atmosphere.
2. All clothing should be flash- and fire-resistant.
3. No smoking and no open flame should be allowed in the capsule.
4. No readily combustible materials (e.g., matches) should be allowed onboard.
5. Explosion-proof circuitry throughout the capsule and wire insulation should be fire resistant.
6. Contact surfaces of the capsule interior, clothing, and shoes should be conductive so as to avoid static charge accumulation.
7. Capsule should be compartmentalized so that areas can be walled off by a fire-resistant curtain.
8. Astronaut should carry self-contained breathing apparatus with fire-resistant hood for emergency use in case of extensive fire so that the entire capsular atmosphere can be saturated with nitrogen and flushed overboard prior to replacement.

Micrometeoroids

Fire

See Prevention and Control of Fire.

Decompression

The Group recommends developmental research and investigation to devise a sealant for capsule perforation.

Capsular Fragments ("Shrapnel") from Impact

See Clinical Medical Support Panel report.

Safety Contour Design of Capsule Interior and Exterior

It is recommended by the Group that all sharp projections be avoided in the design of the capsular interior and that no unanchored supplies or equipment be allowed to free-float in the interior of the capsule.

Extravehicular Hazards

See Atmosphere and Suit Panel report.

Research and Development Prior to Launching the ORL

1. Development of a self-contained emergency breathing apparatus for use inside the capsule as protection against atmospheric contaminants. (See recommendation 8 under Prevention and Control of Fire.)
2. Development of a miniaturized hand-operated, ejection fire extinguisher (e.g., liquid CO_2, N_2, or fabric mesh-covered pellet which, when propelled against a burning surface, would adhere and release fire extinguishing gaseous material.)
3. Space-based study of fire and its propagation at zero gravity.
4. Development of a sealant for capsule perforation.
5. Development of a closed-circuiting mechanical device which would fit tightly against the skin and could be moved over it in order to cleanse the surface of the body with a cleansing solution self-contained within the washing device.

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CLINICAL MEDICAL SUPPORT

Life Support Factors

Flight Crew Medical Selection

The following recommendations are made for flight crew selection:

1. Since the avoidance of illness is best achieved by prevention, a rigorous program of selection should be set up.
2. In the selection process, every attempt should be made to bring to light a predisposition to both functional and organic illness which may interfere with in-flight performance. Among these are susceptibility to motion sickness, seizures, abnormal behavior, functional bowel disturbance, allergies, migraine, Meniere's disease, gall bladder colic, and kidney stones.
3. Excellent history taking is extremely important in this regard. The use of galvanic skin reflex apparatus in this activity is suggested in an attempt to validate the responses.

Illness and Injury Among Crew Members

1. A physician is desirable as a crew member and essential in conducting physiological or medical experiments. In the absence of a physician aloft, one crew member should have medical experience in handling emergencies.
2. Illness of a short term or minor sort may be treated aloft. Appropriate to the facilities and varied depending upon his medical background, the responsible crew member should be briefed regarding this prior to a mission.
3. A medical chest with drugs and supplies should be available for symptomatic treatment or specific therapy of diseases likely to be encountered such as:
   a. respiratory illness
   b. urinary infections and stones
   c. gastrointestinal disturbances such as mucous colitis, gastritis, peptic ulcer, or diarrhea of infectious or other origin
   d. cardiac arrhythmias
   e. disturbed emotional state
   f. aspiration of foreign body
   g. minor trauma
   h. burns
   i. foreign body in the eye
4. Drugs used aloft should, if possible, have been tested in situations with similar atmospheric conditions.
5. A microfilm reader describing diagnosis and treatment of such disease would be especially important to include in the absence of a physician for compiling data for transmission to a medical monitor on the ground.
6. The following suggestions are made with regard to the return of ill crew members to earth:
   a. minor or short term illness should remain aloft

b. serious illness should be returned to earth:
   (1) if something can be accomplished there
   (2) if the patient can withstand reentry. The hazard of reentry should be balanced against the benefits to accrue.

c. every attempt should be made to diagnose early and return to earth before a state develops that would prevent the trip.

7. In the design of the capsular interior, all sharp projections must be avoided and no unanchored supplies or equipment should be allowed to free-float in the interior of the capsule.
8. The danger of a shrapnel effect from micrometeoroid penetration should be investigated prior to flight. If the danger does exist, adequate preventive measures must be developed.
9. If death occurs, the body should be returned immediately to earth or preserved for autopsy at a later date.

Medical Safety Monitoring

For detailed discussion of medical safety monitoring, see the Appendix at the end of Phase I.

*Monitoring of the Environment**

Cabin

If the cabin is compartmentalized, these recommendations apply to all compartments.

1. *Pressure (CD# and GT**):* A fall in pressure below normal range should activate auditory and visual signals.
2. *Wall temperature (CD and GT):* Fire warning system to be decided.
3. *Atmosphere:* (Partial pressure oxygen and carbon dioxide, temperature, and relative humidity.) CD and GT launch and reentry. A "significant" deviation from the normal range should activate a visual signal to astronaut on watch.
4. *Atmospheric contaminants (CD)*
5. *Circulation of air (CD):* Failure should activate a visual signal to astronaut on watch.
6. *Force environment (GT)*
7. *Radiation:*
   a. Environment: Methods and location to be decided.
   b. Hazard: Solar flare warning system to be decided. Onboard as well as ground-based (refs. 1, 2, 9) detection facilities are required inasmuch as ground-to-spacecraft communication will be intermittent.

Suit

The following recommendations are made for suit monitoring:

1. *Inlet temperature, circulation, partial pressure oxygen, and carbon dioxide:* Should be monitored and, within limits of feasibility, telemetered during launch and reentry. Decisions here are still to be made.
2. *Relative humidity:* Should be monitored but need not be telemetered.
3. *Extravehicular circumstances:* Methods to be decided.

Monitoring Fitness of Astronauts

The need for monitoring the *medical* and *professional* fitness of the astronaut during different stages of flight is discussed in the detailed report attached. On the principle that group safety takes precedence over individual safety, it is concluded that a launch abort cannot be justified on the basis of medical unfitness restricted to one astronaut; hence, monitoring physiological parameters during launch must be justified mainly on other grounds. It is further concluded that in orbital flight the big problem centers around the professional and medical fitness of the astronaut for reentry. The importance of taking advantage of "naturally occurring opportunities" aloft, including the use of the astronaut as a "biological sensor," is emphasized. It is assumed and advocated that one crew member will be a physician.

For launch and reentry periods, see the detailed recommendations. The question of "representative" monitoring of physiological parameters on one or two astronauts is still to be answered.

For the orbital period, there should be:

(1) Daily evaluation and reporting of astronaut's fitness. (See suggested form in detailed report.) Emphasis is placed on the value of serial measurements as indicators of early trends (ref. 3).

*Onboard intercommunication (voice and video) and maximal intercommunication spacecraft and ground station are assured.
#CD: continuous onboard display.
**GT: spacecraft to ground telemetry.

(2) Weekly evaluation (see form). A provocative test for physical fitness is emphasized.
(3) Bimonthly evaluation (see form). A medical examination and provocative test of professional fitness is emphasized.

Supporting Personnel

It is suggested that one or more "assistants" be charged solely with the assignment for medical safety monitoring. This would involve setting up a plan and assigning values to stresses and probability values to risks. This plan would undergo constant revision in terms of the great amount of new information becoming available and the changing requirements in terms of how safety monitoring interdigitates with plans dealing with other aspects of the mission.

Animals

The possible use of animal subjects as biological indicators deserves consideration.

Research and Development Prior to Launching the ORL

1. Constant surveillance for more sensitive and more predictive methods to be incorporated into crew selection procedures.
2. Investigation of the effect of transfusion of plasma or blood on man under zero G conditions. Susceptibility may change with loss of circulatory reflexes.
3. Research and development concerning in-flight detection of atmospheric contaminants.
4. The development of methods enabling the prompt detection of solar flares and means of transmitting this information from ground-based stations to spacecraft.
5. The development of a prompt fire warning system.

Ground-Based Experiments Prior to Launching the ORL

1. The occurrence of untoward reactions to all of the medications included in the medical chest should be predetermined for all crew members and notations made and alternate medications included. Any special effect of the ORL atmosphere on drugs contained in the medical chest should also be predetermined.
2. As space flight experience accumulates, a careful check should be maintained of our experience with illness and drugs in space.
3. Continued surveillance should be made of methods used for flight crew medical selection so that they can be constantly evaluated and improved.
4. Evaluate methods of medical safety monitoring during parabolic flight to determine feasibility of their use in a weightless environment.
5. Simulation studies are recommended.
   a. They are required to devise and validate test batteries for medical and professional fitness. Here the emphasis should be on prolonged confinement (ref. 7) rather than simulation of weightlessness.
   b. They are required to obtain background information on prospective crew members under the most realistic simulated conditions possible.
   c. Weightlessness simulation studies are required to identify the most important physiological parameters indicating loss of fitness (refs. 4, 6, 10).

Space Flight Experiments Prior to Launching the ORL

1. The items noted in the clinical test battery for surveillance of astronaut and environmental fitness should be tested in actual space flight aboard Apollo or MOL vehicles during their manned missions. This would be of great value toward establishing their validity and ease of accomplishment.

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Appendix to Phase I

MEDICAL SAFETY MONITORING

Medical safety monitoring is defined as the provision of information throughout a mission to ensure, within an acceptable risk, the return of the astronauts in good health. In tackling the problem in advance of the final "deadlines" when all flight parameters are known and the latest flight experience is available, it is important to reach agreement on the general concepts underlying safety monitoring in order to "update" tentative recommendations with the necessary facility. Accordingly, a limited analysis of the problem is outlined from which may be drawn certain generalities.

Three important guidelines have been followed: (1) parameters of the flight insofar as they have been defined, including six months' exposure to weightlessness; (2) group safety takes precedence over safety of an individual; and (3) the safety information coverage is for one flight with little or no regard for subsequent flights in the program.

The analysis is considered from two related standpoints: (1) the astronaut at different stages of flight and (2) the classes of phenomena to be monitored and their relative significance. The astronaut is at once a person with safety tolerance limits, an essential element in flight systems and operations, and an active or passive biological indicator. The three important stages of flight center around launch, orbit, and reentry.

The Astronaut at Different Stages of Flight

Launch

Launch is further subdivided into three periods:

Preparatory: During this period, vital serial baseline measurements on the astronauts are obtained for future comparison under resting, provocative testing, and simulated flight conditions.

Countdown: Monitoring physiological parameters when it is still possible to delay takeoff and remove the astronauts without risk requires different "tolerance limits" or standards than at later stages of flight.

Power Phase (when "escape" or "abort" entails a risk): At time of launch, the astronauts are demonstrably at peak fitness, and it is almost inconceivable that any diagnosis based on medical information obtained on an astronaut during this phase would justify an abort with its conseqeunt risk to the entire group.

Orbit

In orbit, three periods might be defined:

Transitional: Experience suggests that the transitional period will be well tolerated and that it will not last long. The astronauts should remain suited during the transitional period and until the Life Control Systems have been checked out. Thereafter, whether the astronaut on watch should remain suited to cope with an emergency is a matter to be decided on a "probability-of-occurrence" basis. The need for *continuous* monitoring of the astronaut on watch, whether in or out of the suit, is hardly justified on his use as an indicator of hazard or danger.

Intermediate: Safety monitoring during the intermediate period has daily, weekly, and bimonthly requirements which may vary depending on needs.

It may be assumed that the risk will increase as a function of time in orbit even if no significant effects appear ascribable to weightlessness. We can only speculate on which organs and systems may be significantly affected by zero G. At any given time, fitness for reentry is more critical than fitness to carry out the tasks aloft; hence, safety monitoring in orbit has as its main objective safe return to earth. Whether the astronauts should be fit at all times for reentry or whether special conditioning in the predescent period should be relied upon will be decided, in part, by reliability of LCS and, in part, by experience.

Predescent: The predescent period, unless shortened by emergency, should provide ample time to conduct refresher training, which will also serve as a performance test, and to evaluate general fitness. A critical decision may arise as to whether to use "unusual" procedures to temporarily increase astronaut fitness and whether special provisions (such as reducing elapsed time to pickup) should be made on the ground for the return of a sick or injured astronaut.

It is assumed that one astronaut in the ferry vehicle may ride as "passenger."

Reentry

A comparison of the situation at launch and reentry points up dramatic differences. Takeoff may be delayed indefinitely until all systems and all astronauts are "go," whereas reentry is obligatory within a specified time period. Prior to launch the astronauts are superbly fit when subjected to "full simulation" tests, whereas at reentry they are not only less fit but "full simulation" tests may not be feasible. There is opportunity for abort during launch but minimal opportunity during reentry. Finally, launch ends in the comfortable lap of weightlessness while reentry ends in impact with survival hazards in prospect.

Classes of Phenomena

In discussing "classes of phenomena to be monitored," two main categories will be considered: (1) environmental factors and (2) the astronaut. It is assumed that communications between spacecraft and ground control will provide a full exchange of information at monitoring stations.

Environmental Factors

Environmental factors have been subdivided into "hazards" and "known stresses." A hazard is defined as a stress which has only a probability of occurrence while, inevitably, known stresses will have to be borne. Six principal hazards have been considered:

1. Malfunction or failure of Life Control Systems. Continuous monitoring of environmental parameters of spacecraft and suit, when worn, provides not only the early warning signal to institute countermeasures but also is tantamount to "diagnosis" in predicting effects on the astronaut. This is the most important area in safety monitoring. Using the astronaut as an "indicator" is a secondary, but poor, line of defense and useful only in instances of minor malfunctions.

2. Monitoring the force environment during launch and reentry is not regarded as part of safety monitoring; however, the probability of hazards incidental to a tower escape or launch abort or an impact during the reentry period and survival is related to astronaut fitness.

3. The identification of possible contaminants in atmosphere, water, food, et cetera, represents a difficult and partly unsolved problem which overlaps the considerations of the Panel on Hazards. Because of the difficulties in recognition, a second defense line is needed, namely, diagnosis of their effects on the astronaut. Medical toxicology, which is never easy, is doubly difficult under conditions aloft.

4. If there is a need for early recognition of geomagnetic storms and relativistic flares, the latter, at least, should be monitored aloft.

5. Meteorites deserve special attention in terms of varying probabilities of hits under special astronomical conditions and the need for one astronaut to be suited at all times to cope with emergencies.

6. Survival hazards after impact cannot be monitored per se, but the most likely stresses should be considered in terms of astronaut fitness.

The known environmental stresses fall into two categories, namely, those whose effects on the astronaut are: (1) known or (2) unknown.

1. With regard to "known effects," it is important to correlate the stress profile with the effects to determine if there is an unusual response.

2. Weightlessness is a "known" stress with

"unknown" effects. Prolonged exposure to weightlessness should be monitored in terms of inertial forces generated by the astronaut, restraints which counter the effects of weightlessness, and, possibly, librational forces, inasmuch as their long-term effects may be important. Insofar as measurements on the astronaut are concerned, high reliability and good validity take precedence over feasibility, since it is better to forego a test than interpret an erroneous value. In addition to telemetered items, medical fitness forms which should be filled out daily are proposed for use aloft. The three forms are similar except for the inclusion of additional items at one-weekly and four-weekly intervals.

The Astronaut

Monitoring the astronaut falls into two main categories: (1) detection of physiopathological effects, and (2) evaluation of fitness. Fitness may be considered under two headings, spontaneous illness and weightlessness.

Spontaneous occurrence of serious diseases, while unlikely in young persons over relatively short periods, cannot be neglected. The possibility of certain injuries, infections, and functional disorders would seem to be slightly greater in weightlessness than under ordinary conditions. Accurate diagnosis is the basis for proper therapy, and early diagnosis may be important for safety if the astronaut could not be treated aloft.

Weightlessness is the great independent variable around which the first ORL flight will be centered. It is essential to be on the watch for *beneficial* as well as *harmful* effects. American and Russian experience points to an initial period of adaptation with respect to major bodily systems.

The Russian experience suggests the possibilities of vestibular sickness, first stage heart block, and prolongation of mechanical systole; nearly everything else is speculation, including the possibility of disturbances in vision and sleep. The American experience must be interpreted in the light of physical restraints and multiple stresses. Restraint would have greatly lessened the tendency to vestibular symptoms, and it is possible to account for the symptoms experienced or manifested on factors other than weightlessness. The findings from Project Mercury, nevertheless, when considered along with the results of simulation studies using bed rest and water immersion, suggest that, in the absence of countermeasures at least, special attention should be given to fluid electrolyte balance, reduced blood volume, nitrogen loss, loss of endovascular control, disturbances in vision, sleep, and psychomotor responses, muscular asthenia and fatigue, and possibly personality changes.

The effects of prolonged weightlessness, possibly involving cellular and subcellular systems, might not give rise to familiar syndromes or illnesses, hence might be misdiagnosed, at least with respect to etiology and the time course of the effects in terms of adaptation or progressive deterioration. This points up the need for "undirected" monitoring. It is considered that monitoring the long-term effects of weightlessness is not critical over short periods of time and therefore need not be continuous.

Monitoring astronaut fitness for space flight activities deserves the most careful and detailed consideration. It has important relationships with the monitoring of environmental factors and astronaut health. Monitoring astronaut fitness in orbit has limitations in terms of comparability with ground-based data, test equipment, and the condition of the astronaut at time of testing. This suggests that every element in fitness testing aloft be considered from the standpoint of prior ground-based testing which would serve a useful purpose. As pointed out earlier, since fitness for activities in orbit is less demanding than for reentry, this should serve as the reference criterion for validating fitness tests.

Fitness for reentry falls into two categories: (1) fitness to withstand the environmental stresses and perform the work incidental to survival after impact and (2) fitness to carry out the professional astronautical tasks while undergoing the stresses. Fitness testing may be specific or nonspecific (performance or nonperformance). Every effort should be made to take maximal advantage of the astronaut's activities aloft with regard to their value in estimating fitness for recovery. Simulation of the astronaut's professional tasks on reentry and hard physical work should be feasible. The fact that simulation of the force environment on reentry and transition from weightlessness to one G may not be feasible points up a critical deficiency.

If an astronaut should become unfit for reentry in the conventional manner, such a decision would necessitate his return as a "passenger" with the aid of unconventional procedures.

Tolerance Limits

Arbitrary "tolerance limits" may be misleading unless qualified. With regard to environmental parameters, "tolerance" may be exceeded with the appearance of a contaminant which may have little or great effect on the astronaut over the same period of time. Trends may appear before "tolerance limits" are approached. With regard to the astronaut, tolerance limits may refer to "comfort," "inefficient," or "disability" zones, and time is an important dimension. For example, in a healthy person over a six-month period there is no upper tolerance limit with respect to blood pressure per se; however, there may be if it is used as an "indicator," and here the circumstances become important. The point to be made is that tolerance limits as usually presented may require interpretation in terms of circumstances and especially in terms of any important action to be taken.

Summary

The foregoing remarks may be briefly summarized as follows: Safety monitoring falls into two main categories, environmental factors and astronaut parameters. With regard to the former, monitoring malfunction or failure of LCS, which begins prior to takeoff and ends after impact, represents the most critical need. With regard to the astronaut, the problems incidental to launch and orbit are not as cirtical as those of reentry. Evaluation of astronaut fitness for reentry at periodic intervals is essential and, in addition, early recognition of symptoms or manifestations which might eventuate in "unfitness" will provide invaluable lead time.

The following forms were developed as preliminary guidelines for developing appraisals of onboard physical evaluation techniques.

ASTRONAUT BIOMEDICAL CARE DAILY EVALUATION OR FLIGHT RATING

Name or initials__________ Date______ Hour______

Estimate* of fitness, mental__________ physical__________

Estimate# of performance in professional tasks__________

Any drugs other than vitamins__________

Any indication of illness______ disorder______ injury______ infection______

Sleep: 24 hr. total___; No. periods___; Sufficient______; Insufficient______

Mental attitude: Usual___; Bored___; Irritable___; Anxious___; Phys. restlessness___

Headache______. Ocular disturbance______. Visual disturbance______.

Abnormal odor______. Abnormal taste______. Tinnitis______. Vertigo______.

GI: Food: ate all___ or___% of ration. Appetite: Good___. Fair___. Poor______.

Indigestion__________. Nausea__________.

B. M., No.__________ Char.__________.

HOH: Drank all__________%__________ration.

Resp: Pain___; cough______; sputum______; aspirate foreign material______.

C-V: Unusual dysp.______; unusual palpitation______; substernal pain______.

G-U: Urin. No. × 24 hr.___; pain______; burning______; urgency______.

Neuromuscular: Pain______. Weakness______. Tremor______. Coord.______.

Skin normal______. Sweat normal______; Fatigue*__________.

Other comments:__________.

TO BE FILLED IN BY BIOMEDICAL REVIEWER

Oral temp.______ BP______ PR______ RR______.

General appearance__________ Color__________.

Performance scores, Prof. Tasks__________? Exercise__________.

Concordance of subjective and objective evaluations: Good___ Fair___ Poor______.

Estimated fitness for reentry** Prof.__________ Work__________.

Action items

Onboard__________

Consult ground-based observer__________

Action taken__________

* Based on 10-point score. 5 = usual; 10 = best score.

** 10 = very fit; 1 = unfit.

\# Based on load/time/accuracy: 10 = best; 5 = usual; 1 = worst.

\## Same for all days except every 7th and 28th.

DAYS 7 AND 21 OF EACH MONTH

Body weight centrifugal or best substitutes ______

Times V. C. ______

Flack ______

Submaximal exercise with chest lead V_4. ______

ECG alterations ______

Max. heart rate ______

Recovery time (min) heart rate ______

Symptoms: Pain ______; Palpitation ______;

Dyspnea ______; Fatigue ______

DAYS 14 AND 28 OF EACH MONTH

Medical Examination:

Laboratory

Blood: Morph. ______ Eosinophile Ct. ______

Hematocrit: ______ Bl. vol. or best substitute ______

Urine: Glucose ______ Proteins ______

Bilirubin ______ Ketones ______

Stool: Gross abn. ______ Occult. bl. ______

Estimation of Fitness for Reentry:

Prof. qualif.: simulation test.

Hard work: substitute capacity test for submaximal exercise test.

High-G load: simulation or best substitutes.

1-G Load: simulation or best substitutes.

MONITORING EVALUATION

Item	Hazards and Environment of Cabin				Comments
	Tolerance limits	Tele-meter*	Ground-based effort required	Orbital flight required	
General					Much depends on gas used, config., with Gemini, Apollo and MOL info guides
Leak	>normal	C			
Decomp.	Alarm, visual, and auditory	C			
Wall temp.		C			Function of connection
Atmospheric temp.	Comfort zone long duration Tolerate 110° short periods	C			
Circulation of Atmosphere	On-off basis	C			
Humidity	? 10 mm Hg	? C	Improve equipment		Avoid dew point
O_2	Not less than 100 mm Hg (alveolar) except short periods	C			
N_2	?				Alveolar exchange a ? problem zero G
CO_2	8 mm Hg higher for short periods	C	? Improve equipment		
CO		P			See report on Hazard protection
Contam.		P			See report on Hazard protection
Radiation	Relativistic flare; requires descent	C			Onboard monitoring equipment
Meteorite	?				?Useful monitoring aside from loss of cabin pressure
Gravitational Inertial force	Known				"Profile should be available"

Item	Astronaut				Comments
	Tolerance limits	Tele-meter*	Ground-based effort required	In-flight experience required	
Suit: General					Much reliance should be placed on Gemini, Apollo & MOL experience
Inlet temp.	? 75°(60-100 range)for short periods	C			
Inlet humidity	10 mm Hg $\pm$ 3 G	C			Highly desirable
O_2	>160 mm Hg min.	C			
CO_2	10 mm Hg: higher for short periods	C			
Circulation	On-off signal	C			
Physiological: S - C intercom					
Voice ground	Launch and reentry	C			
Orbit		P			
TV					Not essential
Resp.		C			Essential count down
ECG	Acute cardiac incident	C			Essential count down
BP	Shock levels	P			Essential count down
Body temp.	Unexplained rise >5° F (1.5° C)	C			Great advantage with continuous rect. temp. during count down

* C: continuous; P: periodic.

ONBOARD EXPERIMENTAL DECISION GUIDELINES

(Daily)

Name or initials ______________________ Date ________ Hour ________

Item*	Tolerance limits**	Experiments required		Recommendations or comments*
		Ground-based exper.	Space-flight exper.	
Est. of fitness***		Trial	Trial	OBAI
Mental	A = <4 Δ = dec >1 inc >2	Yes	If pos.	Inc >3 = ? tendency to euphoria
Physical	A = <4 Δ = dec >1	Yes	Yes If pos.	OBAI
Est. of performance Prof. tasks	A = <4 Δ = dec >1	Yes	Yes If pos.	OBAI
Any drugs other than vitamins		Yes		All drugs in chest should be tried on each astronaut for (1) idiosyncracy and (2) influence on tasks
Any indication of				
Illness				Matter of judgment
Disorder				Matter of judgment
Injury				OBAI
Infection				OBAI
Sleep 24 hr total	A = <4 Δ = progressive dec >2 or inc >2			OBAI OBAI
No. of periods	Δ inc or dec > 3 if unexplained			
Sufficient	Discrepancy with tolerance limits			May indicate adaptation May be OBAI

*OBAI: onboard action items; GBO: ground-based observer.
**A: tolerance limits; Δ: change or trend.
***Based on 10-point score: 5 = usual; 10 = best score.
#Based on load/time/accuracy: 10 = best; 5 = usual; 1 = worst score.
##Same for all days except every 7th and 14th of each month.
###10 = fit; 1 = unfit.

(Daily cont.)

Item*	Tolerance limits**	Experiments required		Recommendations or comments*
		Ground-based exper.	Space-flight exper.	
Sleep, cont. Insufficient	Discrepancy with tolerance limits			May be OBAI
Mental Bored				May be used as synonym for "apathy or fatigue"
Irritable				OBAI ?
Concerned (anxious)				OBAI
Physical restlessness				OBAI ?
Headache				OBAI
Ocular abn.				OBAI
Visual disturbance				OBAI
Abnormal sense of smell				OBAI
Abnormal taste				OBAI
Tinnitis				OBAI
Vertigo				OBAI
GI Food Ate all ___ %___ ration				? OBAI
Appetite Good				

(Daily cont.)

Item*	Tolerance limits**	Experiments required: Ground-based exper.	Experiments required: Space-flight exper.	Recommendations or comments*
GI Appetite, cont. Fair	Good to fair unexplained >3 days			OBAI
Poor	Fair to poor >2 days Good to poor >1 day			OBAI
Indigestion	>1 - 2 days depending on severity Trend progressive 3 days even if slight			OBAI
Nausea				OBAI
B. M.: No.	Δ inc >2 longer than 1 day			OBAI
Character of BM				Possible OBAI
HOH Drank all ration				Baseline
%____ration	>or <25%			Possible OBAI
Respiration: Aspirate Foreign Material				OBAI
Pain				OBAI
Cough	Persistent			OBAI
Sputum				Possible OBAI
C-V Dyspnea				OBAI
Palpitation				OBAI
Substernal pain				OBAI
G-U Urin. no. times in 24 hr.	Δ inc 3 days Δ inc 1 night			OBAI

(Daily cont.)

Item*	Tolerance limits**	Experiments required		Recommendations or comments*
		Ground-based exper.	Space-flight exper.	
G-U cont. Pain				OBAI
Burning				OBAI
Muscular Pain				OBAI
Weakness				OBAI
Tremor				? OBAI
Coord.				OBAI
Skin Abn.				Possible OBAI
Sweat Abn.	Inc day Inc night			Possible OBAI OBAI
Fatigue***	Unexplained			Possible OBAI
Other comments				
Oral temp.	Inc 1.0° F			OBAI
BP	Dec any day 30%			OBAI
PR	Inc 10 under controlled cir.			OBAI

(Daily cont.)

Item*	Tolerance limits**	Experiments required: Ground-based exper.	Experiments required: Space-flight exper.	Recommendations or comments*
RR	Inc 25% unexplained			OBAI
General appearance				? OBAI
Color				? OBAI
Performance Scores: prof. tasks	Dec trend 20%			OBAI
Exercise				
Est. fitness for reentry### Proficiency				
Other work characteristics				
Correlation objective and subjective information: Good				
Fair				?OBAI
Poor				OBAI
Action items OBAI				
Consult GBO				
Action Taken				

SUPPLEMENT TO DAILY FORM FOR DAYS 7 AND 21 OF EACH MONTH

Item*	Tolerance limits**	Experiments required: Ground-based exper.	Experiments required: Space-flight exper.	Recommendations or comments*
Body wt. (centrifugal or best substitute)	A $\pm$ 15%	Yes	Yes	OBAI
Respiratory				
Timed vital capacity			Yes	
Status of volume velocity loop				
Calibrated Valsalva maneuver (Flack test)		Yes	Yes	
Heart				
Submaximal exercise with chest lead V_4 until heart rate stabilizes		Yes	Yes	Equivalent to 3-min modified Harvard Step test
ECG alterations	Coronary disturbance evidence of coronary heart disease, bundle branch block	Yes	Yes	OBAI
Max. heart rate	Inc 10 - 15%		Yes	OBAI
Recovery time (min) heart rate		Yes	Yes	
Symptoms				
Pain				OBAI
Undue dyspnea				OBAI
Undue palpitation				?OBAI
Undue fatigue				?OBAI

SUPPLEMENT TO DAILY FORM FOR DAYS 14 AND 28 OF EACH MONTH

Item*	Tolerance limits**	Experiment required		Recommendations or comments*
		Ground-based exper.	Space-flight exper.	
General physical medical evaluation				
Laboratory Blood Morph.				
Eosinophile count				(Dr. Swisher)
Hematocrit	Δ 10%			OBAI
Blood vol. or best substitutes		Yes	Yes	
Urine Glucose	Presence			OBAI
Proteins	Presence			OBAI
Bilirubin	Presence			
Ketones	Presence			OBAI
Stool Gross abn.				? OBAI
Occult bl.				OBAI
Est. of fitness for reentry Prof. qual.		Yes	Yes	Simulation test
Hard work		Yes	Yes	Substitute capacity test for sub-max. exercise test
High-G load		Yes	Yes	Simulation or best substitutes
1-G load		Yes	Yes	Simulation or best substitutes

phase II

INFLIGHT MEDICAL EXPERIMENTS FOR ORL

Neurological and Psychological Functions

Dr. Baldwin
Dr. Buesseler
Dr. Graybiel
Dr. Kubis
Dr. McFarland
Dr. Reitan
Dr. Townsend

Circulation and Respiration

Dr. Carlson
Dr. Forster
Dr. Natelson
Dr. Schmitt
Dr. Warren
Dr. Wood

Digestive, Metabolic, Endocrine, Thermoregulatory, Neuromuscular, Skeletal, Fluid and Electrolyte, Renal, Reproductive, Hematological, Immunological, and Cellular Functions

Dr. Gordon
Dr. Knoblock
Dr. Pollack
Dr. Swisher
Dr. Whedon

Consultants to All Three Panels

Dr. Deichmann
Dr. Grahn

PHASE II

Inflight Medical Experiments for ORL

NEUROLOGICAL AND PHYSIOLOGICAL FUNCTIONS

EXPERIMENT 1

1. *EEG Changes During Arousal and Drowsing*
2. *Estimated Priority*
   Priority 2.
3. *Purpose*
   To observe EEG changes during the phases of the work-rest-sleep (W–R–S) cycle.
4. *Justification*
   From prior ground-based experiments, it seems clear that there is a continuum of EEG patterns which relate to levels of alertness and drowsing. Under the unusual conditions of the manned space flight system, peculiar work-rest-sleep (W–R–S) cycles may be imposed. Therefore, it is extremely important to monitor levels of alertness and concomitants of drowsing in order to increase understanding of these cycles aloft. The problem of adjustment from a 24-hour pattern to the cycles aloft has not yet been solved.
5. *Experiment*
   Hypothesis: Each member of the flight crew will have patterns of EEG activity typical of alertness or drowsing, and, if these are analyzed in sequence of real time, a continuum can be established. Such observations should be correlated with relevant psychological and other physiological experiments which are outlined elsewhere in this phase.
   Materials: 8-channel EEG system with "helmet" scalp electrode holders for ready application. Telemetering capability is desirable. A considerable instrumentation development is also required in order to package satisfactorily for flight.
   Subjects: The inflight personnel.
   Records: A record should be made for a minimum of 15 minutes on each man during each phase of his W–R–S cycle.
6. *Experimental Controls*
   Men will serve as their own controls. Representative records could be taken on the ground before flight and presumably a comparable series after recovery.
7. *Summary of Number and Types of Space Station Personnel*
   Number will be determined by total in-flight personnel status rather than by experimental requirements.
8. *Summary of Onboard Experimental Equipment Required*
   As noted in 5b, helmet application of scalp electrodes in standard symmetrical 8-lead patterns, with transistorized or other packaged recording equipment, preferably with telemetering capability.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    A 15-minute sample from each man during each phase of his W–R–S cycle.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Not related to present experiment.
14. *Telemetry versus Onboard Recording Requirements*

Telemetry is desirable although not essential.

15. *Prerequisite Ground-Based Experiments*
Analysis of EEG patterns according to the Lindsley schedule on all subjects. The preflight data should include records to gravitational stresses and isolation and, if possible, in-flight simulation conditions.
16. *Prerequisite Space Flight Experiments*
None.
17. *Prerequisite Research and Development*
Development of helmet, EEG lead, electrode holder and cabling system, as well as packaged EEG equipment with telemetering capabilities.
18. *Onboard Gaseous Atmosphere Desired*
Sea level equivalent.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
Data should be in such form as to provide for visual, wave form, and frequency analyses.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
Postflight evaluation will consist of EEG records taken under preflight conditions.
23. *References*
Lindsley, D. B.: Psychological Phenomenon and the Electroencephalogram. Electroencaphalog. and Clin. Neurophysiol., vol. 4, 1952, pp. 443–456.

EXPERIMENT 2

1. *The Effects of a Rotating Environment on Man in Space Flight*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To determine the level of "artificial gravity" needed to maintain astronaut fitness, on the one hand, and minimize or prevent the side effects of a rotating environment (difficulty in walking, illusions, and canal sickness), on the other. Insofar as feasible, advantage should be taken of the unique opportunity to study man's intrinsic and extrinsic behavior as a function of subgravity levels of gravitoinertial force.
4. *Justification*
Design engineers will require human performance data to determine the configuration of a rotating spacecraft and some of its operational characteristics. If the rotating ORL under consideration is the first of its type, these "data" must be obtained from ground-based experiments. Investigations aloft are needed to "perfect" the design of "second generation" rotating spacecraft. A very important phase of this undertaking is to determine the validity of ground-based experiments in order to minimize the need for investigations of an applied nature aloft. New information of considerable value should be obtained.
5. *Experiment*
Assumptions: In the following experimental design, it is assumed that the rotating ORL will be capable of generating a centripetal force of approximately one G unit in magnitude and that a counter-rotating facility will permit experimentation in weightlessness. At stations between the "core" and periphery (or at varying velocities of the spacecraft), subgravity conditions would prevail. If this range is not available, the experiments can be tailored accordingly. Although a single "set" of environmental conditions may subserve three cardinal purposes, namely, (1) to determine the one ideal force environment to preserve fitness, (2) to validate ground-based experiments, and (3) to determine the "tolerance envelope," the main emphasis will be placed on the last inasmuch as it may prove to be the limiting factor in spacecraft design for the near future.
Subjects: The astronauts or "space crew" for the rotating ORL should be selected on the basis of (1) previous experience in space flight, (2) low initial susceptibility to stress in rotating environments, (3) ability to adapt or habituate as manifested in training procedures, and (4) general suitability as subjects or experimenters. The assessments covering medical, physiological, and psychological factors should be intensive and extensive, during the course of

which the subject should demonstrate a good understanding of the underlying mechanisms, the technical procedures, and his responsibilities as a subject or experimenter in flight. At the end of this experiment NAVSCOLAVNMED 6500/24 is the Preflight Vestibular Evaluation form from the Navy School of Aviation Medicine.

The Force Environments: The force environments as represented by the vector sums of the forces generated by vehicle and subject will have been carefully estimated prior to going aloft on the basis of measurements made in the laboratory. Nevertheless, it would be essential to repeat, insofar as feasible, the measurements in actual flight and determine the dynamic effects in terms of stimulation of vestibular organs. The beneficial forces would be represented mainly by centripetal force and possibly Coriolis force, while the disturbing forces would be represented by the multiplanar angular accelerations affecting the semicircular canals, the Coriolis forces, and the changing gradients of gastrointestinal forces as the subject moves about the spacecraft.

Apparatus: It is assumed that the ORL will be equipped to carry out all of the necessary procedures except those items related to the assessment of vestibular functions and the effects (or lack of interaction) between vestibular and other sense modalities. The apparatus needed to measure canal and otolith function has been briefly described in Experiment 3, entitled *The Effects of Weightlessness and Subgravity States on the Function of the Otolith Apparatus and the Semicircular Canals (including Their Interrelationships and Their Relation with Other Sense Modalities),* although some newer procedures under development may prove more satisfactory. As presently determined, the major items of equipment would include: (1) litter-chair, (2) nystogmograph, (3) camera and ancillary equipment to measure ocular counter rolling, (4) helmet with self-contained device to measure egocentric visual localization of up-down area, (5) device to measure nonvisual estimates of up-down which is under development. The litter-chair will operate in three modes: (1) oscillation, (2) rotating chair, and (3) rotating litter.

Procedures: These fall into four categories:

a. Measure the time course of adaptation to the force environment in the main portion of the spacecraft and compare with the findings obtained from subjects at other stations. It is expected that the astronauts, having been carefully prepared, will not be affected to a significant degree. Nevertheless, the force environment will be different from anything they have experienced previously, and factors other than the force environment may influence the symptomatology.

b. Exploration studies utilizing the independently rotating center portion of the spacecraft and a litter-chair which should be capable of rotating, when desired, either clockwise or counter-clockwise up to 60 rpm with controllable levels of acceleration.

(1) Definition of the "symptom or tolerance envelope" covering angular velocities greater than that of the ORL. With some reservations, involving Coriolis accelerations, the data obtained would be valid to rotating environments with greater radii. The apparatus described in Experiment 1, entitled *EEG Changes During Arousal and Drowsing,* would suffice.

(2) Explore the best procedure for transition from a stationary to a rotating environment.

(3) Define the best procedure of preconditioning a subject for transition to a stationary environment. This involves not only the symptomatology incidental to a change in force environments but also the possible loss of fitness due to the small magnitude of the inertial forces. There are several possibilities here which need exploration under terrestrial conditions.

c. Explore alternative procedures for the maintenance of fitness by "artificial gravity." One involves, solely, the generation of inertial forces by rotating the spacecraft, except for the initial period, at constant velocity. Another possibility is to supplement the conditioning provided by the constant velocity of the spacecraft through the periodic use of an onboard centrifuge which might consist of an independently rotating central portion of the vehicle. Evaluation of medical and professional fitness and especially physical fitness is the main requirement. It is essential to distinguish between fitness for tasks aloft, during reentry, and postimpact. The procedures described under "Safety Monitoring" are applicable and probably sufficient.

d. Investigate sensory perceptions, particularly interactions of visual, vestibular, and somatosensory cues.

6. *Experimental Controls*
   Astronauts will serve as their own controls, but comparisons, insofar as possible, may be made with the experience of other astronauts under similar conditions and healthy subjects under simulated conditions.
7. *Summary of Number and Types of Space Station Personnel*
   A physician is highly desirable and almost essential for clinical aspects of the experimental program. One astronaut well-trained as a technician is essential. The greater the sophistication of the subjects the better.
8. *Summary of Onboard Experimental Equipment Required*
   Described under 5.
9. *Summary of Animals*
   Effects of exposure of primates to rotating environments is desirable.
10. *Summary of Other Living Forms*
    Not needed.
11. *Summary of Onboard Laboratory Determinations*
    The requirements for measuring the time-course of adaptation have been given. The "exploratory" investigations would require the use of one subject for prolonged periods which are often measured in days rather than hours, but during this time he could be doing some type of useful work which did not require his presence elsewhere. A total of one experimenter's time would be needed while the investigation is in progress; this work load could and should be distributed.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    Not applicable.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Not applicable.
14. *Telemetry Versus Onboard Recording Requirements*
15. *Prerequisite Ground-Based Experiments*
    As indicated above, this constitutes a large program. These efforts fall into two interrelated categories, operational and experimental. The former includes studies which have fairly direct application to the selection, assessment, and training of astronauts in preparation for space flights in rotating spacecraft. The latter is an analytic and synthetic approach designed to provide experimental facts and theoretical understanding of the role of the semicircular canals and otolith organs in man under all conditions.
    Analytic studies deal with: (1) the analysis of gravitoinertial force environments; (2) the mechanics of the semicircular canals and otolith organs as transducer mechanisms; (3) the effects of different force environments on sensing elements in the canals and otoliths; (4) the central nervous system mechanisms concerned with the integration, modulation, and adaptation to sensory inputs from the canals and otoliths; (5) the responses evoked by usual and unusual patterns of stimulation to canals and otoliths; (6) the individual roles of canals and otolith organs and their interrelationship; and (7) the prevention of illusory phenomena and functional disturbances.
    The synthetic approach deals with (1) an understanding of the mechanisms underlying the useful contributions of the canals and otoliths to the human economy in health and under ordinary living conditions, (2) an understanding of the disturbances in homeostatic mechanisms, resulting from disease, functional disorder, or injury of the canals and otoliths and their restoration and (3) the level of inertial force which should be generated in a rotating spacecraft to prevent loss of fitness.
16. *Prerequisite Space Flight Experiments*
    Not essential.
17. *Prerequisite Research and Development*
    Compared with the organ of Corti, our knowledge of the semicircular canals and especially the otolith apparatus is far in arrears. (See 15.)
18. *Onboard Gaseous Atmosphere Desired*
    Not an important factor.

19. *Requirement for Rotation for Artificial G*
Essential.

20. *Comments re Form of Data and Interpretation of Data*
Usual procedures.

21. *Special Comments*
These experiments should provide data which would enable the engineer to design the "perfect" spacecraft for ensuring the maintenance of astronaut fitness insofar as this can be accomplished by generating artificial gravity, on the one hand, and preventing unwanted side effects, on the other.

At the end of this experiment are forms used by the Naval School of Aviation Medicine: NAVSCOLAVNMED 6500/24A, Experimenter's Evaluation of Subject's Fitness for Experiment; NAVSCOLAVNMED 6500/24B, Experimenter's Evaluation of Responses to Procedure; NAVSCOLAVNMED 6500/24C, Subject's Evaluation of Responses to Procedure; and a Diagnostic Categorization Work Sheet.

22. *Postflight Evaluation of the Crew*
None.

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2. Gazenko, O.: Medical Studies on the Cosmic Spacecrafts "Vostok" and "Voskhod." NASA TT F-9207, National Aeronautics and Space Administration, Washington, D.C., 1964.
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PREFLIGHT VESTIBULAR EVALUATION

Name ______________________ Rank____ Age____ Weight____ Height____

Serial No. ______________ Class (if any) ______________ Today's Date ________

Have you ever taken this test before? YES___ NO___ When? ______________

Check one of the following:

Aviator	____
Cadet (MarCad)	____
Aviation Officer Candidate	____
Officer under instruction	____
LDO	____
Enlisted	____
Flight Surgeon	____
Staff Corps Officer	____
Civilian	____
Other (Specify)	____ ______________

Check one of the following:

Navy	____
Marine	____
Coast Guard	____
Other (Specify)	____ ______________

Number of hours in multi-engine aircraft:
(Draw a circle around one or more of the following: (Passenger, Crew, Military or Commercial)

None	____
Less than 10	____
10-50	____
50-200	____
200-1000	____
More than 1000	____

Number of hours in single-engine aircraft: (Passenger, Crew, Military, Commercial)

None	____
Less than 10	____
10-50	____
50-200	____
200-1000	____
More than 1000	____

NAVSCOLAVNMED 6500/24

Study of "Motion Sickness"

Under one condition or another just about all normal individuals get "motion sick". The number of times and the conditions under which this occurs vary with the individuals. It has not yet been determined just which "individual differences" are involved. It is believed the results of this study will give us some indications.

The term "motion sickness" covers a wide variety of subjective symptoms and objective signs and may be experienced over a wide range of severity. Common symptoms are discomfort, lack of appetite, nausea, dizziness and drowsiness; common signs are pallor, sweating, increased salivation and vomiting. Most persons recall accurately severe symptoms but not mild symptoms which, even when experienced, may not have been attributed to motion. The diagnosis or identification of motion sickness depends almost entirely on the close relation of the onset of symptoms to the onset of motion.

1a. In the following, indicate the amount or number of experiences you have had with each activity.

How many experiences with:

	No.
Swings	
Hammocks	
Gymnastic apparatus	
Roller skating	
Spinning on foot	
Roller coaster	
Squirrel cage	
Cartwheels	
Merry-Go-Round	
Other carnival devices	

How many experiences with:

	No.
Long train trips	
Buses	
Motor cars	
Motorcycles	
Elevators	
Cinerama at movies with wide screen	
In a plane in slight turbulence	
In a plane in severe turbulence	
In a plane in acrobatics	
In a plane in Zero "g"	

NAVSCOLAVNMED 6500/24

1b. Disregarding the number of experiences you have had, how many times were you sick ? In addition, check the symptoms you experienced. (You may check more than one.)

	No.	Vomited	Nausea	Stomach Awareness	Increased Salivation	Dizziness	Drowsiness	Sweating	Pallor	Vertigo	Headache	Awareness of Breathing	Other Symptoms
Swings													
Hammocks													
Gymnastic apparatus													
Roller skating													
Spinning on foot													
Roller coaster													
Squirrel cage													
Cartwheels													
Merry-Go-Round													
Other carnival devices													
Long train trips													
Buses													
Motor cars													
Motorcycles													
Elevators													
Cinerama at movies with wide screen													
In a plane in slight turbulence													
In a plane in severe turbulence													
In a plane in acrobatics													
In a plane in zero "g"													

If you had any other symptoms as a result of motion sickness, what were they:

NAVSCOLAVNMED 6500/24

2. a. How many experiences have you had at sea aboard ships or boats?

Many_____ Numerous_____ Some_____ Too few to mention_____ None____

b. Have you ever been seasick? YES____ NO____ If YES, would you describe the experience. Please describe weather conditions, length of voyage, type of vessel, whether you recovered while at sea, (and if you became sick again), and any other factors you consider pertinent.

c. From your experience at sea would you say that you: Always get sick______

Frequently get sick_____ Sometimes_____ Rarely_____ Never______

3. Have you ever been motion sick under any conditions other than the ones listed so far?

YES_____ NO_____ If so, under what conditions?

4. If you vomited while experiencing motion sickness, did you;

Feel better and remain so? __________
Feel better temporarily, then vomit again? __________
Feel no better, but not vomit again? __________

5. In general, how susceptible to motion sickness are you? Extremely________

Very_____ Moderately_____ Minimally_____ Not at all_____

6. In the past 8 weeks have you been nauseated FOR ANY REASON? YES____ NO____ (If YES, Explain)

a. In the past when you were nauseated for any reason, did you: 1) vomit easily__ 2) only with difficulty___ 3) retch and finally vomited with great difficulty____ 4) could never vomit when nauseated___ 5) never nauseated in life____

b. Have you ever vomited in your sleep after heavy partying the night previous?

YES_____ NO_____

NAVSCOLAVNMED 6500/24

7. The following contains a list of recreational activities. Please indicate by a check your past experiences with each, as well as your preference. Please be sure to check one in each section for "amount of experience", and "preference".

	More than 10 times	5 to 10 times	Less than 5 times	Never	Like	Neutral	Dislike
Airplanes							
Shipboard cruises							
Sailing							
Salt water fishing							
Roller skating							
Diving from a board							
Trampoline							
Water polo							
Figure skating							
Dancing							
Riding a motorcycle							
Playing ice hockey							
Underwater spear fishing							
Ice skating							
Roller coaster							
Squirrel cage							
Dive bomber							
Carnival devices							
Skiing (water or snow)							

8. What do you think your chances of getting sick would be in an experiment where 50% of the subjects get sick?

I almost certainly would ______
I probably would ______
I probably would not ______
I almost certainly would not ______

9. Would you volunteer for an experiment where you knew that:

85% of the subjects did get motion sick? YES____ NO____
75% of the subjects did get motion sick? YES____ NO____
25% of the subjects did get motion sick? YES____ NO____

NAVSCOLAVNMED 6500/24

10. a. Have you ever taken part in any activities which involved unusual body rotation, (dance, game, etc.,)? YES____ NO____

b. If yes, what were they?______

c. If yes, how severe was the motion?______

d. If yes, did you get motion sick? YES____ NO____

e. What were the specific symptoms?______

11. What influence do you think the food you ate, before your experience with motion, had on whether or not you got sick?

12. At the time you were motion sick, what type of remedy did you use? (whether medical or otherwise)

13. It is thought that there are two kinds of motion sickness. One starts in the brain, (dizziness, sleepiness), and the other one starts in the stomach or intestines, (vomiting, nausea). Which would you say was most like yours?

14. Were you a passenger or controller of a vehicle when you got sick?

15. Most people experience slight dizziness (not a result of motion) 3 to 5 times a year. The past year you have been dizzy:

more than this ______
the same as ______
less than ______
never dizzy ______

16. Have you ever had a broken bone? If yes, when and which bone? (arm, leg, nose, etc.)

When	Bone
1.______	1.______
2.______	2.______
3.______	3.______

17. Most people experience faintness (not a result of motion) 2 or 3 times a year. During the past year you have felt faint:

more than this ______
the same as this ______
less than this ______
never faint ______

NAVSCOLAVNMED 6500/24

18. How well do you understand your motives and reasons for doing things?

Very well	______
Better than most	______
About average	______
Less than average	______
Not well at all	______

19. If volunteers from your class were requested for a very important flying mission, would you:

a. Not volunteer at all ________
b. Volunteer to lead the mission ________
c. Volunteer and wish to elect a leader ________
d. Volunteer and have the CO designate a flight leader ________

20. Have you ever had an ear illness or injury which was accompanied by dizziness and/or nausea?

21. What can you add that might be beneficial to this study or that would improve this questionnaire?

22. a. Have you ever experienced zero "g"? YES____ NO____
b. How many times? ________
c. Were you restrained? YES____ NO____
d. Have you ever free floated? YES____ NO____
e. Have you ever been motion sick at zero "g"? YES____ NO____
f. If yes, describe the experience:

23. Almost all pilots have had one or more experiences with vertigo and/or disorientation.

Have you had:		Were they: (you may check more than one)	
Less than five	______	Mainly in training	______
Five to ten	______	In operational jets	______
More than ten	______	In operational props	______
None	______	Other (Specify)	________________

24. Would you describe one particular incident when you experienced vertigo, which you consider interesting?

EXPERIMENTER'S EVALUATION OF SUBJECT'S FITNESS FOR EXPERIMENT

Experiment ____________________
Experimenter ____________________
Subject ____________________
Date ____________________

1. Have you been ill in the past week? Yes_____ No_____. If yes, specify:
   a. severity, b. time course, c. where localized, etc.

2. I am_____ am not_____ in my usual state of fitness.

3. Drugs:
   a. How much alcohol have you consumed during the past 24 hours?
      drinks_____

   b. How many cigarettes in past 3 hours?_____ cigars_____ pipefuls_____

   c. Have you taken any drugs or medications of any kind in the past 24 hours?
      Yes_____ No_____ If yes, were they:

      1. Sedative or tranquilizer _____
      2. Analgesic (aspirin) _____
      3. Anti-motion sickness remedy (anti-histamine) _____
      4. Other, (Specify) _____

4. How many hours sleep did you have last night?_____ Was this sufficient?_____
   Insufficient?_____

5. How concerned are you regarding your performance on this test?
   None_____ Minimal_____ Moderate_____ Great_____ Very great_____

6. Do you expect to perform better_____ less well_____ same_____, as average person?

7. Food:
   a. How many hours since your last meal?_____

   b. Approximately how many cups of fluid have you had in the past
      2 hours?_____

Examiner's Estimate of Subject's Fitness for Test:

1. Fit: Will use results in study. ____________________

2. Fit: Will use results only for pilot study. ____________________

3. Unfit: ____________________

4. Other (Specify): ____________________

Purpose of Exposure of Subject:

1. Designated experiment. ____________________

2. Pilot run. ____________________

3. Clinical evaluation. ____________________

4. Other (Specify): ____________________

EXPERIMENTER'S EVALUATION OF RESPONSES TO PROCEDURE

Experimenter: ______________________________

Subject: ______________________________

Experiment: ______________________________

Date: ______________ Hour: ______________

☐ Maximum symptomatology during (entire) ____ period of exposure to force environment.

☐ Maximum symptomatology ________ after exposure to force environment.

☐ Other ______________________________

____

A. Does subject appear:

1. Anxious	No Change	____	____	____	____
2. Apathetic	No Change	____	____	____	____
3. Drowsy	No Change	____	____	____	____
4. Sick	No Change	____	____	____	____

B. Does subject exhibit:

1. Frequent yawning	No ____	Yes ____			
2. Over-ventilation (Overt)?	No ____	Yes ____			
3. Respiratory sighing	No ____	Yes ____			
4. Other respiratory irregularities					
5. Pallor	None ____	____	____	____	
6. Facial sweating	None ____	____	____	____	
7. Axillary sweating	None ____	____	____	____	
*8. Trunk sweating	None ____	____	____	____	
9. Aerophagia	None ____	____	____	____	
10. Restricted head movements	No ____	Yes ____			
11. Retching	No ____	Yes ____	No. of times ____		
12. Vomiting	No ____	Yes ____	No. of times ____		

*Observed with or without clothes.

NAVSCOLAVNMED 6500/24B

C. Does subject report:

1. General discomfort	None ____	Slight ____	Moderate ____	Severe ____
2. Fatigue	None ____	Slight ____	Moderate ____	Severe ____
3. Boredom	None ____	Slight ____	Moderate ____	Severe ____
4. Mental depression	No ____	Yes ____		
5. Drowsiness	None ____	Slight ____	Moderate ____	Severe ____
6. Headache	None ____	Slight ____	Moderate ____	Severe ____
7. "Fullness of the Head"	No ____	Yes ____		
8. Blurred vision	No ____	Yes ____		
9. a. Dizziness with eyes open	No ____	Yes ____		
b. Dizziness with eyes closed	No ____	Yes ____	Not tried ____	
10. Vertigo	No ____	Yes ____		
11. a. Salivation increased	None ____	Slight ____	Moderate ____	Severe ____
b. Salivation usual	No ____	Yes ____		
c. Salivation decreased	None ____	Slight ____	Moderate ____	Severe ____
12. Sweating	None ____	Slight ____	Moderate ____	Severe ____
13. Faintness	No ____	Yes ____		
14. Aware of breathing	No ____	Yes ____		
*15. Stomach awareness	No ____	Yes ____		
16. Nausea	None ____	Slight ____	Moderate ____	Severe ____
17. Burping	No ____	Yes ____	No. of times ____	
18. Confusion	No ____	Yes ____		
19. Loss of appetite	No ____	Yes ____		
20. Increased appetite	No ____	Yes ____		
21. Desire to move bowels	No ____	Yes ____		
22. Other ______________				

*Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

D. Subject did ______ did not ______ complete experimental procedure.

E. Even in L-D subjects the experimental conditions were likely to cause:

anxiety ______, boredom ______, thermal sweating ______,

general discomfort ______, fatigue ______, other ______________

NAVSCOLAVNMED 6500/24B

SUBJECT'S EVALUATION OF RESPONSES TO PROCEDURE

Name ______________________________

Date ______________________ Hours ______________________

The experimenter has indicated in the box below the precise period to keep in mind when filling out the questionnaire.

- -

NOT TO BE FILLED BY SUBJECT

☐ Maximum symptoms experienced during (entire)(_____) period of exposure to the force environment.

☐ Maximum symptoms experienced _____ after exposure to the force environment.

☐ Other ______________________________

Experiment ______________________________

- -

1.	General discomfort	None ____	Slight ____	Moderate ____	Severe ____
2.	Fatigue	None ____	Slight ____	Moderate ____	Severe ____
3.	Boredom	None ____	Slight ____	Moderate ____	Severe ____
4.	Mental depression	No ____	Yes ____		
5.	Drowsiness	None ____	Slight ____	Moderate ____	Severe ____
6.	Headache	None ____	Slight ____	Moderate ____	Severe ____
7.	"Fullness of the Head"	No ____	Yes ____		
8.	Blurred vision	No ____	Yes ____		
9.	a. Dizziness with eyes open	No ____	Yes ____		
	b. Dizziness with eyes closed	No ____	Yes ____	Not tried ____	
10.	Vertigo	No ____	Yes ____		
11.	a. Salivation increased	None ____	Slight ____	Moderate ____	Severe ____
	b. Salivation usual	No ____	Yes ____		
	c. Salivation decreased	None ____	Slight ____	Moderate ____	Severe ____
12.	Sweating	None ____	Slight ____	Moderate ____	Severe ____
13.	Faintness	No ____	Yes ____		
14.	Aware of breathing	No ____	Yes ____		
*15.	Stomach awareness	No ____	Yes ____		
16.	Nausea	None ____	Slight ____	Moderate ____	Severe ____
17.	Burping	No ____	Yes ____	No. of times ________	
18.	Loss of appetite	No ____	Yes ____		
19.	Increased appetite	No ____	Yes ____		
20.	Desire to move bowels	No ____	Yes ____		
21.	Vomiting	No ____	Yes ____	No. of times ________	
22.	Confusion	No ____	Yes ____		
23.	Other ______________________________				

*Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

NAVSCOLAVNMED 6500/24C

1

DIAGNOSTIC CATEGORIZATION WORK SHEET

		Pathognomic Signs	Major Signs and Symptoms						Minor Signs and Symptoms				
No.	Name	Vomiting	Nausea II or III	Increased Salivation II or III	Pallor III	(cold) Sweating III	Drowsiness III	Retching	Nausea I	Increased Salivation I	Pallor II	(cold) Sweating II	Drowsiness II
1.													
2.													
3.													
4.													
5.													
6.													
7.													
8.													
9.													
10.													
11.													
12.													
13.													
14.													
15.													
16.													
17.													
18.													
19.													
20.													
21.													
22.													

1

	Other Signs						Signs of Anxiety		Other Symptoms									
									Gastrointestinal				Mental		Cerebral			
No.	Pallor I	Sweating I	Drowsiness I	Characteristic Facies	Increased Yawning	Restricted Head Movement	Aerophagia	Character Facies	Stomach Awareness	Anorexia	Burping	B.M. Desire	Depression	Apathy	Headache	Dizziness	Vertigo	General Discomfort
1.																		
2.																		
3.																		
4.																		
5.																		
6.																		
7.																		
8.																		
9.																		
10.																		
11.																		
12.																		
13.																		
14.																		
15.																		
16.																		
17.																		
18.																		
19.																		
20.																		
21.																		
22.																		

2

No.	Predisposing Factors: Degree Unfit 0, 1, 2, 3	Predisposing Factors: Subject's Concern 0, 1, 2, 3, 4	Predisposing Factors: Subject's Prediction -1, 0, +1	Concordance of Signs & Symptoms	Noncompletion Warranted	Diagnosis	Diagnostic Terms
1.							**Vestibular Sickness (VS):**
2.							Vomiting or
3.							two major symptoms or
4.							one major and two minor symptoms.
5.							
6.							**Malaise III:**
7.							One major or
8.							two minor symptoms or
9.							one minor and two other symptoms.
10.							
11.							**Malaise I:**
12.							Any subjective symptom or
13.							any sign usually associated with
14.							any subjective symptom.
15.							
16.							**Malaise II:**
17.							All others.
18.							
19.							Note: In addition, an occasional
20.							diagnosis of "Anxiety Reaction" may
21.							be made when signs and symptoms
22.							warrant.

EXPERIMENT 3

1. *The Effects of Weightlessness and Subgravity States on the Function of the Otolith Apparatus and the Semicircular Canals (including Their Interrelationships and Their Relation with Other Sense Modalities)*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To measure changes with time under the force conditions aloft in the function of the otolith organs and semicircular canals and determine their role in lowering the efficiency of astronauts in flight and post impact.
4. *Justification*
   Deafferentation of the otolith apparatus and other gravireceptors has precipitated the most clear-cut first order symptoms experienced or manifested in weightlessness. Second order effects may have contributed to fatigue and a broad spectrum of mild functional disturbances. While it is expected that adaptation will occur within a short period of time, long-term effects might result either from alterations in end organs or changes in CNS "sensitivity" to afferent impulses or both.
5. *Experiment*
   The astronauts serve as their own controls, and comparative measurements are made before, during, and after flight. The principal measurements, in the light of present knowledge, would fall in four categories:

   Otolith function:

   a. Compensatory eye movement response to linear oscillations. Different orientations of head (body) to the rectilinear accelerations desirable. Litter-chair device could be driven with clock mechanism. Subjective sensations, electrooculography and ciné photography would be used. Threshold and supra threshold responses would be obtained at periodic intervals to determine changes with length of exposure. Introduction of active rotary movements of head to observe superimposed nystagmus might yield worthwhile information on combined canal and otolith function. If litter mode is available, compensatory eye movements might be obtained at constant rotation with selective prepositioning of subject. Time (T) inflight 45 to 90 minutes.

b. Egocentric visual localization of the horizontal (EVLH) (ref. 1). Otolith and, to a lesser degree, nonotolith gravireceptors affect the response. There is a "shred" of evidence that these two influences act differently using the A- and E-phenomena as indicators (ref. 2). At all events, with otoliths deafferented the single influence of different contact (pressure) cues could be explored. Moreover, progressive differences under free floating and contact condition would point to relative roles of otolith and nonotolith influences. Not only a wide variety of contact cues but also visual cues could be introduced to measure changes in the interaction of different sense modalities. These tests are sufficiently interesting that they might come under the heading of "diversion." (T, 2–10 min, depending on variety of measures).

c. Before and after measurements, using tilt device (EVLH) and, if warranted, horizontal and vertical oscillations and human centrifuge (refs. 1, 3).

Canal function:

a. Before and after comparative measurements. Threshold and suprathreshold response to thermal stimulation, using precision technique and nystagmographic recordings (ref. 4). (T—one ear, 15–20 min.) Might be tried aloft to determine if response due to endolymph flow in response to heat or cold.

b. Response to angular and Coriolis accelerations, using illusions and ocular nystagmus as indicators (refs. 5, 6). (T, illusions, 3 min; nystagmus, 5 min).

Illusory effects: A special recording form can be devised to chart the changes in illusory phenomena. (T, 2 min.)

Functional disturbances: Only when comparisons are made between subjects with and those without vestibular organs can one gain a firm appreciation of the role of canals and otoliths in causing a great variety of functional disturbances over a wide range of severity (ref. 7). Too much reliance has been placed on nausea as an indicator whereas many persons have a variety of complaints before the nausea stage is reached. Moreover, the adaptation to nausea occurs more quickly, in some force environments at least, than to other symptoms. It would be difficult to attribute nonspecific symptoms to the vestibular organs if the subject acts as his own control, but in a random group of astronauts carefully "calibrated" for susceptiblility to symptoms precipitated by selective stimulation of otoliths, significant differences in symptomatology might show up; subsequent adaptation would suggest that they are of vestibular origin. A brief questionnaire can be prepared for this purpose (ref. 8). (T, 3 min).

6. *Experimental Controls*

   Subjects serve as their own control, but some measurements on groups of normal subjects under terrestrial conditions needed for baseline normative data.

7. *Summary of Number and Types of Space Station Personnel*

   Any astronaut thoroughly trained in the procedure might serve as experimenter but someone with training in physiology preferable. If he also serves as one of the subjects, a second astronaut should receive technical instruction.

8. *Summary of Onboard Experimental Equipment Required*

   Centrifuge: To be decided.

   Litter-chair in lieu of centrifuge: To be decided.

   Horizontal oscillator: To be decided.

   Restraint devices: The one item which might not accompany any rotating device is restraint for head. Dental bite piece and thin partial plastic helmet should suffice.

Nystagmograph: Any two-channel unit for amplifying recording and, if possible, displaying changes in surface potentials with a capability of high gain and low frequency (0 to 50 cps) response.

Thermal stimulation unit: Present irrigation method probably unsatisfactory. Work in progress on more suitable devices.

EVLH device: The one under development for Gemini experiment (ref. 1) or a modification of it is satisfactory.

Frenzel lenses: Weight of present model might be reduced by using plastic lenses.

Power: Except for rotating devices, small battery(s) for EVLH and small requirements for physiological recorder.

Consumable material: Tape for recorder unless telemetered on "paper" for display.

9. *Summary of Animals*

Weightlessness is an elegant method to produce physiological deafferentation of the otolith apparatus. The effect of this deafferentation on the spontaneous discharge of receptor cells of macula and crista should be determined. Also the changes in the resting discharge with time and changes in response to stimulation of otoliths and canals with time would be important to measure. This experiment would require a physiologist trained in these techniques unless the "preparations" were carried aloft which would limit the duration of the experiment. Major requirements are to be decided.

Whether complete deafferentation of otoliths leads to functional and pathological changes in peripheral receptors and cell stations in CNS could be determined in squirrel monkeys, preferably, or on lower animals. Comparison with animal freely moving would establish value of head movements in preventing alterations if they were manifested. Much additional information also could be obtained. Two small "units" each weighing about 50 lbs, occupying about 1 cubic foot, and requiring 2.5 to 5.0 watts during experimental periods would be the major requirements. If biosatellite experiments are conducted, improvement in present day requirement can be expected.

10. *Summary of Other Living Forms*

A second experiment which may be accomplished long in advance of ORL concerns the important question of whether deafferentation alters the resting discharge of gravireceptors in parabolic flight. This might be accomplished with very small nonmammalian "forms," but primates are desirable.

11. *Summary of Onboard Laboratory Determinations*

The experiments utilizing nystagmography are time consuming but might be combined with other investigative procedures involving the use of centrifuge or recorder. The approximate time for an experienced observer and subject has been indicated. The minimal total time for the subject on a complete series adds up to approximately 90 minutes; the preparation would require, in some instances, a longer time unless integrated with another experiment; number of times would depend on the time-course of changes.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*

Not applicable.

13. *Proposed Rendezvous Schedule for Rotation of Crew*

Not applicable.

14. *Telemetry versus Onboard Recording Requirements*

Either satisfactory; onboard preferred.

15. *Prerequisite Ground-Based Experiments*

Baseline measurements would be required both for human and animal subjects. Prerequisite studies would involve mainly miniaturizing or modifying present equipment to generate angular and rectilinear acceleration, to measure nerve potential and eye movements, and to systematize procedures.

16. *Prerequisite Space Flight Experiments*

Desirable but not essential.

17. *Prerequisite Research and Development*

Human: Mainly to ensure test-retest reliability of new equipment; should include trials in parabolic flight.

Animal: Stimulation experiments required on the ground and in weightlessness. Biosatellite experiments may suffice unless equipment significantly different.

18. *Onboard Gaseous Atmosphere Desired*

Not directly related to purpose of the experiment.

19. *Requirement for Rotation for Artificial G*
Barany chair and linear oscillator; small centrifuge or rotation of vehicle with counterrotating central compartment to be decided.
20. *Comments re Form of Data and Interpretation of Data*
See References.
21. *Special Comments*
Integration with the total program is important. It could result in saving time and multiplying uses of equipment.
22. *Postflight Evaluation of the Crew*
None.
23. *References*

1. Graybiel, A.: Vestibular Sickness and Some of Its Implications for Space Flight. *In* Neurological Aspects of Auditory and Vestibular Disorders, Field, W. S.; and Alford, B. R., ed., Charles C. Thomas, Springfield, Ill., 1964.
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8. U.S. Naval School of Aviation Medicine forms for motion sickness symptamotology, pp. 59–67.

EXPERIMENT 4

1. *Intraocular Arterial Systolic and Diastolic Blood Pressure under Conditions of Prolonged Whole Body Weightlessness*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To study the possible effects of weightlessness on the intraocular systolic and diastolic blood pressure.
4. *Justification*
One of the possible major effects of weightlessness on the human subject may be a decrement in cardiovascular reactivity.
The effective arterial blood pressure in the eye is less than that in the brain because circulation in the retina is opposed by a normal intraocular pressure of approximately 18 mm Hg. It is also known that the application of 20 to 30 mm Hg positive pressure to the eyeballs lowers by 1G the positive centrifugal force necessary to produce visual blackout in the human subject. When systolic blood pressure at head level is reduced below 50 mm Hg by positive centrifugal force, disturbances in vision occur although the human subject retains consciousness.
Thus a loss in reactivity of the cardiovascular system under conditions of prolonged weightlessness may well result in untoward variations in intraocular blood pressure which may threaten the limits of visual tolerance of the eye.
5. *Experiment*
Utilizing a plethysmographic goggle type of opthalmodynamometer the astronaut can conduct the experiment unassisted.
Procedure: At regularly prescribed intervals

(e.g.: within the first hour of weightlessness; after 2, 3, and 4 hours of weightlessness; after 1, 2, 4, 8, and 12 days of weightlessness; after 3, 6, and 12 weeks of weightlessness; and just prior to leaving orbit in preparation for reentry into the effective gravitational force of the earth) the astronaut should place the plethysmographic goggles over his eyes. By means of a hand-operated bulb syringe, he can increase the positive atmospheric pressure force exerted on one eye to any level up to 200 mm Hg while the other eye remains at normal cabin atmospheric pressure.

Measurements: While gradually increasing the atmospheric pressure on one eye during each test procedure, the astronaut is to fixate his eye undergoing the test on a visual target situated directly in front of him and at a distance of one to three meters. This visual target is essentially a visual field device containing a central fixation point and points of illumination 15°, 25°, and 50° from the central fixation point.

As the pressure in the goggle increases, the astronaut will observe the gradual onset of "grayout" in the involved eye. When this point is reached, the astronaut will observe that his peripheral vision is reduced to a point where he has just lost awareness of the 15° (and beyond) points of illumination on the visual target area although he can still see the central fixation point. Since "grayout" approximates the diastolic pressure level of compression of the intraocular arterials, the astronaut can manually note this fact by a trigger marking device. When the plethysmographic goggle pressure reaches that of systolic intraocular arterial pressure, "blackout" or complete temporary loss of vision occurs in the involved eye. The astronaut at this point is aware that the central fixation point in the visual target area has also vanished. He then trigger-marks the pressure record at that point and reduces the plethysmographic goggle pressure back to normal cabin atmospheric pressure.

6. *Experimental Controls*

A series of similar preflight tests should be carried out on the astronaut so that he can act as his own pre- and post-flight control subject.

In addition, preflight testing will enable the subject and the equipment to be checked out in regard to standardization of response, familiarity, and reliability.

7. *Summary of Number and Types of Space Station Personnel*

Two trained astronauts.

8. *Summary of Onboard Experimental Equipment Required*

a. Plethysmographic goggle (two pair)

b. Visual target (modified visual field or perimeter)

c. Automatic pressure recording and marking device

9. *Summary of Animals*

None.

10. *Summary of Other Living Forms*

None.

11. *Summary of Onboard Laboratory Determinations*

None.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*

None.

13. *Proposed Rendezvous Schedule for Rotation of Crew*

None.

14. *Telemetry versus Onboard Recording Requirements*

Telemetry desired if no physician is onboard.

15. *Prerequisite Ground-Based Experiments*

a. Verification by means of ophthalmoscopy that "grayout" and "blackout" pressure levels coincide accurately with diastolic and systolic intraocular arterial pressure in the subject astronauts.

b. Adaptation of position of peripheral visual points (15° isopter) on visual target to coincide with diastolic pressure level and grayout of subject astronauts.

c. Establish preflight baseline standards for subject astronauts.

16. *Prerequisite Space Flight Experiments*

None.

17. *Prerequisite Research and Development*

Optimization of design of plethysmographic goggles, visual targets, and recording devices.

18. *Onboard Gaseous Atmosphere Desired*

Earth atmosphere in range from 0 to 5000 feet above sea level and shirtsleeve environment.

19. *Requirement for Rotation for Artificial G*
None.

20. *Comments re Form of Data and Interpretation of Data*
Continuous analogue form during each experiment with adequate number of calibrations to insure reliability of references. Interpretation should be by a physician or ophthalmologist trained to interpret the telemetry reports and who had participated in the preflight phase of this experiment on the subject astronauts.

21. *Special Comments*
Interpretation of the data obtained during flight might prove to be of considerable aid in determining the visual function margin of safety present in regard to the relative difference between intraocular arterial blood pressure and the hydrostatic intraocular pressure of the eye.

22. *Postflight Evaluation of the Crew*
None.

23. *References*

1. Lambert, E. H.; and Wood, E. H.: The Problem of Blackout and Unconsciousness in Aviators. Medical Clinics of North America, vol. 30, 1946, pp. 833–844.
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4. Weeks, S. D.; Jaeger, E. A.; and Duane, T. D.: Plethysmographic Goggles: A New Type of Ophthalmodynamometer. Neurology, vol. 14, no. 3, March 1964, pp. 240–243.

EXPERIMENT 5

1. *Harmonic and Other Analyses of Voice Characteristics for Possible Indications of Anxiety, Depression, Hostility, and Other Emotional Reactions*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To develop a number of indices based on the analysis of voice for possible use in distinguishing between various emotional states; to evaluate the stability of such patterns over time.
4. *Justification and Rationale*
Voice communication between the astronauts in the capsule and the ground crews is a necessary medium for the transmission of essential messages. Since emotional changes are reflected in a neuro-muscular discharge, it is reasonable to assume that the muscles of the larynx would be affected by the emotional condition of a subject. Changes in the tension of selected muscles in the larynx should have a definite influence on a number of characteristics of the voice. It is felt that an analysis of the voice pattern (i.e. when saying the same word) would reveal critical changes under different emotional conditions. Since voice communication will be involved in all orbital flights, no extra equipment would be needed aboard the capsule to conduct this experiment. And if the above hypothesis is correct, we would have a readily available method to objectively evaluate the emotional condition of the astronaut at every stage of his orbital flight.

5–22. Not applicable.

23. *References*
Awaiting appropriate references to determine the feasibility of such analyses with the present quality of voice recordings obtained from astronauts while in flight.

EXPERIMENT 6

1. *Emotional Changes During Prolonged Space Flight*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To determine what emotional changes occur in a space crew during a prolonged space flight and to correlate these changes with whatever

performance data are available at the time the emotional changes are reported.

4. *Justification and Rationale*

A number of investigations suggest that the confining and environmentally monotonous aspects of extended space flight will tend to induce undesirable emotional and behavioral reactions (ref. 1). These in turn may lead to deterioration of social and personal integrity. It has been conjectured that prolonged periods of weightlessness might generate anxiety and apprehension (ref. 2). Prolonged confinement is also considered to produce irritability, hostility, depression, and other negative attitudes (ref. 3) that could be disturbing and disruptive of group morale. Similar results are available from the psychometric studies on the long cruises of the atomic submarines (ref. 4).

Deterioration of efficiency, morale, and motivation may well accompany the undesirable emotional reactions mentioned above and such effects could jeopardize the successful completion of any extended space mission. As a specific example, deteriorating attitudes and inadequate performance may bring about a lowering of standards in the execution of the reconditioning and retraining programs (for reentry) that will have to be periodically instituted aloft.

Aside from such practical considerations, it is of inherent theoretical interest to study the nature of the changes in the emotional life of an individual exposed to the unique, intense, and focalized pattern of stresses experienced by an astronaut during a space mission. The long continued impact of this stressful experience should reveal changes that would not be observable in a short flight. Experimental evidence, obtained from an orbiting laboratory, may provide leads for developing countermeasures against any possible negative effects.

5. *Experiment*

Materials: Three types of measurements are needed to analyze the complex characteristics of what is called emotional behavior: psychological, physiological, and biochemical.

a. *Psychological:* Rating scales (e.g., Nowlis Mood Scale) and sociometric devices. These procedures will help identify the psychological onset and the nature of the emotion experienced by the astronaut. An analysis of the discrepancy between self-ratings and ratings of self by others might provide indices of group cohesion.

b. *Physiological:* Respiratory, cardiovascular (blood pressure, heart rate), electromyographic, and galvanic skin responses should be monitored.

c. *Biochemical:* Determination of catechol amines, ACTH, and adrenal steroids.

Subjects: Assuming a complement of 5 to 6 men in an orbiting laboratory, the subjects of the experiment would consist of 3 to 4 men. The other members of the laboratory crew would be individuals who could be rotated after varying periods of time depending upon the training and experimental needs of the overall program. To control for weightlessness and the "hazard" effects that are unique in being aloft in an orbiting laboratory, a contrast group should be used in a ground-based simulator which would attempt to replicate the physical characteristics of the orbiting laboratory and the activity program of its members.

Procedure: Part of this experiment could be embedded within a much larger experiment dealing with simulation of extended space flights. The data obtained could well serve as feedback for restructuring the experiment in the orbiting laboratory.

Baseline data for all the measurements would be obtained at various time points in the training of the crews for an orbital laboratory assignment. From 4–8 time points should be incorporated into the training procedure and at least the same number should be utilized in the experiment proper. The number of time points will be determined by the time characteristics of the extended space mission.

The minimal experimental mission should last 30 days, followed by extensions to 60 days, 90 days, 180 days, and 360 days. If no detrimental effects are in evidence at the lower time period, the experiment could be escalated to the next higher level. Should evidence of questionable deterioration appear, the experiment should be repeated with the presumed influences for the deterioration eliminated or counteracted. Such an escalated program should provide "developmental" data that would indicate critical phases in the developmental aspects of man's adjustment to conditions which an astronaut would experience on an extended space mission.

6. *Experimental Controls*
The simulation (ground-based) group can serve as a partial control group for the effects of weightlessness and the unique stress conditions of orbital flight. The baseline data would serve as Earth-based standards against which the experimental data can be evaluated. Such baseline data should have reached an asymptotic or "homeostatic" level in order to serve as a valid comparative standard.

7. *Summary of Number and Types of Space Station Personnel*
In a group of five to six, three to four persons will comprise the experimental group. The two nonexperimenters should consist of a physician and a trained astronaut who could be rotated for various other duties or experimental tasks.

8. *Summary of Onboard Experimental Equipment Required*
Amplifiers and multichannel recorders to indicate respiratory, cardiovascular (blood pressure, heart rate), electromyographic, and galvanic skin changes.
Multiple purpose behavior panel which, in addition to serving as a test instrument for various psychological processes, should provide a capability for recording ratings (self and others) and sociometric data.

9. *Summary of Animals*
None.

10. *Summary of Other Living Forms*
None.

11. *Summary of Onboard Laboratory Determinations*
Three determinations of each of the physiological indices at each time point. The number of time points for obtaining the whole set of psychological, physiological, and biochemical determinations will depend on the length of the extended space mission. For the shortest extended mission (30 days), it is recommended that the testing take place at least once a week and at such times that will assure coordination with other psychological measures.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
Initially, it is anticipated that the biochemical specimens will have to be flown to Earth for analysis. These flights should be integrated with other experimental programs which might also require specimens to be returned to Earth.

13. *Proposed Rendezvous Schedule for Rotation of Crew*
Rotation is necessary only for the "adjunct" crew of two members. The rate of rotation should be determined by the training and experimental requirements of the overall laboratory program.

14. *Telemetry versus Onboard Recording Requirements*
Test information can be stored in tapes pending the relaying of this data to Earth. As facilities and the state of the art develops, more and more of such data should be telemetered soon after it is obtained.

15. *Prerequisite Ground-Based Experiments*
The simulation portion of this experiment can also serve as a prerequisite ground-based experiment.

16. *Prerequisite Space Flight Experiments*
None.

17. *Prerequisite Research and Development*
Rating and sociometric devices. Miniaturization of the systems for the physiological recordings.

18. *Onboard Gaseous Atmosphere Desired*
As similar to Earth atmosphere as possible.

19. *Requirement for Rotation for Artificial G*
If provision for artificial G becomes necessary, this could provide a method for controlling the weightlessness variable.

20. *Comments re Form of Data and Interpretation of Data*
Digital wherever possible.

21. *Special Comments*
None.

22. *Postflight Evaluation of the Crew*
None.

23. *References*

1. Burns, N. M.; and Kimura, D.: Isolation and Sensory Deprivation. *In* Burns, N. M.; Chambers, R. M.; and Hendler, E.: Unusual Environments and Human Behavior, Free Press of Glencoe, Collier-Macmillan, London, 1963, pp. 167–192.
2. Schock, G. J. D.: Some Observations on

Orientation and Illusions when Exposed to Sub- and Zero-Gravity. Dissert. Abst., vol. 18, no. 5, 1958, pp. 1832–1833.

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4. Weybrew, B. B.: Psychological Problems of Prolonged Marine Submergence. *In* Burns, N. M.; Chambers, R. M.; and Hendler, E.: Unusual Environments and Human Behavior, Free Press of Glencoe, Collier-Macmillan, London, 1963, pp. 87–126.

EXPERIMENT 7

1. *Evaluation of Spontaneous Activity (Initiative), GSR, and EEG as Indicators of Vigilance on a Prolonged Space Flight Mission*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   Inherent in the title of the experiment.
4. *Justification and Rationale*
   Submarine research indicates that alertness, concentration, and excitation levels tend to decrease as a prolonged mission progresses (refs. 2, 4). Initiative also tends to diminish in an environmentally restricted, high-altitude balloon flight (ref. 3). Degredation of vigilance and initiative could have serious consequences on a prolonged space flight where the success of the mission may depend on the continued vigilance of one or two members at any one particular period of time. The role of vigilance on a prolonged space flight needs to be analyzed and evaluated.
5. *Experiment*
   Materials: Rating scales for vigilance (alertness, concentration, excitation level). A miniature tape recorder into which the subject would dictate any interesting or exciting experiences of the day (or any other time period). The "time spent dictating to this recorder . . . [would represent] . . . a form of initiative or spontaneous activity" (ref. 3) as would the GSR and EEG, using the method of Riehl to develop indices of vigilance. The basal resistance level and extinction rate can also be used as indices of excitation level for the GSR.
   Subjects: Same as in experiment entitled *Emotional Changes During Prolonged Space Flight.*
   Procedure: Physiological measurements and ratings should be taken every second day for a 30-day space flight. Dictation (an indicator of initiative) should be recommended (though not demanded) at the same rate *during the astronaut's recreation period.*

6–22. Same as in experiment entitled *Emotional Changes During Prolonged Space Flight.*

23. *References*

1. Riehl, J. L.: An Analog Analysis of EEG Activity. Aero. Med., vol. 32, 1961, pp. 1101–1108.
2. Ritch, T. G.: Report on the Effects of Prolonged Snorkelling on the Health of the Officers and Men and on the General Habitability of the Guppy-Snorkel Submarine USS Trumpetfish (SS425), U.S.N. Med. Res. Lab., Rept. No. 132, New London, April 1948, 9 pp.
3. Simons, D. G.; Flinn, D. E.; and Hartman, B.: Psychophysiology of High-Altitude Experience. *In* Burns, N. M.; Chambers, R. M.; and Hendler, E.: Unusual Environments and Human Behavior, Free Press of Glencoe, Collier-Macmillan, London, 1963.
4. Weybrew, B. B.: Psychological and Psychophysiological Effects of Long Periods of Submergence. I. Analysis of Data Collected during a 265-Hour, Completely Submerged, Habitability Cruise made by the USS Nautilus (SSN571). USN Med. Res. Lab. Rep., New London, February 1957, 16 (3, Whole No. 281), iv, 43 pp.

EXPERIMENT 8

1. *Effect of Frustrating Situations on Subsequent Psychological Performance During Prolonged Space Flights*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To evaluate the degree of behavioral disruption and disorganization following a frustrating situation in order (1) to determine the overall effects of the stress associated with prolonged flight missions and (2) to assess the need for additional conditioning or training to overcome possible adverse reactions.
4. *Justification and Rationale*
   Experiment 6, entitled *Emotional Changes During Prolonged Space Flight,* may not indicate any dramatic alterations in emotional status from one measurement period to another since changes in stress tolerance may proceed by small increments. Furthermore, ordinary behavior controls may mask significant inner changes. Neither will that experiment show directly how emotional changes can affect subsequent performance.
   An intense but controlled stress input, integrated into the usual program of astronaut activities, could provide a situation sufficiently frustrating to permit an evalaution of (1) emotional overreaction and (2) degradation of subsequent psychological performance. The degree to which both of these effects exceed the baseline preflight data could be attributed in large part to the stresses of space flight. If the degradation of subsequent psychological performance is "excessive," remedial action would seem to be indicated.
   It is recommended that the controlled stress input be incorporated into the astronaut conditioning schedule related to troubleshooting and emergency training. If, for example, the schedule on a particular day demands that the astronaut undergo four different troubleshooting maneuvers, the third of these should be one in which he fails (either to find the trouble spot or to fix it in a specified period of time). The fourth troubleshooting task should be a routine one for which some previous performance data on the astronaut is available.
   Since it is anticipated that such troubleshooting and emergency training will be continued aloft in order to keep the astronaut at peak performance in emergency situations, equivalent frustrating tasks should be incorporated in both ground-based and orbital training sessions. Since the number of possible emergency situations is extensive, it should not be too difficult to construct many relatively equivalent task situations.
   It is anticipated that the frustrating tasks will arouse sufficient emotional reaction in astronauts who presumably have high ego regard and self-confidence. Before reentry and after the completion of the in-flight series of troubleshooting tests, the astronauts should be debriefed concerning the insoluble task so as to minimize any anxiety the frustrating experience of failure may have provoked.
5. *Experiment*
   Materials: The same psychological, physiological, and biochemical measures as those in the experiment entitled *Emotional Changes During Prolonged Space Flight.*
   Subjects: Those in the experiment entitled *Emotional Changes During Prolonged Space Flight.*
   Procedure: Basically similar to that in the experiment entitled *Emotional Changes During Prolonged Space Flight.* In the present experiment, four troubleshooting tasks would comprise one training session. The astronauts are instructed that they might not be able to complete the tasks in time allotted. Of these tasks, one or more would be "failed" by the astronauts; the fourth would be a standard type for which preformance data is available. Immediately following the fourth task, performance on the psychological tasks of the behavioral panel should be evaluated. The psychological rating scales should follow the psychological tests in half of the experimental sessions; they should precede the psychological tests in the other half.

6–22. As in Experiment 6, entitled *Emotional Changes During Prolonged Space Flight.*

23. *References*
    None.

EXPERIMENT 9

1. *Behavior and Performance Levels During Periods of Mental Stress and Relative Relaxation*
2. *Estimated Priority*
   Priority 2.
3. *Purpose*
   To determine psychophysiological effects of concentrated mental stress in relative isolation and compare these to psychophysiological parameters taken during relative relaxation.
4. *Justification*
   As manned space flights develop, various mental stresses will come to bear on the responsible in-flight personnel. Such personnel will be required to perform at relatively high, or even extremely high, levels during the stresses and yet must have periods of relative relaxation. The problem of periodicity or cycling of duty and the relationship of performance levels to it remains largely unsolved. Therefore, this experiment is of considerable importance in that it is designed to provide further information on the relationship of concentrated mental stress, relative relaxation, and periods of drowsing to average mean performance levels.
5. *Experiment*
   The basic postulate is that intense concentrated language instruction constitutes a mental stress which can be evaluated in terms of full scale and verbal performance, as well as memory, and both physiological and biochemical parameters.
   This is a ground-based experiment in which 8 experimental and 8 control subjects will participate. The experimental subjects will be instructed in a language foreign to them by a technique known as total immersion for 3 days, then permitted a relative rest period of 2 days, followed by another intensive language instruction period. The control group will be isolated and relatively restrained in a manner identical to the experimental group, but will not meet the language instruction requirements. On the contrary, the control group will have relatively nonstressful tasks assigned, but will be subject to the same test procedures as the experimental personnel.

   Independent Variables:
   a. The physical parameters of the test area.
   b. The environmental atmosphere.
   c. The personnel strength.
   d. The test cycle.

   Dependent Variables:
   a. Psychological performance as measured by verbal foreign language test, full scale performance test, Minnesota Memory Test, continuous performance test, and other tests to be designed and introduced as the protocol develops.
   b. Physiological measurements.
      (1) Polygraphic recording, including GSR and peripheral temperatures.
      (2) EEG.
      (3) Biochemical profile with particular emphasis on excretion of urinary steroids.
6. *Experimental Controls*
   Eight experimental controls will be included as noted under 5. It seems clear that this number will be a function of the number of experimental personnel.
7. *Summary of Number and Types of Space Station Personnel*
   None.
8. *Summary of Onboard Experimental Equipment Required*
   None.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    None.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    None.
14. *Telemetry versus Onboard Recording Requirements*
    None.
15. *Prerequisite Ground-Based Experiments*
    None.
16. *Prerequisite Space Flight Experiments*
    None.

17. *Prerequisite Research and Development*
None.
18. *Onboard Gaseous Atmosphere Desired*
None.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
None.
21. *Special Comments*
If successful, this test should provide data significant for itself and significant for correlation with the proposed experiments on the W–R–S cycle, the EEG continuum, and various psychological assessments of emotional and isolation states.
22. *Postflight Evaluation of Crew*
None.
23. *References*
None.

EXPERIMENT 10

1. *Effects of Spatial Confinement Variables on Group Performance in Weightlessness*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To help answer questions concerning the effects of certain psychological variables (confinement, social restriction, monotony, and crowding), which are seemingly inherent in space flight, on the individual and group performance of astronauts.
4. *Justification*
As space flights continue, the time spent in such flights will increase. Because of engineering limitations, the space travelers will be faced with confinement to small spaces, restricted socially, crowded by other crew members, face a monotonous existence for long periods of time, and have reduced possibility for normal exercise. The effects of these variables on group performance need to be understood both as single and as interacting variables with weightlessness.
5. *Experiment*
The hypothesis tested is that the spatial confinement, social restrictions, monotony, crowding, and exercise concomitants of space environment for the Apollo and next larger space capsules will operate as both single and interacting variables to affect the performance of individuals exposed to them.

Independent Variables:

a. Spatial confinement (includes social restriction and monotony variables):
Varied between
(1) the space configuration of the Apollo,
(2) the next larger configuration, and
(3) a normal outside environment.

b. Crowding:
Varied from 4 to 5 to 6 in terms of numbers of subjects confined.

c. Exercise:
Varied under the conditions of
(1) programmed considerable exercise,
(2) programmed minimum exercise, and
(3) lack of any programmed exercise.

Dependent Variables:

a. Performance as measured by:
(1) a performance panel consisting of psychomotor and cognitive tasks,
(2) critical flicker fusion,
(3) the Categories Test, and
(4) operational procedures.
(5) Physiological variables associated with weightlessness and/or lack of exercise.

b. The experiment is a modified $3 \times 3 \times 3$ factorial design with subjects assigned to the space confinement variable as follows: replication of Apollo volume size using 4 and then 5 occupants; replication of next larger size using 5 and then 6 occupants; and using 6 occupants only for the normal outside volume.

6. *Experimental Controls*
To determine the effects of weightlessness as a main effect and as it interacts with the other independent variables, the study must be either replicated on the ground or in an artificial gravity environment aboard the space craft.

7. *Summary of Number and Types of Space Station Personnel*
(level of training required, i.e., physician, lab tech, trained astronaut, etc.) All subjects must be either astronauts or of astronaut-like physical and psychological characteristics. Not counting the control replication for the weightlessness variable, seventy-eight subjects would be required. Subjects could be run in a series of groups as small as four to six members at a time.
8. *Summary of Onboard Experimental Equipment Required*
(latest state-of-the-art equipment, size, weight, and power requirements, as nearly as known)
a. *Fixed equipment*
b. *Consumable equipment:* Performance panel, critical flicker fusion apparatus, Categories Test, exercise equipment. All equipment is nonconsumable, will weigh approximately 100 pounds, and occupy approximately 20 cubic feet, exclusive of laboratory equipment required for physiological measurements.
9. *Summary of Animals*
None.
10. *Summary of Other Living Forms*
None.
11. *Summary of Onboard Laboratory Determinations*
(type, frequency, time consumed for each) Physiological determinations decided upon at the time as most relevant to measurement of effects of weightlessness and/or lack of exercise.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
Subjects should not be rotated until after data have been completely collected on them. This period will vary from two weeks in the Apollo-like space volume to three months in the normal outside volume condition.
14. *Telemetry versus Onboard Recording Requirements*
Some onboard recording delayed transmission and readout capability, but for the most part direct telemetered data link with ground station.
15. *Prerequisite Ground-Based Experiments*
The control run for weightlessness should be conducted as a ground-based experiment. Beside yielding control data, it will permit an evaluation of methods and techniques before the weightless phase in space is conducted.
16. *Prerequisite Space Flight Experiments*
None.
17. *Prerequisite Research and Development*
None.
18. *Onboard Gaseous Atmosphere Desired*
Whichever atmosphere appears to be chosen for future spacecraft operations.
19. *Requirement for Rotation for Artificial G*
Not required if weightlessness control group is run as a ground-based experiment.
20. *Comments re Form of Data and Interpretation of Data*
Data should be recorded automatically where possible and in a form convenient for computer reduction and analysis.
21. *Special Comments*
This experiment should be coordinated with researchers presently engaged in the "exercise area" of space flight.
22. *Postflight Evaluation of the Crew*
Complete medical and psychological debriefing examination and interview.
23. *References*
None.

EXPERIMENT 11

1. *Human Performance as a Function of the Work-Rest-Sleep Cycle*
2. *Estimated Priority*
Priority 2.
3. *Purpose*
To help answer questions concerning the effects of prolonged space flight on the well-being and psychological performance of the individual crew members.
4. *Justification*
As space flights continue, the time spent on such missions will increase. Because of engineering limitations, the space travelers will be faced with confinement to small spaces, social restrictions,

crowding by other crew members, monotonous existence for long periods of time and work-rest-sleep cycles adjusted to duties and not to the 24-hour patterns to which they have been adapted in the past. The effects of these variables on the physiological status and psychological functions of astronauts need to be evaluated.

5. *Experiment*

Hypothesis: The physical parameters of the space cabin (size) in combination with its environment (atmosphere) and a work-rest-sleep cycle adjusted to duties (instead of self-selected) will operate as single and interacting variables to affect the performance of the crew members.

Experimental design: Determined by the number of astronauts in flight (for example, 4 or 8) and whether the specific duties would allow for the matching of various hours on and off duty with paired subjects carrying out a different routine or a similar program. In this way it might be possible to obtain optimum well-being and performance in flight.

The first step would be to work out a proposed schedule on the ground previous to flight based upon the findings from present studies and expected operating procedures. The second step would be to repeat the program in flight. The third step would be to readjust the schedule as determined by the requirements of flight operating procedures. The fourth step would involve the collection of data from the various matched subjects in which the basic work-rest-sleep cycles were varied in some and not in others. For example it would be interesting to determine whether the data from the more normal scheduling, as on Earth, would give more efficient performance records compared with 4 hours on duty, 4 hours off, and 4 hours sleep. The various patterns of scheduling for experimental purposes would be set up once the overall operational procedures had been established.

Independent Variables:

a. Physical parameters of the space cabin
   (1) Volume
   (2) Shape
b. Environment (atmosphere)
   (1) Partial pressure
   (2) Oxygen content
   (3) Inert gases
c. Crew size
d. Duration of cycle periods
   (1) The work-rest cycle: dw/dr
   (2) The duration of the work periods; dw
   (3) The sleep-wakefulness cycle; ds/daw
   (4) The duration of the sleep period: ds
   (5) The total daily periodicity: DT

Dependent Variables:

a. Physiological measurements
   (1) Temperature
   (2) Urinary excretion of steroids
   (3) Heart rate
   (4) Blood pressure
   (5) EEG
b. Psychological performance as measured by
   (1) Psychomotor and cognitive tasks
   (2) Critical flicker fusion
   (3) The categories test
   (4) Operational procedures

6. *Experimental Controls*

The men would be their own controls as they participate in the same tasks and tests during the simulation and training runs prior to the actual flights.

7. *Summary of Number and Types of Space Station Personnel*

Number will not be determined by experiments in this phase of testing. Any type crew member chosen will satisfy the requirement for test subjects in this phase.

8. *Summary of Onboard Experimental Equipment Required*

Unless steroid excretion rates are measured and EEG's are taken there will be no need for equipment in excess of that already proposed for other phases of the experimental program.

9. *Summary of Animals*

None.

10. *Summary of Other Living Forms*

None.

11. *Summary of Onboard Laboratory Determinations*

   1. Temperature
   2. Heart rate
   3. Blood pressure
   4. EEG
   5. Urinary steroid levels
   6. Psychological tests

12. *Summary of Laboratory Specimens to be Flown*

to Earth for Laboratory Examination
1. Urinary steroid samples
2. Companion blood samples

13. *Proposed Rendezvous Schedule for Rotation of Crew*
To be determined by factors other than the present experiment.

14. *Telemetry versus Onboard Recording Requirements*
There are no telemetry requirements in excess of those already available within the space cabin as now proposed.

15. *Prerequisite Ground-Based Experiments*
The experimental program as outlined in final draft will include requirements for obtaining complete baseline data on all subjects during ground-based training and simulation maneuvers prior to actual flight in order to evaluate the effects of altered light-dark cycles, altered gravitational stresses, and interaction of these and other parameters.

16. *Prerequisite Space Flight Experiments*
Similar types of experiments in other orbital flights of long duration.

17. *Prerequisite Research and Development*
None.

18. *Onboard Gaseous Atmosphere desired*
Sea level equivalent.

19. *Requirement for Rotation for Artificial G*
None.

20. *Comments re Form of Data and Interpretation of Data*
Data may be recorded by hand in crew members daily logbook or, in the case of the EEG, be recorded onboard for later analysis at ground-based station.

21. *Special comments*
See previous sections of report on work-rest-sleep cycle for more complete discussion of this field of study and for recommendations.

22. *Postflight Evaluation of the Crew*
There will be requirements for thorough post-flight crew evaluation in a manner similar to that in which the crew is evaluated preflight.

23. *References*
See bibliography at end of report on this subject in Phase I.

CIRCULATORY AND RESPIRATORY FUNCTIONS

PREAMBLE

The experiments proposed for the ORL are presented on the basis of a critical review of the physiological mechanisms which may be affected adversely *during space flight.*

These proposed experiments are based, partly, on the currently available results of space flight. In-flight experiments and observations in the Gemini-Apollo, Biosatellite, and MOL are considered to be sources of information that will be available during the design of the experiments.

The group has interpreted an experiment to be a series of measurements and observations designed to test a hypothesis. Certain systematic observations of physiological changes during flight are necessary for monitoring and for more detailed analysis as indicated below. However, the justification of a space station depends on its requirement for the performance of critical experiments. These critical experiments are related to (1) additions to knowledge made possible by features of the space environment which are unique. Prominent among these environmental features are: (a) low acceleration relative to the surrounding vehicle, (b) absence from the terrestrial diurnal cycle, (c) presence of a stress pattern not readily simulated on Earth, and (d) immersion in a radiation flux not simulable at ground level.

These critical experiments are also related to (2) the research and development required to assess man's capability of long-term (one-year) space flight with indication of the support he may require.

Conceptually, a class of experiments that seems most promising is that revolving about examination of the gain (μ), feedback constant (β), and loop transfer function characteristics for the important homeostatic feedback and feedahead loops of familiar physiological regulatory system. In addition to experiments utilizing the normal physiological system, design here would surely seem to include opening the said loops or of exposing their internal characteristics by pushing the system into the $\mu\beta \rightarrow 1$ region where "overload" begins to show.

Although a number of specific experiments are designed to "test" the characteristics of the physiological systems, certain observations are recommended on a daily (continuous) basis to provide data which may be used in a number of data acquisition and reduction procedures. Prominent among these are heart rate, blood pressure, and ballistocardiograms related to cardiac function, and minute volume, respiratory frequency, oxygen consumption, and arterial oxygen saturation related to pulmonary function. There are additional measurements which will be made on a periodic basis in the proposed experiments. Among these measurements are body mass, blood volume, hematocrit, body water, and routine urine analysis.

Experiments that require minimal increases in burden of the experimental subjects with transducers or additional duties or of the vehicle with added weight, complexity, or hazards are highly desirable over manned orbital laboratory for research. Preferably, new experiments are most desirable if they require *no* new data acquisition techniques. Where new techniques are required they should be carefully designed so as to optimize their utilization and minimize their interference and burden on the vehicular resources.

Acquisition of this class of data is especially suited by a bioengineering system which incorporates a small, but fast, central control and processing computer capable of stored program control operation. A compatible slow memory of larger extent (e.g., an incremental multichannel magnetic tape recorder) is also a near requisite.

With a good onboard data reduction system of adaptive type, it becomes feasible to store in a few pounds of tape a detailed running record of hundreds of experiments along with essentially continuous records of routine monitored how-goes-it information.

RATIONALE OF THE EXPERIMENTAL PROGRAM

One of the possible effects of long-duration exposure to the weightless environment is a deterioration in cardiovascular reactivity due to absence of the usual hydrostatic stresses imposed during existence in the 1 G environment of Earth.

If such deterioration does occur, it would be expected to be manifest as a malfunction of one or more of the control loops responsible for homeostatic regulation of the cardiovascular system. Those loops, susceptible to hydrostatic effects such as the systems for regulation of systemic and venous blood pressure and blood volume, will presumably be subjected to minimum stress during exposure to zero G and hence would be most likely to deteriorate during sustained existence in this environment.

Analysis of the mechanism of such deterioration could logically be divided into investigation of possible alterations in the affector, the error-sensing, and the effector arms of the control loop under study. For example, one of the major control systems of arterial blood pressure is the baroreceptor (carotid sinus) system.

Ideally, tests should be carried out on the static and dynamic sensitivity characteristics of the carotid sinus—transducer system in sensing shifts in arterial pressure away from the normal homeostatic level and transducing these shifts to the appropriate variations in frequency of affector nerve impulses in the carotid sinus nerve.

Similarly, it would be ideal to investigate the efficiency of the various effector mechanisms responsible for the maintenance of arterial pressure such as arteriolar and venous tone or compliance and the static and dynamic capabilities of the arteriolar and venous systems to respond in an appropriate manner to effector stimuli for alteration of their caliber.

Since the major concern is with the capability of man to maintain his normal function in the zero G environment and to withstand the stresses of reentry into and subsequent (ideally) immediate adaptation to the Earth environment, studies carried out on man himself will probably be most productive of the practical information required. This is particularly true since man's adaptation to the erect posture in the 1 G environment is not closely simulated in experimental animals.

Investigation of cardiovascular reactivity in man in the zero G environment restricts applicable experimental procedures to those which carry a minimally acceptable risk of causing other than accurately forseeable, temporary restriction of the subject's full mental and physical capabilities. These restrictions preclude most academically ideal experiments involving opening of control loops and study of the static and dynamic characteristics of the affector, error-sensing, and effector components of the system. This type of experimental rationale does, however, provide a logical basis for design and coordination of experiments. An attempt has been made, therefore, to design experiments with this rationale in mind, realizing that full separation of the individual components of a control loop cannot be achieved in conscious human subjects.

PHYSIOLOGICAL VARIABLES TO BE MEASURED

The following list summarizes the variables which may be measured during prolonged space flight. Their priority is listed in the experiments themselves. The purpose of this listing is to present some idea as to the extent of the equipment and techniques required for carrying out the proposed experiments and the day-to-day measurements discussed in the preamble. Some of the variables to be measured require research and development on the ground. The variables are listed in alphabetical order.

1. Arterial pressure (direct and indirect)
2. Ballistocardiogram
3. Blood volume (intra- and extracellular fluid volume hematocrit)
4. Body mass and volume (density)
5. Body temperature and skin temperature
6. Cardiac output
7. Circulation time
8. Electrical activity of the heart (EKG)
9. Heart size
10. Heart rhythm and rate
11. Index of airway resistance
12. Intraocular pressure (tonometer)
13. Left ventricular ejection time (phonocardiography and carotid pulse)
14. Measurement of lung compliance (esophogeal pressure)
15. Oxygen saturation of arterial blood (P_{O2}, P_{CO2} total hemoglobin)
16. Metabolic rate and heat exchange
17. Respiratory rate and minute volume (spirometry)
18. Respiratory gas analysis (O_2 and CO_2)
19. Venous pressure (central and peripheral)
20. Venous tone
21. Chemical analysis of blood (Hemoglobin, hematocrit, catecholamines, cortiosteroids, antidiuretic hormone, pH, protein, CO_2 content, oxygen content, electrolytes (Na, K, Cl, Ca, Mg, P), glucose, urea, uric acid, cholesterol, prothrombin time, thromboplastin generation, transaminase, lactic dehydrogenase, toxicological tests in case of an overdose or exposure (e.g., salicylate, barbiturate, heavy metals, demerol), $O_2 + CO_2$ in gas)
22. Microscopic examination of blood (Examination of red and white cells as to number, morphology and reticulocyte count)
23. Routine urine examination (pH, glucose, protein, sp. gr., sediment examination, 24-hr specimens from time to time for electrolytes (including Ca and P) and nitrogen balance)
24. Other specialized measurements described in the individual experiments, such as urinary hormone analysis (ADH, catecholamines, and steroids)

EXPERIMENT 1

1. *Changes in Blood Volume and Central Venous Pressure During the Weightless State*

2. *Estimated Priority*
   Priority 1.

3. *Purpose*
   To determine the time course of changes in blood volume and venous pressure during weightlessness and the recovery following weightlessness (return to 1 G).

4. *Justification and Rationale*
   Since space flights as well as experiments in the hypodynamic state and following bed rest have indicated that there is a postflight or postexperiment period of abnormal circulatory responses to tilt (refs. 1, 2, 3), heat (ref. 1), and G forces (ref. 1). The mechanisms that may be postulated include (1) reduction in blood volume, (2) abnormal blood pooling, and (3) abnormal regulatory responses. Each of these mechanisms is subject to experimental test and will serve to indicate a rational countermeasure. Russian reports and hypodynamic experiments suggest that a readjustment in fluid volumes occurs in one day.
5. *Experiment*
   No method of determining blood volume is clearly superior. For the purposes of this discussion, a dilution technique will be presented with the general characteristics of the solute and diluent. Proper experimental design will allow determination of a number of other parameters of physiological interest. A solute which is retained in the circulatory system may be injected in a deuterium oxide medium and blood volume and total body water determined. The determination of hematocrit is a necessary part of the experiment. Determination of the body mass will give additional data for calculation of percent body water and lean body mass. Urine volume and sodium analysis and water intake determination will allow determination of fluid balance.
   Determinations should be made daily at the same time for a period of 30 days and, if possible, a second determination made to determine any circadian responses. (Alternative, every fifth day could be used following the first 5 days.) Postflight determinations after 30 minutes in the supine position should continue for 15 days.

   Specific Techniques and Accuracies

Blood volume (red cell and plasma) indicator	± 500 ml
Deuterium determination	± 100 ml
Mass	± 10 gm
Sodium	± 3 meq/l.
Urine volume	± 10 ml
Central venous pressure	± 1 mm Hg

6. *Experimental Controls*
   A preliminary study should be ground-based. Six subjects followed for 45 days are desirable.
7. *Summary of Number and Types of Space Station Personnel*
   Preferably, the experimental team should include:
   1. A physician who has participated actively in the control ground-based experiments on the astronauts just prior to their flight.
   2. A trained laboratory technician.
   3. Two trained astronauts who would alternate in acting as subjects and as the third member of the experimental team.
   4. Other personnel would be measured if possible.
8. *Summary of Onboard Experimental Equipment Required*
   Fixed equipment:
   (1) Apparatus for determining mass and volume of body
   (2) Apparatus for determination of deuterium (Alternative samples may be returned to Earth)
   (3) Laboratory equipment for urinalysis
   (4) Pressure gages and recording equipment

   Consumable equipment: Chemicals for all determinations.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    1. Determination of blood volume (once each day for at least 5 days, then on 15th and 30th).
    2. Measurement of venous pressure daily.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    It may be convenient to return urine and blood samples for analysis.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Rendezvous may be necessary for transfer of samples.
14. *Telemetry versus Onboard Recording Requirements*
    Onboard recording with telemetry facility for

sending data to Earth laboratory.

15. *Prerequisite Ground-Based Experiments*
Complete standardization of techniques and control levels on all subjects.
16. *Prerequisite Space Flight Experiments*
None.
17. *Prerequisite Research and Development*
Standardization of blood volume technique.
18. *Onboard Gaseous Atmosphere Desired*
Sea level equivalent.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
    1. Data should be in continuous analog form (magnetic analog tape or photokymographic record) during each experiment with requisite number of calibrations to insure reliability. Spot checks online by visual monitoring of stored oscilloscope trace or polaroid picture thereof during important phases of each experiment would be highly desirable.
    2. Interpretation should be by a cardiovascular physiologist or a physician with special training in cardiovascular physiology who has participated in the series of these experiments carried out preflight on the astronauts being studied in flight.
21. *Special Comments*
Interpretation of the data obtained during flight, if progressive changes should be observed, may prove to be one of the best objective bases upon which to decide whether or not a flight should be continued or rendezvous for rotation of crew be carried out.
22. *Postflight Evaluation of the Crew*
None.
23. *References*

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2. Graveline, D. E.; and Barnard, G. W.: Physiologic Effects of a Hypodynamic Environment: Short Term Studies. Aero. Med., vol. 32, 1961, pp. 726–736.
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4. Mercury Project Summary. NASA SP–45, May 15–16, 1963.
5. Parin, V. V.; Volynkin, Y. M.; and Vassilyev, P. V.: Manned Space Flight, COSPAR, Florence, Italy, May, 1964.

Experiment 1a

1. *Body Volume*
It has been suggested in association with the previously discussed method of determining weight by an oscillatory method that a method for determining the volume of these by excluding the volume occupied by air in the lungs would give a valuable set of additional information. A suggested method requiring minimal apparatus for accomplishing this purpose would be as follows: a relatively simple, zipper-closed enclosure (preferably translucent and with access to the zipper from the inside so as to provide minimal claustrophobia for the occupant) would be made of a very flexible and thin, but not readily stretchable, fabric. This suit, when inflated at a very low positive ambient pressure, would take up a fixed volume which could probably be held constant to within a few cubic centimeters. Knowing the volume of the container, the volume of the body excluding air would be available if the amount of air in the chamber were measurable. Two methods for measuring this air seem simple and practical. One would include the introduction of an accurately known, small incremental volume of air preferably in a sinusoidally oscillatory fashion. For example, a small cylinder of air could be discharged and reclaimed from the chamber by essentially a motor-driven hypodermic syringe of fairly large volume. Knowing the volume change and the pressure change accompanying it from a simple transducer, the volume of air would be measurable so long as the individual kept his airway open. The air in the lungs would be part of the air of the chamber and thus it could be measured. Alternatively, a tracer

method could be used in which a known volume of a measurable gas is projected into the chamber and rebreathed a few cycles; a sample is then extracted to determine by dilution method the remaining air. Since the experiment would occupy only a fraction of a minute or a little more, there would be no necessity for elaborate provision of additional oxygen or carbon dioxide management.

Experiment 1b

1. *Assessment of Body Mass*
This experiment is concerned with the systematic variations in body weight over a period of days and is almost totally concerned with the provision of a method of a simple, yet precise, measurement of body mass. Notice that it is not important that the method have high absolute accuracy as its interest is concerned mainly with changes in mass of the order of a few ounces with respect to a baseline. However, the method must be intrinsically sensitive and reproducible enough to detect changes of this order of magnitude. If, as has been suggested, there is interest in mass changes of the order of 20 grams, then the precision of the measurement must be sufficient to permit detection of 20 g in 80 kg or about 1 part in 4000, i.e., 1/40 of 1 %. This is not easily achieved with simple scale reading instruments. The method proposed in the experiment calls for an accelerometer measurement of the person when accelerated by a known force or rather a known impulse imparted by a coil spring. While it is quite possible to calibrate a spring to this precision, it is quite difficult to measure accelerations to a necessary degree of accuracy with any reasonably practical transducers.
An alternative procedure which seems much simpler would be one relying on a spring to provide a known compliance when extended to a fiducial mark but would measure the period of oscillation of a system including the experimental subject with the spring as a restoring force. If one assumes that a compliance is used which is sufficiently high to make a period of oscillation long with respect to the natural periods of the body (i.e., long with respect to about a quarter second), then an estimate can be made of the required period of observation and the accuracy with which a cycle has to be measured. If one chooses a period of approximately 0.6 sec, then a measurement period of 1 minute would include something approaching 100 cycles of oscillation using a platform simpler, but of the same general sort, than that proposed in the experiment. The measurement required would be one of stress in the compliant element which need not be quantitative beyond rough linearity, and in a 100 cycle process it would require discrimination of approximately the percentage of the cycle represented by the fraction of a percent tolerable error. Thus, determination of oscillation to the nearest tenth of a cycle which is very easy would give a tenth of a percent accuracy while the previously mentioned 1/40 of 1% precision would require measurement to a fortieth of a cycle which is about 10 degrees of phase—a feasible but not completely easy task. A factor of two enters into the precision measurement to the square root relationship between mass and period. A special purpose device attached to a central computer designed to record the time required for 200 zero crossings of this compliant element would seem entirely suitable for this measurement and would require minimal equipment. Should there be real concern about the slight error induced through shaking of the abdominal structures, this could be detected by providing a pair of compliances and noting the two indicated masses which would differ in terms of the coupling to the movable portions of the body.

EXPERIMENT 2

1. *Assessment of Body Mass in Real Time*
2. *Estimated Priority*
Priority dependent on particular experiment utilizing these techniques.
3. *Purpose*
To measure fluctuation in body mass as a means

of calculating weight gain or loss.

4. *Justification and Rationale*
One of the major medical problems incurred by the astronauts and cosmonauts has been dehydration. By means of daily body mass estimations, it should be possible to estimate significant changes in total fluid balance. Refinement of techniques may lead to the ability to determine major shifts within large segments of the body.

5. *Experiment*
The subject places himself on a suitable platform fixed in the erect position. A vertical bar is firmly attached to the central point of the platform. At the top of the bar is a cap on a ring slide. This is fitted snugly down onto the head of the subject Below this is a cross bar at the ends of which on either side are molded shoulder pads. This is slid down and fixed over the shoulders. At about waist height on this bar are preset band bulbs which are grasped firmly by the hands. Thus it is possible to place the subject in a reproducible position for each subsequent measurement. If a problem arises by virtue of the inertia of large internal abdominal organs it may be necessary to use the sitting position with the thighs drawn up tightly onto the abdomen. This position will compress the abdominal organs into the upper quadrant of the abdominal cavity and insure the whole body mass moving as a unit. Attached to his shoulder pads and head cap is a harness which is loose enough to allow his body mass to be displaced upward for several inches at which point it serves as a restraining mechanism and decelerates him. (The ends of the harness are fixed to appropriate plates on the floor of the capsules.) The platform sits on top of a spring-driven piston of exactly the same surface area which is contained in a cabinet about 1 foot square and 18 inches higher. The spring is wound to a fixed point of tension by a ratchet mechanism. A second member of the crew at a signal of readiness releases the spring tension. The impulse is transmitted by means of the piston to the platform on which the man is standing. This accelerates the subject up into the restraining harness. An accelerometer which is attached to the vertical rod to which the man has been attached is activated by the upward movement of the total mass. The meter is attached by hard wires to a suitable recording instrument. The acceleration by a fixed impulse will vary with the mass. By daily recording at a fixed time of the 24-hour cycle (on awakening, after voiding, and before eating), fluctuations in mass can be determined.
It is calculated that changes in body mass of more than 0.5 lb daily are due largely to fluid balance fluctuations. The metabolic requirements for the man are in the order of 2500Kcal daily. If he eats nothing, he will have a caloric deficit of this magnitude A pound of body tissue is equivalent to 3700 cal. The estimated weight loss of maximum caloric deficit will be 25/37 or 0.66 lb. Rapid catabolic changes will alter these figures. Necessary N_2 excretion data will be available from previous flights which will enable one to make suitable corrections in the calibrations.

6. *Experimental Controls*
Experimental controls will be governed by those of the experiment employing these techniques.

7. *Summary of Number and Types of Space Station Personnel*
Utilization of existing crew. No special training.

8. *Summary of Onboard Experimental Equipment Required*
Inertial displacement machine as described. One accelerometer. Utilization of existing recorder channel for 5 min daily. No additional points. Total weight about 10 lb.

9. *Summary of Animals*
Not applicable.

10. *Summary of Other Living Forms*
Not applicable.

11. *Summary of Onboard Laboratory Determinations*
Five minutes daily for each man.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
Not applicable.

13. *Proposed Rendezvous Schedule for Rotation of Crew*
Not applicable.

14. *Telemetry versus Onboard Recording Requirements*
Daily telemetry to ground monitor. No special band.

15. *Prerequisite Ground-Based Experiments*

Ground-based experience to check feasibility and improve design.

16. *Prerequisite Space Flight Experiments*
Establishment of degree of catabolic response which may increase weight loss.
17. *Prerequisite Research and Development*
Build and ground-test prototype.
18. *Onboard Gaseous Atmosphere Desired*
No special requirement.
19. *Requirement for Rotation for Artificial G*
No special requirement.
20. *Comments re Form of Data and Interpretation of Data*
Ground-based calibration to measure mass in terms of weight. Any change in mass of more than 0.7 lb each day or average over any selected time period may be interpreted as water loss from body.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
23. *References*
Mercury Reports.

EXPERIMENT 3

1. *Changes in Peripheral Venous Compliance and Pressure During the Weightless State*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To determine if the reduced stress on the circulatory system (absence of gravity dependent hydrodynamic effect) effects a reduction in venous compliance or reactivity to stretch (filling) or results in changes in venous pressure.
4. *Justification and Rationale*
Since space flights as well as experiments in the hypodynamic state and following bed rest have indicated that there is a postflight or postexperiment period of abnormal circulatory response to tilt (refs. 1, 2, 3), heat (ref. 1), and G forces (ref. 1), the mechanisms that may be postulated include (1) reduction in blood volume, (2) abnormal blood pooling, and (3) abnormal regulatory responses. Each of these mechanisms is subject to experimental test and will serve to indicate a rational counter-measure. Russian reports and hypodynamic experiments suggest that a readjustment in fluid volumes occurs in one day.
5. *Experiment*
Methods for this determination are equivocal, and effort should be made to increase the confidence in the techniques. For initial purposes, the following are proposed:

    Venous compliance in flight, e.g., measure leg circumference with mercury in rubber strain gage (Whitney) and record pulse. Inflate cuff proximal to gage in 10 mm Hg pressure steps and record change in volume (refs. 4–13).
6. *Experimental Controls*
A series of experiments should be carried out on healthy male subjects (in the same age range as the astronauts) under carefully controlled conditions using the procedure outlined above and variants thereof.

    The objective of these experiments would be:
    1. To standardize in detail the techniques and equipment to be used.
    2. To obtain the baseline data.
7. *Summary of Number and Types of Space Station Personnel*
Preferably, the experimental team should include:
    1. A physician who has participated actively in the control ground-based experiments on the astronauts just prior to their flight.
    2. A trained laboratory technician.
    3. Two trained astronauts who would alternate in acting as subjects and as the third member of the experimental team.
8. *Summary of Onboard Experimental Equipment Required*
The type of plethysmography will determine the equipment list. The influences are given for mercury in rubber strain gage techniques.
9. *Summary of Animals*
None.
10. *Summary of Other Living Forms*
None.
11. *Summary of Onboard Laboratory Determinations*
Experiment should be performed during first 24 hours of flight, if possible, and repeated at 48-hour intervals for about the first week and each week thereafter.
12. *Summary of Laboratory Specimens to be Flown*

to Earth for Laboratory Examination
None.

13. *Proposed Rendezvous Schedule for Rotation of Crew*
Not necessary for these experiments.

14. *Telemetry Versus Onboard Recording Requirements*
If a physician or a highly-trained physiologist or laboratory technician is onboard, onboard recording and visual display online or on playback from tape recorder would be highly desirable. Telemetry to Earth online or on playback from onboard tape recorder would also be highly desirable as a backup and to insure that data were not lost on reentry.

15. *Prerequisite Ground-Based Experiments*
Standardization of method and acquisition of baseline data are necessary prior to experiment.

16. *Prerequisite Space Flight Experiments*
Flights to check out performance of equipment and technics under weightless conditions would be highly desirable.

17. *Prerequisite Research and Development*
Standardization of plethysmographic technique.

18. *Onboard Gaseous Atmosphere Desired*
Earth atmosphere in range from 0 to 5,000 feet above sea level with shirtsleeve environment.

19. *Requirement for Rotation for Artificial G*
None.

20. *Comments re Form of Data and Interpretation of Data*
    1. Data should be in continuous analog form (magnetic analog tape or photokymographic record) during each experiment with requisite number of calibrations to insure reliability. Spot checks online by visual monitoring of stored oscilloscope trace or polaroid picture thereof during important phases of each experiment would be highly desirable.
    2. Interpretation should be by a cardiovascular physiologist or a physician with special training in cardiovascular physiology who had participated in the series of these experiments carried out preflight on the astronauts being studied in flight.

21. *Special Comments*
None.

22. *Postflight Evaluation of the Crew*
None.

23. *References*

1. Beckman, E. L.; Colrun, K. R.; Chambers, R. M.; DeForest, R. E.; Augerson, W. S.; and Benson, V. G.: Physiological Changes Observed in Human Subjects During Zero G Simulation by Immersion in Water up to Neck Level. Aero. Med., vol. 32, 1961, 1031 p.
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11. McCally, M.; and Lawton, R. W.: The Pathophysiology of Disease and the Problem of Prolonged Weightlessness. A Review AMRL TDR 63–3, June 1963, Aero. Med. Res. Lab., Wright-Patterson Air Force Base, Ohio.

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13. Whitney, R. J.: The Measurement of Volume Changes in Human Limbs. J. Physiol., vol. 121, 1953, pp. 1–27.

EXPERIMENT 4

1. *Evaluation of Significance of Ballistocardiogram and/or Kinetocardiogram (Seismo or Rosa Accelerometer) for Estimation of Cardiac Dynamics in the Weightless State*

2. *Estimated Priority*
   Priority 1.

3. *Purpose*
   To determine whether or not ballistocardiographic techniques can be used as a measure of cardiac dynamics and to extend these investigations for the determination of cardiac output during various activities in weightlessness.

4. *Justification*
   An external indication of changes in stroke volume (and heart rate) would serve as a useful measurement in testing effects of weightlessness and in defining the effectiveness of countermeasures. The ballistocardiogram has had a series of ardent supporters, but lacks general acceptance among cardiovascular physiologists. In the weightless state certain objections to the technique may be removed. Bayevskiy (ref. 1) in Russia and Rosa in the U.S. have proposed using the principle of an accelerometer over the heart to indicate the force and duration of the stroke.

5. *Experiment*
   Appropriate ballistocardiographic devices can be mounted on selected astronauts or other spacecraft personnel and the cardiac dynamics assessed. This assessment will be particularly valuable if made during the times in which cardiac output, as suggested in other experiments, are determined.

6. *Experimental Controls*
   While the preliminary study should be ground-based, the primary control will be the determinations made while cardiac outputs are being determined in the weightless environment.

7. *Summary of Number and Types of Space Station Personnel*
   Preferably, the experimental team should include:
   1. A physician who has participated actively in the control ground-based experiments on the astronauts just prior to their flight.
   2. Trained laboratory technicians.
   3. Two trained astronauts who would alternate as subjects and as a third member of the experimental team.
   4. All other personnel would be measured if possible.

8. *Summary of Onboard Experimental Equipment Required*
   Fixed equipment for determining the ballistic response which would include the appropriate recording techniques.

9. *Summary of Animals*
   None.

10. *Summary of Other Living Forms*
    None.

11. *Summary of Onboard Laboratory Determinations*
    A determination would be made at every occasion in which a cardiac output was measured. Further interim measurements could be made during activities of various sorts and the records held for future evaluation.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    None.

13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Not necessary for these experiments.

14. *Telemetry versus Onboard Recording Requirements*
    Onboard recording with telemetry facility for sending data to Earth laboratory.

15. *Prerequisite Ground-Based Experiments*
    Complete standardization of the technique and equipment.

16. *Prerequisite Space Flight Experiments*
Some equipment checkout could be made on preliminary space flights.
17. *Prerequisite Research and Development*
Design and production of the appropriate equipment for use in the weightless state.
18. *Onboard Gaseous Environment Desired*
Sea level equivalent.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
Data should be in continuous analog form during each experiment with requisite number of calibrations to insure reliability. Data should be stored on tape and transmitted to Earth stations at appropriate times.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
23. *References*

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2. Guyton: Circulatory Physiology Cardiac Output and Its Regulation *in* Ballistocardiography, Saunders and Co., Philadelphia, 1963, pp. 91–98.
3. Landes, G.: Uber die Estehung der Hertztöne Klin, Wschr, vol. 36, 1941, pp. 902–906, Rosa L. Die Graphische D[illegible]stallung Gasunder und Krankhafter Hert[illegible]eit als Beschleuigen und Ausschla dar B[illegible]ndpulsation Cardiologia, vol. 8, 1944, [illegible]–112.
4. Parin, V. V.: Development of Ba[illegible]stocardiography in the USSR–Proc. Third Int. Conf. on Medical Eng., IEE, 1961.

EXPERIMENT 5

1. *Changes in Peripheral Arteriolar Reactivity During the Weightless State*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To determine if reduced stress on the circulatory system (absence of gravity-dependent hypodynamic state) affects arteriolar tone.
4. *Justification*
Since space flights as well as experiments in the hypodynamic state and following bed rest have indicated that there is a postflight or postexperiment period of abnormal circulatory responses to tilt, the mechanism that may be postulated includes effects on arteriolar tone. These experiments are designed to determine whether arteriolar tone changes during the weightless state or whether changes can be detected following the weightless state.
5. *Experiment*
1. Venous occlusion plethysmography to determine blood flow following ischemia (reactive hyperemia), e.g., the Whitney gage (as proposed in venous compliance experiment) can be used. Peripheral blood flow will be measured following arterial occlusion, exercise, and a painful stimulus.
2. Observation of skin response to pressure and to wheal-inducing stress (injection of histamine phosphate).
6. *Experimental Controls*
Preliminary study should be made on each of the subjects on ground level to provide baseline experiments.
7. *Summary of Number and Types of Space Station Personnel*
Preferably the experimental team should include a physician who has participated in the ground-based experiments. The subjects will be the remaining personnel onboard.
8. *Summary of Onboard Experimental Equipment Required*
Adequate plethysmographic and pressure-measuring devices and a timing device.
9. *Summary of Animals*
None.
10. *Summary of Other Living Forms*
None.
11. *Summary of Onboard Laboratory Determinations*
These determinations will be made at least once

a day for 5 days and repeated at 5- or 10-day intervals during the flight.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
No rendezvous or rotation is necessary in this experiment.
14. *Telemetry versus Onboard Recording Requirements*
Onboard recording with telemetry facility for sending data to Earth laboratory.
15. *Prerequisite Ground-Based Experiments*
Complete standardization of techniques and control levels on all subjects.
16. *Prerequisite Space Flight Experiments*
Many of the techniques can be checked out on preliminary shorter-term space flights if possible.
17. *Prerequisite Research and Development*
Standardization of plethysmographic technique.
18. *Onboard Gaseous Atmosphere Desired*
Sea level equivalent.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
Data will be acquired by continuous analog form as well as by observation. The analog data should be stored in a suitable form for transmission to Earth laboratory at appropriate times and also should be available to onboard observers for analysis.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
23. *References*

1. Lewis, T.: Vascular Disorders of the Limbs. Macmillan, 1936.
2. Martin, P.; Lynn, R. B.; Dible, J. H.; Aird, I.: Peripheral Vascular Disorders, E. and S. Livingston Ltd., Edinburgh, 1956.
3. Redisch, W.; Tangco, F. F.; and Saunders, R. L. de C. H.: Peripheral Circulation in Health and Disease. Grune and Stratton, 1957.
4. Rothman, S.: Physiology and Biochemistry of Skin. Univ. of Chicago Press, 1954.

EXPERIMENT 6

1. *Changes in the Efficacy of Arterial Pressure Control Systems During Space Flight by Shifts of Blood Distribution*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To study the influence of prolonged weightlessness on the integrity of the reflex and humeral control mechanisms which integrate and sustain the circulation.
4. *Justification*
This is a necessary piece of knowledge relative to the safety of prolonged space travel. There is evidence from American and Russian experience in weightless states over a long period of time that a loss of blood pressure control develops, and there is at least transient postural hypotension. It is interesting to note that this has been noted to occur with a diminished or absent excretion of norepinephrine. Ground-based experiments on individuals in the submerged states also indicate similar results.
5. *Experiment*
Procedures will be used to shift the blood volume in the astronauts by means of simple experimental techniques. Under normal circumstances, such a shift would require a readjustment in vasomotor activity to maintain arterial blood pressure and circulatory inadequacy. If the normal mechanisms are not operative, under the test conditions blood pressure and circulatory adequacy will be disrupted.
The initial test situations will be (1) a calibrated Valsalva procedure (Flack Test) which produces an increase in intrathoracic pressure and, in turn, peripheral pooling of blood; (2) the inflation of blood pressure cuffs about three extremities, two legs and one arm to provide one free arm for measurements (The cuffs will be inflated to 60 millimeters of mercury pressure

for a period of 10 minutes.); and (3) other methods including the development of "artificial gravity" may be used in later stages of this experiment.

Proposed protocol: A minimum of 4 subjects will be studied. The first control observation will be made prior to orbital conditions. Arterial pressure will be measured by the customary cuff technique and heart rate accurately timed. Control observations will be made after the subject has been supine for a minimum of 20 minutes. Then, the test procedure will be applied, pressures and heart rates again measured, and, following this, additional control observations will be obtained. The entire experiment will be repeated a minimum of 3 times prior to orbital flight. Following the assumption to orbital flight, the procedure will be repeated 1 time per day during the first week in orbit, then, 1 time per week unless circulatory difficulties develop. On return to Earth, the observations will be made as soon as possible and repeated at 2-hour intervals, insofar as possible, during the first 24 hours. Thereafter, they will be made 1 time per day for the first 2 weeks, although this may be modified depending upon the test results.

6. *Experimental Controls*
   Ground-based observations will serve as control for each subject.
7. *Summary of Number and Types of Space Station Personnel*
   One physician with physiologic training and one laboratory technician or trained astronaut.
8. *Summary of Onboard Experimental Equipment Required*
   One Valsalva device for controlled resistance to expiration, three blood pressure cuffs for placement about the extremities, and one blood pressure device for pressure measurements.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    None essential; if available, determinations for catecholamines would be of interest.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    None unless norepinephrine assays are available.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    None.
14. *Telemetry versus Onboard Recording Requirements*
    All onboard.
15. *Prerequisite Ground-Based Experiments*
    See *Proposed Protocol* under 5.
16. *Prerequisite Space Flight Experiments*
    Experiments of similar nature on shorter flights will be of interest, but prolonged weightlessness is essential for these observations.
17. *Prerequisite Research and Development*
    None.
18. *Onboard Gaseous Atmosphere Desired*
    Sea level oxygen and nitrogen atmosphere is highly desirable.
19. *Requirement for Rotation for Artificial G*
    None unless experiments show serious cardiovascular deterioration which cannot be prevented by other simpler measures.
20. *Comments re Form of Data and Interpretation of Data*
    None.
21. *Special Comments*
    None.
22. *Postflight Evaluation of the Crew*
    None.
23. *References*

1. Ebert, R.; and Stead, Eugene A.: Effect of the Application of Tourniquet of Henodynamics of the Circulation. J. Clin. Invest., vol. 19, 1940, 561 p.
2. Fitzhugh, S. W., Jr.; McWhater, R. L., Jr.; Estes, E. H., Jr.; Warren, James V.; Merrill, A. J.: The Effect of Application of Tourniquets to the Legs on Cardiac Output and Renal Function in Normal Human Subjects.
3. Graveline, D. E.: Maintenance of Cardiovascular Adaptability During Prolonged Weightlessness. ASD TR 61–707, Wrigh' Patterson AFB, Ohio, 1961.

EXPERIMENT 7

1. *Predictive Tests to Assess Ability of Vasomotor System to Readjust to Reentry Stress and Reaccommodation to Terrestrial Gravity*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To measure the secretion response of catecholamines to standardized stress such as hypoxia and/or thermal stimuli.
4. *Justification and Rationale*
   It has been noted that with increasing time in orbit there has been a degradation of the vasomotor response after return to 1 G. It has been found that in ground-simulated experiments of prolonged bed rest that there is a disappearance of catecholamines and their metabolic end products from the blood and urine of the subjects. It is known that under conditions of hypoxia (about 1.4 psi of O_2) there is a marked increase in the circulating catecholamines. It is assumed that if there is an adequate catecholamine response by an astronaut in orbit to a measured stress that he has sufficient responsiveness to tolerate reentry stress and return to 1 G.
5. *Experiment*
   At a given time each day while the astronaut is in orbit, he will stress himself by a suitable technique chosen from a series to be ground-tested by bed rest simulation. These stresses may be hypoxia, alternating hot and cold exposure in the new pressure suits, etc. After the stress, the astronaut voids into a container. A simple tablet containing ingredients similar to those for the DOPPA test is put into the urine. A positive color reaction indicates an adequate responsiveness. A negative color would be an indication of abort.
6. *Experimental Controls*
   Ground simulation testing to determine validity of response. Since the test will be carried out daily, a diminution in excretion can be detected early.
7. *Summary of Number and Types of Space Station Personnel*
   No special training of astronaut.
8. *Summary of Onboard Experimental Equipment Required*
   Equipment, urine containers, test tablets.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    Daily—1 minute.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    None.
14. *Telemetry versus Onboard Recording Requirements*
    Routine voice report of test results.
15. *Prerequisite Ground-Based Experiments*
    As noted previously under 4 and 6.
16. *Prerequisite Space Flight Experiments*
    None.
17. *Prerequisite Research and Development*
    Develop color-producing reagent tablet.
18. *Onboard Gaseous Atmosphere Desired*
    Not applicable.
19. *Requirement for Rotation for Artificial G*
    Not applicable.
20. *Comments re Form of Data and Interpretation of Data*
    Decreasing concentration of catecholamine metabolic end products indicate failing ability of vasomotor system to respond to stress.
21. *Special Comments*
    None.
22. *Postflight Evaluation of the Crew*
    None.
23. *References*
    None.

EXPERIMENT 8

1. *Changes in Circulatory Responses to Exercise with Duration of Exposure to the Weightless State*
2. *Estimated Priority*
   Priority 1.

3. *Purpose*
As a measure of circulatory integrity, the ability of the heart to respond to stressful situations under prolonged weightless states is an important component of circulatory reflex integration.

4. *Justification*
Maintenance of circulatory function in prolonged weightless states is of great importance in the survival of astronauts during prolonged space travel. New aspects become of critical importance in the integration of the circulation on return to Earth.

5. *Experiment*
The response of the circulation to a stimulus that increases cardiac output under usual circumstances will be studied in the weightless state. The stimulus to increase cardiac output will be (1) exercise and (2) reactive hyperemia. The experimental plan calls for 4 subjects.
Observations will be carried out on Earth and repeated daily in orbit for the first week, then 1 time per week until return to Earth where they will be repeated once a week until the values have stabilized. The experimental plan will include control observations of cardiac output at rest, then under the stress of exercise, and will be followed with observations at rest.

6. *Experimental Controls*
Each subject will serve as his own control.

7. *Summary of Number and Types of Space Station Personnel*
One physician with physiologic training and one technician or trained astronaut.

8. *Summary of Onboard Experimental Equipment Required*
Cardiac output calculator, bicycle ergometer or exerciser, blood pressure cuffs for inflating about extremities.

9. *Summary of Animals*
None required.

10. *Summary of Other Living Forms*
None required.

11. *Summary of Onboard Laboratory Determinations*
Cardiac output by indicator dilution utilizing computer techniques.

12. *Summary of Laboratory Speciments to be Flown to Earth for Laboratory Examination*
None.

13. *Proposed Rendezvous Schedule for Rotation of Crew*
None.

14. *Telemetry versus Onboard Recording Requirements*
All onboard.

15. *Prerequisite Ground-Based Experiments*
See experimental protocol.

16. *Prerequisite Space Flight Experiments*
Not presently known.

17. *Prerequisite Research and Development*
None.

18. *Onboard Gaseous Atmosphere Desired*
Sea level pressure with oxygen and nitrogen preferable.

19. *Requirement for Rotation for Artificial G*
None.

20. *Comments re Form of Data and Interpretation of Data*
None.

21. *Special Comments*
None.

22. *Postflight Evaluation of the Crew*
None.

23. *References*

1. Asmusser, E.; and Nielson: Cardiac Output During Muscular Work at Its Regulation. Physiol. Ref., vol. 33, 1955, 778 p.
2. Bevergard, S.; Holmgren, A.; and Jonsson, A.: Circulatory Studies in Well-Trained Athletes at Rest and During Heavy Exercise, with Special Reference to Stroke Volume and the Influence of Body Position. Reprint from Stockholm, Sweden, Department of Clinical Physiology, Karolinska.
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4. Blount, S. G.; Filley, G. F.; Grover, R. F.; and Reeves, J. T.: Cardiac Output Response to Standing and Treadmill Walking. J. Appl. Physiol., vol. 16, 1961, p. 283.
5. Brostoss, P.; Freedman, M. E.; Katz, L. N.; and Snider, G. L.: Effects of Training on Response of Cardiac Output to Muscular Exercise in Adults. J. Appl. Physiol., vol. 8, 1955, p. 37.
6. Cargill, W. H.; and Hickam, J. B.: Effects

of Exercise on Cardiac Output and Pulmonary Atrial Pressure and Normal Persons and in Patients with Cardiovascular Disease and Pulmonary Enphysema. J. Clin. Inves., vol. 27, 1948, p. 10.
7. Chapman, C. B.; Fisher, J. M.; and Sproule, B. J.: Behavior of Stroke Volume at Rest and During Exercise in Human Beings. J. Clin. Inves., vol. 39, 1960, p. 1208.
8. Dexter, L.: Effects of Exercise on Circulatory Dynamics in Normal Individuals. J. Appl. Physiol., vol. 3, 1951, p. 439.
9. Guyton, A. C.: Circulatory Physiology Cardiac Output and Its Regulation. Mississippi Medical Center, Jackson, Miss.
10. Hoover, George; Mathews, Donald K.; Stacy, Ralph W.: Physiology of Muscular Activity and Exercise.
11. Marshall, R. J.; Shephard, J. T.; and Wang, Y.: The Effect of Changes in Posture and of Graded Exercise on Stroke Volume in Man. J. Clin. Inves., vol. 39, 1960, p. 1051.

EXPERIMENT 9

1. *Study of Possible Effects of the Weightless Environments on the Sensitivity of the Carotid Sinus Arterial Pressure Control Loop*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To study the effect of the weightless environment on the sensitivity of the carotid sinus arterial blood pressure control loop.
4. *Justification*
   It is generally believed that one of the possible major effects of a weightless environment will be a decrement in cardiovascular reactivity associated with the absence of the usual gravitational hydrostatic stresses which this system must withstand on Earth.
   The Baroreceptor carotid sinus mechanism is one of the major control loops responsible for the regulation of systemic arterial pressure and hence its sensitivity might possibly be altered by the relative disuse of the system during existence in the zero gravity state. An objective and quantitative test of the sensitivity and reactivity of this system which could be applied both in the 1 G and the zero G environment would make possible collection of firm data in this regard. If positive results were obtained during the zero gravity state by means of this procedure, there would be a significant probability that the test could be used as an objective means of assessing the severity of this hypodynamic state as well as the efficacy of various types of counter measures.
5. *Experiment*
   An increase in transmural pressure which increases the tension and hence tends to lengthen the stretch receptors in the wall of the carotid sinus is the usual stimulus which will produce an increment in activity of the carotid sinus mechanism.
   An increase in transmural pressure in the carotid sinuses can be produced by applying a known degree of subambient (negative) pressure to the neck. This has been done by Drs. J. Ernsting and D. J. Parry in Farnsborough, England, (Journal of Physiology 137: 45–46, 1957), and confirmed and extended by Drs. John Shephard and Sture Bevegard at the Mayo Foundation using specially fabricated neck casts made of transparent plastic lucite. Subambient pressures surrounding the neck ranging up to 50 to 60 cm H_2O can be produced at will and are followed promptly by a decrease in heart rate and systemic arterial pressure and an increase in forearm blood flow, the magnitude of which is dependent on the degree of negative pressure.
   It is proposed to study this reaction in detail in selected astronauts preflight in the 1 G state and alter varying periods of weightlessness. If a decrement in sensitivity of the carotid sinus mechanism is demonstrable in the weightless environment, then the effects on this decrement of various possible countermeasures, such as graded degrees of exercise, application of negative pressure to the body caudad to the diaphragm, or large amplitude body oscillation (exercises on a double-ended trampoline) will be studied.

   Procedure: In preflight, 1 G studies and observations would be made in the supinehorizontal position under controlled ambient conditions after one-half hour period of recumbency. These observations will be repeated at selected intervals after the launch phase of the flight. The first experiment should be performed within 24 hours after launch if possible. These observations should be repeated about every 48 hours for the first 1 or 2 weeks and approximately once a week thereafter, depending on the results obtained.

If positive evidence of cardiovascular deterioration is obtained, the experiments should be repeated at selected intervals after return to Earth to delineate the recovery phase from the hypodynamic site. Neck cast with seals around base of head and neck-shoulder junction regions will need to be individually fabricated and fitted for each subject. Periods of negative pressure of 60 seconds duration will be used.

Measurements:

a. *Priority 1*

(1) Heart rate continuously for 15 sec prior to, during, and 60 sec after period of negative pressure.

(2) Respiratory amplitude continuously for same period.

(3) Arterial pressure by auscultatory or direct method for same period.

(4) Intermittent measurements of forearm blood flow (plethysmograph) for same period.

b. *Priority 2* (priority based on judgment of technical difficulty of measurement and the value of the data obtained)

(1) Cardiac output (just prior to period of negative pressure to neck and during last 30 sec of period of negative pressure).

(2) Venous pressure via the catheter or needle used to inject the circulatory indicator.

(3) Measurement of compliance of forearm veins (plethysmograph).

(4) Repetition of experiment during circulatory stress associated with exercise.

6. *Experimental Controls*

A series of experiments should be carried out on healthy male subjects in the same age range as the astronauts under carefully controlled conditions using the procedure outlined under 5 and variants thereof.

The objective of these experiments would be:

1. To standardize in detail the technics and equipment to be used.
2. To determine the reproducibility of the reaction to negative neck pressure from subject to subject and in the same subject.

7. *Summary of Number and Types of Space Station Personnel*

Preferably, the experimental team should include:

1. A physician who has participated actively in the control ground-based experiments on the astronauts just prior to their flight.
2. A trained laboratory technician.
3. Two trained astronauts who would alternate in acting as subjects and as the third member of the experimental team.

8. *Summary of Onboard Experimental Equipment Required*

Fixed Equipment

a. Individually-fitted lucite neck casts for the two astronauts and a suitable source of negative pressure with quick disconnect connections to the neck cast.

b. Apparatus for continuous registration of heart rate based on the ECG, ear opacity pulse, or a directly recorded arterial pulse.

c. Forearm plethysmograph for measurements of forearm blood flow and venous compliance of the volume displacement of possible mercury-tube strain-gauge type.

d. Strain gauge and appropriate cannula and Ringer's fluid-flushing system for continuous registration of arterial pressure.

e. Appropriate venous cannula for injection of indicator and strain-gauge manometer for registration of venous pressure via this cannula.

f. Cuvette or ear densitometer for registration of indicator-dilution curve directly on arterial blood flowing from the arterial cannula (mentioned under d) or indirectly through transillumination of the ear (ref. 3).

g. Means of continuous or essentially continuous registration of variables such as an onboard tape recorder with miniature multichannel oscilloscope display (oscilloscope should have trace storage and erase capability) and possible miniature polaroid camera for photographing particularly pertinent traces.

The tape recorder should have playback capability for telemetering back to Earth and for onboard monitoring and analysis of data.

h. Cuvettes and/or earpiece densitometer and oximeter.

Consumable Equipment

a. Sterilized cannula and syringes.

b. Sterile heparinized (20 mg sodium heparin/liter) Ringer's solution.

c. Skin antiseptic.

d. Two percent procaine solution.

e. Indicator dye—indocyanine green (preferably) or Evans blue.

f. Sterilized towels or special drapes and sponges.

g. Sterile surgical gloves.

9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    1. Experiment should be performed during first 24 hours of flight if possible and repeated at 48-hour intervals for about the first week thereafter, depending on the results obtained.
    2. The time consumed for each experiment would depend on the number of parameters recorded. If all parameters mentioned were recorded, approximately 1 to 2 hours would be required for each experiment.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    None, unless experiment reveals serious progressive deterioration of cardiovascular status of astronauts.
14. *Telemetry versus Onboard Recording Requirements*
    If a physician or a highly trained physiologist or laboratory technician is onboard, recording and visual display online or on playback from tape recorder would be highly desirable.
    Telemetry to Earth online or on playback from onboard tape recorder would also be highly desirable as a backup and to insure that data were not lost on reentry.
15. *Prerequisite Ground-Based Experiments*
    Outlined under 6.
16. *Prerequisite Space Flight Experiments*
    Flights to check out performance of equipment and technics under weightless conditions would be highly desirable.
17. *Prerequisite Research and Development*
    1. Optimization of design of neck cast, negative pressure source, and quick disconnect fittings.
    2. Optimization of design of arterial and venous cannula, forearm plethysmograph, pressurized Ringer's fluid-flushing system, ear and/or cuvette oximeter and densitometer with associated hydraulic connections and blood withdrawal reinfusion system, circulatory indicator dispenser and injection syringe, onboard recorder with associated miniature multichannel oscilloscope of storage-beam type for online monitoring and possible recording (polaroid camera), and onboard tape recorder with playback capability for display on oscilloscope and telemetering to ground station highly desirable, special drapes, disposable syringes and cannula (including plastic catheters), skin antiseptic dispenser, strain gauges for arterial and venous pressure with appropriate hydraulic connections for flushing and calibration, apparatus for registration of respiration (preferably oral pneumotachograph).
18. *Onboard Gaseous Atmosphere Desired*
    Earth atmosphere in range from 0 to 5,000 feet above sea level with shirtsleeve environment.
19. *Requirement for Rotation for Artificial G*
    None, unless experiments show serious cardiovascular deterioration which cannot be prevented by other measures such as application of subambient pressure to the body caudad to diaphragm at intervals during each 24 hours (perhaps during the sleep cycle), large amplitude body vibration (double-ended trampoline), etc.
20. *Comments re Form of Data and Interpretation of Data*
    1. Data should be in continuous or essentially continuous form (magnetic tape or photokymographic record) during each experiment with requisite number of calibrations to insure reliability. Spot checks online by visual monitoring of stored oscilloscope trace or polaroid picture thereof during important phases of each experiment would be highly desirable.
    2. Interpretation should be by a cardiovascular physiologist or a physician with special train-

ing in cardiovascular physiology who has participated in the series of these experiments carried out preflight on the astronauts being studied in flight.

21. *Special Comments*

Interpretation of the data obtained during flight, if progressive changes should be observed, may prove to be one of the best objective bases upon which to decide whether or not a flight should be continued or rendezvous for rotation of crew be carried out.

If positive evidence of cardiovascular deterioration during weightlessness is obtained, these experiments may prove to be an excellent objective basis for judging the efficacy of various types of countermeasures which could be employed, e.g., as an unlikely last resort, an onboard centrifuge.

22. *Postflight Evaluation of the Crew*

None.

23. *References*

1. Ernsting, J.; and Parry, D. J.: Some Observations on the Effects of Stimulating the Stretch Receptors in the Carotid Artery of Man. J. Physiol., vol. 137, 1957, pp. 45–46.
2. Reed, J.; and Wood, E. H.: Use of Dichromatic Earpiece Densitometry for Determination of Cardiac Output. The Physiologist—in press.

EXPERIMENT 10

1. ***Study of Possible Effects of the Weightless Environment on the Susceptibility of the Cardiovascular System to a Hydrostatically Simulated Upright Position***
2. ***Estimated Priority***

Priority 1.

3. ***Purpose***

To study the effect of the weightless environment on the capability of the cardiovascular system to compensate for simulated hydroastatic effects.

4. *Justification*

It is generally believed that one of the possible major effects of a weightless environment will be a decrement in cardiovascular reactivity associated with the absence of the usual gravitational hydrostatic stresses which this system must withstand on Earth.

It has been demonstrated by Dr. David Greenfield that application of subambient pressure to the body surface caudad to the diaphragm produces a stress and consequent reactions of the cardiovascular system which are similar to effects of exposure to positive acceleration or to being tilted upright in the normal (1 G) environment. If positive results were obtained during the zero gravity state by means of this procedure, there would be significant probability that the test could be used as an objective means of detecting the onset of a decrement in cardiovascular reactivity and as a means of assessing the severity of this hypodynamic state. There is also a significant probability, if it is demonstrated that countermeasures are required, that this procedure would be an excellent countermeasure to prevent deterioration of cardiovascular reactivity due to the absence in the weightless state of the normal hydrostatic stresses associated with existence in the 1 G environment of Earth.

5. *Experiment*

An effective decrease in resistance to blood flow to dependent portions of the body and increase in the level of venous pressure in dependent veins required to return blood to the heart are the essential effects of being tilted upright at 1 G or exposure to positive acceleration which constitute a stress to the cardiovascular system. These effects of the upright tilt as well as weight-bearing by the lower extremities can be simulated as follows: the lower body is enclosed, in the supine position, in a rigid, elongated (rectangular or cylindrical) container sealed around the lower rib margin by a rubber diaphragm and with the feet resting on a block of suitable thickness to contact the opposite end of the container. Subambient pressure of about 40 to 60 cm H_2O is created in the container by connecting it to a high volume level vacuum source such as a vacuum cleaner mechanism. The negative pressure over the entire lower surface of the body created in this fashion accelerates arterial inflow to the lower body and hinders the return of blood from the caudad portions of the vascular system to the heart. Dr. David Greenfield has demonstrated that this results in compensatory cardiovascular reactions similar to those produced by the upright tilt or exposure to positive acceleration.

It is proposed to study these reactions in detail in selected astronauts preflight in the 1 G state and after varying periods of weightlessness. If a decrement in cardiovascular reactivity to this type of simulated hydrostatic stress is demonstrable in the weightless environment, then the effects on this decrement of various possible countermeasures, such as graded degrees of exercise, repeated applications of negative pressure to the lower body, or large amplitude body oscillation (exercise on a double-ended trampoline), will be studied.

Parenthetically, the negative pressure produces a force tending to push the body into the container. This force amounts to a pound per square inch of cross sectional body area at the point of seal per 52 mm Hg of subambient pressure. For instance, an individual whose lower thorax was 31.4 inches in circumference would experience a caudad force supported by his lower extremities of about 78.9 pounds. This may have some effect on the presumed muscle and skeletal wasting effects of the weightless environment.

Procedure: Lower body containers of minimum volume and optimum design in relation to weight, configuration and ease of obtaining a seal around the lower thorax will be designed and fabricated for interchangeable use between subjects. A suitable high-volume, low-vacuum source with suitable rapid disconnect connections to the lower-body container will be obtained. In pre-flight 1 G studies, observations would be made in the supine-horizontal position under controlled ambient conditions after one-half hour period of recumbency.

Periods of negative pressure of 20 or more seconds will be used. These observations will be repeated at selected intervals after the launch phase of the flight. The initial experiment should be performed during the first 24 hours after launch if possible. These observations should be repeated about each 48 hours thereafter the first 1 or 2 weeks and approximately weekly thereafter depending on the results obtained.

If positive evidence of cardiovascular deterioration is obtained the experiment should be repeated at selected intervals after return to earth to delineate the recovery process.

Measurements:

a. *Priority 1*

(1) Heart rate continuously for 15 sec prior to, during, and 60 sec after period of negative pressure.

(2) Respiratory amplitude continuously for same period.

(3) Arterial pressure by auscultatory or direct method for same period.

(4) Intermittent measurement of forearm blood flow (plethysmograph) for same period.

b. *Priority 2* (priority based on judgment of technical difficulty of measurement and the value of the data obtained)

(1) Cardiac output (just prior to period of negative pressure and during last 30 sec of this).

(2) Venous pressure via the catheter or needle used to inject the circulatory indicator.

(3) Measurement of compliance of forearm veins (plethysmograph).

(4) In some subjects, esophageal pressure should be recorded in order to assess indirectly the effects of application of lower-body negative pressure on intrapleural and pericardial pressures.

6. *Experimental Controls*

A series of experiments should be carried out on healthy male subjects in the same age range as the astronauts under carefully controlled conditions using the procedure outlined under 5 and variants thereof.

The objective of these experiments would be:

1. To standardize in detail the technics and equipment to be used.
2. To determine the reproducibility of the reaction to negative lower-body pressure from subject to subject and in the same subject.

7. *Summary of Number and Types of Space Station Personnel*

Preferably, the experimental team should include:

1. A physician who has participated actively in the control ground-based experiments on the astronauts just prior to their flight.

2. A trained laboratory technician.
3. Two trained astronauts who would alternate in acting as subjects and as the third member of the experimental team.

8. *Summary of Onboard Experimental Equipment Required*

   Fixed equipment:

   a. A suitable lower-body chamber and sealing diaphragm which will fit both astronauts and a suitable source of negative pressure with quick disconnect connections to the lower-body container.
   b. Apparatus for continuous registration of heart rate based on the ECG, ear opacity pulse, or a directly recorded arterial pulse.
   c. Forearm plethysmograph for measurements of forearm blood flow and venous compliance of the volume displacement or possible mercury-tube strain-gauge type.
   d. Strain gauge and appropriate cannula and Ringer's fluid-flushing system for continuous registration of arterial pressure.
   e. Appropriate venous cannula for injection of indicator and strain-gauge manometer for registration of venous pressure via this cannula.
   f. Cuvette or ear densitometer for registration of indicator-dilution curve directly on arterial blood flowing from arterial cannula (mentioned under item d) or indirectly through transillumination of the ear (ref. 3).
   g. Means of continuous or essentially continuous registration of variables such as an onboard tape recorder with miniature multichannel oscilloscope display (oscilloscope should have trace storage and erase capability) and possible miniature polaroid camera for photographing particularly pertinent traces. The tape recorder should have playback capability for telemetering back to Earth and for onboard monitoring and analysis of data.
   h. Cuvette and/or earpiece densitometer and oximeter.

   Consumable equipment:

   a. Sterilized cannula and syringes.
   b. Sterile heparinized (20 mg sodium heparin/liter) Ringer's solution.
   c. Skin antiseptic.
   d. Two percent procaine solution.
   e. Indicator dye—indocyanine green (preferably) or Evans blue.
   f. Sterilized towels or special drapes and sponges.
   g. Sterile surgical gloves.

9. *Summary of Animals*

   None.

10. *Summary of Other Living Forms*

    None.

11. *Summary of Onboard Laboratory Determinations*

    1. The experiment should be performed during the first 24 hours of flight if possible and repeated at 48-hour intervals for about the first week and each week thereafter.
    2. The time consumed for each experiment would depend on the number of parameters recorded. If all parameters mentioned were recorded, approximately 1 to 2 hours would be required for each experiment.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*

    None.

13. *Proposed Rendezvous Schedule for Rotation of Crew*

    None, unless experiment reveals serious progressive deterioration of cardiovascular status of astronauts.

14. *Telemetry versus Onboard Recording Requirements*

    If a physician or a highly-trained physiologist or laboratory technician is onboard, onboard recording and visual display online or on playback from tape recorder would be highly desirable. Telemetry to Earth online or on playback from onboard tape recorder would also be highly desirable as a backup and to insure that data were not lost on reentry.

15. *Prerequisite Ground-Based Experiments*

    Outlined under 6.

16. *Prerequisite Space Flight Experiments*

    Flights to check out performance of equipment and technics under weightless conditions would be highly desirable.

17. *Prerequisite Research and Development*

    1. Optimization of design of lower-body containers, negative pressure source, and quick disconnect fittings.
    2. Optimization of design of arterial and venous cannula, forearm plethysmograph, pressurized

Ringer's fluid-flushing system, ear and/or cuvette oximeter and densitometer with associated hydraulic connections and blood withdrawals reinfusion system, circulatory indicator dispenser and injection syringe, onboard recorder with associated miniature multichannel oscilloscope of storage-beam type for online monitoring and possible recording (polaroid camera), onboard tape recorder with playback capability for display on oscilloscope and telemetering to ground station highly desirable, special drapes, disposable syringes and cannula (including plastic catheters), skin antiseptic dispenser, strain gauges for arterial and venous pressure with appropriate hydraulic connections for flushing and calibration, apparatus for registration of respiration (preferably oral pneumotachograph).

18. *Onboard Gaseous Atmosphere Desired*
Earth atmosphere in range from 0 to 5,000 feet above sea level with shirtsleeve environment.

19. *Requirement for Rotation for Artificial G*
None, unless experiments show serious cardiovascular decrement which cannot be prevented by other measures such as application of subambient pressure to the body caudad to diaphragm at intervals during each 24 hours (perhaps during the sleep cycle), large amplitude body vibration (double-ended trampoline), etc.

20. *Comments re Form of Data and Interpretation of Data*
    1. Data should be in continuous or essentially continuous form (magnetic tape or photokymographic record) during each experiment with requisite number of calibrations to insure reliability. Spot checks online by visual monitoring of stored oscilloscope trace or polaroid picture thereof during important phases of each experiment would be highly desirable.
    2. Interpretation should be by a cardiovascular physiologist or a physician with special training in cardiovascular physiology who had participated in the series of these experiments carried out preflight on the astronauts being studied in flight.

21. *Special Comments*
Interpretation of the data obtained during flight, if progressive changes should be observed, may prove to be one of the best objective bases upon which to decide whether or not a flight should be continued or rendezvous for rotation of crew be carried out.

If positive evidence of cardiovascular deterioration during weightlessness is obtained, these experiments may prove to be an excellent objective basis for judging the efficacy of various types of countermeasures which could be employed, e.g., as an unlikely last resort, an onboard centrifuge.

22. *Postflight Evaluation of the Crew*
None.

23. *References*

1. Greenfield, A. D. M.; Brown, H.; Goei, J. S.; and Plassaras, G. C.: Circulatory Responses to Abrupt Release of Blood Accumulated in the Legs. The Physiologist, vol. 6, 1963, p. 191.
2. Reed, J.; and Wood, B. H.: Use of Dichromatic Earpiece Densitometry for Determination of Cardiac Output. The Physiologist—in press.

EXPERIMENT 11

1. *Determination of the Effect of Weightlessness on Pulmonary Mechanics*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To determine whether prolonged weightlessness produces any alteration in pulmonary mechanics.
4. *Justification*
Respiratory muscles normally are opposed by the weight of the viscera in expiration and the weight of the chest and thorax in inspiration. Absence of gravity may lead to shifts in lung volume (particularly to a decrease in FRC, with an accompanying probatory of atelectasis) and may increase airway resistance, the latter resulting from decreased tissue pull on the conducting airways. Possibly, decreased work of the respiratory muscles may lead to a decrease in muscle strength. These studies will also be helpful in medical care of the astronaut.

5. *Experiment*
Serial measurements of the following will be performed every day for the first week and less frequently thereafter:
    a. Vital capacity and spirometric volumes
    b. Index of airway resistance, such as maximal expiratory flow rate and total airway resistance
    c. Maximum inspiratory and expiratory pressure
    d. Lung compliance with spirometric volumes and esophageal pressure
6. *Experimental Controls*
Similar studies performed once a week for 3 weeks before launching and similarly on return. Subject would be his own control.
7. *Summary of Number and Types of Space Station Personnel*
Subject and technical assistance from one other individual, although subject could be taught to perform the test. Physician or technician would facilitate measurements.
8. *Summary of Onboard Experimental Equipment Required*
    1. Spirometer of wedge- or bellow-type arranged to record on paper.
    2. Pressure transducer arranged to record in same manner.
    3. If cathode ray oscillioscope is available, it could be used.
9. *Summary of Animals*
None.
10. *Summary of Other Living Forms*
None.
11. *Summary of Onboard Laboratory Determinations*
No chemical examinations.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
Results could be transmitted to Earth for permanent record.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
No restrictions.
14. *Telemetry versus Onboard Recording Requirements*
Onboard recording and telemetry required.
15. *Prerequisite Ground-Based Experiments*
Presently available equipment could be redesigned for this experiment to reduce weight and space.
16. *Prerequisite Space Flight Experiments*
Equipment should be tested in flight. All pulmonary function tests should be attempted under zero G.
17. *Prerequisite Research and Development*
Only on the equipment which could be modified from present types.
18. *Onboard Gaseous Atmosphere Desired*
Air in the range from sea level to 5000 ft. If not, controls must be done under same atmosphere.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
Volume-time and pressure-volume records could be stored on paper or tape.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
23. *References*

    1. Comroe, J. H., Jr.; et al: The Lung. Year Book Publishers, Chicago, 1958.
    2. Wood, E. H.; et al: Influence of Acceleration on Pulmonary Physiology. Fed. Proc., vol. 22, 1963, pp. 1024–1041.

EXPERIMENT 12

1. *Determination of the Effect of Weightlessness on Control of Respiration*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To determine whether prolonged weightlessness produces any change in the regulation of respiration.
4. *Justification*
Respiration is controlled largely by arterial P_{CO2}, pH, and P_{O2}, but a number of other factors contribute indeterminant amounts, including the acid base state of the cerebrospinal fluid, body temperature, and reflexes (particularly those from the bones and joints). The effect, particularly long-term, of zero G upon

this control system is not known. An example of a possible derangement is a reduction in respiratory minute volume, particularly while asleep, owing to a reduction in sensory inflow. An alteration in alveolar ventilation can cause disability whether it is raised or lowered.

5. *Experiment*

The following measurements would be made awake and asleep, at rest and during a fixed grade of exercise daily:

a. Respiratory rate and minute volume

b. Expired alveolar P_{CO_2} and P_{O_2}, during steady state breathing and at the breaking point in breath holding

The following would be measured at longer intervals:

a. Arterial pH, bicarbonate, P_{CO_2}, O_2Hb saturation, and P_{O_2}, under steady-state condition

b. Response to breathing increased CO_2 (as by rebreathing) consisting of measurement of alveolar P_{CO_2} and minute volume.

Breath-holding time measured daily.

6. *Experimental Controls*

Comparable measurements would be made over the 3 weeks before launching to establish normal values at 1 G and to familiarize the astronaut with the procedure.

7. *Summary of Number and Types of Space Station Personnel*

One individual to provide technical assistance although the subject could learn to do the measurements himself.

8. *Summary of Onboard Experimental Equipment Required*

1. Flow meter for measurement of minute volume.
2. Gas analyzer for O_2 and CO_2 (could be a mass spectrometer, gas chromatograph, or chemical method).
3. Equipment for the determination of blood pH, P_{CO_2}, P_{O_2}, O_2Hb saturation, and bicarbonate. This and item 2 may be in the general laboratory.

9. *Summary of Animals*

None.

10. *Summary of Other Living Forms*

None.

11. *Summary of Onboard Laboratory Determinations*

Outlined under 8.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*

None.

13. *Proposed Rendezvous Schedule for Rotation of Crew*

Does not apply.

14. *Telemetry versus Onboard Recording Requirements*

Telemetry required.

15. *Prerequisite Ground-Based Experiments*

Only to develop the equipment. The use of it will be checked in the controls.

16. *Prerequisite Space Flight Experiments*

It would be worthwhile, although not completely essential, to have the techniques checked in preliminary space flight.

17. *Prerequisite Research and Development*

This will be needed largely for the refinement of the methods. Usable techniques are available at present, but will need to be modified.

18. *Onboard Gaseous Atmosphere Desired*

Air. If not, controls will have to be done with same atmosphere.

19. *Requirement for Rotation for Artificial G*

None.

20. *Comments re Form of Data and Interpretation of Data*

Data can be obtained in numbers and interpreted aloft.

21. *Special Comments*

All the parameters of the respiratory control system cannot be determined at present, but the measurements suggested are directed towards detecting changes in the most important factors.

22. *Postflight Evaluation of the Crew*

None.

23. *References*

No indication has been obtained that the control of respiration is altered in zero G, nor is there any obvious reason to expect a major alteration. The references are general ones regarding the control of respiration.

1. Comroe, J. H., Jr.; et al: The Lung. Year Book Publishers, Chicago, 1958.
2. Haldane Centenary Symposium: The Control of Respiration. Cunninham and Lloyd, eds. Oxford Univ. Press, Oxford, 1962.

EXPERIMENT 13

1. *Determination of Changes in Blood Gas Exchange with Duration of Exposure to the Weightless State*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To determine if continued exposure to weightlessness results in a lowering of the efficacy of aeration of blood by the lungs.
4. *Justification*
   It is important to learn if any interference with gas exchange in the lungs results from exposure to weightlessness.
5. *Experiment*
   These studies could be combined with those on the control of respiration. The actual study would consist of measuring expired alveolar and arterial P_{CO2}, O_2Hb, and P_{O2} at weekly intervals at rest and during standard exercise.
6. *Experimental Controls*
   Two control studies exactly the same as listed under 5 should be done during the 3 weeks before and after launching.
7. *Summary of Number and Types of Space Station Personnel*
   A physician or technician who could take arterial samples is required.
8. *Summary of Onboard Experimental Equipment Required*
   Equipment to analyze gas for O_2 and CO_2. Laboratory equipment for the analysis of blood for O_2Hb (spectrophotometric), pH, P_{CO2}, P_{O2}, and bicarbonate.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    Blood O_2Hb, pH, bicarbonate, P_{O2}, and possibly P_{CO2}. About two samples per week.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Not applicable.
14. *Telemetry versus Onboard Recording Requirements*
    No telemetry needed.
15. *Prerequisite Ground-Based Experiments*
    Exact equipment and procedures should be carried out in a mock-up to determine expected accuracy.
16. *Prerequisite Space Flight Experiments*
    Use of analytical methods and zero G should be tested, if it is possible. The drawing of an arterial sample would be essential.
17. *Prerequisite Research and Development*
    Only as noted under 15.
18. *Onboard Gaseous Atmosphere Desired*
    Air.
19. *Requirement for Rotation for Artificial G*
    None.
20. *Comments re Form of Data and Interpretation of Data*
    Results will be in single numbers, relatively few in total, and storage should be no problem.
21. *Special Comments*
    None.
22. *Postflight Evaluation of the Crew*
    None.
23. *References*
    This experiment measures the alveolar-arterial differences of CO_2 and O_2, and, of course, the arterial gas tensions. This is a general approach to the study of gas exchange at a basic level and any textbook of physiology will provide the necessary background.

EXPERIMENT 14

1. *Determine Changes in the Self-Cleansing Action of the Lung with Duration of Exposure to the Weightless State*
2. *Estimated Priority*
   Priority 2.
3. *Purpose*

To discover whether the normal self-cleansing mechanisms in the lung are disturbed in the weightless state.

4. *Justification*

The mucus sheet which moves from the bronchioles to the pharynx, propelled by the cilia of the epithelium, is the major protection of the distal parts of the lung against foreign materials, bacteria, and inanimate airborne particles. A cough cannot increase the velocity of air flow in the finer airways sufficiently to expell particulate matter. If the ciliary action is changed or the secretion altered so that this cleansing mechanism is less effective, damage to the lung may result. Below the respiratory bronchiole, foreign particulates are carried away by macrophages. While this should be investigated at some point, intuitively there is less likelihood of an effect of zero G.

5. *Experiment*

Measure the clearance of labeled particles from the lungs of animals. A labeled dust of a size that will deposit largely in the airways, rather than in the alveoli, will be chosen by experiment and introduced into the lungs of a convenient animal (rat or mouse). The animals will be sacrificed and the clearance of the particles from the lung followed over a month.

6. *Experimental Controls*

A similar study will be done on the ground before launching.

7. *Summary of Number and Types of Space Station Personnel*

One individual with at least training as a laboratory technician who can autopsy animals and measure the labeling material, presumably radioactive.

8. *Summary of Onboard Experimental Equipment Required*

Instrumentation to measure the labeling material. This would appear to be a radioactive tracer.

9. *Summary of Animals*

For the first experiments a small convenient animal could be used, the mouse a likely choice. The exact number would have to be determined by preliminary experimentation, but would probably run about 16 in all.

10. *Summary of Other Living Forms*

None.

11. *Summary of Onboard Laboratory Determinations*

No general chemical studies specifically needed.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*

Unless remarkable changes are seen, there is no need to return the specimens to Earth with the exception of a small number of tissue specimens for microscopic section.

13. *Proposed Rendezvous Schedule for Rotation of Crew*

Not applicable.

14. *Telemetry versus Onboard Recording Requirements*

No telemetry required.

15. *Prerequisite Ground-Based Experiments*

The clearance of particulate matter from the lung has not been well-studied, and no good methods are available for man. Experiments should be initiated to determine the best methods of studying mucus flow (possibly in man) and tried out on various animals. The type of animal, the dose of aerosol, the number of animals, and the times of sampling will depend on the results of these studies. The classical studies on ciliary motion in fresh specimens of tracheae in vitro should be repeated to investigate the effect of orientation in relation to 1 G on ciliary motion and mucus flow.

16. *Prerequisite Space Flight Experiments*

Unless a useful technique for the study of mucus flow in man is developed, animals must be employed, and these could as easily be carried out in space flight experiments of long duration without accompanying human beings.

17. *Prerequisite Research and Development*

Outlined under 15.

18. *Onboard Gaseous Atmosphere Desired*

Air which is thoroughly free of particulate matter.

19. *Requirement for Rotation for Artificial G*

None.

20. *Comments re Form of Data and Interpretation of Data*

Data will consist of the remaining concentration of labelled particulates.

21. *Special Comments*

Samples of tissue may be saved for histological section. Finer particulate suspensions, less than 0.5 micron in diameter, tend to deposit in the alveoli where they are removed by macrophages and possibly carried to the mucus sheet. By altering the size of the labelled particulate, the efficacy of macrophage activity could be studied in the same manner as outlined under 5.

22. *Postflight Evaluation of the Crew*
None.
23. *References*

1. Dalhamn, Tore: The Determination in Vivo of the Rate of Ciliary Beat in the Trachea. Acta Physiol. Scand., vol. 49, pp. 242–250, 1960.
2. Dalhamn, Tore: The Electronmicroscopy of the Tracheal Ciliary Mucosa in the Rat. Zeitschrift fur Zelforshung, vol. 44, 1956, pp. 345–412.
3. Laurenzi, G. A.; Guarneri, J. J.; Endriga, R. B.; and Carey, J. P.: Clearance of Bacteria by the Lower Respiratory Tract. Science, vol. 142, 1963, pp. 1572–1573.

EXPERIMENT 15

1. *To Devise and Evaluate Analytical Techniques for the Assay of Blood (Urine, Sweat, and Saliva) for Components of Significance in the Maintenance of Homeostasis in Circulation and Respiration on the Ground and During Short Orbital Flights*
2. *Estimated Priority*
Generally, these experiments should rate first priority, since without analytical techniques one cannot obtain the data required for maintenance of the personnel and for other experiments.
3. *Purpose*
In the condition of weightlessness, certain conventional techniques present problems which may be avoided by designing analytical procedures so that the force of gravity is not necessary. Thus, pipetting in the conventional manner cannot be used. An open container for liquids is impractical in the weightless state.
In preparing for a long-range stay in orbit, the weight of the reagents and equipment to be used must be minimized. Ideally, techniques which require no reagents are to be preferred. Sample size for assay should be at a minimum. These limitations must not decrease the accuracy and precision obtainable with conventional techniques.
4. *Justification*
The level of certain blood components needs to be monitored from time to time and during the performance of certain experiments while in the weightless state. A significant change which is noted and recorded in certain blood components during the mission may anticipate profound changes which may eventually be disastrous to crew performance. Thus, techniques should be available for these components of blood which are simple and rapid so that they may be available for interpretation by the medical team both on the ground and in space.
5. *Experiments*
Obtaining the sample:
   a. *Syringe or vacutainer:* For some purposes such as obtaining blood volume, extracellular and total body water and arterial pressure, it may be necessary to enter the vein or artery. At these times, samples of blood may be sampled for analysis. Conventional techniques are probably satisfactory for this purpose.
   b. *For repetitive analysis:* It is recommended that a capillary tube be developed for finger, toe, or ear prick. Specifications for these capillaries should be chosen after ground-based experiments, and for early tests in space before the orbital research laboratory program is put into effect. This tube could have such a design that the tube itself acts as the puncturing device, collector, measuring device, and cuvette for analysis. Heat- and fracture-resistant glass is recommended. Plastic that is wetted by water is not omitted from consideration. It is suggested that a capillary be developed with a sharpened end similar to that of a hypodermic needle but transparent, of a light absorbency (in the visible near infrared and near ultraviolet which is the same from tube to tube within $\pm 2\%$),

and of a constant bore, length, and outer diameter so that the volume contained is constant. The volume contemplated is of the order of 20 to 50 microliters. This capillary, for certain purposes, may be embedded in a small container of flexible plastic so that it may be emptied by positive pressure if necessary. In Figure 1, when pressure is applied at A (with the finger closing the opening at the top), the sample will be ejected. The capillary may be metal-tipped for a sharper cutting edge without danger of fragmentation. This system can also be used for sampling (quantitatively) urine, sweat, or saliva.

It is suggested, therefore, that samples for analysis be obtained by finger prick and by placing the capillary at the puncture so as to let the blood flow into the capillary. An alternative method is to prick the finger with a blade and use an ordinary capillary, square on both ends, to sample the blood.

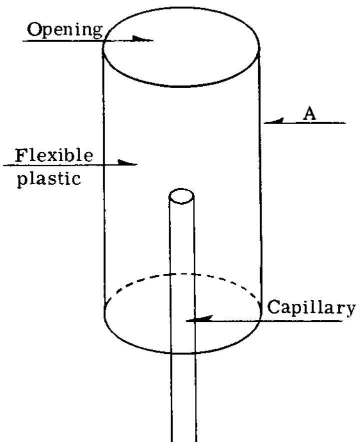

FIGURE 1.

Experiment: The development of a suitable capillary system is subject to ground-based development; however, the best technique for obtaining the specimen can only be decided after attempts are made during weightlessness to obtain the specimen. Thus, the use of the capillary as a means of obtaining and delivering a measured amount of blood is recommended as an experiment to be carried out during short orbital flights. It should be pointed out that capillary blood is essentially arterial blood (93%), and a good estimate of arterial oxygen saturation can be obtained from capillary blood.

Hematocrit value:

Development: Develop a small, lightweight hematocrit centrifuge with a stroboscope attachment coupled to a linear scale so that the capillary full of blood can be observed during centrifugation. Removal of the capillary from the centrifuge during weightlessness will resuspend the cells. Thus, measurements must be made during centrifugation. At the same time, the length of the upper coat of leucocytes may be examined and measured for gross evidence of abnormality.

Experiment: Test the instrument under weightless conditions in preorbital flights for evidence of its practicability.

Hemoglobin and oxygen saturation:

Development: A small lightweight colorimeter, capable of taking measurements at two specific wavelengths, needs to be developed. The capillary full of blood is inserted and a measurement is made at an isobestic point for determining grams of hemoglobin and at another wavelength peak for oxyhemoglobin for its absorbence. From these two values, a table can be constructed for giving the percentage of oxyhemoglobin. If a spectrophotometer is contemplated for other purposes, then an adapter for holding the capillary is all that needs to be developed.

Experiment: Test this instrument in the state of weightlessness for practicability in preorbital flights.

Other chemical components of blood or plasma development: In order to avoid the need for reagent bottles to be carried into space, a general technique is hereby proposed for development.

An ideal method would be one where the capillary is touched to a piece of filter paper, the filter paper containing the reagents and developing a color which can be quantitatively measured. This cannot be done with serum or blood because they are colored and because the addition of a fluid to a piece of paper washes the reagent out of the field, producing chromatographic rings and uneven spots. Further, the presence of cells or proteins vitiates the tests in many cases. For this reason, the following system is proposed for development and is illustrated in Figure 2.

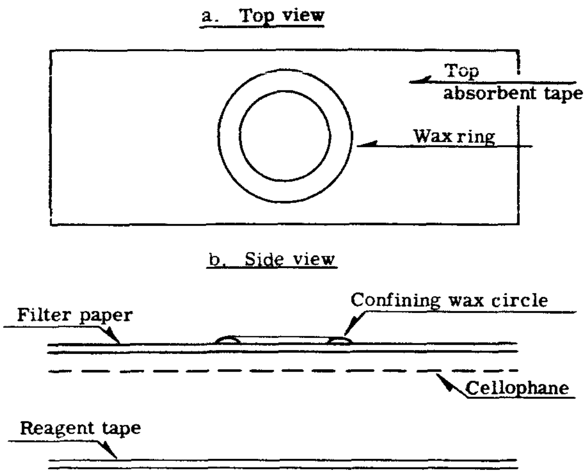

FIGURE 2.

The sampler from the capillary is blown onto a piece of filter paper containing a spot confined by a wax circle. This retains the specimen in a definite area. As an alternative, the blood is placed directly onto the cellophane (or cellulose acetate).

The paper with the sample is placed on a porous sheet (cellophane) underneath which is a reagent paper. When pressure is applied, the proteins will be retained and an ultrafiltrate of plasma passes through to the reagent tape. The color produced on the reagent tape is a measure of the component being tested. The three tapes are contained in a polyethylene or polypropylene bag. A press plate for timing the period of pressing in order to obtain reproducibility will be necessary. This would be hand-operated with a timer which releases the pressure after a fixed time. The reagent tape could then be torn off and placed in a colorimeter for evalaution of the spot.

For whole blood sugar, urea, uric acid, pH, creatine, and creatinine, this system would be satisfactory.

From plasma, obtained by centrifuging the capillaries and cutting at the plasma-cell interface, sodium, calcium, phosphate, potassium, chlorine, CO_2, pH, and other values could be obtained.

If the porous tape is made of thin teflon so as to permit only gas exchange, C_{CO2} and P_{O2} could be measured from whole blood. If the porous tape is perforated so as to let protein through, then total protein and albumin could be assayed. For the elements, the bottom tape can be simple filter paper, using the technique of x-ray spectrometry for assay.

As an alternative, a thin layer of cellophane or cellulose acetate is placed on a reagent paper. A drop of blood from the finger is touched to the cellophane. After a short time (1 min), the blood can be washed off or lifted off with the cellophane. The stain below will vary in size, but the intensity will be a function of the concentrations of the element sought. The stain can then be evaluated by comparison with a color chart or by reading in the spectrophotometer with a beam of light narrower than the stain as shown in Figure 3.

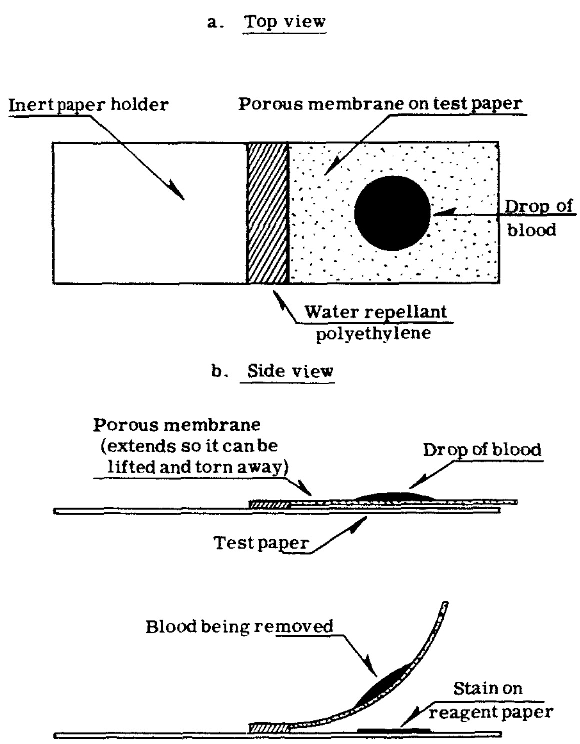

FIGURE 3.

In summary, it is suggested that pads be developed for the various components. That a colorimeter or spectrophotometer be fitted with an adapter to read the colored spots developed and that a radioisotope x-ray source instrument be developed for the elements.

Experiment: Evaluate the instrumentation discussed above during short orbital flights for practicability.

Body water and blood volume:

Development: Evans blue dye, dissolved in deuterium oxide, may be satisfactory as a tracer for these studies. It is recommended that the deuterium be assayed by either gas chromatography or by osmotic pressure measurements with instrumentation available.

Experiment: Attempt to evaluate these techniques in flights prior to the ORL flight.

Corticosteroids and catecholamines: Urine and blood specimens should be stored for assay on the ground. Develop suitable containers and techniques for such storage.

6. *Experimental Controls*
   Methods will be evaluated on the ground and with controls and standards while in flight.
7. *Summary of Number and Types of Space Station Personnel*
   Astronauts can be trained to do the tests.
8. *Summary of Onboard Experimental Equipment Required*
   Consumable equipment: Approximately 10 lb. Fixed equipment: Estimated weight of all equipment needed under ideal conditions varies from less than 10 lb to less than 70 lb, depending upon whether an x-ray spectrometer/spectrophotometer is to be carried with the equipment.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    Number, frequency, and function of other tests and experiments planned.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    Urine and blood serum for catecholamines and steroid hormones.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Not pertinent.
14. *Telemetry versus Onboard Recording Requirements*
    Both telemetry and onboard recording will be used.
15. *Prerequisite Ground-Based Experiments*
    Experiments discussed under 5 all require development on the ground.
16. *Prerequisite Space Flight Experiments*
    Testing of techniques discussed under 5 should all be done during short orbital flights and should be finalized before ORL.
17. *Prerequisite Research and Development*
    Discussed under 5 in experiments.
18. *Onboard Gaseous Atmosphere Desired*
    Gaseous atmosphere onboard immaterial.
19. *Requirement for Rotation for Artificial G*
    No requirement for artificial gravity anticipated.
20. *Comments re Form of Data and Interpretation of Data*
    Interpretation of data to be made by physician onboard and on ground by physician and consultant clinical chemist.
21. *Special Comments*
    No special comments.
22. *Postflight Evaluation of the Crew*
    None.
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METABOLIC, DIGESTIVE, SKELETAL, NEUROMUSCULAR, FLUID AND ELECTROLYTE, RENAL, THERMOREGULATORY, REPRODUCTIVE, AND ENDOCRINE FUNCTIONS

The five experiments proposed in this section are concerned with testing the reaction to prolonged space flight of several systems of the body which are vitally concerned, at the least, with ability to maintain effective working capacity and, in some instances, with ability to maintain life itself. For this reason they are among the more important studies proposed for ORL.

Important preliminary information on the reaction of these systems to weightlessness and to certain other stresses—confinement, threat of danger, thermal and circadian rhythm changes, monotony—will be obtainable from earlier flights and certain ground-based studies. However, the resistance of the body to or its ability to adjust to and compensate for these stresses in flights lasting for weeks or months can best, if not only, be determined by lengthy and precise observations in an orbiting laboratory environment.

The vital functions and reactions principally to be examined in these experiments are (1) biochemical or metabolic processes affecting energy expenditure; utilization of protein, fat and carbohydrate; and acid-base metabolism, all very important for efficient physical and mental function; (2) mineral metabolic processes which, if sufficiently and continuously deranged, could lead to dangerous thinning of the skeleton and possibly to urinary tract stone formation; (3) fluid and electrolyte metabolism and kidney function because of the vital necessity to maintain normal water balance and electrolyte equilibrium and to preserve kidney function for the effective elimination of body wastes; (4) ability of the body's temperature regulatory mechanisms to maintain normal body temperature without undue loss of fluid or other incapacity; and (5) the ability of the body's endocrine glands to make appropriate hormonal responses to the stresses of space flight and to continue indefinitely to provide effective modulation of essential physiologic functions.

EXPERIMENT 1

1. *Effects of Prolonged Space Flight on Various Metabolic Functions*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To determine the qualitative and quantitative effects of various stresses of prolonged space flight on energy, protein, carbohydrate, and acid-base metabolism. Although certain metabolic changes can be predicted qualitatively, there is need to know the quantitative aspects of metabolic derangement with respect to rate,

pattern, and degree, and, further, to learn whether man's metabolism after some or considerable alteration will come into a steady-state physiologically or become medically compatible with long space flight. Knowing the kinds and magnitudes of these derangements, the next step will be to determine the relative effectiveness of corrective or preventive measures, if needed. The stress primarily involved in this experiment is weightlessness, but in the initial stages of flight, at least, and in the first ORL flights there will be combined stress effects of confinement, threat of danger, thermal stress and circadian rhythm changes; less likely to exert effects will be the stresses of monotony, social restriction, toxic substances, and noise. The relative importance of some of these secondary stresses can be determined in either prior or subsequent ground-based studies.

4. *Justification*

Prior detailed studies on the ground (Deitrick, Whedon, Shorr, and others) of the effects of immobilization or confinement to bed had shown significant, and in some respects, striking alterations in a variety of metabolic functions, e.g., decline in basal metabolic rate, increased excretion of nitrogen, phosphorus, calcium, and potassium (resulting in negative balance depending upon the dietary intake level of the element), impaired carbohydrate tolerance, and altered creatine metabolism. Conversely, in the Walter Reed rotating room providing 0.2 to 0.3 + G, increased carbohydrate clearance has been reported. The question is whether or not the greatly diminished effect of gravity and greater physical disuse associated with weightlessness in comparison to immobilization will result in greater disturbance in metabolic functions, perhaps in some instances to an extent incompatible with effective performance unless corrective or preventive measures are devised and instituted.

With respect to acid-base metabolism, the question is raised as to whether reduced movement or immobility associated with weightlessness may result in reduced chest ventilatory movement leading to hypercapnia. This event, if it occurred, would lead to a respiratory acidosis which would tend to have significant outward effects on muscle metabolism and bone. If hypercapnia is found to develop, discussion and investigation should be undertaken with respect to the possibility that allowing the carbon dioxide in cabin atmosphere to reach approximately 0.5% might be a useful ventilatory stimulant. It has been suggested that many of the processes of intermediary metabolism may be gravity or weight dependent, normal function depending on directional orientation of subcellular particles. Although this rather fundamental question should be answered by studies with simpler life forms in earlier space flights, it would be important to find out if the phenomenon held in higher species and might, in part, be responsible for disorders of metabolic function.

5. *Experiment*

Procedure: The human subjects under study would all have to be under well-controlled metabolic observation for an appropriate control phase prior to flight in ORL and for a similar postcontrol phase following return to Earth. These control phases should each extend for a minimum of 2 weeks during which all of the same tests and measurements should be made as would be made during ORL flight; prior to beginning of the actual control phase, some time would have to be devoted to "shake-down" of the various procedures and orientation of subjects and of directly-participating staff personnel. Throughout all phases of the study, control of the metabolic intake will be essentially by keeping dietary intake as constant as possible and recording it and fluid intake with complete accuracy. Collection of all urine (or appropriate aliquots thereof) and stool specimens will be required, and some attention must be given to collection of sweat since important losses of metabolic constituents can occur by this route. Serial blood samples at minimal volumes will also be needed. The procedure employed in this experiment should be planned so that experiments on endocrine function, on skeletal function (or mineral metabolism), and on fluids and electrolytes can be carried out simultaneously and in direct association.

Measurements:

a. *Energy metabolism:* Although it has been suggested that the total energy metabolism of all occupants of the ORL craft could be measured by determining the rates of utilization of oxygen as supplied from the oxygen tanks and of carbon dioxide as picked up by the onboard carbon dioxide scrubbers and making a correction for the determined leak rate of the craft at the existing pressure differential, a much more accurate and finite determination of energy metabolic rates (for specific individuals and during specific activities) can be made by placing onboard electronic continuous stream gas analyzers for O_2 and CO_2 and making continuous expired air collections at desired intervals. Reasonably accurate determinations of 24-hour total energy metabolism can be made from short measurements of sample determinations; the "sample activities during the day" are obtained by a detailed time-and-motion study log, which will permit energy metabolism observation over a few hours to be an accurate representation of a 24-hour day. In this method the O_2 and CO_2 content of the inspired cabin air also has to be made at frequent intervals. From the ratio of oxygen and CO_2 utilized, R.Q. can be calculated for any desired interval, activity, etc., corrected for urinary nitrogen excretion, and the "metabolic mixture" (quantitative proportions of protein, fat, and carbohydrate being burned) for the interval precisely determined.

b. *Nitrogen metabolism:* In order to assess the extent of possible muscle wasting related to inactivity and weightlessness, nitrogen balance would be determined by analyses of urines and stools and knowledge of the protein intake, an effort being extended to keep the latter relatively constant. Urinary nitrogen would be analyzed on a 24-hour basis for balance determinations, but in shorter aliquots in conjunction with energy metabolism determinations.

c. *Carbohydrate and fat metabolism:* Intravenous glucose tolerance tests, 30-minute infusion of 1 gm glucose per kilogram body weight, blood samples for glucose every 30 minutes for 3 hours. Frequency of test approximately weekly, 3 such tests in control phase, and 2 in postcontrol phase. These tests can be combined with serial sampling of serum phosphorus and with continuous expired air oxygen and carbon dioxide analyses for R.Q. to give significantly more meaningful information on carbohydrate metabolism. In addition, by the time minutely detailed protocols are required, methodology for determining metabolism of labeled sugars (carbon–14 in the one and six carbon positions) may be more advanced and be practicable in ORL cabin studies. With development of onboard experimental technology, glucose intravenous tolerance tests can be performed at weekly intervals during flight. Changes in fat metabolism should also be investigated pre- and postflight, and in-flight if feasible, by analyses of blood free fatty acids (FFA). This index of fat metabolism should also be measured in association with changes in blood glucose in response to infusions of insulin and glucose and could be carried out in conjunction with analyses of expired air oxygen and carbon dioxide for R.Q. in association with infusions of insulin and glucose. Measurements of changes in the blood level of growth hormone in association with these studies will also be practicable by the time these studies are ready to be flown (see experiment entitled *Effects of Prolonged Space Flight on Neuroendocrine Function*).

d. *Hepatic function:* In view of the possibility of an impairment of blood supply to and through the liver from confinement, weightlessness, or both, certain relatively easily performed tests of hepatic function should be carried out at 1 to 2 week intervals:—BSP retention, serum protein profile, and certain serum enzymes to be selected at a later time in accordance with what seems pertinent in the light of most recent knowledge.

e. *Acid-base metabolism:* In view of the possible development of some degree of hypercapnia, periodic analyses of serum should be made for pH and pCO_2 and of urine for titratable acidity and chloride.

f. *Mineral metabolism:* The importance of measurements in this area of metabolism is unusual and will be dealt with in a separate experiment.

g. *Body composition:* Of considerable assistance to evaluation of energy metabolism observations will be measurements of body composition with respect to lean body mass, total fat, etc. The key measurements are total body water, body volume, and body weight (*vide infra*) from which the various compartments can be calculated by standard formulae. Determination of lean body mass by whole body counting for the natural radioactive element of potassium does not seem practical with presently available methods, but may later prove feasible.

h. *Body "weight":* This is a critical and difficult measurement under the conditions of space flight. Since an object literally does not have weight in space, the mass of the body equivalent to what it would have under conditions of Earth gravity will have to be determined with an inertial technique (to be developed) using the fact that time period of oscillation of an object suspended between springs is a function of its mass. A variation of this method which has been suggested would use the time and distance the subject moves, suspended between springs, from a motionless start as set in motion by a calibrated impulse. In addition to assessment of mass changes related to metabolism, this measurement will be very useful for determining changes in fluid balance.

6. *Experimental Controls*
   Control is built into the procedure of the experiment by preflight and postflight control phases, each subject in effect serving as his own control. In addition, however, prior ground-based studies of the effects of immobilization or confinement serve as control studies for the effects of weightlessness.
7. *Summary of Number and Types of Space Station Personnel*
   Trained astronauts will serve satisfactorily as subjects. Laboratory technicians will be needed to the extent that laboratory analyses can be performed in the weightless state. One technician who is well-trained in operation of the continuous gas analyzers (competence in electronic maintenance), body volume determinator, and other metabolic procedures will definitely be required.
8. *Summary of Onboard Experimental Equipment Required*
   Basic equipment required is that for collection and storage of blood, urine and stool specimens, preparation of urine aliquots, accurate recording and labeling of all specimens, and recording of fluid intake and all food items consumed. Also required are (1) electronic continuous gas analyzers for O_2 and CO_2, (2) recorders or devices for telemetering to ground data from the analyzers, (3) solutions and necessary infusion apparatus for intravenous glucose tolerance tests, (4) body volume determination (a box of known volume in which subject is placed for brief period while volume of space surrounding the subject's body is determined by dilution of a known injected volume of an inert gas, usually helium), and (5) apparatus for determining body mass.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    Minimum requirements will be in line with equipment described under 8—specimen (blood, urine, stool) collection, recording of food and fluid intake, etc., requiring 1 to 5 minutes several times a day; continuous expired air gas analyses (detailed protocol to be developed) but 20 minutes to 4 hours per determination for certain subjects approximately 1 to 2 times per week; i.v. carbohydrate tolerance requiring parts of 3 hours at intervals to be determined; body volume and total body water requiring parts of 2 hours approximately every 2 weeks; and body "weight" requiring a few minutes daily. Whether or not additional analyses (nitrogen or excreta, hepatic function test samples, etc.) will be done will depend on the relative feasibility of the proposed onboard laboratory analytic function within capacity versus capability of transferring specimens to the ground where the analyses can be done much more simply.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    Until the feasibility of analytic operations onboard has been demonstrated, one would say "as many as possible."

13. *Proposed Rendezvous Schedule for Rotation of Crew*
Not pertinent.
14. *Telemetry versus Onboard Recording Requirements*
Telemetry would be preferable for the energy metabolism measurements, whereas laboratory analyses may as well be recorded.
15. *Prerequisite Ground-Based Experiments*
As indicated, ground-based control observations pre- and postflight are essential. Despite the fact that most of the methods are well established, considerable time and effort should be expended in shakedown, calibration, etc.
16. *Prerequisite Space Flight Experiments*
To the extent possible, various procedures should be evaluated on prior flights in which there is sufficient room. In particular, efforts should be made to devise and test means of carrying out various laboratory biochemical analyses in the weightless state.
17. *Prerequisite Research and Development*
See under 16. A particularly important method to be developed is that to measure mass ("weight") in flight.
18. *Onboard Gaseous Atmosphere Desired*
It is strongly urged that Earth atmosphere be provided; otherwise, a new factor or stress is introduced which may interact with weightlessness and other stresses in a way not yet calculable.
19. *Requirement for Rotation for Artificial G*
Not required.
20. *Comments re Form of Data and Interpretation of Data*
No special comments except that in interpretation there must be awareness of the interaction of several stresses. A number of them can undoubtedly be minimized or eliminated, with planning, in subsequent ORL flights.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
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EXPERIMENT 2

1. *Effects of Prolonged Space Flight on Mineral Metabolism and Bone Densitometry*
2. *Estimated Priority*
Priority 1.
3. *Purpose*
To determine the pattern, rate, and degree of mineral loss from the skeleton associated with weightlessness and inactivity in prolonged space flight.
4. *Justification*
Prior detailed studies of the effects of immobilization in bed (ref. 1), confirmed in several recent observations, have shown an increase in urinary calcium excretion to more than double the control level, an increase in fecal calcium excretion, and development of negative calcium balance at moderate levels of mineral intake. Although demineralization of the skeleton was not demonstrable in the 6 to 7 weeks of immobilization with the techniques of x-ray visualization of the skeleton then available, studies of the immobilization associated with paralytic poliomyelitis (ref. 2) showed definite decrease in bone density in paralyzed lower extremities within 2 months;

and confinement studies of normal subjects currently in progress have implied demonstrable decrease in bone density of the os calcis within a few weeks. It is extremely important to determine whether this demineralizing process will occur at the same or a more rapid rate under conditions of weightlessness, in which the stress and strain of weight bearing, muscle pull on periosteum, and likely changes in circulation to bone are expected to be maximally oriented toward increased bone resorption (ref. 3).

An associated significant problem is whether the factors favoring the development of urinary tract gravel or calculi will be significantly enhanced by weightlessness and associated inactivity. Although the anticipated increase in urinary calcium and phosphorus have commanded maximal attention in relation to the stone problem, other metabolic constituents of the urine are now regarded as having equal or more important significance with respect to stone matrix formation and crystalline deposition, and these must be intensively investigated.

5. *Experiment*

Procedure: Identical to that described for the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions,* which also will be utilized for the experiments entitled *Effects of Prolonged Space Flight on Fluid and Electrolyte Metabolism* and *Effects of Prolonged Space Flight on Neuroendocrine Function.*

Measurements:

a. *Mineral metabolism:* In association with the regulation of relative constancy of dietary intake and urine and stool collections of the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions,* calcium and phosphorus intake will be stabilized and recorded and urinary and stool calcium and phosphorus measured for determinations of calcium and phosphorus balance. For possible utilization of bone-seeking isotopes in conjunction with balance studies, see the experiment proposed by Dr. Grahn as a method of assessment of rates of mineral loss from the skeleton (*Determination of Bone Demineralization During Prolonged Space Flights*). Kinetic studies using radioactive calcium-45 or 47 of turnover, pool size, and "bone formation rate" or "accretion rate" could be performed prior to, during, and post-ORL flight, but it is not clear at this time that such studies would significantly add to the information obtained from balance measurements; such radioisotopic kinetic studies, however, should be brought into consideration for possible later ORL flights. Serum calcium, phosphorus, and alkaline phosphatase should be measured approximately four times preflight, approximately weekly during flight, and four times during the postflight control phase.

b. *Bone densitometry:* The technology of bone densitometry is in rapid flux at the present time, and it is difficult to define a specific protocol for an experiment to take place some years in the future. Minimal recommendation at the present time is that at least 4 determinations of bone density during the ground-based control must be made at each of 4 sites: (1) os calcis, (2) distal end of ulna, (3) lateral of vertebral body L–3, and (4) neck of femur, using a collimated x-ray radiation source, an aluminum graduated wedge on the film, and a scanning technique for determination of density of bone areas and correction of the latter for superimposed soft tissue density. Four additional measurements within a period of 2 to 3 days should be made at each of the sites mentioned immediately following return to Earth. The possibility of taking x-ray films for bone densitometry in flight has been considered, but the weight and volume requirements for this technique preclude this at the present time. Under development is a technique utilizing iodine–125 as a radiation source, which would have a great advantage with respect to weight to be carried on the space craft and would be practical from this point of view; current disadvantages of this new technique are (1) the several minutes required for the radiation source to scan across the body part being viewed so that the body part must be kept immobile for a long period and (2) the fact that the technique can be applied only to extremities. It is hoped that within 1 year a reliable and reproducible bone densitometry technique will be available which will be suitable for this experiment.

c. *Factors related to urinary tract stone formation:* Measurement in urine specimens already planned to be collected prior to, during and after flight of pyrophosphate, magnesium, manganese, zinc, and various mucoproteins and related biocolloids (refs. 5, 6).

6. *Experimental Controls*
Control is built into the procedure of the experiment by preflight and postflight control phases, each subject in effect serving as his own control. In addition, however, prior ground-based studies of the effects of immobilization or confinement serve as control studies for the effects of weightlessness.

7. *Summary of Number and Types of Space Station Personnel*
Trained astronauts will serve satisfactorily as subjects. As of present planning, laboratory technicians will not be required.

8. *Summary of Onboard Experimental Equipment Required*
Basic equipment required is that for collection and storage of blood, urine, and stool specimens as prepared for the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions.* Apparatus for measuring both densitometry and bone is not currently practical, but the techniques for such measurements should be continually reviewed over the next year or more.

9. *Summary of Animals*
None.

10. *Summary of Other Living Forms*
None.

11. *Summary of Onboard Laboratory Determinations*
Blood, urine, and stool collections as described in experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions.* If procedures for onboard biochemical determinations can be worked out, it will be valuable to analyze spot 24-hour urine collections for calcium and serum calcium approximately weekly. Other analyses can be conducted on the ground postflight.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
Until the feasibility of analytic operations onboard has been demonstrated, one would say "as many as possible."

13. *Proposed Rendezvous Schedule for Rotation of Crew*
Not pertinent.

14. *Telemetry versus Onboard Recording Requirements*
Not pertinent.

15. *Prerequisite Ground-Based Experiments*
As indicated, ground-based control observations pre- and postflight are essential. Despite the fact that most of the methods are well established, considerable time and effort should be expended in shakedown, calibration, etc.

16. *Prerequisite Space Flight Experiments*
To the extent possible, various procedures should be evaluated on prior flights in which there is sufficient room.

17. *Prerequisite Research and Development*
Intensive efforts should be made to improve the accuracy and define the reliability and reproducibility of methods for determining bone densitometry.

18. *Onboard Gaseous Atmosphere Desired*
It is strongly urged that Earth atmosphere be provided; otherwise, a new factor or stress is introduced which may interact with weightlessness and other stresses in a way not yet calculable.

19. *Requirement for Rotation for Artificial G*
Not required.

20. *Comments re Form of Data and Interpretation of Data*
No special comments except that in interpretation there must be awareness of the interaction of several stresses. A number of them can undoubtedly be minimized or eliminated, with planning, in subsequent ORL flights.

21. *Special Comments*
None.

22. *Postflight Evaluation of the Crew*
None.

23. *References*

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EXPERIMENT 3

1. *Determination of Bone Demineralization During Prolonged Space Flight*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To detect the time and quantity of calcium mobilization from the skeleton during prolonged flight and to anticipate any physiological complications therefrom as they may occur during orbital flight or reentry.
4. *Justification*
   Calcium is known to be withdrawn from bone during periods of bed rest and during periods of weightlessness. The results of this may have serious effects upon the structural strength of the skeleton and, therefore, upon the capability of the skeleton to withstand excessive G loads. The extent of bone demineralization that may occur in prolonged flights must be carefully anticipated before such flights are programmed.
5. *Experiment*
   It would appear that the phenomenon of bone demineralization is similar to that which occurs in hospitalized patients. In these cases the demineralization accompanying disuse may be sufficient to allow radiographic diagnosis of demineralization following periods of inactivity in excess of 6 weeks or so. However, this is probably subject to considerable individual variation. It is generally felt that radiographic observation of demineralization requires that bone densities be reduced to 60 to 70% of their initial value. One can assume that the skeleton is more or less uniformly demineralized under these conditions. This would involve a loss of approximately 1/3 of the 600 grams of calcium contained in a standard man.

   The most sensitive method for determining calcium withdrawal would be by representative analyses of excreta samples from an individual who had previously been given tolerable doses of either radioactive calcium or one of the alkaline earths which would simulate the metabolic behavior of calcium. Strontium–85 would seem to be the most easily used isotope for this purpose since it decays with the emission of gamma radiation unaccompanied by any electrons and can, therefore, be given safely in the largest doses. The other possibilities would be calcium–45, calcium–47, barium–140, or radium. However, there are technical and radiological problems associated with each of these alternatives.

   A preflight test experiment under conditions of normal physical activity using the person to be flown into space as the experimental subject, should be carried out a few weeks prior to flight. Using good experimental techniques, this could be accomplished with a minimum dose of strontium–85 (possibly as little as 1 μc). The second dose of strontium–85 which would be appreciably larger than this for two reasons: (1) to override residual activity from the first dose and (2) to compensate for inferior instrumental possibilities in flight, would be administered at approximately 10 days prior to flight. The individual should be carefully monitored during these 10 days to determine the preflight baseline and for comparison with the first dose. Dose required for the second intravenous injection could be in the order of perhaps 200 μc. This would deliver a maximum gamma dose to the individual of 20 to 25 millirads per day. This would drop steadily according to power function laws.

   It has been amply demonstrated that the power function descriptions of whole body strontium–85 retention can be used to predict the normal behavior of strontium in humans as well as experimental animals. These would allow for quantitation of the increased mobilization of calcium which may occur. A dose in excess of 200 μc could be safely administered to humans. Using good technique, it is possible to measure the strontium–85 whole body burden of such an individual over periods well in excess of a year.

6. *Experimental Controls*
   In essence, the control is inherent. The individual astronaut must be baselined in a preflight study and the effects of weightlessness will be controlled against the normal ground-based calcium metabolism pattern.
7. *Summary of Number and Types of Space Station Personnel*
   It is anticipated that the study can be done by the trained astronaut.
8. *Summary of Onboard Experimental Equipment Required*
   A minimum requirement for fixed equipment would be one single-channel pulse height analyzer, or its equivalent, for the detection of a gamma-emitter in excreta. If payload is available, the experiment can become more elaborate and look for phosphorus as well as strontium-85.
9. *Summary of Animals*
   No experimental animals required.
10. *Summary of Other Living Forms*
    No other living forms required.
11. *Summary of Onboard Laboratory Determinations*
    The frequency of determinations will have to be determined from preflight studies and will have to be kept flexible during flights to allow for possible abrupt changes in calcium excretion. It can be recommended that all excreta be sampled, at least at the outset. The determination would be simply a matter of evaluating the sample for its content of radioactive isotopes.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    It is not anticipated that specimens will have to be ferried back to Earth during the course of prolonged orbital flight.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Not applicable.
14. *Telemetry versus Onboard Recording Requirements*
    The results of the determinations should be telemetered rather than being read onboard. Telemetering the count rate, for example, will permit immediate analysis of the data with the baseline program stored in the computer. It may be necessary, however, to accumulate count rates over a number of hours and, therefore, an onboard tape storage may be required which can then read out when over appropriate ground stations.
15. *Prerequisite Ground-Based Experiments*
    Each individual astronaut has to be evaluated through preflight ground-based studies in order to define his normal pattern of calcium metabolism. This will also help to determine the required frequency of determinations during flight.
16. *Prerequisite Space Flight Experiments*
    The procedure should be evaluated during one of the Gemini missions. In this case, the excreta would be saved and returned and the counts made in ground-based laboratories. These can then be evaluated against chemical analysis and full calibration of the procedure will result.
17. *Prerequisite Research and Development*
    The only required R and D would be to bring about some miniaturization of the counter and to consider the most effective way of preparing a sample of the excreta for counting.
18. *Onboard Gaseous Atmosphere Desired*
    No unusual gaseous atmosphere required.
19. *Requirement for Rotation for Artificial G*
    The capability for the induction of artificial gravity would make the total experiment more useful, but it is not a prerequisite.
20. *Comments re Form of Data and Interpretation of Data*
    The data can be taken directly in the form of count rate and should be interpreted by processing through the computer and comparison with the baseline metabolic parameters.
21. *Special Comments*
    No special comments.
22. *Postflight Evaluation of the Crew*
    None.
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EXPERIMENT 4

1. *Effects of Prolonged Space Flight on Fluid and Electrolyte Metabolism*
2. *Estimated Priority*
   Priority 1.
3. *Purpose*
   To determine the effects of weightlessness in prolonged space flight on water balance, electrolyte metabolism and excretion, and renal function. Although the primary stress under study is weightlessness, in initial stages of flight, at least, there may be added stress effects from confinement, threat of danger, thermal stress, and circadian rhythm changes.
4. *Justification*
   Various prior studies on Earth have indicated substantial changes in fluid balance and renal function with changes in body position from vertical to horizontal—mobilization of fluid from tissues into the bloodstream, increased renal blood flow, changes in glomerular filtration rate, and increased urinary volume. Such functions have not been studied extensively in studies of the effects of long-term bed rest or inactivity, but are under investigation at the present time (Air Force). Preliminary observations in short space flights have suggested, in a situation having poor control, that marked water loss takes place possibly due to both sweating related to heat stress and to changes in antidiuretic hormonal control of water balance. There is also the possibility that disturbances may take place in the mechanisms responsible for adequate thirst response to dehydration. Since large changes in water balance and possibly associated disturbances in electrolyte metabolism are incompatible with efficient performance of duty, if not life itself, it is expected that pertinent preliminary information will be obtained in earlier flights, but it will be essential to obtain detailed data of the problem in ORL flight to assess its status with respect to prolonged space flight.
5. *Experiment*

Procedure: Identical to that described for the experiment entitled *Effects of Prolonged Space Flights on Various Metabolic Functions.* It is anticipated that this experiment will be run in conjunction with those on Metabolism, Skeletal Systems, and Endocrine Balance.

Measurements:

a. *Water balance:* The various measurements associated with water balance and its control are (1) total fluid intake, (2) urinary volume, (3) fecal water content, (4) body mass (or "weight"), (5) urine and blood osmololity, (6) blood osmololity, (7) blood hemoglobin and hematocrit, (8) blood volume, (9) total body water, and (10) assay of urine for antidiuretic hormone activity. Considerable attention will have to be devoted to methods for measuring or assessing sweat volume losses; in this conjunction, accurate repeated or continuous temperature and humidity measurements of the cabin air and walls must be taken.

b. *Electrolyte metabolism:* With careful regulation of dietary intake and with the urine and stool collections associated with other experiments, balance studies can be carried out for sodium, potassium, magnesium, and chloride. The studies planned on acid-base metabolism and described in the experiment entitled *Effects of Prolonged Space Flights on Various Metabolic Functions* should be mentioned in this section since the changes in fluids and electrolytes related to heat and orthostasis could be complicated by the possible development of hypercapnia which would favor sodium retention and chloride loss; respiratory rate and cabin atmosphere carbon dioxide will need to be monitored and telemetered to ground.

c. *Renal function:* The relatively easily measured indices of renal function are creatinine clearance and blood urea nitrogen (urea can be measured in blood or urine by a paper stick method). Much more precise methods, such as insulin clearance (for glomerular filtration rate) and para-aminohippurate clearance (for tubular reabsorption) require intravenous infusions and various timed urine specimens so that they probably should not be included in initial protocols.

d. *Factors related to urinary tract stone formation:* Measurement in urine specimens already planned to be collected prior to, during, and after flight, of pyrophosphate, magnesium, manganese, zinc, and various muco proteins and related biocolloids.

6. *Experimental Controls*
Control is built into the procedure of the experiment by preflight and postflight phases, each subject in effect serving as his own control.
7. *Summary of Number and Types of Space Station Personnel*
Trained astronauts will serve satisfactorily as subjects. Laboratory technicians will be needed to the extent that laboratory analyses can be performed in the weightless state.
8. *Summary of Onboard Experimental Equipment Required*
Basic equipment is that for collection and storage of blood, urine, and stool specimens as prepared for the experiment entitled *Effects of Prolonged Space Flight of Various Metabolic Functions.*
9. *Summary of Animals*
None.
10. *Summary of Other Living Forms*
None.
11. *Summary of Onboard Laboratory Determinations*
Blood, urine, and stool collections as described in the experiment entitled *Effects of Prolonged Space Flights on Various Metabolic Functions.* Measurements related to water balance will need to be made with extreme frequency during the first week of ORL flight. Tests of renal function, as forecast at present, will need to be made approximately every 1 to 2 weeks.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
Until the feasibility of analytic operations onboard has been demonstrated, one would say "as many as possible."
13. *Proposed Rendezvous Schedule for Rotation of Crew*
Not pertinent.
14. *Telemetry versus Onboard Recording Requirements*
Not pertinent.
15. *Prerequisite Ground-Based Experiments*
As indicated, ground-based control observations pre- and postflight are essential. Despite the fact that most of the methods are well established, considerable time and effort should be expended in shakedown, calibration, etc. Important studies of renal function as affected by inactivity appear to be in progress.
16. *Prerequisite Space Flight Experiments*
To the extent possible, various procedures should be evaluated on prior flights in which there is sufficient room.
17. *Prerequisite Research and Development*
A particularly important method to be developed is that to measure mass ("weight") in flight.
18. *Onboard Gaseous Atmosphere Desired*
It is strongly urged that Earth atmosphere be provided; otherwise, a new factor or stress is introduced which may interact with weightlessness and other stresses in a way not yet calculable.
19. *Requirement for Rotation for Artificial G*
Not required.
20. *Comments re Form of Data and Interpretation of Data*
No special comments.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
23. *References*
No specific ones available.

EXPERIMENT 5

1. *Effects of Prolonged Space Flight on Physiologic Temperature Regulation*
2. *Estimated Priority*
Priority 1.

3. *Purpose*
To determine the effects of various stress of prolonged space flight on physiologic mechanisms of temperature regulation.
4. *Justification*
Thermal comfort of the astronaut is absolutely essential for both his work efficiency and even maintenance of his life. If the effective temperature of the vehicle is too low or if other factors lead to excessive heat loss which is prolonged, his efforts to increase his heat production (by exercise or shivering) or efforts to conserve heat by body positioning will, at the least, take extensive effort away from that required for performance of duties. If the effective temperature is too high, excessive sweating may lead to extensive or even life-threatening water loss and elevation in body temperature. While at first glance the problem would seem to be entirely an engineering one with respect to temperature regulation of the vehicle or of the astronaut's suit, actually nothing is known of the effects of stresses other than thermal on the temperature regulating mechanisms of the body. Engineering design to handle thermal changes or unusual thermal situations can have a much more meaningful direction if it can be determined whether or not weightlessness, confinement, changes in circadian rhythm, threat of danger, etc. (either alone or in combination with vehicular atmospheric conditions different from Earth in either gas composition or pressure) have distinct effects on thermal regulation.
The limited space flight experience to date has suggested difficulty in maintaining comfort on the warm side (because of overheating), and it is not clear whether this difficulty was due entirely to the diminished heat loss attendant to wearing a space suit coupled with faulty cooling apparatus within the suit. An additional possible basis for difficulty in achieving proper rates of heat loss may be related to the currently used atmospheric pressure of 5 psi which would tend to diminish the effectiveness of the convective route of heat loss and may well have other important effects on mechanisms of thermal regulation (see under 15). (The reverse situation was noted in experiments simulating submarine exposure in which the atmospheric pressure was substantially above normal; subjectively, heat loss was considerably increased.) A significant portion of the questions suggested can be approached and at least partially solved by ground-based experiments and by space flights prior to ORL.
5. *Experiment*
Procedure: This experiment logically should be coordinated closely with the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions* since the method of measurement of heat production is identical with the measurement of oxygen consumption and is carried out with the subject in the basal state. Measurements of heat production, loss, storage, and balance will be made on 2 or more occasions during a preflight control phase, at least at weekly intervals in flight, and again on 2 or more occasions postflight. (See under 15 for *Prerequisite Ground-Based Experiments* and see experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions.*)
Measurements:
a. *Heat production:* Heat production is calculated from oxygen consumption on the basis of the caloric value of oxygen for a particular metabolic mixture (relative amounts of protein, fat, and carbohydrate being metabolized) as indicated by the respiratory quotient (RQ). In the resting postabsorptive state, an RQ may be assumed; but it is preferable to determine it accurately by measuring the rate of carbon dioxide production as well as that of oxygen consumption. Correction is then made for the amount of nitrogen excreted during the period of measurement. The apparatus to be used would consist of the continuous expired air collection system and continuous stream gas analyzers described in the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions.*
b. *Heat loss:* There are a variety of ways in which the various partitions of heat loss—conductive, convective, radiated, and evaporative—may be measured, either alone or in combination. The best system will be to set up a number of these methods which in being partially duplicative will increase the accuracy of measurement.
(1) *Nonevaporative heat loss* (*total less the evaporative*)*:* Continuous analogue recording of the output of constantan-silver thermo-

couple thermal gradient disks applied to the surface of the body at a minimum of 9 selected areas for gradient heat flow from the skin. The 9 spots can be sequentially scanned by a continuous multiple-point recorder in approximately 5 minutes. If it becomes important to telemeter these data to ground, the analogue information could be converted as received to digital data and the latter telemetered.

These thermal gradient disks or "heat flow meters" are in general use by a number of physiological research laboratories but provide only relative measure of nonevaporative heat loss, valuable mainly for indicating comparative changes in the same individual from one set of circumstances to another. In order to obtain data via these disks which would indicate heat loss quantitatively, a study of the precision of calibration of sets of disks for quantitative heat loss would have to be requested of the Department of the Navy for performance by the staff of the Calorimetric Research Laboratory of the Naval Medical Research Institute, National Naval Medical Center, Bethesda, Maryland. This Laboratory operates the most accurate gradient calorimeter in the world, and it is the only group capable of performing this valuable research, essential for quantitation of this method of measuring nonevaporative heat loss.

(2) *Evaporative heat loss:* Measure the total air flow volume passing over the subject's total surface (either through a space suit, through a light plastic envelope surrounding the subject, or through some specific space or section of the craft in which the subject is located, the latter two arrangements for shirt-sleeve environment) and multiply by average difference in relative humidity between the point of entrance of the air stream and the point of exit from the suit or specific space. Prior to the experiment the system described would have to be calibrated with measured water loads.

(3) *Convective heat loss:* In the system described under evaporative heat loss (either suit or specific space), place highly accurate heat meters (thermometers) in the inlet and outlet of the air stream. Multiply the inlet and outlet temperature difference by the volume flow of the air stream.

(4) *Conductive heat loss:* The same basic system described under *Convective heat loss* can be applied to the cooling fluid circuit of a liquid-cooled space suit. This system would have to be ground-calibrated for corrections which would need to be made for heat conducted entirely *through* the suit.

c. *Heat Storage:* Heat storage is determined from changes in internal body or "core" temperature as obtained from a continuously recording deep rectal thermometer or from a recording thermometer placed to obtain deep ear temperatures.

d. *Heat Balance:* This calculation for any period of time is obtained from the equations: (1) Heat Production equals Total Heat Loss plus Heat Storage and (2) Total Heat Loss equals the Separate Heat Losses by Conduction, Convection, Radiation, and Evaporation. Actually, since each part of the equation can be measured (although nonevaporative heat loss, particularly conductive and radiated, less accurately than the others), these less accurate partitions can be obtained or checked by difference in the balance equation, e.g., Nonevaporative Heat Loss equals Heat Production minus Evaporative Heat Loss minus Heat Storage.

6. *Experimental Controls*

Control is essentially built into the procedure by preflight and postflight tests and analyses, each subject serving as his own control.

7. *Summary of Number and Types of Space Station Personnel*

Trained astronauts will serve satisfactorily as subjects. In conjunction with the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions,* one technician who is well trained in the maintenance and operation of electronic equipment will definitely be required.

8. *Summary of Onboard Experimental Equipment Required*

Electronic continuous gas analyzer, oxygen, carbon dioxide, and expired air collection system, and recording and possibly telemetering equipment as described in the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions.* Also needed are thermal gradient disks to be attached to the subjects, relative humidity and temperature sensing elements for the air flow system, and rectal and deep ear thermometers.

9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
   None.
11. *Summary of Onboard Laboratory Determinations*
   This experiment consists primarily of physiologic measurements which are to be recorded continuously by electrical and electronic equipment.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
   None.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
   Not pertinent.
14. *Telemetry versus Onboard Recording Requirements*
   The bulk of the data is to be recorded on analogue recorders and the data reviewed onboard and reported by radio to the ground. Digital telemetry of oxygen consumption data might be useful (see experiment 1.)
15. *Prerequisite Ground-Based Experiments*
   In the experimental protocol *per se,* ground-based control observations pre- and postflight are essential. Despite the fact that most of the methods are reasonably well established, considerable time and effort would need to be expended in shakedown, calibration, etc. In addition, however, specific experimental studies should be arranged, if possible, to calibrate the thermal gradient disks for quantitative measurement of nonevaporative heat loss as described under 5, *Measurements,* b, (1). Calibration studies also need to be carried out for conductive heat loss through a space suit if measurements of conductive heat loss are set up using the cooling fluid circuit of a liquid-cooled space suit (see 5, *Measurements,* b, (4)).
   The most important ground-based experiment, however, is a study of the effects of low atmospheric pressure (specifically oxygen at 5 psi) on thermal regulation mechanisms. At least 3 possible ways in which these mechanisms could be affected or altered are suggested: (1) diminished heat loss by reduced convection in a less dense atmosphere; (2) altered evaporative heat loss due to changes in rates of sweating or evaporation from the skin under conditions of reduced pressure (increased water loss from the lungs is also a possibility); and (3) alterations in peripheral (skin) blood flow due to diminished pressure support to skin blood vessels. The most likely possibility is capillary dilation resulting in subjective warmth but increased heat loss by radiation. The number and variety of these possible alterations indicates the necessity for ground-based study of the effects of low atmospheric pressure. The measurement techniques would be identical to those described for this ORL experiment.
16. *Prerequisite Space Flight Experiments*
   To the extent possible, these thermal balance studies should be inserted in the flight plan of earlier flights.
17. *Prerequisite Research and Development*
   None visualized.
18. *Onboard Gaseous Atmosphere Desired*
   It is strongly urged that Earth atmosphere be provided; otherwise, a new factor or stress is introduced which may interact with weightlessness and other stresses in a way not yet calculable. With specific regard to thermal regulation, if ground-based studies show significant effects of low atmospheric pressure, it may be *necessary* to shift to Earth atmosphere.
19. *Requirement for Rotation for Artificial G*
   Not required.
20. *Comments re Form of Data and Interpretation of Data*
   No special comments.
21. *Special Comments*
   None.
22. *Postflight Evaluation of the Crew*
   None.
23. *References*
   No specific ones available.

EXPERIMENT 6

1. *Effects of Prolonged Space Flight on Neuroendocrine Function*
2. *Estimated Priority*
   Priority 1.

3. *Purpose*

To determine the qualitative and quantitative effects of various stresses of prolonged space flight on pituitary, thyroid, adrenal, gonadal, and neurohumoral function.

4. *Justification*

Since the endocrine system through the hormones secreted by its various internal glands exerts a highly important regulatory control over the rates of biochemical reactions in all of the cells of the body and thus regulates to a considerable degree most of the important functions of the body, detailed knowledge of the way in which the endocrine glands will react to and stand up under severe and prolonged stresses is essential. Fundamentally, the degree of success with which the space traveler will meet, adjust to, and continue to withstand the various flight stresses depends upon the appropriateness of response of the endocrine glands and their continuing, effective modulation of essential physiologic functions.

The principal stress to the human organism currently visualized is weightlessness, but in addition, during the early and final moments of flight, there will be high gravity stress and, until further experience is gained and more adequate space provided in the vehicle, there will be the added stresses of confinement, threat of danger, heat, changes in circadian rhythm, monotony, noise, social restriction, and possible toxic substances. If we consider a "stressor" to be any environmental change that disturbs the "steady state" of existence of a living organism, then almost every event taking place in orbital flight may be a significant stress to which adaptive changes must be made. The stressor stimulus, however, whether specific or nonspecific, is followed by a final common pathway of response which is largely neuroendocrine in nature. Adrenal cortical response is best known, but the entire homeostatic function of the central nervous and endocrine systems is almost certainly involved. The capacity of healthy men to maintain health through vigorous physiological response is very great, but the duration of this adaptability in the course of continuous severely adverse environmental conditions is unknown and can be clarified only by further information obtained from carefully planned experiments. Response to single stresses can be studied very largely in ground-based experiments (such as severe confinement, inactivity, abnormal atmosphere, or exposure to toxic materials), but there will almost certainly be a compounding effect of multiple stresses acting concurrently that can be studied only during space flight.

Fortunately for the purpose of this study, endocrinologists have devoted considerable effort to exploration of methods and procedures to assess not only the level of function of the various endocrine glands, but also their response to various forms of physical, biochemical, and, to some extent, psychological stress. Methodology has advanced prodigiously from the point 20 years ago when the only test available for evaluation of adrenal cortical response to stress was the circulating blood level of eosinophiles; in fact, by the time this experiment is actually flown it will need to be updated for advances on techniques expected in the near future.

5. *Experiment*

Procedure: The various measurements of endocrine function all depend upon sampling of venous blood at various intervals and upon analyses of urine, usually collected in 24-hour samples, all such samples to be returned to Earth for analysis at the present state of methodology. The various measurements will need to be made during a preflight control phase and also postflight, as well as during flight to the extent possible. For these reasons this study can be reasonably easily integrated with the experiments on Metabolism, Fluid and Electrolytes, and the Skeletal System. The measurements proposed consist of those believed to be most useful and revealing within the feasibility limits of urine samples and periodic venous blood samples of modest size; tests involving complex procedure, administration of radioisotopes, or large blood samples have been generally excluded.

Measurements:

a. *Thyroid function:* The oldest procedure for testing this function is measurement of the rate of oxygen consumption in the basal (postabsorptive and resting) state, the basal metabolic rate. This index can be obtained automatically in conjunction with the measurements of energy metabolism proposed in the experiment entitled *Effects of Prolonged Space Flight on Various*

Metabolic Functions; the instrumentation suggested is continuous stream gas analyzers for oxygen and carbon dioxide to be used with a hood arrangement for continuous collection of expired air. These measurements should be obtained periodically before, during, and after flight.

At a minimum pre- and postflight venous blood samples should be taken for protein-bound iodine (PBI), circulating total thyroxine, circulating free thyroxine, tri-iodothyronine red cell uptake, and thyroxine binding pre-albumin (TBPA) capacity. To the extent that space for storage and facilities for blood collection are available in the vehicle, the value of these indices would be considerably enhanced by in-flight blood sampling for this purpose. The currently best available test which indicates rapid response in free thyroxine to stresses such as surgery and severe exertion is TBPA capacity.

Among the various radioactive iodine procedures, it is now possible to do I^{131} neck uptake scanning with sufficiently low dosage of isotope (5 to 10 microcuries) that it should be carried out pre- and postflight. If the vehicle can carry the weight of counting equipment, I^{131} uptakes can be done periodically during flight, but whether or not this test is selected will depend on the total radioactivity burden from all sources. If this procedure is used, I^{131} neck decay curve as measured daily will be useful to separate increased from normal thyroid activity.

Various other radioactive iodine tests are not recommended. PBI^{131} requires an I^{131} dosage in the neighborhood of 50 microcuries. Although I^{132} produces a much smaller radiation exposure and is excellent for repeated tests of neck uptakes on Earth, it produces a hard gamma ray and so requires heavy shielding which would present a weight problem in flight; further even if $tellurium^{132}$ is carried as the source for I^{132}, its half-life would be too short to be of use on flights longer than 2 weeks.

b. *Adrenal cortical function:* At a minimum, 24-hour urine samples should be collected preflight, during, and postflight for 17 hydroxy corticords (17–OHCS). Initial control analyses should be carried out many days or weeks prior to takeoff to be certain of obtaining true control values; adrenal corticosteroid secretion could well be increased above normal during the days just preceding takeoff. It is anticipated that increased secretion will take place during and shortly following takeoff, but it will be important to examine excretion levels thereafter during flight to determine how long this evidence of stress continues to be present, and, if continued, to look for later suggestion of adrenal cortical exhaustion.

The next most feasible analysis would be of plasma levels of 17–OHCS (or of free cortisol soon to be available). Normal adrenal cortical function (on Earth) is indicated by a diurnal variation, higher values being noted in the morning, lower values in the afternoon and evening; absence of this pattern, or flattening, is noted in adrenal hyperplasia and might be expected from chronic stimulation in association with continuing stresses. It would thus be useful periodically during a long flight to obtain blood samples for 17–OHCS. (Four or more per period, preferably at 12-hour intervals related to the flight day if the latter should be altered from 24 hours). Their value would be greatly enhanced, of course, as a guide to the state of endocrine response to stress, if methodology could be developed so that these analyses could be performed during flight.

When in-flight analytic methodology for plasma 17–OHCS has been developed, it would then be feasible to carry out, periodically, tests of adrenal cortical response to stimulation with pituitary adreno corticotrophic hormone (ACTH). The simplest form of this test is to obtain collections of urine for 17–OHCS before and immediately following an 8-hour continuous intravenous "drip" of 25 units of ACTH; obviously, in flight the ACTH infusion will have to be administered by an infusion pump since gravity will not be available. Although seldom if ever used now, in this test in Earth studies, ACTH gel intramuscularly would avoid the in-flight gravity problem of administering an intravenous "drip". In any case, it is recommended that this test be performed as soon after flight as possible. If response to an 8-hour infusion of ACTH is low or absent (which would suggest adrenal cortical exhaustion), consideration should be given to testing for the response to a 48-hour infusion.

Measurement of possible alteration in adrenal cortical salt-retaining regulatory function may be obtained by analyzing 24-hour urine samples for aldosterone. This measurement is closely allied to the measurements of urinary sodium proposed in the experiment entitled *Effects of Prolonged Space Flight on Fluid and Electrolyte metabolism.* If increased urinary aldosterone excretion is noted, it would be well to obtain venous blood samples for plasma renin. Normal or increased amounts of plasma renin will be present if the increased aldosterone stimulation is of renal origin, whereas plasma renin will be undetectable if increased aldosterone activity is primary in the adrenal cortex.

c. *Pituitary function:*

(1) *Circulating ACTH:* An immuno-assay for blood levels of this pituitary hormone has just been reported. This analysis should be carried out pre- and postflight and blood specimens should be taken for this analysis during flight.

(2) *Pituitary ACTH reserve:* Until in-flight laboratory and physiological testing methodology becomes well advanced, this test will be feasible only during observations pre- and postflight. A synthetic steroid known as SU–4885 is capable of suppressing 11-beta-hydroxylation by the adrenal cortex. In the resulting absence of cortisol production by this gland, the pituitary is normally induced to produce ACTH in increased amounts. The result is production by the adrenal cortex of steroids other than cortisol, and the test measurement currently is analysis of the urine for increased amounts of "Compound B"; a three- to four-fold increase is normal. SU-4885 is administered orally every 4 to 6 hours for 2 to 3 days. With availability of the circulating ACTH immuno-assay, its response to SU-4885 should be measured as well as urinary "Compound B".

(3) *Circulating TSH:* An immuno-assay for blood levels of this pituitary hormone which regulates thyroid function is anticipated soon and should be added to the protocol when available.

(4) *Pituitary antidiuretic hormone (ADH):* From the limited space flight experience to date, a suppression of pituitary ADH has been suspected. At present, this hormone can be analyzed in the urine by bio-assay; an immuno-assay for blood levels, which will be much more precise and pertinent, is anticipated in the near future. Preflight, in-flight and post-flight 24-hour urine samples (and blood samples for immuno-assay) will be required.

For further definition of the function of regulation of water retention and excretion, consideration should be given to the following pre- and postflight functional tests: Urine concentration test—restrict fluids overnight and obtain urine specimen in morning for urinary specific gravity; if there is apparent inability to concentrate, the test may be repeated with the administration of pituitrin. Carter-Robbins salt-loading test—after a water diuresis has been established as measured by urine volumes in successive 30-minute periods, an infusion of hypertonic saline is administered following which there is normally a prompt reduction in urine volume; if this does not occur, attribution of the disturbance in function to the pituitary rather than to the kidney can be determined by administration of pituitrin when it is clear that salt-loading has had no effect.

d. *Gonadal function:* Two potential threats to reproductive function of man in space are recognized.

The first of these is ionizing radiation. Fortunately, a great deal of factual information is available from unmanned flights, both relatively close to the Earth and far out in free space. These data indicate that the constant flux of radiation in free space probably is not dangerous except during solar flares when it may rise to as high as 80 rads total for very brief periods. Satellites in polar orbit also would be subject to much higher and even dangerous levels of radiation, up to possibly 21 rads daily. So long as the polar orbits are excluded, therefore, genetic damage of significant degree probably is unlikely, and the only remaining danger would occur when a space vehicle, far out in space was "caught" in a solar flare with no alternative except to take the radiation that occurred.

The second threat is the possibility of a disintegration of cellular function as a consequence of zero gravity. It has been reported that mitotic activity of cells deteriorates under these conditions, and, accordingly, the intense rate of cell division of germinal tissues would be expected to reflect this abnormality. Furthermore, the male should be more severely affected than the female. Inasmuch as *no* dependable factual data are available upon which to establish a judgment, further observations of these functions must be made.

The most readily available analysis reflective of gonadal function is the 24-hour urinary excretion of 17-ketosteroids (17-KS). These steroids in the male are produced principally by the interstitial cells of the testes, but significant quantities are produced by the adrenal cortex. Among the various steroids of this group, certain ones are more indicative than others of adrogenic function. Whether or not partition specifically for urinary adrogens (by column or double-isotope dilution methods) would contribute information not indicated by total 17-KS is debatable at the present time.

In disease the pituitary trophic hormones most susceptible to impairment are the gonads-trophic. Bio-assays are currently available for both follicle-stimulatory hormone (FSH) and luteinizing hormone (LH), the latter being closely similar to interstitial cell (of the testes) stimulating hormone. Immuno-assays for both FSH and LH will ultimately probably be available. For these assays blood samples and 24-hour urine specimens pre- and postflight will be required.

With specific reference to reproductive function, when space flights of longer than approximately 60 days become feasible, it would be important to collect semen specimens pre- and postflight to detect any impairment in total sperm count and motility. It would also be important in at least two astronauts to obtain a testicular biopsy before and after a long flight. This procedure under local anesthesia is associated with only minor discomfort and is a distinctly more sensitive index of spermatogenic function than sperm counts.

e. *Other immuno-assays:* Immuno-assays just becoming available or to be available soon are those for blood levels of pituitary growth hormone, insulin, and parathyroid hormone. When the relative case of analysis of these endocrine indices becomes more clear, they will need to be integrated into this experiment and those on Metabolism and the Skeletal System.

f. *Neurohumoral function:* Recent additions to the considerable number of indices of physiologic reaction to stress are the neuropressor amines known as catecholeamines. These may be determined on 24-hour urine specimens by bioassay for total catecholeamines or by chemical analysis for metanephrine or VMA. The closely associated substance, 5-hydroxy indole acetic acid (serotonin) may also be determined and might be particularly useful in conjunction with tilt table tests of the circulatory adjustment to the upright position. In-flight collection and preservation of urine for these analyses will present a special problem in that specimens must be promptly acidified; in contrast, urine specimens for 17-OHCS and 17-KS must *not* be acidified and should be refrigerated.

6. *Experimental Controls*

Control is essentially built into the procedure by preflight and postflight tests and analyses, each subject serving as his own control.

7. *Summary of Number and Types of Space Station Personnel*

Trained astronauts will serve satisfactorily as subjects. Laboratory technicians will be needed to the extent that laboratory analyses can be performed in the weightless state.

8. *Summary of Onboard Experimental Equipment Required*

Basic equipment required is that for collection and storage of blood and urine specimens. On board analytic apparatus will depend on development of techniques for analysis in the weightless state.

9. *Summary of Animals*

None.

10. *Summary of Other Living Forms*

None.

11. *Summary of Onboard Laboratory Determinations*

Determination of basal metabolic rate will be made by gas analysis equipment described in the experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions.* Of the numerous analytic procedures on blood and urine described in this experiment, probably the most useful, if an onboard method can be devised, would be that of 17-OHCS in urine and free control in blood.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
As many as possible, since it would not be necessary to set up onboard determinations for more than those described under 11, and storage space on the vehicle is expected to be limited.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
Not pertinent.
14. *Telemetry versus Onboard Recording Requirements*
Digital telemetry of oxygen consumption data would be useful (see experiment entitled *Effects of Prolonged Space Flight on Various Metabolic Functions*). All other data to be recorded.
15. *Prerequisite Ground-Based Experiments*
In order to separate the influence of weightlessness from inactivity, confinement and all the various other possible stresses, it would be useful to set up ground-based studies of the effects on the various indices described from the several individual stresses, particularly inactivity and confinement. Earlier studies of the effects of immobilization were done prior to the availability of the present array of tests of endocrine function.
16. *Prerequisite Space Flight Experiments*
To the extent possible, various procedures should be evaluated on prior flights in which there is sufficient room for apparatus and specimen storage. In particular, efforts should be made to devise and test means of carrying out various laboratory biochemical analyses in the weightless state.
17. *Prerequisite Research and Development*
Laboratory analysis in the weightless state, although not absolutely essential, would particularly enhance the value of these studies of effects of stress on the neuroendocrine system.
18. *Onboard Gaseous Atmosphere Desired*
It is strongly urged that Earth atmosphere be provided; otherwise, a new factor or stress is introduced which may interact with weightlessness and other stresses in a way not yet calculable.
19. *Requirement for Rotation for Artificial G*
Not required.
20. *Comments re Form of Data and Interpretation of Data*
No comments.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
See 5c.
23. *References*
No specific ones available.

HEMATOLOGICAL, IMMUNOLOGICAL, AND CELLULAR FUNCTIONS

EXPERIMENT 1

1. *Observations Related to Assessment of the Dynamics of Hemic Cell Proliferation, Distribution, and Destruction*
2. *Estimated Priority*
Priority 2. Probably first feasible in extended Apollo.
3. *Purpose*
These observations are not experimental in type; rather, they are in the nature of screening observations to determine the characteristics, trends, and magnitudes of possible changes in the hematopoietic function and the body distribution of the formed elements of peripheral blood.
4. *Justification*
A variety of possible mechanisms may operate in the situation of actual space flight which could induce significant hematological changes. Among the stresses which may activate these mechanisms are weightlessness, radiation, psychological stresses, artificial atmospheres, toxic substances, and microorganisms of the environment. Multiple patterns of interaction of these stresses may operate. Furthermore, if these interactions do occur, the nature and extent of the interactions which may involve weightlessness are totally unpredictable and cannot be studied by ground-based simulation. For example, if weightlessness seriously alters processes of cell division, the rapidly proliferating cells of the hematopoietic tissues might be strongly affected. This, in turn,

might alter such parameters as the dose-response relationship for radiation injury to these cells.

5. *Experiment*

The observations should consist of periodic examination of all available subjects exposed for periods longer than 24 hours to the space flight environment. The examination should include:

Red blood cells:

a. Hematocrit by a micro method.
b. Reticulocyte counts.
c. Periodic estimates of red cell mass. These may be available by calculation of the data used in determining blood volume.
d. Red cell life span measurements by the Cr51 technic. This observation has lower priority and a higher requirement for skill of crew; thus, it probably will require deferral until later flights with larger crews. It is mentioned here for the sake of completeness.
e. Determination of blood hemoglobin content.

White blood cells:

a. White blood cell counts.
b. Differential leukocyte counts.
c. Determination of selected parameters of leukocyte function (see related experiment).

Platelets:

a. Determination of platelet counts.
b. Measurement of selected parameters of platelet function (see related experiment).

Examination of the morphology of the formed elements of the blood on Wright's stained blood smears.

Frequency of determinations: All of these observations should be made at least every 3 to 5 days during missions less than 30 days in duration, and every 7 to 10 days in longer missions. To some extent, these determinations can be coordinated with other schedules of drawing blood samples. Red cell mass calculations can be coordinated with blood volume determinations.

6. *Experimental Controls*

Control observations should be determined by the same method to be used in flight and by parallel standard methods at similar intervals during both preflight and postflight control study periods of the subjects.

7. *Summary of Number and Types of Space Station Personnel*

The simplest level of these observations may be performed by a trained astronaut, utilizing simplified apparatus for the measurement, dilution, and storage of capillary blood samples and preparation of blood smears for return to Earth and later analysis on missions of short duration. In this case, hematocrit determinations will not be feasible.

More sophisticated studies will require a specially trained crew member who will have to function at the level of a routine hematology technician, again utilizing a variety of special apparatus.

8. *Summary of Onboard Experimental Equipment Required*

Fixed equipment: If hematocrits are to be measured, a centrifuge comparable to a clinical machine will be needed. With appropriate engineering, this should weigh no more than 3 to 5 lbs, have a power requirement of less than 250 watts, and require a cube space of less than ⅓ cu ft. Such a machine could be multipurpose in dealing with a variety of samples. Otherwise, there is need for no fixed equipment.

Consumable equipment: Consumable equipment will have to be developed for the automatic measurement, dilution, and storage of blood samples for short flights. Pipettes of this general nature can be developed from existing automatic plastic pipettes, preloaded with diluent. The stability of the preserved cells will have to be proven in the diluent chosen, and possibly modified diluents will have to be developed for these purposes.

At the moment, it seems impractical to consider microscopy of wet samples of any type under weightlessness. Cell sedimentation will not occur in counting chambers, for example, and it would be difficult to construct a completely closed system to prevent atmospheric contamination. If a gravitational field is available, the problem becomes much simpler, and modified standard microscopy could be employed, permitting onboard determinations of blood cell counts. Alternatively, an electronic particle counter could be employed, possibly utilizing an onboard scaler of multipurpose type. Many possible designs for such an instrument exist, of which the Coulter type seems most promising. The basic apparatus, exclusive of the scaler, might occupy

0.1 cu ft, weigh less than 1 pound and require less than 50 watts with proper engineering miniaturization.

Equipment can be designed for staining of blood films in a closed system if onboard examination is possible. This might occupy less than 0.1 cu ft, weigh less than 1 pound, and require no power.

9. *Summary of Animals*
None.
10. *Summary of Other Living Forms*
None.
11. *Summary of Onboard Laboratory Determinations*
Determination frequencies are suggested under 5. Each complete determination would require about 10 minutes to collect (technician and subject) and 5 minutes to process if only sample storage is involved. These time allowances are generous and anticipate difficulties secondary to restricted space and mobility.
If onboard processing is possible, each determination would require about 30 minutes after the samples had been obtained. Saving of time could be accomplished if multiple samples can be processed simultaneously.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
If samples cannot be processed onboard, they will have to be either saved or returned periodically to Earth. For flights of less than 30 days, storage onboard seems best. The same is probably true of flights of less than 90 days, unless other samples are returned for other reasons. Beyond 90 days, some type of onboard processing seems desirable, particularly if any of the parameters measured are found to have implications for crew safety. If crew safety is not a consideration, return of samples every 90 to 120 days would probably be satisfactory, if adequate specimen preservation can be obtained.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
Does not apply.
14. *Telemetry versus Onboard Recording Requirements*
Onboard recording is adequate with voice transmission of results as able.
15. *Prerequisite Ground-Based Experiments*
Validation of technics by parallel study with standard methods.
16. *Prerequisite Space Flight Experiments*
Preliminary checkout of technics on flights of short duration.
17. *Prerequisite Research and Development*
See under 8, 15, and 16.
18. *Onboard Gaseous Atmosphere Desired*
Not pertinent.
19. *Requirement for Rotation for Artificial G*
See under 8.
20. *Comments re Form of Data and Interpretation of Data*
Standard clinical format of report and preliminary interpretation.
21. *Special Comments*
These observations may be of basic biological importance as well as of significance for operational purposes. It may not be possible, for example, to study certain of these parameters in animals in a preliminary way.
22. *Postflight Evaluation of the Crew*
See 6.
23. *Reference*
Dacie, J. V.: Practical Haematology. Blackwell, London, 1957.

EXPERIMENT 2

1. *Cytogenetic Studies of Human Hemic Cells*
2. *Estimated Priority*
Priority 2. Pre- and postflight examinations could be carried out on crew members of any flight of more than several days' duration.
3. *Purpose*
To determine if chromosomal abnormalities, which may be reflected in the rapidly proliferating hemic cells, are induced by some combination of stresses of the space environment.
4. *Justification*
Reported Russian studies suggest that the weightless environment may affect the mitotic mechanism of cells. This might affect the function of hematopoiesis in some way. Cytogenetic technics provide a sensitive means of detecting certain types of alterations in the processes of nuclear replication and division. More impor-

tantly, these technics may permit identification of this type of abnormality at levels of alteration or injury which might not affect the function of the entire hemopoietic organ because of the capacity of unaffected cell clones to increase their activity.

5. *Experiment*

   Pre- and postflight cytogenetic examinations of crew members in a graded series of flights of increasing duration is all that is deemed possible at present. If this can be done, there will probably be a great advantage, since the technics are very demanding and might well be impossible in the weightless state.

   Standard cytogenetic methods can be employed, utilizing peripheral blood leukocytes with phytohemagglutinin stimulation. Since the detection of an increase in chromosomal abnormalities is essentially statistical in nature and since the control level of these abnormalities and the possible increase are expected to be very small, the statistical design of these studies must be carefully considered. It is probable that large numbers of metaphases will have to be examined and complete karyotyping carried out on any anomalous or suspected anomalous cells. (Details of design will depend upon available methods and upon the findings of preflight control observations.)

6. *Experimental Controls*

   Preflight observations of selected crew members.

7. *Summary of Number and Types of Space Station Personnel*

   Does not apply.

8. *Summary of Onboard Experimental Equipment Required*

   None.

9. *Summary of Animals*

   None.

10. *Summary of Other Living Forms*

    None.

11. *Summary of Onboard Laboratory Determinations*

    None.

12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*

    None.

13. *Proposed Rendezvous Schedule for Rotation of Crew*

    None.

14. *Telemetry versus Onboard Recording Requirements*

    None.

15. *Prerequisite Ground-Based Experiments*

    As part of 6, repeated preflight observations should be made at intervals roughly equal to proposed flight durations to test the stability of the cytogenetic pattern of these subjects on the ground working area environment.

16. *Prerequisite Space Flight Experiments*

    Program can start on any flight longer than 24 hours.

17. *Prerequisite Research and Development*

    Experiments will require development of acytogenetic laboratory. Since large numbers of karyotypes may have to be examined, thought should be given to application of the several technics of automatic classification of chromosomes.

18. *Onboard Gaseous Atmosphere Desired*

    Does not apply.

19. *Requirement for Rotation for Artificial G*

    Does not apply.

20. *Comments re Form of Data and Interpretation of Data*

    Standard nomenclature (Denver classification) for types and locations of chromosomal anomalies, with appropriate statistical analysis for significance.

21. *Special Comments*

    It should be recognized that the possibility of finding major cytogenetic changes in these experiments is very low. However, a finding of "no change" will be of nearly equal interest and importance in that it will yield some assurance as to safety of crew in terms of possible effects of the space environment on proliferating cells.

22. *Postflight Evaluation of the Crew*

    None.

23. *References*

    There are no known publications, beyond those of Russian origin on space-flight-induced cytogenetic changes. The literature on cytogenetics is now so vast that specific references are not particularly helpful. In general, the literature dealing with radiation-induced cytogenetic changes, both short- and long-term, provides a model of the type of study herein outlined.

EXPERIMENT 3

1. *Survey of Immunoglobulins, Complement, and Antibodies in the Sera of Selected Astronauts*
2. *Estimated Priority*
   Priority 3. Flights of longer than 30 days with multiple crew members (MOL, ORL).
3. *Purpose*
   To assess changes which may occur in the amount and type of serum immunoglobulins, complement, preexistent, and newly-formed antibodies of subjects exposed for prolonged periods to the space flight environment.
4. *Justification*
   If cellular processes of proliferation, differentiation, and function are affected by the weightless space flight environment, it might be expected that ultimately these changes will be reflected in the immune apparatus. This would be of basic biological interest. Operational considerations might be involved as well, since resistance to disease, i.e., invasion by mutant organisms or flora of other persons in the environment, may be influenced by alterations in immune processes.
5. *Experiment*
   Basically, the experiment involves only periodic collection of blood samples with separation of serum and storage in the frozen state at less than —20°C for return to Earth and later analysis. Samples every 14 to 30 days would be adequate for survey purposes. Samples of 2 to 3 ml volume would be required, although micro techniques might be used if less than this is available. Determinations should include immunoelectrophoresis, electrophoresis, on starch gel, measurement of γ_2, γ_1a, and γ_1M globulin levels, measurement of whole hemolytic complement, titration of blood group antibodies, and measurement of preexistent antibacterial antibodies. It would also be of interest to test the capacity of subjects for anamnestic recall of antibodies and primary immune responses by in-flight immunizations after varying periods of exposure to space flight conditions. However, this would be reasonable only on long-term flights, i.e., longer than 90 to 120 days, and it should be recognized that with small numbers of individuals tested, absolute standards for responses cannot be applied. It is also impossible for the individual to serve as his own control in such immunization experiments.
6. *Experimental Controls*
   Pre- and postflight samples on each individual.
7. *Summary of Number and Types of Space Station Personnel*
   A person capable of drawing, centrifuging, and separating a blood sample; this could be a trained astronaut at the least.
8. *Summary of Onboard Experimental Equipment Required*
   a. Centrifuge (see experiment entitled *Observations Related to Assessment of the Dynamics of Hemic Cell Proliferation, Distribution, and Destruction*).
   b. A closed system of tubes or small bags which can be centrifuged, frozen, and stored; weight less than 0.5 lb for 10 determinations. No additional power required. Syringes, needles, and blood drawing equipment.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    None.
12. *Summary of Laboratory Speciments to be Flown to Earth for Laboratory Examination*
    See under 5.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Does not apply.
14. *Telemetry versus Onboard Recording Requirements*
    Does not apply.
15. *Prerequisite Ground-Based Experiments*
    Ground and preliminary space flight checkout of sample handling technics.
16. *Prerequisite Space Flight Experiments*
    Ground and preliminary space flight checkout of sample handling technics.
17. *Prerequisite Research and Development*
    Equipment only.
18. *Onboard Gaseous Atmosphere Desired*
    None.
19. *Requirement for Rotation for Artificial G*
    None.

20. *Comments re Form of Data and Interpretation of Data*
Standard immunological methods.
21. *Special Comments*
Storage of samples under even optimal conditions may result in slow deterioration of complement activity and certain antibodies. The possibility of onboard determinations seems remote; thus, these limitations will have to be considered in the interpretations of results.
22. *Postflight Evaluation of the Crew*
None.
23. *References*

1. Gell, P. G. H.; and Coombs, R. R. A.: Clinical Aspects of Immunology. Blackwell Scientific Co., Oxford, 1963.
2. Kabat, E. A.; and Mayer, M. M.: Experimental Immunochemistry. C. C. Thomas, Springfield, Ill., 1948.

EXPERIMENT 4

1. *Studies of Selected Parameters of Leukocyte Function in the Space Environment*
2. *Estimated Priority*
Priority 2 or 3. Multiple crew member flights of longer than 1 week.
3. *Purpose*
To determine effects of the space environment upon physiological functional capacities of leukocytes.
4. *Justification*
Space vehicles are characteristically small, closed, ecological systems. As such, a rapid interchange of microflora is to be expected in the crew; low-grade pathogens and pathogenic mutants of ordinarily saprophytic organisms will thus be rapidly spread. Infections may result if host resistance is altered unfavorably. Although many factors are undoubtedly involved in maintenance of normal host resistance, many of them unknown and unmeasurable, certain pertinent aspects of leukocyte function are amenable to measurement. These measures, along with measurements of immune responsiveness, may provide a first order approximation of host defenses, particularly if they can be correlated with inflight experiences with infectious processes of several crew members.
5. *Experiment*
Three types of observations are proposed:

Observations of leukocyte mobility under weightless conditions: It is thought that leukocyte mobility is primarily crawling, i.e., the cell moves by pseudopodial motion over a surface or over other cells. Under ordinary conditions of terrestial observation, cells are seen to move over the surface of a slide. In the absence of gravity, the force which orients a motile cell to the surface may be lacking and mobility may be impaired or in a different mode, i.e., swimming. It is proposed that apparatus be developed to permit observation of leukocyte mobility under weightless conditions. This might take the form of a prepared microchamber with 2 flat sides spaced between .05 and .01 mm apart. This could be loaded with capillary blood directly by capillary action or with a predetermined amount of diluent-anticoagulant. Alternatively, a centrifugal separation of leukocytes can be made, and the WBC-rich plasma loaded in the observation chamber.

The onboard microscope proposed for use in connection with surveys of hematological parameters can be used for these observations. Phase contrast capability would be valuable but not essential. An attachment to keep the sample at 37°C will be required. This may take the form of an electrically heated, thermostatically controlled stage with a stage hood.

Determination of the mode of leukocyte motility can be made by a trained observer. Determination of the rate of movement can probably be made as well, utilizing an eye piece disc micrometer and distance standard.

Determination of leukocyte phagocytic capacity: Qualitative observations of phagocytosis can be made in the system described under *Observations of leukocyte mobility under weightless conditions* by the addition of particles such as starch, polystyrene, killed staphylococci, or opsonized red blood cells.

A semiquantitative method is also recommended. In such a test, a leukocyte suspension is prepared, particles are added, and, after a constant period of incubation, the leukocytes are recovered by gentle centrifugation, smeared, stained, and examined for phagocytosis. The percentage of potential phagocytes which have ingested particles is determined. Because a great deal is known about the system, erythrophagocytosis would be a very useful method. On the other hand, it is technically more demanding in that opsonized red cells and complement must be provided. The exact method chosen should be based upon a feasibility study. Specimens need not be stained and examined onboard; only the smears need to be prepared at the time of the study. These can be preserved for later study.

Studies of leukocyte mobilization: These studies are designed to test the capacity of the stressed subject to mobilize leukocytes at the site of a sterile inflammatory lesion which is artificially created. Two general methods have been developed and standardized. These are the skin window method of Rebuck and the quantitative leukocyte washoff method of Finch, et al. Both methods require the preparation of a small abraded area on the volar forearm. In Rebuck's method, this area is covered with a cover glass which is removed with adherent leukocytes and replaced periodically. The pattern of time of appearance and proportions of the several types of leukocytes in such a lesion has been well studied in normal subjects and in a variety of abnormal states.

The method of Finch, et al. involves the qualitative recovery of the leukocytes from the lesion by a system of closed flushing of the area. These cells can then be counted and differential leukocyte counts can be made as well.

The two methods complement each other in that better morphological observations can be made by the Rebuck method, but better quantitation can be achieved by the latter method. Both methods can be carried out simultaneously on the same subject. The quantitative method is much more time consuming and technically demanding.

6. *Experimental Control*
   Comparable periodic preflight and postflight studies of all subjects for control periods of at least several weeks.
7. *Summary of Number and Types of Space Station Personnel*
   These experiments will require an advanced level of general training and a period of training in the specific technics involved. The general level of required competence lies between that of an advanced research technician and a trained professional biomedical investigator.
8. *Summary of Onboard Experimental Equipment Required*
   Equipment and power as needed for general hematology observations plus a small amount (less than 1 lb) of disposable equipment and supplies.
9. *Summary of Animals*
   None.
10. *Summary of Other Living Forms*
    None.
11. *Summary of Onboard Laboratory Determinations*
    With no knowledge of the nature or magnitude of changes which might be encountered, only the most tentative of schedules can be proposed. It seems unlikely that it would be practical to carry out these studies more frequently than every 5 to 7 days on a single subject. A determination within 1 to 2 days after entry into orbit would be of interest, as would a determination shortly after reentry. On longer flights, intervals of 10 to 15 days would seem feasible.
    It is estimated that each study will require 6 to 10 hours of the observer's time and ½ this amount of the subject.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
    If blood cell counts can be done onboard, these can be determined in flight. If not, samples can be stored, as for general hematology determinations, and returned with the crew.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
    Does not apply.
14. *Telemetry versus Onboard Recording Requirements*
    Does not apply.
15. *Prerequisite Ground-Based Experiments*
    As under 6.
16. *Prerequisite Space Flight Experiments*
    Does not apply.

17. *Prerequisite Research and Development*
Equipment and method development and adaptation.
18. *Onboard Gaseous Atmosphere Desired*
Does not apply.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
As outlined under 5 and as currently utilized in laboratories carrying out comparable studies.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
23. *Reference*
Perillie, P. E.; and Finch, S. C.: Inflammatory Reaction in Acute Leukemia. J. Clin. Inves., vol. 43, 1964, pp. 425–430.

EXPERIMENT 5

1. *Studies of Selected Parameters of Blood Coagulation and Hemostatic Function*
2. *Estimated Priority*
Priority 2 or 3. Probably not feasible until flights where a trained biomedical investigator is a crew member (ORL).
3. *Purpose*
To determine if the space flight environment, including weightlessness, affects the measurable parameters of blood coagulation and hemostasis.
4. *Justification*
It seems probable that the weightless state will affect a variety of cardiovascular functions, specifically vascular tone. As a consequence, patterns of vascular perfusion and venous return can be expected to be affected. If blood is pooled in the venous circulation, the possibility of thrombosis must be considered. Although there is no hemostatic function which is directly correlated with thrombosis, it nevertheless seems advisable to carry out those observations which can be made. Furthermore, the behavior of these physiological processes in the space environment has inherent biological interest and justifies a survey in this area even in the absence of a practical consideration.
5. *Experiment*
It is proposed that a wide variety of coagulation and hemostatic functions be surveyed on selected subjects. Not all of these observations need be carried out on all subjects or on every flight, but it is hoped that data in all these areas might be obtained in the course of a number of flights.
The following observations are recommended:

Coagulation time of freshly-drawn whole blood: Coagulation of blood in glass and siliconized containers should be determined. In addition, it should be possible to see for the first time if blood will clot spontaneously in the absence of contact with any surface. It should be possible to place a small volume of freshly drawn blood in suspension in the center of a containing flask and observe it periodically for coagulation without allowing it to contact the sides of the flask. Unless the atmosphere provides a surface activation effect, the coagulation time of such a sample might be greatly prolonged.

Bleeding time: Methods of Duke and Ivy.

Platelet count: Either by onboard determination or preparation of stable fixed samples for later determination.

Observations of clot retraction.

Measurements of platelet adhesiveness: By the glass bead adherence method.

Measurements of fibrinogen concentration.

Measurements of fibrinolytic activity: By the euglobulin clot lysis technic or by measurement of the release of I_{131} from iodinated fibrinogen.

Measurements of prothrombin complex activities.

Measurements of antihemophilic globulin (AHG) and plasma thromboplastin component (PTC) activities: These observations have the greatest technical requirements and lowest priority.

Observations of coagulation time of freshly-drawn whole blood through measurements of platelet adhesiveness should be carried out onboard. The remainder of this study probably cannot be carried out in flight and will involve obtaining samples for postflight analysis.

6. *Experimental Controls*
Pre- and postflight determinations, utilizing the methods to be used during flight and standard methods in parallel on all subjects.
7. *Summary of Number and Types of Space Station Personnel*
These studies might be carried out by a specially trained person operating at the level of an advanced technician. A trained biomedical investigator would be preferable.
8. *Summary of Onboard Experimental Equipment Required*
Equipment and power as for general hematology plus approximately 2 lbs of special purpose consumable supplies.
9. *Summary of Animals*
None.
10. *Summary of Other Living Forms*
None.
11. *Summary of Onboard Laboratory Determinations*
Only a tentative schedule can be proposed. Determinations oftener than every 7 to 10 days are probably not needed. Observations every 2 to 4 weeks on long flights would probably be adequate if definitive trends do not appear during shorter flights.
Each examination can be expected to take 2 hours of observer's time and ½ hour of subject's time.
12. *Summary of Laboratory Specimens to be Flown to Earth for Laboratory Examination*
If adequate preservation methods can be developed, the specimens can be returned with the crews. If other specimens are to be returned, these should probably be included, since many of these activities are quite labile.
13. *Proposed Rendezvous Schedule for Rotation of Crew*
Does not apply.
14. *Telemetry versus Onboard Recording Requirements*
Does not apply.
15. *Prerequisite Ground-Based Experiment*
Does not apply.
16. *Prerequisite Space Flight Experiments*
Does not apply.
17. *Prerequisite Research and Development*
Development of onboard methods by adaptation of existing methods. Development of special onboard disposable equipment and methods of sample preparation and preservation.
18. *Onboard Gaseous Atmosphere Desired*
Does not apply.
19. *Requirement for Rotation for Artificial G*
None.
20. *Comments re Form of Data and Interpretation of Data*
Standard current nomenclature and units as used in leading coagulation laboratories.
21. *Special Comments*
None.
22. *Postflight Evaluation of the Crew*
None.
23. *References*
None.

phase III

DESIGN AND OPERATIONAL RECOMMENDATIONS

Design and Operational Recommendations

SPAMAG chose to formulate its recommendations as discussions of a number of critical topics. These contributions developed over the course of eight meetings. The topics are not proposed as being inclusive of all significant ORL related problems. However, they appear to include all the major problems of which we are currently aware.

NEED FOR ORL FLIGHT OF DURATION LONGER THAN 30 DAYS FOR BIOMEDICAL INVESTIGATION

The consensus was that it is highly probable that important medical questions will remain unresolved after the 30-day MOL and, in fact, after the 90-day MOL missions which are currently considered a future possibility. Important questions will probably be revealed by these missions. In order to resolve these questions, there will be a need for space flights of longer than 30 to 90 days, carrying crews larger than 2 to 3 men, providing more space than the current configuration, and including among the crew members medical scientists. The Group was unanimous in its opinion that a year-long ORL investigational flight is essential if very long, manned flights, such as a Mars mission, are planned for the future. In addition, it was concluded that an ORL is required in the interest of pure science as well as for the actual undertaking of prolonged missions by man at some time in the future.

PREFERRED METHOD OF APPROACH

The Group concluded that the most feasible approach would be to design a single vehicle for very long-duration flights, preferably one which would remain in orbit virtually indefinitely, rather than to design a series of different vehicles for different flights. The interior of the vehicle could be redesigned according to the latest technology for whatever duration and purpose of mission is desired. This vehicle or class of vehicles would, in this sense, serve in the same manner that a ship or class of ships does, being capable of undertaking many varieties of missions as required.

TYPE OF VEHICLE

In general, the Group thought that the most desirable form of ORL would be one which is somewhat similar to the MORL concept. It should carry a crew of 6 to 12 persons with the optimum figure set at an 8-man crew. It should allow 400 to 550 cu ft of free space per man with an additional 1000 cu ft volume reserved for a common laboratory area. Each man has to be allowed his own small area of privacy. (See also *Volume (Space) Requirements* recommendations in Phase I).

DURATION OF FLIGHT FOR AN ORL

The Group was of the opinion that we can safely proceed from the 30-day experience to a 90-day experience unless unanticipated prohibitive factors develop within 30 days. If no insurmountable difficulties develop within the 90-day experience, then we are justified in *designing* for a 1-year or more ORL. Regarding the ORL as a vehicle and operational configuration which can be characterized as a forgiving flight, then a 1-year forgiving experience onboard the ORL should enable us to undertake a 1-year ($\pm$ 10 to 20%) unforgiving mission. The group considered the physiological end points serving as criteria for extending flight durations to be roughly exponential, specifically, 30 days, 90 days, and 360 days.

TYPE OF REENTRY VEHICLE

The Group was unanimous in favoring a high *L/D* vehicle as a more desirable form of reentry vehicle. It did not, however, establish this as a requirement. A reentry vehicle which can operate over an incremental range of reentry gravitational profiles would provide a great safety factor in long-duration missions.

COST EFFECTIVENESS PARAMETERS

The Group was unable to suggest particular cost effectiveness criteria from the medical standpoint. It did, however, suggest that a payoff ranking method be used, i.e., that potential medical payoffs be first stated, then placed in order of importance utilizing a broad base of informed opinion.

ORBIT

The Group advocated an equatorial orbit of approximately 30° inclination, circular, with an apogee of 250 to 300 nautical miles. A polar orbit is to be avoided because of the hazard of excessive exposure to ionizing radiation. If minor adjustments in altitude can be made to provide subharmonics of a 24-hour cycle, i.e., on or just off the circadian rhythm, this may be desirable.

NEED FOR ARTIFICIAL G: ROTATION OF THE SPACECRAFT, ONBOARD CENTRIFUGE, OR BOTH

The Group first considered whether or not some form of artificial G will prove to be required for an ORL in which persons would be exposed for 1 year. Opinions consisted entirely of educated guesses. With that understood, a vote was taken: 11 of 18 felt that no artificial G will be required; 6 of 18 voted in favor of artificial G; and 1 did not vote.

The type of artificial G preferred, centrifuge or rotation of the vehicle, was also expressed by vote: 8 of 18 preferred rotation of the spacecraft, with counterrotating core; 10 of 18 preferred an onboard centrifuge.

A portion of the spacecraft must provide weightlessness at all times. A centrifuge may be used as a provocative test or for conditioning of crew.

However, 16 of 18 voted to recommend deferral of a specific decision at present, and, instead, to design for both an onboard centrifuge and vehicular rotation in parallel until a specific decision can be made on the basis of Gemini, Apollo, biosatellite, and MOL findings.

Several members of the Group agreed that quite apart from physiological considerations, intermittent rotation of the vehicle is desirable for simple "housekeeping" purposes, i.e., assisting the performance of various laboratory procedures, cleaning up the laboratory, etc.

VOLUME (SPACE) REQUIREMENTS

In addition to the recommendations made with respect to the volume of living space to be provided per crew member (see under Type of Vehicle), the Group made several comments with respect to volume allowances for equipment:

1. As a general principle, it is important to integrate as many experiments and measurements as possible into the equipment which is to be provided.
2. The laboratory area must be separate from the living area.
3. The laboratory area must measure at least 6½ ft in the "vertical" dimension and 8 ft in one "horizontal" dimension in order to allow the medical examiner to assume his full height and the subject to "recline" fully stretched out with hands over his head. If a double-ended trampoline is provided, it will require a dimension of at least 12 ft in the direction of movement of the subject.
4. Some of the required laboratory equipment will consist of the following: a general purpose scaler with pulse height analyzer, radiation detectors, an incubator for cell cultures, an electronic computer and special purpose sensors, electronic gas analyzer, microscope, miniature oscilloscope, tape recorder, x-ray unit, and bone density measuring device (using isotopes or x-ray unit or other method which may be developed).
5. A specimen storage area should be provided which is to include a refrigerator, freezer, and lyophilization apparatus. The storage capacity requirement is dependent upon frequency of rendezvous and the experimental program.
6. An x-ray laboratory is recommended as a first priority item on clinical grounds and as a second priority item from the standpoint of medical investigation.

WEIGHT AND POWER REQUIREMENTS

These are to be determined primarily on the basis of total experimental payload and represent relatively basic engineering considerations. Large power requirements are not anticipated for laboratory purposes.

SIZE OF THE FLIGHT CREW

The Group was generally agreed that the number of personnel to be carried should range between 6 and 12 with 8 as an optimum number. It was also the consensus of the Group that a crew size of 24 is unnecessary for medical research purposes.

TYPES OF PERSONNEL COMPRISING THE FLIGHT CREW

The group made the following recommendations:

1. A physician-physiologist must be a member of the crew. He must have research as well as clinical experience. It may be additionally advantageous if he were also an engineer and a pilot or had had additional experience in these two fields.
2. A well-trained medical person (a medical clinician) should also be included as a crew member.
3. A technician, one who has had training in experimental physiology and also in electronics and who is able to repair and maintain the sophisticated hardware involved in the experimental package, must also be included as a member of the crew.
4. In general, the crew must resemble flight crews which will later embark upon unforgiving missions beyond ORL.

UTILIZATION OF ANIMALS ONBOARD

The panel concluded that provision should be made for a small animal laboratory (mice, rats, and squirrel monkeys) aboard the ORL. This conclusion was based on the fact that techniques can be performed on animals which cannot be performed upon man and that animals can be sacrificed and examined for biochemical changes and microscopic as well as gross morphological changes. Furthermore, if considered as substitutes for additional personnel, animals provide a much better payoff per weight, volume, power, etc. requirements.

CYCLING OF PERSONNEL AND ANIMALS UTILIZING RENDEZVOUS TECHNIQUES

In general, the SPAMAG favored an 8-man crew with replacement of 2 members at 90 days, 2 members at 240 days, and removal of all at 360 days. As an alternative procedure, 2 crew members may be replaced at 60 days, 2 at 120 days, 2 at 240 days, and all removed at 360 days. The latter suggestion is considered preferable if rendezvous capabilities and logistic considerations will allow. Provision must be made for the removal of the entire crew at any time during the orbital stay of the vehicle in case of an emergency.

Recommendations for cycling of animals were for the same intervals and the same proportionate replacement cycling to provide greater scope of information at the same data points used for evaluation of the crew. This would permit thorough study of the animals at these same critical points by means of intensive physiological and performance examinations and by means of gross and histologic studies of morphological changes on sacrificed specimens of each animal group.

ONBOARD LABORATORY AND BIOINSTRUMENTATION REQUIREMENTS

(See also *Volume (Space) Requirements.*)

Onboard laboratory and bioinstrumentation requirements in addition to those mentioned under *Volume (Space) Requirements* will include at least the following: computer using central package of logic, ECG, VCG, impedance pneumograph, temperature measurements, blood pressure, EEG (at least 4 leads), electroretinography, tonometry (spring loaded), ophthalmodynamometry, electrooculography (EOG), ballistocardiogram and/or seismocardiogram, oximetry, densitometry, strain gauge or other manometer, electromyography, analog display, tape recorder, measurement of sweating rate, body mass measurement, body volume measurement, bicycle ergometer, negative lower-body pressure apparatus, and additional laboratory methods.

The following additional laboratory equipment is suggested: measurement of volume of respiratory gases, measurement of flow of respiratory gases, measurement of blood gases, measurement of acid-base chemistries, radioactive tracers, microscope, method of making frozen sections, swallowable instrumentation for measurement of core temperature and pH of the GI tract, galvanic skin response, a behavioral testing panel, head restraint and camera for measurement of ocular motions, Barany chair device for semicircular canal studies, swing device for otolith studies, device for measurement of egocentric visual location of the horizon, pupillometry and eye tracking devices, visual field device, a laboratory centrifuge, spectrophotometer or colorimeter, possibly an x-ray spectrometer, an osmotic pressure apparatus (as a substitute for measurements of specific gravity of specimens), and provision for storage, refrigerated storage, frozen storage, and lyophilized storage of specimens.

The Group also recommended that designers be mindful of the necessity for carrying spare parts for much of the above equipment. In the opinion of the Group, virtually all of the laboratory equipment will require redesign from that used in Earth-based laboratories for use in the weightless environment.

GROUND SUPPORT PERSONNEL AND EQUIPMENT

The Group made the following recommendations:

1. A display system should be worked out to enable ground-based monitors to have baseline data quickly available to them at all times.

2. Serious consideration should be given the use of a selective data sampling system based upon formal information content analysis in place of a "total data dump system."

3. A group comprised of clinical medical consultants and of chief investigators should be available for communication at all times for both clinical consultation and consultation with respect to biomedical investigations for the ORL, should the need arise. The responsibility for experimental protocols and procedures and their control should rest with the chief investigators on the ground. Should questions of illness or other clinical problems arise, both the medical consultants and the experimental consultants should be informed and should advise, since the welfare of the experimental subjects will markedly influence experimental protocols.

4. It would be advisable to investigate the possibility of a special "ambulance" vehicle with an easier reentry mode (high L/D), perhaps with a specially trained medical attendant as a crew member.

NECESSITY FOR TOTAL GROUND SIMULATION PRIOR TO FLIGHT

The Group recommended that baseline studies performed on flight simulators should be of 2 types. One type would employ the actual flight crew as subjects for relatively short periods of time so as not to endanger their subsequent usefulness as inflight experimental subjects. The other would employ astronaut-like subjects exposing them to long-term simulations (although very probably less than the full duration of the flight).

Simulations for purposes of training and testing of equipment, systems, and methodologies will be of relatively short duration and will reveal their own end points.

As a general principle, wherever possible, all onboard equipment should be spaceflight tested in advance of the ORL flight or flights.

POSTLANDING MEDICAL EXAMINATIONS

In the opinion of the Group, confinement and intensive observation for at least 1 month will be a postflight requirement. During this period of time, studies will be extensive, very probably even including tissue biopsy. It may also be necessary to have ad hoc postflight simulations to obtain baseline information relative to a particular flight finding or situation. The flight crews will be under general observation for a long period of time, perhaps many years after the flight. It is even likely that their offspring, both preflight and subsequent, will be under long-term medical observation. All of this must be thoroughly explained and acceptable to the flight crew prior to selection.

USE OF DOUBLE-ENDED TRAMPOLINE ONBOARD THE ORL

As indicated under *Onboard Laboratory and Bioinstrumentation Requirements,* in the opinion of the Group, the use of the double-ended trampoline, as an in-flight technique for exercising the cardiovascular system, is worthy of investigation.

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