APR 28 1970

MM

TO: M/Associate Administrator for Manned Space Flight

FROM: MM/Director, Space Medicine

SUBJECT: Artificial G Questions

The following summarizes answers to specific questions related to the subject of artificial g in space flight.

QUESTION 1(a): If no artificial g is provided, what are the measures required to assess crew condition in flight?

ANSWER: In light of today's knowledge, the following measurements are the minimum required:

a. Cardiac output as a function of exercise response and lower body negative pressure (LBNP).

b. Heart rate and rhythm.

c. Blood pressure.

d. Serial body mass.

e. Fluid intake and output.

f. Selected blood electrolytes, protein, sugar and pH.

g. Bone density.

h. Muscle size and strength.

i. Vestibular symptomatology.

j. Urinalysis

k. EEG - possible.

QUESTION 1(b): What measures will be required to keep crew in acceptable physical condition for exposure to g fields in long duration zero g flight?

ANSWER: The following are best-guess candidates today:

a. Whole body and special exercises.

b. Lower body negative pressure (LBNP) or a variant thereof such as positive pressure gradient suit.

c. Diet and fluid control.

d. On-board human centrifuge.

e. Medications (chronic), as an undesirable method.

QUESTION 2: What factors must be considered and worked out to give practical answers to define optimum artificial g environment for man in space flight?

ANSWER: The following factors, grouped by priority, must be worked out to determine optimum artificial g:

PRIORITY 1

Physiological problems and tolerances to rotation rates provided and corrective techniques.

Performance effects of rotation rates and g levels provided.

Habitability and human engineering requirements for meal preparation, hygiene facilities, sleep, ladder climbing, etc.

Physiological problems and tolerances associated with transitions from one radius to another and corrective techniques.

PRIORITY 2

Is coriolis threshold in space a function of rotational rate alone as on earth, or also influenced by angular velocity or g level?

Specific physiological values of various g levels in preventing the physiological effects of weightlessness -- in correcting them:

Is this a linear function?

What are the effects of duration and frequency of application of specific g levels as preventives and correctives?

How do coriolis thresholds in space relate to those on earth?

What are the differences in the undesirable effects of head movements in space as compared to earth?

PRIORITY 3

How do subgravity rotational environments influence circadian rhythms, reproduction and progeny, plant growth, etc.?

QUESTION 3: What methods are available to produce artificial g or an analog stress on man in flight and which is most desirable?

ANSWER: The only two known practical methods of producing artificial g in space are rotation of the spacecraft or rotation of the crewmen within it on a centrifuge arrangement. The two methods are compared below. It is obvious that spacecraft rotation is, by far, the most effective and that an on9board centrifuge has its best use as an experimental tool.

Factors	Spacecraft Rotation	On-board Human Centrifuge
1. Prevent physiological deconditioning of zero g	+	+
2. May enable broader segment of population of participate in space flight	+	0
3. Housekeeping; particulate contamination	+	0
4. Waste management	+	+
5. Handling of materials	+	0
6. Up-down familiarity for mission tasks	+	0
7. Reduce complexity of restraint design (for mission tasks)	+	0
8. Traction for mobility	+	0
9. Scientific investigation capability	+ (greater)	+ (lesser)

Attached hereto is the rationale and details to support the above answers.

Original Signed by
Hugh W. Randel
Colonel, USAF, MC
J. W. Humphreys, Jr.
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Enclosures

ANALYSIS AND RECOMMENDATIONS ON ARTIFICIAL G

Space Medicine, OMSF

Abstract

April 1970

ARTIFICIAL G IN FUTURE MANNED SPACE FLIGHT OPERATIONS

Advantages

- Can prevent deleterious physiological effects of zero g
- May enable broader segment of population to participate in space flight
- Provides more normal environment
  - a) Housekeeping advantages; particle control
  - b) Waste management advantages
  - c) Handling of materials--esp. liquids (meal prep., washing, experiment tasks, clinical therapeutic techniques, etc.)
  - d) Provides up-down familiarity
  - e) Reduce complexity of restraint design
  - f) Provides traction for mobility
- Provides enroute capability for scientific investigation of sustained subgravity forces and rotating environments.

Disadvantages

- Impact on cost
- Impact on vehicle system complexity
- Impact on operational complexity
- Impact on other experiments (astronomy, meteorology, photography, and earth resources)
- Complicates crew training
- Introduces vestibular problems
- Interferes with study of human responses to zero g
- In some activities, may impair human performance
- System will have to include capability to operate in zero g and artificial g
- Introduces problem of transitions between zero g and positive g
- Introduces physiologic problems of g gradients
- Restricts the use of available volume

EXPERIMENTAL SPACECRAFT ARTIFICIAL G

Purposes:

- Aside from engineering and navigational purposes, to determine optimum means of operationally applying artificial g to future spacecraft crews by evaluating human tolerances, physiological performance, habitability, engineering design, and work proficiency.

- To determine the specific value of various imparted g levels in preventing and/or remedying the effects of weightlessness on human functional systems.

- To obtain scientific information on subgravity and rotational effects on living systems.

MEDICAL/BEHAVIORAL EFFECTS OF WEIGHTLESSNESS AND CORRECTIVE TECHNIQUES WITHOUT SPACECRAFT ARTIFICIAL G

MAJOR EFFECTS	MEASUREMENTS *	CORRECTIVE TECHNIQUES
Cardiovascular . Deconditioning	Cardiac Output with Exercise and LBNP Heart Rate & Rhythm (ECG - VCG) Blood Pressure	Conditioning (Estimated Order of Effectiveness and Feasibility) . Whole Body Exercise and Special Exercises . LBNP or variant (e.g., gradient positive pressure garment, lower leg negative pressure) . Dietary . Positive Pressure Breathing . On-Board Centrifuge
Fluid Volume . Redistribution	Fluid Intake and Output Serial Body Mass Selected Blood Electrolytes, Protein, Sugar, and pH Urinalysis	
Bone and Muscle . Deterioration	Bone Density Muscle Size and Strength	
Vestibular Effects . ("Space Sickness")	Symptomatology EEG	Supportive . G-suit or Elastic Legotards . Mechanical Aids . Medications

(* Integrated Medical and Behavioral Laboratory Measurement System (IMBLMS) is being designed to include this capability).

MEDICAL/BEHAVIORAL INFORMATION REQUIREMENTS
of
SPACECRAFT ARTIFICIAL G EXPERIMENTS

PRIORITY 1

- Physiological problems and tolerances to rotation rates provided, and corrective techniques
- Performance effects of rotation rates and g levels provided
- Habitability and human engineering requirements for meal preparation, hygiene facilities, sleep, ladder climbing, etc.
- Physiological problems and tolerances associated with transitions from one radius to another and corrective techniques

PRIORITY 2

- Is coriolis threshold in space a function of rotational rate alone as on earth, or also influenced by angular velocity or g level?
- Specific physiological values of various g levels in preventing the physiological effects of weightlessness -- in correcting them:
  - -- Is this a linear function?
  - -- What are the effects of duration and frequency of application of specific g levels as preventives and correctives?
- How do coriolis thresholds in space relate to those on earth?
- What are the differences in the undesirable effects of head movements in space as compared to earth?

PRIORITY 3

- How do subgravity rotational environments influence circadian rhythms, reproduction and progeny, plant growth, etc.?

POTENTIAL OPERATIONAL VALUE OF SPACECRAFT ROTATION VS. ON-BOARD HUMAN CENTRIFUGE

		Spacecraft Rotation	On-Board Centrifuge
1.	Prevent physiological deconditioning of zero g	+	+
2.	May enable broader segment of population to participate in space flight	+	0
3.	Housekeeping; particulate contamination	+	0
4.	Waste management	+	+
5.	Handling of materials	+	0
6.	Up-down familiarity for mission tasks	+	0
7.	Reduce complexity of restraint design (for mission tasks)	+	0
8.	Traction for mobility	+	0
9.	Scientific investigation capability	+ (greater)	+ (lesser)

SUMMARY AND CONCLUSIONS

1. Artificial g will probably not be required operationally for long duration flights of the future. Other countermeasures against physiological deconditioning, habitability problems, and performance disadvantages will probably prove to be sufficiently effective without introducing the vestibular, cost, and other (navigational, spacecraft design, etc.) impacts of spacecraft rotation.

2. An artificial g experiment is needed to determine how to apply artificial g optimally in case it is required or desired, i.e., there is sufficient probability to warrant inflight artificial g experimentation.

3. The determination of how to apply artificial g requires a rotated spacecraft experiment and the evaluation of flight crew responses.

4. This experiment should be accomplished relatively early in the series of prospective flight programs, preferably Skylab II (or Shuttle Module), for operationally oriented human and design data. This should be followed by experiments aboard the rotating space station for more definitive human response data and information of purely scientific interest. The space station should include a non-rotating hub for continuing studies of long term zero g.

5. The initial spacecraft artificial g experiment should be designed to yield physiological, performance, habitability, and human engineering information on:

   a) The effects of various rotation rates and transitions from one radius to another (rate durations of one to two days each).

   b) The effects of at least two sustained subgravity g levels, such as 0.5 g and 0.2 g.

ANALYSIS AND RECOMMENDATIONS ON ARTIFICIAL G

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ANALYSIS AND RECOMMENDATIONS ON ARTIFICIAL G

Space Medicine, OMSF

I. INTRODUCTION

Initially, it is important to distinguish between the question of the operational need for artificial g in future manned space flight and the question of the need for a spacecraft artificial g experiment in manned space flight. Factors to be considered and our recommendations on the two issues are:

A. Artificial G in Future Manned Space Flight Operations

Advantages

physiology

- Can prevent deleterious physiological effects of zero g
- May enable broader segment of population to participate in space flight

habitability

- Provides more normal environment
  - a) Housekeeping advantages
  - b) Waste management advantages
  - c) Handling of materials--esp. liquids (meal prep., washing, experiment tasks, clinical therapeutic techniques, etc.)
  - d) Provides up-down familiarity
  - e) Reduce complexity of restraint design
  - f) Provides traction for mobility

Science

- Provides enroute capability for scientific investigation of sustained subgravity forces and rotating environments.

Disadvantages

- Impact on cost
- Impact on vehicle system complexity
- Impact on operational complexity
- Impact on other experiments (astronomy, meteorology, photography, and earth resources)
- Complicates crew training
- Introduces vestibular problems
- Interferes with study of human responses to zero g
- In some activities, may impair human performance
- System will have to include capability to operate in zero g and artificial g
- Introduces problem of transitions between zero g and positive g
- Introduces physiologic problems of g gradients
- Restricts the use of available volume

Comments:

From the medical standpoint, spacecraft artificial g can ameliorate the physiological changes of weightlessness, but it can also introduce new physiologic problems, in particular, vestibular disturbances due to rotation.

Recommendations:

All things considered, spacecraft artificial g will probably not be required operationally for long duration flights of the future. (However, substantiating--or contraverting--evidence continues to be an essential medical/behavioral objective.) The potential advantages of this procedure appear to fall into three categories, as noted above. With respect to each of these:

- Physiology - Simpler methods of dealing effectively with the physiological problems of long term weightlessness are, or can be, available.

- Habitability - Techniques such as laminar flow, vacuum cleaners, high air flow toilets, orientation by color coding, etc., should provide a sufficiently habitable environment without need for resorting to spacecraft artificial g.

- Science - The question of supplying artificial g for the purpose of studying subgravity and rotational environments in the absence of earth g calls for value judgments pitting potential scientific gain against the disadvantages outlined above. Two modifying factors should be noted, however. First, scientific experiments of this type can be carried aboard spacecraft rotated experimentally for other primary reasons and, secondly, such experiments may achieve their purposes satisfactorily by utilizing lower animals (and perhaps plants) and an onboard centrifuge.

B. Experimental Spacecraft Artificial G

Purposes

- Aside from engineering and navigational purposes, to determine optimum means of operationally applying artificial g to future spacecraft crews by evaluating human tolerances, physiological performance, habitability, engineering design, and work proficiency.

- To determine the specific value of various imparted g levels in preventing and/or remedying the effects of weightlessness on human functional systems.

- To obtain scientific information on subgravity and rotational effects on living systems.

Disadvantages

(Same as outlined in Section I. A. above)

Comments:

The three purposes outlined above can be considered to be listed in order of priority. The overall mission complexity and cost will increase, although not necessarily proportionately, as these purposes are encompassed.

Recommendations:

Despite our current judgment that spacecraft artificial g will not be required operationally for future missions, our present state of knowledge does not provide sufficient confidence for us to move exclusively in this direction without the option of providing artificial g if we need it. It is therefore recommended that spacecraft artificial g experimentation should be invited to accomplish at least the first priority purpose above. It is further recommended that we obtain this experience early because of the expected impact of the resultant data on vehicle design and mission planning of flight programs already on the drawing boards. The following sections will amplify these considerations.

II. MEDICAL AND BEHAVIORAL EFFECTS OF WEIGHTLESSNESS; PREVENTION WITHOUT THE USE OF SPACECRAFT ARTIFICIAL G

A. Anticipated Effects of Long-Term Weightlessness

1. Cardiovascular deconditioning - reduction of circulatory responsiveness to g environments.

2. Fluid volume redistribution with associated questions re electrolyte and acid-base disturbances and hormonal controlling mechanisms -- influences cardiovascular responses, state of hydration, thermal responses, and general systemic well-being.

3. Bone and muscle deterioration - bone softening, loss of muscle size and strength, possible problems of altered blood calcium, possible renal stones.

4. Vestibular disturbances, i.e., "Space Sickness" - motion sickness of the type noted in Apollo with initial free motion in weightlessness.

5. Other possible changes:

- Decreased glucose utilization
- Relocation of bacterial flora and altered resistance to infection
- Changes in wound healing
- Other neuroendocrine changes (sleep, alertness, and thyroid, parathyroid, and adrenal cortical homeostasis)

B. Evaluation of Crew Responses to Weightlessness

1. The major variable in these evaluations is duration of flight.

2. Measurements required to evaluate anticipated problems of weightlessness are:

Cardiovascular:	cardiac output vascular compliance vascular reactivity heart rate blood pressure venous pressure regional blood flow (including limb plethysmography) lower body negative pressure exercise response
Fluid Volume Distribution:	fluid volume compartments fluid balance electrolyte balance body mass urinalysis
Bone and Muscle:	mineral balance bone density muscle size and strength
Vestibular:	symptom thresholds spatial orientation testing oculogyral illusion nystagmography EVLH (egocentric location of the horizon) (Rotating litter chair used for several of the above measurements)

(Note: IMBLMS is being designed to include the foregoing and more to permit exploration of more subtle questions of weightlessness, potential problems of other environmental factors than weightlessness, and general systems monitoring).

C. <u>Techniques to Prevent Undesirable Medical/Behavioral Effects of Weightlessness Without Spacecraft Artificial G</u>

Because the imparting of artificial g to the spacecraft carries with it disadvantages as well as advantages, alternative remedial techniques are important to consider.

1. <u>Conditioning</u>

a) Exercise - whole body exercise appears to be the best candidate technique to reduce cardio-vascular, fluid volume, and bone and muscle changes. It should have little effect on "space sickness," but this can be expected to clear spontaneously within a few days in susceptible crew members. Distinctions must between specific types of exercise (whole bo resistive, inertial, isometric, isotonic, et in conducting R&D to establish an optimal re The double-ended trampoline (or inflight equ lent) is a specific kind of exercise combini musculo-skeletal activity with changing g vectors acting on the cardiovascular system i the longitudinal axis (more extreme but simi to the 1g environment). Further research an development into the effectiveness of this technique is needed. The problem of inertial interference with movement of the spacecraft need resolution.

b) Lower Body Negative Pressure (LBNP) - This is con-trolled stress technique which has so far be used exclusively as a test. By drawing the circulating blood toward the lower extremitie it simulates the gravity condition. Explorati its effectiveness and that of likely variants such as gradient positive body pressure garmen and lower leg negative pressure as conditioni techniques are indicated.

c) Electrolyte and Fluid Control by Diet (Vitamins, Minerals, and Electrolytes), and Hormones - High Vitamin D, sodium, calcium, phosphate, and protein intakes have all been suggested as means of preventing calcium and fluid losses. Aldosterone could also have fluid retaining properties, but,if so, it is likely that such fluid would be retained in the tissues rather than to maintain circulating fluid volume. Recent evidence obtained from an NIH bed rest study seems to indicate that phosphate supplements may be of value in preventing negative calcium balance. This is an area in need of more research.

d) Positive Pressure Breathing - This technique theoretically imposes a back pressure on the venous system, in effect, exercising it to maintain its ability to support the weight of columnal blood after weightlessness. Its trial in a long term bed rest study was not successful. Research to determine the effects of various modifications of the technique alone or combined with others such as gradient positive body pressure may prove to be of value.

e) Onboard Centrifuge - By actually providing a gravity environment to the individual, the onboard centrifuge might be considered potentially capable of conditioning against the effects of weightlessness. While it has many attributes as a research tool, its use as a flight crew conditioning technique poses several problems. Because of its relatively short radius, a proportionately high spin rate must be imparted in order to obtain adequate g levels. This imposes new vestibular difficulties and a marked g gradient down the long axis of the body. Coupled with this, its effectiveness has not yet been established, a satisfactory regimen has not been determined, its safety is questionable (two cases of cardiac arrest in one study), its cost is great, and simpler techniques offer sufficient promise of equivalent or greater benefit without ill effect. As compared with spacecraft rotation, the crew can only use it intermittently and it offers few advantages in the realm of habitability.

Nevertheless, continuing ground based R&D is important because the technique provides gravitational force to the body. These efforts should utilize a radii of sufficient length to avoid excessive rotational rates and high g gradients to the body (g from head to toe), yet be kept within a practical length for spaceflight. Research efforts should attempt to establish its effectiveness in preventing and correcting the effects of sustained bed rest, identify and correct associated problems, and determine optimal regimes. Questions concerning transitions from one g level to another, vestibular response problems, etc., can be approached at the same time.

f) Medication:

- Vaso-pressors - Medications which constrict arterial vessels to increase blood pressure. Chronic or long-term use will probably be associated with decreasing effectiveness. Furthermore, such use is probably contraindicated because of side effects. They can probably be used supportively, however, at or preceding landing on planetary surfaces.

g) Miscellaneous:

- Resistive (GASS) suit - Of potential benefit to the musculo-skeletal system only, this suit consists of a network of springs or elastic bands which increase the muscle work required to perform any ordinary activity.

- Slightly Hypoxic Environment - An environment similar in oxygen partial pressure to a mountainous altitude such as Denver has been postulated as a possible conditioning technique. The mild hypoxia causes the cardiovascular system to work harder in order to maintain the same level of arterial oxygen pressure. This has been explored only in theory, but it has appeared to many investigators to be so unphysiological generally that it has had little attention.

- Electrical Stimulation of Muscles - Possibly beneficial to the musculo-skeletal systom only, it is too complicated and uncomfortable to have received favorable consideration.

- Ultrasonic Stimulation of Muscles - Could increase muscular circulation locally, but probably of little value.

2. Supportive (On Planetary Surface)

a) G-suit or legotards - Supply pressure on the lower extremities and lower portion of the abdomen to shunt effective circulating blood volume into the more vital areas permitting maintenance of adequate cerebral blood flow. Should be highly effective in supporting the cardiovascular system during planetary activities following space flight.

b) Mechanical assists - A variety of devices to enhance the effective power of weakened muscles for particular manipulative purposes.

c) Medications - Specific symptomatic therapy such as antimotion sickness medication, amphetamines to increase blood pressure and heart rate, etc. These are known to be effective on earth and should prove to be equally so in space and on distant planets.

D. Research and Development Requirements

1. Ground based research must be carried out and/or continued for each of the conditioning techniques as listed in roughly descending order of priority. The investigaand evaluation of specific forms of whole body exercise should be given a great deal of emphasis. The onboard centrifuge, on the other hand, is viewed with some reservation as a candidate inflight countermeasure in terms of cost-effectiveness compared with other techniques. R&D is required, however, to determine this in greater detail, but radii of rotation should be sufficiently long to obviate potential problems of safety. A relatively small amount of R&D is required for further study of the supportive techniques listed.

2. The study and development of improved bioinstrumentation and techniques for the evaluation of man in space requires continuing emphasis. Regardless of prognostications made on the basis of present knowledge, we must be in a position to carry out scientifically valid studies of flight crews during space flight to explore possible problems which may demand greater emphasis than presently forecast. Our ability to do so will depend on the adequacy of available flight-adapted measurement techniques.

3. Adequate provision must be made for ground based simulations to provide scientifically valid control data for comparison with inflight findings. This is especially important when treating spaceflight data because opportunities to gather data are infrequent and the number of subjects is small. At the same time, the validity of future planning is greatly dependent upon the accuracy of conclusions drawn from antecedent flight data.

4. Current efforts to develop an adequate inflight medical/behavioral measurement capability for flexible, short lead time response to evaluative requirements (IMBLMS) must be continued.

E. Comments:

- Physiologically, the changes induced by weightlessness may be looked upon generally as an adaptation to the weightless environment which entails a simultaneous loss of adaptation to the 1g environment. This type of problem poses two major questions: (1) At what point will the curve of these changes plateau in the weightless environment? and (2) How well and how quickly will flight crews readapt to the level of performance effectiveness in a postflight planetary environment?

- At the same time, there are problems which are unique to the weightless environment and which do not fall into the above category. Such problems are the transitory vestibular disturbance called "space sickness," the potential respiratory and microbiological hazard of particulate contamination in zero g, and differences in ease of task performance and housekeeping.

- The maintenance of adequate in-gravity function during weightlessness involves conditioning procedures. In addition to these, supportive techniques can be used postflight if needed, primarily for the cardiovascular system.

F. Recommendations:

- It is probable that adequate physiological conditioning can be maintained during weightless flight without resorting to spacecraft artificial g.

- The most promising conditioning techniques are whole body exercise and a special exercise similar to the double-ended trampoline.

- Research and development is required to determine the usefulness and define the optimal application of several conditioning techniques, and to a lesser extent, supportive techniques.

- Efforts must be continued to evaluate crew responses to the weightless space flight of increasing durations by means of medical/behavioral experiments. Supportive ground based R&D, the IMBLMS program, the parallel development of new and improved measurement instrumentation and techniques, and adequate provision for simulations and ground based data are an integral part of the evaluation of human responses to weightlessness.

- If spacecraft artificial g experiments are to be undertaken in manned space flight, flights not exceeding that of our maximum experience in weightlessness should be utilized for this purpose. Flights of increasing length should be used for the study of weightlessness since these will determine if artificial g will be needed at all.

III. THE DETERMINATION OF REQUIREMENTS FOR PROVIDING AN OPTIMAL SPACECRAFT ARTIFICIAL G ENVIRONMENT IN SPACE

A. Principles - In attempting to derive a valid guideline for approaching this question, the first logical step is to review the purposes, problems, medical information requirements, and measurement capabilities needed in a spacecraft artificial g experiment.

1. <u>Purpose of a Spacecraft Artificial G Experiment</u>:

The purposes of a spacecraft artificial g experiment are outlined in Section I. B. They are set forth in order of priority, the first being operationally mandatory information; the second consisting of physiological information of distinct operational value; and the third directed toward scientific information with little direct or immediate operational bearing.

2. <u>Undesirable Medical/Behavioral Effects of Artificial G by Spacecraft Rotation</u>:

- Vestibular effects -- coriolis effects
- Performance effects -- influence on task accomplishment of such things as objects falling along a curved path, greater gravitational effect when walking in one direction as opposed to the reverse direction, etc.

3. <u>Medical/Behavioral Information Requirements of Spacecraft Artificial G Experiments</u>:

Priority 1

- Physiological problems and tolerances to rotation rates provided and corrective techniques
- Performance effects of rotation rates and g levels provided
- Habitability and human engineering requirements for meal preparation, hygiene facilities, sleep, ladder climbing, etc.
- *. Physiological problems and tolerances associated with transitions from one radius to another and corrective techniques

Priority 2

- *. Is coriolis threshold in space a function of rotational rate alone as on earth, or also influenced by angular velocity or g level?

Priority 2

*. Specific physiological values of various g levels in preventing the physiological effects of weightlessness -- in correcting them:

-- Is this a linear function?

-- What are the effects of duration and frequency of application of specific g levels as preventives and correctives?

- How do coriolis thresholds in space relate to those on earth?

- What are the differences in the undesirable effects of head movements in space as compared to earth?

Priority 3

- How do subgravity rotational environments influence circadian rhythms, reproduction and progeny, plant growth, etc.?

4. Measurements Required to Obtain Medical/Behavioral Information Needs Aboard Spacecraft Artificial G Experiment:

- Physiological measurement requirements are generally the same as those for information on weightlessness (Section II. B.; vestibular measurements especially important here)

- Performance information to be obtained from TV or motion picture questionnaires, and anecdotal reporting

- Habitability and human engineering measurements will be quantitative for physical characteristics and mainly subjective for convenience and arrangements.

(Note: IMBLMS is being designed to contain these measurement requirements.)

B. Comments and Guidelines

Because of the probability of differences in medical/behavioral responses to rotational environments in space, as compared to earth, the only truly satisfactory means of obtaining the information sought (as listed above) is from actual space flight. However, ground based research and development can contribute significantly to several areas, particularly those Priority 2 information requirements labeled with an asterisk in the above list (See under R&D, below). Although Priority 3 information can be obtained satisfactorily only in space, experiments using animal and plant subjects and an onboard centrifuge should provide the desired information adequately.

The only practical approach to these information needs is to fly a spacecraft artificial g experiment coupled with a well coordinated ground based R&D program. The flight experiment must at least fulfill requirements for operationally needed information (Priority 1). This cannot be accomplished with an onboard centrifuge because it would not provide adequate habitability and performance data.

Although much of the information on physiologic response is listed as Priority 2, a good portion of it has clear-cut operational impact and can easily be obtained in reasonable depth at the same time. The notable exception is the requirement to determine the absolute physiological benefits of a sliding scale of spacecraft artificial g, together with the optimum duration and frequency of each toward preventing, and also correcting, the effects of weightlessness. Yet, it is entirely reasonable to attempt to determine inflight the physiological benefits of a fixed g level, or perhaps two. Some Priority 3 experiments utilizing plants and/or animals may also be candidates for inclusion aboard the rotating spacecraft experiment.

C. <u>Required Research and Development</u>

1. The specific benefits of various subgravity g levels in preventing and/or correcting the physiological problems of weightlessness should be partially resolvable by means of bed rest experiments utilizing tilted beds. Beds fixed at specific angles of tilt can impart specific subgravity g vectors with respect to the long axis of the body and should therefore prove to be a valid source of supportive information, particularly with respect to the cardiovascular and musculo-skeletal systems. This work has not been done to date.

2. Experiments utilizing rotation on widely different radii of long radius centrifuges should contribute

significant information concerning problems of transitioning from one radius length to another. Such experiments might also yield valuable information on the existence of other factors than rate of rotation influencing the development of coriolis effects. Thus far, rate of rotation has been the single critical factor identified, but our experience has been limited to the relatively short radius rotating room.

3. Strong emphasis should be placed on attempting to identify correlates between inflight and earth-based rotational and artificial gravity effects. This will make it possible to utilize earth-based rotation and other techniques to accurately study and predict flight effects, selection criteria, remedial medications and procedures, etc., for space flight with far less cost, restriction, and complexity. Correlative information from two spaceflight subgravity g levels rather than one would be highly valuable for these purposes by providing two points to establish a curve between 0 and 1g.

D. <u>Recommendations</u>

- The high priority artificial g information needed can only be obtained by means of an inflight spacecraft artificial g experiment.
- Lesser priority information can also be obtained with little or no additional difficulty from the same space flight experiment.
- Specific ground based R&D efforts can provide needed data for operational guidance as well as knowledge of physiological responses. Identifiable correlates with flight data should be sought.
- The spacecraft artificial g experiment should include a comparison of medical/behavioral data with zero g data of equivalent flight duration as well as with ground based data for evaluation of the salutory effects of artificial g.

IV. RECOMMENDED FLIGHT APPROACHES TO DEFINE SPACE FLIGHT ARTIFICIAL G REQUIREMENTS AND ENGINEERING DESIGN SPECIFICATIONS

A. Principles - Assuming that a decision has been made to fly a spacecraft artificial g experiment, the next steps toward determining optimal flight approaches are to establish the desired timing and some basic assumptions upon which to proceed.

1. Timing

- Since the primary purpose of the spacecraft artificial g experiment is to obtain design, operational, navigational, and human physiological and performance tolerance data for use, if needed, on future manned space flight missions, the timing of this experiment must be determined by back-dating from the earliest expected time or program of need.

- Current space station planning includes the capability of rotation for artificial g because of present uncertainties about human responses to very long duration weightlessness.

- If artificial g proves to be necessary for very long duration manned missions, its first truly operational requirement will probably be manifest in the flight program following the space station or space base, assuming that this will be a long duration interplanetary mission program.

- It seems reasonable to assume that this interplanetary program will be on the drawing boards by the time the space station flies.

- Basic design information substantiated by space flight should be available prior to this time.

- Because of the complexity and cost of the space station, it would be distinctly advantageous to be able to feed substantiated design information (from spaceflight) into the design of the space station before completion of its design.

- If future OMSF program plans are altered, it would be beneficial for the planning of alternatives to have obtained basic spacecraft artificial g information as early as possible.

- It is concluded that the flight of a spacecraft artificial g experiment as early as possible offers distinct advantages over delaying until the flight of the space station. The most likely candidate mission would be Skylab II (or possibly a shuttle module).

2. Basic Assumptions

- Spacecraft rotation is the only practical means of supplying artificial gravity in space. Much consideration has been given this point, but no other feasible means has been found.

- Operationally usable data from spacecraft artificial g experiments can only be obtained from man.

- Human tolerance to rotation is dependent solely upon the rate of rotation. Ground based research to date supports this position. Whether or not this holds true in space is presently unknown.

- The beneficial effects of artificial g in preventing or correcting the medical/behavioral effects of weightlessness are proportional to the amount of g provided up to 1g. This is also to be determined.

- Flights of increasing durations must continue to be utilized for evaluation of the effects of long term weightless space flight on man because the determination of the need for artificial g will depend on these findings. For this reason, and for reasons of safety, the spacecraft artificial g experiment should not exceed the maximum duration of previously experienced weightless flight. The simultaneous use of a zero g hub in the space station would resolve this conflict if longer duration artificial g experimentation is needed.

- In arriving at the desired experimental g levels to be explored in space, the upper limit is determined by the maximum rate of rotation reasonably expected to be tolerated by the crew within the rpm envelope anticipated to be utilized in an operationally rotating vehicle to produce up to 1g. The lower limit is the least g expected to be effective in improving the physiologic changes of weightlessness. The two g levels suggested below are considered to fall within this range and be sufficiently different to produce two significant data points between 0 and 1g.

- It is assumed that future manned space flight will consist of Skylab I and II, Space Shuttle, and Space Station.

B. Recommended Flight Approaches

In light of the preceding comments, two flight approaches appear to be feasible for a spacecraft artificial g experiment. In order of desirability they are, first, the obtaining of fundamental design and operational information aboard Skylab II (or a shuttle module) plus more detailed physiological and scientific information from the space station; and secondly, delaying the spacecraft artificial g experiment until the space station. The recommendations for each mode, indicated below, are based on the recommendations of the working group on the artificial g experiment, and are suggested modifications thereof.

1. Skylab II (or Shuttle Module) and Space Station

a) Skylab II

- A 56-day or 90-day maximum flight duration (same as maximum weightlessness previously achieved)

- Pre-select astronaut crew members in the upper portion of the normal range of resistance to vestibular effects of rotation to assure success of the mission as well as applicable data.

- Near beginning of mission, after orbit is stabilized, initiate two rpm increases in spacecraft rotation at one-day intervals up to 6 rpm.

- In the absence of crew symptomatology, maintain vehicle at 6 rpm for one to four days to allow time to work out navigational, design, and other operational problems.

- Return to 2 rpm by 2 rpm decrements at two days each.

- Spin up to half-g level (approximately 6 rpm, assuming 33 ft. radius) and maintain for two weeks while performing medical/behavioral evaluations.

- Stop rotation and continue measurements while the crew is weightless for two weeks.

- Then spin up to slightly over 4 rpm for a g-level of .2g and maintain for two weeks continuing measurements of medical/behavioral responses.

- This is to be followed by a zero g period of three to seven days and finally a step-wise daily increase of 2 rpm to 6 rpm prior to re-entry.

- Experiments to determine the influence of length of radius arm (angular velocity) and the effects of transitions from one radius arm to the other can be incorporated using two levels or radius lengths as outlined in the recommendations of the working group on the artificial g experiment.

- Efforts should be made to utilize a six-man crew for this mission, if at all possible, to increase the validity of data obtained.

b) <u>Space Station Only</u>

- The space station should include a zero g hub to enable the continuing investigation of the effects of personnel exposure to increasing durations of weightless space flight.

- At a fixed rotation, more definitive studies can be made of the ameliorating effects of various g levels on the effects of weightlessness by utilizing stations at different radii.

- Similarly, the effects of transitions from one radius or g level to another and the factors influencing coriolis thresholds can be studied definitively.

- More refined information on design, navigational and other operational requirements can also be obtained from this configuration.

2. Space Station Experiment

With the exception of the time delay in obtaining the required information and the fact that experiments with various rotation rates will be needed, the same comments apply as in 1b above concerning the space station. Detailed planning of the space station artificial g experiment should be modeled after the recommendations of the medical and physiological working group on the artificial gravity experiment.

C. Comparison - Spacecraft Rotation vs. On-board Human Centrifuge for Artificial G

The only two known practical methods of producing artificial g in space are rotation of the spacecraft or rotation of the crewmen within it on a centrifuge arrangement. The two methods are compared in the following chart. It is for this reason that antecedent experimentation prior to operational use should be oriented to spacecraft rotation rather than the human centrifuge.

POTENTIAL OPERATIONAL VALUE OF SPACECRAFT ROTATION VS.

ON-BOARD HUMAN CENTRIFUGE

		Spacecraft Rotation	On-Board Centrifuge
1.	Prevent physiological deconditioning of zero g	+	+
2.	May enable broader segment of population to participate in space flight	+	0
3.	Housekeeping; particulate contamination	+	0
4.	Waste management	+	+
5.	Handling of materials	+	0
6.	Up-down familiarity for mission tasks	+	0
7.	Reduce complexity of restraint design (for mission tasks)	+	0
8.	Traction for mobility	+	0
9.	Scientific investigation capability	+ (greater)	+ (lesser)

V. SUMMARY AND CONCLUSIONS

1. Artificial g will probably not be required operationally for long duration flights of the future. Other countermeasures against physiological deconditioning, habitability problems, and performance disadvantages will probably prove to be sufficiently effective without introducing the vestibular, cost, and other (navigational, spacecraft design, etc.) impacts of spacecraft rotation.

2. An artificial g experiment is needed to determine how to apply artificial g optimally in case it is required or desired, i.e., there is sufficient probability to warrant inflight artificial g experimentation.

3. The determination of how to apply artificial g requires a rotated spacecraft experiment and the evaluation of flight crew responses.

4. This experiment should be accomplished relatively early in the series of prospective flight programs, preferably Skylab II (or Shuttle Module), for operationally oriented human and design data. This should be followed by experiments aboard the rotating space station for more definitive human response data and information of purely scientific interest. The space station should include a non-rotating hub for continuing studies of long term zero g.

5. The initial spacecraft artificial g experiment should be designed to yield physiological, performance, habitability, and human engineering information on:

   a) The effects of various rotation rates and transitions from one radius to another (rate durations of one to two days each).

   b) The effects of at least two sustained subgravity g levels, such as 0.5g and 0.2g.