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WEIGHTLESS MAN: A SURVEY OF SENSATIONS AND PERFORMANCE WHILE FREE-FLOATING

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FOREWORD

This report was prepared by the Human Engineering Branch, Behavioral Sciences Laboratory, 6570th Aerospace Medical Research Laboratories, under Project 7184, "Human Performance in Advanced Systems," and Task 718405, "Design Criteria for Crew Stations in Advanced Systems."

The authors wish to express their appreciation to Capt. J. E. Wade, formerly of 6570th Aerospace Medical Research Laboratories; Cdr. C. Bond and Dr. K. Schaefer, U. S. Navy Medical Research Laboratory; Mr. H. Wilson, Convair Astronautics; and Dr. S. Gerathewohl, National Aeronautics and Space Administration, for their many comments and aid in writing this report. Special acknowledgment is made to M/Sgt. Charles W. Sears, 6570th Aerospace Medical Research Laboratories, who helped accomplish the inflight research, and to Dr. Melvin J. Warrick for his assistance in preparing the manuscript for publication.

This research was performed during the period October 1960 to February 1961.

ABSTRACT

The effect of surface-free behavior on work performance in space has been investigated to determine what techniques should be developed to aid the orbital workers. While they performed gross motor activities under weightless conditions, subjects reported their sensory and performance experiences during Keplerian parabolas in a C-131B aircraft in both lighted and dark cabin conditions. Their experiences were categorized into sensation influences upon orientation and body motion influences upon body attitude and position control. Unique examples of short-term weightless behaviors were found and their causes are briefly discussed. Potential applications of these weightless responses to hardware development and to crew training and selection are discussed, and significant areas for future research are proposed.

PUBLICATION REVIEW

This technical documentary report has been reviewed and is approved.

Walter F. Grether

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Technical Director
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INTRODUCTION

The emergence of 1-g matured man into the weightless environment of space requires, among other things, an evaluation of his ability to orient himself and to work within this unique condition.

Gerathewohl (ref. 9) states, "There can be no doubt that the differentiation between 'sensation' on the one side, and 'performance' on the other side, is an artificial one because both factors are so closely linked together and interrelated that any separation can serve as a working hypothesis only. It is mainly for the sake of a schematic classification of symptoms that we confine ourselves to the treatment of the 'subjective' or personal experiences of weightlessness. Thus, psychological and somatic effects of weightlessness may stem from the same source; and they may affect the well-being of the individual as well as his task performance." The present report explores the performance of weightless man and discusses some of the factors that appear to influence his performance and orientation. Problems are discussed in terms of simulation, crew selection, and training, and implications for the actual orbital situation.

The Results section lists sensation and performance effects noted during an inflight survey and are only briefly discussed in an attempt to acquaint the reader with these new effects. Several of the effects are currently being investigated as separate, individual studies, and the rather cursory treatment of the effects as given by the authors is meant only to provide familiarization with the effects in question. The major intent of this section is to identify problem areas pertinent to the weightless orbital operator.

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METHODS

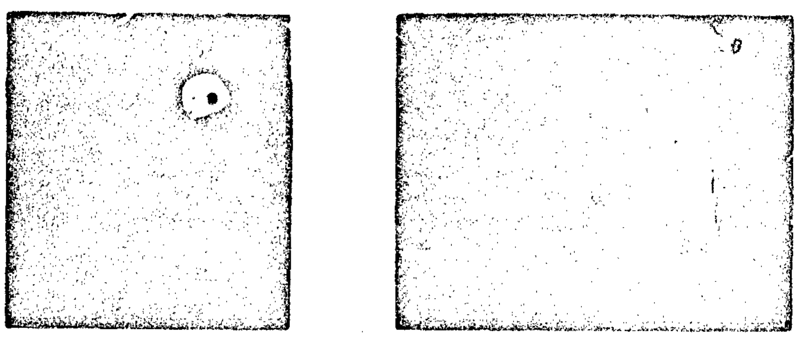
The subjective comments of free-floating personnel and their performance as observed by the task scientists were recorded during and after a series of weightless maneuvers in a C-131B aircraft (ref. 17). Naive subjects and experienced "free-floaters" were briefed before each trial and were interviewed during, between, and after single and double parabolas. Voice recordings of their subjective comments were made on a compact tape recorder carried in a leg pocket of their flying suits.

These observations were made under weightlessness in a lighted and darkened cabin, or a dark cabin augmented with an artificial moon (fig. 1). Weightlessness as experienced by a free-floating subject was characterized by the following conditions:

Low Friction: The absence of cohesive force between adjacent masses (whether moving or stationary relative to one another).

Free-Body: Body segment movement interactions, possible only in a surface-free environment, permit subjects to stand on or orient to any room surface.

G-Free Stimulation: The freedom from the effects of gravity on the mechanoreceptors (postural, tactile, labyrinthine senses).



A B

A. Subject in lighted cabin.
B. Subject in dark cabin, with moon display.

Figure 1. Subject and Moon Display in Lighted and Darkened Cabin

The following conditions were considered as peculiar to the aircraft maneuver:

<u>Rapid g Transition</u>: A g transition from 2 1/2 to 0 g, (or vice versa) lasting 2-3 seconds (ref. 17).

<u>Environmental Stress</u>: The influence of extreme aircraft attitudes, excessive g and engine noise variations during the maneuver.

<u>Short Time Duration</u>: A weightless period of approximately 14 seconds per maneuver.

<u>Aircraft Motion</u>: The effects of air turbulence and pilot-initiated control movements that imparted spurious accelerations to the subject and his environment.

The participants were dark-adapted in the aircraft cabin for 15 minutes by wearing opaque goggles. An illuminated electroluminescent panel (referred to as the moon) was mounted on the rear bulkhead and emitted approximately 0.003 millilamberts evenly across the face of the display (fig. 2). The low light level was used to eliminate reflections and to avoid illumination of the darkroom interior. The moon served as a single visual stimulus, and its round shape was chosen to reduce the knowledge of the location of cabin surfaces for the subjects. A zippered curtain isolated the experimental area from the forward fuselage. The experimenter, who monitored the experiment from the experimental area, wore an interphone headset to communicate with the pilot.

Figure 2. Electroluminescent Panel - Moon Display

The subjects were instructed to perform the gross motor activities listed in Appendix I. Tasks of gross motor behavior were chosen for their ability to free the subject from a surface, move a subject between surfaces, cause collisions with surfaces and influence the up-down (ceiling-floor) frames of reference for the subjects. The tasks were presented in order of increasing complexity; i.e., successive tasks required more proprioceptive activity and the stimulation of more receptors. Simple tasks were selected so that they could be performed easily in the dark and within the brief weightless period. Instructions to subjects were standardized to control the sequence of task presentation and to insure completion of the activity.

The 11 subjects in the first group were nonpilots and a large percentage of their comments dealt with sensory artifacts rather than responses to the weightless condition. In an effort to reduce attention to these conditions, the authors drew additional subjects from the pilots at Wright-Patterson AFB.

Appendix II is a verbatim transcript of a Mercury astronaut's flight as recorded in the darkroom. This transcript reveals the wealth of information that can be obtained from subjects acquainted with the effects of self-initiated and externally imposed forces on body performance. It further convinced the authors that more productive data could be obtained from an aircrew-type population. As a result, 18 pilots (cargo, bomber, and fighter aircraft) were selected as subjects. Later, 12 Navy deep sea divers were selected, because of their experience in the dark and buoyant underwater environment that has often been compared with the weightless state.

RESULTS

A. Limitations -

A limitation of the observational method is that the process of observing may itself influence the subject being studied (ref. 2). We thought that the act of recording into a private microphone, unobserved by the experimenter, would reduce the possibility of subtle influences being exerted on the subject's behavior by the knowledge that he was being studied.

The observational method often yields seemingly unrelated data in which it is difficult to find significant relationships. The table of hypotheses (fig. 18) is at best a collection of hunches of causal relationships based on unsystematically controlled observations; however, this is the intent of this report and many observational methods; i.e., to generate some possible fruitful hypotheses.

Another disadvantage of this technique is that the investigator may collect data on irrelevant operations, because he does not know in advance what is important. The authors, however, did not wish to reduce the probability of the appearance of unknown sensations by structuring the tests around previously connected notions of what factors were important. In order to reduce this influence the tasks were structured so as to minimally interfere with the subject's freedom of motion or action. As the test progressed, the authors became more selective with their selection of subjects (see METHODS); however, the instructions to the subjects remained unchanged. The only useless data not used in this report dealt largely with environmental descriptions of temperature, vibration, noise, turbulence, static electricity, and odors from the padding used in the experimental area.

The lack of generality of findings is one of the most serious limitations of the observational technique. The authors are not suggesting that subjects confined in the rear of a dark airplane are environmentally equivalent to personnel free-floating in space. We are suggesting, however, the probability of high correlations between many of the sensory and physical relationships in the two weightless conditions.

Originally, the authors had intended to record the frequencies of each effect within each trial in an attempt to relate the effect to the specific task being accomplished. Unfortunately, approximately 67% of the data gathered was unusable because of inadequate recording equipment (noise interference), recording techniques (unintelligible remarks), and inadvertent spoilage of the tapes by the transcribing agency. This shortcoming eliminated the possibility of a study of task-effect relationships and any attempt to qualify either the frequency or criticality of the enumerated effects. This situation forced the authors to selectively sample tape excerpts for intelligibility, and arbitrarily categorize them into like effects.

In addition to the free-floating activities listed in Appendix I, the next section also contains selected observations of subjects' behavior during other studies. These observations were included because of the authors' feeling that there were definite relationships between these activities and the simpler ones listed in Appendix I. Such observations are identified by the word "extra" in parentheses (Extra).

The unsatisfactory audio recording mentioned above suggests that a better system would be desirable in future research. Such a system was developed for the Air Force by the Seismograph Service Corporation, Tulsa, Oklahoma and is described in Appendix IV.

B. Sensations and Effects - The following reflects the sensory experiences and effects reported by the subjects, as interpreted by the authors:

1. Exhilaration During Surface Freedom - Subjects who were not annoyed by the acceleration history of the maneuver (see B 10, page 25) almost invariably smiled and laughed, appeared to enjoy their g-free soaring and reported symptoms of euphoria or exhilaration. These symptoms were more pronounced in the lighted than in the darkened room.

Examples:*

(Astronaut) "Exhilaration is the proper word." Bond:** "The euphoria is similar to, but not identical with, the euphoria of the free swimmer. Major factors, I believe, are (1) abrupt and complete environmental alteration and (2) abrupt modification of all sensory and 'posturogravel' clues. Increased visual array enhances euphoria, of course. I am reminded, however, that in poorly motivated and naive subjects, panic may result from this 'threatening' transposition." Diver: "This [task no. 8 - lights on] is better than the last time [task no. 7 - lights off], I can feel what I'm doing. I'm moving around now, I enjoy it more when I can see what's happening." Diver: "This [task no. 8] is more enjoyable the length of the run, much more so than when it's dark. When you're oriented, a more enjoyable experience."

Discussion:

Bond's suggestion of panic is in accord with Gerathewohl's earlier prediction (ref. 8) that "There is a possibility that the man's response to this eerie situation might be one of befuddlement and uneasiness, if not actual terror"; however, this response was noted only with the few subjects whom, the authors believe, were fearful of inflight weightless-producing maneuvers.

* Quotations listed after the term Examples are either excerpts from tape recordings, written statements on questionnaires gathered during debriefing session, or statements made by observers. Most sources are identified, such as (diver) or (pilot). The examples are included only for the purpose of suggesting the scope of the effect. The authors did not attempt to integrate these excerpts because they represent highly subjective opinions and any attempt to systematically explore the effects would require independent studies (several such studies are currently in progress).

** Personal Communication, Commander G. Bond, Officer in Charge, U. S. Naval Medical Research Laboratory, New London, Conn., 11 Jan 1961.

Gerathewohl does say later (ref. 9) that the "mental sensation of weightlessness can best be described as one of incredulousness or even slight amusement." Haber (ref. 15) has predicted extreme reactions: "The lack of gravity in a space ship will heighten the sensitivity of the gravity senses. The gravity sense organs will react vehemently to the smallest forces acting on the body. If he merely stretches his body or turns his head, he may be overwhelmed by the sensation that he is being lifted and jerked back and forth or that he is suddenly spinning around. A man liberated from the shackles of gravity would most probably be in a constant state of physiological and psychological tension." Our observations failed to confirm such dire predictions.

The sudden capability for 6 degrees of relatively unhindered body motion could be a general stimulus source. The almost effortless achievement (see ref. 6 for force requirements) of unusual body locations and attitudes and the sudden emergence into a novel "floorless and up-downless" environment (refs. 35, 36 and 34b, Knowledge of Body Position in Aircraft) apparently pleases subjects unconcerned with inflight fears.

Application:

G-free training and design should most likely be based upon the advantages of placing man in a potentially exciting and enjoyable environment. Workspace layout and self-maneuvering designs will probably not have to consider the previously postulated fear evoking aspects of the weightless environment.

2. Comfort of Tactualess Support - Subjects found tactualess "support" to be comfortable.

Examples:

(Diver) "Relief from g." "It's like floating without the water" (fig. 3). (Diver) "It's like dreaming." "Actually there is quite a little bit of difference in being weightless here and being weightless in water because there you can actually feel yourself, you know you can't feel anything here."

Discussion:

This perception was most frequently reported when subjects performed Task No. 1, which was a prone static position without limb movements (App. I). The sudden elimination of body weight and positive supporting reflexes which "increase extensor tone in order to make the body rigid against gravitational pulls" (ref. 30) tended to induce posture characteristics of withdrawn limbs. The force that must be exerted by the calf muscles to maintain the upright position on earth has been calculated to be equal to about one-quarter of the body weight and results in a metabolic cost of 14 per cent more calories per minute than a lying posture (ref. 30).

In terms of musculo-skeletal requirements, weightlessness is a lazyman's environment. Craveline (ref. 26) notes that as in the zero-gravity

Figure 3. Tactualess Comfort

state, "there is a marked decrease in the amount of muscular effort required" for most activities in hypodynamic environments.

This pleasure of comfort effect may be influenced by the excessive g load immediately preceding the weightless state. Walker stated after his first X-15 parabola, "One consciously appreciates the sensation of resting after the greater physical effort while power is on."*

Application:

(1) A 1 g tactual bed violates the g-free criterion (Sec. IV). (2) The weightless sleeper may need nothing more than a tether to restrain him from drifting. (3) Man's sleeping posture may be determined by his own 3-dimensional torso adjustment and not forcefully influenced by a mattress configuration.

3. Sensation of Falling - Under weightlessness, sensations of falling and the associated manifestations of apprehension, fear, even panic, might be expected (ref. 9). Our observations, however, lead us to believe that even the simple sensation of falling is rarely experienced, and that weightlessness itself does not induce fear and panic.

Examples:

(Pilot) "There was no falling sensation at all. I expected to fall but I didn't. Even when I hit something, I didn't feel as though I was falling." (Diver) "On our first g before coming out of the zero, I did have the sensation

* Official Letter from J. A. Walker, Subj: Flight "2-14-28," National Aviation and Space Administration, 3 April 1961.

of falling." (Physiologist*) "This sensation is in my experience to a certain extent related to the euphoria. Even if one hits an object, one barely feels it." (Psychologist) "The meaning of height above the floor in terms of fear is lost."

Discussion:

Since the subject and the aircraft both traverse the same general parabolic arc, the subject is not falling in respect to his immediate frame of reference - the aircraft. We found a few subjects experienced a sensation of falling only during the transition to or from the weightless portion of the flight trajectory. Following the transition to 0 g, whatever sensation of falling that occurred during this transition subsides quickly. If the transition to 0 g is made gradually by flying an aircraft out from under the subject (rather than transiting rapidly from + 2 1/2 to 0 g), there appear to be no sensations of falling - rather a transitory sensation of being buoyed-up or floating. Sudden disturbance of the aircraft may, however, induce falling sensations through the resulting visual, tactual, kinesthetic, and proprioceptive cues. During Joseph Walker's first 150,000 ft. X-15 parabola, he mentioned that "I found myself waiting for thrust cutoff. After that there was a mild sensation similar to falling. This was recognized and forgotten in a very short period of time."**

Application:

During the nonacceleration portions of space flight, an astronaut probably will not experience sensations of falling. Therefore, his performance will probably not be impaired by any continuous fear of falling, and no special precautions need be taken in systems design to assuage the possible consequences of fear of falling. Since the transition to and from weightlessness and transitory disturbances of the vehicle may result in fleeting but potentially disturbing sensations, including that of falling, planned exposure to such experience is recommended.

4. Orientation Effects - The next four effects are concerned with the subject's awareness of his own body position and motion. Gerathewohl defines this awareness in terms of orientation, i.e., "the ability of the individual to localize his position with reference to the three-dimensional space is understood in which the act of localization is guided by a complex of visual and gravitational cues."

The postulated contributions of visual, vestibular, and kinesthetic senses to orientation during weightlessness are manifold (ref. 20, 24) and will require extensive study. No attempt is made in this report to isolate

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* Personal Communication, Dr. K. Schaefer, Chief Physiologist, New London, Connecticut, 12 Jan 61.

** Walker, J. A., op. cit.

these contributions. Rather, the phenomenological approach was used to determine potential orientation difficulties.

a. Knowledge of Limb Position: The subjects knew during all of the conditions the static position of their limbs; however, moving their limbs may have resulted in confusion, initial overreaching, and an oscillating center-of-mass.

Examples:

(Pilot) "I know where my arms and legs are. I get confused when I'm spinning." (Physiologist*) "It was surprising to me that I always knew where my arms and legs were. In experiments in which I had subjects submerged in a tank containing water (at body temperature) in a dark, echoless room, everyone had the sensation - 'I do not know where my arms and legs are' - within two hours. Maybe the reported knowledge and control of limb position is lost if the period of gravity free state is extended."

Discussion:

Strughold comments (ref. 30) "If we move our arm, we would not feel its weight. [This is not precisely correct, as a rapid acceleration may be felt as a weight sensation; however, slow accelerations may be below the perceptual threshold.] Tension of the tissues and not gravity represents an adequate stimulus for accurate movements of the limbs."

Limb control improves with practice. As Gerathewohl (ref. 11) noted with blindfolded, harnessed subjects stabbing at targets with a stylus, "subjects adjusted to the situation during the first six exposures to weightlessness." The Behavioral Sciences Laboratory's tests illustrated that gross overreaching was adequately corrected during the first parabola with eyes open.**

Coordination of the upper extremities, known as the Finger-to-Nose Test (ref. 6), was performed by two subjects during three weightless trials (Extra). The test was made with two blindfolded subjects, highly experienced in weightless flight. Test performance was smooth and accurate, indicating at least a matched muscle balance (fig. 4).

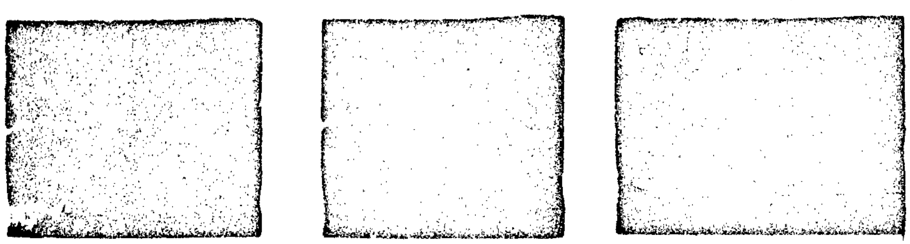

Figure 4. Finger-to-Nose Test

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* Dr. K. Schaefer, IBIB

** Gerathewohl's studies included one trial per each Keplerian parabola. Behavioral Sciences Laboratory's studies included several trials per Keplerian parabola.

Many subjects moved their limbs rapidly (Task 7, 8), thereby oscillating their center of mass. Confusion regarding body attitude and position apparently increased when these subjects performed the tumbling task with lights out, because they mistakenly thought their arm and leg motions resulted in successful body rotations.

Application:

(1) The orbital worker will probably develop new free-body limb positions (relaxed posture), and g-free controls should require less of an actuation force. Muscle decrements should be established for the operator over long weightless periods and reentry periods.

(2) Overshooting occurs in darkness, but knowledge of results rapidly decreases errors (ref. 11).

(3) Universally jointed levers (fig. 5) may be more appropriate to the free-floater. These may reduce the requirement for him to align himself to a single-axis actuation system but could introduce control motion standardization problems.

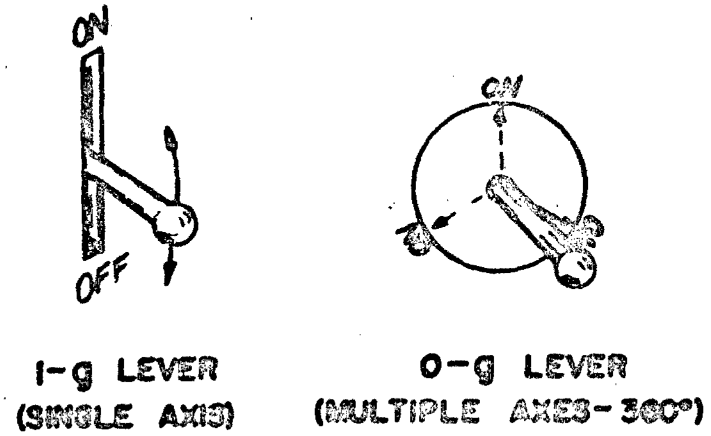

Figure 5. Examples of One g and Zero g Controls

b. Knowledge of Body Position in Aircraft: Nonrotating subjects use their body posture as a focus for orientation rather than an environmental frame of reference.

Examples:

(Astronaut) "The first time I have ever been so completely and quickly disoriented - with lights on, orientation is no problem."

(Physiologist*) "I subscribe fully to your proposal to use the posture sense orientation as a basic reference plane for the worker outside the spaceship for a number of reasons. Visual sense contributes more to illusions or to the conflict among gravitational and visual cues. I mentioned to you that I personally had no problems with disorientation after the first run and had no sensations related to air sickness and I contribute this to the fact that I was the first subject. I was not exposed, as Dr. Aquadro, to the visual-gravitational sensory conflicts in looking out of the window of the airplane and going through the motions prior to the actual test. I would hazard a guess that you would find a lower percentage of disorientation and airsickness in those subjects who were the first to enter the darkroom. If this is the case, you could strengthen your argument for the posture sense as a basic reference plane." [Unfortunately, a record of the sequence of subject testing was not made for this study. Normally from two to four subjects flew per flight.]

(Astronaut's Flight Surgeon) "On one run I was having an erudite discussion with John Glenn (astronaut) and it was not until the run was over and we were in the pullup that I realized that, in relation to one another, I was upside down. The important thing here to me is that it didn't make any difference! There was never any realization on my part that there was anything abnormal with our being face to face, yet with chins pointing in the opposite directions. From this, at least, I am convinced that astronauts will soon acclimate to the agravic state."

(Diver) "As soon as my feet were placed on the ceiling, I regained my orientation with the ceiling as down." "As long as I can keep my eyes on that moonglow, I can keep my relative position quite easily - I can tell whether I'm vertically positioned or whether I'm horizontal and which way I am going from it."

Discussion:

King notes that "All of the sensory receptors of the body concerned with maintenance of posture, except for the eye, are stimulated by mechanical forces. An important aspect of visual function in postural orientation and motor performance is its adaptability. Response modification can be effected through learning and reinforcement. The relative importance of visual information in determining spatial orientation will be increased in weightlessness. For postural orientation, the major determinants of response are learned expectancies about the relation between physical environment and sensory input. A visual field providing cues which permit the individual to construct a reference frame should be provided to aid spatial orientation in weightlessness." Margaria (ref. 25) downgrades this requirement for a visual field and indicates that individuals who suddenly have their information for spatial orientation reduced from three sense organs to one, at first lose

*Dr. K. Schaefer, op. cit.

their sense of orientation but later adapt and regain this orientation. King (ref. 20) later proposes that "since correct postural perception is mandatory, confusion can best be alleviated by suppression of unreliable information in favor of cues that are not nullified by weightlessness." (The emphasis is by Simons and Gardner).

Strughold (ref. 39) may be overemphasizing the visual sense and deemphasizing the tactile sense when he proposes that "orientation for movement in the spaceship will have to be accomplished optically, whereas on the earth it is done optically, gravireceptorially, with the vestibular sense and pressure sense of the skin"; and Gerathewohl (ref. 10) later stated, "It is the opinion of many investigators that the force of gravity exerts the most fundamental influence upon our spatial orientation. However, there is no need for the organism to obtain a conscious knowledge of the direction and amount of gravity. The basic need is for a mechanism that adapts the body automatically to their effects." This might be done by means of the so-called postural reflexes which are thought to serve to maintain or restore normal position and posture of the body.

Simons (ref. 35) has proposed the posture sense (foot-down) orientation as a basic reference plane for the worker outside his spaceship. Bond* adds a front-forward aspect to this concept; i.e., "in relation to blacked-out, weightless, disorientation spins in water, - with relation to up and down; but in all cases save one out of about 50 runs, the plane of reference was to the frontal aspect of the body, never to the posterior aspect."

Ray (ref. 31) supports the dominance of postural cues in the perception of the gravitational vertical. Moreover, postural factors were found to influence the judgment of the visual vertical, although the converse, the modification of the postural vertical by visual factors, was not demonstrated. Thus, in any situation in which an individual, such as a pilot, is subjected to this type of conflict, reliance tends to be placed on postural rather than visual cues and disorientation or misinterpretation of instruments may result. The body of evidence strongly supports postural factors as being the primary ones for the perception of the postural vertical and as exerting a very strong effect in the perception of the visual vertical.

Much has been written of studies concerned with the differences between field and body (postural) oriented subjects. Cohen (ref. 3) has emphasized the behavioral complexities of extreme body and extreme field oriented subjects and noted differences in these diverse groups in cortical alertness (EEG), nonspecific fluctuations (GSR), two-point sensory thresholds, pain thresholds, discomfort, adrenaline levels, pulse-rate variability,

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* Commander Bond, ibid.

projections of internal precepts, menstrual periods, anxiety ratings, and even psychopathological impulses. He suggests that these perceptual differences have many important general biopsychological theoretical implications, as well as having specific implications toward responses to stressful experimental situations of importance in Air Force operations. Although there is a large variance in individual differences, his findings are consistent with Cohen's (ref 3) that extreme body or extreme field oriented subjects are more likely to show pathology or a greater susceptibility in reacting to stressful situations. This suggests that a "middle" or non-field or non-body group would suffer least as orbital workers and these personality variables might serve as crew selection criteria. Subjects with less distinct body or field perceptual characteristics may show less disorganization (i.e., more stable orientation) in a low sensory input environment.

Diefenbach's summation (ref 5) appears realistic, "Orientation to space, visual and postural, is the outcome of an integrative function which involves not only the receptor organs but motor discriminative responses as well. Considering the available orientational information, it may be presumed that any cues will be drastically different from normal experience. Vision of surroundings apart from the cockpit will be unique in man's experience, and bear little relationship to any experimental background. Proprioceptive information will be based on body members with mass, but no weight. Vestibular stimuli of an otolithic nature will be limited to those produced by acceleration forces and those arising from head movements. In total, the prospect of a person being able to orient to his surroundings does not seem favorable."

Future experiments could explore the interaction of visual, proprioceptive, and vestibular cues on both orientation and motor control under varying g loads. Both this report and Shock's reports (ref 34) show that "disorientation due to complex accelerations produced by the parabola motions have to be carefully judged for implications with regard to conditions of true weightlessness."

Applications:

(1) Work station layout could be designed toward a posture orientation; i.e., the operator and not the vehicle or the space could be the focal point of orientation.

(2) Displays should not require an arbitrary operator-to-display alignment for display interpretation.

(3) A vehicle-to-man frame of reference might be based on elements of a posture orientation.

(4) A crew selection criterion may be the elimination of those candidates who exhibit extreme body or field orientation characteristics in a one g environment.

c. Knowledge of Rotation: Subjects tended to underestimate their own rates of rotation in the dark condition. Inadvertent or purposeful tumbling maneuvers did not appear to induce symptoms of dizziness or vertigo although disorientation was prevalent.

Examples:

(Astronaut) "I had an unexpected lack of dizziness, as I am prone to dizziness." "When not touching a surface, I had no feeling of rotation." "Sense of rotation is that of self-rotation, rather than aircraft rotation." "Disorientation without vertigo." "Disorientation with exhilaration." "Could maintain orientation at slow rpm." "I thought I was spinning less that I did."

Discussion:

The fact that many subjects were often surprised to find themselves in unanticipated positions at floor contact may mean that a perceptual decrement (underestimation) of knowledge of rotation may exist in the weightless state in darkness. The manner in which this perception is obtained is unknown (ref 24), however, difference thresholds to angular accelerations may be determined at a later date for subjects accelerating in a rotating chair in the aircraft. A later comparison between 1 and 0 g thresholds may aid researchers in defining the contribution of the graviceptors pertinent to this perception.

Vertigo (visual, gravital sensory conflicts) sensations may be more difficult to induce because of the fewer conflicting inputs from the gravireceptors. Physiological tumbling tolerances may be higher because of decreased cardiac activity. Small amounts of subject rotation can cause loss of visual contact with target and result in disorientation.

Applications:

(1) Indices of plane and direction of spin are probable minimum information requirements for tumble recovery and attitude control designs.

(2) Rotation thresholds and tolerances should be established for weightlessness.

d. Knowledge of Surface Location: Knowledge of surface location was poor and knowledge of body-to-surface alignment was almost nonexistent with surface-free behavior under semidark and dark conditions. Surface behavior tended to be inefficient, but increasing body-surface contact area helped with body-to-surface alignment tasks.

Examples:

(Physiologist**) "I needed only a fingertip to keep track of things." "Once I had determined the size of my environment with tactual cues, I became disinterested in the aircraft position relative to the earth and from there on I felt completely secure." (Diver) "It was like a bottom search plan used for recovering objects in water with no visibility." (Diver) "You can feel enough to right yourself once you get started."

Discussion:

A single tactual contact offered surface location information but poor attitude information, since the subjects had a number of potential body-to-surface alignments.

Both subjects and observers were often confused as to whether a given motion was due to their motion or aircraft surface motion. A free-floating mass (pillows were used to avoid injury) was introduced for detecting differences between aircraft and subject motion.

Inability to prepare for surface contact because of poor surface information produced greater apprehension and accidents in the dark environment.

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* Pers nal Communication, Dr. S. Gerathewohl, Office of Life Sciences, NASA, 19 Apr 61.

** Dr. K. Schaefer, op. cit.

Applications:

(1) Emergency techniques for returning to a surface in dark conditions should be developed and practiced.

(2) Crew Stations design might emphasize total surface area availability and deemphasize a single inefficient floor concept (ref. 35, 36) because of the between-surface behavior of the free-floater. The worker's rotational motion could describe a sphere of activity with the workspace area represented by an outer sphere.

5. Concern over Collision-Difficulty in Absorbing Inertia - Concern with potential body injury during a surface collision was a dominant apprehension. The unawareness of approaching a surface (dark condition) and the inability to self-rotate and prepare for a landing (dark and light condition) were reported as major fears.

Examples:

(Astronaut-see App. II) "I have to realize that wherever I am, or what position I am in, it is comfortable to me and not harmful, even though upside down." "The big factor with me was the fear of injury upon completion of the maneuver." "Your mind is continually trying to think, well, which way am I going and when am I going to hit on what part of my body." (Diver) "I feel better if I have both hands free." "Actually, your feet and hands aren't too much help. When you're in the dark, you can't see where to put them." (Diver) "Started to land when I had my feet against something so it made it much easier."

Discussion:

Inexperienced soaring subjects often rotate uncontrollably during translations. Subjects unknowingly push off from a given surface with a thrust misaligned from their center of mass and spin while soaring, thereby losing visual contact with their destination. As a result, they often collide with surfaces in awkward positions and cannot properly absorb shocks (see Fig. 10). Early exhilaration appears to promote overconfidence, and subjects could easily be injured were it not for the padding within the area.

Unsuccessful flailing responses are usually noted when the subject becomes aware that he is rapidly closing with an object. In the dark cabin, many subjects continuously protected their faces with upheld arms in efforts to fend off collisions with unknown objects. (Standing in the dark was difficult - several subjects had hard falls during the excessive g period, because of their inability to align and hold themselves perpendicular to the floor.)

Techniques for properly dissipating momentum should include the following considerations:

(1) Velocity at moment of impact - self-propulsion units should be in low thrust class (ref. 36); long tether lines should not snap the worker when

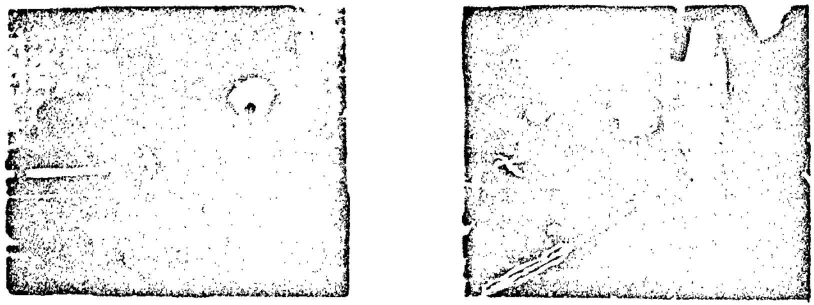

Figure 6. Inadvertent Soaring Collision

the line becomes taut (the proper damping characteristics of a tether are being determined);free soaring should be held to 10 mph or less.

(2) Impact of landing is directly proportional to the mass of the body - it is best to discard high-mass objects before impact; it is extremely dangerous to be caught between two colliding masses.

(3) The amount of body surface area through which the impact is absorbed - the standard break-falls of judo represent effective methods for spreading the impact over large arm and body areas.

(4) The distance through which deceleration takes place - the arms and legs should be used as shock absorbers; like the standard stance of the parachutist, the limbs should be nearly but not quite extended at the moment of impact. Limbs locked at the joints may cause high-g low-time shocks to the torso.

(5) The part of the anatomy subjected to impact - damage to the head and vertical and whip-lash extensions and compressions on the spinal column must be avoided by developing proper restraint and tether designs.

(6) Properties of the surface on which the body lands - extensive padding will be necessary. The deformability and compressibility of the landing surface will make an enormous difference in the seriousness of impacts.

Applications:

(1) Collision anxiety can be reduced by extensively padding all surfaces, by providing safety guards over moving equipment, and by having the subjects wear protective gear (helmets, suits).

(2) Overcontrol, the main cause of inadvertent collisions, can be sharply reduced with short training flights.

(3) Augmented self-stabilization may be a minimum requirement for accomplishing orbital transfers in order for the worker to maintain a proper visual reference and to close feet first with the target surface (ref. 36).

6. Illusions - The complex acceleration pattern of the aircraft maneuver sometimes induced real and apparent motions of the moon and rotations of the environment but these illusions tended to decrease with continued exposure.

Examples:

(Diver) "I'm floating on the ceiling, I can see the moon, I feel exactly as if I was standing on my hands." (Diver) "I had the sensation of being on my back, going straight up, when I was walking down the cabin." (Pilot) "I am standing and the moon is moving up." (Astronaut) "The moon moved in a jerky motion, I think because of the turbulence of the aircraft." (Diver) "The moon moves during the 2 1/2 g." "I was walking toward the moon and had the feeling that I was walking in a vertical plane, actually straight up."

Discussion:

Gross motion activity by the subjects during the weightless interval in the dark often increased disorientation and surface-reversals. Often these motions were interpreted as confusions over surface location (surface-reversals), for example, "I'm not sure whether I'm on the floor or the ceiling." These motion induced illusions were noted by many subjects and were frequently noted by spinning subjects who experienced a rapidly moving visual field. Schock (ref. 34) notes that, "Utricle stimulation during the g transition periods of the parabola often induce illusory motions of the target. Illusions incurred during aerial flight have been reported since the beginning of aviation. In the dark, changes of the apparent position of a fixed target result when subjects are exposed to linear and radial acceleration while flying a ballistic trajectory." Gerathewohl (ref. 7) also found with harnessed subjects that during the weightless portion of the trajectory the target appeared to stabilize, then to oscillate up and down as the subject (by virtue of aircraft motions) made excursions into negative g and positive subgravity states. Graybiel (ref. 12) found a direct relationship between the acceleration acting upon the human body and the apparent displacement of the visual target.

Frequent turbulent oscillations of the aircraft also caused many real and apparent motions of the environment about the subject.

Applications:

(1) G transition periods and activity under weightlessness may induce apparent target motions; the rates of onset of these illusions may determine desired rotation rates.

(2) Planned exposure in aircraft facilities, which may reduce illusion propensity, should be included in training programs.

(3) Illusion resistance might serve as a crew selection index.

(4) Self-maneuvering units should have low thrust levels due to complex line-of-sight and deceleration programming requirements coupled with this potentially hazardous effect.

(5) Autokinesis (apparent target motion without subject motions) might be investigated with weightless subjects suspended with six degrees of freedom of motion.

7. **Sense of Zero, Fractional and Excessive g's** - Subjects often commented on their kinesthetic and tactual responses to changing g loads. The frequency of these comments increased with subjects who were making surface contacts and performing in the dark (no visual distractions).

Examples:

(Non-pilot subject in dark trial) "I'm at .5 g now, feel a slight rising of the head...the g's are increasing now, it started on 3/10 of a g." (Non-pilot subject in dark trial) "Still feel bodily sensation in the seat of my pants and back...becoming lighter all the time...very light, feels like I'm on 0 g." (Astronaut) "Feeling of weightlessness approaching is more apparent when seated than when standing, at .1 g, this is all you need for locomotion." (Chief, USAFSAM) "I had the feeling there was an upward force on my arms."

Discussion:

The sensation of tactual release following a surface contact was constantly reported. King (ref. 20) postulates that "Man's total sense of touch input is determined by the number of stimuli received and the adaptation characteristic of the stimulated receptor. It may be anticipated that there will be a reduction in the total sensory impulses from these receptors." The total input and rate of tactual decay might be measured in a future study by comparing two-point thresholds under 0 and 1 g conditions. The kinesthetic response to fractional g loads (between +1 and 0 g) is currently being explored in the aircraft with the use of a decay maneuver. The g level can be gradually diminished from .5 to 0 g over a 30-second time period at the rate of -.017g/sec. This capability offers the experimenter the potential of identifying the particular g level associated with a behavioral response.

Haber (ref. 16) points out, "The function of the gravity sense becomes particularly critical in the proximity of g = 0. As can be read from the curve (Weber-Fechner Law, which maintains that the intensity of the sensation is proportional to the logarithm of the corresponding stimulus) strong sensations are caused by minute changes of acceleration, if man is subjected to states of gravity close to zero. Yet accelerations of critical amounts are already produced by voluntary and nonvoluntary movements accompanied by correspondingly strong sensations of acceleration at g = 0. At g = 1, such small additional accelerations are below the threshold according to the Weber-Fechner Law." Loftus (ref. 24) discusses the unique opportunity that a reduced gravity environment will offer to study these lower ranges of sensory phenomena.

Haber (ref. 15) correctly assumes that "during body movements the forces of inertia will lend weight to the body in proportion to the acceleration applied." In other words, weightless subjects may perceive limb accelerations as increased weight sensations.

Applications:

(1) Definition and development of g cues may aid workers in aligning materials where small accelerations of mass and man may be important factors.

(2) Crew selection and various induced g criteria may be developed for orbital workers and rotating crew stations design by establishing the exact g load that caused some of the effects discussed in the report. For example, the start of reentry of the first Mercury flight was the transition from 0 to .05 g (ref. 4). In emergency conditions, man may be called upon to sense this reentry mode.

8. Sense of Heaviness after Maneuver - The sensation of having more than 1-g body weight appears to be most pronounced when subjects walk immediately after the excessive g portion of the parabola. This sensation was reported to exist for hours after a flight of 20-30 successive maneuvers.

Examples:

(Author) "I perceived myself as being heavier than normal in the 1 g condition after the run, however, the 2 1/2 g recovery undoubtedly influenced this perception." (Diver) "Comparable to heavy sensation after coming out of water after several hours of immersion." (Diver) "Heaviness seemed to be much greater, two times as much, after weightlessness than before it." (Pilot) "When I drove my car home after the flight, I felt different and the steering wheel felt lighter."

Discussion:

The giddy feeling of free-soaring is suddenly replaced with a captive sensation of increased heaviness. Any psychophysiological measure of this effect, however, would have to carefully consider the subject sample; i.e., (Navy psychologist subject) "Any significant short term effects, experimentally, can be found only in persons who are highly tolerant of g stress. Without such tolerance, the g effects probably persist throughout the short weightless period and mask the effects of weightlessness, if there are any."

Applications:

(1) Gravelin's (ref. 13) concern with the reentry phase, "Operator performance and human tolerances will probably vary during reentry into g

fields. The faster the reentry rate, the more pronounced will be the behavioral changes" suggests special requirements for the operator. For example, a basic psychomotor task concerning vehicle control may involve the operator's movement of a control, while referring to a moving display element. The ratio of these two movements is called the control/display ratio. Because of the previously mentioned behavioral changes affecting control motions, a variable, g geared control/display ratio system might compensate for psychomotor adjustment during the reentry period.

(2) Periodic active work schedules involving gross motor activity may help to alleviate the post-flight adjustment problem.

(3) A possible crew selection criterion may be the ability to tolerate excessive g loads following weightless periods. As McKenzie (ref. 26) noted, purposeful activity which also includes counteracting gravity adds to the neuromuscular "debt" and individual response to this "debt" after reentry may differ between individuals through wide ranges.

9. **Decrease of Clothing Pressures** - The first subjective indications of fractional g for many subjects was their tactual response to a decrease of clothing pressures. Loose clothing lost its "down hang" and tended to configure itself as dictated by the last limb motion.

Example:

(Non-pilot subject) "I feel my clothing pressure decreasing." (Non-pilot subject) "My leg hairs were tickled by my pants."

Discussion:

Movies of subjects wearing loose clothing (Extra) reveal that apparel tends to oscillate out of phase, or lag behind limb manipulations (see fig. 11).

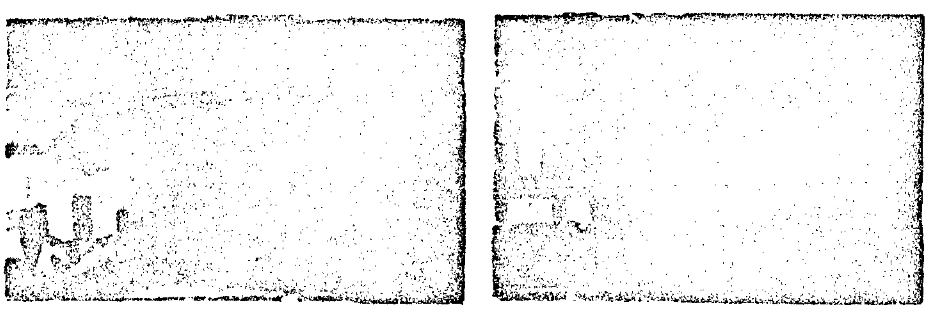

Figure 7. Out-of-Phase Clothing Motion

Applications:

(1) Crews not requiring pressurized apparel should probably wear form fitting, easily flexed clothing with elastic cuffs on limb extremities. Clothing designs should allow g-free limb activity and not be based on an earth bound "hang" motif.

(2) The response to decrease in clothing pressure might serve as a tactile measure for g perception, especially during the 1.1 to 0 g transition period.

(3) Pockets should fasten securely so that their contents will not inadvertently be released.

10. Nausea and Motion Sickness - The majority of naive subjects showed various symptoms of motion sickness. This effect may have been stimulated by physiological responses to excessive g and the rapid g transition periods, apprehension over inflight hazards, conflicts between visual and gravital inputs, and rapid introduction to an unusual environment in which the subjects have had no experience.

Examples:

(Excerpts from non-pilots' transcription. Flight was aborted due to subject's intense malaise) "Here we go... okay, I'm tightening up ... feel my head, my stomach, my hands are all okay it's kind of an up-raiser but I'm tightening up okay ... got a little bit of a headache ... starting to get warm ... starting to get warm ... I felt like I thought everything was going to come out my back because I'm laying on my stomach ... I'm a little bit dizzy right now a little bit dizzy I feel myself starting to pull away from the floor ... ooh, I feel my throat oh, it feels light ... just ever so light ... still feel tight around the throat ... just loosen my collar a little bit ... pretty warm ... I feel prickly ... oh, felt a little bit gassy in my stomach that time ... starting to sweat ... feel like coughing quite a bit ... my arms are, my hands rather, tingle like I guess some poor circulation ... I feel a terrific pressure in my feet now in my hips and my stomach - right in the pit of my stomach ... it seems to be laying right there and my calves felt a little bit tight there ... my calves feel like they are real thick ... now I feel real loose ... (cough, cough) and dizzy ... feels like I have a rock in the pit of my stomach ... I don't feel like moving my head for when I do I get dizzy - my back feels cold like water and moisture is drying ... oh, that rock in my stomach just lifted a little bit ... oops, now it started bouncing around ... now I'm swaying all over ... feel real heavy ... feel real heavy ... oh my, the muscles tighten up so on that ..." (Dr. Clemen, Chief, USAFHAM) "Visceral sensations disappear during weightlessness, but are excessive during the transition period."

Discussion.

Dr. H. von Beckh thought that he became sick as a C-131 subject: "largely because of the extremely short recovery (physiologic adjustment) period at the end of the maneuver. I have flown parabolas in fighter aircraft for many years and had never been ill. The fighter aircraft parabola involves more g's (4-4 1/2 g); however, the transition periods are much longer."*

Von Beckh (ref. 39) reports an incidence of motion sickness of one-third of his subjects used for experiments in fighter aircraft. He notes that (a) "the subject in the fighter aircraft is highly restrained within the small cockpit, which is further reduced in size by numerous recording devices. In the C-131, however, the subject is allowed to float freely and is even able to perform some acrobatics like forward and backward somersaults. Additional labyrinthine stimulation is therefore probably present. In addition, in the fighter aircraft the subject is restrained in the harness of the parachute and tied down by shoulder and lap belts. It is obvious that this restraint would diminish the 'Ballottement' of the viscera, especially of the abdominal organs of greater weight; e.g., the liver. (b) In the fighter aircraft experiments, the subject is busy from takeoff to the landing attending the often rather complex recording devices such as the motion picture camera, -- etc. In addition he retains visibility out of the cockpit, can follow the flight maneuvers and feels, therefore, more a part of the aircraft than the free-floating subject in the C-131. (c) In the fighter aircraft the subject hears the voice of the pilot, who gives him instructions, but he does not feel observed by crew members and other subjects as in the C-131. The fear of becoming motion sick in the presence of others may in itself precipitate vagal symptoms." In addition, motion sickness can be induced by the examples of others through visual, auditory and olfactory pathways. Gerathewohl (ref. 9) points out that during the pushover there was less sensation of viscera displacement with unharnessed seated subjects than with harnessed subjects (in fighter-type aircraft). Early in 1959, Minkervitzova (ref. 27) flew with three doctors in several consecutive 5-second long parabolas over Austria and reported that "all of the test crew became ill and nauseated, including reporter."

Haber reported that disassociation between various qualities of perception and sensation may well produce a spatial counterpart of airsickness (ref. 15). Recent investigations (ref. 39) have revealed that a disharmony of the perception and sensation complex (in a normal 1-g environment it would be a conflict among gravital and visual cues) can induce certain forms of seasickness. Crossfield (ref. 8) reported befuddlement during the g transition, but this feeling disappeared after the fifth flight. He stated that he experienced vertigo occasionally on the pullout.

Dr. Clamann** suggested that the reason his twelve flight surgeons did not become ill on successive weightless indoctrination flights in the C-131B was because of their intensive training in positive g. He proposed that

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* Dr. H. von Beckh, Personal Communication, Aerospace Medical Field Laboratory, Holloman AFB, New Mexico, 8 August 1960.

** Personal Communication from Dr. Clamann, Chief of Space Medicine, USAFSAM, San Antonio, Texas, 26 June 1961.

centrifuge activity, including rapid g transition periods and extensive Coriolis effects following head motions, would be an ideal method for selecting and training space candidates.

Airsickness appeared to decrease among (a') pilots (when flying the aircraft), (b') subjects who entered the maneuver from a supine position, (c') subjects in flights that used less than a 2 1/2 g parabola entry, and (d') experienced subjects. Airsickness tended to increase (a) among idle subjects, (b) whenever the cabin became uncomfortably warm, or (c) when maneuvers were flown in consecutive pairs.

In general, those suffering from nausea, vomiting, and vertigo complained that the increased acceleration and the changing gravity encountered during the trajectory were probably responsible for those disturbances.

Applications:

(1) The lack of this symptom may be a useful crew selection criterion. This effect may not be an important weightless problem <u>after</u> crew selection, since exposure time and practice appear to be physiologically beneficial for adaptation to the weightless state. This agrees with Gerathewohl's findings in earlier work on the same topic (ref. 9). Lawrence (ref. 23) agrees that "95% of individuals studied can develop a tolerance to unusual motion. Suppression of sensations and responses may develop in non-professional skaters in 6-7 weeks."

(2) Motion sickness might be anticipated in space when workers undergo rapid g changes.

(3) Supine or prone positions should be used during transverse accelerations.

(4) The rate of g transit can be lengthened in the maneuver by sacrificing weightless time for entry and exit time. In addition, a 1-g entry (rather than 2 1/2 g) by the C-131B will yield 6-8 seconds of weightlessness and thus a normal entry can be used as a control condition.

11. Task Incompletion - Decrease in Span of Attention - Many subjects failed to accomplish simple tasks during the short weightless period. This effect was considered as a typical stress response and not specific only to the weightless condition.

Examples:

Several subjects successfully performing gross psychomotor motions became confused when their seat belts were loosened (Extra). Monitors who had extensive training and who were indoctrinating the Astronauts in methods of self-locomotion occasionally forgot specific tasks to be performed immediately after instructing their subjects. (Diver) "I became completely disoriented when untangling myself from a rope." (Photographer) "Requires more concentration to do even simple tasks." A free-floating photographer forgot to operate the camera shutter on four successive parabolas. Pigeon handlers needed an independent monitor to call out simple tasks to them to insure program completion (Extra).

Discussion:

This behavior may be a stress response by naive subjects performing in unfamiliar environments during short periods of time. During the exhilaration and excitement of the moment, subjects frequently, and monitors occasionally, do not perform simple duties. Bond* suspects that "since the physical phenomena are novel, one centers on one item at a time; however, increasing experience should eliminate this."

Under actual long term weightlessness, King (ref. 20) supposes that "a decrease in the state of alertness and a performance decrement can be anticipated due to the lower total sensory input" whereas the subjects in flight are reacting to higher than normal acceleration inputs over extremely short time periods (transition periods).

Applications:

(1) A criterion for space crew selection might be the adaptation rate of subjects to unusual environments over short time periods.

(2) Emergency tasks should be assigned to tethered operators rather than free-floaters.

(3) Task analyses of operator duties in space vehicles should include a time constant to allow free-floating workers to reorientate to a work position.

(4) Training periods tend to rapidly increase self-confidence as shown by the subjects' ability to shift their attention from concern over body position to task completion.

12. Harness Irritations - When parachute harnesses were securely snubbed, they tended to limit g-free activity.

Example:

"My harness seemed tighter under zero g."

Discussion:

Subjects have complained of harnesses that gouge them and have readjusted buckles after free-floating. A basic kinematic description of the dynamic interactions of body segments in a surface-free environment may be needed to indicate optimum restraint points.

Applications:

(1) Harnesses and wearing apparel should be designed for g-free limb activity. They should allow for unusual limb positions and sudden limb accelerations.

* Personal Communication, Commander Bond, Ibid.

(2) Harnesses should protect against accelerations and decelerations.

13. Helplessness between Surfaces - Subjects who have dissipated their linear motion by colliding with other subjects or who had the floor "flown out from under them " have found themselves unable to reach a surface.

Examples:

(Diver) "I'm coming off the floor, ain't doing nothing, floating up, I'm in the air now, bumped something, I hit the top, I think I don't know where I am, I'm just hanging here motionless." (Diver) "The feeling of helplessness comes from the fact that I don't know which way I'm going to end up or how hard I will end up." (Diver) "Helplessness feeling is diminished after successive runs." (Diver) "I was never dizzy, but very helpless." "I'm in a ball but I can't make myself tumble."

Discussion:

Once free of a surface, the subjects could only oscillate (by use of limb movements) in one place or return to the surface by throwing an object (expending mass) in a direction opposite to the surface.

Implications:

(1) Life lines will probably be required for all workers outside the vehicle.

(2) Emergency techniques (expending mass) for returning to a surface should be developed and included in training programs.

C. <u>Motion Effects</u> - The short term effects of weightlessness on the harnessed, surface-attached operator are aptly summarized by NASA pilot Joseph Walker.* After an extensive discussion of the panoramic details of his first 2-minute weightless parabola in the X-15, he concludes, "All the foregoing was accomplished at zero-g and serves, I think, as a fit commentary as to whether the human can function under these conditions. In fact, I was mildly disappointed that my stay wasn't longer. Two minutes of weightlessness are no more of a problem than lesser periods." The Russian cosmonaut selection program included training flights with periods of weightlessness lasting 40 seconds. It was found that all trainees stood up well to weightlessness. "In addition, they could take in liquid, semiliquid, and solid food, perform subtle coordinated movements (writing, purposeful movements of the hand), maintain radio contact, read, and orient themselves in space visually" (ref. 37). In his flight,

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*Walker, J. A., op. cit.

Cosmonaut Gagarin reported that he felt well throughout the period of weightlessness and his working ability was completely unimpaired (ref. 19).

The unharnessed operator, however, faces new problems of body control and this section discusses some of the unique problems he will have in maintaining on and off-surface body positions.

1. **Body Resilience Motions** - Passive subjects showed a tendency to leave surfaces following surface-to-body directed accelerations of the vehicle. The sudden relaxation of g-compressed tissues and padding may compose enough force to launch passive subjects.

Example:

(Astronaut) "Body resilience will force you off the floor."

Discussion:

Passive subjects lying prone on the floor sometimes rose from the surface after attaining weightlessness while hard (nonresilient) objects of the same approximate mass remained on the surface. Compressible items with greater mass than man (such as mattresses) may have been accelerated at a slower rate and never were seen to leave the floor. This spring-type reaction may follow from body or vehicle motions.

A plot of body and body on cushion deflection might appear as shown on figure 12. A very low order nonlinear body motion response may follow either a rapid excessive g push and release condition, or a simple push of the subject into the seat while weightless.

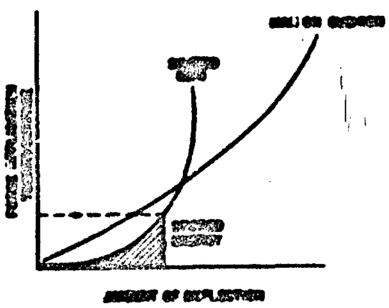

Figure 8. Plot of Probable Body Resilience Deflections

Applications:

(1) Sleeping crew members must be restrained against their surface directed motions.

(2) Compressible masses containing spongy materials should be restrained during varying vehicle accelerations. The increased spring constancy of a cushion would probably increase the subject's launch velocity after a surface-to-body directed motion of the vehicle or body-to-surface directed motion of the subject.

2. Self-Induced Motions - The next five effects deal with self-induced limb motions and their effects on body motion. Motion performance can be characterized in terms of speed and accuracy of the movement, and of the strength that is required or that can be applied in executing the maneuver (ref. 2); however, for the purpose of this report, only observed gross body motions were noted and standards or scales of speed and accuracy and force application were not recorded. Only the resultant motion behavior of the free-floater after performing the eight gross motor activities used in this report (App. I) were observed. The activities were chosen for their ability to suspend the man between surfaces, cause translations and rotations, and increasingly promote proprioceptive feedback.

These action-reaction motions of surface-free subjects indicated new problems of overcontrol, stabilization, self-rotation, and orientation that do not concern the harnessed operator.

a. Swimming Motions: In the lighted cabin naive subjects showed an initial preference for swimming or flailing limb motions (fig. 13). These motions appeared to be attempts (unsuccessful) to self-rotate or regain surface contact.

Examples:

(Pilot) "I am confident of control because there is air to swim in."
(Diver) "Swimming motions effective in altering position."

Discussion:

Subjects reported these motions as attempts to (1) move forward, (2) stabilize themselves and (3) turn around. The motions rarely accomplished factors (2) or (3) and tended to aggravate motion instead of allowing the subjects to stabilize. A few self rotations were awkwardly accomplished, but precise control was absent. One cannot translate or move the center of gravity (attempt (1) without expending mass from the system or applying an external force.

Applications:

Techniques for self-rotation are being developed, and training in these methods are being accomplished in short-term weightless facilities. The techniques are based on biomechanical analyses of methods for transferring angular momentum by limb manipulation (ref. 22).

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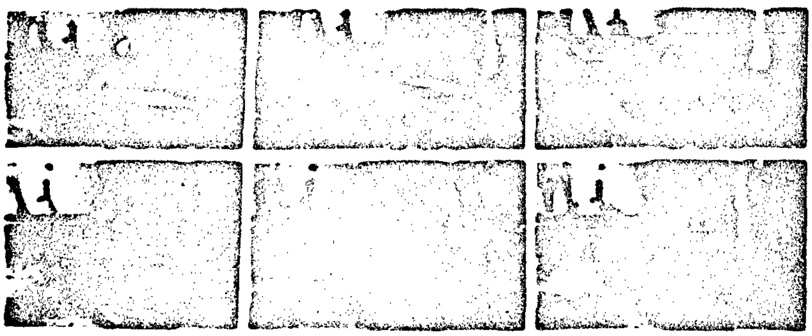

4 5 6

Typical Unsuccessful Swimming Attempt at Zero "g"

Figure 9. Swimming Motion

b. Cross-Coupled Motions: Subjects absorbing foreign (aircraft motions, etc.) or self-imposed inertial forces found themselves initially rotating about a single axis. Successive movements often induced coupled or multiaxis rotations.

Discussion:

Three-axis freedom complicates the control problem for an unstable g-free, flexible subject who has an oscillating center of mass and interacting products of inertia among his limbs and body. Single-axis rotations may immediately couple into multiaxis rotations. Almost any motion by the subject to alleviate a spin only increases his spin complexity.

Subjects expending mass by throwing articles or utilizing air-reaction devices were spun into three-dimensional spins (Extra). Two subjects attempting to handle a material between them by cooperating with simple torque tasks on a common board (fig. 14) normally ended their trials in a tangle of arms, legs, and material (Extra).

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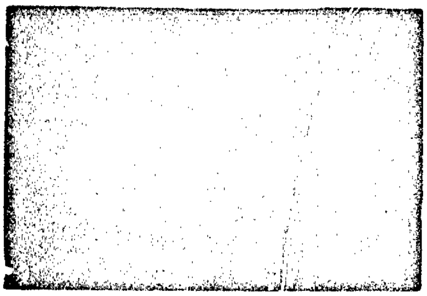

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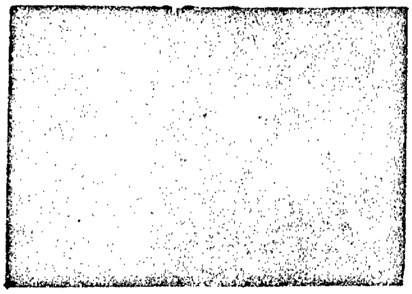

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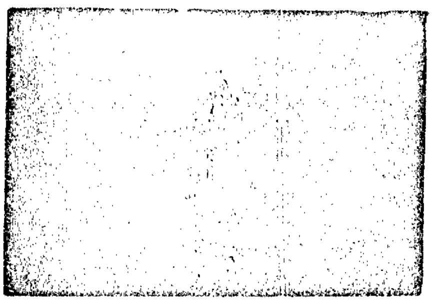

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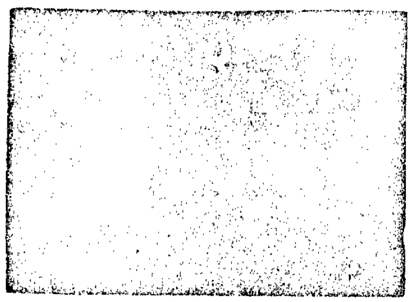

Figure 10. Torque Tasks on a Common Board

Applications:

(1) Techniques for shifting a multiple-axis rotation to a single-axis spin of the body could be computed with dynamic analyses of a flexible form and verified inflight in order to predict orbital tumble behavior.

(2) The extension of limbs will reduce the rate of spin and this rpm decrement could be established for the flexible worker for various postures and additions of mass.

c. Uncontrolled, Pendulous Motions: Subjects tended to wobble about their point of anchorage. Self movements of the limbs produced residual oscillations throughout the body causing unstable work performance, poor translation, and poor attitude and position control. Limb motions toward the surface often suspended the subjects adjacent to the surface.

Examples:

(Diver) "My legs seemed awkward." (Diver) "I was ungainly suspended, didn't have the control I have in the water, even with a handhold." (Diver) "No problem of fine tasks requiring finger dexterity, however, movements involving elbows and shoulders more difficult." (Diver) "As soon as I dropped my arm down my feet came off the floor and I started floating around."

Discussion:

A point of surface contact helps the subject remain at a surface; however, surface-free interacting moments of inertia of the limbs may induce sloppy performance. Surface-attached subjects tend to oscillate about their ankles and look as though there were water currents disturbing them as they expend much energy trying to stabilize themselves against their own self-induced motions (ref. 35).

Subjects moving masses toward the surface, move their center of mass away from the surface, and leave the surface.

Applications:

(1) Unharnessed subjects should not be required to perform motions requiring accurate movements without training.

(2) Open muscle systems must be avoided and man should exert a force against himself (ref. 18); e.g., a window washer, using his safety belt attached to a building, is employing a closed muscle system when he pushes against the belt with his back and the building with his feet.

(3) Hazardous machinery should be guarded against uncontrolled operator motions.

(4) Tether designs may be based on the minimum degrees of freedom of motion required for completion of a job.

d. Soaring: Subjects are able to soar through space with comparative ease, but without extensive training they will usually suffer undamped slow rotations (inadvertent tumbling), because of poor launch techniques (fig. 15).

Examples:

(Diver) "Soaring is very similar to training tank at neutral buoyancy." (Pilot) "The biggest enjoyment in free-floating is the sailing." (Diver) "The trip to the moon (task 5) pretty much corresponds with a dive starting from neutral buoyancy and perhaps passing through neutral to negative buoyancy. Of course you have a relative water (sic) around you and it isn't exactly the same, but the feeling, I believe there is some correlation."

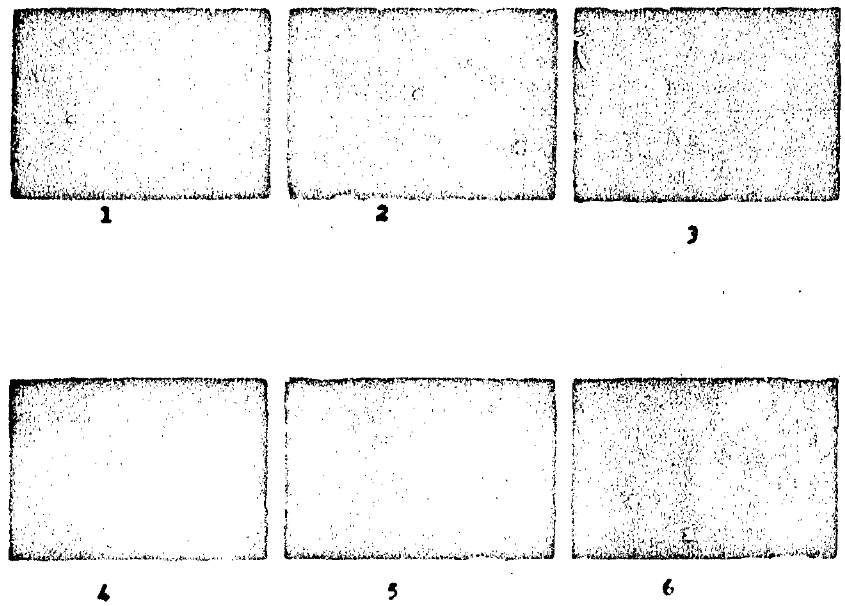

Figure 11. Free-Soaring Failure

Discussion:

Haber (ref. 15) states, "In a state of weightlessness, the muscles would need to overcome only the body's inertia, but they would behave as if they also had to reckon with its weight. Hence the slightest effort by the space traveler to move his body would jerk him across the room." Actually, the slightest force will not jerk a subject, but will gently release him from a surface (see ref. 36 for propulsion force requirements). The maximum speed attained with full leg pushoffs is only 10 mph (ref. 28).

Soaring subjects often propel other subjects or materials on contact and transfer some of their energy to a rotation of the second party. This is similar to the way a billiard ball can propel another ball, with the angle of divergence dependent upon the closeness of the points of contact to the balls' respective centers of mass.

Applications:

(1) Subjects will require training for accomplishing short, straight, and stable flight paths.

(2) Attitude control will be a requirement for flight paths requiring more than one thrust impulse.

(3) Orbital trajectories for single-impulse motion performance (soaring) indicate a need for safety lines for all personnel outside a vehicle and their knowledge of and training in orbital motions.

(4) Minimum soaring volumes should be established and configuration and arrangement of handholds determined for locomotion within space vehicles.

e. Difficulty in Walking (Task 4, see App. I): Without handholds or attachment devices, normal walking is impractical during weightlessness and propels the walking subject from the surface.

Examples:

(Diver) "Walking seems awkward." (Photographer) "I'm continually looking for something fixed to the aircraft to hold onto." (Diver) "It appears to be slippery."

Discussion:

The 1-g walking gait is a push-pull operation. The push is upward and forward through the longitudinal axis of the body. The swinging leg moves forward and decelerates. There is a transfer of energy (pull) from the decelerating (swinging) leg to the remainder of the body, thus promoting a smoother forward motion of the center of mass. The heel of the swinging leg then strikes, following which, the toe is eased down placing the foot flat on the ground. The next cycle begins with a pushoff by the other leg.*

The initial push propels the subject from the surface under weightlessness. Subjects usually expend more energy keeping themselves in contact with a surface than they would require to soar above it. Subjects are able to walk spider fashion, i.e., hands on one surface and feet on opposing one, between close parallel surfaces.

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* Personal Communication, Dr. H. J. Ralston, Biomechanics Laboratory, University of California, San Francisco, California, 5 June 1961.

Divers report that, in water, a gliding, acquisitive motion of the feet (pussy-catting), with all of the body mass accelerated in the horizontal (parallel to surface) direction, produces a successful walk as long as there is no vertical motion or bounce.* This technique may be adequate for low, positive gravity fields.

Applications:

(1) Handholds in large vehicles, adhesive footgear, and/or tethering hardware will be required for walking. Some of these are being or have been tested at the 6570th Aerospace Medical Research Laboratories (fig. 16, ref. 17).

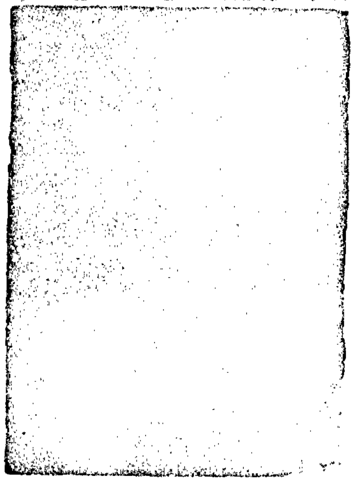

Figure 12. Weightless Walking - Adhesive Footgear

(2) The walking gait should be studied in order to determine motion principles and hardware requirements for walking under weightlessness, partial g, Coriolis forces, excessive g conditions, and on curved surfaces that may be encountered on other planets and vehicles.

D. Miscellaneous Effects

1. Rigidity of Powered Tools (Extra) - Subjects using free-floating gear containing electric motors can feel the rigidity-in-space characteristic of the rotating motor. Some rotation about the motor axis may be encountered due to the motor's bearing friction.

Example:

(Photographer) "I can feel my (motor driven) camera fighting me when I turn it on."

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* Personal interview, Diver, U. S. Naval Submarine Base, New London, Conn.

Discussion:

Subjects who attempted to reposition handheld electric drills (power on) may turn themselves about the drill when they apply torques against the spin axis of the motor. This principle was used to stabilize subjects and as a method for controlled rotation (ref. 36).

Applications:

(1) Orbital workers using handheld powered equipment may require different stabilization requirements.

(2) Workers performing aligning-of-material tasks may find that simple motor-stabilized assemblies tend to resist external forces and thus serve as semistable platforms.

(3) Camera motors, etc., within free-floating capsules may impart forces to the entire assembly.

2. Suspension of Dust and Objects - Inadequacy of Open Containers - Particles, fluids, and objects float freely, and soaring subjects dislodge and propel this debris. Loose objects within closed containers have become damaged and open containers have lost their contents during aircraft turbulence or when touched by subjects in motion.

Example:

(Diver) "I thought I was seeing spots before my eyes until I realized they were dust particles."

Discussion:

Free-floating subjects continually lose paraphernalia from unzipped pockets. Cameras, socket wrenches, parachutes, sandwiches, and even standby subjects have floated off when not properly restrained or when touched by other objects or persons. Brittle foods carelessly eaten will crumble and litter the environment. Mislaid tools are often difficult to find after a mission, because continuous aircraft oscillations tend to sift them into small crevices.

Applications:

(1) Continuous air filtering may be a requirement around intricate equipment.

(2) All objects should be secured and padded or smoothly configured if they are used frequently.

(3) Containers of the shaker and sprinkler type should be avoided for their contents will only contaminate the air.

(4) Damageable objects should be restrained within containers and tools should be tethered to the worker as well as to the storage surface.

Tethers should be short in length, since an accelerated object on a long tether could encircle and bind the operator.

(5) A tiedown system enabling a limitless object arrangement and rearrangement might help relieve the boredom of long periods of travel in a confined space. Haber (ref. 14) may have been somewhat overconcerned when he suspects that, "unremitting struggle with the weightless objects would add to the psychological stress of the travelers."

3. Physiological Effects - The following incidental physiological factors were noted or conjectured by selected subjects and were not studied for accuracy or reliability. They are included only as potential problems of interest to bioastronautics personnel and may be caused in part by the maneuver artifacts previously discussed or may reflect an idiosyncratic response of the subject. Knight (ref. 21) warns that "Physiologic measurements as can be made in a given zero-g ellipse represent responses not to a simple experience, but rather to the entire complex of accelerative change demanded by the flight profile."

The following list of physiological factors does not appear to contradict Haber when he states that, "The condition of weightlessness is not likely to produce any disturbances in the major functions such as respiration or circulation" (ref. 19).

a. (Diver) "Nasal drip - was forced down throat with normal swallowing motion."

b. Tears - adhered to the eye because of surface tension and spread over the surface of the eyeball [noted by Psychologist referring to an airsick subject].

c. Eye sensation - Gerathewohl (ref. 9) reports that a "lifting sensation that resembles pressure on the lower portion of the eyeballs is felt but failed to prevent the eyes from functioning normally." (This has not been noted during AMRL tests and might be a response to the higher g entry of fighter-type aircraft).

d. Talking - (Diver) "Every time I started to free float I could not talk for a few seconds." This never appears to happen with experienced subjects, but was reported by two naive subjects and may have been due to the stress of the inflight situation.

e. Changing ear pressures - In both aircraft, the cabin pressure rate-of-change indicator needle often traveled to the plus and minus limits, indicating extreme changes during the maneuver (2500 ft per min.). This artifact, produced by the aircraft system, has induced such comments as "Weightlessness is making my ears pop," and "I feel a pressure on my ear drum." Two subjects spinning at rapid rates mentioned ear sensations; however, the spin axes and rates were not recorded. These sensations may have been stimulated by centrifugal forces acting on the head.

A diver noted that, "any movement in the water can directly be felt, in the water the pressure change is much greater and you can tell if you are moving up or down by pressure changes in the ear drums."

f. Valsalva - Difficulty was reported in performing the valsalva maneuver after free-floating by two subjects. (This is a method of equalizing pressure on the eardrums by forcing ambient air through the eustachian tubes to the inner ear.)

g. Chills - were infrequent symptoms of nausea and a cold cabin. The temperature was kept low (45° to 65°F) in an effort to lower the airsickness rate.

h. Regurgitation - Many motion-sick subjects regurgitated constantly, and one officer assigned to this project for over two years (logging 600 parabolas) emptied his stomach almost every flight. As King postulates (ref. 20), "In the absence of nongravitational force, no density gradients can exist. Thus, regurgitation of semisolid stomach contents would probably increase, since this function, dependent on differences in density, will be inoperative in weightlessness."

i. Sweating - Because most airsick and some non-sick subjects sweated profusely, cabin temperature was maintained at a chilly level. Body cooling is dependent upon heat convection and may not function in weightlessness. King (ref. 20) notes that heat loss by convection and evaporative cooling will be reduced, and also that subjects may be trained to aid heat exchange by voluntary movements of limbs and body.

After the first U. S. Suborbital space flight (ref. 7), physiological responses to five minutes of weightless flight (interrupted by 23 seconds of retrofire) were found to be uneventful. Vision, semicircular canal function, and hearing appeared intact throughout the flight. Astronaut Shepard was able to operate a complex vehicle with no significant reduction in performance; however, Cosmonaut Titov, an unharnessed, relatively free operator, apparently suffered canal sickness (ref. 19).

SUMMARY AND CONCLUSIONS

A general design concept, named g-free, was derived from and applied to the various sensations and performance factors listed in Table I. This concept reflects the use of the gravity-free environment as a focus, rather than forcing earth oriented behavior into the weightless state.

Table II lists the free-floating sensations and performance effects and hypothesizes the differences and similarities between weightless facilities and simulators in reproducing these effects. Meaningful future areas of research are also listed.

Admittedly, the behaviors in this report are limited to responses to very short weightless periods and their validity remains to be verified in orbital vehicles. The fact that the crude and short-term recording techniques used in this report have revealed unique responses suggests that there may be many long-term behavioral changes yet to be detected. Examples of unique weightless behavior are rapidly being documented: Simons (ref 38) has stated that the g-free walking gait is different than the 1-g gait. Ballinger (ref 1) noted "that orientation disturbances were observed when the subjects moved their heads during zero-gravity." Gerathewohl (ref 10) notes that "what we know is that disturbances are caused by additional accelerations. We cannot expect any Coriolis forces to be produced by head movement - when the vestibular system is at rest." Dr. McCabe* is conducting tests of rotatory nystagmus on the KC-135 and has hypothesized that there will be a sharp decline of this involuntary response during weightlessness. Strughold (ref 33) holds that "sensations around the nerve endings in the membranes around the stomach and intestines are not to be expected - and a space version of motion sickness is not necessarily to be reckoned with." Reese (ref 34) has found a significant difference limen between mass and weight discrimination abilities of subjects handling objects and Pigg (ref 29) suspects a small decrement of visual acuity.

The first consideration for developing hardware and optimizing performance should be the appreciation, acknowledgement, and use of these weightless behaviors. Restrictions and control of motion will be required; however, the potential power of g free man as controller, computer, servo-mechanism, power source, drive mechanism and material handler - i.e., the most intimate man-vehicle relationship ever conceived should guide all of our applications. Free-floating man is indeed both man and machine, vehicle and driver in one component.

*Personal Communication, Dr. B. F. McCabe, University of Michigan, Aero. Eng. Labs, June 1961.

TABLE I

SUMMARY OF SENSATIONS AND PERFORMANCE EFFECTS, INCLUDING HYPOTHETICAL AND KNOWN CASUAL RELATIONSHIPS AND APPLICATIONS

	CONDITIONS THAT PROMOTE OCCURRENCE OF EFFECT (See Methods)										POTENTIAL APPLICATION OF EFFECTS		
	Light Conditions			Weightless Conditions			Maneuver Conditions						
SENSATIONS EFFECTS	Light Cabin	Dark Cabin and Moon	Dark Cabin	Low Friction (Surface Behavior)	Free Body (Segment Interactions)	G-Free Stimulation	Rapid g Transition and/or Excessive g	Stress	Short Weightless Period	Aircraft Motion	DISCUSSION	Space Crew Selection	Space Crew Training
1. Exhilaration during Surface Freedom (pg 6)	X			X		X					Surface freedom can produce an exciting and enjoyable environment; training can eliminate preconceived fears and stresses; over-control due to enjoyment has been a hazard.		X
2. Comfort of Tactualess Support (pg 7)					X	X	X (Relief from)				Seating and sleeping accommodation design requirements may be based upon the relaxed posture of weightless man.		X
3. Sensation of Falling (pg 8)					X	X					Falling sensation may be induced by excessive g; g-free training quickly dispels fear of falling; surface free subjects do not report falling sensations.		X
4. Orientation Effects													
a. Knowledge of Limb Position (pg 10)	X								X		Posture orientation proposed as basic reference plane; orbital or space crew stations could be man-oriented rather than floor oriented; possibly	X	X

											those orbital candidates who exhibit body or field orienta-tion in a 1-g environment may be eliminated; omnidirectional (many operator-to-display position alignments) displays and controls may enhance work performance; knowledge of body attitude within dark field decays rapidly with g-free support.		
b. Knowledge of Body Position in Aircraft (pg 11)					X	X	X				"Overshooting" occurs in darkness, but knowledge of results aids quick adjustment; g-free controls may require less actuation force; single axis controls may restrict the worker's performance envelope; rapid movements are often perceived as limb weight.		X
c. Knowledge of Rotation (pg 15)		X									False rotation and underestimation of rotation knowledge are suspected; physiological tumble tolerances may be higher; even small rotations may cause visual target loss; attitude displays may require rate sensed indices of direction of spin.	-	X
d. Knowledge of Surface Location (p. 11)	•			X							Techniques must be developed to enable return to surface; g-free posture orientation reduces need for surface information; any surface may become a floor to the individual.		X
5. Concern over Collision-Difficulty in Absorbing Inertia (p. 17)	-					X	X		X	-	Difficulty in self-rotation produces collision anxiety; padding requirements are extensive; open machinery must be forbidden; over-control may be reduced with practice. Augmented self-stabilization and self-rotation are basic requirements.		X

6. Illusions (pg 19)		X				X	X				With proper crew training and selection plus display information there should be few [illegible] problems; high g self maneuvering units may induce illusions; autokinesis should be investigated.		X
7. Sense of Zero g, Fractional g and Excessive g's (pg 20)			X	X			X				Development of g cues may aid workers in aligning materials; crew selection and various induced g criteria may be developed for the precise g that induces each effect, normative behavior might then be estimated for functioning on planets and rotating space stations.		X
8. Sense of Heaviness after Maneuver (pg 21)						X	X				Variable control forces may aid psychomotor adjustment upon re-entry, active work schedules may aid in the maintenance of muscle tonus; a crew selection criterion may be the ability to tolerate g following the weightless period.		
9. Decrease of Clothing Pressures (pg —)					X	X					Apparel tends to oscillate out of phase on moving limbs; crews requiring only normal clothing should wear form fitting, easily flexed clothing with cuffs on the extremities; the sensation could serve as a tactile perception of weightlessness. All pockets should fasten securely.		
10. Nausea and Motion Sickness (pg 23)						X	X	X	X		Rapid g transition and perceptual sensation conflicts can cause discomfort that may be valuable crew selection criterion; supine position should be uses during transverse accelerations.		

11. Task Incompletion-Decrease in Span of Attention (pg 25)				X	X	X	X	X		X	This stress constant may serve as a crew selection criterion; emergency tasks should be assigned to restrained operators; task analyses for free-floating workers should include a reorientation time constant; training periods rapidly increase the span of attention.	X	X
12. Harness Irritations (pg 26)				X	X	X	X				Harnesses need not be designed to restrain a 1-g mass; harnesses tightened for 1 g activity tend to limit g-free limb activity.		
13. Helplessness between Surfaces (pg 27)			X	X	X	X					Emergency techniques for returning to a surface; e.g., expending mass, should be developed. A worker moving masses may inadvertently suspend himself.		X
14. Motion Effects (pg 27)													
15. Body Resilience Motions (pg 28)				X			X			X	Compressible masses should be restrained during varying vehicle accelerations; sleeping crew members should be restrained.		
16. Self-Induced Motions (pg 29)													
17. Swimming Motions (pg 29)	X			X	X	X		X			One cannot translate by swimming. These motions were mostly unsuccessful attempts to translate, stabilize, or rotate; turning requires extensive training in techniques of self-rotation.		X

b. Cross-Coupled Motions (pg 30)				X	X	X					A continuous external force misaligned from the center of mass, moves the center of mass (translation) and rotates it. Spinning subjects should extend limbs in order to reduce RPM. A stabilization device could control rotation before, during, and after translation. The addition of mass to the man should consider a dynamic analysis.	X	X
c. Uncontrolled, Penduleus Motions (pg 32)				X	X	X				X	Self-induced motions tend to oscillate a body causing unstable work performance, poor translation, attitude and posture control. Unharnessed operators should not be required to perform gross motions requiring discriminating movements. Open force systems must be avoided and man should work against himself. Hazardous machinery should be guarded against uncontrolled operator motions.	X	X
d. Soaring (pg 32)	X	X			X	X					Improper launches cause inadvertent rotations. Subjects can be trained to accomplish straight and stable flight paths. Attitude controls will be required for flight paths requiring more than one impulse. Tethers will be required for all personnel soaring outside of a space vehicle. Minimum soaring volumes and handhold requirements should be established for crew station design.		X
e. Difficulty in Walking (pg 34)			X	X	X	X	)			X	Attempts at walking propel the worker away from the surface. Handholds, tethers, and adhesive footgear should be developed.		X

Miscellaneous Effects (pc 35)												
Rigidity of Powered Tools (pc 35)						X					Powered tools may be a source of stabilization, but are difficult to align and reposition. Motors impart motion to g-free equipment. Assemblies with motors may be arranged to provide semistable platforms.	X
Suspension of Dust and Objects - Inadequacy of Open Containers (pc 36)				X		X			X		Filters, screens, air circulation, padding, restraint of objects within containers, and smooth configuration of objects are requirements. Shaker and sprinkler containers should be avoided. Tools fastened with long tether cords could encircle the worker. Brittle foods should be avoided.	

TABLE II

SUMMARY OF SENSATIONS AND PERFORMANCE INCLUDING AREAS FOR RESEARCH

	WEIGHTLESS FACILITIES			RECOMMENDED CRITICAL RESEARCH AREAS
FACTORS	Frictionless Platforms	Water Submersion	Aircraft	For Space Activity
1. Exhilaration from Surface Freedom	X		X	
2. Comfort of Tactualess Support		X	X	Maintenance of muscle tone.
3. Sensation of Falling		X	X	
4. Orientation Effects				
a. Knowledge and Control of Limb Position		X	X	Arm work envelopes; multiaxis controls.
b. Knowledge and Control of Body Position		X	X	Omnidirectional displays; 3-d attitude displays.
c. Knowledge of Rotation			X	Single and multiple axis angular acceleration thresholds.
d. Knowledge of Surface Location		X	X	Work-to-surface alignment envelopes.
5. Concern over Collision-Difficulty in Absorbing Inertia	X		X	Attitude control techniques; visual cues for rate of closure.
6. Illusions			X	Line-of-sight programming in orbit; contribution of graviceptors to vertigo; autokinesis.
7. Sense of g			X	Neurological sensory-motor model; cues and thresholds.

8. Sense of Heaviness after Weightless Period	X	X		Psychomotor readjustment rates; variable control/display rates.
9. Decrease of Clothing Pressures		X		
10. Nausea and Motion Sickness	(Primarily a maneuver derivative)			Contribution of sensory-perceptual conflict; x-rays of organ displacement.
11. Decrease in Span of Attention	(Primarily a short period derivative)			
12. Harness Irritations			X	Multiaxis (min. interference) harnesses; tethering orbital projections; damping characteristics of tether lines.
13. Helplessness Between Surfaces	X		X	Emergency return to surface techniques.
14. Motion Effects				
a. Body Resilience Motions	X	X	X	
b. Swimming Motions	X		X	Attitude control techniques (self rotation).
c. Cross Coupled Motions		X	X	Spin and tumble analyses; oscillation of C/M envelope; force opposition techniques (posture to work alignment).
d. Uncontrolled, Pendulous Motions			X	'Closed force' work techniques; non-torque tools; segmented man moments of inertia analog.
e. Soaring		X	X	Single impulse programming; line of sight programming.
f. Difficulty in Walking	X (air shoes)		X	Walking behavior (mechanical-mathematical model); adhesive footgear; partial, excessive g criteria.
15. Miscellaneous Effects				
a. Rigidity of powered tools			X	Self-maneuvering unit studies.
b. Suspension of Debris			X	
Facility advantages	Time period	time period	6° freedom true 0-g	
Facility disadvantages	3° freedom	isolation motion resistance	complex g pattern short time period	

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APPENDIX I

GROSS MOTOR TASKS

TRIAL #

1. Lying Down - On the first trial the subject lay face down, looking aft, next to the cargo door, in the center of the aircraft. He was instructed to keep his eyes on the moon. The subject was instructed not to hold on, not push off and not use his hands or feet for any purpose except to aid him during the maneuver recovery. The subject was told that he may or may not float off of the floor, and was not to resist either case.

2. Lying Down - The subject lay in approximately the same position as in trial number 1. He was to keep his eyes on the moon but was to push himself off of the floor. After suspension he was to use hands or feet to keep himself floating.

3. Standing - The subject entered the maneuver standing. He held on to the overhead with at least one hand, making sure that his stance was firm so that he could not fall or injure himself during the 2 1/2 g pull-in to the parabola. When the zero-g condition had been reached, he released his handhold and allowed his body to float freely. After reaching zero g he was not to hold on to anything.

4. Walking - The subject entered the maneuver in the same position as in trial number 3. He started this maneuver with his back approximately 1 foot from the forward blackout curtain. When zero g was attained he was instructed to walk to the aft bulkhead, using one hand on the ceiling to keep himself erect and keep his eyes on the moon. He was then to turn around and walk to the forward blackout curtain.

5. Soaring - The subject entered the maneuver lying face down, feet touching the blackout curtain. He was instructed to keep his eyes on the moon. Upon achievement of zero g he was to lift himself slightly off of the floor and push with his feet against the curtain in order to sail toward the moon. The subject was instructed to try to hit the moon itself. Upon achieving this, subject was to endeavor to soar back to the experimenter by pushing off of the aft bulkhead.

6. Pulling in (Gathering) - A rope was attached to the aft bulkhead. The other end of the rope was placed in the subject's hand in a medium-taut configuration. The subject was positioned as in trial number 5. Upon reaching zero g the subject's instructions were to pull himself aft with the rope, toward the moon.

7. Tumbling - The moon was turned off. The subject positioned himself as in trial number 3, in the center of the cabin beside the cargo door. When zero g was achieved, he was to throw his head and hands down and forward and feet up and backward to achieve a tumble (as in diving into water). The subject was informed that trial number 7 would be directly followed by another zero-g parabola (trial number 8).

8. Lights on - During the entry of the maneuver, the lights in the compartment were turned on. During this last trial the subject was informed that he may do anything he desired. (Trials 7 and 8 were flown as a double maneuver so that the subject might quickly compare the dark and light cabin conditions).

The subject was told to use the recorder during the entire maneuver and record sensations, observations, achievement of experiment, etc. Before each trial he was told to record the trial number and the instructions for that trial.

APPENDIX II

TRANSCRIPT OF A SUBJECT'S RESPONSES (Astronaut Scott Carpenter)

All right, this is Carpenter at 1 g, 21 September 1960. We plan to do sev
or eight zero-g trajectories this morning, and I will be recording during the z
g pushup. This is all to be done in the darkroom of the C-131 with the only th
visible a very faint moon. Looks like fun. All right, this is just prior to
the beginning of the first run. My instructions are to - first of all I am lyi
on my stomach in the forward part of the blacked out section - on my stomach -
and I can see the moon on the aft bulkhead. My instructions have been to push-
up slightly just clear of the floor and move very slightly forward, this I hope
will keep me suspended in the air and I am to record my sensations while we are
weightless. All right, we are beginning the pushover. I imagine we are about
at half a g at this moment and here comes the pullthrough. I get a slight, -
I get the feeling that the back end of the airplane is going down, its just the
rotation. Now I am pushing free of the floor moving to the right, hit the
bulkhead, now I still have the sensation now of moving forward, I'm against the
floor, now I feel upside down, I will push free - I hit the floor again. I
1 definitely have the sensation of turning , but there was just a very short perio
There were two or three short periods at which time I wasn't touching or up agai
2 the bulkhead or floor. When the run was over, I was completely disoriented, I
no idea which way was up or down.

All right, now we are getting ready for the second run. Instructions this time are to go through the pushover and pullup in a standing position holding on the ceiling with one hand. When we get to zero-g, I am to release my hold on the ceiling and that's all. We will see what happens. I think the one thing that might be improved on is this helmet. It fits down on - the front part fits down very close to the eyes and with imperceptible amounts of rotation the helmet could obscure the moon and create some disorientation that might put some noise in the data that you are trying to get. I might add that on the first run I made no effort to change in a body position, I think I stayed in a stretched erect position throughout, until, of course, the end of the run when I sort of crumpled on the floor. This time I think we start standing - I think that when we get to zero-g I will just sort of fold my legs up underneath me as though I am sitting with legs crossed and see what happens. I tried this before - it's relatively relaxing. Another thing that I could add here, your mind is not really able to devote itself exclusively to evaluating the weightless condition.
3 Now I am recording at about, well, 0.5 g going into the pushover. The reason that you can't really devote yourself 100 per cent to evaluating this data is because you are in too confined a spot and your mind is continually trying to think; well, which way am I going and when am I going to hit on what part of my body. We need a bigger spot and a better padded one so it doesn't make any difference where you hit.

And now in the pullup of about 2 g, I'm still standing. Here comes zero-g (second run). All right, I'm letting go now, OK, I let go now. OK, I'm

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*The numbers in left margin refer to the involved factors shown on page 64.

floating. OK, I'm moving forward and I'm tumbling up and down. It's hard to
evaluate just exactly what is going on, because that actually wasn't too good
a run and I was busy trying to tell whether or not it was time to let go.
About the only thing I can say about it is that it is completely disorienting,
and the only feel you get which you really can rely on is where do you hit.
If you hit on the right side, you know that you might have traveled to the
5 right, but you always get a sense of motion somewhere . There is no sense of
being truly suspended so that you are stationary with respect to the airplane.

OK, this time I'm to go through the pullup standing. At zero-g, I'm to
walk toward the aft end of the airplane toward the moon or until I get to the
end of the walkway on the ceiling, which I will be able to feel with one hand.
When I get down there, I'm to put my feet on the ceiling and walk backwards
toward the front of the airplane keeping the moon in sight at all times. OK,
starting the pushover and reduced g now, 0.5. I've just been told that I can
hold onto the ceiling as I walk down. This makes an impossible task possible,
I would say. All right, we are starting the pushover again. We aborted the
first one (aborted first try of third run, lost sight of Clinton County). I
am now recording at about 0.7 g. My head is just clear of the ceiling as I
stand erect. This is going to make it a little bit easier to get aft to the
ceiling as you couldn't force yourself back on the floor. By pushing on the
ceiling you wouldn't be able to locomote very well this way. OK, now we are
6 at about 2 g . Begin the walking at 2 g. I get the rotation of the tail, and
now I'm at zero-g, and it is really no problem at all to walk toward the moon
at zero-g pushing down on the ceiling and up on the floor. OK, I'm now going -
Oh, Oh! (laugh) - I didn't quite get my feet up on the ceiling before we got
back to positive g. It wouldn't turn out much of a problem to turn yourself
around and get your feet on the ceiling. There is a ring here you can hang
7 by, push your feet up, force your head to the ceiling - I mean to the floor -
and you should be able to get back as easily as you got forward. There just
wasn't time to reorient myself before we went back to positive g. I might
add that as long .... my feet never left the floor and my hands and head really
8 never left the ceiling and there was no disorientation at all.

OK, next run is about to commence [fourth run]. Instructions this time
are to go into the run standing. At zero-g, I'm to begin twisting about at
vertical axis or so that the moon will alternately appear and disappear. I'm
to stay more or less erect, and we will see what happens. Another thing that
I noticed standing here going through the pushover and the pullup: I get the
definite feeling of the moon rising as we push over, and when the g increases,
9 I can actually see the moon go down . I really feel the rotation of the fuselage,
although I can't feel, I'm convinced that [it actually does]*. OK, pushover
at just slightly reduced gravity, now I still get the sensation of the tail
going up. I also have an idea that when this twisting begins, it's rapidly
10 going to change axis , and I will be again completely disoriented. The tail is
going down, the moon is going down, I have hold of some wire above me with my
left hand. Here is zero-g, and I'm twisting to the right. And, Oh! I hit the
11 floor - let's see, is that the floor? I can't make sure I have lost the moon.

* Poor recording.

I'm now completely free! There is the moon, and I am upside down. No, Sir!
I am right side up. I am facing aft - again completely disoriented, and I
floated free for some time without touching a thing, but in more or less a
12 sitting position that seems to be the position you normally go to . Also,
it keeps you in a smaller ball so that you are not as likely to hit the wall,
ceiling, or the floor. Our main inverter just went out, and we're going to
hold off now for a couple minutes. There is one other thing I might mention,
particularly in that last run when I was free in the air for at least the
longest time today, I didn't touch the ceiling, wall, or floor for maybe seven
or eight seconds, but even so I didn't have the feeling that I was suspended.
13 I felt that I was turning slowly, but still turning, not motionless . It also
felt like sort of a sideway, turn, not a front or backwards somersault type of
motion. I might make another observation here. All the zero-g work that I
have done has been an exhilarating thing for me. The freedom that it gives
you, you are so unencumbered, you can float like a feather and twist and spin,
etc. It is always a lot of fun for me, but in this darkroom where you don't
get any cues and are completely in the dark about where you are and what you
are doing, the fun is gone. Its not unpleasant but you don't get any visual
14 cues to make it fun anymore . Well, I think another thing that I might say
here. I think the fun is gone out of this business when you are blacked out
like this, because you really are in doubt as to which way is up. And the
psychologist will say, "Ah! there is a need for the people to know which way is
up," this is true as long as you understand up is defined only as up with respect
to the vehicle you are riding in. It may be down toward the earth, but if men
15 can orient himself inside whatever he is riding as being right side up in
respect to it or upside down or sideways then that is all he really needs.

All right, this time I have been told to just sit here. I have in my left hand a rope attached to the aft end of the airplane. At zero-g, I will try to propel myself with the use of the rope alone back toward the moon. Of course, unless I fall right in line with the center of gravity, I am going to get a tumble, and with only being able to use one hand it will be hard to do this and talk at the same time without tumbling and be able to grab the rope again after I have done the first pull with it. Talking may be in fits and starts for this one (fifth run). OK, starting the pushover now. Sitting on the floor cross-legged. Now, it would be much easier to do this with a rope attached fore and aft. As it is, this is going to be hard to do. Here is the 2 g pullup. I can see the moon going down again. Now we are at zero-g. I'm floating a little off to the left. Ah! Yes! this is not bad. I'm floating right back toward, I'm taking four pulls, five, floating completely free. My head hit the ceiling, now I'm on the floor and back to about normal 1 g, and it appears to me that I'm about 3 feet short of the moon. I never left the cross-legged sitting position and I felt like I floated gradually aft gently rising until just short of the moon. My head hit the ceiling, we then pulled through, and I got back onto the floor quite gently, and I was able to take 5 or 6 pulls on the rope without tumbling. Another interesting thought: I thought that if I let go of the rope that last time with one hand and tried to grab it again; ordinarily a rope at 1 g would grow slack and fall to the floor before you could get another hold on it, but this rope of course, stayed stretched out all the time and so grabbing it again was not hard.

This time I'm just supposed to lie on my stomach and sail toward the light. This is more like it! I will lie on my stomach, and I won't try to push off much. Yesterday, in the 135, I found that just pushing with your feet or off
16 the floor your body resilience will force you off the floor and I expect I can make it all the way back there using this method without hitting the ceiling. Here is the 2 g pullup [sixth run]. And here is zero-g, and here we go! Now this is not a very good one, we didn't quite - OK, here we go, but I got carried away from the floor before I could get much traction. I didn't get a good enough push off that time. I pushed away from the forward bulkhead before we were really at zero-g, and the friction of the floor slowed me down so that when we got zero-g later I didn't have anything left to push on.

OK, we are going to try that one again [seventh run]. OK, here commencing the push over at reduced g. This will be another run of the same kind. I am going to wait until we get to zero-g and then push off from the forward end of the airplane and try to float back to where the moon is. This felt like a rather long dive and a pretty good pull through. Maybe we will get a long zero-g period this time. OK, here is zero-g. Pushing gently off of the floor, forward I go completely free. Now I am upside and spinning and twisting, and I had no purchase to get back to the back side. Oh, Man! that was a pretty good run. I would say there was velocity to get all the way back but I hit the ceiling before I made it all the way. Ah, lets see, then what happened. I hit the ceiling on the right-half side looking aft. I think I tried to push off the ceiling to get aft again and went to push sideways too hard and hit another bulkhead somewhere. Some time during the run, I got back nearly to the aft bulkhead, but at the end of the run I ended up just about in the middle of the cabin. I made a couple of turns to completely upside down, and that is all I can think of.

OK, my instructions this time are to do one front flip, try and stop, and then sail back to the moon. My eyes are to be closed during the one tumble, then open the eyes when you think you are through one tumble, try and find something to grab hold of to propel yourself, diving toward the moon. The only way I can get a tumble like this started is to lie on my stomach at zero-g, bring your knees up underneath you; actually what I will do is kneel, crouched down on my knees, and at zero-g I will push gently off with my toes. This commences a front flip. Now being able to stretch out after one turn is not going to be hard but to be able to catch something to stop the tumble at the end of one turn will be a problem. Here is the pull through [eighth run]. This helmet again is a bother. OK, here is zero-g - going down. I think that I have one tumble - no, I hit my back first and I'm OK. I can see the moon and I'm upside down on the ceiling trying to get back to the moon. I have no picture ....that was one of the harder landings. That's not bad, I stretched when I felt that I had made one tumble, but actually I had only gone out half the
17 way, my back hit the floor, I bounced off, finished the tumble, twisted a couple of times so I was completely disoriented and tried to make my way back to the moon but from that point on I couldn't find anything to get any purchase on so it was just sort of a useless struggle. Another thing that might be of some interest here. Yesterday I cracked my back a couple times good in the 135, and the fact that I hurt myself - not bad, but I got some good bruises out of it - the fact that I did that yesterday reduces the - well it makes you not quite so

ready to really give it your all. You don't start to spin too hard to too quickly because this generally sends you off in one direction or another where you could hit something hard. If everything was very well padded, then you could really give it your all.

This time my instructions are to lie down and try and propel myself back toward the light just be grabbing onto the floor. I think talking during this one is going to be a little bit of a hinderance, this is going to take two hands. So, I will put this "mike" away and tell you about it afterwards [ninth run]. OK, that was a pretty good one. I was able to get all the way down to the moon and all the way back to the front end. That time I used both hands and
18 surprisingly enough just a small pinch hold on the canvas floor mat here is enough to direct yourself with. I kept my hands on the carpet all the way down, although it was a good zero-g run and I was floating. I had to hold myself down. I got all the way to the aft end of the aircraft in about three or four grabs of the carpet, I touched the bulkhead, I turned around and started on the way back. After about two grabs on the carpet I lost of hold, I went up to the ceiling and
19 ricocheted off of that and finally ended up in the lap of the monitor back here.

OK, this is the last double run coming up. I am going to get about in the middle of the cabin. The moon is now gone [turned off] and the first run I am to do anything I want, but it will be completely blacked out. I think what I will do is just try and get free. I may start a tumble or may just sit in a sitting position. The second run will be the same ground rules, but with the lights on. I am not even sure which way I am facing now and that is good. It seems like I am facing a little bit off to one side toward the port of the airplane. Yes, there is a leak in the cabin wall and I know I am - a light leak, that is. OK, have commenced pushover, and I found that I was looking toward the
20 moon to try and verify that the pushover was actually commencing. It is gone, so I just have to do it by the seat of my pants. I am sitting cross-legged again facing the aft of the .... Pull through is commencing now [tenth run]. I think I will try - I don't know - I am going to lie on my stomach, changing to my stomach now. During the 2 g, I am going to do a front flip again, they are more fun. Zero-g, Ah, phooey! I'm floating, floating forward now I think, and now I started to pitch (laugh) I'm floating - well I don't know what happened or who I hit - Oh, here he is - the monitor! OK, that time I really
21 felt like I was motionless like I was not turning at all.

This time the lights are now on. I will do the same thing [eleventh run]. ....at the start of the run that I was floating forward. Oh boy, that was a
22 good one! (laughter) Oh boy! OK, that is a lot more fun when you can see what you are doing. I did 2 or 3 flips front and sidewards - now let's see, what is the upshot of all of these runs. The thing that counts in my mind is that without any light at all this is a very disorienting thing, you have no
23 idea which way is up . With the lights on it is not disconcerting at all. It's mainly just fun.

FACTORS INVOLVED IN SUBJECT'S RESPONSES (APPENDIX II)

1. False perception of rotation (Ref. Results, B, 4c)
2. Complete disorientation (Ref. Results, B, 4b)
3. Sense of partial g (Ref. Results, B, 7)
4. Concern of collision (Ref. Results, B, 5)
5. Sense of continuous motion (Ref. Results, B, 6)
6. Sense of excessive g's (Ref. Results, B, 7)
7. Possible foot-down orientation (Ref. Results, B, 4a)
8. Lack of disorientation with tactual contact (Ref. Results, B, 4b)
9. Oculoagravic illusion (Ref. Results, B, 6)
10. Anticipation of cross-coupled motion (Ref. Results, C, 2b)
11. Loss of direction (Ref. Results, B, 4b)
12. Relaxed posture (Ref. Results, B, 2)
13. Sense of constant motion (Ref. Results, B, 4c)
14. Loss of euphoric sensation in darkness (Ref. Results, B, 1)
15. Satisfaction with vehicle rather than earth orientation (Ref. Results, B, 4b)
16. Self imparted motion from body resilience after excessive g's (Ref. Results, C, 1)
17. Underestimation of rotation (Ref. Results, B, 4c)
18. Surprise at small magnitude of holding forces required (Ref. Results, B, 12)
19. Need for communication required between two people (Ref. Results, B, 11)
20. Possible use of illusion as cue to vehicle behavior (Ref. Results, B, 6)
21. Possible dependence upon visual cues for feeling of continuous motion (Ref. Results, B, 4)
22. Sense of exhilaration (Ref. Results, B, 1)
23. Disorientation with respect to distance as well as direction (Ref. Results, B, 4)

APPENDIX III. SELF CONTAINED AUDIO RECORDING SYSTEM

The unsatisfactory audio recording of verbal statements by free-floating subjects suggested the need for a better system for future research. Such a system was developed for the Air Force by the Seismograph Service Corporation, Tulsa, Oklahoma and this appendix was abstracted from a Seiscor report titled "Technical Manual for SRT-11 Repeater Station and SPT-11 Personal Radio Unit, Seiscor, Box 1590, Tulsa, Oklahoma," undated.

The equipment furnished was designated the Repeater Station (RS) and the Personal Radio Unit (PRU). Basically the RS receives transmissions from a personal unit while simultaneously rebroadcasting this information to all other personal units in the system. The Repeater Station can be operated with or without an operator present. Whenever an operator at the repeater station makes a transmission, a voice operated switch automatically interrupts any transmission being made by a personal unit. The present PRU is a two-channel unit but can be converted to a multi-channel unit. The RS is a single-channel unit and other channels must have individual repeater stations. All units in this system are equipped with a voice operated switch. When the operator speaks into the microphone the unit automatically switches from receive to transmit and likewise when the operator ceases to speak the unit returns to the receive mode of operation.

The PRU utilizes the headset cord as an antenna while the RS requires an antenna approximately 66 inches in length. The RS antenna may be placed at a remote location and connected to the unit by a length of RG-58/U coaxial cable. The RS supplied operates on channel one, the transmitting frequency is 42.5 mc and the receiving frequency 31.5 mc. The PRU supplied operates on channel one, the transmitting frequency is 31.5 mc and the receiving frequency 42.5 mc, and is equipped for channel two operation, the transmitting frequency being 31.55 mc. and the receiver frequency 42.55 mc. Channel two can be furnished in any additional Repeater Station.

Transmitter power output is approximately 50 milliwatts, and the receiver sensitivity is 1 microvolt into the receiver antenna terminals for a 10 db signal to noise ratio. The audio amplifier will deliver 15 watts into the earphones. The PRU is powered by re-chargeable batteries which will deliver approximately 10 hours of continuous operation under conditions of 50% transmit and 50% receive. An external charging unit is provided and five hours are required to completely recharge the batteries. The RS contains a rechargeable battery and a built-in charger.

The microphones furnished are of the noise cancelling type and the operator must speak directly into it in order to produce the necessary modulation level. The following specifications have been included.

Receiver Specifications

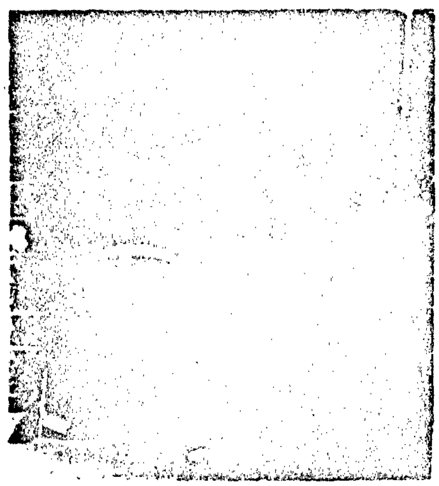
Crystal controlled superheterodyne
455 kc I. F.
Built-in noise limiter

Adjustable squelch
Amplified AGC
1 microvolt sensitivity for a 10 db signal to noise ratio

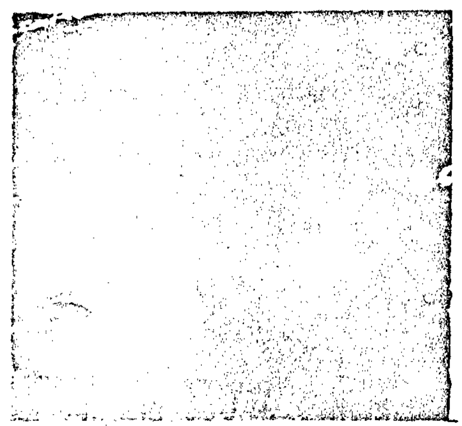
Transmitter Specifications

Crystal controlled oscillator
High level modulated power amplifier
100 milliwatts input to power amplifier
Speech compressor for high average modulation
Voice operated switch for transmitter control

Pictures of the units are shown in Figure 17 and block diagrams for both of the units are included in Figures 18 and 19.



Repeater Station



SPT-11 Personal Radio Unit

Figure 13. Repeater Station and Personal Radio Unit

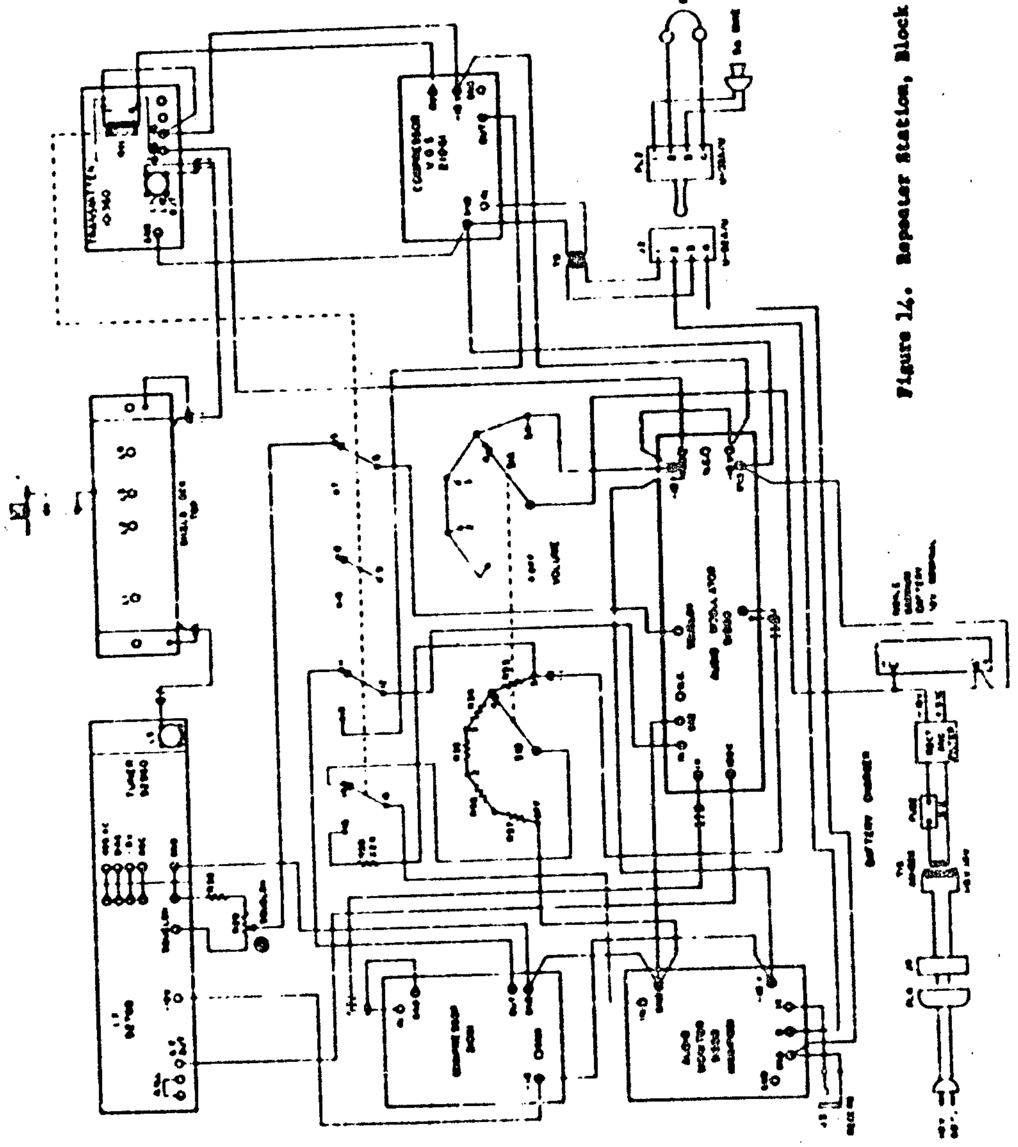


Figure 14. Repeater Station, Block Diagram

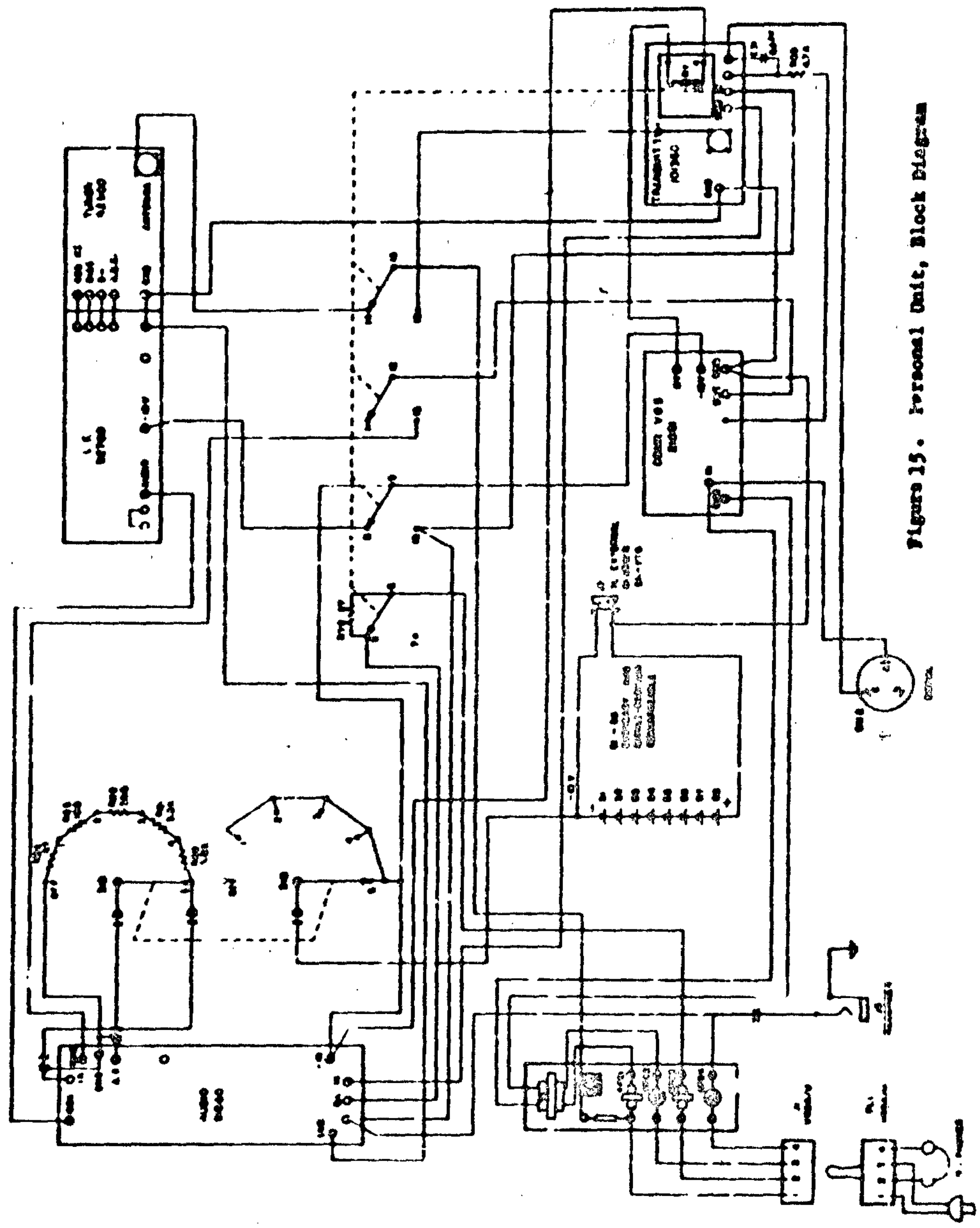


Figure 15. Personal Unit, Block Diagram

Aerospace Medical Division
6570th Aerospace Medical Research
Laboratories, Wright-Patterson AFB, Ohio
Rpt. No. AMRL-TDR-63-114. WEIGHTLESS MAN: A SURVEY OF SENSATIONS AND PERFORMANCE WHILE FREE-FLOATING. Final report, March 1963, vii + 65 pp incl. illus., tables, 39 refs. Unclassified report

The effect of surface-free behavior on work performance in space has been investigated to determine what techniques should be developed to aid the orbital workers. While they performed gross motor activities under weightless conditions, subjects reported their sensory and performance experiences during Keplerian parabolas in a C-131B aircraft in both lighted and dark cabin

(over)

conditions. Their experiences were categorized into sensation influences upon orientation and body motion influences upon body attitude and position control. Unique examples of short-term weightless behaviors were found and their causes are briefly discussed. Potential applications of these weightless responses to hardware development and to crew training and selection are discussed, and significant areas for future research are proposed.

UNCLASSIFIED

1. Weightlessness
2. Orbital Worker
3. Behavior (Zero-Gravity State)
4. Performance Evaluation
5. Human Engineering

I. AFSC Project 7184; Task 718405
II. Behavioral Sciences Laboratory
III. J.C. Simons, M.S. Gardner
IV. In ASTIA collection
V. Aval fr OTS: $2.00

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