THE EFFECT OF ZERO GRAVITY AND ARTIFICIAL GRAVITY ON LEISURE ACTIVITIES IN SPACE HABITATS

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BY

PATRICIA MUNDORFF KNAUS, B.A.

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ORIENTATION TO THE STUDY

Introduction

On April 12, 1961, Yuri Alexeyvich Gagarin made a single orbit around the Earth in the Russian space vehicle, Vostoc 1, and mankind entered a new epoch. Following this flight, both American and Russian manned space programs have expanded in size and scope. Man has now landed on and surveyed the moon and has explored the benefits and problems associated with living and working in space, primarily in the Skylab and Salyut programs.

Reasons given for man being in space are as varied as the groups interested in space. These groups include the military, business, scientific, and the general public.

The military became involved in space through satellites. Reconnaissance satellites such as the U.S. "Big Bird" and KH-11 have made possible the monitoring of strategic arms agreements without on-site inspection. The NAVSTAR satellite system provides both a two coordinate navigation capability for land and sea use and an altitude capability for aircraft navigation. Satellites transmit nearly 70% of all military messages. Their vulnerability coupled with their increased importance have resulted in satellite protection becoming an important part of military planning. The space shuttle will be used for military missions, piloted by military astronauts. Future Department of Defense space activities will be conducted from a new center for space operations.

The Soviets have been developing A-SATS, satellites designed to destroy other satellites. They have developed their own reconnaissance satellites, one of which was orbited to keep track of the special navy task force sent into the Indian Ocean by President Carter when the Iranian crisis broke in the winter of 1979.

In addition to these unmanned satellites of the military program and the continuing manned Salyut program, the Soviets have announced plans to establish a permanent, orbital station. Some analysts expect this to be a 12-man space station. Plans for an American 12-man station were terminated in the early 1970's because of budgetary problems. Covault (1989), however, described recent thinking by the National Aeronautic and Space Administration (NASA) about a Shuttle-serviced permanent manned low earth orbit space station, which they call a Space Operations Center (SOC). This space station would be used for the construction, assembly, and servicing of space systems and spacecraft.

Dula (Note 1) surveyed 378 companies selected at random from both the Fortune 500 list of American Industries and the Fortune 300 list of American Service Industries concerning their interest in a shuttle-based program of space industrialization. Forty-seven percent of the companies who responded felt there was some possibility that their company would be interested. An additional 26% indicated that the possibility their companies might become involved was either "fair" or "large." Interest was primarily in solar power satellites and communication satellites. However, some companies indicated they were interested in exploring new manufacturing techniques and in developing new products. Puttkamer (Note 2) estimated that in the decades ahead, there will be a need for many highly qualified workers in space.

David Crisswell (Note 3) of the Lunar Science Institute has indicated that the continued development of a technologically advanced civilization requires the dissemination of man into space in worldlets. When man began manipulating nature he became partially decoupled from the restrictions and balances imposed by nature. This partially decoupled environment which man is developing is basically and unavoidably at odds with the natural system which has evolved over the past three billion years. The ideal and necessary solution to the problem of this rapid technological growth, according to Crisswell, is an actual decoupling of the human population from its terrestrial roots.

Straw (Note 4) described the interest that many members of the scientific community have in returning to space in order to resume investigations begun during the Skylab program and terminated with that program. Physicist-astronomers, he explained, hope to answer the question of the formation of the universe and to discover fundamental properties of matter, energy, and electromagnetic and gravitational forces by utilizing the perfect observatory conditions found in space. Proponents of solar energy await proof of concept testing of their designs which can be done only in space. The aero-space industry, he indicated, is interested in investigating solar electrical propulsion, plasma propulsion, and materials and construction techniques in space.

Most of the general public who are interested in space are attracted by a sense of adventure and the desire to explore a new frontier. In response to this interest, several groups have organized to push for a commitment to man in space.

The L-5 Society, Cloud (Note 5) explained, is comprised of people who are interested in space colonization. There are chapters nation-wide. Members are scientists and lay persons whose purpose it is to interest other people in space and to lobby for space oriented projects in Congress.

Bell (1978) reported the recent formation of the Planetary Society which is dedicated to focusing public interest upon space activities. The Society also considers the Space Age as a cultural as well as a technological revolution and for this reason includes people on their board of advisors from diverse fields. Dr. Carl Sagan is President. Other members include Bruce Murray, NASA's Jet Propulsion Laboratory Director, entertainers Paul Newman and Johnny Carson, Scientists James Van Allen and Louis Thomas, authors Dianne Ackerman, Ray Bradbury, and James Michener, and U.S. Senators Harrison H. Schmitt and Adlai Stevenson III.

Another recently formed group (Bell, 1980) is the World Space Foundation, which was founded on the belief that there is broad public interest in the exploration of space. The foundation's president, Robert Staehle, believes there are enough people who desire a vigorous space effort to build a space program of their own. Members join the World Space Foundation by contributing to any of the Foundation's space related projects that they consider important or exciting. One such project is the solar sail for space transportation.

Activities associated with and supportive of man's entry into space have been dominated by the technology necessary to build and launch space vehicles and the physiological needs and adaptions of humans to the space environment. Consequently, social scientists and humanities scholars, who are interested in the impact of space on society and the human factors involved in people actually working in space, have joined together in the Institute for the Social Science Study of Space. They publish the Space Humanization Series for the purpose of facilitating the systematic investigation of the human factors which will have a bearing on the development and utilization of space (Cheston & Webb, Note 6).

To date, no studies have been made of the impact that the space environment will have on the traditional forms of leisure time activities which have evolved on Earth. When man enters space in the future, he will have leisure time and he will undoubtedly pursue various forms of activities during this time. The impact of leisure time activity scenarios portrayed in popular movies and television series such as 2001, a Space Odyssey, Star Wars, and "Star Trek," have led to visualizations of leisure time activity in space such as the following dream vacation submitted to Psychology Today as a response to their survey of how Americans view vacations.

> My dream vacation would be the ultimate getaway via the Space Shuttle to one of the giant orbiting resorts. Here you can have 24-hour entertainment, gambling, swimming in low-gravity pools, pseudo-flying on winged bicycles, or you can simply relax in low gravity for that deep, restful sleep. All the comforts of home, right here. You've got horseback riding, football games, the ballet. You can attend the non-stop athletic events and marvel at the grace of the performers as they glide slowly and softly back down to the shell. (Rubenstein, 1980, p. 66)

Whether these scenarios and dreams are valid and realistic with respect to leisure time activities in space habitats is yet to be determined. The use of leisure is the special interest of the members of the recreation profession. Space offers a new opportunity for recreation professionals to contribute and to become involved. Space habitats are, however, the results of painstaking engineering which require the integration of all facets of design into a closed system. There is little or no margin for error or post construction changes without serious impact on performance. The recreation professional wishing to be included in this design process must be prepared to propose programs for leisure time activity that conform to limiting parameters inherent in space habitats and habitation. Exploratory study of the impact of these parameters on leisure time activity is a necessary prerequisite to this task. It is therefore proposed that a study of two conditions which will impact leisure time activity in space, specifically zero gravity and artificial gravity will be of value to the field of recreation by providing a basis for further exploratory work.

Purpose of the Study

When man enters space, he enters a man made world built to surmount a hostile environment of airless space, temperature extremes, and radiation bombardment. Gravity, which gives man weight on Earth, will be either absent or artificially created.

The purpose of this study is to explore the physical characteristics of zero gravity and artificial gravity and relate these to leisure activities.

Statement of the Problem

The study problem is to determine what effect the parameters of zero gravity and artificial gravity will have on the leisure time activities of man in space. Man's leisure time activities have evolved in the Earth's gravity environment. The effects of this gravity are so pervasive in all aspects of man's activities, that a consideration of how the absence of Earth gravity would change a given activity and what adaptions would be required in order to conduct a similar activity, both in zero gravity and in artificial gravity, is a necessary prerequisite to man's return to space for extended periods of time.

Definition of Terms

The investigator defines the following terms as they specifically apply to the study.

Acceleration. The rate of change of velocity expressed in units of displacement per unit of time squared, i.e. feet (or centimeters) per second squared (Chambers, 1965).

Acoustic vibration. Vibration, with respect to operational environments, transmitted through a gas. The vibration may be sonic, subsonic, or ultrasonic (NASA, Note 7).

Adhesion. The act or state of adhering, or of becoming united (NASA, Note 7).

Aerodynamics. Science of motion of bodies relative to the air and the forces acting on the bodies, especially in flight through the air (NASA, Note 7).

Ambient condition. Environmental conditions such as pressure, temperature, etc, which are normal for the location under discussion (NASA, Note 7).

Angular dimensioning. A method for indicating the position of a point, line, or surface by means of a linear dimension and angle, other than the 90 degree angle implied by the horizontal and vertical center lines (NASA, Note 7).

Artificial gravity. An apparent gravity created by imparting a linear acceleration or imparting uniform circular motion to a particle, thus producing a centrifugal force (NASA, Note 7).

Attitude. The position of a vehicle, craft, etc., as determined by the inclination of its axis to some frame of reference. If not otherwise specified, this frame of reference is fixed to the Earth (NASA, Note 7).

Bioastronautics. The study of the effects of space flight upon animals or plant life (NASA, Note 7).

Biodynamics. The study of forces acting upon bodies in motion or in the process of changing motion, as they affect living beings (NASA, Note 7).

Bioengineering. The science by which knowledge of properties of matter and sources of power are applied to the design of structures and machines that will be directly used by man (NASA, Note 7).

Center of mass. The point in a body at which the entire mass of the body can be considered to be concentrated (NASA, Note 7).

Centrifugal force. The apparent force in a rotating system, deflecting masses radially outward from the axis of rotation, with magnitude per unit mass v^2R, where v is the angular speed of rotation; and R is the radius of curvature of the path. This magnitude may be written as V^2/R, in terms of the linear speed V. This force (per unit mass) is equal and opposite to the centripetal acceleration (Allen, 1965).

Centripetal acceleration. The acceleration on a particle moving in a curved path, directed toward the instantaneous center of curvature of the path, with magnitude v^2/R where v is the speed of the particle and R the radius of curvature of the path. This acceleration is equal and opposite to the centrifugal force per unit mass (Allen, 1965).

Cohesion. The state or process by which the particles of a body or substance are bound together (NASA, Note 7).

Coriolis force. The force acting on a particle mass when it moves linearly relative to a rotating environment. Also, the particle cross-coupled forces acting when the particle mass rotates relative to a rotating environment (NASA, Note 7).

Coriolis reaction. A mixed sensory illusion (eyes and semicircular canals) of the oculogyral type where in if a person in a spin moves his head in the opposite direction, resultant fluid movement in the canals produces severe vertigo (dizziness, nausea, pallor, etc.) (NASA, Note 7).

Dynamic behavior. The behavior of a system or component under actual operating conditions, e.g., acceleration, vibration (NASA, Note 7).

Dynamic environments. Environments consisting of dynamic forces such as those due to vibrations, shock and acceleration (NASA, Note 7).

Dynamic pressure. (1) The pressure exerted by a fluid, such as air, by virtue of its motion. (2) The pressure exerted on a body, by virtue of its motion through a fluid (NASA, Note 7).

Fly-wheel type resonance. Resonance between a once-per-revolution forcing function, either mechanical or aerodynamic, and a natural mode of rotor vibration in the direction of the rotor plane (NASA, Note 7).

Free fall. The motion of any unpowered body in a gravitation field (NASA, Note 7).

g or g-force. The measure or value of the gravitational pull of the earth as modified by the earth's rotation, equal to the acceleration of a freely moving body at the rate of 9.8061 meters per second^2 (32.174 feet per second^2) (NASA, Note 7).

Gravireceptors. Specialized nerve endings and organs in skeletal muscles, tendons, joints, and in the inner ear, furnishing information to the brain on body position, equilibrium, and direction of gravitational forces (NASA, Note 7).

Gravitation. Force of mutual attraction between all matter in the universe. Varies directly as a product of the bodies' masses and inversely as the square of the distance between them (NASA, Note 7).

Gravity. Force of gravitation which tends to pull objects toward the center of mass of the attracting body, giving them weight (NASA, Note 7).

Human engineering. The application of scientific knowledge concerning human limitations and performance capabilities to the establishment of requirements for the accomplishment of the mission. The purpose is to minimize demands upon human skill, training and manpower resources, and to maximize the effectiveness of man-equipment combinations (NASA, Note 7).

Human factors. Used in a broad sense to cover all biomedical and psychosocial considerations pertaining to man in the system. It includes principles and applications in areas of human engineering, personnel selection, training, life support requirements, job performance aids, and human performance evaluation (NASA, Note 7).

Hyperacoustic zone. The region in the upper atmosphere where the distance between the rarified air molecules equals the wave length of sound, so that sound is transmitted with less volume than at lower levels. Above this zone, sound waves cannot be propagated (NASA, Note 7).

Inertial force. The force produced by the reaction of a body to an accelerating force, equal in magnitude and opposite in direction to the accelerating force. Inertial force endures only as long as the accelerating force endures (NASA, Note 7).

Leisure time. That part of our lives in which we are free of the tasks required of us (Wadsworth, 1953, p. 38).

Mass. The measurement of the amount of matter in a body, thus its inertia (NASA, Note 7).

Occulogravic illusion. A mixed sensory illusion of flight involving the eyes and semicircular canals of the ear, e.g. graveyard spin, Coriolis reaction, and rotation illusion (NASA, Note 7).

Physiological acceleration. The acceleration experienced by a human or an animal test subject in an accelerating vehicle (NASA, Note 7).

Physiological factors. Factors which effect a crew's health and ability to function (NASA, Note 7).

Tangential velocity. The velocity of a particle freed from the constraints dictating uniform circular motion (NASA, Note 7).

Velocity. The rate of change of position expressed in displacement per unit of time, i.e. centimeters per second (feet per second) (NASA, Note 7).

Weight. The force which is the product of the mass of a particle times a gravitational acceleration constant for a given celestial body. Weight in artificial gravity is the product of particle mass and the acceleration acting upon it (S.A.W.E., Note 8).

Weightlessness. The absence of any apparent gravitational pull on an object (NASA, Note 7).

Zero gravity. Weightlessness (NASA, Note 7).

Zero gravity effect. The change in the behavior of a substance or system introduced into an environment free of gravitational force (NASA, Note 7).

Study Delimitations and Limitations

This study was subject to the following delimitations:

1. Zero gravity will encompass gravity levels from the true absence of gravitational effects to 1×10^{-4} times Earth gravity.

2. Artificial gravity levels will be expressed as decimal parts of Earth's gravity. Artificial gravity produced by constant linear acceleration will be explained but will not be considered in this study.

3. Habitation rotation rates in excess of three revolutions per minute will not be considered in accord with the consensus that higher rates would have unacceptable effects upon inhabitants. Radii of rotation considered in this study are limited by habitat size proposed in studies conducted by recognized scientists for large structures, and by the gravity level required/rotation rate allowable restrictions for small structures.

This study was subject to the following limitations:

1. There is a paucity of material which directly concerns leisure time activities performed under the conditions which will be found in space habitats.

2. There are no data for artificial gravity effects upon humans in a true zero gravity field. Data derived from Earth bound centrifugal artificial gravity/Coriolis effects will be considered for use in this study with due consideration given to the fact that these experiments were conducted in an Earth gravity field.

CHAPTER II

REVIEW OF RELATED LITERATURE

Zero Gravity

A review of the literature concerning zero gravity manned missions in space indicates there was little time in the mission schedule which could be devoted to leisure time activity. Additionally, astronaut resistance to leisure time studies resulted in limited planning for leisure time activity (Louviere, Note 9).

> Skylab engineers had provided recreational equipment to vary the routine of long hours in space. There were dart sets (without sharp points), playing cards, balls, books, exercise equipment, and a tape player. But much of this went unused. Earth gazing during orbital night became principal diversions. (Belew, 1977, p. 78).

Skylab missions were comparatively short, the longest being 83 days. Still, the lack of provision for leisure time resulted in the statement by Carr (Note 10) that if it hadn't been for looking out the window, it would have been very dull up there. Recognition of the need to provide leisure time activities for long duration space missions is found in Frazer (1968) and in Berry (1973).

There is no mention in the literature of possible effects which zero gravity may have on the planning for leisure time activities. However, Frazer (1968) stated, "Provision of opportunities for furtherance of creative leisure activity within a vehicle must of necessity be limited by the constraints of the vehicle and the mission" (p. 484). Skylab crew experiences, unrelated to leisure time per se, but pertinent to an understanding of the effect of zero gravity on human activity and for planning leisure time activities in space are found in Belew (1979), Cooper (1976), and Cromie (1976).

Oberg (Note 11) reported that the Russians did not have a transport vehicle which could withstand more than 30 days in space. Therefore a new vehicle had to be sent into space periodically. The Russians utilized this drawback to send mail, newspapers, surprise packages, fresh food, and even visitors to the Cosmonauts living in Salyut 6. On later missions they were able to enjoy television transmitted from Earth. Artist-cosmonaut Leonov (1980) described his pleasure in sketching Earth from space. Salyut crew experiences are found in Makarov (1979), Shatalov (1980), and Vasilyeu (1979).

Berry (1973) described physiological changes in returning astronauts and cosmonauts which include redistribution of total blood volume from the periphery to the heart and lungs, reduced blood volume, loss of red cell mass, muscle atrophy and decalcification of bones with resulting osteoporosis. These changes have led to the consideration of space habitats which have artificial gravity.

Artificial Gravity

O'Neil (1974) proposed building rotating space habitats which would provide artificial gravity. It is this author's premise that space habitats can be built which would be far more comfortable, productive, and attractive than is most of Earth. He designed a habitat which consists of two joined cylinders surrounded by agricultural pods. In the cylinder pairs, the entire land is devoted to living space, parkland and forest, with lakes, rivers, grass, trees, animals, and birds; an environment similar to the most attractive parts of Earth.

The author also stated:

> All Earth sports, as well as new ones are possible in the communities. Skiing, sailing, mountain climbing (with the gravity decreasing linearly as the altitude increases) and soaring are examples. As an enthusiastic glider pilot, I have checked the question of thermal scales: The soaring pilots of the colonial age should find sufficient atmospheric instability to provide them with lift. A special, slowly rotating agricultural cylinder with water and fish can have gravity 10^{-2} or 10^{-3} times that on Earth for skin diving free of pressure-equalization problems. Noisy or polluting sports, such as auto racing can easily be carried out in one of the cylinders of the external ring. (p. 36)

Interest in the O'Neil study led to a more detailed study of space habitat design by the 1975 Summer Faculty

Fellowship Program in Engineering Systems Design at Stanford University (Johnson & Holbrow, 1977) and the 1977 Summer Study at Ames Research Center, Sunnyvale, California (Billingham & Gilbreath, 1979). There is little attention paid to the provision of leisure time activities in these two studies. Johnson and Holbrow (1977) described a possible scenario of habitat life wherein "A few workers on their lunch break can be seen cavorting in the almost zero-g of the central hub playing an unusual type of ballgame, invented by earlier construction workers" (p. 90). Also,

> Stopping for a mug of Space Blitz on the way back to your apartment you happen to catch the Princeton-Stanford ball game on television from Earth and learn that, to everyone at the bar, the three-dimensional ball game played in the central hub is much more thrilling. (p. 103)

There is no description of this game or any indication why colonists find it more thrilling than traditional Earth games.

Heppenheimer (1978), a member of the 1975 study group, provided more details on the pleasures the future space colonists can enjoy. The recreational van of the space colonist was described as a self-contained spacecraft which comes with a roomy interior suitable for decorating with comfortable rugs or waterbed mattresses and large wraparound windows. Low gravity swimming pools which are doughnut shaped and have high waves were pictured. The waves, according to Heppenheimer, will be like the waves at an ocean beach, yet will travel quite slowly. Diving boards will provide many with an opportunity to show grace and skill, and the common garden variety dive will be a breath taking slow-motion arc as the diver rises dozens of feet above the boards and then slowly turns and glides into the water. In addition, some people will set themselves spinning when they leave the board and float into the air, tumbling so rapidly that they will not know where they are going; then several seconds later, their tumbling will end when they hit the water. There will probably be three or four sets of diving boards, and some people will try to leap from one to the other, gaining an extra spring at each bounce. The author also described swimming in the air, making private swimming pools out of water globules, walking on water, and soaring up into the air after attaining zero gravity by swimming with sufficient speed in the direction opposite to the colony rotation. Hang gliding and human flight utilizing strap on wings are other activities which are described as possible in the space habitat.

A student project in systems engineering conducted by the Department of Aeronautics and Astronautics of the Massachusetts Institute of Technology (MIT) (Smith, Note 12) contains the following reference to leisure time activities:

> The role of "leisure counseling" and the therapeutic value of recreation would be central to making pleasurable this frontier experience. The role of these personnel must be carefully analyzed. Counselors should be individuals capable of encouraging a wide variety of activities without displaying overtly directorial control: any resemblance to the activities director of an ocean liner or a resort camp would only emphasize the contained feeling inherent in the colony. (p. 6.123)

The MIT report also contains a table of leisure activities that will be possible in space including sports such as swimming, tennis, track, and pingpong; education activities such as lectures, evening courses and reading; and cultural activities such as ballet, opera, sculpture, and painting.

Actual research in the field of artificial gravity and how it will affect the activities of human beings has been limited to that done on Earth and is thus influenced by Earth's gravity. According to Stone and Letko (Note 3), however, the semi-circular canals are not responsive to linear accelerations and for this reason the presence of a gravitational vector in a simulation will not affect the stimulation of the semi-circular canals. Thus, results using Earth based simulators are valid for this area of research.

The dynamic characteristics of artificial gravity, Coriolis acceleration, and cross-coupled angular accelerations which are produced by rotation affect a person as a function of radius length, decreasing with longer radii. Increasing the radius, however, brings about increasing weight, inertia, momentum, and increases difficulty in control and stabilization, and fuel requirements. Trade-offs are essential for practical planning. For this reason, boundaries for walking, climbing, material handling, postural balance, and nominal head movements were established by Stone (Note 15). He further stated that adaption to any given environment is possible, but influences of rapid transition back and forth between different environments remains relatively unexplored. Additional research on physiological aspects of artificial gravity have been conducted by Cramer and Graybiel (Note 5); Letko (Note 16); Niven, Hixson, and Correia (Note 17); Piland, Hausch, Macaman, and Green (Note 18); and Thompson (Note 19). Although well seasoned, experienced subjects have been able to withstand 50 rpm for short periods of time with minimal head movements, the general consensus is that a limit of 3 rpm be set for normal subjects. Rates of 8 rpm are beyond the limits for even selected individuals for any period of time.

Salked (1979) utilized a rotation rate of 3 rpm in his designs for space habitat living, while Winkler (1978) believes that 1 rpm is necessary for general populations living for prolonged periods of time. Gerard O'Neal compromised by recommending 2 rpm in a report to Congress (Heppenheimer, 1977). It has not been possible to conduct research in space in order to establish the angular velocity limitations for desirable living of a large, general population.

The effect of angular velocities, ranging from 1.7 to 10 rpm, on the accuracy of dart and ball throwing was studied by Clark and Graybiel (1961) and on throwing darts and balls during prolonged exposure to 1 rpm by Kennedy and Graybiel (1962). Scores achieved above 1 rpm were erratic. Apparently learning time was insufficient, because in the latter study, mention was made that with time and practice, subjects were able to attain accuracy. At 1 rpm, however, Kennedy and Graybiel reported that there was no need to compensate for the effects of artificial gravity, yet adaption to 1 rpm rotation was sufficient to cause a post-adaption phenomena.

There have been no studies of the psychological effect of centrifugally generated gravity on humans, but studies utilizing monkeys and rats by Altman (1973) demonstrated that increased weight is adversive. This may have implications for selecting the location of recreational areas along the g gradient in a rotating habitat where trade-offs may be necessitated by the need to maintain physiological well being. Without a rotating space habitat, research into these areas is severely limited and must perforce be hypothetical rather than empirical.

CHAPTER III

PROCEDURE FOR THE STUDY

A review of literature associated with the effects of zero gravity and artificial gravity upon human performance and activity was conducted. A computer search was utilized to identify source material within the extensive NASA library system. This review of pertinent literature was complemented by interviews with members of the space community associated with the manned space center at Houston, Texas, members of relevant technical societies in the Houston area, and speakers at symposia and technical meetings in the Houston area which related to activity in space. Many trips were made to the space museum at NASA/JSC to view exhibits and movies, go on guided tours, attend lectures, and question speakers.

Interpretation of findings was made relating the effects of zero gravity and artificial gravity upon the performance of traditional leisure time activities which have evolved in Earth's gravity. Conclusions regarding these effects were drawn where possible. A bibliography and appendices were prepared as part of the study.

The final draft of the study was reviewed by Willie Heineman, Jr. of the Program Development Office of the Lyndon B. Johnson Space Center in Houston for accuracy of the technical content.

CHAPTER IV

ZERO GRAVITY

The activities that mankind has pursued during his leisure time have evolved in an environment in which the effects of gravity are so pervasive that its absence is difficult to imagine. When gravity no longer affects matter, matter no longer has weight. Without weight, there is no traction, thermally induced convection, buoyancy, or sedimentation. The predominant forces affecting matter become inertia, surface tension, and adhesion.

The astronauts on Skylab performed several experiments with water which provide a graphic illustration of zero gravity effects on matter. When the astronauts expelled water from a syringe in Skylab, it formed a perfect ball which clung to the end of the needle until the syringe was jerked away. One time a ball floated across the room until it hit a wall. It remained there looking like a blister, until it evaporated. The astronauts also placed a ball of water between two points on a lathe. By drawing the two points apart, they could stretch the water ball into a cylinder. They could even form a rope of water by revolving the two points of the lathe in opposite directions or inflate a water ball like a balloon by injecting it with air (Cooper, 1976).

The water formed perfect balls because surface tension, not a strong influence on Earth, was now the dominant force governing its shape. When the water ball moved away from the syringe, it was by reason of Newton's third law which states that, "For every action there is always an equal and opposite reaction" (Highsmith & Howard, 1972, p. 52). The ball floated across the room until it hit the wall in accordance with Newton's first law which states that, "A body continues in a state of rest or uniform motion unless acted upon by an outside force" (Highsmith & Howard, 1972, p. 54). The velocity of its movement across the room was a factor of the initial force used in jerking away the syringe, as Newton's second law states that, "The rate of acceleration is proportional to the force impressed and in the direction of the force" (Highsmith & Howard, 1972, p. 54). It clung to the wall, looking like a blister, because adhesion caused the surface of the water to spread out until the ball became a hemisphere.

To illustrate the changes that zero gravity can have on the leisure activities enjoyed on Earth, imagine a swimming pool in zero g. Water flowing into a swimming pool normally falls to the bottom of the pool where it spreads out to cover the bottom and then rises, filling the pool. In zero g, the water would not fall to the bottom of the pool. Instead, it would form an enormous ball of water at the mouth of the outlet. The water cannot be contained in an open pool because any movement could cause it to move away. Although the water is weightless, it still has the same mass it has on Earth. A large ball of water floating free in zero g has a destructive potential equal to its mass times the velocity of its movement. It is obvious that swimming in zero g is not possible except in an enclosed tank equipped with an air lock. The swimmer would have to use a self contained breathing system to prevent air bubbles from increasing the pressure inside the tank and from obscuring vision. Should a swimming tank be provided in a space habitat, the scuba diver, who is ballasted for neutral buoyancy on Earth, would find little difference swimming in zero g, except the water would spread like an oily film over his body and would be difficult to remove when he finished his swim. This characteristic of water, to cling to walls and the body, also affects showering. Carr (Note 10) reported that it took 45 minutes to dry and clean up after a 15 minute shower. The need to shower and the difficulties in removing water from the shower and one's self may influence a person's decision to participate in an activity.

Walking, running, jumping, and their variations are basic to many leisure time activities. However, without traction, these are no longer possible. In the movie, 2001, A Space Odyssey (Kubrick, 1968) Arthur Clark, the eminent science fiction writer, overcame this problem by providing a stewardess with velcro soled shoes and a velcro carpet. In his book, Islands in the Sky (1952), actors in a stage production of Macbeth wore magnetic shoes. NASA tested both velcro and magnetic shoes for walking in weightless conditions. Testers found the velcro shoes annoying. They reported that the shoes were too noisy and that walking in them was similar to walking through sticky mud. Ferrous flooring in Skylab was impractical because of weight and electromagnetic considerations which precluded the use of magnetic shoes (Louviere, Note 9).

Cromie (1976) reported a triangular grid floor and special shoes were used on Skylab to provide walking and standing capability for the astronauts. These shoes were equipped with rubber coated aluminum soles to which two different types of cleats could be fastened. One type resembled a mushroom which slipped in and out of the floor grid fairly easily and provided some traction, but did not hold an astronaut securely. The second type was a triangular cleat which fit the triangles of the floor grid exactly and could be locked into place by twisting the foot. When an astronaut used this cleat, his feet were held securely in place. However, positioning the cleat into the grid and locking and unlocking it, was time consuming. This rendered the shoes impractical for walking. Toe straps and foot restraints were used for standing in areas without a grid floor.

On the lower deck of Skylab, where the crew quarters were located, and in the multiple docking adapter where the solar console was located, ceilings were low. Carr (Note 10) reported that the low ceilings allowed the astronauts to move about by a means of a modified walk by alternately pushing against the floors and ceilings with both hands and feet.

In the large upper deck, which contained the workshop, this method of locomotion was impossible, and the astronauts moved from place to place by pushing against a surface in order to propel themselves through the air to their destination. Like the water ball, they would travel in a straight line opposite to the direction of push and at a velocity determined by the force exerted by the astronauts at the initiation of movement.

The astronauts also had the same mass in zero g that they had on Earth and collisions could be painful and damaging. Astronaut Conrad dislocated a finger and the astronauts sustained many bruises while propelling themselves through the hatches. Cooper (1976) reported that the astronauts limited themselves to a velocity of 61 cm. (2 ft.) per second.

Cooper also stated that the astronauts would add summersaults and twisting movements as they propelled themselves through Skylab for enjoyment. Lousma, he said, "liked to leap from the workshop floor, do a variety of gainers before reaching the ceiling, and then--just before he reached the ceiling of the dome--straighten out as cleanly as a diver hitting the water, in order to disappear through the hatch without touching its sides" (p. 74).

A dive in zero g, however, is not entirely the same as its counterpart on Earth. On Earth, a diver falls towards the water at a velocity of 9.75 m. (32 ft.) per second^2. Gravity thus imposes a time limitation within which the diver must complete his dive. The time can be varied only by changing the height of the board or platform, or the height achieved by the diver during his takeoff. The velocity of a dive in zero g, such as Lousma's, is determined by the force exerted at initiation of the dive and is constant throughout the duration of the dive. The variation in duration of a dive performed in zero g can be considerably greater than the dive that is performed in Earth's gravity. Skylab astronaut Gibson once spent 20 minutes reaching an opposite wall when he inadvertently pushed away from a work area (Cooper, 1976). Because there is no weight to depress a spring, spring boards have no purpose in zero g. Diving platforms would be unnecessary and the long climb to the top of the 10 meter platform would be eliminated. In zero g there is no gravity imposed "up" and "down," there is only "away" and "towards." On Earth, errors in execution of the initiation of the dive which, could cause the diver to miss the intended finishing point, are modified by gravity. In zero g, this modification would be absent, and any error in initiation of the dive could cause the diver to end his dive at a considerable distance from the intended landing area. However, Cromie (1976) stated that "all of the astronauts became more agile, for in one of the medical experiments designed to test their reflexes, their feet kicked more than an earthling. In weightlessness, their nervous systems sped up like those of birds whose reactions must be swift" (p. 74).

The astronauts could initiate summersaults and twists after beginning a flight across a room because, although the center of mass must move in a straight line at a constant velocity, the body can be put into rotational motion by the transfer of momentum from one body part to the whole (e.g. moving arms and legs with respect to the torso). By using muscular force, the body can summersault and twist around its center of mass. The speed of the summersault or twist depends upon the distance of the moving mass from the center of mass, and the velocity imparted to the moving mass (Frolich, 1979).

Standing in zero g, even if the feet are secured to the floor in some manner, is also quite different. Skylab astronaut Jerry Carr (Note 10) said that he would sway and could get into a nearly horizontal position which, if it happened on Earth, would surely result in broken bones. This means that in zero g, a person can cover a much larger area of space than he could in Earth's gravity, but he can exert less leverage and can easily be knocked from an upright position. Movies of Skylab (NASA, Note 21) show that one method the astronauts used to stand and work in Skylab was to use a triangular cleat on one shoe and a mushroom cleat on the other. They would lock the triangular cleat into the grid to fix one foot. The foot with the mushroom cleat could be moved about to counteract trunk movement and thus provide stability.

Throwing, catching, or hitting balls are also skills which are basic to many leisure activities. These too, will be greatly affected by zero g. A person throwing a ball imparts energy to it by the force of the arm propelling it. Because the momentum of the arm will put the rest of the body in motion, some amount of backward force will be exerted on the person throwing the ball. On Earth, the traction of the feet against the ground's surface counteracts this force. In zero g, there will be no gravity induced traction to stop the backwards movement. Nevertheless, ball games are possible in zero g because the velocity of this movement is equal to the force exerted in throwing the ball divided by the mass of the body. The force needed to throw the ball is small in relation to the mass of the body, and thus there will be little movement.

Techniques of throwing and catching will also be changed in zero g. In Earth's gravity, when a person throws something, he compensates for gravity by aiming at a point above the target. In zero g, this would result in missing the target. On Skylab, the astronauts sometimes threw velcro tipped darts at a velcro dart board. At first the darts always missed the target because the astronauts aimed high, the way they would on Earth to compensate for gravity. When they learned to aim directly at the target, their scores improved (Cooper, 1976). Spin put on a ball not subject to Earth's gravity will result in curve ball trajectories not possible on Earth. The person catching the ball will be moved backwards by the force of the ball. The velocity at which the person moves is determined by the mass of the ball and the ball's velocity. This is true because the product of the person's mass and velocity after catching the ball will be equal to the ball's mass and velocity before impact. Movement will be in a direct line if the ball is caught near the point of the person's center of mass. Movement will be rotational if the ball is caught peripherally to the center of mass.

If a person misses catching a ball in zero g and it hits a wall, the ball will not conveniently bounce off the wall, fall to the ground, and roll to a stop where it can be easily picked up. In the elastic collision of a ball with a rigid structure, most of the kinetic energy is returned to the ball as it rebounds, as only a small amount of energy is lost to heat and permanent deformation. The weightless ball, losing only a small amount of its energy as it bounces, will return at nearly the same velocity, and if caught, will have nearly the same impact. The Skylab astronauts sometimes threw a rubber ball around a ring of lockers in the workshop. Astronaut Weitz once threw a ball so that it bounced 111 times before it stopped (Cooper, 1976).

It is apparent that in zero g, ball games will be greatly changed in character. To illustrate this difference, let us imagine what might happen to a bowler on Earth if gravity were suddenly taken away as he is about to release the ball. The ball suddenly becomes weightless, but it still takes considerable energy to propel the ball forward because of its mass. Without traction, and thus leverage, the bowler is not able to impart the same force to the ball as in Earth gravity, so the ball proceeds down the alley at a much slower velocity. For illustrative purposes, let us say that difficulties in releasing the ball, due to lack of traction, cause the bowler to release the ball some twelve inches above the floor of the alley. The ball will continue down the alley at this same height and will hit the tops of the pins. These are set spinning while the ball, only slightly deflected from its path, continues on to hit the back of the alley. The ball then rebounds along the alley to be caught by the bowler who has been slowly moving back from his starting point. When he catches the bowling ball, the bowler's velocity will increase according to the ball's mass and velocity. The spinning pins must now be caught. Once caught, the pins can't be put back into place without imparting some movement; thus, the game cannot continue.

If gravity is removed from a game of baseball, new elements must be considered. The person pitching the ball, which has much less mass than the bowling ball, will be less affected by the throw than the bowler and will remain essentially in place. The people batting the ball will find that as their arms and bat swing in one direction, their legs and torso will rotate in the opposite direction. Thus the batters are swinging their arms and bats against the inertia of their legs and torso. Consequently, batters will not be able to hit the ball with the same amount of force which they could on Earth. As a result, balls will travel at a proportionally slower velocity. Because the two opposing forces within their bodies are nearly equal, batters will remain essentially in position until they initiate some action which will propel them towards first base. One method which could be used is to throw the bat upwards. This action will force the feet of the batters into the "ground" which may give them sufficient traction to initiate movement towards first base. "Runners" must now concern themselves with either stopping at the base or changing direction. Unless the runners can use a fixed plate to stop and turn, they must continue their path until they contact another object. Should this be the equally weightless person playing first base, they will carry this person off with them. Both players will proceed at a reduced velocity. Persons who are skillful may, by utilizing

Newton's third law, push the person playing first base away in a manner which propels them towards second base. At each base, these same options face the runner.

Persons wanting to catch a ball must calculate a trajectory and a velocity which will intercept that of the ball. If the calculations are correct and they catch the ball, they can throw it to the appropriate person. Then, the person must continue, on a slightly deflected course, until contact is made with another object. If a person calculates the relative trajectories incorrectly or is unable to initiate the planned trajectory, the ball cannot be caught. The person must continue on until some force, such as a wall, intervenes. At this point, the person can initiate a new attempt to catch the ball or return to position if someone else has caught the ball. At a velocity of 61 cm. (2 ft.) per second, baseball in zero g would be a very slow game.

Agility and the ability to judge velocities and trajectories will become the important skills necessary for ball games in zero g. Strength will be of much less importance. Changing direction to elude players will be impossible without providing traction or by using some external force.

A fact which must be taken into consideration by anyone involved in the planning of leisure activities is the effect movement has on the space habitat. A person pushing against the Earth has negligible impact on the movement of Earth because of the vast differences in the two masses. In a small habitat, however, the movements of its occupants can have considerable effect. Carr (Note 10) reported that the astronauts in Skylab had devised a method of running around a ring of lockers that lined the wall of the workroom. They would start by holding on to the lockers with their hands and assuming a position similar to a runner at the beginning of an event in a track meet. The toes of the back foot would be wedged between the lockers to get traction. By using a combined push off with the feet while holding on with the hands, the astronauts could work up sufficient velocity to create a centripetal force which gave them weight for traction. They would then run and perform handsprings and the like for enjoyment. This activity had to be curtailed because of malfunctioning of the moment gyroscopes which maintained the stability of Skylab. Activities which affected the movement of the habitat also had to be curtailed during times when habitat stability was required such as during photography sessions or when astronomical observations were being made. Oberg (Note 11) stated that the Russian cosmonauts also reported having to limit their movement when performing delicate experiments.

Another factor to be considered when designing an area for sports in a zero g environment, is the lack of a gravity imposed vertical orientation. Players may become disoriented in their three dimensional world unless other cues are provided to determine direction. Sound does not travel well in the reduced atmospheric pressure currently used in space habitats. Astronaut Carr said that about 4.57 m. (15 ft.) was the maximum distance that a loud speaking voice carried on Skylab. For this reason visual cues may have to be planned.

Exercise in some form will be a necessary part of the daily program in order to counteract the cardiovascular deconditioning and muscular atrophy which occur as a result of living in zero g. The Russian cosmonauts have spent more time living in zero g and have the more comprehensive exercise program. They spend up to two and a half hours a day in exercise, using a bicycle ergometer, a treadmill, and expansion exercisers. In addition, they wear portable lower body negative pressure suits for several hours a day which cause the heart to pump harder and tight, elastic suits which require muscular tension to stand erect or to move the arms and legs ("Cosmonauts Increase Exercise," 1979; Makarov, 1979; Oberg, Note 11). The Skylab crews spent a maximum of one and a half hours a day in exercise.

They did not have portable lower body negative pressure suits or exercise suits. Instead they spent thirty minutes, every third day, in a lower body negative pressure machine (TRW, Note 22).

Kornberg, Chapman, and Glasser (Note 23) considered that it would be unrealistic to expect workers in space to exhibit the exceptional self-discipline and self-motivation exhibited by these pioneers in space. These authors suggest exercise could involve new team games. From the foregoing examination of the effect of zero g on the elements of sports, it appears doubtful that games could replace an exercise regimen. Only the hydrodynamics of water offer a means of counteracting cardiovascular deconditioning and muscular atrophy with a sports program. Theoretically water games, such as water polo, can be transferred to space in a modified form. The problem of the transport of the necessary water alone, however, render them impractical at this time. Combining certain passive activities, such as listening to music or watching television with the daily required exercise might be another answer to the monotony of the required exercise.

Another alternative would be running, as the astronauts did, around the circumference of Skylab. Carr (Note 10) reported that while running he thought he had attained almost 1 g. Running for 30 minutes each day might provide not only a method of preventing deconditioning of the cardiovascular system and muscular atrophy, but also provide a method of reversing calcium resorption. This condition has been found in all the astronauts and cosmonauts despite all the methods of exercising and providing tension on the limbs during space flight. Berry (Note 23) speculates that a pharmacological agent will be found which will stop the loss of calcium and the resulting osteoporosis. Meanwhile, in tests which involve bed rest, Berry reported that standing on a tilt board for 30 minutes daily had maintained the calcium balance in the subjects.

Leisure activities other than sports will also be affected by zero g. The Skylab astronauts selected books to take with them and read during some of their leisure time. Astronaut Kerwin (1977) found that his shoulders rose in zero g whenever he relaxed and this was annoying when he was trying to read a book held on his lap. Astronaut Conrad found reading no problem. "If we're reading, we free float and wind up wherever we wind up--on the ceiling, on the floor, ricocheting off the walls, even in the corner. And it doesn't seem to bother us" (Cromie, 1976, p. 42). Changing light, however, could be annoying for a reader in motion. Carr (Note 10) reported that book pages would fan out and anything loose, like book marks, would float away. If the astronauts put a book down open, the hinges of the book would force it slightly closed which caused it to rise and float off. A book put down closed, could be put in motion by an accidental touch or by habitat movement.

Handcrafts, hobbies, and games will undoubtedly be a part of leisure activities on long sojourns in space. Protracted journeys in space are reminiscent of the long voyages of American whalemen. Scrimshaw, the incising of pictures on whale bone and teeth, is a legacy of these isolated, monotonous journeys. In their spare time, the sailors used sail needles to cut out a design. They then used lamp black to rub into the cuts for contrast. At this time, the astronauts are limited to materials taken into space with them. In the future, material from the moon and the asteroids will be available for use, and possibly a new art form will evolve as a legacy of voyages in space.

Work methods, however, will be changed from those whalemen of the past. For one thing, the astronauts did not sit to do their work on Skylab. Carr (Note 10) reported that they removed the seats from both the bicycle ergometer and the solar console. Duvall (Note 25) stated that to sit in a chair required being strapped in and that the astronauts found this quite uncomfortable. Kerwin (1977) reported that when he stood in Skylab that the shoulders, elbows, and hips flexed 20 to 30 degrees so that the body naturally assumed a posture comfortable for working. If the work area was too low however, stomach muscles had to be employed to assume and maintain a working position. Carr reported that the stomach muscles were the only muscles which increased in strength during the astronauts' stay in zero g. Tables to be used in space should be positioned at a comfortable, weightless standing height, and made adjustable when possible. A tilted top might be more comfortable for working.

For another, all the miscellaneous parts, tools, fasteners, colors, finishes, glues, waste products, and the project itself, are also weightless. At first thought, this might seem an advantage. A tool or part wouldn't have to be put down somewhere, it could just float there, waiting to be picked up again. Carr (Note 10) reported however that in zero gravity, it is almost impossible to place something in space without imparting some motion to it. When several items were loose, it was difficult to keep an eye on all of them. If an item got lost, it was difficult for them to find it again for it might be anywhere. Not knowing where or how far to look confused them. Something might be right in front of their eyes, but if the astronauts were focusing farther away, they couldn't see it.

Methods of confinement will be a necessary consideration in the design of any work area because not only would it be annoying if there were no way to contain needed items, it would be dangerous for small objects, sandings or chips to float around. Carr reported the astronauts were not given hack saws, drills, or files because of the danger of inhaling sandings and chips. Kornberg et al. (Note 23) suggested that protective masks might be necessary in work areas. Tools could be magnetized, slipped under individual restraints, or stuck in some plastic substance. Work could be held by vices, clamps, velcro, magnets, or tethers. All liquid supplies, such as paints, finishes, and glues will have to be prepared beforehand in dispensers that will prevent the liquids getting into the environment.

Special care will have to be taken to vent noxious fumes, because without buoyancy, they will not disperse from the work area. In addition to the effect of zero g on the behavior of these fumes, care will have to be taken that all outgassing can be handled by the filtering system.

Most lost objects on Skylab were eventually caught up in the air currents caused by the air conditioning system and were found held by the current against the filter screens. Carr (Note 10) reported that astronaut Gibson utilized those screens for an improvised work bench, making what he called an aerodynamic work bench. A vacuum work bench would solve many of the problems of doing hobbycraft in zero g. It would hold down tools, parts, and instructions, while carrying off sandings, chips, and fumes. An on/off switch and a variable power knob would increase its capabilities. Foot restraints should be provided, and for certain types of work, a waist restraint might be provided for better leverage.

One of the student experiments conducted on Skylab tested eye-hand coordination to see if it is affected by zero g. Kathy Jackson, a student at Clear Creek High School, League City, Texas, suggested the experiment. The astronauts had to follow a certain sequence of inserting a thin stylus into 119 small holes arranged in a maze. They did this before the mission, three times during the mission, and after splashdown. Kathy compared their performances to discover if a long period of weightlessness impaired an astronaut's ability to do fine skillful work. The results showed no decrease in the astronaut's coordination after 84 days in weightlessness (Cromie, 1976). Carr (Note 10) reported however, that greater eyeball pressure causes the lenses of the eye to flatten out and there was some change in visual acuity as a result.

Games, such as dice, chess, and cards which have a long history on Earth, would be impossible in zero g without some method of adaption. Magnetizing the pieces or using velcro was done on Skylab, as mentioned before. Another possibility is using electronic games which are currently quite popular.

Getting together to eat and drink is considered a leisure activity by many and provides an occasion for social interchange. The cosmonauts on Salyut are more fortunate than were our astronauts on Skylab in that they are able to have visitors. Makarov (1979) who visited Salyut 6 said:

> We hug our friends . . . afterwards all four of us sit down at a table, just as we would have on earth. We lean elbows on the table, lift tubes of fruit juice to toast our meeting, chit chat for a long time about earth, about friends, and relatives. We pass on countless greetings, letters, notes, and small parcels.

Included in the parcels brought up to the cosmonauts were fresh foods such as strawberries, nuts, milk, garlic, and curds to add variety to the meals prepared and packaged beforehand on Earth ("Salyut 6/Soyuz," 1978).

The American astronauts did not have the luxury of guests aboard Skylab, but they made it a point to get together for their meals each day. Cromie (1976) described cooking and eating on Skylab. He reported that all food was prepared on Earth. One astronaut was assigned as cook each day. He would check the menu, then arrange frozen, canned, and dehydrated food on three trays and set the timers. Each tray contained eight holders, three of which could be heated for thawing and cooking the food. The trays used conduction units for heating because conventional or microwave ovens used too much electricity (Duvall, Note 24). Cromie also reported that hot and cold water hoses at the table supplied drinking water and enabled the astronauts to prepare dehydrated food and beverages. Food on Skylab was superior to that of the earlier missions and the astronauts were able to eat in zero g much as on Earth. NASA's experimental kitchens designed food items such as spaghetti and peas with a sticky consistency so they would stay on the spoon and not float away. Gravies held meat and vegetables together. Also, covers were put over the contents of cans so that the astronauts could slice these open to get at the food. The covers kept the uneaten portions from floating away.

Cooper (1976) stated that the silverware was magnetized to hold it in place, but astronaut Pogue complained that there was no secure place to put his knife, fork, or spoon. He put rubber bands around his tray to hold his silverware down. Despite this precaution it still got kicked off the table, and he complained once to NASA Control that his spoon was stuck on the ventilating screen upstairs.

Eating in zero g requires a certain amount of skill. Once a portion of food is lifted from its container, it will continue on its trajectory. If an astronaut paused or turned toward another astronaut, the food would keep on coming which could get messy. Carr (Note 10) reported that the astronauts found that the best method was to use a smooth, archlike motion, tipping the utensil slowly so that it was always in back of the food in relation to the mouth. If any stray globules of food, or the gravies which held meat and vegetables together, floated away, these had to be caught or washed off the walls or the filter screens. Numbers of people eating together in zero g risk getting spattered, aspirating floating food or liquids, or being hit with stray silverware.

As yet no food has been prepared in zero g. At the University of Houston, the Hilton School of Hotel and Restaurant Management and the Environmental Design Center are working together to design the first restaurant for zero g. They are now exploring ways of bulk packaging some food for preparation in zero g and designing kitchens, tables, and containers suitable for weightless conditions. Trotti (Note 25) reported that in the current state of the art, many procedures will still have to be performed on Earth. Such things as chopping onions or frying eggs and bacon just are not possible at the present time.

The person who likes to cook as a hobby must consider that the storage, measurement, preparation, and mixing of ingredients will have to allow for the absence of gravity. The astronaut's difficulties with putting salt and pepper on their eggs indicates the difficulties that aspiring cooks will face. The salt was in solution and was squirted out of dispensers. The nozzles became plugged up with dried salt, and to make them work, the astronauts would squeeze them. They squeezed too hard once and the bag broke. As a consequence they spent days picking salt off the walls of the wardroom. The pepper, brought along by the second crew, floated about inside its box. It was almost impossible to shake it out. What did come out, instead of settling on the eggs, swarmed off in a cloud, diffusing throughout the workshop (Cooper, 1976).

The food in space will not taste the same as on Earth. Lack of convection inhibits food odors from rising. Smell is an important part of taste. Cooper reported that the astronauts found the food bland. The second crew took a variety of condiments and spices, including horseradish and Tabasco sauce, but nothing seemed to give the food much taste.

The first garden in space was an experimental study by members of the Soyuz 11 crew during June of 1971.

Riabchikov (1971) reported that a space garden was set up on the upper level of the Salyut. A growing medium had been prepared and seeds of cabbage, flax, and onion were placed in it. Vitkor Patsayev became the first "space gardener" when every evening he squeezed a rubber bulb to administer to the plants from a special reservoir tank filled with water and nutrients. The hydroponic method of cultivation was used. The seeds sprouted and the space garden turned green. An automatic camera recorded the growth of the plants.

Vasilyev (1979) reported however, that experiments conducted at the Institute of Lithuania Academy of Science where plants were grown in horizontal clinostats in which plants could "feel" weightlessness indicated that plant roots sometimes "swam" in space while stems went into the soil. Plants grew badly, some died. Later experiments on Salyut 4 confirmed these findings. Later, Russian researchers discovered that plants grew normally if the pull of gravity was only slightly increased. A special container which rotates, thereby creating artificial gravity, was developed and is now used successfully in space by the Russians.

At the University of Arizona, researchers are experimenting with an eight-foot plastic drum that revolves at 50 rpm for growing plants in zero g. A fluorescent tube runs down the center to provide light. The roots poke through holes in the inner surface to a separate compartment where they are sprayed with nutrients ("Vegetable Crops," 1981).

Johnson and Holbrow (1977) in their imaginary tour of a rotating space habitat mention parks, trees, and a profusion of flowers. Pots of tomatoes and lettuce are being grown on one balcony, while a patio below is lined with dwarf apple and peach trees. Scenes like this are not possible in zero g and the absence of plants undoubtedly will affect the quality of life in space for some people. When cosmonauts Lyakhov and Ryumin returned to Earth after 175 days in space, one cosmonaut was presented with a bouquet of daisies. He was reported as saying that he could not get enough of the smell (ABC News, Note 26).

Storage, adequate space and ease of retrieval are often a consideration for the person in charge of leisure activities. Zero g adds an additional component to this consideration which Carr (Note 10) referred to as the "jack-in-the-box" phenomenon. He reported that when locker doors were opened, the stored items flew out [with the resulting air currents]. These items had to be collected, replaced, and held within the locker until the door was closed. When drawers were pulled open, their contents flew to the rear.

They flew forward when the movement was stopped or in the process of closing, and then they ricocheted out of the drawer. To complicate matters, the contents of the drawer below would flow into the space freed by the opened drawer, jamming it open.

By using mesh doors on lockers, the strength of the currents would be minimized and the contents would be visible through the door. Sliding doors would redirect currents, minimize openings, and allow opening from either side. Individual restraint of stored items using velcro, springs, magnets, clips, or other suitable means is indicated. Drawers should have transparent faces and lids. Room, locker, and drawer walls should be built of materials that allow their maximum use for securing items. Ease of handling and usage should dictate the form and design of containers and storage areas. Unitization may be more practical than storing items separately and having to open several storage containers for one activity.

Stored items will be a part of the mass of the habitat and a factor in its management. In a large habitat, this would be a minor consideration, but in a small habitat, the mass of the equipment for leisure time activity and the location of its storage area would be an important part of the design.

It can be seen that zero gravity effects present varied inconveniences for work and daily living. Also physiological changes resulting from the adaption of the human body to weightlessness have presented problems for which no solution has been found at this time. Supplying artificial gravity has been suggested as a means of providing an environment more conducive to normal living. Artificial gravity will be discussed in the following chapter.

CHAPTER V

ARTIFICIAL GRAVITY

Space habitats which have artificial gravity have been studied by the 1975 NASA-ASEE Engineering Systems Design Summer Program (Johnson & Holbrow, 1977), MIT (Smith, 1976), the 1977 Summer Study at NASA Ames Research Center (Billingham, Gilbreath, & O'Leary, 1979), and Salked (1979). These studies have been primarily concerned with details of structure and life support. Limited studies of movement and human performance which are basic to leisure time activities have been conducted by Clark and Graybiel (1961), Kennedy and Graybiel (1962), Letko (Note 16), and Stone (Note 14). Stone stated:

> There is no past experience that can serve as a basis for establishing these conditions. Through knowledge of the unique characteristics of artificial gravity we must estimate what influence these characteristics may have on specific performance. (p. 27)

Newsom (1972) stated:

> Not enough is known at this time about the many interacting relationships to be certain of optimum design parameters for the use of artificial gravity in a large space station or orbiting base. Therefore every opportunity should be taken to define the questions for which we have no answers at present. (p. 196)

In order to estimate the effect that artificial gravity will have on leisure time activity and to identify the questions which need answering before a detailed analysis can be performed, it is necessary to understand the difference between true gravity and artificial gravity. In true gravity, there is a real attraction between two bodies and energy must be expended to keep them separate; analagous to a magnet and a nail. Artificial gravity can be generated by two methods and each has its own characteristics.

Constant acceleration is one method of generating artificial gravity. Albert Einstein developed the classic elevator "thought" experiment which demonstrates the similarities and differences between gravity and constant acceleration (Greenberger & Overhauser, 1980) (see Appendix A for illustration). In this experiment there are two hypothetical elevators in space, each containing a person holding two masses in his hands: one large, one small. The person in elevator A is experiencing a real gravitational field due to a large mass which is near him (Earth), and so he feels pulled down toward the floor of the car. If he drops simultaneously the large mass (M) and the small mass (m) they will fall with the same gravitational g and reach the floor at the same time. The person in elevator B is not attracted by a large mass, or gravity. Instead a rocket pulls the elevator upward with uniform acceleration equal to the pull of Earth's gravity. The person in elevator B will feel himself pulled down toward the floor of the elevator with the same force. If he releases the two masses, they will maintain a constant upward velocity in accord with Newton's first law. Because the elevator is rising with acceleration g to meet them, the two masses appear to be falling with acceleration g. The persons in each elevator experience the two situations in the same manner and cannot tell the difference between them.

Constant acceleration requires propulsion means beyond current capabilities and is unsuitable for space stations which must remain in orbit. For these reasons, no further discussion of this method of generating artificial gravity will be undertaken in this study.

The other method of generating artificial gravity is rotation, which produces centrifugal force. A person can gain an understanding of the effects of rotation by performing an experiment which is often done in elementary physics classes. A person attaches a rope to a bucket of water and swings the water-filled bucket in a vertical circle. The person doing this experiment will observe that the bucket can be swung so that the water will remain in the bucket. The experimenter will also note that the bucket must be spun more quickly when the rope is short than when it is longer and that if the bucket is swung at a constant rate of rotation and the rope is progressively lengthened, it requires progressively more strength to hold on to the rope. If the experimenter lets go of the rope, or if the rope breaks, the bucket will cease its circular path and fly off in a straight line tangential to the circular path it had been following.

The explanation for the fact that the water remains in the bucket can be found in Newton's first law which states that bodies continue in a state of uniform motion unless acted upon by an outside force. In this case, the outside force is the centripetal force provided by the confining bucket and the rope. In the same way, the floor of a rotating habitat acts as the opposing centripetal force to the centrifugal force generated by rotation and provides a sensation of gravity to a person because he feels pushed against the floor. The radial structure of the habitat is analagous to the rope.

Artificial gravity generated by rotation resembles gravity in the following ways:

1. It provides an up/down orientation.
2. It provides traction for locomotion.

3. It provides a sense of falling.

4. It provides stability--things stay where they are put.

5. It allows convection currents, buoyancy, and sedimentation.

However, artificial gravity, thus generated, substantially differs from a true gravitational field. There are both static and dynamic characteristics which should be understood before planning leisure time activities for a rotating space habitat. Several of these characteristics can be extrapolated from the experiment with the bucket of water.

In order to keep the water in the bucket, the bucket of water has to be spun more quickly when the rope is short than when the rope is long. Thus, the rate of rotation and the radius of rotation or the length of the rope, determine the force of the water acting against the bucket. Rotating space habitats are subject to the same basic laws. Habitats with a shorter radius must be spun more quickly than habitats with a longer radius to achieve the same degree of gravity at their periphery.

It requires progressively more strength to hold on to the rope if the rope is progressively lengthened while the rate of rotation remains the same. The longer the rope (radius) the stronger the force (artificial gravity). At increments along the rope, the force will be progressively stronger. An example of an activity that demonstrates this fact is a line of ice skaters, each holding the other, traveling in a circle. The person in the middle skates slowly in a small circle. The people on either side skate in slightly larger circles and they hold on to the person in the middle quite easily. As the number of people in the line increase, the people on the ends have to skate faster and faster and have increasing difficulty holding on. In a rotating habitat, points along a radius travel in increasingly larger circles at faster and faster velocities. The skater in the center has no centrifugal force pulling on him while the skaters on the ends experience more force, which pulls them away from the people nearer the center. If one imagines these people standing along a radius of a rotating space habitat with a floor perpendicular to their feet providing centripetal force, the person standing in the center will be weightless while the people standing nearer the periphery will have more weight. In order to calculate the weight or apparent gravity of a person or object at any point along the radius of a rotating habitat, the formula $a_n = \frac{v^2}{R}$ is used, with a_n representing normal acceleration (Wylie, 1958). An explanation of this formula is found in Appendix B. Appendix C tabulates the radius, circumference, velocity per minute, and apparent gravity from .02 to 1.0 for habitats rotating at one, two, and three rpm.

Using this equation, there is sufficient information to examine the statement by Skylab astronaut Jerry Carr (Note 10) that he thought he had attained nearly 1 g while running around the circle of lockers in Skylab. By measuring a drawing of the Skylab workshop, a radius of 2.62 m. (8.6 ft.) was obtained. A running circumference of 16.47 m. (54.04 ft.) was obtained by multiplying the radius by 2 pi. At this radius, Mr. Carr would have to run at a velocity of 304.2 m. (998.03 ft.) per minute or 18.25 Km. (11.34 mph) to attain a force of 1 g at his feet. This pace is slower than a four minute mile which equates to 24.14 Km. (15 mph) but is faster than a good marathon pace of a six minute mile which is 16.09 Km. (10 mph). Assuming that most astronauts can run at a marathon speed of 16.09 Km. (10 mph) or 268.22 m. (880 ft.) per minute, an astronaut running in a habitat similar to Skylab could attain a gravity level at his feet of .78 g.

Movies of astronauts running around the circle of lockers show that they ran in a crouched position (NASA, Note 20). Assuming arbitrarily that the astronaut's head is at a radius of 1.33 m. (4.75 ft.) less than the radius at his feet, the level of gravity at his head will be .35 g. In rotating environments, the gravity gradient along the body is determined by the varying velocities at each point on the body. Longitudinal stress on the bones will vary and the effect this will have on the calcium resorption which occurs in zero g is untested. There will also be differing degrees of stress on the cardiovascular system which is directly proportional to the gravity level (Stone, Note 14). Although the lower body negative pressure machines used by the astronauts and cosmonauts in zero gravity also caused varying degrees of stress, it is not known how this would affect an astronaut running in zero g for thirty minutes or more. There would also be an apparent shift of gravity towards the feet which may impact the runners' sense of balance and affect his performance.

The rate of rotation is calculated by dividing 268.22 m. (880 ft.) by the circumference of the lockers, 16.47 m. (54.04 ft.) which results in a rotation rate of 16.28 rpm. Whenever the head is moved out of the plane of rotation in a rotating environment, there are cross-coupled angular accelerations in the vestibular organs which can cause side effects consisting of visual and postural disturbances and motion sickness symptomatology. Based on pure gyroscopic theory, Thompson (Note 19) described the effect on a person turning in a full circle as a sensation of toppling sideways and then pitching as the person turns. The severity of symptoms experienced by subjects in Earth based experiments has been related to the rate of rotation. He also reported that a rate of 6 rpm would be tolerable for nominal head movements of trained crews. An astronaut living in zero g, who runs for exercise by creating his own centripetal force, would have no time to become habituated to the rotating environment. Any head movement out of the plane of rotation at 16.28 rpm would cause an undetermined but probably severe reaction.

Because research on reaction to cross-coupled angular accelerations on the vestibular system has been limited to nominal, prescribed head movements at varying rotation speeds in rotating environments on Earth, there is nothing to indicate how these accelerations will affect the often rapid, complex head movements associated with athletic games, gymnastics, ice skating, etc., in slower rotating habitats. Clark and Graybiel (1961) have noted that random movement of the head produced more stress than controlled testing movements. Thompson (Note 19) considered that this effect of artificial gravity would be a primary limitation to performance. Therefore, realistic planning for leisure time activity in artificial gravity will be limited until studies and testing develop parameters of tolerance for this phenomenon.

In a rotating habitat, a person who moves in the direction of rotation increases his velocity. As a result, a person moving in the direction of rotation also increases his weight because gravity, hence weight, is a function of velocity squared divided by the radius. Conversely, a person moving counter rotation decreases his velocity and gravity level; he weighs less. If a person moves counter to the rotation at a velocity which equals the velocity of the rotating habitat, that person will become weightless and will no longer be subject to rotational forces. He will be governed by the laws of motion described in the preceding chapter on zero gravity, in an environment which continues to rotate.

Letko (Note 16) studied this effect (Coriolis acceleration) in the Langley Rotating Space Simulator. Subjects walked both in and counter to the direction of rotation; increasing or decreasing the nominal levels of gravity by an amount that depended on their walking rate. The subjects were suspended by a system of cables and harnesses which were attached by a boom in order to eliminate Earth's gravity as a component. The radius of the simulator was 6 m. (19.69 ft.). The rotation rate was from 3 to 10.5 rpm, producing g-levels of from .05 to .75 at the subject's feet before commencing to walk. Both a circular and a flat, segmented floor were used. The subjects reported body and leg heaviness. At g-levels of .5 and .75 these sensations were quite disturbing. Velocity was not recorded in this reference, thus it is not possible to calculate actual gravity levels while walking. When walking opposite to the direction of rotation, the subjects would float free of the floor.

Activities which involve walking, running, etc., cannot be planned until the parameters of gravity levels for successful performance are established. When these are established, the activity can be analyzed to determine whether it can be performed in a particular habitat.

Fluids will also be subject to changing gravities when movement is into or counter to rotation. For example, a person handing a cup of coffee to a person so that the movement is counter to the direction of rotation, could accidentally put the coffee into weightlessness. The circulation of water through the pumping and filtering system of a swimming pool would also be affected by this phenomenon and would have to be considered in the design.

In addition to Coriolis force, the direction of the centripetal force in relation to a surface, floor, ramp, apparatus, etc., used for an activity must be determined. In the Langley simulator, a flat, segmented floor was laid out inside the similator circumference. The direction of centripetal force was perpendicular to the floor only at the center of each segment. When the subjects walked along the floor in the direction of rotation, they were subjected to a component of gravity acting opposite to the direction of walking when on one side of the perpendicular and acting in the direction of walking when on the other side of the perpendicular. The result apparently would be as if the subjects were walking first uphill and then downhill. Letko took movies of these subjects which showed them walking aligned with the local artificial gravity vector rather than the surface of the floor. The subjects reported, however, that they felt they were walking on a level surface. Letko (Note 16) stated "the reason for this is not completely understood at this time" (p. 69). Calculating the angle of force to the floor at the far edges of the segments which were 2.44 m. (8 ft.), it was found that this angle is 78°. The subjects thus, were leaning 12° at most during the experiment. This may not have been sufficient to stimulate the gravireceptors of the subjects to override the visual stimulus of the flat floors. The subjects did report that at g-levels near .1 it appeared more difficult to initiate or stop walking, indicating movement was affected by the angle of force with respect to the floor.

When a person moves radially, the body and its parts have an angular velocity corresponding to the velocity of the point on the radius where the person is standing. When a person moves into a slower or faster moving area of radius, this will cause the person to lean into or away from the direction of rotation according to whether the person is moving into a slower or faster revolving environment relative to the initial location. A person ascending a ladder would want to face into the direction of rotation and face away from the direction of rotation when descending (see Appendix D).

A person's weight would increase during movement towards the periphery. Packages will feel progressively heavier. If movement is rapid, the increase in g-forces on the body may cause orthostatic intolerance (Stone, Note 14).

Stone (Note 13), with respect to motion parallel to the axis of rotation, has stated,

> Axial motion causes no Coriolis effects except for those created by lateral movement of limbs or lateral body sway. The influence of the characteristics of artificial gravity on human mobility is probably least during axial motion. (p. 26)

In a rotating environment, objects which are dropped or thrown behave differently than they do on Earth. This behavior can be shown by the same experiment with the bucket. When the circling bucket of water was released, it flew off in a straight line, tangential to the point where it was released. Likewise, an object which is released or dropped inside a revolving habitat will also travel in a straight line perpendicular to the radius at the point where it is released. The velocity of the bucket is imparted to it by the amount of centrifugal force acting upon it at the point where it was dropped. At the same time, the floor of the habitat is continuing to move and when the trajectory of the object intersects the floor, it appears to have fallen (see Appendix E). Relative to this phenomenon Stone stated, "Objects thrown or dropped will always fall in a direction counter to the direction where normally expected" (p. 26).

Any object, such as a ball, which is thrown or batted, will have two force vectors acting on it which will determine the trajectory of its flight; the direction and force imparted by the throwing arm, bat, etc., and the centrifugal force which is imparted by the rotating environment. Clark and Graybiel (1961) conducted tests of ball and dart throwing as tests of eye-hand coordination in the Pensacola Slow Rotation Room, a nearly circular, windowless room having a diameter of 4.59 m. (15 ft.) used for experiments concerning the effect of rotation on human performance. The ball test consisted of having the subjects stand near the wall and throw 20 tennis balls into a basket. Dart throwing was studied using a standard Sportcraft Dartboard and five darts. The dartboard was mounted 2.74 m. (9 ft.) from where the subjects stood. The room was rotated at the rates of 1.71, 2.2, 3.82, 5.44, and 10 rpm. Not all subjects could perform at the higher velocities. The most outstanding characteristic of the two tests was the extreme variability of scores. Clark and Graybiel concluded that a major contributing factor to this condition was the fact that throwing balls and darts while being rotated at constant velocity placed a new task before the subjects. If the ball was thrown straight toward the bucket during rotation, it appeared to curve sharply and missed the bucket completely. Little learning appeared to take place during the individual runs. There was no difficulty in throwing, but the subjects were apparently unable to learn the task sufficiently well during the trial to obtain high scores.

The rotation rate of a habitat will remain constant, but changing the radial distance of the playing area from the axis will change the angular velocity and change the degree of correction necessary to throw and hit a target. Competitive games would have to be played at the same angular velocity or the home team would have more than the usual home court advantage enjoyed on Earth. Changing the angular velocity could be made a factor of competition; using it as a variable instead of distance in sports such as target shooting.

There is another phenomenon associated with the fact that zones of smaller circumference move at a slower velocity than zones of greater circumference. Objects, such as balls, which are propelled at a constant velocity perpendicular to a radius, will appear to move more quickly as they move toward the axis and more slowly as they again approach the periphery.

Stone stated, "The use of tools . . . will be certainly influenced by Coriolis forces. It is not clear what magnitudes of these forces may influence these actions" (p. 31). Arm movements were studied by Newsom (1972) who reported that operators could make very rapid arm motion with no degradation in button-pushing tasks. There might be significant degradation of performance in a game like Ping Pong played in a small habitat. The paddle, as it is swung about, would be giving changing and perhaps disturbing stimuli to the hand and arm. In the random situation of a game, it may be difficult to learn to judge the effect of these changing stimuli and thus to learn to hit the ball accurately.

There are a variety of levels of gravity in a rotating habitat and it is possible to choose among these levels for a particular activity. The most obvious fact about varying gravity levels is that weight will vary, and with it the degree of traction a person will have for locomotion. Studies have been made concerning the amount of traction necessary for locomotion. Thompson (Note 19) has reported on the work of Yougonov of the U.S.S.R. who experimented with the rotation of mice and rats in parabolic flight. With accelerations of .28 g and above, the behavior of animals was the same as under 1 g laboratory conditions. Loret (Note 27) arrived at a similar value of between .2 g and .3 g in studies of a human walking in an aircraft flying a modified Keplerian trajectory. Stone stated:

> In reduced gravity and with the peculiar forces encountered in a rotating environment, postural balance may be more difficult than in Earth gravity . . . experience at 1/6 g on the Moon by four American astronauts certainly indicates this boundary is not significant for a normal man. (p. 51)

The types of work required by the astronauts on the Moon were limited. They set up equipment, picked up and carried rock samples, took photographs, all of which required rather limited locomotion. NASA (Note 28) reported that the best method of locomotion was a sideways gallop. An Apollo astronaut on the moon weighed, on an average, 180 lbs. The suit and life support system which he wore weighed another 180 lbs. This in effect doubled his mass so that in the 1/6 gravity of the moon, he actually had the amount of traction he would have at 1/3 g.

At low gravity, the mass, and thus the inertia of a person, remains constant. The length of the lever arms of the body will also remain constant. This constant inertia and body appendage length coupled with greatly lessened traction will produce instability. The complex movements found on Earth may not be able to be performed satisfactorily at low gravity levels.

The buildings and other facilities which are used for leisure activities will need to be designed as parts of a whole which must be in balance. The importance is easily understood if a bicycle wheel is used as an analogy to a rotating space station. If a lead weight is attached somewhere along the wheel or on one of the spokes, it will no longer spin truly but will develop a wobble. This will cause stress to the structure of the wheel. Likewise, a mass that disturbs the balance of the rotating habitat will cause the habitat to wobble and cause stress to the structure. Newsom (1972) has stated that "wobble in a habitat under certain situations could cause disturbing disorientation in people" (p. 26). Thus, the mass of recreational facilities will have to be a consideration of design in addition to the considerations of function. Also, an activity which would draw large numbers of people as spectators could concentrate sufficient mass at that location to upset the balance of the habitat. Large numbers of people moving from the periphery of the habitat toward the axis will increase the rotational rate of the habitat, and conversely large numbers of people moving from the axis to the periphery will slow the rate of rotation, according to the laws of conservation of angular momentum. The effect of these factors upon habitat wobble and rotation rate is relative to the mass of the habitat with respect to the moving mass and its location.

All these phenomena will have their effect on leisure activities which are transported to rotating space habitats from Earth. The magnitude of their effect will depend on the strength of the phenomenon at the particular location in a habitat. The data concerning the impact of these phenomena on human performance is insufficient to render a realistic assessment of a leisure program in these habitats. There is, however, sufficient data to indicate the manner in which these phenomena will affect these activities and to allow a cursory examination of the effect of artificial gravity on some of the activities described or listed in the literature.

Heppenheimer (1978) described doughnut shaped swimming pools which had a gravity level of .02 g or .05 g. Table 1 tabulates the radius and circumference of pools at these gravity levels for one, two, and three rpm. At these low gravity levels a person would not have enough traction to walk. A dressing room for changing clothes and showering, located at the swimming pool level, would not be practical. There could be no walking in the pool area except in the direction of rotation or at an angle to it whereby persons could increase their angular velocity and weight. Any diving boards would have to be aligned with rotational direction so that persons could increase their weight during the approach both for traction and to depress the board.

Table 1

Swimming Pool Dimensions at .02 g and .05 g

rpm	.02 g		.05 g	
	R (ft.)	C (ft.)	R (ft.)	C (ft.)
1	58.68	368.70	146.69	921.68
2	14.67	92.17	36.67	230.40
3	6.52	40.97	16.30	102.42

Heppenheimer (1977) described the common garden variety dive as a slow motion arc as the diver rises dozens of feet above the board and then slowly turns and glides into the water. Divers in artificial gravity must travel in a straight trajectory determined by the force and angle of their take off and the centrifugal force acting on them at the time. It would not be possible for a dive in artificial gravity to arc. The dive will be longer in duration than on Earth because the movement of the dive will be at a constant velocity as opposed to the constantly increasing velocity of a dive in Earth's gravity.

The water of the pool would be like waves at an ocean beach yet would travel quite slowly, according to Heppenheimer. Numbers of people playing in the water would cause waves travelling in all directions, resulting in a turbulence which would be unsuitable for swimming and dangerous for diving.

Among the games Heppenheimer described is flying fish. In flying fish, people skim across the surface of the water counter to rotational direction at an altitude a few inches above the surface of the water by slapping at the water with the palms of their hands and with the flippers on their feet until they attain sufficient speed to become weightless. People can then become a real flying fish and soar up into the air until they lose speed and the rotation of the air takes them back to the water again. In the event that these people attain a velocity which will render them weightless, and there are no waves to redirect their movement, they cannot soar up into the air. They must continue the trajectory they were on when they became weightless. The cylindrical pool will shortly intersect their trajectory and they will reenter the pool at an angle which coupled with the direction of the moving water, will be similar to entering a water fall.

Another activity Heppenheimer describes is building private swimming pools in the central, zero gravity zone. He explained people will jump into this central zone carrying pails of water. By dumping several pailfuls of water in the zero gravity zone, the water, by coalescing, will form individual "swimming pools." There are some practical difficulties in this plan. Leaping into the central zone of the pool will impart the same force and trajectory to the water in the pail as the person doing the leaping. The person can change the trajectory and velocity of the pail of water by using muscular force and body inertia. However, it is unlikely that a person can "dump" the water into the zero g zone without imparting some force and direction to it, thus the water will continue on in a new direction until it makes contact with the revolving pool.

O'Neil (1974) stated, "All Earth sports, as well as new ones are possible" (p. 36). Skiing, sailing, mountain climbing (with gravity decreasing linearly as the altitude increases) are examples. He also stated,

> It is possible to recreate certain Earth features . . . the mountain profile [shown in the O'Neil study] is taken from an actual photograph of a section of the Grand Teton range in Wyoming. (p. 34)

Skiing involves moving through zones of increasing angular velocity, subjecting skiers to Coriolis forces which will deflect them from the path they would normally expect from their experiences on Earth. The slope would need to be designed so that skiers would be facing in the direction of rotation where they would be deflected into the slope instead of outward or laterally. During descent, skiers will experience increasing weight. Orthostatic intolerance could occur if the descent is rapid and of long duration. In order to maintain a constant velocity vector, the angle of a ski slope, with respect to a habitat radius, would have to be continually increasing. Skiing may have to be restricted to a course essentially straight down a slope because large, swift turns may cause disruptive Coriolis forces.

Mountain climbing would be subject to the same forces as skiing. Coriolis force would be less a factor because of the slower movement. A fall, however, would cause a person to move through the zones of increasing angular velocity more rapidly and the degree and direction of deflection would be more important. The varied angles of the slopes of a simulated Earth mountain would present different challenges to a climber where gravitational direction is radial. In the interest of safety, beginning climbers should ascend slopes which allow them to face the direction of rotation and descend the opposite side facing away from rotational direction.

Sailing would not be materially affected by artificial gravity. A boat sailing in the direction of rotation would weigh more and ride lower in the water, thus increasing water resistance and decreasing velocity through the water. Conversely, a boat sailing counter to rotation would weigh less and its velocity would increase. In racing, this could be used as a factor of competition. On Earth, sailing is accomplished on a large body of apparently flat water. In a rotating habitat, a lake would curve around the boat and the person in the boat would appear to be sailing up the inclined sides of the lake or down towards the trough in the middle of the lake.

In hang gliding, a person would not find the sport materially changed if the air resistance and thermal updrafts are sufficiently similar to Earth. Such gliders are subject to stalls, however, which could be more dangerous in artificial gravity than on Earth. A stall in a rotating habitat would cancel out the centrifugal force and the glider would become weightless and non maneuverable, subject to possible collisions with the rotating environment. Man powered flight would be feasible in areas of low gravity and would provide a means of control and safety lacking in hang gliding.

Most sports on Earth are played on surfaces which are flat. In a space habitat, the playing surface may be cylindrically curved or flat. In a cylindrically curved playing area, each player will stand perpendicular to the floor at his location and thus the players will be standing at various heights and angles with respect to the other players. It is possible, that in a game of baseball, played in a small diameter area, that a fielder could be standing upside down in relation to the batter. In a flat playing area, all the players will be standing at the same height, but each player will stand aligned with his local gravity vector and thus at various angles to the other players. When designing a playing area, it will be necessary to assess the impact upon player performance at these angles. It will also be necessary to determine the possible trajectory of balls in relation to the playing surface and height above the surface. This is necessary not only to ascertain if the game can be played within the designated area, but to determine whether the purpose of the game is possible. For example, basketball requires that a ball be thrown up into the air and dropped down through a hoop. This is not possible in a rotating habitat. The game, if played, would have to be modified. This could be accomplished by either changing the angle of the backboard so the ball can be deflected into the hoop or by changing the angle of the hoop. Another example is baseball, which may be possible only in an area with a low ceiling. The ceiling would cause a high hit ball to be deflected down towards the playing surface. In this example, it is perceived that though the game of baseball is preserved, the playing of the game would necessitate compromise. The possibility of a home run is lost except through player error, not batting skill.

Ballet was one of the cultural activities included in the MIT study (Smith, Note 12). One of the basic laws of ballet dancing is aplomb. Aplomb is perfect balance, equilibrium which a dancer must have to retain stability in any pose or movement. Chujoy (1936) stated, "aplomb is the prerequisite quality of a ballet dancer. To dance well, the body must be firm and steady, motionless and unshaken during the movements of the legs" (p. 94). Maximum stability would require ballet to be performed at 1 g. Any cross-coupled accelerations in the vestibular organs would seriously impact the movements of ballet, especially in the allegro. Elevation is also required of a ballet dancer and an appearance of lightness is highly desirable. Lightness en l'air would be enhanced in artificial gravity because a dancer who leaps into the air will descend at constant velocity, lengthening time in the air and lessening the force of impact.

Fine motor performance which is used in leisure activities such as arts and crafts, games, and hobbies involves dexterity and eye-hand coordination with head motions. Stone (Note 13) stated,

> Fine motor performance probably will not be influenced appreciably by the Coriolis forces, since the motions involved will generally be small. However, if head motions are involved, the tolerance and adaption to cross-coupled acceleration may be of significant influence. (p. 31)

This chapter has presented a description of artificial gravity and the adaptations that would be necessary for specific leisure activities. A discussion of zero gravity and artificial gravity with implications for recreation professionals is contained in Chapter VI.

CHAPTER VI

DISCUSSION

It was discovered in the course of this study that there was a sizeable, diverse population interested in an expanded program of space utilization and exploration. Several studies have been made concerning space habitat design. These studies have been concerned primarily with problems of fabrication and life support systems. Such documentation that exists in the literature concerning leisure activities in space habitats has been done by engineers, physicists, and others who are primarily interested in the technical aspects of habitat design. Examination of this documentation indicates that much of the material is of doubtful validity.

It seems reasonable, that professionals in recreation should undertake the responsibility for leisure planning in space. However, the ambient conditions of space habitats will place new challenges on recreators for which their experience on Earth will not prepare them. In order to prepare for a role in space planning, recreation professionals will need to become cognizant of all the ramifications that these conditions will impose on human performance. They will also need to be able to work in cooperation with bio-engineers and habitat designers to insure that facilities for leisure activities are included in the design of space habitats and that these facilities will serve the purpose of the recreator. A background in bioastronautics, bio-dynamics, and human factors will be necessary in this endeavor.

This study was concerned with exploring only two environmental conditions of space habitats, namely zero gravity and artificial gravity. Both these conditions were found to have a profound effect on human performance. Documentation concerning the effect of zero gravity on leisure activities is limited. However, the experiences of the American astronauts and the Russian cosmonauts provide sufficient data for realistic leisure planning for the small habitats currently under consideration by NASA. Experience in artificial gravity in a zero gravity environment is lacking. Experiments concerning human performance in simulators have been limited in scope. These tests indicate, however, that artificial gravity differs substantially from Earth gravity. Stone (Note 14) stated:

> Because the peculiar elements of the new environment will alter performance, we cannot expect that man will function in the new environment as well as in his normal earthly environment. With a period of adaption, performance may improve, but man in artificial

> gravity may never perform as effectively as in Earth's gravity. (p. 27)

Until more is known about the effectiveness of human performance in artificial gravity, worthwhile studies of leisure planning cannot be made. However, the recreation professional can perform an important service by defining the questions necessary to obtain the data which will form the basis for valid leisure planning.

Further studies should address the need of modifying activities, which have evolved on Earth, for space habitats. Can certain activities be modified? If they are modified, will they still be enjoyable, or will the changes so affect the activity that it is no longer a satisfactory pursuit? If the activities which are enjoyed on Earth are unsuitable for space habitats, what new activities could take their place? To what extent would a different leisure life affect the ties between space habitants and their brethren on Earth? Communication between people is based on shared experiences. It sometimes leads to cooperation and sometimes to conflict. Our language contains many allusions and metaphors derived from our leisure activities. These would be unintelligible to persons who are unfamiliar with the experiences upon which they are based. They might also lead to confusion or conflict if the experience has been so modified that the language of allusion is modified beyond its ability to convey the intended message.

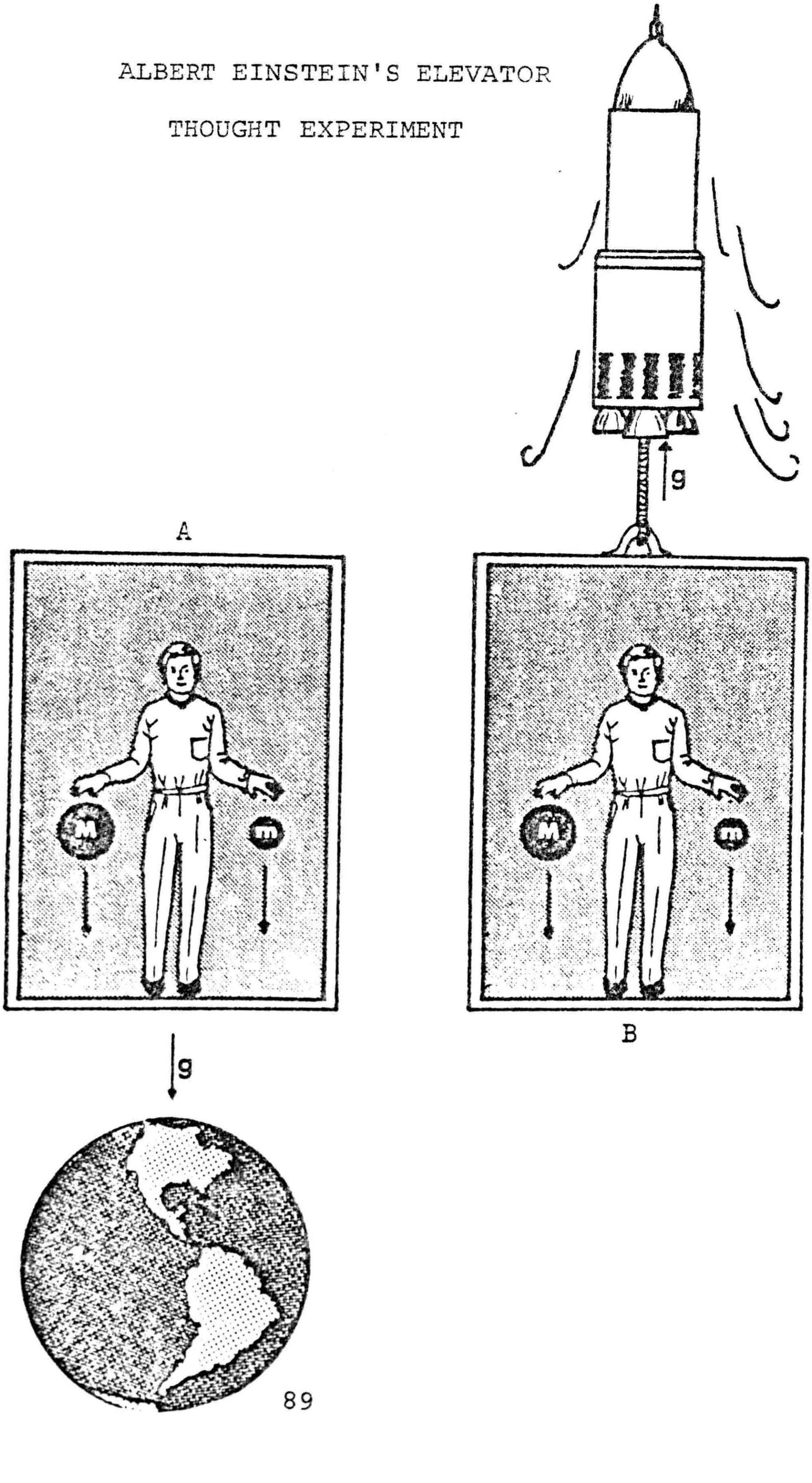
In conclusion, defining the role that leisure programs will play in space habitats will cause the recreation professional to reexamine the role of these programs on Earth. This may bring about a greater understanding of leisure activities and their relation to our humanness.

APPENDIX A

ALBERT EINSTEIN'S ELEVATOR THOUGHT EXPERIMENT

ALBERT EINSTEIN'S ELEVATOR

THOUGHT EXPERIMENT



APPENDIX B

EXPLANATION OF THE FORMULA

$$a_n = \frac{v^2}{R}$$

EXPLANATION OF THE FORMULA $a_n = \frac{v^2}{R}$

Disregarding the effect of mass, rotationally induced centripetal acceleration acting in a direction toward the center of circular rotation and normal to a tangent to the circle is equal to the square of the velocity of a point on the circumference of the circle divided by the radius of the circle. The equation $an = v^2 \div R$ as developed by Wylie is used both in its original form and in a form expressing centripetal acceleration as a function of radius and the square of the rate of rotation.

$a_n = v^2 \div R$

Substituting:

$115,820.43 = (2\pi R \times rpm)^2 \div R$

$115,820.43 = (39.4786 \times R^2 \times rpm^2) \div R$

$R(rpm)^2 = 2933.7522 \ ft/min^2$

$R(rpm)^2 \div 2933.7522 =$ one Earth gravity.

Units:

a_n = Earth gravitational constant

= $32.1723 \ ft/sec^2$

= $115,820.43 \ ft/min^2$

v = circumferential velocity

= $2\pi R \times rpm$ (ft/min)

R = radius (ft)

APPENDIX C

RADIUS, CIRCUMFERENCE, AND VELOCITY OF SPACE HABITATS AT ONE, TWO, AND THREE RPM AT GRAVITY LEVELS FROM .02 TO 1.0

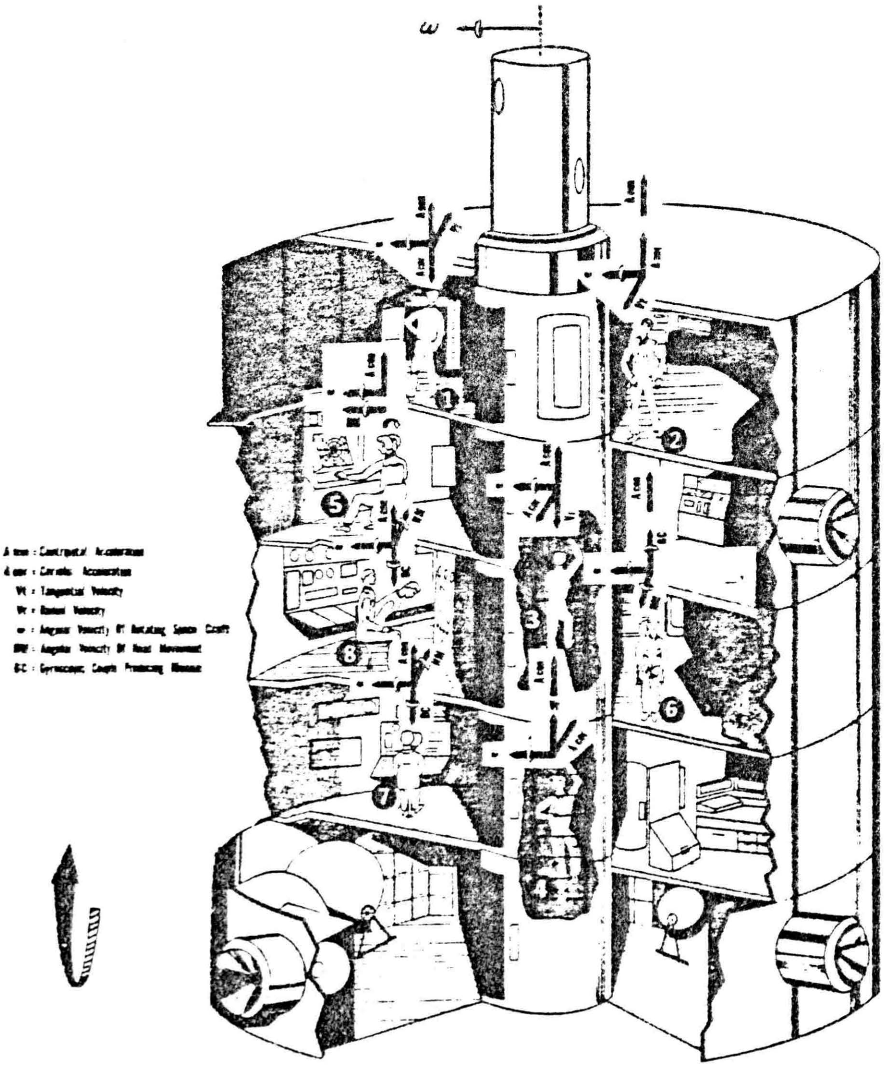
RADIUS, CIRCUMFERENCE, AND VELOCITY OF SPACE HABITATS AT ONE, TWO, AND THREE RPM AT GRAVITY LEVELS FROM .02 TO 1.0

Gravity Level	1 Revolution Per Minute			2 Revolutions Per Minute			3 Revolutions Per Minute		
	Radius (ft.)	Circumference (ft.)	Velocity (ft/min)	Radius (ft.)	Circumference (ft.)	Velocity (ft/min)	Radius (ft.)	Circumference (ft.)	Velocity (ft/min)
1.0	2,934	18,433	18,433	733	4,608	9,217	326	2,048	6,144
.9	2,640	16,590	16,590	660	4,147	8,295	293	1,843	5,530
.8	2,347	14,747	14,747	587	3,687	7,373	261	1,639	4,916
.7	2,054	12,903	12,903	513	3,226	6,452	228	1,434	4,301
.6	1,760	11,060	11,060	440	2,765	5,530	196	1,229	3,687
.5	1,467	9,217	9,217	367	2,304	4,608	163	1,024	3,072
.4	1,174	7,373	7,373	293	1,843	3,687	130	819	2,458
.3	880	5,530	5,530	220	1,383	2,765	98	614	1,843
.2	587	3,687	3,687	147	922	1,843	65	410	1,229
.1	293	1,843	1,843	73	461	922	33	205	614
.05	147	922	922	37	230	461	16	102	307
.02	59	369	369	15	92	184	7	41	123

APPENDIX D

ILLUSTRATION OF CORIOLIS FORCES

ILLUSTRATION OF CORIOLIS FORCES



Legend: Crewman 1 is walking in a direction opposite to rotation; hence his weight is decreased. Crewman 2 is walking in the direction of rotation, hence his weight is increased. Crewman 3 is descending the ladder, thereby experiencing an increase in weight proportional to the lengthening of his radius; the Coriolis acceleration resulting from his descent will tend to keep him against the ladder. Crewman 4 ascending the ladder will experience a decrease in weight, and the Coriolis acceleration, because he is on the opposite side of the ladder compared with crewman 3, will also tend to keep him against the ladder. Crewman 5 is moving his head from the upright to his right shoulder which is in the plane of rotation, hence cross-coupled angular accelerations are not generated and there are no illusions. Crewman 6 is making the same head movement as crewman 5, but the plane is now perpendicular to the plane of rotation, and cross-coupled angular accelerations are generated, resulting in charcteristic illusions. Crewman 7 is making the same motion as crewman 6, but the illusions are reversed because he is facing in the opposite direction. Crewman 8 facing the center and bending forward generates forces similar to crewman 7.

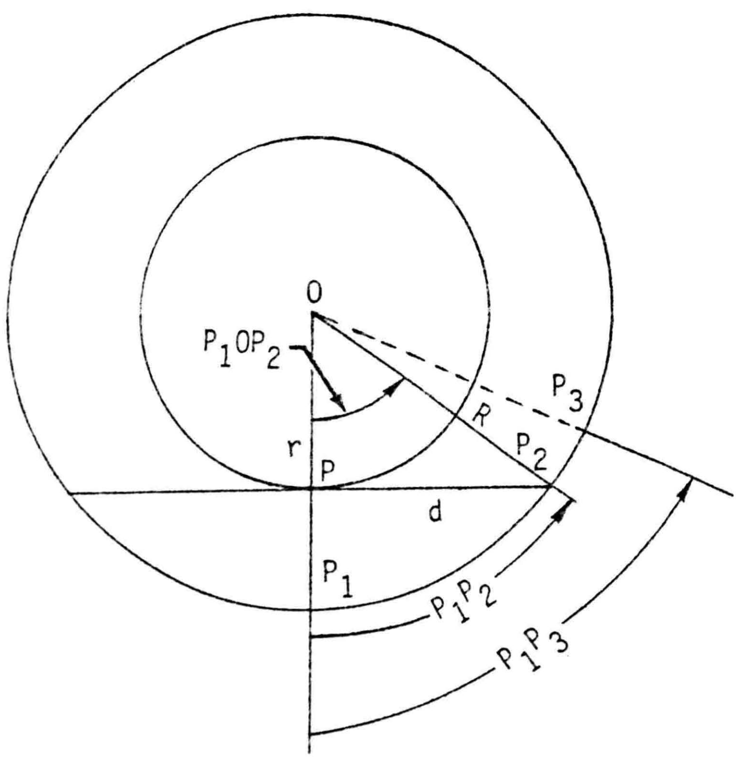
Drawing by Dr. D. B. Cramer, courtesy of NASA/JSC Public Information Branch.

APPENDIX E

THE TRAJECTORY OF FALLING OBJECTS

THE TRAJECTORY OF FALLING OBJECTS

An object which is dropped at point P of circle radius r will not fall upon point P_1 of circle, radius R because of the difference in velocities of the two circles, the slower of which (circle, radius r) is the "falling" velocity of the object. The trajectory of the object is line P-P_2, distance d. In the length of time (t) the object takes to reach P_2, the outer circle has rotated to point P_3, which because of the greater velocity of circle, radius R is beyond the point of actual impact.



Example:

What is the distance between the point of actual impact (P_2) and expected impact (P_3) of an object dropped from four feet above the floor of a 1.0 gravity, three rpm habitat? (reference Appendix C).

$R = 325.97$ ft

$C_R = 2048.13$ ft

$V_R = 6144.39$ ft/min

$r = 325.97 = 4.0 = 321.97$ ft

$d^2 = (R^2 - r^2)$

$d^2 = (325.97)^2 - (321.97)^2$

$d = 50.91$ ft

$V_r = \text{rpm} \times 2\pi r$

$V_r = 3 \times 2 \times \pi \times 321.97 = 6069.00$ ft/min

$t = d \div Vr = .00839$ min

$P_1P_3 = VR \times t = 51.55$ ft

Tan Angle $P_1OP_2 = d \div r = 50.91 \div 321.97$

Angle $P_1OP_2 = 8.99°$

$$P_1P_2 = \frac{\text{Angle } P_1OP_2}{360} \times C_R$$

$$= \frac{8.99}{360} \times 2048.13 = 51.15 \text{ ft}$$

$P_1P_3 - P_1P_2 = 51.55 - 51.15 = .40$ ft $= 4.8$ in

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