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Zero-G Devices and Weightlessness Simulators

A special report
prepared by
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PREFACE

This report has been prepared under the auspices of the Armed Forces-National Research Council Committee on Bio-Astronautics. Under the approved mission of the Committee's Panel on Acceleration, namely, to review and report upon the research and development problems concerned with the biological effects of mechanical forces, this review of the problem of weightlessness is the first of a series of such studies designed to cover a number of areas of importance in the acceleration field. The reviews are designed to assist the investigator and the development engineer by placing before him a summary of the present state of knowledge of the area, together with as complete a bibliography as practicable, both prepared by a recognized authority. It is in the hope that this initial review meets an immediate need of the Committee on Bio-Astronautics that it is forwarded by the Chairman of the Acceleration Panel.

JAMES D. HARDY

FOREWORD

The chief mission of the Panel on Acceleration Stress, NRC-Armed Forces Committee on Bioastronautics, is to evaluate the research problems and development activities associated with the biological effects of mechanical forces which will be encountered during space flight operations. This also includes the area of ground-based research concerned with the production and simulation of these forces. In view of the importance of this field of investigation, and because of the complexity and the rising costs of such activities, a review of available facilities and research devices was initiated by the Chairman of the Panel. The objective of this survey is to assure maximum usefulness of such devices, optimum cooperation between agencies, and to guarantee that new requirements of the future be incorporated in research proposals on bioastronautics.

This report concerns the devices, methods, and techniques which have been used for the investigation of the effects of zero-G and weightlessness by many investigators. A letter was therefore sent out to investigators who were familiar with these devices or had proposed their use for zero-G research (see Appendix 1). Moreover, several proposals have been included concerning the construction of advanced facilities and the utilization of unorthodox methods. While some of them have been analyzed and treated in detail, only a few results were presented in this context. The report, therefore, is not a scientific treatise of the problem of weightlessness and the effect of sub- and zero-gravity upon the organism, but rather a description of research equipment and techniques.

The description of the zero-G devices and simulators was prepared in accordance with a 10-point scheme furnished by the Chairman of the Panel. Its objective was to assure a classification of information which was thought to be necessary for a practical and economical utilization of these devices. These guidelines are given in Appendix 2.

The material was arranged in two separate sections. The first one deals with devices which can be used for producing sub- and zero-gravity. They encompass the vertical motion simulators, by means of which short periods of weightlessness can be produced alternating with periods of relatively high accelerations. By the application of this principle, sub-gravity periods can be produced for several seconds only.

Weightless periods up to about one minute and more occur during aerodynamic parabolas in high performance aircraft. The chapter on this subject contains general descriptions of the aircraft and techniques for flying parabolic trajectories and some of the results obtained. These data may also be applicable to other advanced types of aircraft to be used in weightlessness research.

In a similar way, some of the advanced missile systems used and available for zero-gravity research were treated in the last chapter of Part I. The objective of this chapter is to familiarize the reader with those fundamentals of rocketry which must be known in order to utilize this type of space vehicle for weightlessness research. While the Saturn vehicle is still in the construction and testing stage, it may play an important role in the investigation of the zero-G conditions in an orbiting manned satellite laboratory. The periods of weightlessness produced by the use of rocket vehicles ranges from several minutes to several days, or even weeks if the big boosters are made available.

A simple mathematical treatment of the physical parameters involved in sub- and zero-G conditions precedes each of the three chapters.

The devices treated so far actually produce sub- and zero-G conditions. In Part II, instruments and techniques for the simulation of weightlessness are described. In several instances the effects observed during simulated weightlessness are different from those obtained under actual zero-G conditions. New experiments have been done at the USAF School of Aviation Medicine, Brooks Air Force Base, Texas, and at the Naval School of Aviation Medicine at Pensacola, Florida, using the immersion method for longer periods of time. Although the data could not be included in this report, techniques and results very closely resemble those obtained through previous experiments.

S. J. G.

CONTENTS

INTRODUCTION

The state of reduced acceleration of gravity has become an important subject of research in the advanced study of human behavior and tolerance. In aircraft, because of the limitations in speed and altitude, such a condition occurs very infrequently during certain maneuvers, such as pushovers and zooming, and then for relatively short periods of time only. But with rocket propulsion the situation is quite different. After burnout the rocket cruises entirely unsupported, and in this coasting state the missile and its passengers are in a condition of zero-G. Hence, weightlessness is the psycho-physiological steady-state in rocket flight. This pertains to the relatively short durations of IRBM and ICBM missions, as well as to the longer exposures during orbital trips and travel into outer space.

Although the aviation physiologist has been long acquainted with the principles of powered flight and the effects of increased acceleration, he was not aware of the phenomenon of reduced acceleration and weight until very recently. Moreover, it was not always sufficiently clear which physical quantities were involved in the entire spectrum of these biodynamic processes, and which designations, terms, and symbols are adequate for the description of their effects. The consequence was the improper use of terms, such as, "gravity-free", "zero-gravity", "null-gravity", "subgravity", and "weightlessness". However, from the standpoint of a proper terminology it is absolutely necessary that the conditions of reduced gravity are clearly defined, and that these definitions are in complete agreement with the concepts of physics and mathematics.

In bioastronautics it is convenient to express acceleration as a multiple of the standard acceleration g_o, and any force as a multiple of the standard weight W_o of the body upon which a force is acting. This is equivalent to setting up an auxiliary system of practical units, in which the

UNIT ACCELERATION: 1 g (in magnitude) = 32.2 ft/sec^2; and the

UNIT FORCE: 1 W (in magnitude) = 32.2 m lb.

It should be noted that the unit of acceleration in this system is always a true constant, while the unit of force may differ for bodies of differing masses. Since we define

$$\frac{a}{g_o} = \frac{F}{W_o} = G* \qquad (1)$$

the quantity G is dimensionless, being the ratio of two accelerations or of two forces. This unit indicates how much force or accéleration is present in a given dynamic situation. Since the actual force on a body---due to the acceleration---is the weight of the body, G also indicates weight. It should be emphasized that the small letter "g" has been quite rigidly established by the physicist as the symbol for a specific physical quantity, namely, as the unit for the acceleration of the earth's gravity = 32.2 ft/sec^2, normally. Any other usage constitutes a distortion of meaning that may create unnecessary confusion. In this age of technology it is mandatory that we fully comply in our denotations with the symbols representing mathematical and physical quantities.

In a recent paper,** an attempt has been made to define weight and weightlessness parameters which correspond to the physical conditions and physiological experiences of man in aircraft and rocket maneuvers. These concepts may also be of benefit for the preparation of experiments involving motion simulators and zero-G devices.

In all cases of freely moving bodies, the force of inertia compensates the gravitational force at any point of their trajectory, thereby creating the so-called "agravic" or "gravity-free" state. However, this is not necessarily so because the body is always under the influence of gravitation, either of that of the earth or of any other celestial body (e.g., the artificial earth satellites gravitate around our planet; the early "lunar probes", around the sun). In this state the components of a body or a system are identically affected by the prevailing gravity-inertia relationship; that is, they are not appressed in the direction of the original gravitational vertical. Consequently, this state has been designated as "appressionless"; but it is more accurately defined as the "zero-G"

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*W_o = standard weight of a body
g_o = standard acceleration of gravity

**Ritter, O. L. and S. J. Gerathewohl: The concept of weight and stress in human flight. A. U. School of Aviation Medicine, USAF, Randolph AFB, Texas, 58-154, January 1959.

or "null-G" condition, since the resultant force exerted on a body due to gravity and inertia is zero.

Weightlessness, on the other hand, has been widely used to describe the psycho-physiological experience of an individual in an unappressed state. For example, a body immersed in water---although supported by the surrounding medium and under normal gravitational conditions---is apparently weightless and not appressed to a scale placed under it. The true "agravic" and the "zero-G" condition, on the other hand, occur only if there is no gravitational force acting, or when the acceleration of gravity is fully counteracted by inertia, respectively. According to the physical characeristics of the agravic and zero-G condition; i. e. , the gravitational-inertial relationship extended to at least the molecular level of the masses involved, their technological and biological effects generally should be the same wherever and whenever they occur; that is, within or outside of any gravitational field, and during free fall as well as during free ascent. However, the inhomogeneity of the field forces involved may give rise to intermolecular forces, which may account for a non-identity of the biological effects of the agravic and the zero-G condition. This can be decided only by future experimentation.

1. DEVICES FOR PRODUCING THE ZERO-G CONDITION

A. Vertical Motion Devices

The simplest method to produce the zero-G condition for biomedical and physical experimentation consists in the utilization of the vertical free-fall state. If a body moves vertically downward, an upward acting force of inertia which compensates the body's weight becomes effective.

The basic equations for presenting the physical conditions for a free-fall body in a vacuum are:

$$h \text{ (height)} = \frac{g}{2} t^2; \tag{2}$$

and,

$$v \text{ (velocity)} = g.\, t. \tag{3}$$

However, strong frictional forces from the air will soon be produced so that the free fall of the body is slowed down and its original weight restored because of these forces. Speaking in terms of kinematics, the acceleration of gravity acting on the body during its free fall cannot be maintained for an appreciable length of time, and therefore the velocity of the falling body soon approaches a constant value.

In order to find the general formula which can be applied for determining the parameters pertaining to a body falling within the atmosphere, it is assumed that the total weight of the body is designated by G. The final velocity, where the weight of the body and the drag brought about by the resistance of the air are balanced, may be called the terminal velocity or the equilibrium velocity, and is designated by v_e. In order to arrive at v_e, we assume that

$$G = D \tag{4}$$

$$D = \frac{(C_D \cdot \rho \cdot A. \, v_e^2)}{2} \tag{5}$$

$$v_e = \sqrt{\frac{2G}{C_D . \rho . A}} , \tag{6}$$

where C_D is the drag coefficient, ρ represents the density of the atmosphere, and A is the area of the body in the direction of fall.

Assuming drag as expressed in (5), and since

$$\frac{dv}{dt} = g - a_d, \tag{7}$$

a_d represents the acceleration of the drag forces. Then

$$\frac{dv}{dt} = g - g. \left(\frac{v}{v_e}\right)^2 , \tag{8}$$

$$\frac{1}{g} \cdot \left(\frac{dv}{dt}\right) = 1 - \left(\frac{v}{v_e}\right)^2 = \frac{v_e^2 - v^2}{v_e^2}, \tag{9}$$

$$dt = \frac{1}{g} : \frac{v_e^2}{v_e^2 - v^2} . dv. \tag{10}$$

In order to find the height (h) at which G = D, we must find the integral of v. dt for the values from v to 0. Thus,

$$h = \int_0^v v' dt = \frac{v_e^2}{g} \int_0^v \frac{v}{v_e^2 - v^2} \cdot dv \cdot \tag{11}$$

In solving this equation for h, we obtain

$$h = \frac{v_e^2}{2g} . \ 1n \frac{v_e^2}{v_e^2 - v^2} \tag{12}$$

or,

$$v = v_e \sqrt{1 - e^{-2gh/v_e^2}} . \tag{13}$$

With increasing time of fall v reaches the value v_e. By assuming

$\frac{v}{ve}$ to be smaller than unity, and by designating this quotient as k, we obtain

$$\frac{v}{ve} = k = \sqrt{1 - e^{-2gh/v_e^2}} \,, \tag{14}$$

$$k^2 = 1 - e^{-2gh/v_e^2} \,, \tag{15}$$

$$e^{-2gh/v_e^2} = 1 - k^2 \,, \tag{16}$$

$$-2gh/v_e^2 \quad \ln \, (1 - k^2) \,, \tag{17}$$

$$h = -\frac{v_e^2}{2g} \ln \, (1 - k^2) \,. \tag{18}$$

Equation (18) yields the sought relationship of height, gravity, and final velocity for any finite value of k; i. e., for any condition of free fall in which the falling body has not yet reached its terminal velocity.

Practically, a few seconds of virtual weightlessness have been obtained in free-fall experiments from drop towers. In order to produce longer free-fall periods, it would be necessary to ascend to higher altitudes and regions of reduced air densities. Moreover, it was suggested to drop the body from a balloon, because its release from an aircraft would give rise to considerable frictional forces from the air associated with relatively high decelerations. There are a lot of other difficulties involved, such as slowing down the body before impact, the recovery procedures, safety measures in case of human and animal experiments, and the relatively small yield compared with the considerable preparations required for a single experiment.

If a body is subjected to a downward acceleration smaller than that of gravity, the forces of inertia associated with acceleration are subtracted from the gravitational force. This condition has been designated as the subgravity state. Similarly, if a force of inertia is added to the gravitational force, as for instance, during centrifugation or liftoff of a rocket, the forces involved add vectorially and produce a state of "super-gravity" or increased weight. This would also be the case during a powered approach of the earth with an acceleration larger than that of the earth's gravity.

The Drop Tower

1. The SAM dropping experiments consisted of small payloads dropped from the School of Aerospace Medicine Building in 1948-49.

2. A schematic picture of a drop tower is shown in Figure 1. Actually, experimental payloads can be dropped from any structure, if a free-fall condition is secured. In most cases, recovery of the payload can be obtained by an elastic damping device.

3. The height of drop towers is limited by the resistance of the air which compensates the acceleration of gravity completely after about six seconds. Thus, only a few seconds of zero-G and subgravity can be produced in this manner. A body falling from an altitude of about 400 feet obtains its final speed (v_e) of about 180 feet per second at the end of this fall.

4. Basic equations are given above.

5. During early experiments made by scientists from the School of Aviation Medicine, Randolph Air Force Base, Texas, the behavior of a burning candle during the state of weightlessness and of solidified carbon dioxide (dry ice) was filmed. The payloads were manually dropped from a height of about 50 feet and manually recovered by means of an elastic canvas.

6. No other instrumentation was used than that described in Paragraph 5.

7. No special safety measures necessary except protecting the recovery crew from the falling body. In case of human and animal experiments dropped from high altitudes (aircraft or balloons), special safety requirements are needed.

8. No actual cost figures are available. Generally, the expense of a simple drop tower is relatively low.

9. No information available.

10. Copies of the film mentioned in paragraph 5 above are available from the Department of Research Photography, School of Aerospace Medicine, Brooks Air Force Base, San Antonio, Texas.

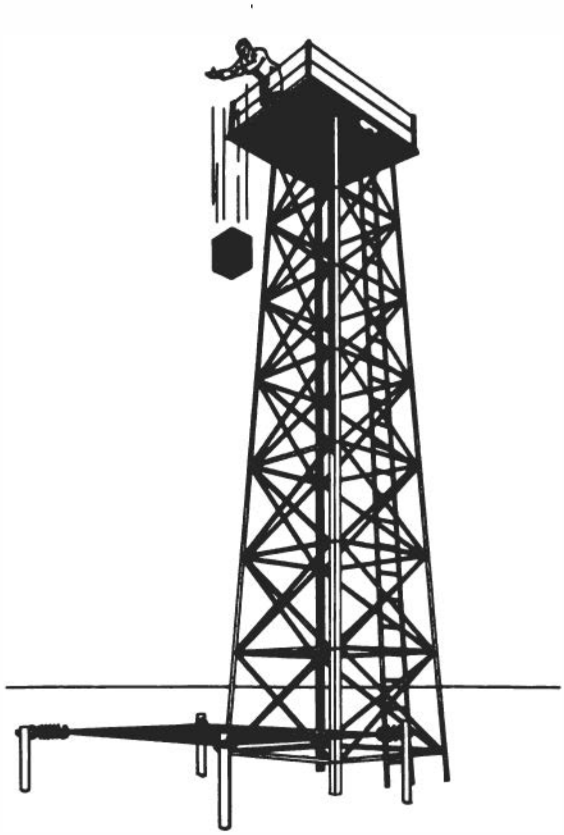


Figure 1. Drop Tower

WADC Vertical Deceleration Tower (Drop Tower)

1. The Vertical Deceleration Tower was undergoing proof testing at the Aerospace Medical Laboratory, Wright Air Development Center, Air Research and Development Command, Dayton, Ohio. The device is operated by personnel of the Escape Section, Biophysics Branch. Size of the present staff unknown.

2. Two very heavy I-beams 70 feet in height constitute the major structure components of the tower. They are mounted in a pit 20 feet deep and extend 50 feet above floor level. On each beam is mounted a precision rail which guides the test cart during its drop. This cart, which weighs 1900 pounds, is so designed that the test items such as seats, capsules, etc., can be mounted in any orientation to the direction of the G-forces, which is parallel to the rails. This cart is dropped from a given height and falls

freely (for all practical purposes) to floor level where a tapered plunger, approximately 4 feet in length and 8 inches in diameter at its widest part, mounted on the bottom of the cart, enters a tube filled with water. About 2 seconds of virtual weightlessness occur during the drop. Figures 2 and 3 show the structure and location of the test subject.

3. Although the tower was designed to investigate deceleration effects on men and equipment only, it can also be utilized for the study of very short periods of subgravity. If the device is used in its present form, the subgravity state is uniform and stopped by a deceleration not exceeding 4 G-units of force. However, by the installation of an acceleration control various degrees of subgravity should be obtained. The tower could then be used as a device to investigate the effects of different amounts of subgravity.

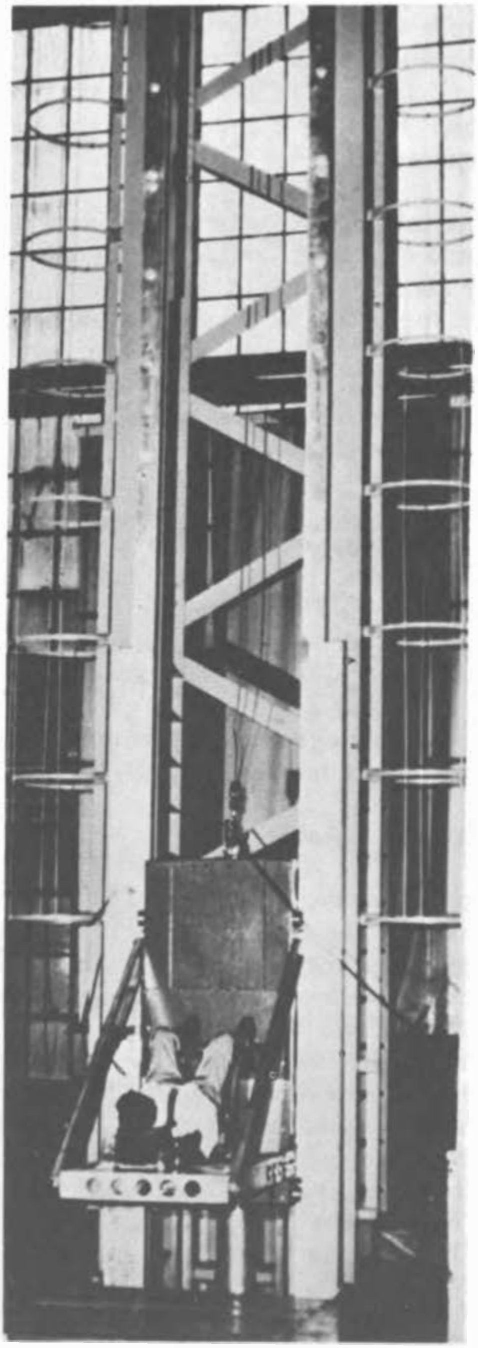
4. The acceleration-deceleration pattern depends on drop height, total cart weight, friction between rail and guide, and finally, the degree of plunger tapering. By either controlling the friction or the acceleration of the suspension cables, any subgravity pattern ($0<a<1$) can be produced.

5. Electronic and photographic instrumentation will be integrated with a common time base.

6. No information available.

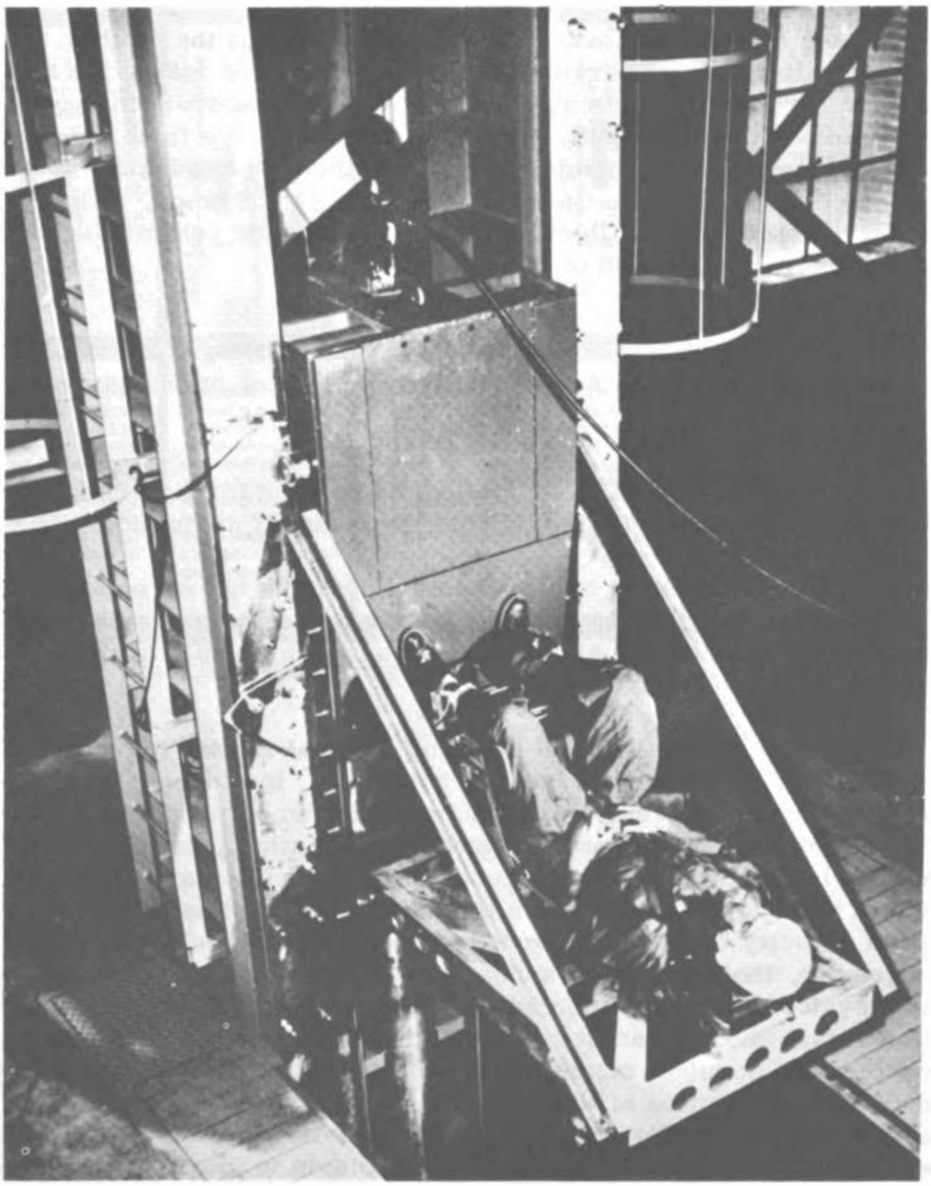
7. For maximum safety, only the top 50 feet of the tower is normally used for testing, the remaining 20 feet which are all below floor level, is reserved for safety overruns. In the event that the primary deceleration device (tapered plunger) should fail, the cart would continue to fall into the pit, where it would first engage mechanical brake shoes, and then actuate a metal cutting type of decelerator. Both of these devices are completely independent of each other, and either is capable of stopping the cart with full payload, falling from the top of the tower, with a deceleration of no more than 4 g. However, as they would normally both operate simultaneously, the emergency stopping deceleration would approach 8 g, still well below the normal tolerance level of the human body.

8. As the only materials needed for operation are gravity, water, instrumentation recording material, and operating personnel, the cost of testing is small. No actual figures available.



(Official USAF Photo)

Figure 2. WADC Vertical Deceleration Tower



(Official USAF Photo)

Figure 3. WADC Vertical Deceleration Tower:
Location of the Subject

9. In view of the planned deceleration program of the Aerospace Medical Laboratory, it is expected that the facility will be utilized almost exclusively for this purpose during the next 18 months. Experiments which do not involve elaborate instrumentation can be arranged, subject to Aerospace Medical Laboratory's priority commitments, by request through Headquarters, WADC. At present, the Chief of the Biophysics Branch, and Mr. Charles Demsey, Chief, Escape Section, are responsible for control and direction of this facility.

10. Reference:
WADC Vertical Deceleration Tower (Drop Tower). Report prepared for the NRC - Armed Forces Committee on Bioastronautics.

The Elevator

1. Various types of elevators can be used for subgravity research. No information available about actual utilization.

2. Description of the mechanical systems can be obtained from companies which construct such devices. A schematic representation of the various states of subgravity obtainable in an elevator is given in Figure 4a and 4b.

3. The possibilities of utilizing vertical motion for our purpose are not bound to the free-fall condition. In elevator type locomotion, various amounts of subgravity can be produced during ascent and descent. From the laws of kinematics it follows that the acceleration must be kept constant in experiments of this kind; i. e., one is free to begin the motion of the elevator with any initial velocity desired. In order to obtain maximum periods of subgravity, the experiment must be started with the highest velocity the elevator can attain in an upward motion. A state of subgravity of a certain amount can be produced by superimposing an upward acceleration upon the normal acceleration of gravity. Under these conditions the motion of the elevator car is such that the upward velocity will gradually be consumed by gravity, so that after having reached the maximum elevation the car starts to drop and reverses the pattern of motion in its downward course.

4. The total acceleration $\frac{dv}{dt}$ of a body in a straight upward or downward motion is given by

$$\frac{dv}{dt} = a - g, \tag{19}$$

if the direction of acceleration is upward. It is convenient to express the acceleration a in terms of g by writing

$$a = n. g, \tag{20}$$

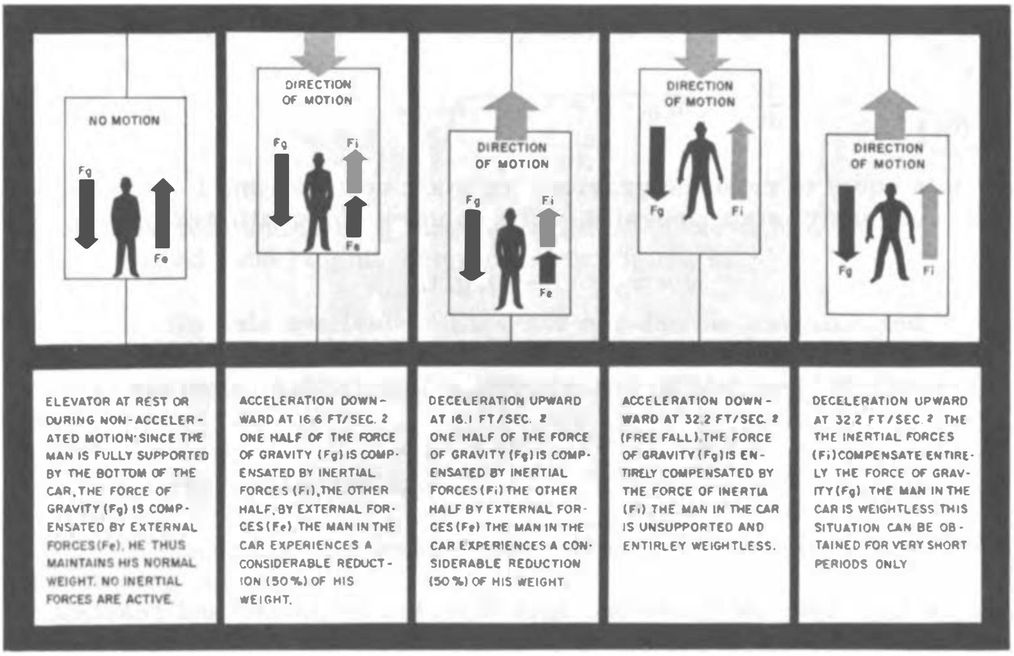
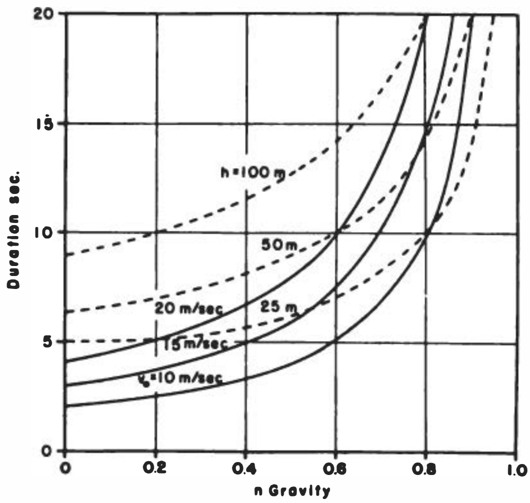


Figure 4a. Sub-gravity and Zero-G in Elevators



(From F. Haber, 1952. Epitome of Space Medicine, USAF Sch. of Aviat. Med.)

Figure 4b. The Duration of Subgravity as Obtainable in Elevators.

thus transforming Equation (19) into

$$\frac{dv}{dt} = n.\,g - g = -\,(1 - n).\,g. \tag{21}$$

If n is equal to zero the gravity free state results, and if $o<n<1$ the subgravity state prevails. The solution of Equation (20) is

$$v = v_o - (1 - n).\,g.\,t. \tag{22}$$

For $t = 0$, v equals the initial speed v_o. With increasing time, v reaches the value zero:

$$v = o = v_o - (1 - n).\,g.\,t_o\ , \tag{23}$$

$$t_o = \frac{v_o}{(1 - n)'g}\ . \tag{24}$$

After this time the speed becomes directed downward and reaches the value $-v_o$. The pertinent time is

$$t_d = \frac{2v_o}{(1 - n)'g}\ . \tag{25}$$

The elevation of the body as a function of time is the integral of Equation (22) and is

$$h = v_o.\,t - \frac{1 - n}{2}\,.\,g.\,t^2. \tag{26}$$

The height is zero for t - 0 and becomes zero again for

$$h = o = v_o' t_d - \frac{1 - n}{2}\,.\,g.\,t^2 d\ , \tag{27}$$

$$t_d = \frac{2v_o}{(1 - n)g}\ , \tag{28}$$

which is identical to Equation (25). This equation gives the duration t_d as a function of gravity and initial speed. For some purposes it is convenient to have the duration as a function of gravity and elevation. This is achieved by introducing Equation (23) in Equation (26) and obtaining

$$h = \frac{{v_o}^2}{2(1 - n).\,g}\ . \tag{29}$$

By this equation the speed v_o in Equation (25) can be replaced by the elevation h yielding to

$$t_d = \sqrt{\frac{8}{(1 - n).g} . h} . \qquad (30)$$

Equations (25) and (30), giving the relation of elevation, gravity, initial speed, and height, are plotted in Figure 4.

5. No data available. Elevator car can be instrumented to measure physiological variables and performance characteristics of test subjects, behavior of materials and substances, of animals, etc.

6. See Paragraph 5.

7. Safety factors and requirements in accordance with regulations for operating elevators.

8. Since elevators of various types are available (the use of elevators in the Empire State Building, the Carlsbad Caverns, and mine shafts, were previously considered), costs may have to cover the operating costs of these devices. Special safety equipment and scientific instrumentation optional.

9. No information available.

10. References included in the general bibliography attached to this report.

The Subgravity Tower

1. This is a device for producing short periods of increased and decreased weight to study their physiological and psychological effects. The device is available at the Aviation Medicine Research Center in Rome, Italy. A schematic picture is given in Figure 5.

2. The Subgravity Tower consists of a metal-trestle tower, about 14 m high. Inside of this structure is a platform weighing about 50 kg which, in turn, holds the subject, medical instrumentation, film camera, and ballast to compensate for weight differences among subjects. The following parts are necessary for proper functioning of the device:

a. Power device: Consists of four bundles of elastic (rubber) cords. When they are brought under tension by a mechanical winding procedure, a certain amount of potential energy is available for propelling the platform upward.

b. Release device: Consists of a set of levers which arrest the platform at the base of the structure. The rubber cables lift the platform upon release.

c. Braking device: Consists of two vertical steel cables which diverge at the upper end and exert an effective braking action without any jerks.

d. Recovery device: Allows arrest of the compartment or platform upon completion of motion and to engage it to the launching device.

e. G-control: Consists of an accelerometer attached to the right and level with the head of the subject.

3. At the beginning of an experiment the release device holds the platform at the base of the tower. The elastic ropes are not under tension. All preliminary preparations (mounting of camera, seating and securing of subject, balancing of platform, etc.) are carried out under these conditions. After the elastic ropes are placed under tension, the platform is released and stopped only after the completion of the series of vertical oscillations.

4. During the oscillations in the vertical plane, the subject is exposed to accelerations of varying magnitude. The values obtained during a typical experimental run on the subgravity tower are as follows:

TABLE I.

Time Sequence (Seconds)	Amount of G	Duration of Subgravity (Seconds)
Stationary	1	
0 - 0.75	1; 3; 1; 0	
0.75 - 2.35	0	1.70
2.35 - 3.85	0; 1; 2.8; 1; 0	
3.85 - 5.15	0	1.30
5.15 - 6.65	0; 1; 2.5; 1; 0	
6.65	0	1.00
7.65 braking action		

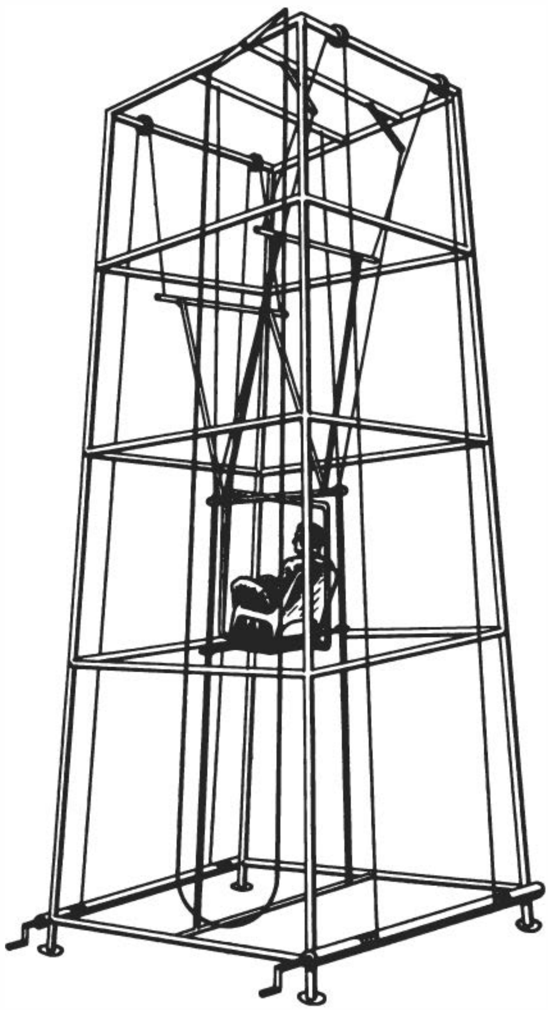


Figure 5. Subgravity Tower

The maximum distance covered by the subject is about 7.70 m (from the moment of release to the highest point of the vertical trajectory). The force exerted through the elastic ropes in a typical experiment amounted to about 300 kg. One set of experimental G-exposures lasts about 8 seconds. It was repeated 10 times for one experiment on physiological or psychological responses to subgravity.

5. The system can be designated as an "open loop" system because the subject has no control of the situation. Film coverage of the experiment and actual performance tests were carried out.

6. The instrumentation of the Subgravity Tower was rather crude; but a multichannel was installed for recording the EKG and heart rate. Other physiological and psychological measurements of the effects of changing accelerations and subgravity states of short duration can be taken by means of improved equipment.

7. Although the majority of test subjects displayed rather dismaying symptoms similar to those observed with seasickness, no serious trauma or injuries can be expected in experiments employing accelerations and accelerative changes within the range given above.

8. Cost figures not available.

9. Information on projects and workload not available.

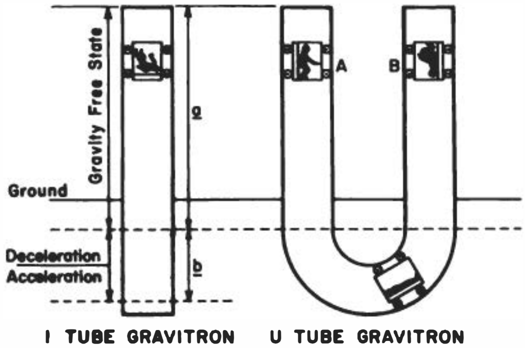
10. References are included in the general bibliography given at the end of this report.

The Gravitron

1. The Gravitron was suggested by H. Walton as a device to study the subgravity conditions and the zero-G state at ground level. Since Mr. Walton died in an aircraft accident on November 5, 1955, no action has been taken to construct the device; but the principle of his proposal is worth-while to be considered for realization.

2. The basic idea of the gravitron is to induce a state of free fall in a vertical tube. At the end of the fall the motion is reversed by means of deceleration-acceleration so that the same tube can be used for the next phase of subgravity.

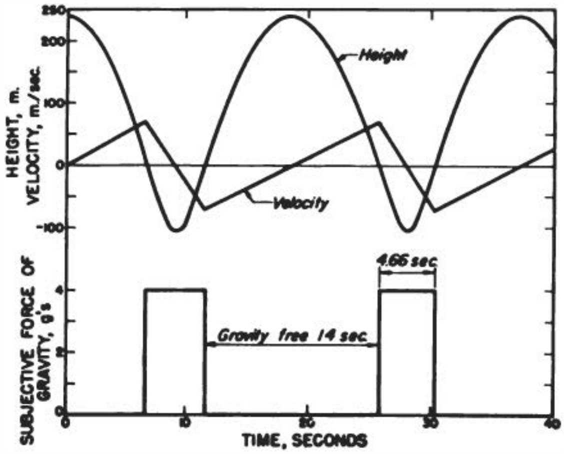
Figure 6 shows the I-tube gravitron. The subject enclosed in a pressure chamber falls freely in segment "a" of the vacuum type vertical tube. In segment "b" he decelerated to a standstill; then accelerated upward again to repeat the cycle. The schematic drawing in the right half of Figure 6 shows a different arrangement, one in which the only external power input necessary is the relatively small amount to compensate for friction of the cabin gliding wheels. The reversal in the direction of motion occurs in a curved part of the device. Care must be taken however that no jerks occur by the change of the directional vector component during the transition from vertical fall to non-linear motion. The deceleration due to friction in the curved section of the tube may be compensated for by added acceleration.



(From H. Walton, Jr., Journ. of Aviat. Med. 28:291-294, 1957)

Figure 6. Gravitron

3. Figure 7 shows typical velocity and gravity cycles in an I-gravitron. Zero-G states are alternating with states of increased acceleration. The vertical tube has a height of 350 m (1,148 feet). This would allow a zero-G state of about 14 seconds, and deceleration-acceleration at 4 g for 4.66 seconds.



(From H. Walton, Jr., Journ. of Auiat. Med. 28:291-294, 1957)

Figure 7. Height, velocity and subjectively felt gravity force in an I-tube gravitron, of hypothetical dimensions: height of free fall "b" = 240 meters; height for deceleration-acceleration "a" = 1000 meters. Notice that subject is alternately in gravity free state for fourteen seconds and under 4g for 4.66 seconds (lg = 980 cm sec $^{-2}$).

Figure 8 shows typical velocity and acceleration cycles in an imaginary U-gravitron of 240 m (750 feet) height and 120 m (375 feet) radius. Fourteen seconds of zero-G or subgravity would alternate with 5.6 seconds at 4 G. However, it is necessary to adjust design of the curved section to allow for a smooth onset of deceleration.

4. Table II gives the mathematical treatment of acceleration, velocity, and course in the device, neglecting frictional forces between cabin rollers and tracks. Looking at the acceleration pattern as given in Table II, we see that there is an abrupt change from the linear acceleration at the end of the straight section of the U to $\frac{v^2}{r}$ at the beginning of the non-linear section. Thus, the value of r changes from infinite* to a finite one; and this results in an unsteady change of motion (change in acceleration) at a fraction of a second. A smooth transition from linear to radial acceleration must be provided if a gradual onset of the G-forces is to be obtained.

5. There is no control system particularly designed to operate in the gravitron. Certain principles of other free fall and acceleration devices could be applied and incorporated, however. This pertains specifically to performance testing and scoring, telemetry, photography, and other data collecting techniques.

6. The device could be used to investigate some physical effects of short zero-G states; such as, convection, diffusion, dilution, and heat transfer of gasses and liquids; and equipment to be used in zero-G conditions, such as, electronic cooling equipment that relies on convective air movement or on boiling a liquid and recondensing the vapor within the system; ventilation devices, some uncooled electric lights; gyros, artificial horizons, bank indicators, rotometers and manometers, level indicators and controls; hydraulic heads, systems, drives, and bearings, lubrication systems; conventional purge boilers, dry sump lubrication of gear boxes, and artificial gravity devices (regenerative algae systems).

7. For maximum safety, the height of the device should not exceed the measures given in Figure 7, and the acting G-forces should be kept at or below the values given above, if no special damping equipment or anti-G suits are used. It is possible to adjust design of both I- and U-models to secure a

*During the free fall in the straight part of the gravitron $r = \infty$.

TABLE II.
Acceleration, velocity, and course (path) in the gravitron.

1 Gravitron Section	Acceleration	Velocity	Path	Inside Gravity	Velocity Path
Straight, free fall	g	gt	$1/2gt^2$	0	0
At end of section	g	$vo = gt_o$	$1/2gt^2{}_o$	0	0
Straight, deceleration acceleration	$g - d$	$v = gt_o + (g - d)(t - t_o)$	$x = x_o + v_o(t - t_o) + \frac{(g - d)(t - t_o)^2}{2}$	$-d$	0
At end of deceleration $(d - g) = gt_o$	$g - d$	0	$xs - x_o = \frac{g^2}{2(d - g)} t^2{}_o$	$-d$	0
U gravitron first two lines same as	$\frac{v^2}{r}$	$v^2 - v^2{}_o = 2gh$	circular	$\frac{v^2}{r} + g$	0
At bottom of U	$g + \frac{v^2max}{r}$	$v^2max - v^2{}_o = 2gr$		$g + \frac{v^2max}{r}$	

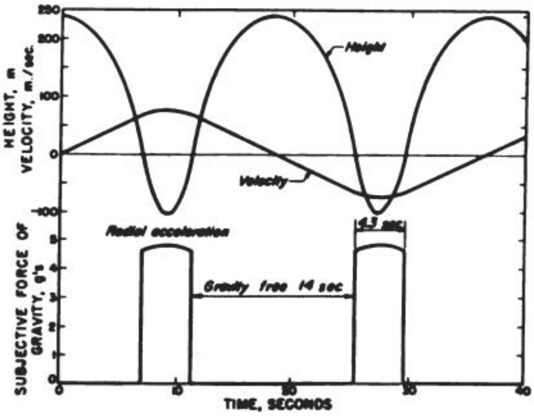
From: H. Walton, Jr. Journal of Aviation Medicine: 28: 291-294, 1957.

gradual onset of G-forces. For further precautions see "WADC Vertical Deceleration Tower (Drop Tower)".

8. No cost figures or estimates available.

9. No projects formulated as yet.

10. References included in general bibliography at the end of this report.



(From H. Walton, Jr., Journ of Aviat. Med. 28:291-294, 1957)

Figure 8. Height, velocity, and subjectively felt force of gravity in a U gravitron of hypothetical dimensions: "a" = 240 meters, "r" = 100 meters. Subject is alternatively in gravity free state for fourteen seconds, and under about 4.7 g for 4.3 seconds (1g = 980 cm sec^{-2}).

George C. Marshall Space Flight Center Vertical Linear Accelerator ("Pogo Stick")

1. The George C. Marshall Space Flight Center Vertical Linear Accelerator ("Pogo Stick") is located in Building 4487, Guidance and Control Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama. It was constructed in 1958 and has been modified several times since its first installation. The device is operated and maintained by a staff of four.

2. The Vertical Linear Accelerator is a pneumatic device which generates linear acceleration for test purposes. It consists of a carriage which moves freely up and down on rollers between a set of vertical guide rails, a cylinder located at the bottom

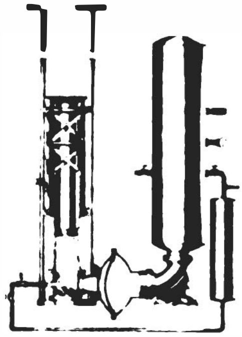
of the accelerator, and a rubber diaphragm which separates the cylinder from a large air tank. A picture of the device is included in Figure 9.

The carriage, consisting of a test table, piston and its supporting framework, is set into motion by pushing the start button and manually adjusting a hand-operated valve until the desired amplitude has been reached. The carriage falls within the guide rails until the piston, beneath and integral with the table, enters the cylinder near the bottom of its travel. The work done in adiabatically compressing the trapped air reduces the kinetic energy of the falling piston until the pressure in the cylinder reaches the pressure in the air tank. At this time the diaphragm between the cylinder and the tank starts to move away from the cylinder side of the diaphragm housing. The kinetic energy of the piston has not been exhausted so it continues to move downward, displacing the air beneath it at constant pressure. It is this period of constant pressure that imposes constant deceleration on the piston, thereby producing the desired G loading. The G value obtained is a function of the tank pressure and the piston travel, and may be varied within the limits of the machine.

After the lowest point of piston travel has been reached, the stored air in the diaphragm housing accelerates the piston upward with approximately the same G value reached during deceleration. Constant acceleration continues until the air in the diaphragm housing is completely expelled. Stored energy from compression continues to move the piston, but with decreasing acceleration, until it leaves the cylinder.

Due to energy losses from friction and heat, the piston will not regain its original height. Therefore, it becomes necessary to introduce additional air into the cylinder. A cam operated contact switch, actuated by a cam rail on the carriage, operates a solenoid valve which feeds the make-up air into the system, thereby regulating the height of piston travel.

The characteristics of the linear acceleration vs time can be modified to prepare the accelerator for specific tests on subgravity requirements. The maximum velocity obtainable with this device approximates 26.6 ft/sec. The peak acceleration can be set continuously between 5G and 30G for payload weights up to 80 pounds. The capabilities and limitations of the device are given in Table III. By adjusting the deceleration pattern, states of subgravity and zero-G can be obtained. A special feature of the device is the capability of cyclic operation which is essential for



(US ABMA)

Figure 9. Vertical Linear Accelerator

the performance of long duration tests. Although the free fall is limited by friction of guide rails and air drag, a period of 1.6 seconds of zero-G and subgravity can be produced at the rate of 30 cycles/min.

4. Theoretical basis and equations representing the subgravity conditions similar to the ones applying to free fall and vertical motion as given before.

5. The control system is manually operated.

6. The instrumentation consists of 22 shielded leads, air supply, and RF connector.

7. There are automatic safety devices which block the device from operating if the door on either the upper or lower level is open, if the hoist is not making contact with the switch at the top of the tower, or if the air pressure in the main tank is below 15 psi. If the piston comes within four inches of the safety block in the bottom of the cylinder, an alarm will sound; if it comes within 2 inches of the block, the power will automatically be cut off. There is a remote control stop which the operator may carry at all times when the accelerator is in operation. Moreover, the hoist meter will not operate if the crank for manually operating the hoist is not hanging on its hook.

8. Approximate cost of the device and its use not available at present. The person in charge of the operation is Mr. W. N. Allen, Applied Research Branch, Guidance and Control Laboratory, Marshall Space Flight Center. In case of participation of

outside agencies, Dr. W. Haeusserman, Director of the Guidance and Control Laboratory should be contacted.

9. By means of this accelerator, highly sensitive devices (for example, gyros and drift rate indicators) are subjected to the influences of linear acceleration and subgravity, whereby their functioning is continuously controlled. The projects included experiments on air bearings, missile instrumentation packages, sea urchin eggs, and satellite instrumentation packages. The workload during the previous year has been relatively small. The schedule for the next year is unknown.

10. "Operation Instructions for Vertical Linear Accelerator", prepared by the Development Design Section, Electro-Mechanical Engineering Branch, Guidance and Control Laboratory, and by Mr. J. Boehm, Guidance Design Section, Guidance and Control Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama.

TABLE III.

VERTICAL LINEAR ACCELERATOR
Capabilities and Limitations of Test Apparatus

Linear Acceleration (In G)	30	20	15	5
Approximate Duration of Peak Acceleration (In m Sec)	0	0	50	220
Capacity	Volume = cylinder; 10" diameter, 15" height Weight = 80 lbs.			

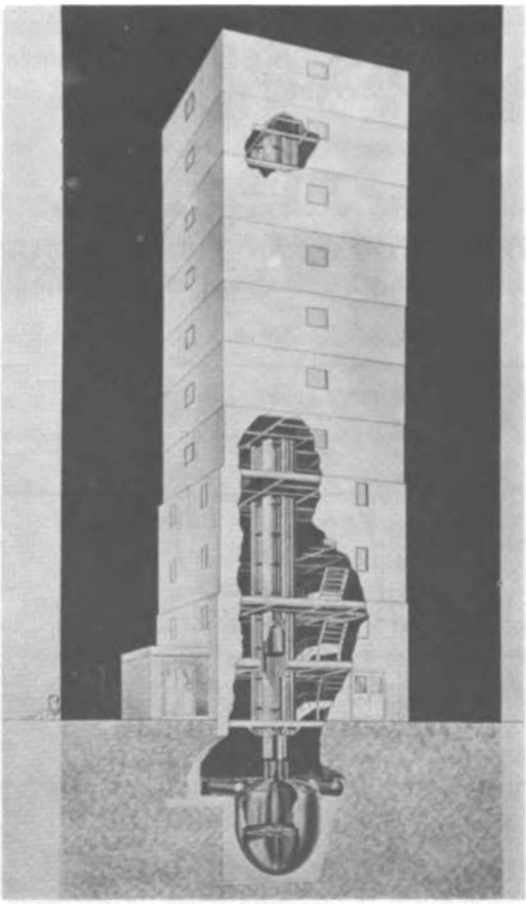
The Sulinac (Super Linear Accelerator)

1. The Sulinac is a device proposed by the Guidance and Control Laboratory, George C. Marshall Space Flight Center, Huntsville, Alabama. The construction of the device is pending upon receipt of available funds.

2. An artist's conception of the proposed device is given in Figure 10.

3. The limiting size of the payload will be about 23"x32"x44" (the latter dimension indicates the weight of the payload); the weight limitation will be about 600 pounds.

The motion will be vertical linear; the acceleration and time spectrum is given in Table IV. The maximum velocity will be 64 ft/sec. The free-fall motion enhanced by air jets for compensating frictional losses will provide a duration of the subgravity state of about 4 sec/cycle. The operation of the device at 13 cycles/min can be maintained for any period of time.



(US ABMA)

Figure 10. Proposed Sulinac (Super Linear Accelerator)

TABLE IV.

Sulinac Capabilities (Based on a Payload Weight of 200 lbs.)

Cylinder No.	Linear Acceleration (In G)	Approximate Duration of Peak Acceleration (In m Sec)
	10	250
I	20	155
	30	115
	30	97
II	40	79
	50	67
	30	77
	50	52
III	70	41
	90	33
	100	30

CAPACITY:
VOLUME = PRISM WITH MOUNTING BASE 19.75"x31.5";
HEIGHT = 44"
WEIGHT = 700 LBS.

4. Theoretical basis of equations as given before.

5. The control system will be semi-automatic; the device will be started manually; operation of the device and control of the payload through open loop.

6. The instrumentation will include records of the accelerative forces and of subgravity and zero-G. Moreover, 120 signal leads will be available for recording technical and scientific information, as indicated in ABMA research projects concerning the use of the Vertical Linear Accelerator.

7. The device will have completely interlocked safety features.

8. The estimated costs of the device are approximately $250,000, and of the housing and laboratory building also about $250,000.

9. Data not available.

10. Design and development was performed by the Guidance and Control Laboratory, ABMA. Dr. W. Haeusserman and Mr. J. Boehm can be contacted for further information.

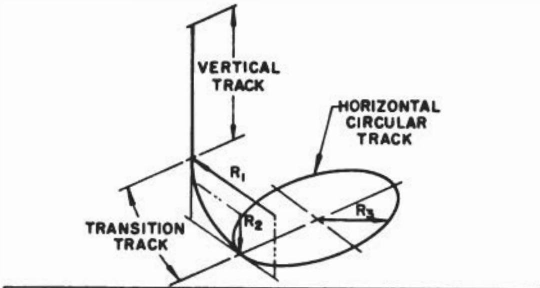
George C. Marshall Space Flight Center
Space Flight Acceleration Simulator

1. The construction of a Space Flight Acceleration Simulator Facility, utilizing natural differences in altitude on earth (such as that to be found in the Grand Canyon and Yosemite Park, California), has been proposed. An artist's conception of the device is given in Figure 11.

(US ABMA)

Figure 11. Artist's Conception of ABMA Space Flight Acceleration Simulator Facility

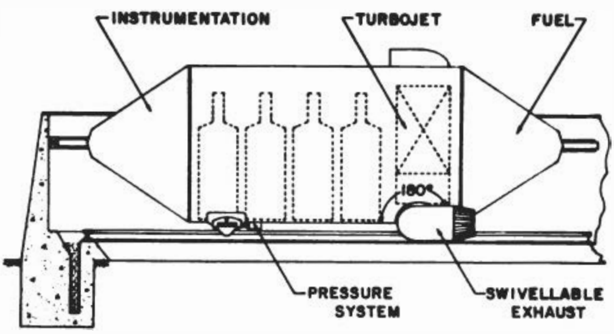
2. It consists of track captured capsule traveling on circular horizontal track capable of switching into a vertical track and return. Typical track, switch, and capsule details are shown in Figures 12, 13, 14, 15, and 16. There are no apparent limitations on payload size or weight. The sled considered herein is a 2-ton, 8-foot diameter, 24 feet long, turbo jet powered version carrying four men.



	LENGTH	RADIUS
VERTICAL TRACK	3622	—
TRANSITION TRACK	1395	1210 — 500
CIRCULAR TRACK	3142	500
TOTAL HEIGHT	4519	

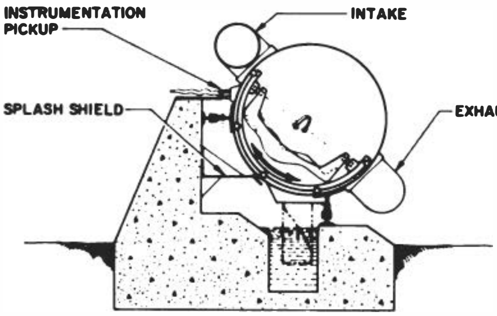
(US ABMA)

Figure 12. Track Layout



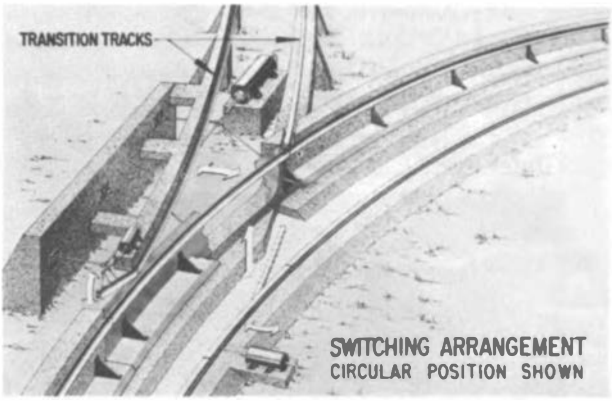
(US ABMA)

Figure 13. Typical Sled



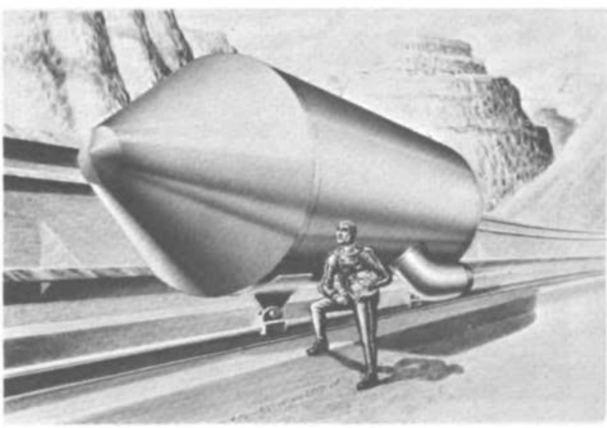
(US ABMA)

Figure 14. Typical Sled and Track Section



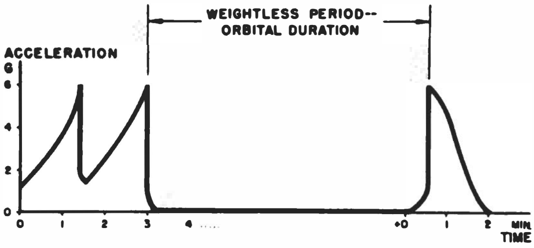
(US ABMA)

Figure 15. Switching Arrangement



(US ABMA)

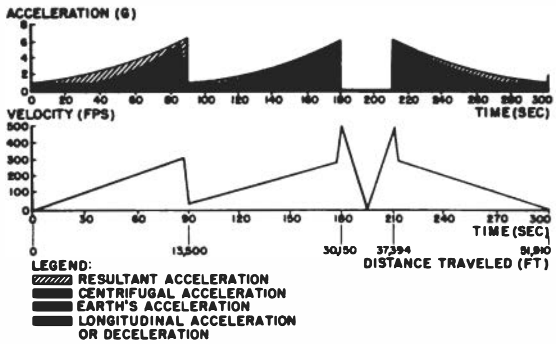
Figure 16. Artist's Conception of Sled Unit



(US ABMA)

Figure 17. Typical Acceleration Pattern Two-Stage Booster

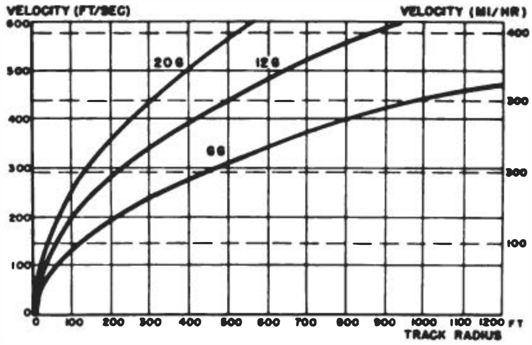
3. Figure 17 shows typical acceleration-time history to be duplicated. Figure 18 shows simulator capability to duplicate the acceleration pattern giving sled (capsule) velocity and distance figures for the typical 500-foot radius track. Figure 19 indicates acceleration as a function of velocity and track radius. Figure 20 shows the height of the vertical track vs time at zero-G and compares time-around-the-clock and time at zero-G for given velocities. Figure 21 indicates velocity buildup for longitudinal accelerations vs time during the travel on the circular track. Figure 22 covers the distance traveled by the sled and the deceleration forces involved for given velocities and time parameters.



(US ABMA)

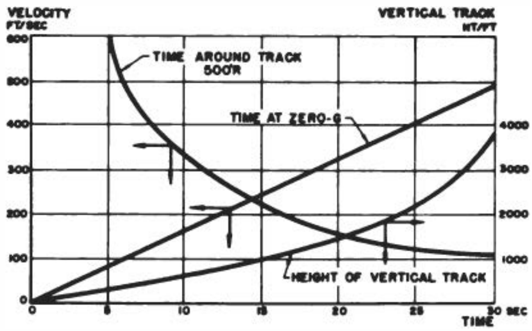
Figure 18. Typical Two-Stage Boosted Capsule

In operation the vehicle starts on the circular track making one or more circuits as required, during which the vehicle is subjected to longitudinal, earth-G and centrifugal forces. The resultant of these forces is displayed in Figure 18 as running from 0 to 180 seconds and 210-300 seconds. Stage burnout at 90 seconds



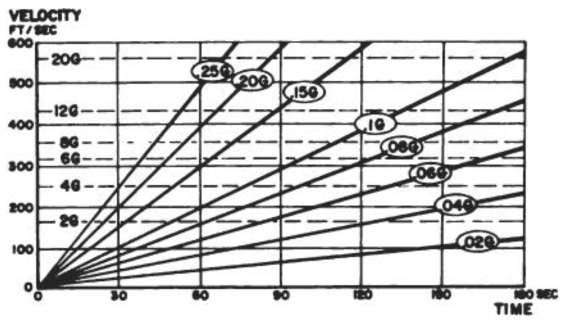
(US ABMA)

Figure 19. Track Curvature Considerations



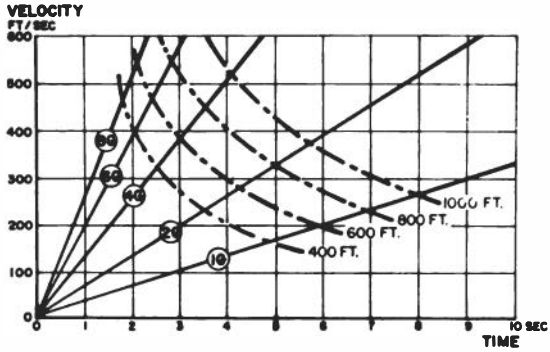
(US ABMA)

Figure 20. Sled Velocity Parameters



(US ABMA)

Figure 21. Longitudinal Acceleration Study

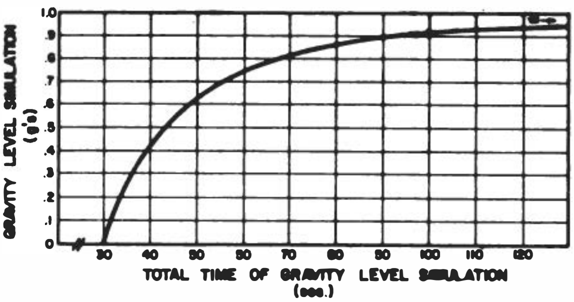


(US ABMA)

Figure 22. Sled Deceleration Considerations

is simulated by proper programming of the continuous water brake which reduces velocity and therefore centrifugal force. The zero-G state is obtained during the vertical up and down "flight" after the switch to this track. Thrust is maintained to offset frictional and drag losses, thereby obtaining zero-G within sensor tolerances.

4. Simulation of subgravity other than zero-G is possible by entering the vertical motion with the variable vertical thrust component required. Control of the sled thrust vector is by a 180° swivel nozzle. The typical design shown allows a true zero-G capability to be maintained for 30 seconds. Figure 23 illustrates the increase in time possible for producing various levels of subgravity.



(US ABMA)

Figure 23. Endurance of Sub-Gravity Simulation for a 3622.5 Ft. Track

Other programs might include physical and biomedical experiments under sustained high G forces by refueling of the sled or through electrical drive units. Ejection of manned or instrumented capsules may be accomplished under acceleration or weightless states. Angular, oscillatory and jostling accelerations may also be added to provide any desired combination of forces.

5. Physical orientation of the subject within the sled is optional. Preselected or variable orientation is possible for any "flight".* Subject can be part of an open or closed loop.

6. All standard track type instrumentation systems are possible with this simulator. Due to the liberal sized cabin, either a board viewing of the subject or trainee or TV to the adjoining laboratories is possible. Recording channels and noise levels are not known.

7. Since the device is ground-based and track-captured, the safety problems associated with free flight or controlled aircraft flight are eliminated. Other safety considerations are obvious for the circular track operation. Several systems exist for halting and holding the sled on the vertical track such as those used in elevator shafts, etc.

8. Facility cost estimated at approximately 20 million dollars, which would include the technical facilities, the technical support, administrative and logistical support facilities, housing and community facilities access and utilities. Operational costs would be relatively low due to the possibility of round-the-clock operation of the sled itself.

9. The simulator would provide a highly desirable link in the selection and training of future astronauts. The ability to observe the candidates with an operator on board, to increase the performance outputs of the system, to allow the subject to be in a mockup of his flight vehicle, and to perform his actual duties during the "flight" should increase the number of acceptable space flight personnel.

10. ABMA Report No. DSP-TR-1-59 entitled "Space Flight Simulator", dated 16 March 1959.

*Theoretical basis and equations representing the physical forces acting on the subject are similar to those given for the Gravitron. As in case of the latter, the characteristics of the ABMA Space Flight Acceleration Simulator does not provide for a smooth transition from linear acceleration into angular acceleration. In order to avoid jolts during the change from linear to angular acceleration and vice versa, another transition than proposed seems to be necessary.

B. Aircraft

From the laws of kinematics, it can be followed that the true state of zero-G can be obtained in a dynamic situation only. The aircraft, with its six degrees of freedom of motion, seems to be the most promising means available at present for human experiments in the zero-G state. Some general remarks concerning the motion, acceleration and velocity characteristics will precede the discussion of particular types of aircraft used in zero-G research.

Within the gravisphere of the earth, an aircraft is truly weightless when it is flying on a Keplerian trajectory. The characteristics of such a curve indicate that it can be represented by a parabola with vertical axis. Strictly speaking, the zero-G parabola is a trajectory described by an unpropelled body in ideally frictionless space subjected to a centrally symmetric gravitational field. Generally, such a trajectory is a conic, one focal point of which coincides with the center of attraction around which the body revolves. For sufficiently small velocities, such as are achieved with present day aircraft, the conic is a very elongated ellipse. The small section near the apex of the ellipse, emerging from the surface of the earth, can well be represented by a parabola. The condition for good approximation is that the dimensions of the section are small compared to the radius of the earth, or alternately, that the part of the earth's surface arched over by the section can be considered flat instead of spherical.

For the mathematical analysis of a parabolic flight pattern, which is a vertical planar maneuver, an orthogonal coordinate system can be employed. The angle of climb is then determined by the direction of the vehicle at the beginning of the push-over; that is, at point 0 in Figure 24. The important information to be obtained from an analysis of the curve concerns the duration of the weightless state and its dependency upon other flight parameters.

In ballistics, the duration of the trajectory is defined as the time required for the projectile to again reach the level of its initial projection. In our flight pattern, T is the duration of the weightless state. From Figure 24 it can be seen that the vertical location of any point of the parabola can be expressed by:

$$y = v_o t \sin \epsilon - \frac{g}{2} t^2 \qquad (31)$$

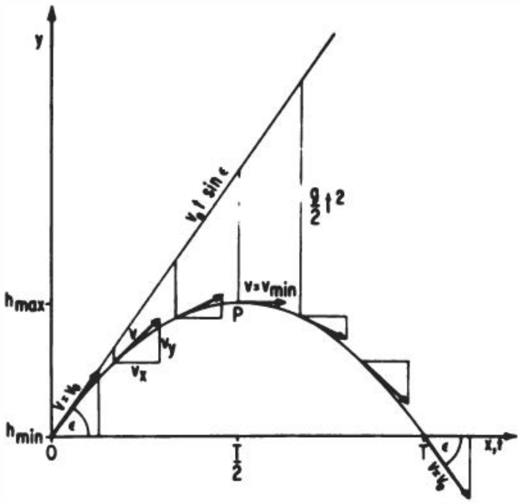


Figure 24. Schematic of Parabolic Arc. In the absence of gravity, a craft starting from point 0 at an angle ϵ would follow the straight line $v_o t \sin \epsilon$. Gravity causes the craft to fall. The vertical line segments between the straight line and the parabola represent the height of fall at the corresponding points of the trajectory. Also shown are directions and relative magnitudes of the velocity and its horizontal and vertical components. The velocity reaches its minimum at the peak P of the parabola where the vertical component vanishes. The magnitudes of the speed at beginning and end of the parabolic arc are equal. The same holds for the angle ϵ.

where v_o = the initial velocity of the craft, and ϵ = the angle of climb. In order to find T, we determine the value t for which y again becomes 0:

$$T = \frac{2}{g} v_o \sin \epsilon . \qquad (32)$$

Equation (32) shows that T depends upon the value of g, the velocity v_o, and the angle of climb ϵ, the latter quantities measured at 0. At a given v_o the longest duration is obtained when $\epsilon = 90^o$. However, the aircraft cannot rotate about 180^o at zero speed on top of a straight-up ascent. Hence, our problem is to find the optimal value of ϵ withrespect to the initial velocity v_o and the minimum maneuvering speed of the airplane v_{min}.

The optimal angle of climb can be found by considering the velocity diagram at point P in Figure 24. Since the horizontal component of the velocity must be constant, $v_x = v_{min}$. Thus, we write:

$$v_x = v_{min} = v_o \cos\epsilon \; , \tag{33}$$

$$\cos\epsilon = \frac{v_{min}}{v_o} \; . \tag{34}$$

Equation (34) shows that the optimal angle of climb depends upon the ratio of excess thrust and minimum controllability speed.

Finally, we want to know what relationship exists between the duration of the weightless state and the peak altitude of the maneuver. The maximum height h_{max} is defined as the greatest vertical distance reached by the aircraft as measured from the ground. In Figure 24 the maximum height is that of the peak P of the parabola:

$$h_{max} = h_{min} + \frac{v_o^2}{2g} \sin^2 \epsilon \; : \tag{35}$$

Another simple representation results, if the peak of the parabola is chosen as origin of the coordinate system. In this system, the altitude at any time is

$$y = h_{max} - \frac{g}{2} \; t^2, \tag{36}$$

the downward vertical component of the velocity is

$$v_y = gt. \tag{37}$$

From the total velocity

$$v = \sqrt{v_x^2 + g^2 \; t^2} \tag{38}$$

the duration of one leg of the parabola is found

$$\frac{T}{2} = \frac{1}{g} \sqrt{v_o^2 - v_x^2} \; , \tag{39}$$

where

$$v_{oy} = \sqrt{v_o^2 - v_x^2} \qquad (40)$$

is the vertical component of the velocity at the endpoints of the parabola. In terms of maximal and minimal altitudes, this vertical component and the total duration can be represented by

$$v_{oy} = \sqrt{2g(h_{max} - h_{min})} \qquad (41)$$

$$T = \sqrt{\frac{8}{g}(h_{max} - h_{min})} \qquad (42)$$

Finally, the optimal angle of climb is again given by formula (34).

In Figures 25, 26, and 27, the total duration T of the maneuver, the height $h_{max} - h_{min}$ of the parabolic arc, and the optimal angle of climb ϵ_{opt} are given in the range of maximal speeds between 400 and 2000 knots for three values of the minimal speed.

Convair C-131B

1. The Convair C-131B Aerospace Medical Airborne Laboratory is located at WCTOC, Wright-Patterson Air Force Base, Ohio. The C-131B aircraft was built in 1953 and designed as an electronic test bed facility with modifications of increased flooring structure to handle electronic test apparatus. The Aerospace Medical Laboratory projects are monitored directly by two officers and one airman.

2. A photograph of the Convair-131B is attached (Figure 28). Weight limitations are programmed by aircraft station (approximately 350 lbs/4 ft) and normally the volume requirement (33 1/2X 75"X26" test racks) is the limiting installation factor. The free-floating area (25'X5'5"X7') can be used for large portable apparatus, weight distribution permitting. (Ref. T. O. IC-131A-1 for full payload weight, vs fuel limitations.)

3. The attached C-131B parabola dynamics chart is reprinted for your convenience (Figure 29). The X-abcissa represents degrees of pitch, the Y-ordinate represents maneuver entry speed (our maximum diving speed is 266 knots IAS), the upper right curves represent "positive" G Pulleys parameters (our

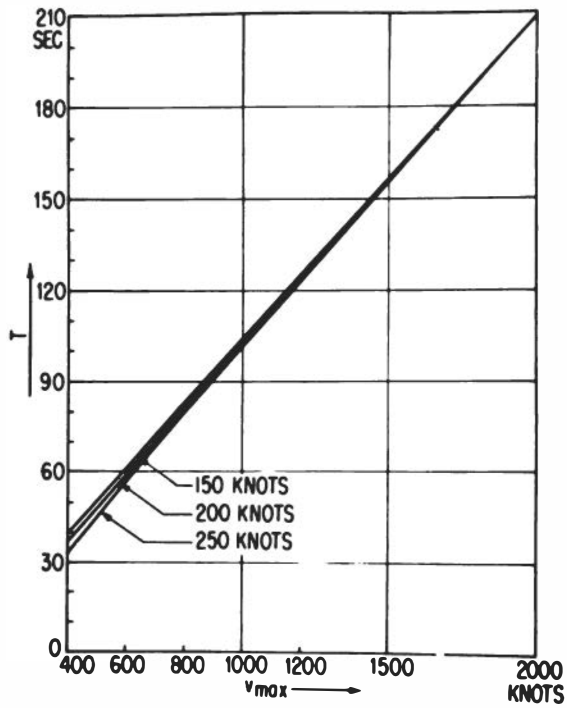


Figure 25. Duration T of parabolic maneuver as related to maximal and minimal speed.

The duration is approximately proportional to the maximal speed the craft can achieve. The minimal controllable speed has little influence unless it amounts to an appreciable fraction of the maximal speed.

maximum G load is 2.5 for structural safety limitations). The vertical lines represent zero-G duration in seconds, reading from pitch over point at right (normally +45^{o}) to recovery point at left (normally -35 to 40^{o}).

4. Continuous head-to-toe recordings have shown sustained parabolas averaging 0 + .01 g for 14 seconds. Fore and aft g recordings have shown more variation (0 + .05 g). The latter problem exists because of the difficult throttle programming required to overcome the relatively slow changing aircraft momentum during initial acceleration. The maneuver itself is easy to fly; however, the aircraft flies through potentially dangerous pitch

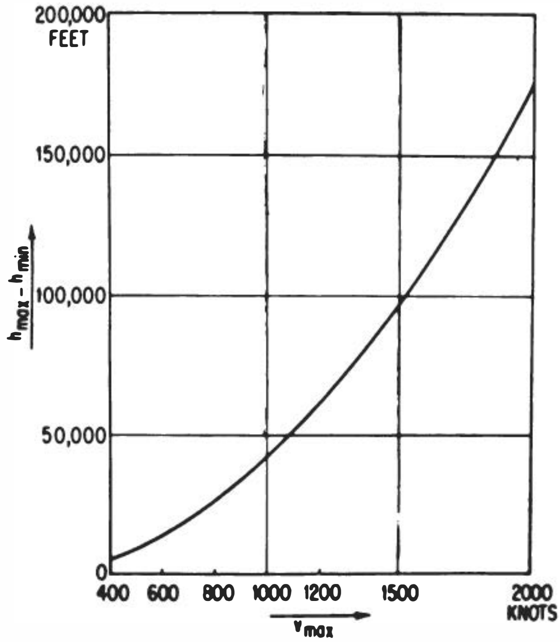


Figure 26. Height of the parabolic arc vs maximal speed, for a minimal speed of 200 knots.

The height increases approximately with the square of the maximal speed. For minimal speeds of 150 and 250 knots, the curve is shifted up or down, respectively, by approximately 1000 feet.

attitudes and we have restricted the maneuver to experienced pilots (Figure 30).

5. Each experiment requires its own specific gear; however, the following equipment has been installed to cover most projects:

a. Heiland 24 channel photo-oscillograph.
b. Head-to-toe and fore-and-aft oscillograph recorders.
c. Altitude, airspeed, pitch and roll oscillograph recorders.
d. Sequenced 16 mm camera coverage.
e. Response switch tie-ins to oscillograph (psychomotor tasks, value judgements, etc.).

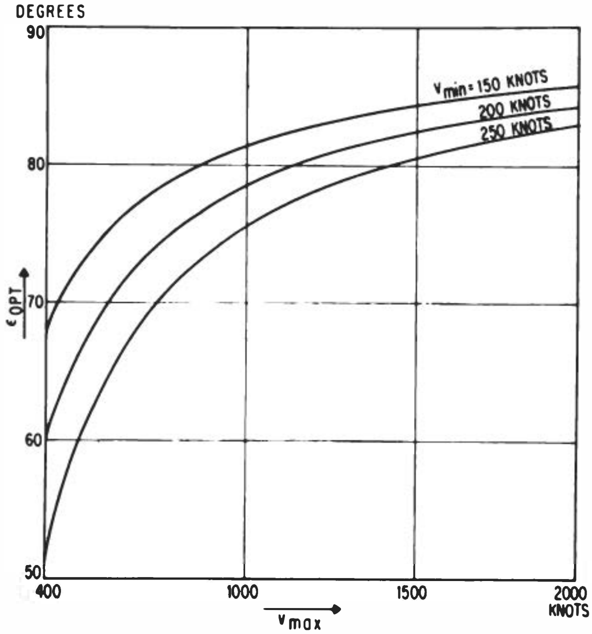
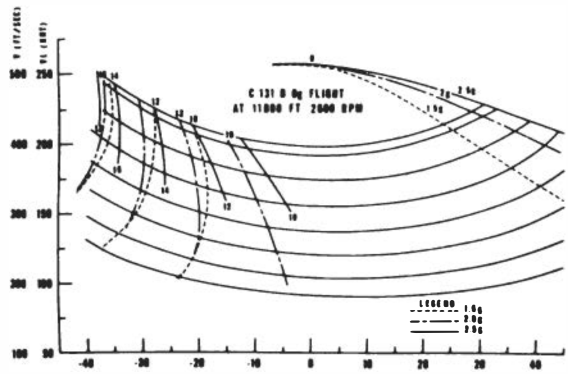


Figure 27. Optimal value of the initial angle of climb as related to maximal and minimal speed.

The optimal angle increases with increasing maximal speed and approaches 90° for very large speeds.

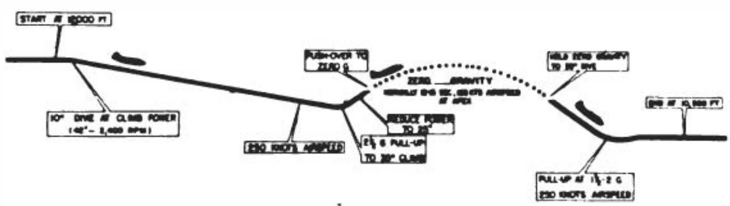
(Official USAF Photo)

Figure 28. Convair C-131B Aerospace Medical Airborne Laboratory



(Official USAF Photo)

Figure 29. Velocity-Time-Acceleration Nomogram for C-131B Flight Parabolas



(Official USAF Photo)

Figure 30. Zero Gravity Experiments

f. Physiological tie-ins to oscillograph (cardiac outputs, respiration outputs, etc.).

Through experience with temperamental in-flight research it was learned to keep airborne gear as absolutely simple as possible. Mission aborts become very expensive and as a result the programs require portable, simple-to-repair and reliable test equipment.

6. (Covered by Paragraph 5.)

7. The loss of oil pressure with inadvertent "negative G" operation has necessitated the addition of propeller pitch locks and a supplementary oil expulsion system. Fighter type battery caps were added to prevent acid spillage. The aircraft undergoes periodic structural inspection to foresee possible structure failures. Head helmets are normally worn by free-floating subjects over a mattressed area.

8. Aircraft use is requested through WCLDPPS, WADC, W-PAFB, Ohio. Formal arrangements are then signed with the Programming Office, Directorate of Flight and All-Weather Testing. Experiments in non-areo med experiments, such as fluid behavior and tool evaluations under weightless conditions, are routed by WCLDPPS to the appropriate laboratory for direct control; however, these programs are still monitored by WCLDPPS. The only costs involved may be film and oscillograph papers procurement because the aircraft has been assigned full time to the Aerospace Medical Laboratory for in-flight research.

9. Current physiological and psychological research efforts:

Project	Project Engineer
Weightless effects on entering supine seat	Captain Morrison
Effects on cardiac output	Dr. Zinn
Effects on vestibular canal	Dr. Dzendolet
Effects on self-locomotion	Mr. J. Frost
Effects on non-torque tools	Mr. Spencer
Effects on pigeon orientation	Dr. Belleville
Effects on positioning mass	Mr. Reese
Effects on visual measures	Major Pigg - Captain Pitt
Effects on self-propulsion and muscle force	Dr. Hertzberg

The following experiments were prepared for the Aerospace Medical Convair during the period 1 July 1959 to 1 October 1959:

Experiment	No. Flts.	No. Subjects	Runs/Flt.
Magnetic Devices - Channel magnetic sandals and electro-magnetic shoes, "Project Hotfoot", are being completed for weightless walking (Simons, Nicholson).	4	2	
Semi-Supine Seat - Free-floating subjects will enter and exit seat during weightlessness (Caton).	2	2	

Experiment	No. Flts.	No. Subjects	Runs/Flt.
Propulsion Units - Velocities obtained by known thrusts will be studied with four sequenced cameras (Hertzberg). Self-control capabilities will be studied (Gardner).	7	2	
Project "Skyhook" - Rotational velocities will be measured (Simons, Hall).	4	1	
Non-Torque Tools - A special lock washer and non-torque wrench will be applied by a free-floater (Spencer).	1	1	
Psychomotor Panel - Duration measures of switching motions on six controls will be studied. Pitch, G's, and control actuation will be recorded (Wade). (Fig. 31-b)	6	12	30
Vestibular Canal - Subjects will record rotation sensations as pitch, roll, and G's are recorded (Dzendolet).	4	12	16
Animal Performance - Four pigeons will be released in various positions during weightlessness on two flights. Animal feeder and watering units will be tested (Sears, Grunzke).	2	1	
Mass Discrimination - Vertical and horizontal mass positioning of weights will be completed (Rees).	6	12	
Visual Acuity - Ortho-Reter trials on harnessed subjects will be run (Pigg, Kama).	4	12	
Pressure Suit - Astronauts will free-float with integrated oxygen supply units (Vail).	3	8	

Experiment	No. Flts.	No. Subjects	Runs/Flt.
Self-Locomotion - Subjects will generate four arm and leg movements in front of grid and free-floating mass (Frost).	4	2	
Flash Blindness Goggle and Gradient Density Lenses will be subjectively evaluated (Alder).	3	1	
Retinal Deformation - Eikonometer tests will be administered during weightlessness (Alder).	3	3	
Blood Pooling - Cardiac outputs, pitch, and acceleration will be recorded during five tilt conditions (Olson, Zinn).	3	3	
Skin Resistance - GSR measures will be taken on harnessed and unharnessed subjects during weightlessness (Johnson).	4	8	
Fatigue Flight - A subject will fly a seven-hour cross-country mission in the copilot's seat with intermittent GSR recordings made (Ruff).	1	1	

Many of the above experiments will be flown concurrently. The Propulsion Laboratory (Fluid Behavior During Weightlessness) will use approximately 40% of the flight time and their short negative-zero G maneuver is not compatible with the tests. WADC ISO will fly news media personnel on several occasions.

10. Literature:

Zero-G Experiments: Major E. L. Brown
In-Flight Study of Magnetic Shoes: Captain J. C. Simons
In-Flight Study of Stabilization Unit: Captain J. C. Simons
Man's Ability to Apply Certain Torques While Weightless: E. Dzendolet and J. F. Rievley

A picture of three floating astronauts during a familiarization flight in the C-131B is shown in Figure 31a.

Figure 31a. Three of the NASA Astronauts free-floating in a C-131B during indoctrination and conditioning to the peculiar effects of weightlessness.

Supplement 1.

Walking Under Zero-Gravity Conditions

The first complete experiment with magnetic shoes, which enable man to walk with an approximately normal gait under weightless conditions, was conducted by J. C. Simons (1959). A pair of magnetic sandals was made by attaching 12 Alnico magnets to aluminum soles. Although the plates were rigid, rubber shims allowed a $\pm 3^{\circ}$ ankle rotation transverse to the walking surface.

Figure 31b. Psychomotor Performance Test
During Zero-G in the C-131B.

Each sandal required a break-away force of 21-22 lbs. at right angles to the contact surface. A plantar flexion of 8-10^{o} was sufficient to induce an air gap between the magnets in the sandal and the floor to eliminate the magnetic force.

A soft iron plate, 18"x1/8"x13' was bolted to the ceiling of the rear part of the C-131B aircraft cabin. The plate served as a way for upside-down walking during the zero-G parabola (see Fig. S-1). This arrangement was chosen because of the need for reorientation of the subject.

Results: The subjects had difficulty in walking with a normal gait. They walked flat-footed and stepped lightly, as though walking on eggs. This was probably due to the broad contact area of the sandals (4.5 inches square on the heel and 7.5 inches square on the ball of the foot.)

No acute disorientation problems were found when subject entered the weightless condition from a supine position. Instead, all four subjects reported an immediate reorientation of "down" being where their feet were, as soon as their body rotation stopped.

A basic index was formulated to define magnetic requirements in terms of the inductive forces required to hold a subject stationary. Moreover, a vector analysis of the 1 G walking gait was made, which is also applicable to man's locomotion under zero-G conditions.

Reference: Simons, J. C.: Walking Under Zero-Gravity Conditions. WADC TN 59-327, Wright Air Development Center, Air Research and Development Command, Wright-Patterson Air Force Base, Ohio, October 1959.

(Official USAF Photo)

Figure S-1. Walking with Magnetic Shoes Under Zero-G Conditions

Lockheed T-33A

1. One Lockheed T-33A each was assigned to the former School of Aviation Medicine, Randolph Air Force Base, Texas, and to the Aeromedical Field Laboratory, Holloman Air Force Base, New Mexico, in 1955. They were powered by a J-33A-35 jet engine developing 4,600 lbs. thrust. The aircraft is a tandem two-seater plane as shown in Figure 32. The pilot was seated in the front seat and the subject in the rear seat of the cockpit. A film camera (16 mm) was installed in the rear compartment for recording the subject's reaction to weightlessness and for related studies. Two pilots flew alternately, and a crew of four maintained the aircraft.

(Official USAF Photo)

Figure 32. Lockheed T-33A

2. The aircraft was not specifically equipped for use as a zero-G facility. In all the experiments flown, the test subject was accommodated in the back seat. In addition, small equipment for experiments and animals were carried along.

3. Subgravity and zero-G states were produced by flying aerodynamic parabolas as described before. A schematic picture of the T-33 zero-G flight pattern is shown in Figure 33.

Figure 33. T-33 Zero-G SAM Flight Parabola: The maneuver starts at an altitude of about 18,000 feet, reaches almost 21,000 feet at the top of the parabola, and yields about 28 seconds of virtual weightlessness.

Since the performance of this aircraft was rather limited, relatively high accelerations before and after the push-over maneuver had to be tolerated. In order to obtain subgravity states of about 25 - 30 seconds, a sharp dive was started at 20,000 feet with engine r.p.m. at 96%. As the IAS reached 350 knots, the aircraft was pulled up at about 17,500 feet at an angle of climb of 55°, producing a force of 3 G-units acting on the body. As the IAS dropped to 300 knots at full throttle, forward stick pressure was applied and a push-over initiated. At this point of transaction, a slight and momentary yawing often occurred, but was easily controlled by aileron motion. Slight changes in forward pressure of the stick were necessary to maintain the aircraft on the parabolic arc.

Minimum controllability speed was about 180 knots at a peak altitude of about 21,000 feet. As the apogee was reached, forward stick pressure was continued until the plane dived at 350 knots. When the angle of dive was about 55° again and the aircraft back at 17,500 feet, a pull-out was started early enough to prevent the aircraft from passing its safety limit and avoiding excessive accelerations during recovery. Usually at this point the maneuver was repeated using the pull-out acceleration for propelling the aircraft into the next parabola.

4. The theoretical basis and equations representing the physical conditions for the subject seated in the back seat of the aircraft has been given before. Since no special zero-G instrumentation was available at that time, the accuracy of keeping the aircraft on an ideal Keplerian trajectory was dependent upon the skill and experience of the pilot. Since the latter was in control of starting and concluding the maneuver, he acted as experimenter insofar as timing and communicating with the subject was concerned.

5. The control system of the aircraft was purely manual, and the maneuver (including the amount of G forces acting on pilot and subject) was initiated and monitored by the pilot. An automatic device for producing and controlling the zero-G state had been proposed, but was not available for the T-33 zero-G studies. Thus, and because of safety features described below, only short periods (3 - 5 seconds) of zero-G were produced, and the remaining condition of subgravity was generally designated as "virtual weightlessness." In addition, yaw and roll movements of the aircraft produced undesirable accelerations in all three axes because of the sensitive aileron boost at low air speed, and the rolling motions exaggerated by tip fuel.

6. The standard accelerometer installed in all U. S. fighter type aircraft was employed as main reference. Further, the subgravity state was indicated by the floating of some small objects, and by the feel of lost support by pilot and subject. The scientific information was mostly recorded on tape and film and later evaluated on the ground. Experiments at that time mainly concerned the tolerance of human subjects to changing accelerations including weightlessness; studies of eye-hand coordination; the reflexes of cats and humans; and demonstration of the capability to react, eat and drink, and to demonstrate the weightless state pictorially.

7. Because of safety limitations, all experiments were performed while the subject was seated and held by the safety belt. Moreover, parachutes, O_2-mask, and helmet had to be worn because the flights were not without incident. During the subgravity state at altitude, fuel in the main tank had a tendency to evaporate, resulting in an overflow from the tank out through the vent drain line. This vaporization and lack of contact of the fuel prevented the pump from supplying enough fuel to the engine to maintain the required r. p. m. The few power reductions which occurred during zero-G maneuvers were corrected immediately by reducing throttle and producing accelerative forces. Complete loss of oil pressure also took place but was of little concern because the engine was

built to run for longer periods with no lubrication. The aircraft's hydraulic system was unaffected.

8. The cost for one flight, in which normally 8 - 10 parabolos were executed, was estimated in between $1,000 and $1,500. Although the T-33 is not an ideal aircraft for producing weightlessness, it proved to be an economical and practical tool. It is still used at many USAF installations for training and other purposes.

9. No information available.

10. References on zero-G experimentation with the T-33 are included in the general bibliography at the end of this report.

Lockheed F-94C, Zero-G Facility

1. The Lockheed F-94C "Starfire" is a two-seater interceptor powered by a Pratt & Whitney J-48-P-7 jet engine, developing with after-burner a maximum of 8,750 lbs. of thrust (Figure 34). For the sake of safety and lack of turbulence, the working altitude in between 20,000 and 25,000 ft. was found to be most satisfying. From this altitude a dive was entered, engine r.p.m. at 100%, and as the IAS reached 425 knots a climb of 65° to 70°

(Official USAF Photo)

Figure 34. Lockheed F-94C

from the horizontal was executed. With airspeed dropping off, forward stick pressure produced a stable and lengthy parabola yielding almost 40 sec. of subgravity and zero-G.

2. Since the F-94C has a fully pressurized fuel system, the power remained constant during the parabola. Stable in flight because of the 6° dihedral wing shape, the variable elevator boost made minor control changes easy and instantaneous, allowing small corrections to be made without varying the G-conditions appreciably. The high Mach rating eliminated the necessity of too early a dive recovery (Figure 35).

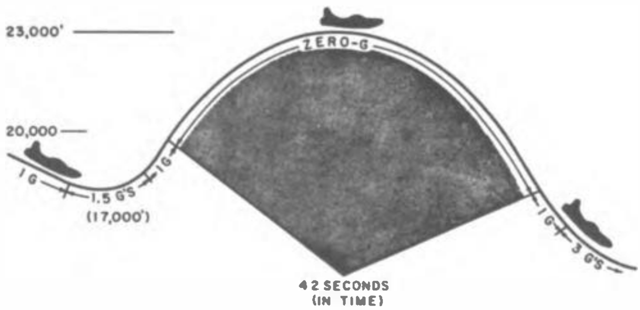
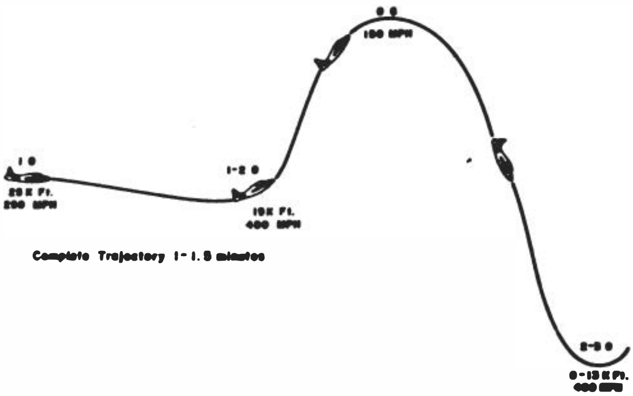


Figure 35. F-94C Zero-G "SAM" Flight Parabola: The maneuver is started at an altitude of about 18,000 feet, reaches about 23,000 feet at the top of the parabola, and yields about 40 seconds of virtual weightlessness.

3. With after-burner, the longest time recorded was 43 sec. of subgravity (1956). In this maneuver at 20,000 ft. with elevator boost ratio at 11:1, engine r.p.m. was increased to 100% and the after-burner actuated. IAS was increased to 430 knots, and the aircraft eased up into a climb of 75° from the horizontal. The after-burner was used until this angle was reached to obtain an IAS of somewhat over 400 knots. At that time the after-burner was cut off and the parabola begun. The aircraft was pulled out at 12,000 ft. at an IAS of somewhat in excess of 450 knots producing a force of about 4 1/2 G for several seconds (Figure 36).

4. The theoretical basis and the equations representing the physical conditions of the subject were given before. In preparing the instrumentation, a sensitive visual indicator of the G-forces

involved was designed by Schock and Simons (1957) consisting of two microammeters, with a range of 25-0-25 micro-amperes, connected to a set of sensitive Statham accelerometers with a range of ±0.5 G. One accelerometer was mounted to measure the forces acting in the vertical axis (z), and the other in the longitudinal (x) axis of the aircraft. Each division on the microammeters was equivalent to ±0.014 G. If the needles of both devices were on the zero mark, the pilot knew that he was exactly on the parabola (Figure 37).



(Official USAF Photo)

Figure 36. The F-94C Zero-G "Holloman" Flight Parabola: The maneuver is started at an altitude of about 20,000 feet, reaches about 25,000 feet at the top of the parabola, and yields about 45 seconds of virtual weightlessness.

5. Another set of sensitive accelerometers was fixed to the subject with a chest band to provide the recording to forces acting directly on the individual (Figure 38). Two Statham accelerometers were attached to a leather band which the subject wore around his chest. The output of these accelerometers was fed into a Century Model 409 recording oscillograph, a galvanometer type instrument sensitive enough to record the output of the accelerometers without further amplification.

6. Pilot, subject, and experimenter were in continuous voice communication. The subject carried a tape recorder (Mohawk "Midgetape"); and the pilot could tune in the ground station whenever he deemed necessary. The subject was photographed during the maneuvers using a Bell & Howell B-1A camera with

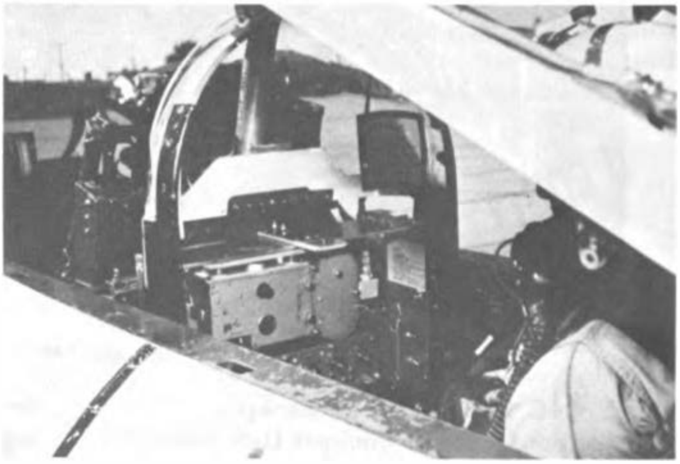
(Official USAF Photo)

Figure 37. F-94C instrumented cockpit. Visual zero-G display in front part of cockpit (left side of the picture) and base for mounting film camera in rear part of cockpit (right edge of picture).

(Official USAF Photo)

Figure 38. F-94C instrumentation. Preparation of test subject for flight experiment. On his left leg pocket is the Midgetape recorder; on chest belt is accelerometer for recording G-forces.

a wide-angle lens (Wollensack, F:1.5, 89 degrees). The camera was mounted on top of the instrument panel in the back seat of the cockpit (Figure 39).



(Official USAF Photo)

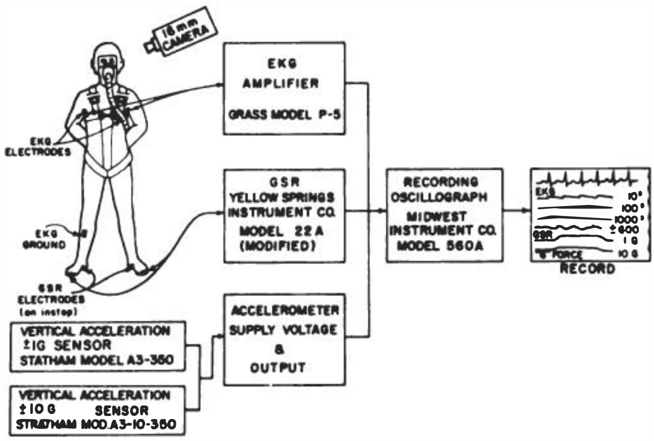
Figure 39. F-94C zero-G instrumentation. Base of film camera, which was turnable and should be moved about 90° to the left, so that the subject would not be injured during ejection. The GSR - Dermo-Ohm-meter is installed below the camera base.

For EKG and GSR recording an instrument rack was constructed in the rear part of the cockpit, which contained an EKG amplifier (Grass, P-5), a "Dermohmeter" (Yellowspring-Fels, 22-A, airborne), the oscillograph mentioned above, and battery power supplies. Two EKG electrodes were placed on the chest; the other on the right ankle. The GSR electrodes were applied to the sole of each foot. All five electrode leads were combined to form one cable. A plug was provided for a quick release between the subject and the amplifier, to avoid hazard or delay in case of emergency ejection (Figure 40).

7. Safety requirements identical to those applicable to experimental flights in fighter type aircraft.

8. No cost figures available at this time.

9. No information available from the School of Aviation Medicine, USAF, Randolph Air Force Base, Texas, nor from the Aero Medical Field Laboratory, Holloman Air Force Base, New Mexico, where F-94C aircraft were employed in zero-G research.



(After H. von Beckh, 1958)

Figure 40. Instrumentation for Zero-G Research in Fighter Aircraft F-94C.

10. References are included in the general bibliography at the end of this report.

KC-135

1. A KC-135 tanker plane has already been modified for use as a "Zero-G Flying Laboratory." Modification concerned (1) the three Sundstrant electrical oil drives to provide electrical power for the aircraft and test instrumentation under zero-G, (2) the hydraulic system and speed brakes to be used during the parabolic maneuver, (3) the engine oil system, (4) the fuel system to provide enough pressure to the pumps under conditions of weightlessness, and (5) provision for installation of test equipment and scientific instrumentation. The contractor is Boeing Airplane Company.

2. The characteristics of flight parabolas and of aircraft suitable for this purpose are similar to those of the C-131B; however, the large dimensions of the KC-135 will allow much more testing space (particularly with respect to unrestrained and free-floating subjects) and heavier test equipment of greater volume. A photograph of the airplane is shown in Figure 41. The gross weight will have to be limited to about 130,000 pounds in order to keep within the safety requirements during the parabolas.

(Official USAF Photo)

Figure 41. KC-135.

3. The performance date for the KC-135 aircraft has been calculated as follows:

Weightlessness and subgravity time during one parabola	30 - 35 seconds
Number of parabolas during one flight	20
Accumulated time of subgravity and weightlessness during one flight	10 - 12 minutes
Maximum acceleration during pull-out before and after the parabola	3 - 3.5 g
Maximum angle of climb at start of parabola	50 degrees
Working altitude	25,000 - 35,000 feet
Velocity at entry into parabola	.8 Mach

Calculations show that the CG will not shift enough throughout the parabola to affect the pilot's control over the vehicle. However, it is anticipated that buffeting will occur at 25,000 feet, at the normal gross weight of 150,000 pounds, when the limiting Mach number is approached at a 2.4 g pullout. Thus, less gross weight will have to be used as indicated above.

4. The equations and mathematical presentation of the physical conditions were given above. Because of the larger weight and space available, practically any type of instrumentation for experiments with one or several subjects can be used.

5. The control system and instrumentation will be similar or advanced of that described under "C-131B, Zero-G Facility."

6. Instrumentation and data reduction similar to that applicable for zero-G parabolas.

7. Safety requirements are same as that applicable for zero-G parabolas in aircraft. Special safety measures necessary in case of experimentation with rocket propellants and liquid H_2 as required for the CENTAUR start tests.

8. No cost figures available at present. Since the first modified KC-135 will be stationed at Wright-Patterson Air Force Base, WADC personnel will monitor the test program. Requests for participation in this program should be directed to Commander, Wright Air Development Center, Dayton, Ohio, ATTN: Mr. H. R. Shows, WADC-WCLOR.

9. The research program for the KC-135 is actually the expanded C-131B research program. Information on the research subjects are listed below.

a. Aerospace Medical Laboratory, WADC. Human muscle and body control, mass discrimination, microswitch actuation, non-torque tools, self-locomotion, human stress, eye protective equipment, supine seats, visual perception, human engineering for space, human performance in pressure suits, fluid action, heat exchangers, boiler condenser unit, airsickness and nausea, bonded magnetic materials, pigeon orientation, vestibular canal, magnetic suspension devices, visual activity, evaluation of oil expulsion, gyro-stabilized man, human propulsion unit, and animal performance for behavior.

b. School of Aviation Medicine, USAF. Cardiovascular functions, blood circulation, pulmonary functions, and fluoroscopy and x-rays of the body and selected organs.

c. Jet Propulsion Laboratory. Venting and phase separation of cryogenics, heat transfer of cryogenics, ion propulsion, capillary action tests, centrifugal orientation, mercury condenser, liquid N_2 and O_2 converters, space vehicle reaction control systems, propulsion systems for human locomotion, energy conversion units, fluid motion effects, and CENTAUR restart tests.

d. Aeronautical Accessories Laboratory and AEC. Determination of heat transfer coefficients, and behavior of liquids and gases in pumps and turbines; experiments concerning nuclear power conversion loop using the Rankine cycle---fluids may be sodium, potassium, mercury, sulphur, and rabidium; experiments on the effect of weightlessness in conjunction with SNAP I and II programs.

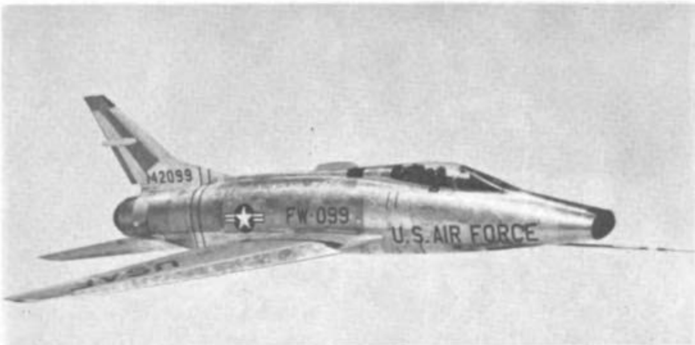
e. Convair Astronautics. Experiments concerning the evaluation of CENTAUR's restart capability under weightless conditions. It is planned to install a 30-foot test vehicle containing a test cell 31 inches long by 12 inches wide. The cell will be suspended at three degrees of freedom so that pitching and yawing of the airplane will not affect it during weightlessness.

10. "Trip Report" by James W. Carter, Chief, Crew Engineering Unit, Missile System Analysis Section, Future Projects Design Branch, Structures and Mechanics Laboratory, Development Operations Division, Army Ballistic Missile Agency, Redstone Arsenal, Alabama, dated 3 November 1959.

TF-100F Aircraft

1. The School of Aviation Medicine, USAF, has two 1956 TF-100F aircraft that have been completely instrumented to conduct weightless studies. These aircraft are maintained at SAM Flight Operations, Kelly AFB, Texas (Figure 42). The total staff and personnel assigned and engaged in our zero-G studies is fifteen.

2. The TF-100F aircraft has undergone extensive testing of various system components; but no modifications of the basic structure have been necessary. The enclosed photographs show the instrumentation that has been accomplished to record physiological response and performance data during flight. The size of the rear cockpit of the TF-100F aircraft limits the size of test objects to relatively small items that can be easily controlled by the subject and not jeopardize flying safety.



(Official USAF Photo)

Figure 42. Lockheed F-100

3. Sustained periods of zero-G up to 60 seconds can be produced by flying the TF-100F aircraft through the parabolic flight maneuvers. The parabola is entered at a true air speed of about 655 knots following an initial dive and pull-out at 2.5 - 3.0 g. The minimum velocity at the apex of the parabola will be about 100 to 150 knots IAS (indicated air speed). The altitude covered from apex of the parabola to the final pull-out is about 40,000 to 20,000 feet.

4. As given before.

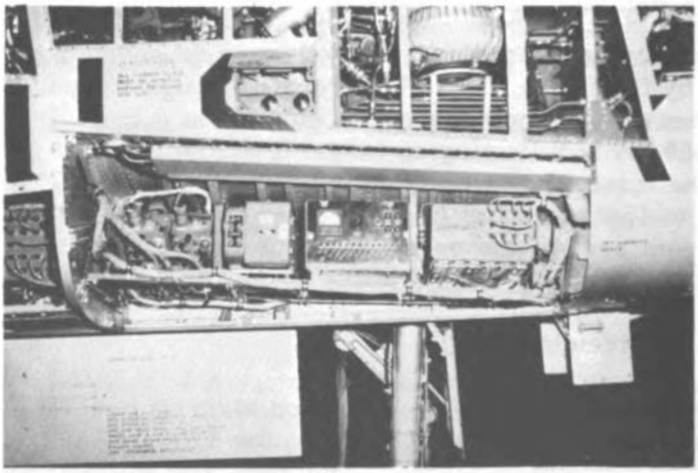
5. Control systems are standard aircraft control. Subject is not usually in the control loop since the TF-100F is not used primarily as a reaction control simulator, but subject can be in control loop if desired.

6. The instrumentation seen in Figures 43, 44, and 45 will allow 14 different parameters of information to be recorded continuously and simultaneously. This can be recorded on the onboard oscillograph at the present time. The capability of telemetering this information or recording it on magnetic tape is expected soon.

7. Normal safety regulations are followed. All connections to the subject are of the quick disconnect type.

(Official USAF Photo)

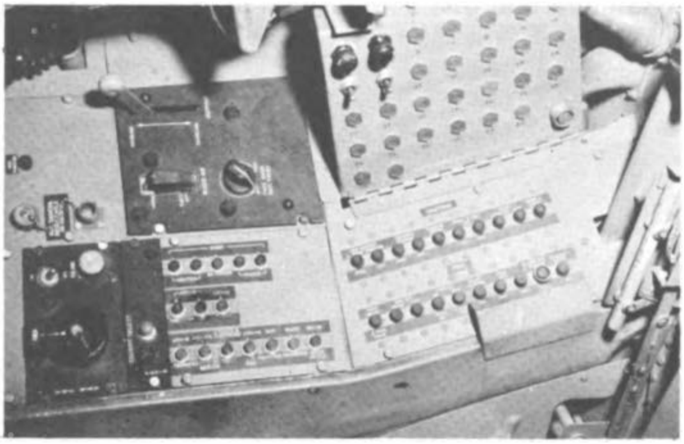
Figure 43. F-100F Instrument Panel for Zero-G Tests



(Official USAF Photo)

Figure 44. TF-100F: Zero-G Test Instrumentation

8. Requests for use of these zero-G research planes should be made through official channels to the Commandant, School of Aviation Medicine, Brooks Air Force Base, San Antonio, Texas.



(Official USAF Photo)

Figure 45. TF-100F: Connector Plugs for Zero-G Experimentation

9. The year 1958 was spent in instrumenting and testing of the two TF-100F airframes and engines. The final testing was completed in July 1959. The data recording systems have undergone extensive development and modification since that time, and the coming years will see continuous use of these aircraft in carrying out the zero-G research program of the School of Aviation Medicine, USAF, Brooks Air Force Base, San Antonio, Texas.

10. References are included in the general bibliography at the end of this report.

F-104A "Starfighter"

1. The Lockheed F-104A "Starfighter" is available in two versions: the fighter type aircraft for operational use (F-104A), and the two-seater version which has been designed for training purposes, and which can also be used for zero-G experimental flights (F-104B). It is available at several USAF fighter commands and also at the Test Flight Center, ARDC, Edwards Air Force Base, California. A picture of the F-104A is given in Figure 46.

2. Since the F-104A is one of the foremost operational aircraft, most of the performance data are classified. Specific data on speed, peak altitude, angle of climb, range, etc. can be found in the appropriate technical manual. From the data available,

it can be concluded that one subject can be carried along in the two-seater version, with the pilot acting as experimenter, similar to the case described before.

(Official USAF Photo)

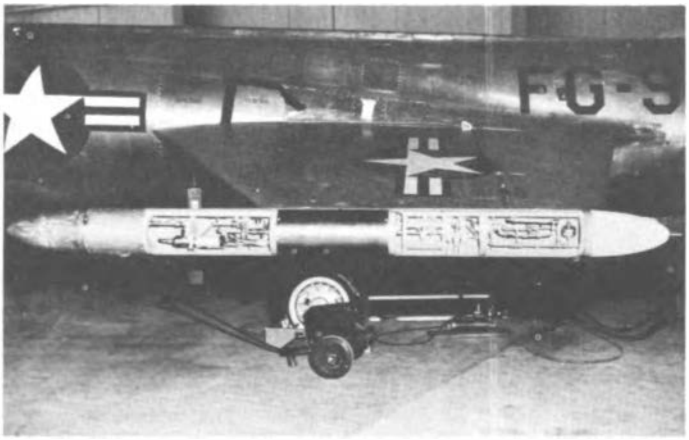
Figure 46. Lockheed F-104A Starfighter

3. In this context, a special purpose version of the F-104 is described. An H_2O_2 jet reaction control system has been installed in an F-104 aircraft to investigate roll, pitch, and yaw control parameters during high altitude flights at low aerodynamic pressure. The controls are actuated by a 3-axes, side-located controller which operates electric servo-valves. A photograph showing details at the wing-tip reaction control installation is included (Figure 47).

4. The theoretical basis and equations representing the use of the 104A as a zero-G facility can be deducted from the mathematical treatment of flight parabolas given in the introductory section of the report. The characteristics for obtaining maximum periods of weightlessness are given in Table V.

5. The rockets provide angular accelerations of $10^{\circ}/\text{sec}^2$ in roll, and $5^{\circ}/\text{sec}^2$ in pitch and yaw. The present system is open loop, but it is planned to incorporate a closed loop system (velocity command and attitude command) at a later date.

6. Instrumentation and channels for technical data and information on weightlessness will be available. No details are available as yet.



(Official USAF Photo)

Figure 47. F-104 Reaction Control Instrumentation

TABLE V

Characteristics of Flight Trajectory of Various Types of Aircraft to Produce States of Weightlessness of Maximum Duration*

Aircraft	(Knots)	$h_{max} - h_{min}$ (Feet)	ϵ (Deg)	T (Sec)
C-131B	250	2,000	35	15
T-33A	350	5,000	55	30
F-94C	425	8,000	65	40
KC-135	500	10,000	50	35
F-100F	685	20,000	75	60
F-104A	800	30,000	75 1/2	80
X-15	4,500	500,000	---	300

*The figures given in this table are approximations only.

7. Proposals to use the F-104B for the zero-G maneuver were not favorably received, however, because of anticipated lubrication problems of the engine similar to those observed in the F-100. They require lengthy and costly engine modification. The high altitude which will be reached in flying trajectories of a long zero-G duration will require pilot and subject to wear high altitude pressure suits.

8. Approximate cost of engine modification is $100,000 per aircraft. The cost of one flight is unknown.

9. Several zero-G flight experiments were made; the maximum duration of zero-G exposure was about 50 seconds. Installation of the reaction control system was completed in 1959 and flight tests were completed which yielded information on jet reaction control during normal gravity and in subgravity.

10. No information available.

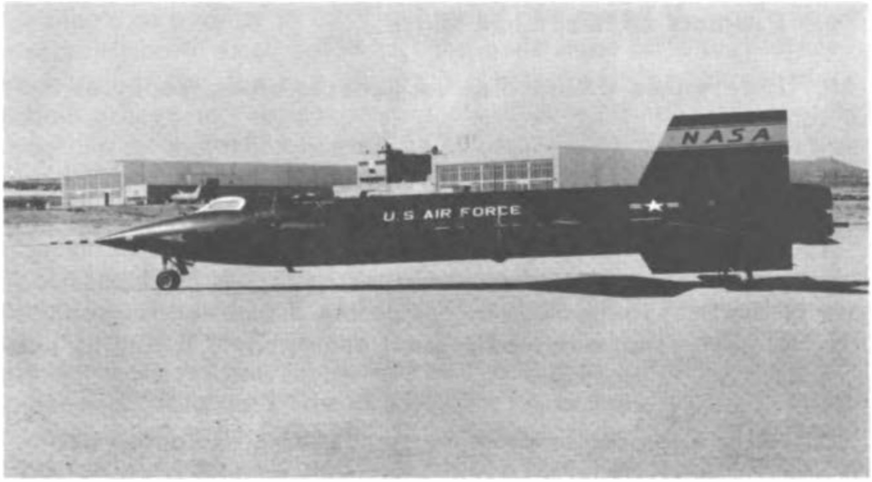
The X-15 Research Aircraft

1. The X-15 Experimental Research Aircraft will be available for experiments at the NASA Flight Research Center, Edwards, California, in 1962. Flights for the express purpose of obtaining zero-G data are not anticipated in the near future, although certain flight profiles will impose some period of zero-G on the pilot.

2. Flight duration of 200 seconds at low dynamic pressure will be obtained. Moreover, these flights will provide appreciable test duration at zero-G, with the maximum duration depending upon the maximum altitude capability. (See Figure 48.) It appears that test durations of 300 sec. at zero-G may be feasible. However, since the airplane is still in the early flight test stage, the maximum zero-G capability will not be attained for some time.

3. The instrumentation for the X-15 flights will include the recording of accelerations in three axes, so that the duration of zero-G will be obtainable. Furthermore, it is anticipated that, incidental to these flights, some physiological data, EKG, body temperature, respiration, as well as subjective observations of the pilot, will be available.

4. An X-15 pilot training program was conducted on the centrifuge at the Naval Air Development Center, Johnsville, Pennsylvania, in 1960. This program covered the X-15 flight profile, particularly the occurrence of high accelerations.



(Official USAF Photo)

Figure 48. X-15 During Powered Flight

5. The X-15 will carry over 1300 lbs. of instruments. The full-pressure suits to be worn were specifically designed with 24 electrical contact points for connections between the physiological sensors and the telemetry transmitters.

6. The physiological package to implement the measurements indicated above has been developed by North American Aviation for both the on-board recording and telemetering of physiological data. This system has a growth potential for recording additional variables, particularly those associated with and typical for zero-G effects. Evaluation of the North American Aviation physiological data package began at the Air Force Flight Test Center in March of 1959.

7. Safety features include the MC-2 full-pressure suit and the open ejection seat, incorporating fins and twin booms for roll and yaw stability. A 24-foot, back-type parachute is mounted in a special container on the ejection seat. Upon actuation of the ejection handles, the canopy deploys ballistically, initiating the proper sequence of events. Man-seat separation and parachute deployment are dependent upon present altitude and dynamic pressure sensors. The escape system will operate in the region of 600 knots IAS, or a dynamic pressure of 1500 lb/ft^2.

8. No information available.

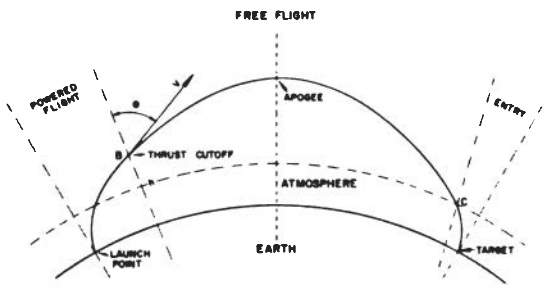
9. Projects as described above.

10. References included in the general bibliography at the end of this report.

C. Ballistic Missiles

As the jet aircraft is the best available means of studying the effects of subgravity and zero-G upon men, so the ballistic missile is the best means for investigating the effects of subgravity and zero-G on other biological specimens, including animals, today.

Ballistic missiles are generally accelerated during the initial part of their trajectory only; namely, from the start (or liftoff) to burnout (or cutoff). They are started vertically, because this simplifies the launching operations and shortens the time necessary to penetrate the atmosphere. After this initial vertical climb the vehicle undergoes a programmed turn toward the target. During this turn the guidance system begins to function and continues to do so until the desired altitude h, speed V, and angle θ are attained (at B, Figure 49), whereupon it gives the



(Air Univ. Qtrly. Rev., Vol. 9, Summer 1957)

Figure 49. Trajectory of an ICBM

signal for cutoff of the propulsive power. Perception and correction of vehicle attitude, exercised by the control system, are continuous during the powered flight. Both the attitude of the vehicle and the motion of its center of gravity relative to the required trajectory are adjusted by altering the direction of the thrust of the rocket engines, for instance, by putting jet vanes in the exhaust stream or by gimbaling the rocket thrust chambers.

There are many sets of values of the speed V, angle θ, and spatial position of B that will put the nose cone on a trajectory terminating at the desired target; but some sets are more favorable than others in respect to amount of propellant consumed by the engines or required precision of aim. It is the function of powered flight to impart to the nose cone, as accurately as possible, a favorable set of these parameters.

The energy expended in propelling the vehicle during the powered flight increases with the weight of the vehicle. Because both the kinetic and the potential energies are approximately proportional to the weight of the vehicle at thrust cutoff, it is desirable that this weight be as little as possible in excess of the weight of the nose cone. This objective is aided very materially by dividing the vehicle into two or more parts, or stages, with each stage containing a rocket propulsion system. Launching is accomplished by starting the engines of the first stage and, in some designs, also of other stages. At some time during the powered flight the first-stage engines are shut down, and this stage is jettisoned from the remainder of the vehicle. The engines of the next stage are then started, if they are not already operating, and they propel the vehicle on toward B. As the missile nears B, the engines on the last stage are shut down, and the final adjustment of the velocity needed to keep the nose cone on a trajectory that will reach the target is accomplished with rocket engines of comparatively small thrust, called vernier engines. Thus the term thrust-cutoff point B refers, accurately speaking, to the point where the vernier engines are shut down rather than to the shut-down point of the engines of the final stage.

The trajectory beyond the thrust-cutoff point B may be divided into two segments: the free-flight portion, from B to the point C of re-entry into the atmosphere; the re-entry portion, from C to the impact point T (see Figure 49). For a long-range missile the free-flight portion BC is above the sensible atmosphere; hence the missile during this phase is a freely falling body, the only force action on it being gravitational attraction. During re-entry of a freely falling body, the aerodynamic forces also come into play, and these slow the missile and cause it to become heated.

The length and shape of the free-flight trajectory are determined by the speed V of the missile at thrust cutoff, the angle θ between the local vertical at B and the direction of V, the altitude h of B, and the values of the acceleration due to gravity g along the trajectory.

Considering a given point B and a given target T, one finds that for every thrust-cutoff speed V between the lowest and the highest values needed to reach the target, there are two values of the angle θ that yield trajectories connecting B and T. One of these trajectories is steep, of high apogee; the other is flat, of low apogee. As one decreases the thrust-cutoff speed V, these two possible trajectories approach each other, the steeper trajectory becoming flatter, and the flatter trajectory more arched. In the limit, when V attains the minimum value for which the missile will reach the target, the two trajectories merge into a single one of medium height (Figure 50). Because this medium trajectory requires the smallest speed V, and therefore minimum kinetic energy at thrust cutoff, it is optimum with respect to propellant requirements. It is also more favorable in other respects. For the steeper trajectory the re-entry speed is higher, thus presenting a more formidable heating problem. For the flatter trajectory the re-entry path through the atmosphere is longer. Both very steep and very flat trajectories require a more precise guidance system.

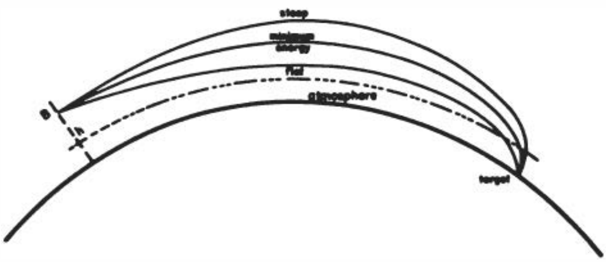
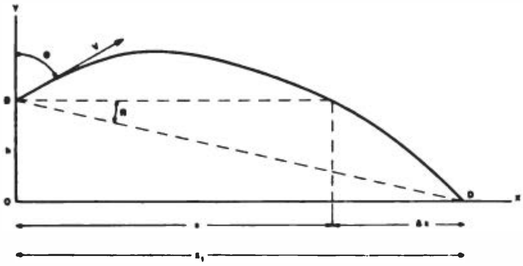


Figure 50. Schematic Representation of Missile Trajectories with Different Launching Angles

A simple picture of a free-flight trajectory may be obtained by considering first the case where the range and time of flight are so small that the missile can be assumed to be traveling over a flat and motionless earth, above which the acceleration due to gravity g is at every point the same in magnitude and always directed normal to the flat surface (Figure 51). For this situation, the horizontal range from thrust cutoff to impact can be obtained as follows:

$$y = \frac{g}{2}\, t^2 - vt \cos \theta \qquad (43)$$

$$x = vt \sin \theta. \qquad (44)$$



(Air Univ. Qtrly. Rev., Vol 9, Summer 1957)

Figure 51. Effects of the Earth Spin and Curvature on Missile Trajectory

At impact time

$$y_i = h = \frac{g}{2} t_i^2 - vt; \cos\theta \quad , \tag{45}$$

$$x_i = vt_i \sin\theta \quad , \tag{46}$$

$$\frac{y_i}{ti} = \frac{h}{t_i} = \frac{g}{2}^{t_i} - v\cos\theta \quad , \tag{47}$$

$$\frac{g}{2} t_i = \frac{h}{t_i} + v\cos\theta \quad , \tag{48}$$

$$t_i = \frac{x_i}{v\sin\theta} = \frac{2h}{g} \; \frac{v\sin\theta}{x_i} + \frac{2}{g} \; v\cos\theta \quad , \tag{49}$$

$$x_i = \frac{2v^2 \sin^2\theta \, h}{g \, x_i} + \frac{2v^2}{g} \sin\theta\cos\theta. \tag{50}$$

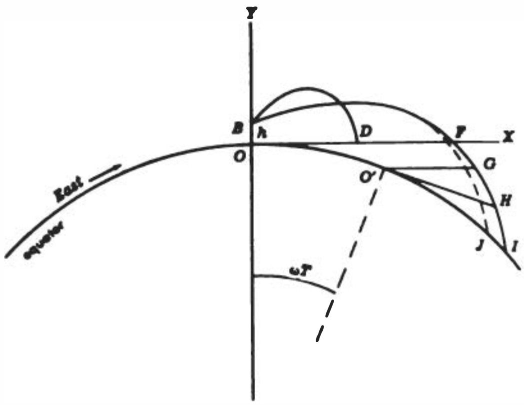
Since

$$h = x_i \tan\beta, \tag{51}$$

we obtain

$$x_i = x + \Delta x = \frac{2v^2}{g} \sin\theta \; (\cos\theta + \sin\theta\tan\beta), \tag{52}$$

where Δx is the additional range gained because thrust cutoff occurs at B instead of on the ground at O, and where β is the angle between the horizontal and the straight line drawn from B to the point of impact. As the range is increased, the effects of the earth's curvature and rotation become more and more important. Figure 50 shows the situation on an imaginary point in space. If the earth would be at rest, a missile leaving the thrust-cutoff point B would follow the same path as in Figure 51, except that OX is now to be regarded as the tangent to the equator at O. Let us see how this path is changed because the earth actually is rotating and its surface is not flat. In Figure 52 the coordinate system XOY is to be thought of as fixed in space, as not participating in the earth's motions. This means that the origin O does not move and that the missile leaves B at the moment when B is vertically above O.



(Air Univ. Qtrly. Rev., Vol. 9, Summer 1957)

Figure 52. Increase in Range Due to Earth Curvature and Rotation

The trajectory is extended from D to F because the horizontal component of the missile's velocity at B is increased from the locally imparted value $V \sin \theta$ to $V \sin \theta + \omega R$, where ω is the earth's angular speed of rotation and R is the earth's radius. The circumferential speed ωR, which the missile has before it is launched and retains during flight, is about 1600/ft sec eastward; this is a sizable correction even for missiles for which $V \sin \theta$ might be as much as 20,000 ft/sec. Note that for westbound missiles, this effect of the earth's rotation would reduce the length of the trajectory. For motion along any parallel of latitude β other than the equator, the correction would, of course, have the smaller value $\omega R \cos \beta$ eastward.

While the missile is traveling from B to F, the point on the earth's surface directly beneath B has advanced from O to O'. This extends the trajectory to the point G because the impact area has been displaced downward, from OF to O'G, during the missile flight. Such an extension would also occur for a westbound missile.

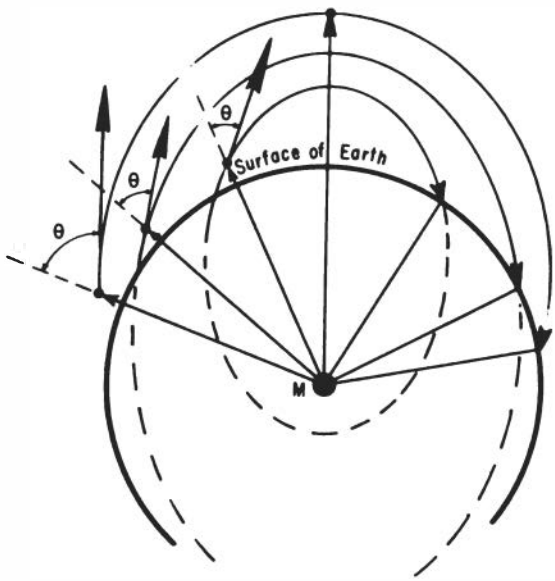
At O' the apparent horizon is the line O'H, which cuts the trajectory at H, and thus the trajectory is extended to H. Notice that this particular extension results from a downward rotation or tilting of the apparent impact area with respect to OX during flight. For a westbound missile the rotation of the impact area, as observed from O', would be upward, resulting in a reduction of trajectory length.

The trajectory is still farther extended, from H to 1, because of the curvature of the earth, which gives the missile additional time to acquire range. This extension is positive, no matter in what direction the missile is traveling, and would occur even if the earth were not rotating. The longer the range, the greater will be this extension, because the separation of the spherical surface from the plane OX occurs at an increasing rate as the distance from O increases.

The missile would reach point 1 only if the gravitational force on it were at every point parallel to the Y-axis. Actually this force is directed toward the center of the earth at every instant of the flight. Consequently a backward component of gravitational force sets in as soon as the missile leaves the thrust-cutoff point B, and its magnitude increases steadily with the time since the missile left B. The net effect is to shorten the trajectory, so that impact occurs at some point J, rather than at 1. Actually the backward component of the gravitational force is associated with two different factors. One is the displacement of the missile from the fixed point O as a result of its locally imparted velocity V. This part of the backward component increases with the duration of flight, decreases as the distance of the missile from the center of the earth increases, and would exist even if the earth were not rotating. The other factor is the departure of the missile from O because of its velocity ωR resulting from the earth's rotation. This part of the net backward component is always westward, thus reducing eastward ranges and extending westward ranges.

Although our interest has been mainly to show in a qualitative way how the rotation and curvature of the earth affect the range, it should be said that the method used here can be generalized to cover the case of a missile projected at any latitude and in a trajectory the plane of which is directed in any desired azimuth. For any case, however, the approximations involved in deriving the mathematical expressions for the various independent correction, or perturbation, terms are least objectionable for missiles having small velocities at thrust cutoff.

In order to compute trajectories in a simplified manner, we assume that the earth is a homogenous sphere and therefore attracts a missile as if all the earth's mass M were concentrated at its center (Figure 53). We have then a two-particle problem,



(Air Univ. Qtrly. Rev., Vol. 9, Summer 1957)

Figure 53. Variation of Trajectory Due to Changes in Velocity

that of a missile of relatively small mass m in free flight under the gravitational attraction of another particle, the earth, of exceedingly large mass M. Notice that the only role played here by the earth's surface is to provide launching and impact areas for the missile.

The trajectories to be used in coordinating the preliminary designs of the major subsystems of any particular type of missile are called reference trajectories. For this preliminary phase the trajectories will be sufficiently accurate if computed with respect to a nonrotating spherical earth. Thus the earth in Figure 53 is to be thought of as motionless in an inertial frame of reference--a nonrotating set of coordinates in space that, for all present purposes, may be regarded as having its origin fixed with respect to the center of the sun. Newton's equations of motion then apply in their simplest form, and from them an equation for the various possible free-flight trajectories of a missile may be derived. This equation turns out to be the general equation of a conic section. As to whether any particular trajectory will be a parabola or an ellipse is found to depend on whether the ratio of the missile's kinetic energy to its potential energy at thrust cutoff is equal to unity or is less than unity. Knowing this, one can then show that the speed V of the missile at cutoff determines the type of path as follows:

An ellipse with its farther focus at the earth's center if

$$v < \sqrt{\frac{g_o M}{R + h}} \;; \tag{53}$$

where g_o is the Newtonian constant of gravitation, M and R are the mass and the radius of the earth, respectively, and h is the altitude at the cutoff points;

a circle around the earth if

$$v = \sqrt{\frac{g_o M}{R + h}} \;; \tag{54}$$

i. e., approximately 5 mi/sec, and $\theta = 90^o$ (for other values of θ the path will be elliptical);

an ellipse with its nearer focus at the earth's center if

$$\sqrt{\frac{g_o M}{R + h}} > v < \sqrt{\frac{2 g_o M}{R + h}} \;; \tag{55}$$

i.e., if v is between about 5 and 7 mi/sec; and a parabola or a hyperbola, if

$$v \geqq \sqrt{\frac{2 g_o M}{R + h}} \,. \tag{56}$$

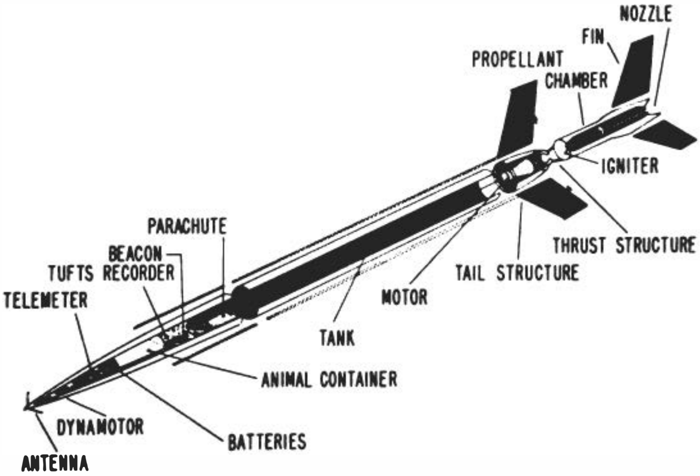
At these velocities and any value of θ the missile will escape from the gravitational pull of the earth. Other factors, such as motion and gravitational anomalies of the earth, cannot be discussed in this context.

The principal characteristics of a missile used in bio-astronautic research is its ability to carry instruments and specimens to greater heights and for longer durations than will any other known type vehicle. However, the experimenter must keep in mind the dynamic characteristics of a rocket flight pattern, which will determine the type of experiment to be made and also affect the kind of measurements obtained. In experiments with a squirrel monkey in a U. S. Army JUPITER IRBM nose cone in December 1958, a subgravity period at about 0.03 G was maintained for approximately 500 seconds. Already, 13 months earlier, the first biosatellite had been placed in orbit, permitting the study of the physiological effects of zero-G on Laika during an exposure of about 8 days.

Thus, technical and scientific space research, including zero-G by means of rockets and satellites, has already started and has yielded valuable data. Some of the advantages of this type of research tool are clearly defined by its flight characteristics, namely, the extremely high altitudes obtainable by means of rockets, and its powered flight outside and independent of any atmosphere. Its outstanding feature, of course, is that of producing zero-G for practically any length of time. This is naturally dependent on the development of rocket boosters powerful enough to accelerate a payload to reach orbital velocity.

At present, there exists no rocket in this country that has been designed particularly for biological experimentation. Even the vehicles used in the "Discoverer" program of the USAF, are conventional IRBM and ICBM components. Moreover, this experimentation is done almost exclusively on a non-interference basis with technological and military requirements. On the other hand, special sounding rockets have been particularly designed to meet the requirements of astronautical research. This may be one of the reasons why progress in space medicine is so slow and "falling behind engineering advances."

The first rockets employed for biomedical research in this country were the Aerobee (Figure 54) and the V-2. In both vehicles, weight and space for biological specimens and instrumentation were rather limited. For example, the nominal payload for the Aerobee was 150 lbs., with which the normal peak altitude was about 70 miles. Space in an Aerobee was about 6.25 cu. ft. In the large rockets, like the V-2, REDSTONE, JUPITER, THOR, ATLAS, etc., much more space exists. Even so, the nose cones which usually carry the payload are crowded with equipment, mostly because of the need to obtain as many measurements as possible,



(USAF Sch. of Aviat. Med., Randolph AFB, Tex.)

Figure 54. Aerobee Rocket

and also because of the non-interference type of mission mentioned above.

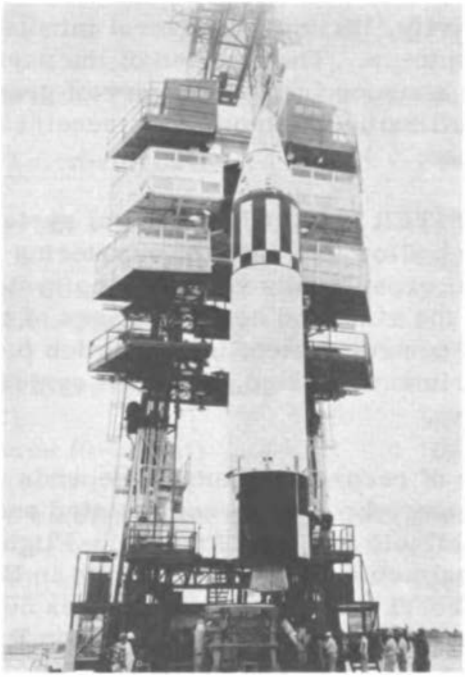
Some of the restrictions and limitations of this type of research must be pointed out to the rocket enthusiast, however. First of all, the great expense of rockets will doubtless often prevent the execution of an experiment despite its desirability. Most of the present-day rockets are in the million dollar bracket. Secondly, they are still not reliable enough to guarantee the accomplishment of the mission. Thirdly, only a few of them are recoverable and special provisions must be made for the telemetering of biological data, loss of the specimens involved, or their recovery by means of specially designed retrieving techniques. Fourthly, the payloads must be prepared so that they can withstand the long checkout periods on the pad before liftoff, the high accelerations and decelerations during the flight, and the stresses involved in re-entry and recovery. Generally, the nose cone is pressurized and climatized, but the bio-package must be protected against the hazards of space factors and secured in case of equipment failures. Fifth, most of the rockets and satellites available today are spun for stabilization. When it is essential to keep the specimen in a state of subgravity or zero-G, special precautions must be undertaken to stabilize the missile by gyros or to place the payload in the center of gravity or in the spin axis of the nose cone. Finally, an IRBM or ICBM covers the distances of about 1,500 to 5,000 miles, during a 15- or 45-minute period, respectively, of which only a certain part is spent in zero-G (4 and 6 minutes in JUPITER flights AM-13 and AM-18, respectively; 40 minutes in the THOR-ABLE combination employed in Project MIA). The yield in zero-G duration is spectacularly greater through the use of larger boosters. At any rate, the significance of these relatively short times for the investment of large sums of money, long preparation time, and instrumentation must be plain to prospective experimenters.

Since we cannot duplicate the zero-G condition in ground-based laboratories, we are forced to venture into rocket flight experiments in weightlessness research. As in the past, we are faced with the necessity to establish the basis for experiments with men through the exposure of animals to new and unexplored conditions. Contrary to the subject in a manned vehicle experiment, the animal can be expended; and in this case, it must be instrumented and connected to a multi-channel transmitter. In the worst case we are faced with a test, the only yield of which consists of the experience gained through the preparations of the experiment. However, this and the results already obtained in rockets and satellites justify animal experiments on the biological and medical effects of zero-G as an essential step in achieving manned orbital and space flight. It does not seem to be coincidental either that the Soviet scientists have successfully carried out a larger number of space biological experiments in the last decade in conjunction with their development of larger boosters than was done in this country; and only the Sputniks could make possible a biological experiment, which concerned the effect of zero-G over a longer period of time.

U.S. Army JUPITER (SM-78)

1. The U. S. Army JUPITER IRBM is an operational weapon system available at various missile installations of the USAF (Figure 55). Developed by the Army Ballistic Missile Agency, Huntsville, Alabama, it was used as carrier vehicle for biological payloads in 1958-59. The experiments were done by scientists at ABMA, the U. S. Army Medical R & D Command, and the U. S. Naval School of Aviation Medicine. The missile is now built by the Chrysler Corporation.

2. The missile signified the ultimate in simplicity. Its constant diameter cylindrical body is slightly under 60 feet in length and 9 feet in diameter. The control and guidance section



(US ABMA)

Figure 55. U. S. Army JUPITER Missile

is located in the conical instrument compartment on top of the liquid propellant tank. The nose cone, mounted on top of the instrument compartment, is a continuation of the conical section with a bluff re-entry tip. Operational nose cones were successfully recovered after 1,500-mile flights. Biological payloads up to 250 pounds (including life support system) were flown and recovered.

3. JUPITER is powered by an S-3D Rocketdyne engine, developing approximately 150,000 pounds thrust. The motor is gimbaled to correct deviations from course. The body has no wings or fins. Roll control is provided by swiveling the exhaust of the gas generator. Zero-G and subgravity occur after cutoff and spin-up, respectively. Maximum acceleration during launch is about 15 g; maximum deceleration during re-entry about 38 g for several seconds. The range of the missile is about 1,000 miles, maximum altitude 300 miles, and velocity about 10,000 m. p. h.

4. The accelerations prevailing during free-floating have been calculated as practically zero; after spin-up, as varying

degrees of subgravity, lasting for several minutes depending on the beginning of spin-up. The location of the payload within the nose cone and its distance from the center of gravity as well as spin rate and stabilization determine the accelerative forces acting on the specimen.

5. The JUPITER IRBM flight control system is fully automatic. It does not allow for inflight monitoring of the payload. In some biological experiments an open loop system has been employed to trigger the start and certain phases of the experiment. Since the missile control system is to function independently of payload and experimental design, separate systems must be used for payload control.

6. Number of recording channels depends upon the telemetry system employed. Twelve commutated and 7 straight channels were available in U. S. Army Bio-Flight No. 2. Details of the experimental setup and measurements in Bio-Flight No. 1 are given in Tables VI and VII, and in Figures 56, 57, 58, 59, and 60. Telemetry measurements available in Bio-Flight No. 2 are listed in Table VIII.

7. Preparation and execution of the experiment must concur with range safety requirements for ground and flight operations. Payload will be destroyed with missile if deemed necessary by range safety officer.

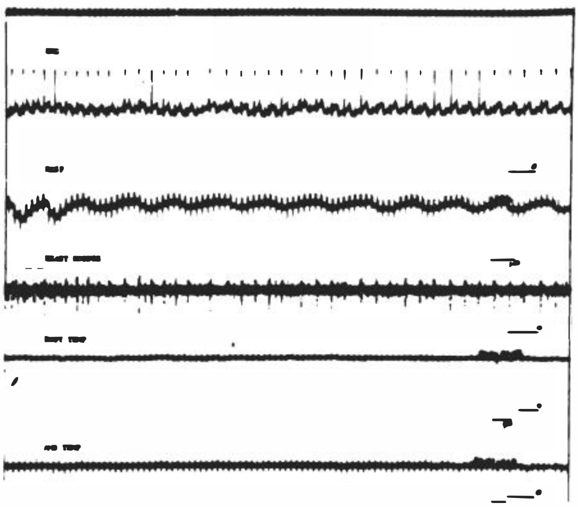


Figure 56. Oscillographs of Bio-Flight No. 1

TABLE VI

Telemetry and Measurements of Bio-Flight No. 1

Measurements - Telemetered*	Frequency Response
Electrocardiogram 1-2 millivolts input	160 cps
Heart sounds	600 cps
Respiration thermistor	10/second
Body temperature Thermistor (90^{o} - 110^{o}F)	10/second
Ambient temperature thermistor (15^{o} - 40^{o}C)	10/second
Ambient pressure (0-18 psi)	10/second

*Also recorded on electromagnetic tape throughout re-entry.

Measurements - Physical	Method
Heavy nuclei cosmic rays	Nuclear track plates
Atmospheric composition	Chemical analysis of absorbents and air

Measurements - Pre- and Post-Launch

Physiological laboratory evaluation

TABLE VII

Payload Characteristics of Bio-Flight No. 1

Total Volume, Internal	670 Cu. In.
Total weight	29.5 lbs.
Over-all dimensions, internal	9.75x12.5x6.75 in.
Volume of mobilebead	12.5 cu. in.
Volume of baralyme	35 cu. in.
Oxygen supply	22 cu. in. at 1800 psi
Volume of O_2 (std. cond.)	44.15 liters
Insulation	.5 in fiberglas - .5 in rubber
Heat source	8.5 w
Temperature control	Thermostat 55^{o} - 65^{o}F.
Circulation	Convection
Missile connection	1 - 13 pin elec. connector
Time of installation	5 1/2 hrs. prior to takeoff
Electric requirements	1.5 watts
Electrical source	28 v nose cone batteries

TABLE VIII

Physiological Factors and Telemetry of Bio-Flight No. 2
(FM/FM: Carrier Frequency 239.5 mc)

Meas. No.	Variable	RDB Channel	RDB Response	Sub-Carrier Frequency
12A12	EKG B	5-14	330 cps	22 kc
12A13	Respiration B	5A-1	10 per sec.	30 kc
12A14				
12A15	Body Temperature B	5A-2	10 per sec.	30 kc
12A16	Ambient Temperature B	5A-3	10 per sec.	30 kc
12A17	Ambient Pressure B	5A-4	10 per sec.	30 kc
12A18	Ambient Temperature A	5A-5	10 per sec.	30 kc
12A19	Ambient Pressure A	5A-6	10 per sec.	30 kc
12A20	Relative Humidity A	5A-7	10 per sec.	30 kc
12A21 (12A23)	Pulse Velocity A_1	5-6	25 cps	1.7 kc
12A22	Percentage CO_2	5A-9	10 per sec.	30 kc
12A23 (12A21)	Pulse Velocity A_2	5-6	25 cps	1.7 kc
12A24	Respiration A	5A-13	10 per sec.	30 kc
12A25	Body Temperature A	5A-14	10 per sec.	30 kc
12A26	EKG A	5-13	220 cps	14.5 kc
12A27	Behavioral Response A	5A-15	10 per sec.	30 kc
12A28	Reinforcement Shock A	5A-16	10 per sec.	30 kc
12A29	EMG_1 A	5-17	790 cps	52.5 kc
12A30	EMG_2 A	5-16	600 cps	40 kc
12A31	Heart Sound A	5-18	1050 cps	70 kc

8. Cost of experiment depending on type of mission (non-interference with prime mission or biological experiment mission of flight), system adaptation and checkout, modification and integration of payload into missile system, electronics, etc. May approach price of missile if major alterations are necessary.

9. Number of recovery missions unknown.

10. Bibliography, including classified reports, is included in the general section at the end of this report.

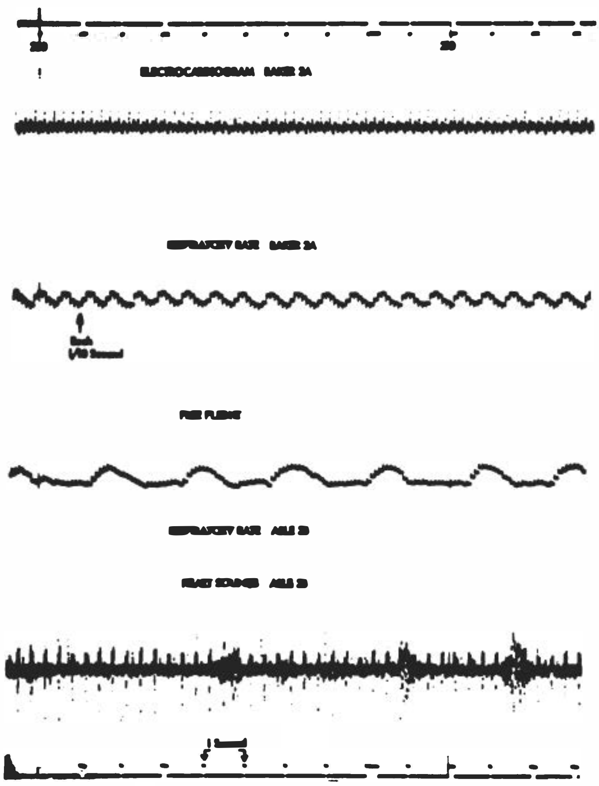
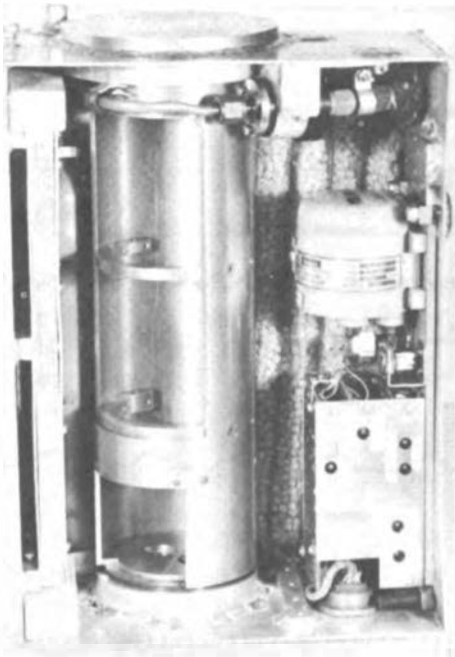


Figure 57. Oscillographs of Bio-Flight No. 2

THOR and THOR-ABLE Combinations

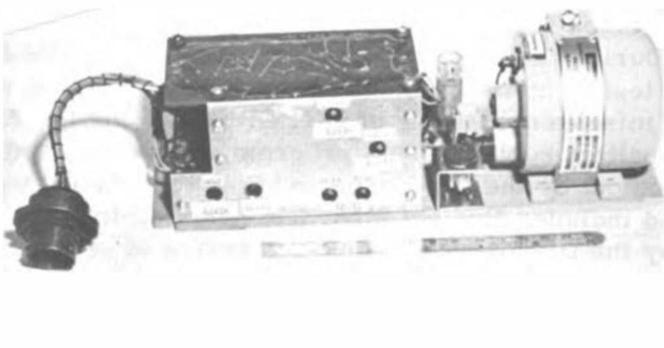
1. During the first half of 1958, a series of ICBM re-entry nose cone tests was performed, using as the launching vehicle a two-stage missile consisting of a THOR IRBM and the Aerojet 1040 liquid-propellant rocket. This program, known as Project Able, was carried out by the Air Force and Space Technology Laboratories, and included Project MIA: i. e., Mouse-In-Able. It was followed by the Discoverer Project, a series of recoverable satellite shots, established on 28 February 1958 under the authority of ARPA. A staff of about 30 scientists and professionals is engaged in the preparations of experiments, the primary objectives of which include the exploration of extended periods of zero-G on animal behavior. The shots are prepared and launched at the Pacific Missile Range.

As of November 1, 1960, 16 Discoverer shots have been made, several with animals. Two capsules have been recovered from



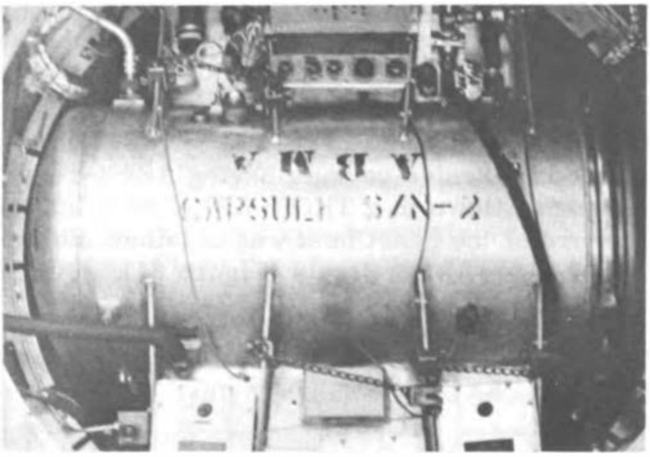
(US ABMA)

Figure 58. Interior of Bio-Capsule for Squirrel Monkey



(US ABMA)

Figure 59. Electronic Package for Squirrel Monkey Capsule



(US ABMA)

Figure 60. Bio-Capsule for Rhesus Monkey Installed in JUPITER Nose Cone

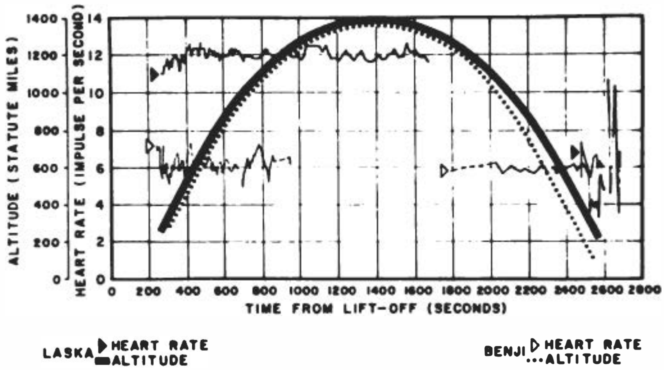
orbit, neither with animals. On August 21, 1960 the Soviets recovered two dogs, 40 mice, and a variety of other organisms and tissues from a 24 hour orbit ("Sputnik 5"). On October 13, 1960, 3 black mice were recovered by the USAF from a 650 mile high, 5000 mile range flight in the RVX-2A 2800 pound reentry vehicle, boosted by an Atlas.

2. THOR is powered by a 150,000 lb. thrust liquid propellant engine (Rocketdyne) burning liquid oxygen and RP-1 high grade kerosene. In addition to the gimbaling action of the sustainer, thrust adjustment and roll control are obtained by two vernier engines located at the base of the missile on each side of the sustainer. The inertial guidance system is completely self-contained within the missile and cannot be deterred from a preset course. The nose cone is built by General Electric Company. They are protected by heat shields of ablation material, some of which have been recovered after re-entry shots over 1,500 miles at 10,000 miles per hour. THOR-ABLE combinations carried a bio-pack of about 20 pounds to a maximum altitude of 1,400 miles over a range of almost 5,500 miles.

3. Total flight duration of THOR about 15 minutes; of THOR-ABLE, about 45 minutes. Maximum acceleration liftoff about 12 g for THOR; about 5 g for second stage (ABLE). Period of virtual weightlessness in THOR about 500 seconds; in THOR-ABLE about

43 minutes. Peak decelerations at re-entry of THOR about 40 g; of THOR-ABLE about 60 g.

4. Physical conditions of specimen similar to those in the JUPITER IRBM, but less space in nose cone. Project MIA consisted of a mouse in a sealed capsule having a self-regenerating artificial atmosphere flown in a THOR-ABLE combination. A telemetered record of the heart beat was obtained intermittently throughout two of three ABLE flights (Figure 61).



(After van der Wall and Young: ARS Journ., Oct. 1959)

Figure 61. Heart Rate and Altitude During Weightlessness Able Nos. 2 & 3

5. The animal was harnessed so that it could turn about a pivot point. The electrodes were implanted and attached beneath the skin. In designing the electronic system the mouse was considered as an electrical generator having the following characteristics: open circuits volts, 1.5 mv peak-to-peak; impedance, 5,000 ohms; frequency range, 3 to 18 pulses per second. A pair of two-stage transistorized amplifiers was included in the unit and an attenuator was used to allow for variations in mouse output signal amplitude. Each amplifier circuit included about 10 db of negative feedback. This increased the input impedance to match the mouse impedance and stabilize the amplifier gain versus environmental changes.

6. Subsequent to amplification, silicon diodes rectified the heart beat pulses and an RC filter in the output circuit elongated them to increase the low-frequency component. It was necessary to avoid multi-vibrators because of their instability, although they would have increased the low frequency pulse rate component. Also, in order to prevent power supply decoupling networks, separate batteries were employed for the two amplifiers so that

only under very improbable circumstances could they oscillate. The millivolt-level mouse output pulses were transformed into 5-volt signals with a time-constant of about 50 milli-seconds, throughout the 4-day period of useful battery life. No evidence of adverse environmental effects on the electronics was detected in the records obtained from the flight.

7. Safety features and requirements were according to range safety regulations. Since the project was not classified as a hold item, Zero minus 16 hours was established as MIA-unit ready time. This preflight time, including possible holds during countdown, flight time, anticipated recovery period, and safety factor led to the design of a system which was to function properly for at least 72 hours.

8. Data on costs available at STL.

9. Experiments with the Mark I and Mark II biomedical recovery capsule were scheduled through 1960-61. Experiments will include rhesus monkeys with life support system weighing up to 300 pounds. Recovery is to be accomplished through parachute and air snatch technique. Less than 5 G will be experienced by specimen on air snatch. Surface vessels will back up air recovery operations. Six biomedical vans are available at Vandenberg AFB for ground support of this project.

A biomedical experiment in Discoverer III, launched from Vandenburg Air Force Base on 4 June 1959 was only partly successful because of failure of the vehicle to gain sufficient velocity. However, part of the biomedical mission objectives were achieved. The life support system of the Mark I biomedical recovery capsule, developed by the AFBMD Directorate in coordination with the U.S. Air Force School of Aviation Medicine, functioned satisfactorily from liftoff to 790 seconds. The capsule atmosphere, continuously moved through a ducted gas control system, varied between 330 to 360 mm Hg oxygen partial pressure, maintained a low pCO_2 and low relative humidity (below 60%) with a constant but relatively low temperature of 56°F. During flight, no leaks occurred in the capsule or oxygen system and the latter functioned normally to maintain a satisfactory cell pressure between 6.3 to 7.0 psia from an oxygen cylinder maintaining approximately 1200 psig.

Four C-57 black mice were specimens for the Discoverer III flight. An analysis of telemetry records revealed that all four animals lived through the burning stage and free-flight period until final loss of telemetry at 795 seconds. The animals were active, particularly during the 500 seconds of weightlessness. Frequently, all four specimens showed movement simultaneously in response to vibration, tumbling, noise, and similar effects. Respiratory and EKG patterns could not be differentiated because of amplifier oscillation in all channels. However, on one viability signal, 29 seconds of EKG were reproduced from one specimen during the ballistic trajectory, and marked activity was recorded during weightlessness. The experience gained from this experiment seems to justify the enormous effort expanded on the Discoverer III launch and indicates the probability of success of subsequent bio-satellites of the Mark I and Mark II Discoverer series.

10. Discoverer III Biomedical Data Report. Directorate of Bioastronautics Projects, AFBMD, Hq, ARDC, WDZPB Report No. 2.

ATLAS, AGENA and CENTAUR

1. ATLAS, AGENA and CENTAUR are some of the space vehicles to be employed for research purposes within the National Aeronautics and Space Administration program. Of these, only the ATLAS is available at this date.

2. The ATLAS (SM-65) ICBM having a range of about 5,500 miles is produced by Convair Division of General Dynamics Corporation, San Diego, California, which builds the airframe and integrates the subsystems; General Electric Company, Philadelphia, Pennsylvania, and Syracuse, New York, manufacture the nose cone and the Radio Guidance System; Burroughs Company produces the computer; American Machine and Foundry furnished the power supply accessories; and North American Aviation, Rocketdyne Division, manufactures the propulsion system.

The ATLAS, which has been undergoing flight tests since June, 1957, at the Air Force Missile Test Center, Atlantic Missile Range, Cape Canaveral, Florida, begins its flight with all three engines in operation developing about 400,000 pounds of thrust. Several seconds after liftoff, the booster engines drop away and the missile continues with the lower thrust sustainer, reaching approximately 15,000 mph maximum. Two small vernier rockets located on the lower portion of the 10-foot body supply roll control and thrust adjustment throughout the powered flight. The ATLAS will be used as booster in the second phase of the Discoverer and of the Mercury project.

It is difficult to make an exact estimate of the payload weights which will be carried by any of these vehicles on the various missions. By and large, it can be assumed that these larger systems can put in earth-near orbits payloads which amount to about 1% of their liftoff weight. This ratio becomes more favorable with the bigger boosters. In all cases, the advanced space program is primarily aimed at the exploration of the moon, the planets, and interplanetary space, and is not intended to directly contribute to the Man-in-Space and other bioastronautical projects. However, test flights will most probably precede the actual assigned missions of the vehicles; and the Saturn will be employed for a moon-miss development test. There exists a certain possibility that biological payloads could be carried on some of the earlier sub-orbital and orbital flights, and that some of them could be recovered after ejection from the upper stages.

3. Guidance and attitude-control systems will be employed to control the trajectories of these vehicles. During the launch phase, injection guidance will be used, but radio and inertial guidance seems to be more desirable for the upper stages. The development of these systems will rely upon developments which have already been undertaken in guidance systems for military rockets. The first vehicles will be equipped with devices which are the same as, or similar to, those already available. As the projects accelerate, lighter weight and more advanced guidance systems designed specifically for the space vehicle application will be employed.

4. Not available at this time.

5. Not available at this time.

6. The magnetic tape recorder will be the primary data-storage tool in the next years. Flaws in telemetry, particularly due to wow and flutter and to signal drop out, will have to be overcome in order to improve this type of frequency-modulated telemetry. The maximum frequency which can be recorded today is in the order of 100 kc with a tape speed of 60 in/sec. By utilizing new techniques of recording and amplification, an upper limit of 500 kc at 60 in/sec, or 250 kc at 30 in/sec tape speed, can be obtained. Future developments in the area of field data presentation will be primarily directed toward the improvement of analog data plotting on a direct-writing oscillograph, and toward the addition of the digital data to the analog record in order to provide one record containing good-accuracy analog with high-accuracy digital data.

7. According to range safety and vehicle requirements.

8. Not available.

9. Not available for sub-orbital and satellite flights.

10. "Exploration of the Moon, the Planets, and Interplanetary Space", (Edit. by Albert R. Hibbs). Report No. 30-1. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, April 30, 1959 (Unclassified).

LITTLE JOE Vehicle

1. The LITTLE JOE rocket is used as a research rocket by the National Aeronautics and Space Administration. Its vehicle airframes were designed and constructed according to NASA specifications by the Missile Division of North American Aviation, Inc. Motors were built and supplied by the Thiokol Chemical Corporation. The propulsion system consists of a cluster of eight solid propellant rocket engines which can be made up of either four Pollux or Castor main rocket motors and four Recruit auxiliary rocket motors. The four Recruit rocket engines and two of the main rocket engines are fired simultaneously at launch. The remaining rockets are fired together at some pre-determined time after launch.

Two biomedical experiments have been done so far with LITTLE JOE rockets at Wallops Island, Virginia.

2. A sketch of the LITTLE JOE vehicle is shown in Figure 62. This vehicle was built specifically to obtain flight performance data on Project MERCURY research and development type capsules. It is conceivable that a variety of payloads could be designed and flown on the LITTLE JOE booster system. Photographs of the LITTLE JOE booster and capsule payloads before and after mating are shown in Figures 63 and 64.

3. Motion, acceleration, and velocity characteristics are classified and can be obtained from the NASA Space Task Group, Langley Air Force Base, Virginia. By and large, periods of weightlessness of several minutes can be obtained, depending upon payload weight and flight trajectory.

4. The gross weight of the capsule payload shown in Figures 62, 63, and 64 was about 3,000 pounds. The interior capsule pressure was 1 atmosphere at 100% oxygen at the start of the

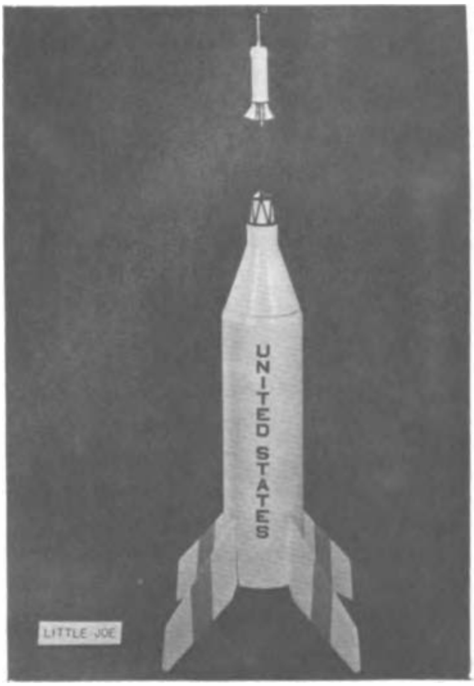


Figure 62. Schematic Model of LITTLE JOE Vehicle

experiment and reduced to 350 mm Hg through breathing during flight. The capsule temperature was kept between 10^{o} and 20^{o}C in both flights. The NASA capsule can be position stabilized through the use of reaction control jets which operate on compressed gas.

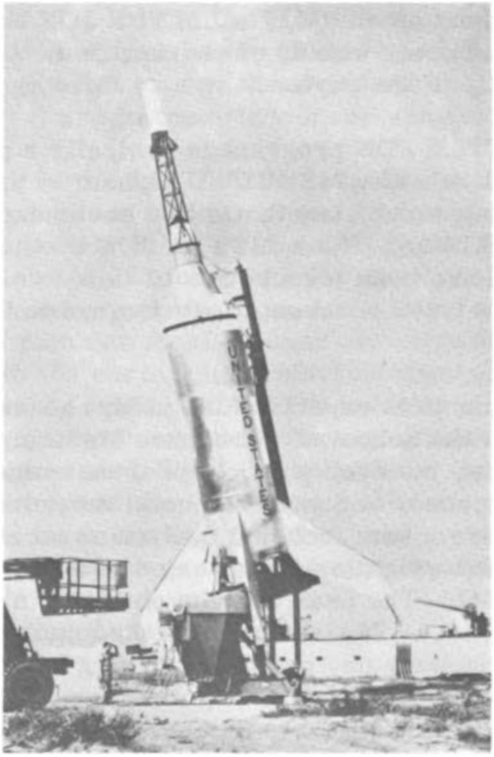
5. The LITTLE JOE booster is a fin-stabilized vehicle and employs no guidance and control system. A method of compensating for winds which affect the flight path has been developed, utilizing adjustment of launch azimuth and elevation, and has been used successfully.

6. Typically instrumented NASA capsule used on LITTLE JOE boosters provide from 50 to 100 channels of information depending on the nature of the test. Some measurements are recorded onboard the capsule, others pass through a telemeter link. The following list of instrumentation is a sample list for one of the NASA LITTLE JOE capsules. The "T only" notation indicates measurements that were telemetered only. The items with just a "T" are recorded onboard and telemetered. All other items were recorded onboard. The number of instruments is indicated in parentheses.

Accelerometers	(3)	"T"
Rate gyros	(3)	
Internal pressures	(2)	
Capsule air temperature	(1)	
Voltages	(2)	
Frame counters GSAP	(3)	
Bio-pack channels	(11)	
α and β vanes	(2)	"T only"
Manifold pressure monitor	(1)	
External pressures	(9)	
Total pressure	(1)	
Up camera	(1)	
Side camera	(1)	
Down camera	(2)	
Onboard timer	(1)	"T"
Noise pickups	(2)	
Impact accelerometers	(3)	
Drogue chute tensiometer	(1)	
Capsule Marman band release	(1)	"T only"

(NASA)

Figure 63. LITTLE JOE Booster and Capsule Before Mating



(NASA)

Figure 64. LITTLE JOE Research Vehicle

Capsule separation	(1)	"T"
Escape tower Marman band release	(1)	"T"
Drogue cover separation	(1)	"T"
Main chute deploy	(1)	"T"
Camera in bio-pack	(1)	

The data from LITTLE JOE firings are reduced by the NASA and suppliers of special test packages.

7. All circuitry on the LITTLE JOE vehicle is carefully checked before and during countdown. Nearly constant monitoring of important circuits or instrumentation can be provided during the countdown.

In case of an emergency the booster is equipped with a command destruct system. The destruct system is actually a system for terminating the thrust of the main rocket motors.

8. The approximate cost of a LITTLE JOE booster is $500,000. Payload costs would, of course, be dependent upon the size and complexity of the payload.

9. The LITTLE JOE program is basically a program to test the escape capabilities of a MERCURY capsule at the maximum aerodynamic loading conditions that might occur during an escape off a MERCURY-ATLAS. Four LITTLE JOE boosters with their capsule payloads have been launched as of this date. All four flights have been termed successful with regard to booster performance.

The two biomedical experiments, using rhesus monkeys, done by scientists from the School of Aerospace Medicine, Brooks Air Force Base, Texas, involved physiological instrumentation, psychological performance, and environmental measurements. The flight profile of the rockets included maximum accelerations of about 10 - 12 g, and weightlessness period of about 3 minutes at plus or minus .02 G. The peak altitude obtained in the 3rd flight was about 300,000 feet. Measurements taken concerned the EKG, respiration, eye movements, and bar pressing behavior, but only partial results were obtained due to malfunction of equipment. The attempt to obtain inflight pictures during the first experiment only partially successful because of malfunction of the camera equipment. Moreover, O_2 tension, total pressure, capsule temperature, and relative humidity were recorded. The second animal experiment (January 1960) was done in conjunction with an engineering flight test, reaching a maximum altitude of about six miles.

10. NASA Space Task Group: Information Concerning LITTLE JOE (Confidential report specially prepared for use in "Zero-G Devices and Weightlessness Simulators"). Further information can be obtained from the Director of the Space Task Group, NASA, Langley Field, Virginia.

SATURN

1. The SATURN development program calls for initial vehicle of two or three stages, depending on specific mission. It will be about 200 feet high in the three stage configuration. NASA assumed technical direction over SATURN under a NASA-DOD agreement of 18 November 1959.

The SATURN booster project was initiated in August, 1958. The first booster flight with dummy upper stages is scheduled for the 1961-1962 time frame.

The objective of Project SATURN is to provide by the 1963-1964 time period an efficient and reliable system for lifting multi-ton loads into high orbit around the earth and into deep space. It will be for general use in the heavy space vehicle field.

First stage of the SATURN vehicle will be a super-booster with 1,500,000 pounds of thrust, plus upper stages. The super-booster is under development at Marshall Space Flight Center. It can put a payload of 15 tons into a low satellite orbit, about 5 tons around the moon, and about one ton softly on the surface of the moon. Two men can make a lunar circumnavigation with subsequent return to the earth. If a refueling maneuver is carried out in a low satellite orbit, a SATURN vehicle will be capable of landing two men on the moon, and of bringing them back home a few days later. In short, SATURN will be the first American-made vehicle that opens the lunar space to man. Pictures of the SATURN system, lunar landing vehicles, and a proposed orbital station to be developed as part of this system are shown in Figures 65 and 65 a-d.

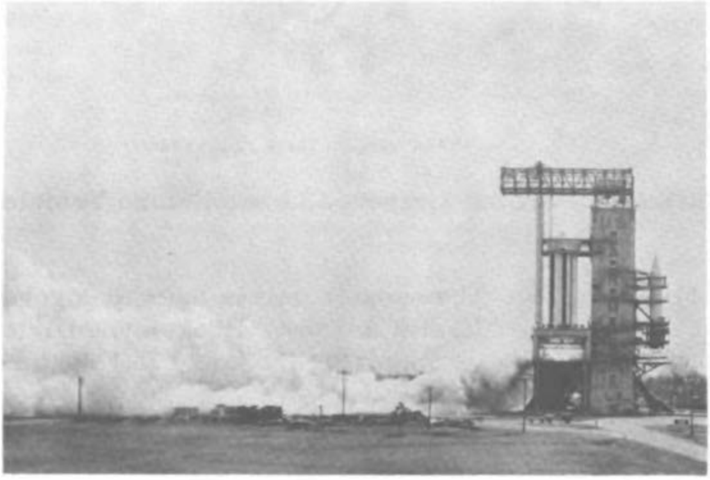


Figure 65. SATURN Booster During Static Firing

2. The SATURN booster uses a grouping of engines built from existing JUPITER and THOR components. The cluster concept was chosen because of the proven reliability of the existing engine. The H-1 engine is considerably more compact than companion JUPITER and THOR engines in the same 150,000-pound thrust range, resulting in a major move for simplification and high reliability. The first of these engines was delivered to

(NASA Marshall Space Flight Center)

Figure 65a. Orbital Launched Lunar Return Vehicle

AOMC on May 1, 1959. The booster unit is being designed, fabricated, and tested at the Missile Agency. Rocketdyne Division of North American Aviation is supplying the basic H-1 engines.

The individual H-1 engines used in the propulsion system develop thrust from the propulsive gases created by the combustion of liquid oxygen and RP-1, a hydro-carbon fuel similar to that used in turbo-jet engines. Combustion within the thrust chamber occurs at temperatures above 5000 degrees Fahrenheit. The walls of the thrust chambers are formed of thin, lightweight metal through which fuel is forced at high speed. The fuel flow prevents the metal from melting under the extremely high temperatures encountered. Lightweight turbopumps, proven in repeated flights of JUPITER and other ballistic missiles, are utilized in the H-1 engine to draw the propellants from the storage tanks and force them at high flow rate into the combustion chamber.

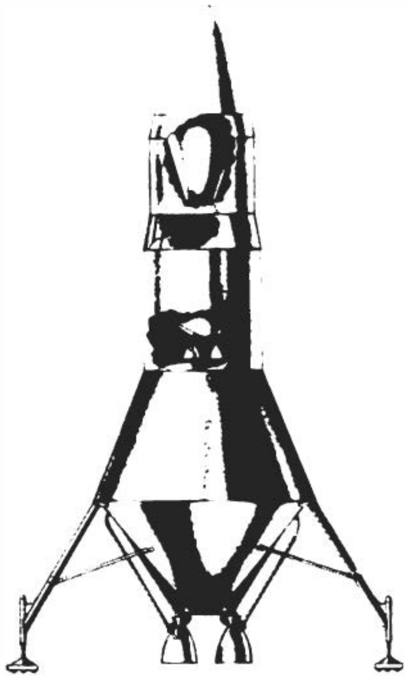
The booster is powered by a cluster of eight Rocketdyne H-1 engines using liquid oxygen, and RP-1 propellants contained in 9 tanks. Total thrust of the clustered engines will be equivalent to 30,000,000 horsepower.

The first stage cluster of H-1 engines will be about 80 feet tall, 22 feet in diameter, and will produce about 1,500,000 pounds of thrust at liftoff. The vehicle will use an all-inertial guidance system. This system will automatically compensate for deviations resulting from loss of thrust should one of the first stage booster engines fail to function.

The first stage cluster was static tested on a special 177-foot tower at Marshall Space Flight Center in the spring of 1960. Flight tests will be made from the Atlantic Missile Range at Cape Canaveral, Florida, where a 245-foot self-propelled service stand is being built to handle the huge rocket.

(NASA Marshall Space Flight Center)

Figure 65b. Manned Orbital Transport



(NASA Marshall Space Flight Center)

Figure 65c. Lunar Landing Vehicle

Directional stability of the entire missile will be maintained by swiveling the four outer engines of the cluster. These engines will be mounted on gimbals--a part of their assembly--and moved by struts actuated by the guidance equipment of the space vehicle.

3. The SATURN program in general offers the following capabilities in the area of weightlessness and space missions:

a. The earliest and most economical possibility for surpassing all presently known payload capabilities for orbital and trans-orbital research flights.

b. Earliest capability for large orbital space stations and bioastronautical laboratories.

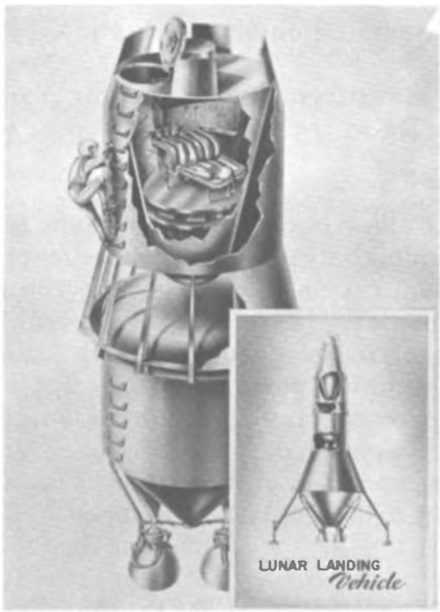
c. Earliest capability for manned lunar circumnavigation and return.

d. Earliest capability for manned lunar landing and return.

e. Earliest available booster for research on large winged and manned space vehicles.

The acceleration and deceleration stresses expected to occur with the SATURN system vehicles are within the range of human tolerance. However, we are dealing with relatively low accelerations over a considerable period of time, or higher accelerations (decelerations) of relatively short durations. In either case, it will be necessary to furnish adequate protection against the physiological effects, and particularly to provide for an adequate safety factor in case of emergency.

Whatever the size of the capsule or cabin may be, we assume that the passenger will be protected either by seats or couches similar to those used in the MERCURY capsule, or by dynamic positioning during peak acceleration. Moreover, high G suits and similar devices may be used during take-off, orbital maneuver associated with high accelerations, and decelerations during return and landing.



(NASA Marshall Space Flight Center)

Figure 65d. Lunar Earth Return Vehicle

It seems almost unnecessary to say that the state of weightlessness will prevail during all periods of non-accelerated or free flights.

4. The theoretical basis and equations representing the physical conditions for the subject have been given before. A representation of the various trajectories and orbits associated with booster capabilities and payload penalties cannot be given in this context, nor is it possible to cite the physical parameters and equations pertaining to orbital and trans-orbital flights.

5. Control system variables concern payload attitude controlling and control loop in which the subject is the human link.

The control of the attitude of the payload may be required for:

a. Physiological reasons (tolerance of the passenger to angular acceleration associated with spinning and tumbling).

b. Position and orientation maneuvering (guidance observation).

c. Radio communication and navigation.

d. Scientific measurements, including photography, aiming of solar cells at the sun, taking fixes, measurements, etc.

The function of an attitude control system is to maintain prescribed relationships between reference directions in the vehicle and an external frame of reference. The attitude sensing device may include radiation detectors, such as photo cells, and inertial elements, such as gyroscopes. This latter type is limited by its inability to maintain a reference direction over a long period of time. On the other hand, the radiation detector can maintain a reference direction over an indefinite period of time. Furthermore, accurate determination of direction is possible with optical devices, particularly if the vehicle is manned.

A distinction must be drawn between attitude control systems intended only to maintain the angular attitude of the vehicle, and systems which are capable of varying and controlling the attitude in accordance with commands. Systems utilizing spin stabilization or differential gravity effects belong to the first class. Command signals of a more complex nature will be used for most space missions, at least during mid-course corrections and terminal guidance. The accuracy of these systems may be greatly increased if human navigational aid is supplementary.

The role of the human passenger in the SATURN space vehicle system must be considered from two aspects. The first concerns his proficiency as part of the control link. Careful consideration must be given to his control and performance parameters so that he is protected against the possible hazards of space and his proficiency is maintained. For this, he must be furnished adequate and reliable information under the zero-G condition. Preparatory investigation of zero-G human engineering by means of weightless flights in rocket vehicles described before will furnish preliminary information. Secondly, the effects of weightlessness on the human subject must be determined, which are needed for the improvement of control link design adequate for zero-G conditions. Since large payloads can be put in orbit, all sorts of experiments on zero-G effects can be carried out. This includes the testing of the space cabin, the engineered environment, and the adequacy or practicability of space cockpit designs. The immediate goal is the development and testing of an advanced, integrated, and reliable cabin and life support system which proves to be adequate under weightless conditions of actual orbital flight.

6. The collection and processing of biomedical information in a SATURN type space vehicle will not pose any serious problems. The use of magnetic recorders for this purpose has been dealt with in the description of the ATLAS, AGENA and CENTAUR class. In addition, a world-wide system of ground stations will be available for bio-telemetry. The amount and type of data which are presented in the individual field stations will depend greatly upon the requirements for real-time data analysis. Generally speaking, any type of presentation needed in the final data reduction can be made.

Improvements in existing communication facilities will make it possible to receive tracking signals and scientific information from a distance of about two million miles. The areas in which improvements will be made to obtain greater communication ranges concern energy sources, miniaturization, antennas, and amplifier systems. The weight required to transmit vehicle and scientific information is proportional to the expression

$$2\pi \int \frac{KTMLR^2}{EDA_t A_r} \, dt \qquad (57)$$

where:

K	=	Boltzmann's constant
T	=	effective temperature of the receiver detector
M	=	sampling rate of the experiment
L	=	effective signal-to-noise ratio desired from the receiver
R	=	distance of information transmission
E	=	effective efficiency of transmission system
D	=	storage capacity of batteries
$A_t A_r$	=	effective areas of the transmitting and receiving antennas, respectively, and the integral is taken over the time of transmission. The product $KTMLR^2$ is directly proportional to the power output of the system.

Each field station available for the recording of scientific data will contain adequate display such as a direct writing oscillograph and digital print-out systems. With good design and proper calibrations, data from these records are read with greater accuracy than the oscillograph analog method provides. The accuracy of the digital data is limited by the data frequency, counter-sampling, frequency of the subcarrier channel, and the accuracy limit of the counter.

However, the present systems used for the mass accumulation of scientific information are inadequate for long-range measurements. At present, electrical signals representing physiological or physical quantities are registered continuously in real-time at the output of these systems. Each signal source requires an individual channel, monopolizing transmission, and final display facilities regardless of signal activity or information content. The equipment bandwidth and the weight and power penalties are fixed in accordance with the maximum potential demand by signals in all channels irrespective of the normal or average signal value. With the significant signals averaging less than 2% of the total, the over-all efficiency of the system is notoriously low. The same flood of signals imposes serious problems at the output end because of equipment limitations on the one hand, and because of the restricted capacity of the human operators on the other hand. Thus, the read-out becomes a real problem when days, weeks, and continuous operations are involved.

In order to remedy this situation, McClennan (WADC) has proposed a "viability monitor" which would discriminate between the flood of insignificant data and the significant bits of information. The technique suggested assumes that every biomedical measurement can be defined in such a way as to allow an electronic decision whether a bit of information is significant or otherwise. Such a device would include a normalizer, a gating unit, and a decision unit. In this circuit, the standardized voltage for gating is normally supplied from the decision unit. The decision to pass signals is made by amplitude coincidence of the signal voltage with a fixed reference voltage. In order not to lose significant information, a preselector may be applied to "alert" the decision unit after long periods of insignificant flow of information.

By employing modern automatic data reduction methods, the telemetry measurements can be rapidly and efficiently reduced to a presentable form. To accomplish this, a data handling net is necessary in conjunction with a world-wide tracking system. Since many field stations located around the globe will receive signals only part of the time, a central data processing center must be established. After the data are reduced at the acquisition site, they will be transmitted to the central headquarters. A global radio communication system will be available for this purpose.

In summary, it is believed that signals selection, storage, and burst transmittal (the latter by command or automatically) will be applicable for biotelemetry in SATURN space vehicles. On the other hand, normal data collection and evaluation within the vehicle will also be feasible because of the relatively high payload allowances for orbital flights.

7. The SATURN engines are profiting by the ten-year development period on the REDSTONE, JUPITER, THOR, and ATLAS engines. Continual analysis of the static test firing reports on these engines have permitted design of the H-1 on the basis of elimination of trouble spots, and improvements of other components. Each of the eight H-1 engines comprising the SATURN cluster operates independently with its own gas generator and turbopump. The propellant tankage supplying liquid oxygen and RP-1 fuel is a common source for all engines. The start sequence is the simplest of any yet provided in the family of liquid propellant

engines. Safety devices have been built into the engine--an added factor in manned flight. One of the safety factors is the assurance that all eight engines of the cluster must be functioning normally before the missile can be released. Hypergolic ignition (self-igniting) will further increase the reliability of the H-1.

The potential use of the SATURN vehicle for manned space flight does not necessarily increase the reliability of the system. However, there is a strong belief that reliability of the planned missions can be increased substantially through the participation of a human crew. Another effort must be made to obtain a manned rating for the SATURN through test and experience, even though the basic design features and requirements for the safety of human occupants have been incorporated early in the design of SATURN vehicles.

8. The SATURN system promises to become the most economical means for space research and transportation in the foreseeable future. The cost for orbital flight will be reduced to approximately $500 per pound or less in the SATURN program. Moreover, booster recovery seems to offer a potential saving. A special system employing parachutes and retro-rockets is being developed by the Cook Electric Company, Morton Grove, Illinois, to enable recovery of the first stage booster for post-flight inspection and possible further use.

9. NASA's space science efforts in terms of its present program concern various scientific programs within the areas of planetary space sciences, astronomy, and astrophysics. A life science program was developed in 1960, which includes the use of SATURN vehicles after they are available.

In general, weightlessness research in the SATURN type vehicle will continue where the limitations of the research aircraft made further investigations impossible. The following tentative areas appear to be worth-while for further investigation:

a. Basic biological study. Research concerns the development of life under zero-G conditions, and the processes of growth, maturation, fertilization, reproduction, aging, and decay of living matter. Specimens for this type of research are single cells and cell systems, tissue, plants, and animals of a relatively low phylogenetic standing. Related subjects are the adjustment of lower organisms to the zero-G condition, geotropism, and the effect of other environmental factors (temperature, pressure, C_2, CO_2, radiation, nutrition, etc.) upon the weightless organism.

b. Studies on the consequences of relativity theory and related subjects on the organism. These investigations concern possible mass changes due to time dilation, including alteration of growth rates and aging. Although it appears doubtful that such effects may be detected with this type of research vehicle, preliminary or feasibility studies of these problems may be possible. Moreover, the effect of differential gravitational forces during orbital and trans-orbital flights, and possible differences between the zero-G and the true agravic state upon organic matter and the human organism, will be investigated.

c. Human tolerances and adaptation to long exposure to weightlessness and readjustment to the 1 g condition after prolonged flights. These studies include (1) clinical investigation of certain critical physiological functions (e. g., cardiodynamics, hemodynamics, respiration, digestion, hormone production, etc.) under conditions of extended weightlessness, (2) disturbances of sensory perception and neuromuscular condition during prolonged states of weightlessness, (3) the possible occurrence of muscular atrophy due to inactivity of the skeletal muscles, (4) perception, orientation, and performance characteristics, and (5) the possible physiological and psychological stress of extended periods of weightlessness, the effect of drugs and medication upon tolerance, and preventative measures and exercise. This also includes preventative means for readjustment of the astronauts to the normal gravitational condition.

d. Human engineering parameters in extended periods of weightlessness. The main subject of research in this area must be to develop devices, instruments, means, and other hardware which will help the astronaut to live, work, and relax in the weightless state. This mainly concerns the manufacturing of seats, beds, tools, and equipment adequate for the life in a weightless world. Since our instruments and devices were developed on the principles of the normal force of gravity, every tool and device which depends upon the attraction of the earth or is constructed according to the open loop principle must be redesigned for the mechanics of weightlessness. It is important that only the mass of a body be used in all calculations, for mass--and not weight--is constant under these conditions. Moreover, the application of accelerations to produce an artificial gravity and its effect upon man will be studied.

e. Selection of space crews. Flights in the SATURN vehicle will be used to test human tolerances to weightlessness and to select astronauts and space crews.

f. Training of space crews. It is believed that the SATURN vehicle can be used for the training of personnel with regard to adjustment to and performance in the weightless condition.

g. Research and psychological consequences of prolonged states of weightlessness. There is a certain possibility that the physical conditions which personnel of an artificial satellite or in a space ship will have to endure may have detrimental effects upon the emotional condition. Since many of the habit patterns, which were unconsciously established over the years, will suddenly be brought to an awareness, mental effort will have to be employed to do what formerly was automatically performed. It is in these conditions that man must work, rest, and sleep. The possibility of traumatic experiences and the prevention of emotional disturbances will be subjects of investigation.

h. Studies of the effects of subgravity. Lunar landings and stay on the surface of the moon will permit the investigation of the effects of subgravity (about one-sixth of the terrestrial gravity) on plants, animals, and man.

10. References:

a. ABMA Report No. DSP-TM-13-59, (U) SATURN System Study II, CONFIDENTIAL report, dated 13 November 1959.

b. ABMA Report No. DSP-TM-1-59, (U) SATURN System Study, SECRET report, by H. H. Koelle, F. L. Williams, and W. G. Huber, dated 13 March 1959.

c. AOMC SECRET report, (U) Supplement No. 2 to Development and Funding Plan for ARPA Order 14-59, dated 24 July 1959.

d. ABMA Report No. DIR-TR, 2-59, (U) Semi-Annual Technical Summary Report on ARPA Orders 14-59 and 47-59, SECRET report, dated 13 July 1959.

e. (U) Final Report - Economical Boost Systems Study, MD 59-147, CONFIDENTIAL report, Missile Division, North American Aviation, Inc., Downey, California, dated 2 October 1959.

f. (U) Missile Road Transport Survey, M-M-M1-59-53, Unclassified report, by L. M. St. Ours, Martin Company, Denver, Colorado, dated September 1959.

g. JPL Report No. 30-1, Exploration of the Moon, the Planets, and Interplanetary Space, Unclassified report, dated 30 April 1959.

II. WEIGHTLESSNESS SIMULATORS

In the search for methods of studying the effects of weightlessness on the ground, immersion in water has attracted considerable interest. According to the Archimedian Principle, a body which is partly or wholly immersed in a fluid loses its weight by an amount equal to that of the displaced medium:

$$W = V(\delta - \delta')g, \tag{58}$$

where V is the volume and δ and δ' represent the densities of the body and the surrounding fluid, respectively. The apparent weight W_a of a body, being equal to the sum of the forces of gravity and inertia, can be expressed as:

$$W_a = F_g + F_i = -F_s, \tag{59}$$

where F_g, F_i, and F_s represent the forces of gravity, inertia, and support, respectively. It is evident from (58) and (59) that a body can be made weightless not only by counterbalancing F_g through F_i (free-fall), but also by placing the body in a fluid of the same density (i.e., by making $\delta = \delta'$). Theoretically, the density of the body can be larger, equal to, or smaller than that of the fluid. Accordingly, the weight of the immersed body can be positive, zero, or negative, respectively. The body, being a three-dimensional and extended object, is at least partly compressed by the hydrostatic pressure of the surrounding fluid. If the body is submerged at greater depth, this pressure is considerable, no matter whether the weight of the displaced fluid is smaller or larger than that of the body (note that the numerical value of this weight differs from the apparent weight described above, although the concepts, logically and operationally, are identical).

Within the body, gravitation produces a hydrostatic effect, too; i.e., the pressure which a certain column of fluid (such as blood) exerts on the walls of the vessel. This pressure is no longer exerted if the body is immersed in water, because it is counteracted by the hydrostatic pressure of the fluid surrounding the body. Since no particular surface area of the body has to carry weight and the exteroceptors of the skin are neutralized because of the pressure equilibrium inside and outside of the body, the latter is neither stressed nor deformed. All this would strictly be true only if the body were homogeneous in density and elasticity. However, the human body is not even approximately homogeneous, and the various parts of the organism are differently affected by the acceleration of gravity. Nevertheless, the individuals who participated in weightless experiments were impressed by the similarity between the sensation of weightlessness in flight and that of suspension in water.

Null-Gravity Simulator

1. Null-gravity simulation was obtained by immersing subjects in water. The experiment was conducted at the U. S. Air Force School of Aviation Medicine, Randolph Air Force Base, in September 1956.

2. For the experiment the swimming pool was used, and a tilt-table was placed at a depth of about seven feet on the bottom of the pool. A large protractor, calibrated in degrees, measured the angle of tilt. The subject was blindfolded, and respiration was secured by means of a portable high-pressure air-lung device with a regulator and a mouthpiece. The subject was attached to the tilt-table by an aircraft safety belt.

3. The table was hand-moved slowly by an observer through varying angles of tilt. Starting positions varying from 0° to 90° with the vertical were used in a random fashion.

4. The theoretical basis and equations representing the physical conditions for the subject were given above. An attempt was made to keep any change of acceleration at a value less than the threshold of stimulation of the semi-circular canal.

5. The subject was required to signal the instant he was certain that his position had changed from the original position and to indicate the direction of change. In general, major changes in the position of the tilt-table were necessary before they were identified by the subject.

6. The modest experimental setup, using hastily assembled equipment, was not sufficient to provide accurate quantitative results. However, an average of about 17° was necessary to detect positional changes. In almost every experiment the clues to change of position were factors unrelated to vestibular stimulation, but rather to the crudeness of the setup--factors such as change in pressure within the middle ear and sinuses, bubbles passing over

the skin, change of water temperature, or rough movement of the tilt-table. Moreover, it was noted that beginning from a vertical head-down position (180^{o}) very large movements of the table (of the order of 100^{o}) did occasionally take place before their direction could be identified.

7. The technical problems which were encountered could not be solved satisfactorily. Although the subject could get to the surface immediately after loosening the safety belt, the three main participants developed bilateral, acute, otitis externa, thus terminating prematurely the experiment.

8. Cost of the devices used and expenses for the experiment were very low due to the availability of the equipment at Randolph AFB.

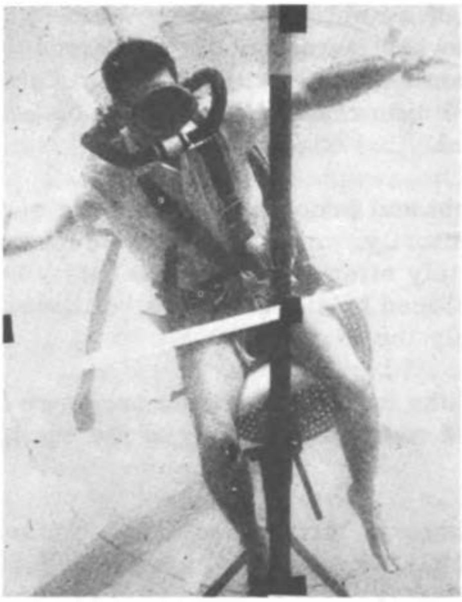
9. The study was terminated with the transfer of Major L. A. Knight, USAF, (MC), in 1957.

10. References included in the general bibliography at the end of this report.

Supplement 1.

In the spring of 1957, Captain Grover J. D. Schock, Assistant Chief, Biology Branch, Aeromedical Field Laboratory, AFMDC, Holloman AFB, conducted a series of similar experiments in the El Paso YMCA's indoor pool. The subjects were placed on a tilting seat in eight feet of water and blindfolded (see Figure 66). Later in the same year, underwater experiments were made in the pool of the New Mexico School for the Visually Handicapped in Alamogordo, N. M. These tests demonstrated an impairment of orientation somewhat like that found in aircraft experiments without visual clues. In one type of underwater experiment, subjects were tilted as much as 22^{o} before perceiving the tilt.

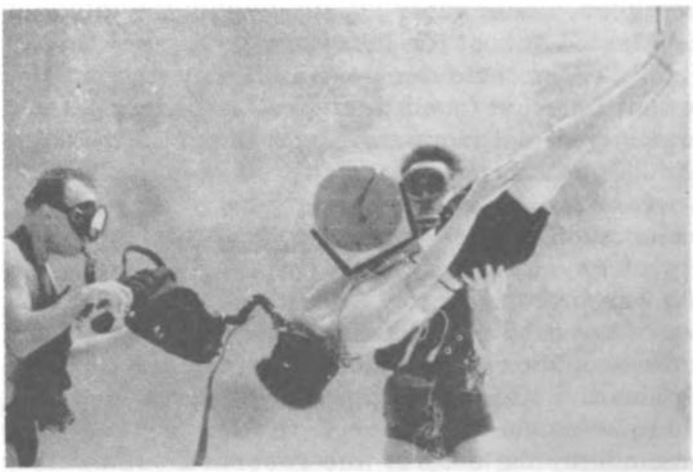
Similar studies were performed by R. M. Margaria of the Laboratory of Physiology, University of Milan, Italy. Position orientation was investigated by attaching a watchlike indicator to the body of the subject. A pointer rotating about the center of the indicator was used by the subject to indicate the subjective vertical. The direction of the gravitational vertical was given by an air bubble released from time to time in front of the indicator. The error made by the subject was recorded. His respiration was maintained through an automatic underwater oxygen-breathing



(Official USAF Photo)

Figure 66. Experiments on the Effect of Simulated Weightlessness Through Water Immersion

apparatus which was carried by an experimenter to prevent any possible pull of the subject's body, while an assistant was in charge of placing the subject in different positions and of recording the data (see Figure 67).



(Journ. of Aviat. Med. 29: 1958)

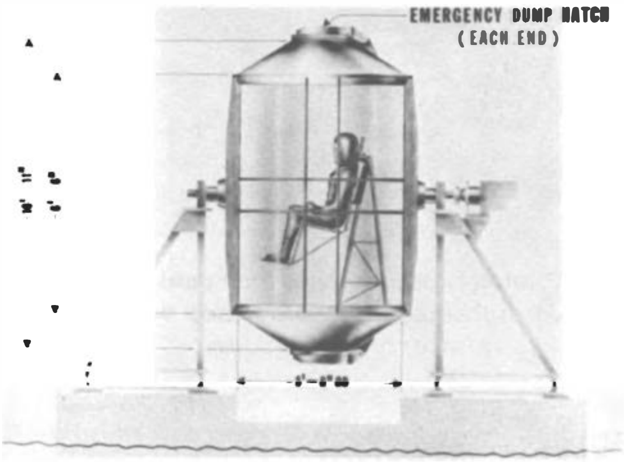
Figure 67. Experimental Setup for Orientational Experiments Under Water

The results of these experiments were very interesting. The subject seemed to be completely disoriented at first, the vertical was estimated at random, and errors up to 180° occurred; i. e., the subject often indicated the direction opposite to that requested. Only after four or five tests did the subject achieve more reliable results. In positions close to normal, and after a period of training, an average deviation of about 12° from the true vertical direction was obtained.

NASA Weightlessness Simulator

1. Work with the NASA weightlessness simulator was conducted at NASA-Langley Research Center, Hampton, Virginia. Size of the present staff unknown.

2. The simulator which consists primarily of a water-filled tank is driven by an air motor at various rates of rotation up to two cycles per second. The air supply for the subject is located in the water tank and the air exhaust is to atmosphere (See Figures 68 and 69).



(NASA Langley Res. Cen., Hampton, Va.)

Figure 68. NASA Weightlessness Simulator

3. The subject can be oriented in the tank as shown in Figure 69 and also can be turned 90° so that the axis of rotation would pass through his shoulders. The vertical location of the subject is arbitrary and can be changed so that the axis of rotation passes through any level between the subject's buttocks and his ears. (See Figure 70).

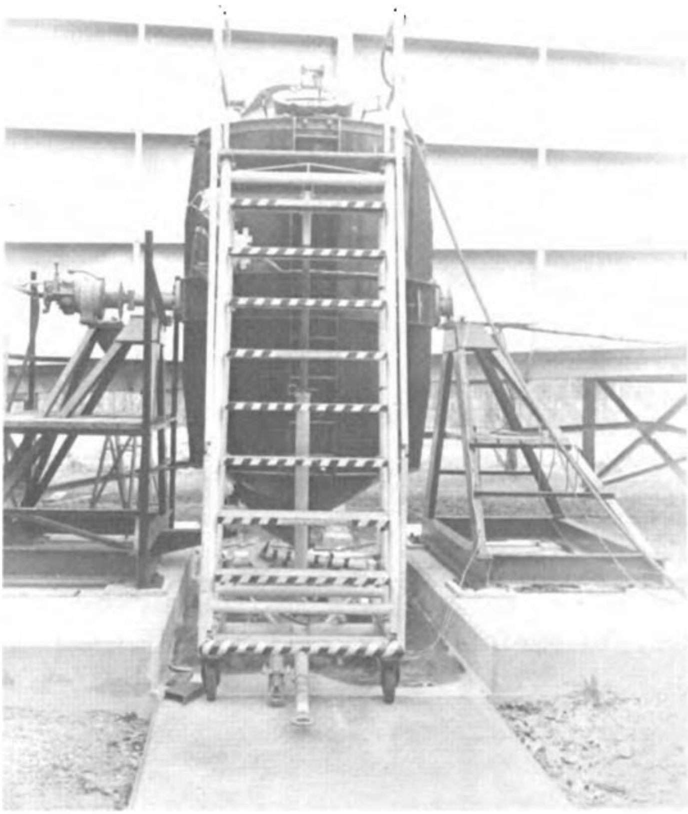


Figure 69. Photograph showing external configuration of NASA weightlessness simulator with access platform in position.

4. See above.

5. A communication system is provided so that the subject can communicate directly with the operators. No information available at present about the type of loop system used and about the types of recording facilities.

6. The rate and depth of the subject's respiration will be continuously monitored. In some of the tests, the subject will be required to perform simple tasks. Electrocardiographs and skin resistance are among the measurements to be made in some of the first experiments with a human subject, as well as the breathing rate and depth.

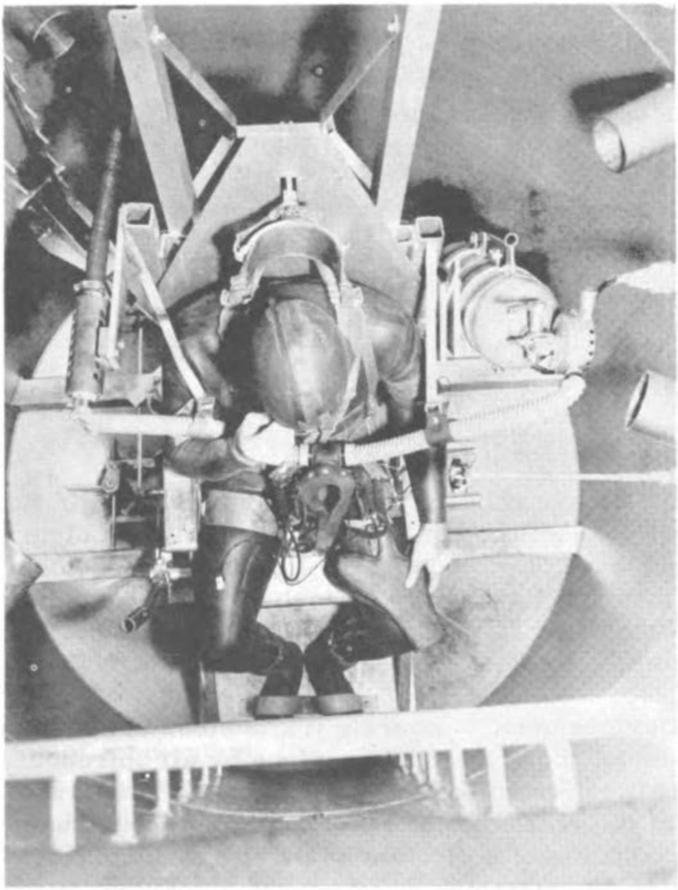


Figure 70.

7. Provision has been made so that either the subject or the operators can dump the water in case of emergency. Time to empty is estimated to vary from four to fifteen seconds depending on test conditions. Air valves have been provided to prevent cavitation when dumping.

8. The approximate cost of the use of the simulator is estimated at about $160 per hour. Arrangements for use should be made through NASA headquarters. The prospective subject should have some previous training in underwater diving with self-contained breathing equipment. No experiments are scheduled at the present time.

Messrs. Ralph W. Stone, Jr., and William Letko will be in charge of the use of the simulator. Mr. Stone is a Research Engineer and Assistant to the Chief of the Stability Research Division. Mr. Letko is a Research Engineer from the Missile Systems Section of the Stability Research Division.

9. Preliminary tests of the tank not involving humans or animals were scheduled for July 1959. Tests with a human subject were made in 1959-60. They were discontinued in 1960-61.

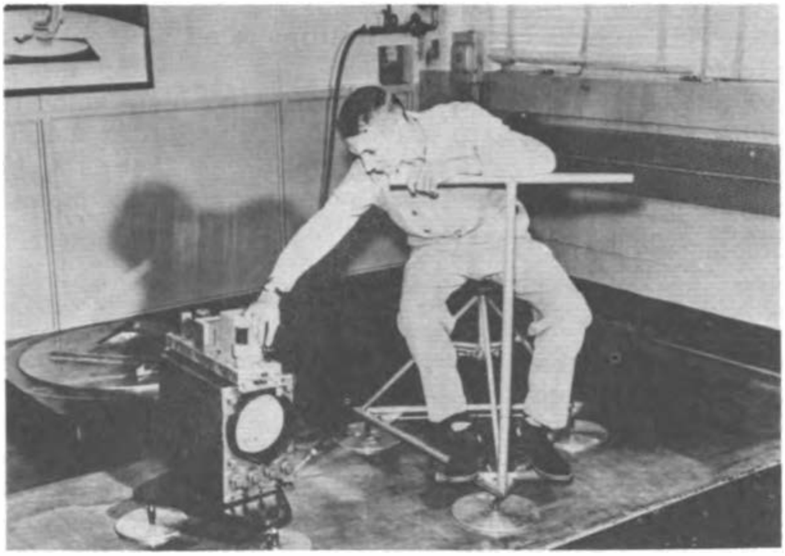
10. NASA-Langley Research Center, Langley Air Force Base, Hampton, Virginia.

WADC Frictionless Device

1. One of the aspects of human performance in the weightless state is lack of friction. In order to study this problem, some devices have been developed by the Unusual Environment Section of the Engineering Psychology Branch of the Aeromedicine Laboratory, Wright Air Development Command. Size of the present staff unknown.

2. Devices used to operate frictionless are, in general, metal discs supported above a smooth surface by air introduced under pressure between the discs and the surface. The first such device employed at the WADC is the rotary platform constructed by D. A. Huber. It consists of a circular plate 36" in diameter, pivoted in the center and supported by pressurized air. By virtue of its center pivot, it has only one degree of freedom, that of rotation. In an attempt to obtain complete freedom in the horizontal plane, another device was developed in which compressed air is delivered through a center hole from the top of a circular plate rather than through the surface under the plate. This allows the circular plate to float freely over the surface, thus giving it three degrees of freedom--two for translation in the horizontal plane, and one for rotation about a vertical axis. This development was carried out by D. A. Huber and M. J. Warrick, also of the WADC.

In another design, three of these plates are mounted under a tubular framework to produce a tricycle-like device capable of carrying a man (see Figure 71). This model was constructed by J. F. Rievley, WADC, based in part on information provided by the Ford Instrument Company. Further improvements included a triangular platform mounted on three of the plates and a square platform mounted on four of the plates. These platforms were developed to handle equipment and carry loads in excess of 400 lbs. without "grounding" or sticking.



(Official USAF Photo)

Figure 71. WADC Frictionless Device

3. The motion of the device is in accordance with the law of conservation of momentum; i.e., $m_1v_1 = m_2v_2$, for the linear case where m_1 and m_2 are the masses, and v_1 and v_2, the velocities of the bodies involved. For the case of rotation, the law is that of conservation of angular momentum, and is expressed by $I_1w_1 = I_2w_2$, where I_1 and I_2 are the moments of inertia, and w_1 and w_2 are the angular velocities. From this it follows that a most difficult situation occurs, if a man is performing a bodily task in a frictionless state. Any force applied by the man will, by its reaction, move him away from the equipment. This is in accordance with Newton's third law, while the magnitude of the man's motion is described by Newton's second law.

The experimental situation is an unstable one. If a man wants to work, he will have to attach himself to the equipment. Thus, the situation changes immediately to the converse of the case with the man attached and free equipment; i.e., the man himself will tend to rotate about his point of attachment when he applies a force to the equipment. His rotation, as that of the equipment before, will depend upon his moment of inertia in this position, and the torque he applies.

4. As mentioned earlier a direct consequence of the zero-G condition is loss of the friction normally occurring as a result of

gravity. This follows from the definition of a frictional force. This is the force which must be overcome in order to start a supported mass in motion or to keep it in motion at a constant velocity. The former is called the static frictional force; the latter the sliding frictional force. The frictional force in either case is a certain fraction of the force normal to the plane on which the mass rests or moves. Expressed mathematically,

$$f = \mu F, \tag{60}$$

where f is the frictional force, F the normal force, and μ the coefficient of friction, the constant of proportionality relating these two forces. The value of μ is different for the static and sliding conditions, being generally greater in the static case. From the equation, it follows that when there is no normal force, as in the weightless state, there is no frictional force; i.e., when $F = 0$, $f = 0$, too. Frictionlessness, then, accompanies weightlessness; and a device or situation in which friction is effectively eliminated can be used to simulate one important aspect of weightlessness.

In early experiments, a six-inch piece of 7/8-inch hexagonal steel stock material was used as a handle for the subject. The material was oriented with its longitudinal axis placed horizontally, and one end fastened in a torque-meter. The subject stood normally and grasped the handle which was at about waist level. The subject was instructed to apply and maintain torques by twisting the handle clockwise and counterclockwise, respectively, and their magnitudes were read directly on a torque-meter.

In another experiment, the rotation of a man by reaction to a torque was investigated. Figure 72 shows the rotary frictional platform with a subject about to exert a torque on the overhead handle. The experiment at the left was set up to time a single revolution, and thus determine the rotation rate caused by the reaction to the torque. The measurement was accomplished automatically by use of a microswitch actuated by the platform. Reaction force to a torque applied to handhold by a subject on the frictional scooter was measured by a strain-gauge device at his right hand.

6. A continuous record of the subject's applied force was obtained on an ink oscillograph receiving the output of the bridge amplifier used with a strain-gauge.

7. No data available.

(Official USAF Photo)

Figure 72. Torque Tests on the WADC Frictionless Platform

8. Cost of device and of its use by others unknown. Request for the use of frictional device by other agencies should be directed to: Commander, Aerospace Medicine Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio.

9. Future tests involve the development of a six-degree of freedom mechanical, frictional device, the investigation of mass-force relationships in the frictionless condition, and the development of tools and equipment adequate for work under weightless conditions. Moreover, a twin gyro backpack will be developed for the stabilization of man in the zero-G condition.

10. References included in the general bibliography at the end of this report.

<u>Orbital Air Bearing Simulator, Space Task Group, Langley, Virginia National Aeronautics and Space Administration</u>

The simulator is a device being constructed for training of pilots for Project Mercury. It consists of a couch, such as those to be used to increase the pilot's G tolerance in Project Mercury, mounted on top of a five inch diameter ball. This ball is in turn supported in a hemispherical cup but rides on a cushion of pressurized air rather than a metallic contact. The subject lies on his back on the couch which is inside a mock-up of the Mercury capsule. He has a side-arm controller which can give the simulated capsule angular motions but not translational motion. The capsule can rotate up to ±45° in pitch or roll with unlimited rotation in yaw ($\dot{p}$, $\dot{q}$, $\dot{r}$). The over-all weight of the apparatus from ball up is approximately 1,000 pounds. No damping is provided; however, the device does closely simulate the torque-to-inertia ratio of the full scale vehicle. The rotational cues to the pilot should therefore be realistic.

The pilot will be provided with instruments and will have the periscope-type display system to be utilized in the flight vehicle. Through his periscope he will see on a screen a back-projected view of the earth scaled to correspond to his expected flight altitude. With this device, he will be able to realistically simulate his control problems for manual flight while in orbit, except for those brief times when longitudinal accleration (x) is dominant.

A picture of the simulator is shown in Figure 73.

The Multi-Axis Test Facility

1. The Multi-Axis Test Facility was constructed during 1959-60. It is located at the Lewis Research Center, NASA, in Cleveland, Ohio. The present staff consists of about 25 professionals and technicians.

2. The device, shown in Figure 74, consists of three concentric supporting structures that have been fabricated from thin-wall aluminum tubing two and one-half inches in diameter. Each of the cages is gimbal-mounted to permit rotation through 360° at rates up to 360°/sec. The entire system is mounted in a yoke, 21 feet in diameter, in the Lewis Research Center's Altitude Wind Tunnel. A 50 foot diameter section of the Tunnel has been converted to accommodate the facility. The Wind Tunnel is capable of operating at a pressure equivalent to an altitude of 100,000 feet. Payloads up to about 2,000 lbs. of thrust can be tested.

3. Pitch, roll, and yaw maneuvers are possible, either independently or in combination, to simulate random tumbling. Propulsion of the two outer cages is produced by a jet-reaction system, wherein gaseous nitrogen contained in spherical tanks at

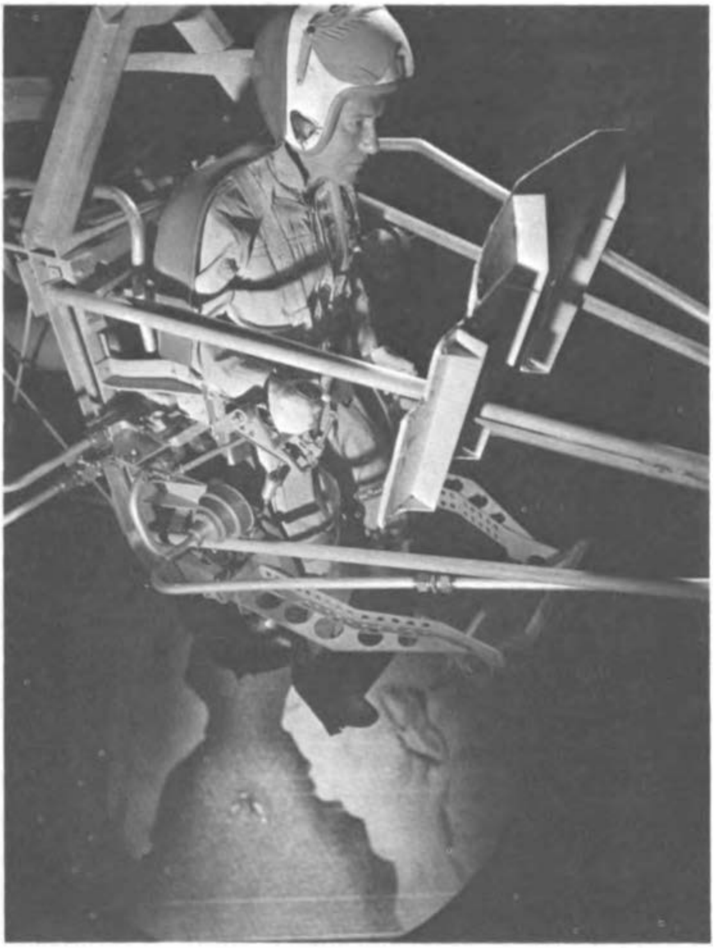


Figure 73. Orbital Air Bearing Simulator

2,200 psi is expelled through small nozzles located on the periphery of each cage. Further, the innermost cage has installed on it ten reaction motors, eight of 20 lbs. thrust each and two of 5 lb. thrust. A total of 5 lbs. of thrust is provided in the innermost cage in the roll direction and 40 lbs. in each of the yaw and pitch modes. Rotation can be initiated from the ground control station as well as from the subject's position within the facility.

4. The objective of the facility is to test the behavior of payloads during tumbling motion. This also includes the reactions and control capabilities of a human subject in a state of frictionless motion depending primarily on the inertia of the moving mass. The

assumption that the pilot of a space vehicle will counter each component of a multi-axis rotation individually leads to the conclusion that the energy required to counter multi-axis rotation would be the sum of the energies required to counter each single axis component. However, the fixed position of the jets used to counter the rotation of the multi-axis test facility makes this untrue. The pilot cannot react fast enough and with sufficient accuracy to apply counter thrust at high rates of rotation. The instruments he uses usually move too rapidly from a full scale position in one direction to that in the other so that he is unable to follow. Moreover, during rotation of 30 rpm or higher about all three axes, a feeling of discomfort was experienced, which took the usual forms of motion sickness after a prolonged exposure to continuous spins.

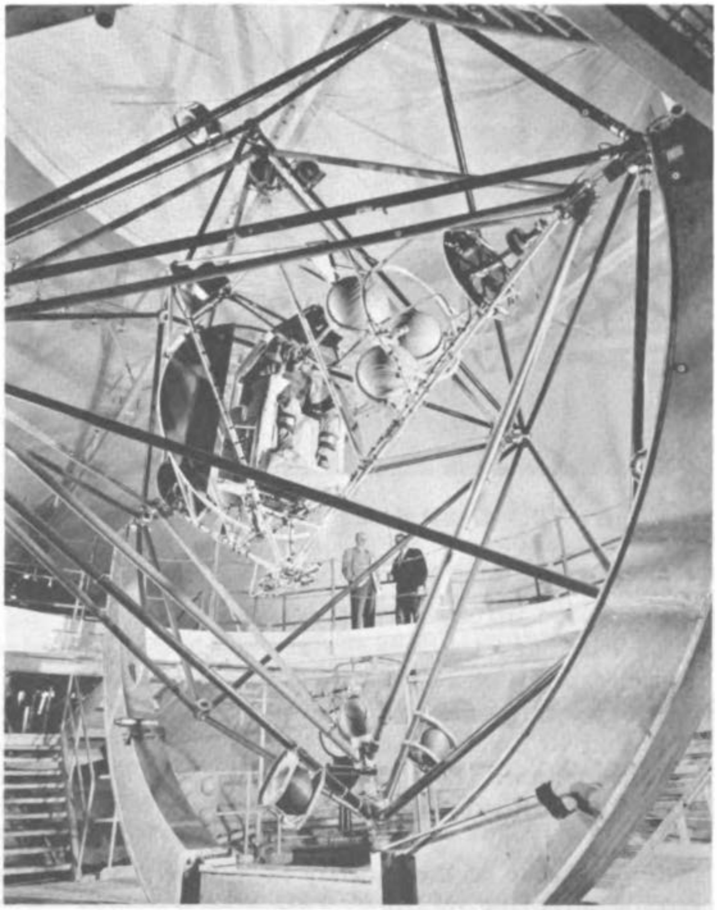


Figure 74. The Multi-Axis Test Facility installed in the altitude wind tunnel. A pilot is shown in the support couch.

5. The test subject is seated at the center of the innermost cage in a specially molded Styrofoam couch to reduce body shifting during maneuvering. He is restrained by means of leg and thigh straps and a chest support harness. The subject's head is held in place by a Lombard flight helmet that is maintained in a fixed position. The upper part of the subject's body is enclosed in a light-proof compartment to eliminate visual orientation during the tests. Only the subject's arms are free to move. The axes of rotation converge near the chest of the subject. Communication is maintained between the pilot and the ground control station by radio.

Orientation is accomplished by instruments. The on-board instrumentation display has been kept to a minimum and provides only an indication of rate and direction of rotation. The rates of pitch, roll, and yaw are indicated by individual meters. Also, a combined rate indicator (a modified LABS indicator) is provided to display the rates of rotation in a single instrument. Small panel lights are provided to indicate the direction of counter thrust applied by the pilot during control operation. These are connected directly to the solenoid valves of the reaction motors and give an immediate indication of inadvertent cross-coupling, a usual and undesirable by-product of a single three-axis hand controller. The nitrogen supply and operating pressure are also displayed.

The pilot's control system consists of a manually operated on-off type controller that actuates five pairs of nitrogen jet nozzles located on the innermost (roll) cage. A hand controller, capable of three degrees of motion is operated by the pilot's right hand. Movement of the hand controller to the left or right will induce a roll motion. Forward and backward motion will cause pitch, while twisting the controller will cause a yaw movement. The pilot can either start a tumbling motion or he can counter the rotation started from outside the vehicle and thus stabilize the attitude of the vehicle.

6. Three rate gyros are used to measure the rates of rotation about the orthogonal axes. The gyros are mounted beneath the pilot's seat such that they are perpendicular to each other. They operate about the longitudinal, vertical and horizontal axes as viewed from the pilot's position; that is, the vertical axis is defined to pass through the length of the pilot's body. Rotation about this axis is termed yaw motion. When the pilot is seated upright, this maneuver coincides with the familiar use of yaw as it occurs in an airplane. If the pilot is turned 90° about the horizontal axis, either on his back or face downwards, lateral movement

to his left or right is still yaw motion. Similarly, roll is defined as rotation about the axis passing through the pilot's body from front to back; and pitch is motion about the axis passing from the pilot's left to right side.

In addition to the gyroscopic instrumentation, each cage is equipped with a potentiometer that indicates the relative position of the cage with respect to the other two cages. Both the position and rate indications are recorded on a high-speed oscillograph outside the test vehicle. In addition, the duration of activation of each set of jet nozzles is also recorded.

7. Motion can be stopped by means of an automatic brake, which can be initiated by the subject or by the controller on the ground.

8. Inquiries about use by other agencies than NASA, and cost estimates, should be made to the Director, Lewis Research Center, NASA, Cleveland, Ohio.

9. Projects are active on the study of physiological conditions during spinning and tumbling. One study on ocular nystagmus by personnel of the Lewis Research Center has been concluded.

10. (1) Pilot Control of Space Vehicle Tumbling, and (2) Pilot Reaction to High Speed Rotation; both by James W. Useller and Joseph S. Algranti, Lewis Research Center, NASA, Cleveland, Ohio.

Martin Reaction Control Simulator

1. The construction of a Reaction Control Simulator has been proposed by the Space Medicine Section of the Martin Company, Denver, Colorado. A similar device, based on the principle of frictionlessness by means of air bearings, is now under construction at the Ames Research Center, NASA, Moffett Field, California. The size of the present staff is unknown.

2. The Martin simulator is a spherical shell 10 feet in diameter (see Figure 75). The shell will be made from two hemispheres of fiber glass construction. The sphere is supported on a contoured base from which a stream of air forms an air bearing between the base and the sphere, reducing friction to a minimum during rotation. The supporting air will be directed from a nozzle in such a way as to suspend the sphere above the base, with no connection between. It will require approximately 6 psi to support

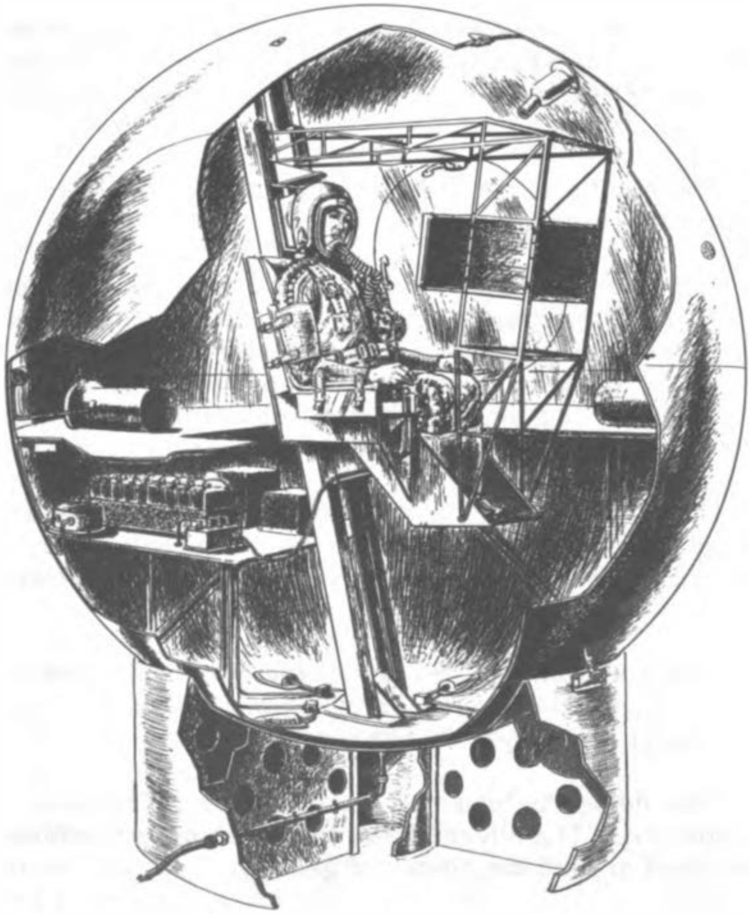


Figure 75. Martin Reaction Control Simulator
General Arrangement of Basic Unit

this sphere. The 84 inch diameter base is supposed to have a spherical seat to support the simulator when it is not supported by the air stream. The seat of the base will match the radius of the sphere with the exception of a small area around the air nozzle. It will be covered with a resilient material to protect the sphere's smooth surface. The gross weight of the sphere, including a 230 lb. man and the basic instrumentation, will be approximately 1,500 lbs.

The center of gravity of this sphere will be its geometric center, and the installation of instruments and other hardware is arranged to achieve this balance. Within the sphere, a honeycomb floor, structurally supported by extruded aluminum members, is installed on either side of the seat and serves as a convenient landing for servicing the simulator and for access to the pilot's seat. The area under the floor can be utilized for the location of equipment.

3. The simulator described in the Martin proposal has the following dynamic characteristics:

(a) The sphere, supported by the air cushion, is capable of rotating about any of the three axes in the same manner as a space vehicle. Reaction jets at the surface can be used to orient the sphere in any direction. These thrust jets simulate the hydrogen peroxide jets applied in manned space vehicles.

(b) The mass and moment of inertia is compatible with current space vehicle designs and these factors can be varied over a wide range to give a more exact simulation of specific designs.

(c) The reaction jets are energized by an on-board air supply which the pilot must learn to conserve as he would in an actual space vehicle situation.

4. The device is based on the air bearing principle, as described before. The advantage of this system is complete freedom of rotation around the center of gravity.

5. A pneumatic reaction jet system, consisting of 12 fixed air jets, will be located on the periphery of the sphere. A set of four jets is located at each pole of the sphere, while four single jets are located on the equator of the sphere. With the sphere supported by the air bearing, it has unlimited rotation in any plane by means of the control stick mounted to the arm of the pilot's seat. This is an unrestrained movement control stick designed for fingertip operation; i.e., full range of movement of the stick will be accomplished by use of the fingers only without movement of the wrist or arm. The reaction jets impart movement to the sphere in any of the three principle axes. The control stick is spring-restrained to hold it in a central position when no finger pressure is applied. The stick is twisted to achieve a pure yaw; moved to the right or left for a roll; and forward or backward to achieve pitch motion.

6. The simulator is capable of being instrumented for the more sophisticated program of space flight training such as inertial

guidance, radar displays, celestial navigation, terminal landing control, etc. The control system is capable of accepting a programmed flight through an on-board tape recorder and signal-mixing circuit. Any degree of complexity in the programming is feasible. Flight attitude indicators and communications systems are available.

7. For operational safety, revolutions are limited to a rate where the stored energy due to rotation of the sphere is less than the work required to roll the sphere over the edge of the base. Maximum revolution rate is therefore established by calculation at 20 rpm. Malfunction of the air supply will cause the bearing to collapse and stop the sphere. The pilot may then be stopped in any position. In this case, the sphere can be relocated to release the pilot. The doors are equipped with flush mounted latches and may be opened from inside or outside.

8. Approximate construction costs are unknown. Information about the use of the NASA Air Bearing Reaction Control device by other agencies may be obtained from the Director, Ames Research Center, Moffett Field, California.

9. No information is available at the present time on projects planned for the NASA device.

10. The description of the Reaction Control Simulator is based on the Martin Report M-M-P-58-51, which contains proprietary information of the Martin Company not to be utilized by any other agencies without permission. The Martin Reaction Control Simulator has been described in the company report as of November 1958. It is assumed by the author that the air bearing reaction control device constructed at Ames is based on the same main principles.

SUMMARY STATEMENT

The investigation of animal and human responses to weightlessness has become an important field of research in bioastronautics. However, experimentation is rather difficult because of the unusual conditions in which the state of reduced gravity and weightlessness can be obtained. In general, three types of environmental situations have been employed; namely, the free-fall situation, the dynamic condition in aircraft and rockets, and the simulation of weightlessness by immersing a body in water. The devices employed in this research were described.

With the exception of Laika, who was exposed to weightlessness in an artificial earth satellite (Sputnik II) for seven days, exposure to subgravity and zero-G states was of only short or moderate duration. There is neither experimental evidence nor indication through subjective experience that subgravity and zero-G states as such have serious physiological consequences. However, deviation from normal behavior by individuals with a low tolerance was observed. This may be due to either faulty research design, such as changes of the acceleration pattern involved, or it may concern individuals having an extremely low or pathological motion sensitivity. On the other hand, relatively fast and reliable adaptation to these states was observed if normal or pre-conditioned subjects were employed, and if preventative and protective measurements were taken.

While the early experiments on weightlessness only concerned the seated and safely secured test subject, later studies were done with subjects acting and floating about in the weightless state. The analysis of the experiments shows that subjects at rest can very well tolerate the weightless state, and that no deleterious Coriolis effects occurred during head and body movements. As far as performance was concerned, no special provision, such as wider spacing of switches and levers, or springs or other restraints to prevent the arm from over-shooting when reaching or aiming for objects, need be considered. Without exception, the subjects have been able to adjust themselves to weightlessness in a matter of seconds; then their motor performance was as accurate and rapid as during normal conditions. In fact, subjects who performed experiments in which the arm must be extended and then raised and lowered over a considerable portion of reach reported that it was easier to work during zero-G. However, it is necessary to work at a solid position in order to maintain performance during weightlessness. A normal seat with a tight safety belt has proven quite adequate in this respect. Tools, specially designed for work under zero-G conditions, facilitate the work.

The most interesting experiment is the one in which human subjects were allowed to float without restraints of any kind. The experiments were done to study the ability of the individual to move during weightlessness; and to maintain his position orientation during the zero-G condition. With a little practice it was possible to maneuver in the weightless space as though it were filled with water.

While the swimming type movements were not as effective as they are in a liquid, they were useful for accelerating the body and for changing its direction while floating through the weightless environment. A great number of subjects have gone through the floating experiments without ill effects or disorientation. However, all subjects who have performed tumbling motions during the weightless period reported extreme disorientation, sometimes bordering on a severe case of vertigo, after a few revolutions. Undesired physiological effects were also observed during post- and pre-acceleration weightlessness; that is, when the state of weightlessness was preceded or followed by high accelerations. We are furthermore concerned that when the exposure becomes longer, there may develop minor physiological disturbances which, if cumulative and irritating, may cause or enhance psychological effects.

Subjects immersed in water reported a rapid loss of orientation when visual clues were excluded; and large changes in body position were made before they were noticed by the test subjects. However, the immersion technique provides a rather crude simulation of the weightless state with respect to the neurological and psychological parameters involved. Although the results obtained by immersion may not be directly applicable to the prediction of psychophysiological response during the true zero-G condition, further improvement of this technique may be valuable for the investigation of the vestibular factors involved.

In summary, research on subgravity and zero-G effects must be emphasized in the following areas:

a. Animal and human performance. Although no practical implications for short and moderate periods of time are anticipated, physiological and psychological deviations from the normal pattern may occur after exposure to long periods of zero-G.

b. State of consciousness, well-being, and performance during rocket acceleration patterns including states of post- and pre-acceleration weightlessness.

c. Clinical studies of certain critical physiological functions such as cardio- and hemodynamics, respiration, digestion, and basal metabolic rate, under conditions of changed gravitational vectors.

d. Perception, orientation, and performance characteristics under abnormal gravitational conditions. This mainly concerns research on visual and vestibular functions under true or simulated weightless conditions.

e. Application of drugs and other remedies for the prevention of adverse effects associated with accelerative changes and weightlessness.

f. Design and construction of protective devices adequate for work and life in the weightless environment.

g. The design of new devices and the improvement of existing methods for training and conditioning of the astronauts.

h. Studies on readaptation to the normal gravitational conditions after prolonged exposure to weightlessness.

i. Research on the metabolism, growth, reproduction, and decay of organic matter, such as lower organisms, tissue cultures, cellular systems, plants, and lower animals.

j. Investigation of the effects of the artificial gravity, subgravity, and differential gravity on the organism while resting and moving.

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APPENDIX 1

MEDDH-PS Date:____________________

Dear

The panel on acceleration of the Armed Forces-National Research Council Committee on Bioastronautics is conducting a survey on motion simulators. I have been appointed by the chairman of the panel to report on zero-G devices and simulators, including USAF, NASA, and Cornell Aeronautics Laboratory aircraft; subgravity, water immersion, and frictionless devices; and similar facilities. In view of the importance of this area of investigation, and because of the complexity and rising costs of such activities, this review appears desirable to assure maximum usefulness of such facilities, optimum cooperation between agencies, and to guarantee that new requirements of the future be incorporated in the proposals. It is planned that the information will be distributed later by the Armed Forces - NRC Committee on Bioastronautics to the various agencies and individuals interested in acceleration and subgravity research.

Since you are using a device falling in the category indicated above, your cooperation in this survey is requested. Please use the attached outline in describing your device, and have your description returned to me at your earliest convenience.

Sincerely yours,

DR. S. J. GERATHEWOHL
Chief, Bioastronautics Research Office -
AOMC (ABMA)
U. S. Army Medical R&D Command

1 Incl
Proposed Outline

APPENDIX 2

DESCRIPTION OF ZERO-G DEVICES AND SIMULATORS

1. Name of the device, location, and dates of construction and modification. Size of the present staff.

2. Description of the mechanical system, with photographs or diagrams. Size and weight limitations of payload.

3. Motion, acceleration, and velocity characteristics. Modes of producing or simulating subgravitational and weightless states. Duration of sub- and zero-G condition.

4. If available, theoretical basis and equations representing the physical conditions for the subject seated on the device or simulator in a specified and typical manner. If available, indications of the time delays (or input-output transfer functions) of the control system inputs and simulator responses should be included.

5. Description of the control system (manual, automatic, tape, film, computer, etc.). Open loop (command signal only) or closed loop (with feedback of actual performance) control. Status of mechanization and automation. Can a subject on the device be in the control loop?

6. Instrumentation and data reduction. Recording channels and noise levels. Types of information which have been, or will be, recorded.

7. Safety features and requirements.

8. Approximate cost of the device or simulator and of their use by others, and procedures for arranging such a use. Names and positions and organizational relationships in charge of the use of the device.

9. Description of projects and workload during the past year. If available, the schedule of planned use for the next years.

10. Bibliography, including classified reports, of journals and available government or industrial reports of all studies with the zero-G devices and weightlessness simulators of biological application.