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AERONAUTICAL SYSTEMS DIVISION STUDIES IN WEIGHTLESSNESS: 1959-1960

COMPILED BY

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FOREWORD

The material contained in this report was contributed by scientists from the Aeromechanics Division, Deputy for Technology, and the Aerospace Medical Laboratory and covers the period 1959-1960. It was compiled by Lois Hmmer, Human Engineering Branch, Behavioral Sciences Laboratory of the Aerospace Medical Laboratory under Project 7184, "Human Performance in Advanced Systems," Task 71585, "Human Engineering Design Criteria for Space Vehicle Systems," Capt John Simons was the project officer. This work was performed at the request of the joint Air Force Systems Command/National Aeronautics and Space Administration Zero-g Survey Panel, which expressed the need for a periodic summary of Aeronautical Systems Division efforts in the area of weightless research. The authors are indebted to the various Air Force, Navy, and industrial researchers who conducted programs on the Aeronautical Systems Division facilities for weightless research; a contributor has been named for each study reported.

This report will serve as an interim progress report until Volume III of Handbook of Instuctions for Weapon Systems Development is published by Systems Design Principles Branch, Directorate of Engineering Standards, Deputy for Engineering, ASD.

ABSTRACT

Facilities and techniques used at Aeronautical Systems Division to study the effects of weightlessness are described; completed experiments and those started before January 1961 are discussed. Topics are grouped under two main headings: aerospace medical studies and aeromechanics studies. Specific problem areas and methods of experimentation are emphasized. Findings are briefly stated.

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I. INTRODUCTION

THE AERONAUTICAL SYSTEMS DIVISION WEIGHTLESSNESS PROGRAM

Weightlessness (also termed zero g in this report) is the absence of any apparent gravitational pull on an object. An orbiting object above the earth's surface is a special case of "free fall" as in an aircraft when flying a parabolic curve. A normal condition on orbiting satellites, it can be achieved only for brief periods by an aircraft in parabolic flight. Weightlessness is characterized by such unfamiliar conditions as lack of friction, lack of weight vectors, the instability of free-floating bodies, and a preponderance of previously neglected minor forces. Before man and machines are subjected to these unusual factors for an extended period, a major research effort must be conducted.

The purpose of this report is to describe recent and current research designed to obtain information about the effect of weightlessness upon performance.

The problems of research in this area are especially challenging because of the difficulty in attaining weightlessness for a sufficient duration to obtain performance measures not influenced by extraneous conditions of flight. The terms "weightlessness" and "zero g" used in this report are defined operationally as the condition existing on board the laboratory aircraft during the time that it is traversing its parabolic flight path. During the zero-g flights, it is possible that, in addition to weightlessness, changes in sound level and vibration, changes of cabin pressure, or the existence of minor, transient accelerations due to air turbulence may affect the dependent variables under investigation. Similarly, excessive g preceding and following weightlessness probably influences human reactions to the zero-g environment. Results of zero-g investigations, therefore, must always be interpreted with the effects of the uncontrolled experimental conditions in mind.

The request to develop a weightless condition to study muscle force capabilities and propulsion requirements for free-floating man launched the Aeronautical Systems Division's program for weightless studies in February 1958. A C-131B aircraft that, in contrast to fighter planes used by previous investigators, offered a large cabin area for a laboratory was proposed for these studies.

Since the initial effort by the first small working group, the program has grown to include scores of personnel from five Aeronautical Systems Division Laboratories, National Aeronautics and Space Administration, numerous contractors, and other agencies. Two aircraft, the C-131B and the KC-135, are now being used to produce subgravity and weightlessness; air-bearing and water-submersion facilities are in use as partial-simulation devices.

Much of the early research in the unique facility of the cargo plane was necessarily of an exploratory nature; thus, only qualitative observations and anecdotal reports defined the problem areas. However, as the program expanded, more formal and better-controlled experiments could be conducted. With the expansion of the ASD program and the programs carried out by other agencies, the following major efforts were suggested to be essential to attack the problem properly:

1. Determine potential problem areas within the fields of physiology and psychology, heat transfer, and fluid dynamics;

2. Investigate other potential problems by surveying those equations containing g terms that may affect airborne systems and determine possible solutions;

3. Organize an information center that will compile, coordinate, and distribute data on past, current, and projected studies and descriptions of available research facilities.

The first effort was accomplished at the direction of AFSC. ASD is currently studying the second effort and AFSC has directed that the information center, effort 3, be established. The center is being established by the Deputy of Engineering, ASD.

The following areas appear to be of major concern to researchers:

1. Fluid dynamics and heat transfer: In designing space vehicles it is necessary to understand the problems associated with the functioning of propellant tanks and power systems in a zero-g environment; weightlessness will prevail during the coast periods between firings of rocket stages and while a vehicle is in orbit. Since fluid orientation affects heat transfer, venting, and liquid transfer systems, its effects on these related problem areas must be determined. The major problem in venting tanks and supplying vapor to the turbine in the Rankine cycle power system is phase separation. Liquid would demolish a turbine in a few seconds and it is undesirable to vent liquid overboard. The problem of phase separation must be considered in order to make possible the transfer of propellant to the engines of a vehicle with re-start capability and in order to pump liquid from the condenser to the boiler in the Rankine cycle system. Heat transfer information is needed to establish design criteria for condensers and boiler of power units and to establish tank insulating and venting requirements.

2. Operator performance: Preliminary findings suggest that harnessed operators will adjust quickly to short-term physiological changes; however, the free-floating orbital worker may be overwhelmed with problems of orientation, inadvertent tumbling, locomotion and stabilization, and material handling. Devices and aids must be developed to enable the worker to perform simple maintenance, supply, and inspection functions on space vehicles.

3. Human limitations: Short term measures of physiological functions have revealed tendencies toward nausea, blood pooling, intestinal deformation, postural "closure," and vestibular disturbances. The long-term effects of these and other possible changes, such as muscular atrophy and decrements in visual acuity and verbal intelligibility, will affect seat design, control forces, panel arrangement, cockpit lighting, rotation rates, and acceleration and vibration re-entry limits. Criteria will be developed for crew selection and training and vehicle envelope limits for vehicles such as Mercury and Dyna-Soar. This program has a unique potential for basic research on human and animal functions that are gravity-based, such as the vestibular and postural reflexes.

This first report presents studies completed on ASD facilities. It serves to document the more informal, early observations that were not of sufficient scope to warrant separate publication, and to summarize in one source data from the more rigorous investigations. The intent and method of investigation are briefly described, the findings given, and related references listed. In many cases, more detailed accounts can be found in ASD technical reports or other papers devoted to the experiment discussed.

The pertinent data from these and non-ASD studies will be published with 90-day revisions in a forthcoming AFSC manual, Handbook of Instructions for Weapon Systems Development, Vol. III, dealing with design requirements for new regimes of flight vehicles. This volume is planned to serve as a subgravity handbook for the space vehicle designer.

II. FACILITIES AND METHODOLOGY

1. C-131B (CONVAIR 340)

Capt. Jerry Carlile, Test Pilot

Cargo Test Branch

Flight and Engineering Test Group

FLYING TECHNIQUE

The C-131B, Number 53-7823, assigned to the program, was thoroughly studied and tested for two years. During that period flight techniques were developed, an engineering study of the structural stresses likely to be encountered was made, and computer studies of the optimum trajectory were obtained. Flight tests were based on these studies, and the airspeeds and angles shown in figure 1 represent modifications that incorporate the pilot's experience in flying the maneuver. The resulting parabolic flight path yields from 12 to 15 seconds of zero g.

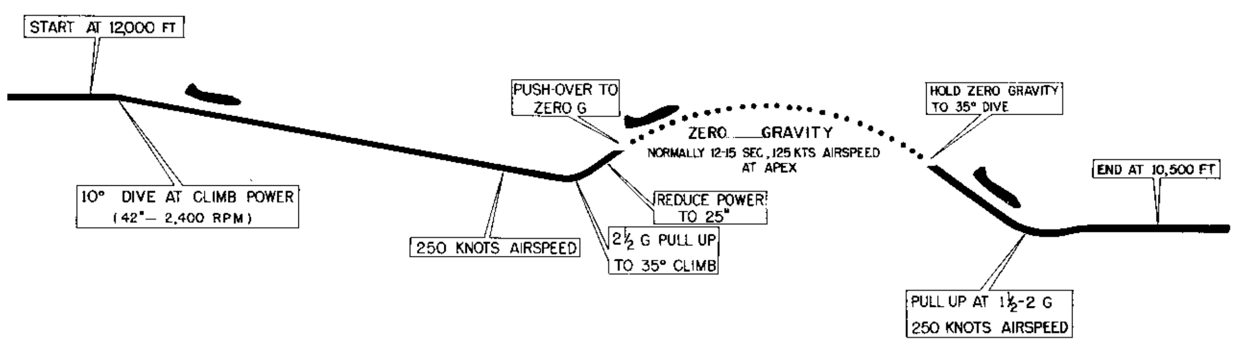

Figure 1. C-131B parabola

Instruments used by the pilot consisted of a sensitive (standard) g-meter and a 1/2-inch cork floating in a plastic sphere filled with water (figure 2). A caging mechanism for the cork consists of an attached string pulled through a loose gasket at the bottom of the sphere. The caging string can be used to pull the cork to the center of the sphere during maneuver entry and then to release it when the plane enters zero gravity.

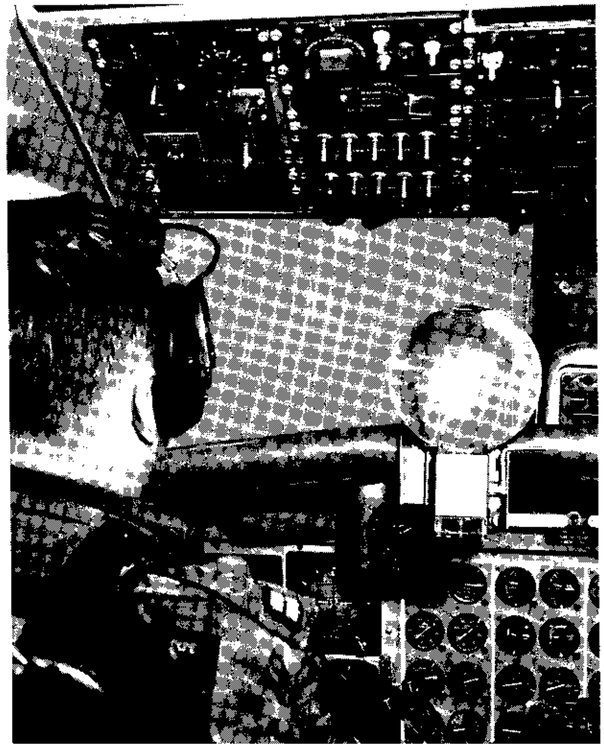

Figure 2. Cork-and-sphere zero-g indicator in C-131 cockpit

Actual flight technique requires close crew cooperation. Pilots continuously monitor the radar controller and VHF-emergency, UHF-guard-radio channels. The laboratory crew is alerted on the intercom to prepare to start the run. Power is set to METO (maximum except for takeoff). A 15° dive is initiated. The aircraft is trimmed laterally and vertically for about 220 knots during the dive. As 220 knots indicated airspeed is achieved, the test crew is warned, "fifteen seconds to pullup." At 250 knots indicated, the 2.5-g pullup is initiated until the attitude reaches +45°. The copilot retards power to a value, discovered by experimentation, that will nearly cancel the longitudinal acceleration. At nose-up the aircraft is "pushed over" by the pilot, who uses the sensitive g-meter to monitor his approach to zero vertical acceleration.

Near zero g the pilot switches his attention to the sphere and cork, which is much more sensitive than the meter and also provides information about lateral accelerations (yawing movements). Control forces and control sensitivity vary with airspeed, so the pilot must correct the controls continuously. The copilot adjusts the power slightly during the run to compensate for changes in aircraft drag due to airspeed changes, and thereby controls longitudinal acceleration. An in-flight monitor in the test cabin describes the behavior of free-floating materials. Longitudinal accelerations are probably the most difficult accelerations to control since there is an appreciable lag between a movement of the throttles and a change in power.

The copilot must anticipate required changes in power and adjust the throttles accordingly.

The flight engineer monitors engine oil pressures and propeller RPM. He calls for an abort if the RPM fluctuates and stands ready to control any over-speed tendency with the feather buttons.

As the dive angle reaches -40° at the end of the maneuver, the pilot gently applies about 0.05 g to allow floating objects or persons to descend safely to the floor. Pullup is then increased to about 2 g until the attitude for entry to a second maneuver is reached, or a zoom climb angle is reached, whichever is desired. Double runs are frequently made if the test allows. This makes more runs possible in a given flight time.

During the maneuver the pilots are watching instruments too intently to permit safe VFR flight; therefore, zero gravity parabolas are always flown in an area restricted for flight test, or with complete radar coverage. The aircraft also remains in an area from which a safe dead-stick landing can be made.

The altitudes selected were based on a reasonably safe bailout clearance above the terrain, yet low enough to permit a reasonable speed range to be used. During the run the airspeed varies from 250 to 130 knots indicated airspeed (IAS). The lower airspeed is above 1.2 V_s (1.2 times stall speed) for the normal weight and configuration of the flight.

At starting airspeeds above 250 knots IAS an undesirable elevator buzz was encountered, and at lower starting speeds the duration of zero g was unduly reduced. Higher entry angles can be used, but as the speed over the top decreases, the aileron and rudder sensitivity are reduced greatly. Under conditions of reduced control surface sensitivity the pilot cannot avoid undesirable lateral and transverse fluctuations.

The g-loading during the pullup was also varied within available limits. The aircraft is basically limited to 3.15 g with full fuel load of 10,400 pounds. A high g-loading would be desirable to reduce airspeed loss during pullup; however, the potential turbulence loads and the safety requirements indicate a g-loading not exceeding 2.5.

When negative gravity is desired to churn fluids within containers or to remove test items from their containers or from the aircraft floor, the aircraft is flown at -0.05 g, followed immediately by a return to a zero-g condition.

Partial g (0.5, 0.2, 0.1) maneuvers are being flown for subgravity experiments, as is a gradual g-decay maneuver (0.5 to 0).

The zero-gravity maneuver has been flown by the Air Force during the past few years in a variety of airplanes, including the F-94, the T-33, the F-100, and the F-104. Troubles have been encountered with wing-flap motors and inverters, owing to damage by engine heat and lack of air circulation during zero-gravity conditions. Tacan installations appear to be too delicate to operate during the maneuvers and slaved gyros also appear to wear excessively. Maintenance personnel have been requested to give special attention to differences in life of, or excessive maintenance on, any component or system which might be effected by the test maneuver.

Little change in flight instrumentation or technique is anticipated in the near future; however, a g-sensed zero reader, g-sensed autopilot, and g-nulled throttle control are being investigated. Since the limits of the aircraft are not reached, we consider that the maneuver is being flown relatively safely and test requirements do not yet justify any approach closer to the aircraft limits.

MODIFICATIONS

Figure 3. Propeller pitch locks

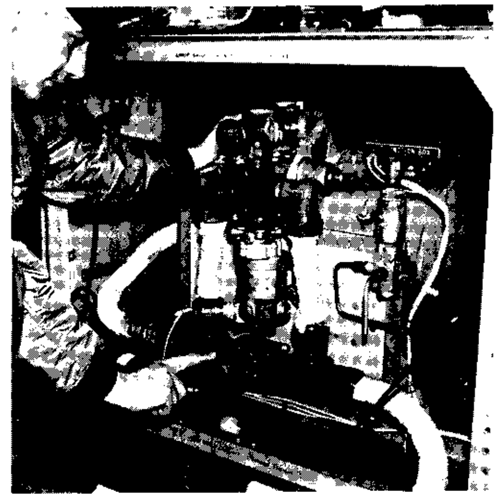

Figure 4. An engine oil expulsion system

The following modifications and procedures were implemented for the C-131B:

1. Special pitch-lock domes were added to the propeller domes to prevent propeller overspeeding if oil pressure is lost during the parabola.

2. An oil expulsion system was installed for each engine. The systems supply low pressure oil to the engine oil pump during the maneuver.

3. Special battery caps were added to prevent acid-spillage during the maneuver.

4. Ensolite plastic flooring and other padding were added in the aft free-floating compartment, and lights and camera mounts were installed for gathering data. A Heiland 24-channel oscillograph recorder was installed that continuously records acceleration parallel to the aircraft's three axes, aircraft pitch angle, and airspeed.

5. Power available includes (a) 20 KVA, 115-volt, 400-cycle, 3-phase, (b) 500-ampere, 28-volt DC, (c) 2500 VA, 115-volt, 400-cycle, A & C phase, and (d) 750 VA, 115-volt, 60-cycle.

6. A special structural inspection is performed every 150 hours to check aircraft structural fatigue and stress. Oil sumps are checked after every flight for excessive engine wear.

Persons who were responsible for the succes of these modifications are: Jerry Eaglin, Cargo Maintenance; Capt. J. Edwards, Cargo Test Branch; M/Sgt C. W. Thompson, Aero-mechanics Division; and T/Sgt C. W. Sears, Aerospace Medical Laboratory.

REFERENCE

Ritchey, R. L., Oil Expulsion System Evaluation, WCT Flight Test Report 59-65, Flight and Test Engineering Test Group, Wright-Patterson Air Force Base, Ohio, December 1959.

2. KC-135

Capt. Neil R. Garland, Test Pilot

Bomber Operations Branch

Flight and Engineering Test Group

FLYING TECHNIQUE

Air Force acceptance tests on KC-135, Number 55-3129, to determine the functional adequacy of the zero-g modifications made by Boeing were completed during four flights at Boeing Airplane Company, Seattle, between 21 and 26 April 1960. The technique for flying the zero-g maneuver was also developed during this period. Computer studies made by the Aircraft Laboratory at ASD and the Aerodynamic Section of Boeing Airplane Company were used to help determine entry altitude and angles. Structure, flight control, and safety techniques had to be considered. The final maneuver represents a compromise among these factors.

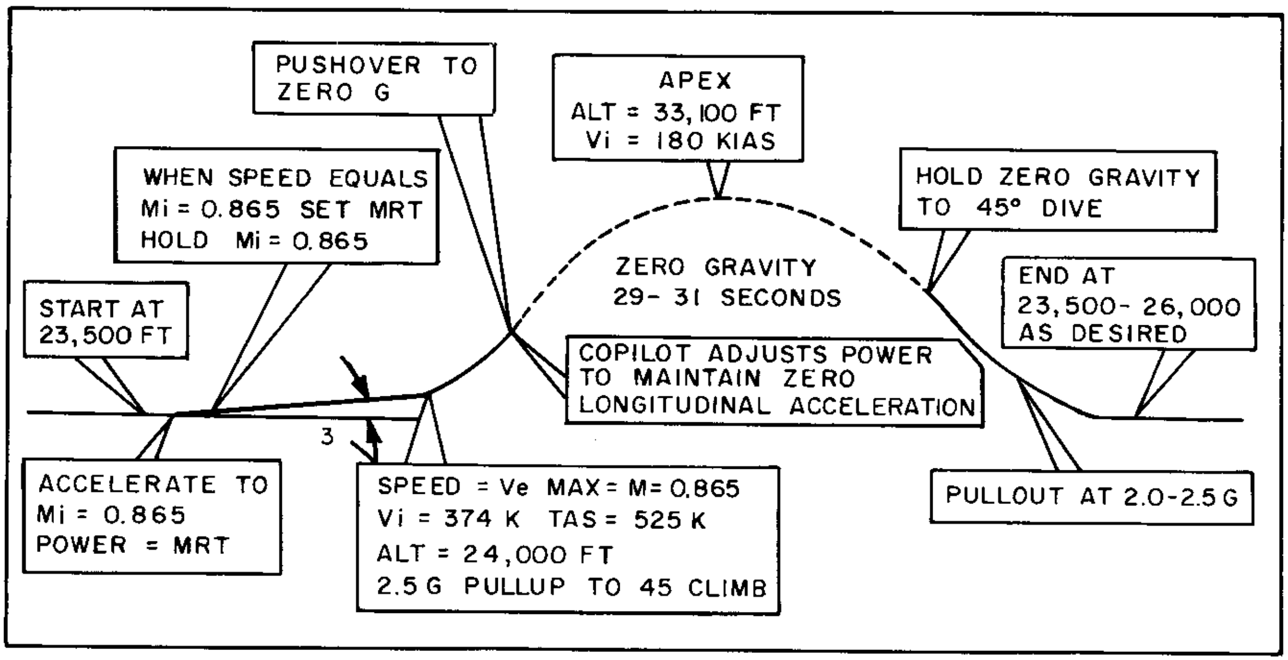

Figure 5. KC-135 parabola

The present technique is to accelerate the airplane using Military Rated Thrust (MRT) to V_e Max (Maximum allowable entry velocity) at the altitude where V_e Max equals M_i (Mach indicated) = 0.865 (about 23,500 feet, dependent upon temperature). The aircraft has sufficient power to reach this speed in level flight with MRT, but less time is lost in reaching this speed by using a slight (5°) dive from 25,000 feet. When level at V_e Max, the normal acceleration is increased smoothly to 2.5 g and held until a 45° climb angle is reached on the flight indicator. The pull force required for the pullup is then released and a 20- to 30-pound push force applied to the yoke, which causes the aircraft to start pitching down and the normal acceleration to decrease to zero.

During the transition from 2.5 g to zero g, the copilot reduces the power to a predetermined setting that will make thrust equal to the drag of the airplane at the midpoint of the maneuver. This constant power setting is used to eliminate additional elevator corrections that would be necessitated by power being varied during the zero-g phase of the maneuver. If test requirements dictate, power can be varied by the copilot during zero g by reference to a longitudinal accelerometer to keep longitudinal acceleration zero.

Recovery is initiated at a 45° dive angle with idle power, a maximum normal acceleration of 2.5 g, and a maximum airspeed of V_e = 350 knots.

The rudder mode of the autopilot is used throughout the flight to damp yaw and dutch roll and to eliminate lateral acceleration. Precise fuel management is exercised to control the aircraft center of gravity and to keep the lateral balance of fuel even.

Stabilizer trim is not used for this maneuver because of the low service life of the stabilizer trim actuator clutches. Aircraft CG is kept at 30% mean aerodynamic chord to reduce stick forces and to decrease the possibility of stick force lightening when maneuvering. Some stick force lightening was noted during initial tests using a 28% CG. Maximum pull and push forces approximate 50 pounds and 30 pounds, respectively. At a gross weight of 131,000 pounds, a zero-g period of 31 seconds has been attained.

The pilot uses a self-contained mechanical accelerometer to control entry and exit acceleration and a sensitive ±0.2 g-range remote-indicating accelerometer to control acceleration at zero in the maneuver.

A Kentel closed-circuit TV system has been furnished by Convair Astronautics to improve techniques of free-floating weightless objects. The screen is installed on the pilot's panel in the space normally occupied by the N-1 slaved magnetic compass, and the camera is mounted in the rear facing the cabin test area. Technique in floating capsules is to fly the aircraft into the parabola by reference to the accelerometer until a zero-g condition is achieved. The capsule is then released by the observer, and the TV screen is scanned for motion of the capsule. When a vertical motion is detected, the pilot, by reference to the sensitive accelerometer, makes a pitch correction to stop the relative motion between aircraft and capsule. When a relative lateral motion of the capsule occurs, the copilot corrects with rudder pressure to bring the capsule back to center. Use of the televised information in addition to the accelerometer has not lengthened the maximum free-floating time that was achieved by use of the accelerometer only, but has increased the regularity of the long-duration runs. The crew can provide 1- 15 seconds of free-floating time for the capsule on one out of three runs in smooth air.

Figure 6. View of the KC-135 cockpit. Note TV screen (1), attitude indicator (2), and accelerometer (3).

Because the maneuver involves speeds from 350 to 170 knots IAS and an altitude change from 23,500 feet to 34,000 feet, the parabola must be flown in restricted air space (R-109) under positive radar control (ASD Flight Test Radar) to insure separation from other aircraft.

Since the maneuver requires maximum performance operation of the aircraft, close supervision of pilot training is maintained. Both pilot and copilot on the zero-g mission are primary duty pilots, qualified in the KC-135. All pilots, copilots, and flight engineers who operate the aircraft receive formal ground schooling on the aircraft modifications, are required to read the Boeing Airplane Company Difference Document describing the modifications, and receive a complete preflight briefing before their initial zero-g flight. Each pilot is required to observe as a third pilot before progressing to checkout as copilot and then pilot on the zero-g maneuver. The project pilot maintains continuous standardization of all pilots qualified to perform this maneuver.

MODIFICATIONS

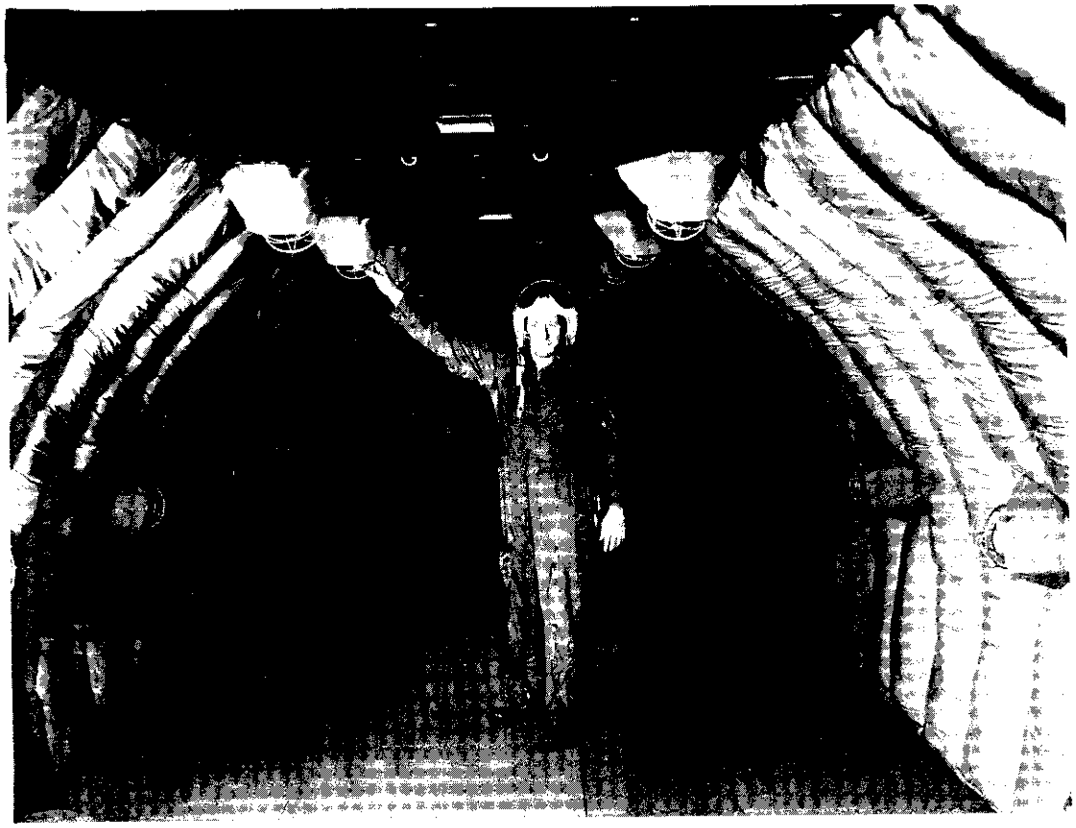

Figure 7. KC-135 test area showing padding and light installations

The KC-135 has been modified by Boeing Airplane Company from its basic tanker configuration into an experimental test airplane capable of providing a zero-g environment. All aircraft systems essential to control and safe operation of the airplane have been modified to provide two consecutive 40-second zero-g trajectories, with recharge time, if required, between double trajectories not to exceed 4 minutes.

1. The entire fuselage test section was covered with protective padding and insulation to protect test personnel and other floating objects and to reduce environmental noise levels to permit normal conversation throughout the test area. The test section surfaces were covered with panels of 1-inch thick Ensolite, a polyvinyl sponge-like material (figure 7).

2. Easily detachable web net partitions were installed at four stations to restrain moving or floating objects during unusual maneuvers.

3. The hydraulic system was modified to provide an uninterrupted flow of hydraulic fluid to necessary systems. Air is automatically prevented from entering the system by two hydraulic reservoirs containing anti-g valves. Variable volume compensators were installed to operate in parallel with each of the reservoirs to provide additional quantities of oil when required.

4. A 50-gallon fuel expulsion tank, separated into two sealed sections by a movable diaphragm, was installed to supply an uninterrupted flow of fuel to the engines. A sufficient

reserve of fuel for operation of the engines during two consecutive 40-second zero-g trajectories is maintained. Nitrogen pressure is supplied from two high pressure nitrogen bottles through a pressure regulator.

5. Five tubing runs were provided for overboard venting of cryogenic fluids, including liquid hydrogen. These tubing runs discharge into the airstream through a drain mast attached to a dummy scanner window in the pod.

6. A check valve was installed in the air cycle machine oil sump vent tube to prevent loss of oil from the sump; however, it did not prove satisfactory. The Propulsion Laboratory has modified this system with a 2-inch internal extension of the vent tube.

7. The constant-speed-drive oil system was modified to eliminate entrained air from the oil supply to the generator drives. A deaerator can and a sealed supply chamber insure a steady flow of oil to the generator drive. Pump cavitation, which would cause the generators to trip "off," is prevented.

8. The filler cap of the engine oil tank was relocated to the top tank port so that approximately 3 additional gallons of oil could be carried in the tank.

9. Four electrical power distribution systems were installed in the plane to provide power to various test equipment: (a) 28-volt DC, 3 KW, (b) 110-volt, single-phase, 60-cycle, 4 KVA, (c) 210-volt, three-phase, 400-cycle, 20 KVA, and (d) 115-volt, single-phase, 400-cycle, 16 KVA. The 60-cycle power is obtained from a 60-cycle alternator, belt driven from a 400-cycle motor.

10. A photo-flood lighting system was installed in the fuselage test section to illuminate with equal intensity all parts of the test section.

11. Precision accelerometers were installed in the airplane to record various g loads during maneuvers and to assist the pilot and copilot in flying a zero-g flight path.

REFERENCE

Boeing Airplane Company, Difference Document KC-135 Zero Gravity Modifications, Document No. D6-5353, April 1960.

3. FREE FLOATING TEST CAPSULES

Robert G. Clodfelter and Lt. R. C. Lewis

Propulsion Laboratory

When zero-g work was first begun by the Propulsion Laboratory, its experimental apparatus was tied down to the C-131 and thus was subjected to the same accelerations as those undergone by the aircraft. As might be expected, even the most experienced pilots were unable to fly perfect trajectories. In addition to aircraft vibration, there were yaw, vertical accelerations caused by deviation from the trajectory, and longitudinal acceleration caused by lack of balance between thrust and drag. At best, the first experiments were studies of fluids in reduced gravitational fields, but much was learned about trends and problem areas. However, it soon became necessary to develop new ways of increasing the data gathering of the g acceleration force time.

To this end the Propulsion Laboratory and Convair Astronautics developed a four-poster carriage arrangement to float an experimental capsule. The capsule was suspended by eight nylon cords, four on each end. The carriage was mounted on a track inside the aircraft and could be moved fore and aft to correct for longitudinal acceleration. On entry into zero g the tension on the suspension cords was released by a deslaving gear. In actual use the capsule very quickly floated to the limits of the cords. At this point violent movements of the fluid would take place. Even with this disadvantage, however, Convair Astronautics estimates that usable time of 4-6 seconds was obtained.

The next step was unrestrained free-floating with no cables attached in the same manner that the Aerospace Medical Laboratory had been floating personnel. Initially the capsule was floating freely except for a line providing power for the instrumentation, camera, and lights. Even this lead imparted transient accelerations, however slight. This left no alternative but to use entirely self-contained test capsules, with observers restraining the capsule only when collisions appeared imminent. When this technique is used, the main limitations on zero-g time are the size of the aircraft and the method of lifting the capsule completely off the floor. At first the pilot applied a brief negative acceleration before entering zero g. As an improvement, the Aeromechanics Division has fabricated a retractable table that can be dropped out from under the capsule on entry into zero g. Using the drop table, the major remaining problem is the ability of the pilot to fly the aircraft around the capsule. While the length of free-floating time is seldom longer, the frequency with which 10- to 15-second runs are obtained has been increased. Further improvements in flying techniques may be expected from integrating the information displays that the pilot must refer to in flying the parabola.

REFERENCE

Convair Astronautics, May-July Progress Report for the Combined Laboratory and Airplane Zero-G Test Program, Convair Astronautics Division, General Dynamics Corporation, San Diego, California, August 1960.

4. CAMERA TECHNIQUE

John J. Genari, Project Officer

Flight Engineering Test Group

The Optical Branch, Test Data Division, Flight and Engineering Test Group has been responsible for the photographic support required for engineering studies and for documentation of the zero-g experiments. The photographer must perform his duty under the same zero-g conditions as those experienced by the test subject, but no operational difficulties, such as adverse effect on camera performance, have been encountered. The cameraman either secures himself in the required position or, if greater detail and constant positioning are required, uses fixed cameras and illumination.

The only difficulties arising from the requirements of this program were inadequate illumination to perform photography with all types of emulsions and at diaphragm stops that provide the greatest depth of field.

Certain test units undergoing zero-g condition studies do not lend themselves to photography with a hand-held camera, as when a detailed or close-up study of an event is desired. This necessitates installation of special fixed lighting and cameras on the test unit.

For optimum photographic coverage in black and white and in color, special illumination was installed in the KC-135; however, it has not proved entirely satisfactory because of frequent burnout of the PH/RFL-2 bulbs due to vibration of the filaments during maneuvers. These bulbs should be replaced with PAR-38 flood lamps and "Color-Tran" transformers.

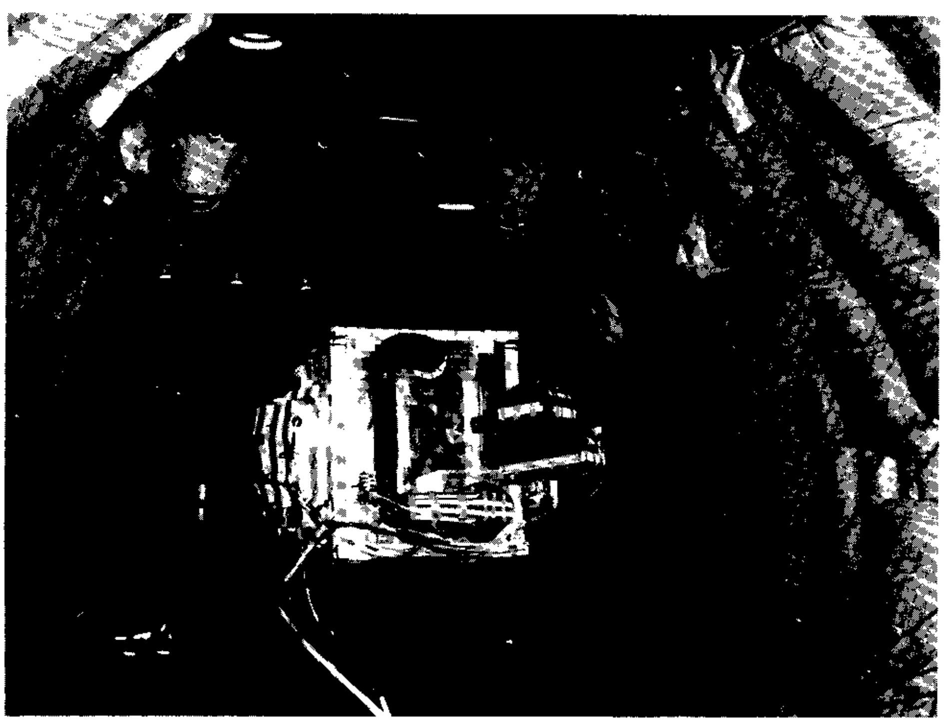

Figure 8. Fixed camera on test unit operated by photographer at left

5. F-104B

Capt. W. Shawler, Test Pilot

Fighter Operations Branch

Flight and Engineering Test Group

The F-104B can produce relatively pure weightlessness for 40 seconds. Four zero-g parabolas may be obtained during each flight. The duration of the reduced gravity state may be extended to 55 seconds if the researcher is willing to tolerate the presence of a 0.1-g longitudinal acceleration.

The size of the experimental apparatus is extremely limited because there is only room for such equipment on the lap of the observer. There must be no interference with either canopy closure or ejection seat operation. The rear crew station stick, however, may be removed if more space is required for the investigation.

The aircraft is equipped with an oscillograph, which records g forces in three planes, and photoflood lights that illuminate the rear station. Motion pictures may be taken of the instruments and the observer or his equipment. Twenty-eight-volt DC power is normally available; other AC or DC power may be made available through aircraft modifications.

6. FRICTIONLESS DEVICES

Maj. Leroy D. Pigg, Project Officer

Behavioral Sciences Laboratory

Among the facilities used to study subgravity conditions in the laboratory are those known as frictionless or air-bearing devices. Developed several years ago at Aeronautical Systems Division, these devices are used to simulate the tractionless characteristic of weightlessness. At the present time there are three different types of frictionless devices in use by the Aerospace Medical Laboratory; all of them use a layer of air to reduce friction essentially to zero.

1. Rotary platform (figure 9). This platform consists of a circular disk, 36 inches in diameter, mounted on a heavy steel base and pivoted at the center. The plate is supported by a cushion of pressurized air delivered through holes under the plate. This device has only one degree of freedom: rotation.

Figure 9. The rotary frictionless platform with a subject about to exert a torque on the overhead handle

2. 3-D scooter (figure 10). This tricycle-like device is supported by three 8-inch disks. The scooter is used on a smooth steel plate. Pressurized air is delivered through a 1/4-inch hole in the center of each of the disks. The scooter offers three degrees of freedom: fore-and-aft, left-to-right, and rotation.

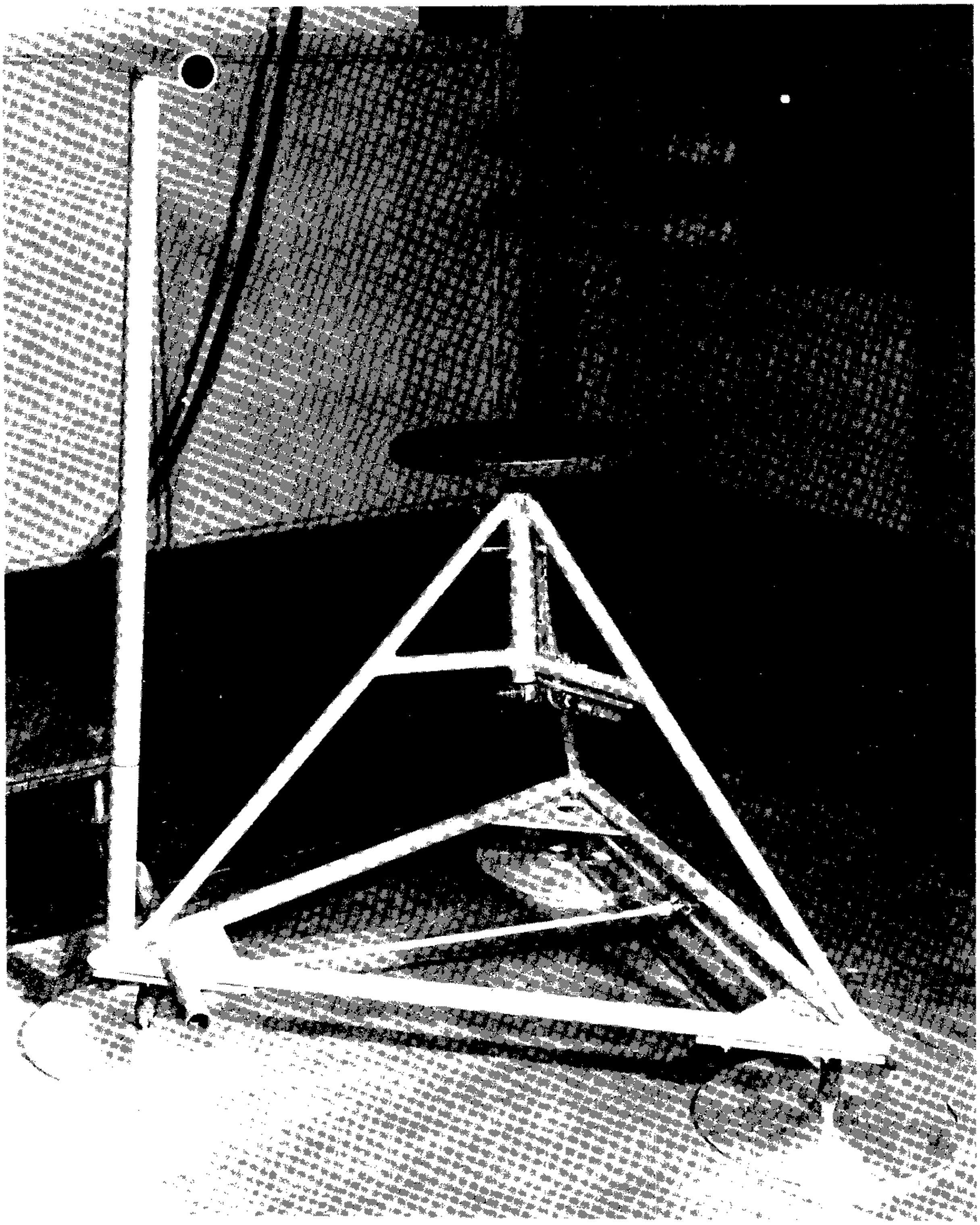

Figure 10. The frictionless "scooter." The air hose is connected to the coupling between the two disks on the right.

3. Frictionless table (figure 11). The table consists of two metal plates fastened together to form a hollow cell, 30 inches long, 10 inches wide, and 2-3/4 inches deep. The top plate is perforated with 260 holes, 1/64 inch in diameter. Pressurized air is delivered through a 1/2-inch hole in the bottom plate. The table has been used to support weights used in studies designed to provide some indication of man's differential sensitivity for mass and his ability to position objects under weightless conditions.

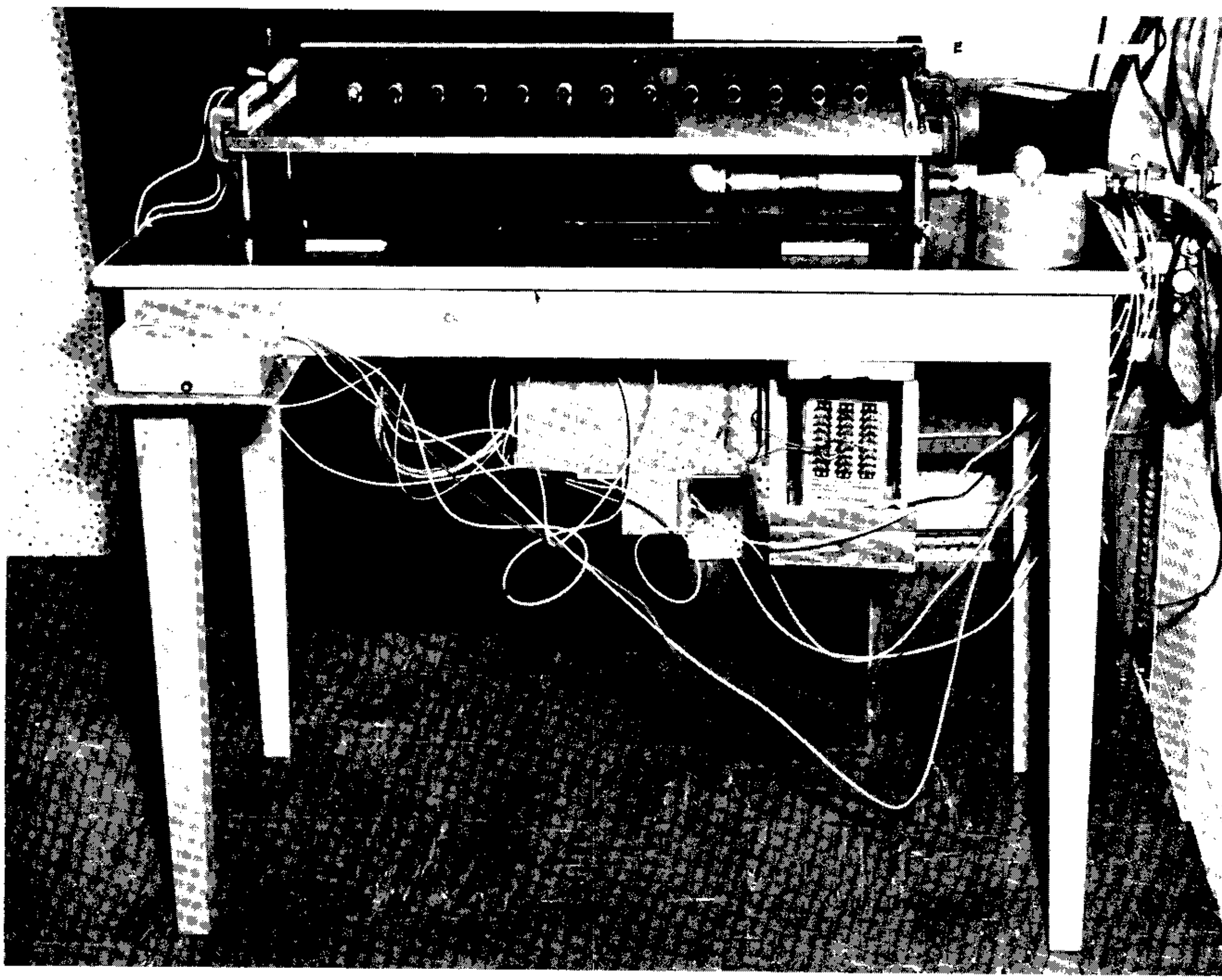

Figure 11. The frictionless table on which objects supported on a cushion of air are virtually tractionless

7. WATER SUBMERSION TANK

Capt. George Barnard

Biomedical Laboratory

In addition to the air-bearing devices, the Aerospace Medical Laboratory also uses a water submersion tank to simulate a weightless environment in the laboratory. The tank, 90 inches long, 33 inches wide, and 48 inches deep, is large enough to contain one human subject and his associated equipment.

Subjects clothed in skin diving apparel can remain in the tank for several days at a time. Equipment is provided for respiration, feeding, waste disposal, and two-way communication between the subject and the experimenter. Forty-five-volt DC and 110-volt AC power sources are provided; water temperature is constant. Apparatus is available to record electroencephalograms (EEG), electrocardiograms (ECG), respiration rate, galvanic skin response (GSR), and heart rate. A tracking task and instrumentation for other tests will be installed to measure the subject's behavior during submersion.

This facility simulates selected sensory aspects of the weightless condition and is advantageous because a subject can remain in this environment for a long period.

III. AEROSPACE MEDICAL STUDIES

1. PHYSIOLOGICAL PHENOMENA

CARDIAC MEASURES

Lt. Robert Olson and Capt. Leonard Stutman

USAF Hospital, Wright-Patterson AFB

How the circulatory system functions while the body is weightless and, in particular, how the system is affected by loss of weight, have been factors of great concern. A drop in blood pressure during weightlessness and pooling of the blood in the lower extremities upon return to normal gravitation could be expected. This could be most detrimental to the astronaut during transition from zero to 1 g in the reentry phase when sudden loads are placed on a cardiovascular system adjusted to pumping weightless fluid through a passive body.

The purpose of this investigation was to study the effects on the cardiovascular system of entry into zero g and reentry to positive g.

To change the attitude of the subject's body, a tilt table was placed in the rear of the aircraft along with recording devices that measured simultaneously ECG, blood pressure, pulse rate, and blood volume in the subject's extremities. Three of four subjects were placed at 0°, 45°, and 90° from the vertical during weightless parabolas to differentiate the effects of zero g from the effects of the 2.5-g entry in the C-131.

All the subjects experienced an abrupt decrease in heart rate during transition to weightlessness and an increase in rate during reentry to positive g: Blood pressure also decreased during weightlessness. Position of the body did not seem to affect circulation.

The blood pressure and plethysmographic devices may have been affected by the positive acceleration during the maneuvers, and much of the equipment proved inadequate for short time measures. Limiting conditions for the experimental variables were determined by the conditions of the aircraft maneuver, with its brief period of weightlessness (12 - 15 seconds).

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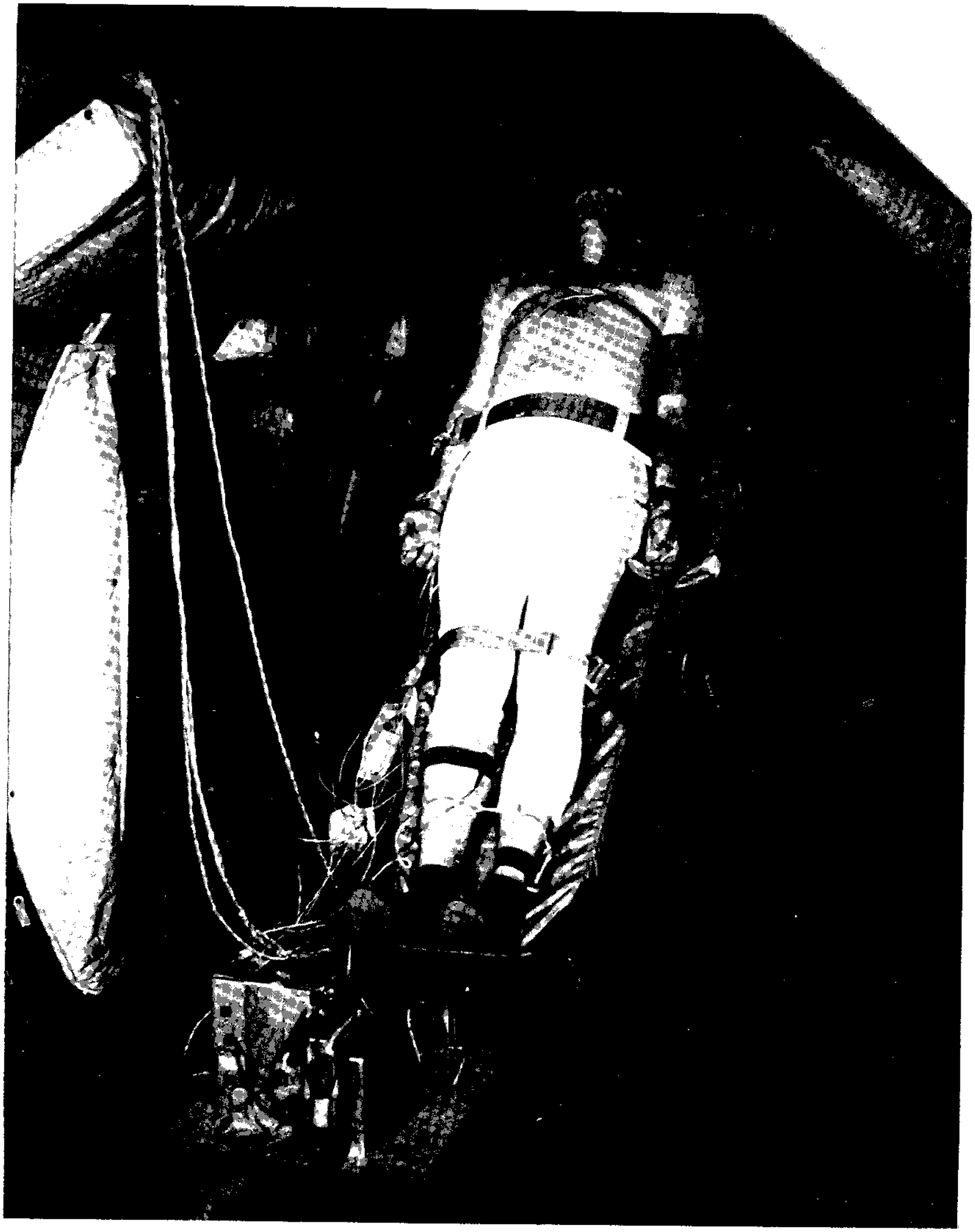

Figure 12. A subject is strapped to the tilt table in the 45° position. Recording equipment is mounted on floor of aircraft.

CARDIOVASCULAR REACTION TO ZERO-G FLIGHT

Capt. Marvin A. Feldstein

Biomedical Laboratory

In a further study of various parameters of cardiovascular physiology, the effect of weightlessness on circulatory functions is being observed, rather than the effects of changing acceleration.

The longer duration of zerc g in the KC-135 and the use of improved research instrumentation are expected to reduce problems encountered in previous cardiac research.

Pulse, blood pressure, respiration, and cardiac output are being measured in human subjects, and the same factors plus distributional blood flow will be measured in dogs.

Preliminary data on blood pressure of human subjects have been obtained, suggesting a 10 to 30 percent decrease of the zero-g resting pressure from the 1-g resting pressure.

CHEWING AND SWALLOWING

Beatrice Finkelstein

Life Support Systems Laboratory

Figure 13. Attempt to drink milk from open cup while weightless

The inadequacy of open containers for liquids and the difficulty in drinking from them during weightlessness have been demonstrated. Therefore, various packaging methods and the subject's ability to handle, chew, and swallow food under subgravity conditions are being evaluated in an F-104 aircraft. Liquids and semisolids, packaged in various ways, are provided for consumption during the 55-second parabola. An oscillograph located in the nose of the aircraft records the vertical and longitudinal acceleration of each parabola. The subject's ability to chew and swallow are documented on 16-mm movie film. During flight the subject is continuously photographed while wearing a P-4 helmet with an attached accelerometer and free-floating tethered cork to indicate the g-force history of the experiment. In addition, the subjects are interviewed after each flight to obtain information about chewing, swallowing, gastrointestinal disturbances, and difficulties experienced in handling the food.

There have been no problems from digestive upsets or the process of eating the food. However, the development of a feeding device that can dispense one bite of food at a time directly into the mouth is desirable. Moreover, the solid foods must not crumble. Crumbs in the weightless state will float in the atmosphere and might be inhaled by the operator or infiltrate systems essential to the successful operation of the space vehicle.

REFERENCE

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MOTION SICKNESS AND NAUSEA

Lt. Joseph P. Loftus, Jr.

Behavioral Sciences Laboratory

As a result of the rather high incidence of motion sickness and nausea noted among participants in routine zero-g flights, a questionnaire was prepared to discover whether any unusual aspect plays a part in the sickness encountered on these flights.

As a routine procedure, all personnel participating in zero-g flights filled out a questionnaire indicating the degree of discomfort felt, if any, during the flight, past history of motion sickness, and other pertinent information. The following tables show the results, with respect to two variables, of the questionnaire study on a sample of 90 persons.

Table 1. Motion Sickness History

		Vomited	Reported Nausea	Reported no Discomfort
Prior motion sickness	(N = 35)	33%	33%	33%
No prior sickness	(N = 55)	20	25	55

Table 2. Previous Flight Experience

		Vomited	Reported Nausea	Reported no Discomfort
Crew member	(N = 46)	11%	33%	56%
Passenger only	(N = 44)	35	16	49

The acceleration profile of the flight maneuver, with sudden transition from 2.5 to zero-g may in many cases be responsible for feelings of nausea, owing to movement of the viscera or changes in tension of internal organs. Therefore, an experiment has been planned to determine the effectiveness of preventing nausea by using modified anti-g suits to restrict visceral movement. Persons with a record of chronic sickness or weightlessness flights will serve as subjects. Only the stomach bladder of the suit is inflated and pressure is maintained throughout the parabolic maneuver. Effectiveness of this measure is judged by reduced incidence of illness or discomfort. As a further effort, a certain drug is being tested for its effectiveness in preventing motion sickness during these flights. No data are available yet on the effectiveness of the modified anti-g-suit.

2. STRESS

EFFECTS OF LOW-FREQUENCY VIBRATION AND VARIABLE G-LOADING UPON HUMAN PERFORMANCE

Robert Simpson

Behavioral Sciences Laboratory

Although considerable information is available on human tolerance to g-loading and to vibration, almost no measures of human performance capabilities under vibration have been reported. Furthermore, no information is available on effects upon human performance of the interaction of acceleration and vibration as may be encountered during the reentry phase of space travel.

No ground facility has yet been devised to simulate the combination of variable and steady-state g-loading with low-frequency vibrations. Hence this investigation consists of two phases: a feasibility study of the utility of the laboratory aircraft for generating low-frequency vibrations under variable conditions of gravity; and an effort to determine whether performance measured under isolated conditions of acceleration or vibration are adequate to define man's capability to perform in the reentry environment.

Low-frequency vibration may be produced during the zero-g maneuver through controlled desynchronization of the aircraft propellers or turbines. In the C-131, desynchronizing the propellers by approximately 100 RPM results in a vibration of about 3 cps. The condition may be superimposed on accelerations ranging from zero to 2.5 g during the trajectory.

The resonance characteristics of the human body for vibrations under the various g-loads are measured by three helmet-mounted accelerometers, oriented parallel to the three major axes of the body.

Data thus far accumulated indicate that vibration amplitudes produced in the C-131 may prove adequate for experimentation on human performance under conditions of positive g-loading. Under zero-g conditions, resonance characteristics of the human body disappear and vibrations throughout the critical spectrum are effectively damped, thus rendering them relatively insignificant in performance under these conditions.

No data are available on performance under the combined environmental variables.

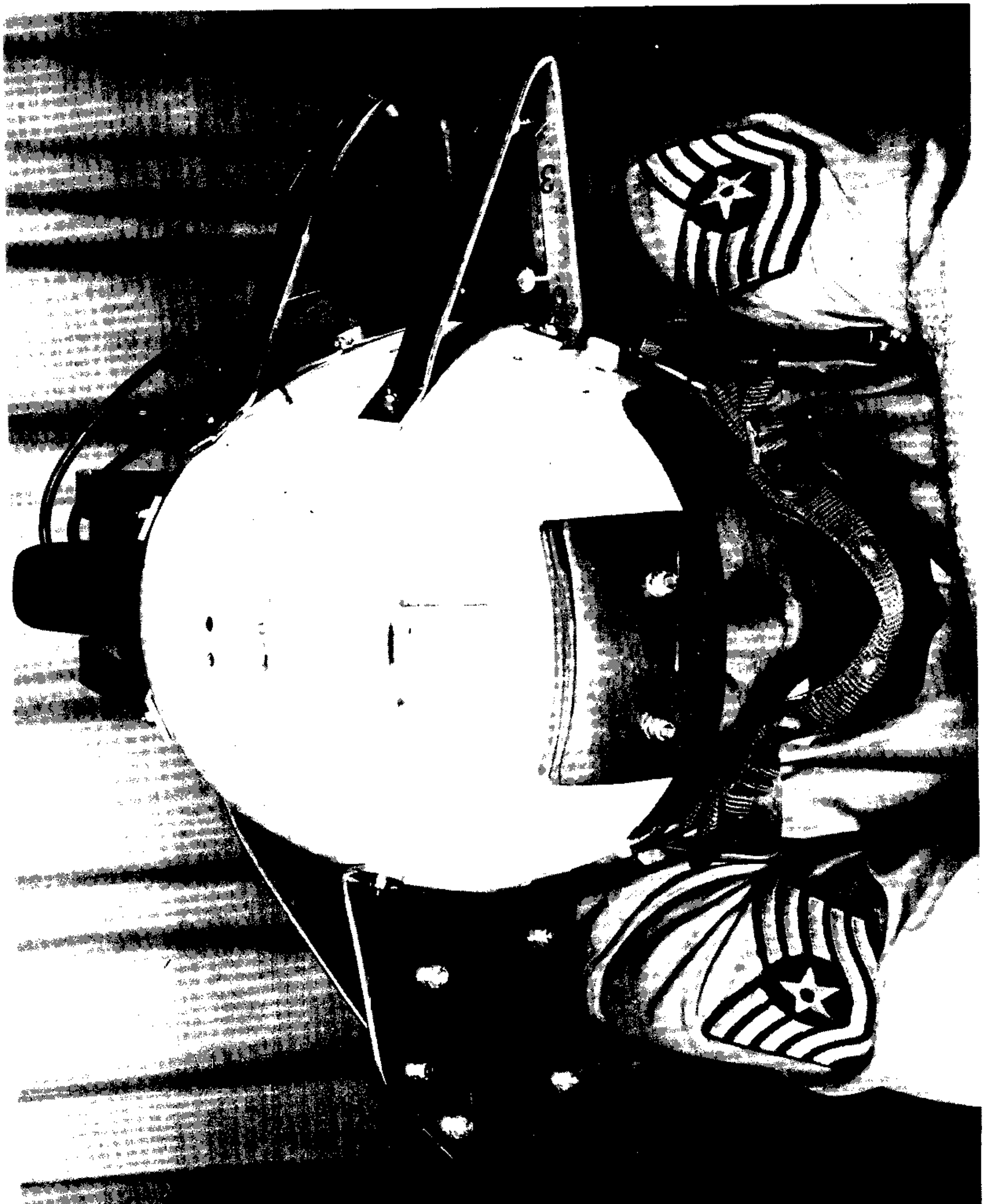

Figure 14. Accelerometers mounted on subject's helmet indicate resonance characteristics of body

PROJECTED SURFACE AREA OF PERSONAL PROTECTIVE EQUIPMENT

Charles Clauser

Behavioral Sciences Laboratory

A significant problem of protecting a man in space free of shielding vehicle or structure is maintaining his thermal integrity. One of the parameters that must be investigated to develop effective protective equipment for a man in space is the determination of the projected surface area of his suit that is exposed to thermal radiation.

A series of motion pictures was made showing a man wearing an inflated full-pressure suit while floating in a weightless condition. From these photographs outlines of the man in a number of positions were measured and the projected surface area calculated. The apparent size of ping pong balls attached to the suit served as size cues to the distance from the camera of different areas of the suit.

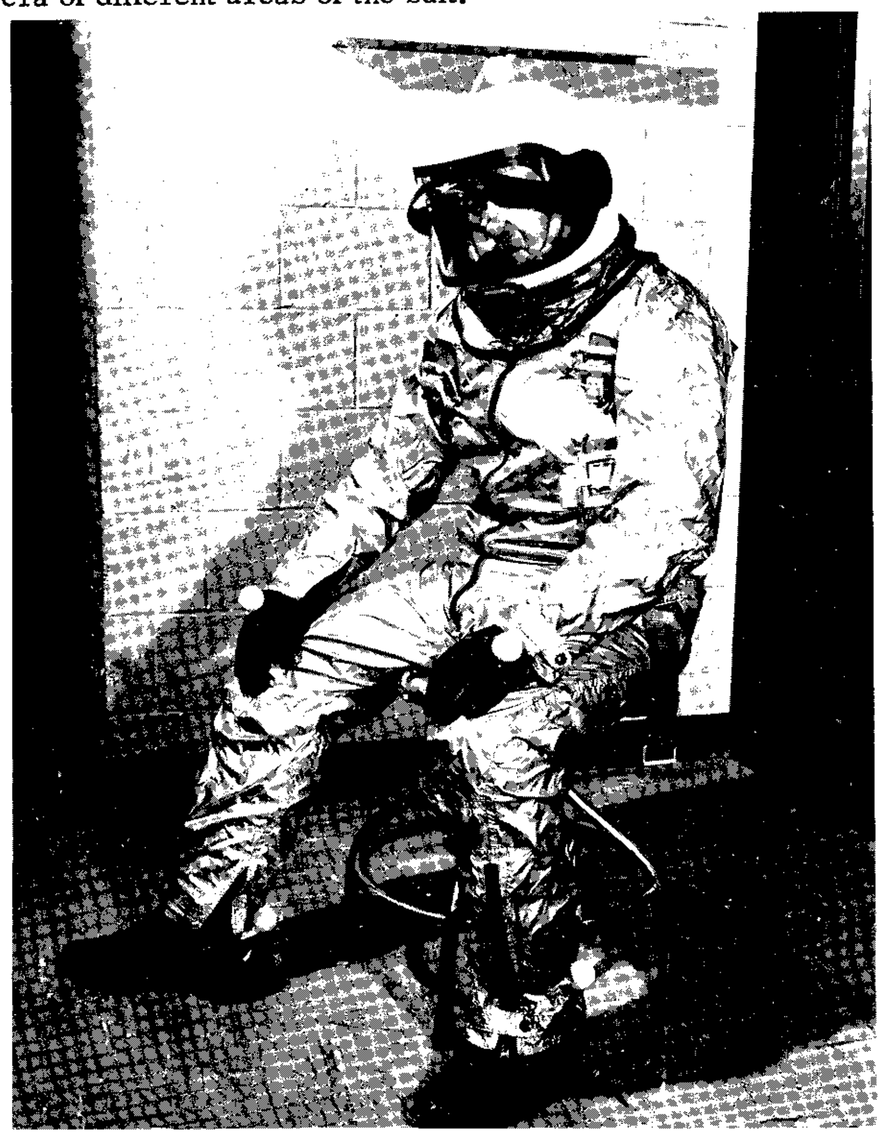

Figure 15. Man in full-pressure suit used in determining projected surface area

PSYCHOPHYSIOLOGICAL EFFECTS OF PROLONGED WEIGHTLESSNESS

Capt. George W. Barnard and Capt. Harold D. Wolff

Biomedical Laboratory

Data concerning the effects on the human of exposure to zero gravity for more than a few seconds or minutes await development of an orbital laboratory. Meanwhile, simulation techniques can be used on the ground to study the effect of some aspects of weightlessness on man's physiological and psychological well-being.

Subjects are suspended under water kept at a constant temperature for prolonged periods of time. Means are provided for communicating between subject and monitor, feeding subjects, and collecting urine for chemical analysis.

The stress on the cardiovascular system is being monitored by ECG, and the subject's tolerance to positive acceleration is measured on the centrifuge after varying intervals of simulated zero g. Muscle strengths are being recorded to determine whether any change occurs. Serum biochemical studies of sodium, potassium, calcium, phosphorus, and blood-urea-nitrogen (BUN) are being made to determine changes in muscles and bones after prolonged exposure.

Psychological variables are also being measured. States of alertness are monitored by means of galvanic skin response (GSR) and electroencephalograph (EEG), and an attempt is being made to determine the minimal sensory input required to keep subjects alert and oriented. Psychomotor performance will be tested on a tracking task. Further, attempts will be made to find personality traits common to those who best tolerate this environment.

3. SENSORY PROCESSES

GROSS VISUAL ACUITY

Maj. Leroy D. Pigg

Behavioral Sciences Laboratory

Previous study on the centrifuge has shown a progressive decrement in visual acuity under increasing positive acceleration. Displacement of the lens by inertial forces other than the 1-g stress to which the eye is adapted was proposed to account for the decrement. On this basis, it is reasonable to expect a loss of acuity resulting also from subgravity conditions.

The effect of transient weightlessness on gross visual acuity was studied in the C-131, using the Armed Forces Vision Tester with checkerboard targets and the American Optical Sight Screener (Snellen Test). Results under zero g were compared with those found in (1) straight-and-level flight and (2) the laboratory (aircraft) environment on the ground. The first condition was a necessary.control for vibration of the aircraft in flight. Thirty-six subjects were tested for binocular and monocular near and far vision on both instruments and in all three environments in counterbalanced order.

Figure 16. Visual acuity test situation aboard the aircraft. Floating cardboard tube near the center indicates weightlessness.

Scores were converted to visual angles, and means and standard deviations were computed. While loss in acuity was less than that observed under positive acceleration, a decremental trend was found under both flight conditions, with vision under zero g poorer than under 1-g. Both t-tests and nonparametric tests showed differences to be statistically significant at the 0.05 level of confidence or higher. There was no systematic difference between near and far acuity and, with one exception, binocular vision was superior to either left or right eye alone.

We concluded that visual acuity as measured is decrementally affected by short-term exposure to weightlessness in the aircraft, although the loss is probably too small to be handicapping.

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THE OCULOGRAVIC ILLUSION

Lt. Joseph P. Loftus, Jr.

Behavioral Sciences Laboratory

The so-called oculogravic illusion, the apparent motion of a fixed target while the observer is undergoing radial or linear acceleration, has been studied extensively under positive accelerations. Gerathewohl and Schock have extended these investigations to subgravity and weightlessness, but were restricted by the physical limitations of the fighter cockpits in which the experiments were carried out. In the present study, quantitative measures of direction, rate, and extent of the apparent movement are being sought under weightless conditions produced in cargo aircraft.

The apparatus to be used in this experiment consists of a cone fitting over the subject's eyes and restricting his view to a collimated star at the apex, and an inertially damped controller used by the subject to indicate the direction, rates, and extent of movement of the target. The manipulation of the controller records a trace on a Heiland photo-oscillograph, which also records the acceleration profile of the aircraft.

Figure 17. Cone worn by subject with target light at apex

The nature of the oculogravic illusion is being studied in four subgravity and weightless profiles. Subjects are seated in three orientations to the acceleration vectors -- facing fore, aft, and at 90° to the flight path. Preliminary findings have verified postulated directions of perceived motion; however, equipment modifications are being made to record rate and extent of apparent movement more accurately.

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VESTIBULAR FUNCTIONS

Dr. Barry G. King, Operations Research Inc., Silver Spring, Maryland

Capt. James E. Wade, Behavioral Sciences Laboratory

The otolith organs of the inner ear sense the direction of linear acceleration vectors, give cues as to the position of one's body, and help maintain subjective directional orientation. Predictions of disorientation under weightlessness have been based on expected changes in sensations arising from the otoliths.

A goldfish (Carassius auratus) was selected for observation of otolith functions under weightlessness, because of the similarity between human and fish otoliths. Under normal gravity this species swims with its ventral side down and parallel to the bottom of the aquarium. The goldfish, in a closed plastic tank, was flown through a series of trajectories. During the weightless period the fish's orientation was erratic. Several times an extreme position was assumed in which the head was oriented toward the bottom of the tank. It was concluded that changed stimulation of the graviceptors resulted in this unusual behavior, suggesting further research on the role of the otoliths.

The effect of weightlessness on static postural reflexes in the pigeon was investigated. When a pigeon is rotated about its longitudinal axis, compensatory movements of the head occur to keep the head in its original position in relation to the ground. Based on the role of the otolith organs in the postural reflexes, it was reasoned that in a weightless state the otoliths would cease to function normally and the head-turning response would not occur.

Two normal and four decerebrate birds were tested during trajectories in the C-131. Decerebrate birds were used because their compensatory reflex is less subject to distraction or suppression by the higher nerve centers and, therefore, more predictable in its occurrence.

The birds, wrapped in cheese cloth, were hand held for observations during normal gravity; during weightlessness, they were rotated, then released and allowed to float freely for a brief period. Motion picture and still photo records were made in flight.

Figure 18. Normal pigeon on left and two decerebrate pigeons on right during zero g. The two decerebrates demonstrate no compensatory head movements while being tilted. The normal bird is in the normal position.

Both groups of pigeons showed normal reactions under 1-g, while the posture reflexes failed to occur under weightlessness. The normal birds often showed apparently random movements, while the decerebrates floated motionlessly.

Compensation for the changed vestibular functions evidently did not occur through visual mechanisms during the course of six trials, since the reaction failed even though the birds were not blindfolded.

It was concluded that failure of the compensatory responses to occur is evidence that the utricular otoliths do not function under zero-g conditions.

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VERBAL INTELLIGIBILITY UNDER WEIGHTLESS CONDITIONS

Donald J. Baker and Charles W. Nixon, Biomedical Laboratory

Capt. C. E. Waggoner, Behavioral Sciences Laboratory

The purpose of this study was to determine whether changes in the spectral characteristics of speech occur when the speaker is in a weightless state. Deriving from changes in the musculature of the vocal apparatus, possible changes in the phonetic alphabet could affect verbal intelligibility under this condition.

Recordings of two sentences that contain all of the sounds used in the English language were made under 1, 0, and 2.5 g. Front, middle, and back vowels also will be recorded. The sentences were heard in noise and evaluated by the listener on a rating scale, while both sentences and vowels are to be analyzed in terms of frequency and amplitude to determine the changes that may be attributed to weightlessness.

Preliminary results show inadequate subject control of voice volume. An improved rating scale is being devised to permit better evaluation of this factor.

4. GROSS MOTOR PERFORMANCE AND LOCOMOTION

SELF-PROPULSION SYSTEMS

Capt. Melvin S. Gardner

Behavioral Sciences Laboratory

Linear locomotion requires an accurately applied external force, or release of energy, to move a center of mass along a desired path and a counter force to stop the movement. While the ultimate objective of this program was to study human engineering design requirements for developing a complete system for translating the free-floating orbital worker, a simple propulsion unit had to be produced to study the required forces and their application. The following discussion outlines the development and testing of the unit as it has been accomplished so far.

The first self-contained compressed-air unit for studying control requirements was fabricated in November 1958. It consisted of six high-pressure bailout bottles enclosed in a padded metal case to be strapped to the experimenter's back. A 1/8-inch high-pressure line terminated in a simple trigger nozzle. The working pressure was from 400 to 600 psi, producing a thrust of about 3 pounds, which preliminary trials on air-bearing platforms and in the C-131 proved to be inadequate.

The following month the simpler Mark II unit was fabricated , consisting of a single high-pressure bottle and valve, a 7-foot length of 1/2-inch ID high-pressure hose, and a specially developed pistol-type nozzle, yielding a thrust of 15-17 pounds. Tests in flight showed the 1/2-inch hose was too stiff for easy maneuvering.

A Mark III unit has been fabricated and ground tested. A pistol grip and surge tank for the valve have been made so that a flexible, 1/8-inch high-pressure line can be used. In addition, an improved cold gas convergent-divergent nozzle has been fitted to the valve, producing thrusts up to 20 pounds.

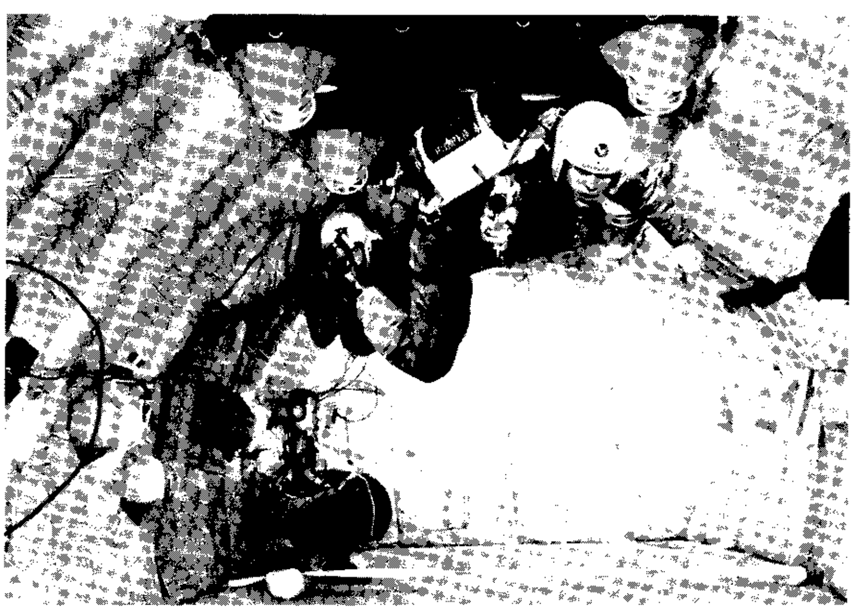

Figure 19. Mark III propulsion unit in operation

Performance was measured by direct observation and motion picture analysis. Evaluations are made on the basis of whether or not the desired control and translation are accomplished by means of the unit.

As of June 1960, one familiarization flight had been made with the latest single-nozzle propulsion unit. Several gross, straight-line translations with small amounts of rotation were made through the 25-foot free area of the cabin.

Uncontrolled movements, i.e., rotation about all three major body axes occurred when the thrust was applied a few inches from the experimenter's center of mass. When the nozzle was held at arm's length, a single, 1-second blast from the unit produced about 360° of rotation in approximately 1 second. When the nozzle was held at arm's length either over the head or toward the feet, varying degrees of the same effect were produced.

Analysis of films has shown the need for a free-floating reference mass in the aircraft. Because of turbulence and variable pilot techniques, transient forces are imparted to the aircraft throughout the maneuver. Without a reference, the experimenter had difficulty differentiating the subject's motion from the motion of the aircraft around the subject.

It has been hypothesized that a weightless man will not be able to exert complete control of his movements with a single-nozzle propulsion system. The single test flight that has been made with the Mark III unit seems to bear out this hypothesis; nevertheless, the experimenter believes that with practice a subject can become proficient in straight-line translations.

Translation force requirements have been computed for a 250-pound rigid man model and will serve as a base line for future studies. Inflight tests of actual units will be made under contract.

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Simons, J. C., and Gardner, M. S., Self-Maneuvering for the Orbital Worker, WADD Technical Report 60-728, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, December 1960.

HAND-HELD WHEEL GYROSCOPE (PROJECT SKYHOOK)

Capt. John C. Simons

Behavioral Sciences Laboratory

On an early zero-g flight, a worker with a hand-held power drill (power on) had difficulty repositioning the drill because of the rigidity-in-space characteristics of its motor. As a result of his attempts to re-position, rotation occurred around a point between himself and the drill.

This phenomenon lead to the development of the "skyhook" for studying the stabilization requirements for a weightless man, self-rotation by application of a force coupled to the axis of a gyro, and cessation of rotation with applied counter torques.

The 16-pound skyhook unit consisted of a rim-weighted wheel, 9 inches in diameter and 4 inches wide, mounted on a 15-inch axle. The unit was friction-started against a rubber flywheel to 3650 RPM.

Figure 20. Stabilization by means of a moment wheel is tested in weightless flight

To verify its stability the wheel was rotated and lifted from the floor by a string as the aircraft approached its weightless state. It remained in its original plane as the aircraft pitched forward during the weightless maneuver. Later, a subject held the spin axis perpendicular to the parabolic flight path and remained stabilized as the aircraft pitched around him. The one-axis skyhook stabilized the worker succesfully in one plane and permitted precession about one axis. He could rotate indiscriminately at will during weightlessness; however, he was incapable of stopping at a desired position.

Trials were also made on an air-bearing platform. Precession was induced, and a 125-pound subject turned 360 degrees in 1.1 seconds. Subjects could track the platform to pre-establish floor targets with ease and decelerate to avoid overshooting.

The complexity of cross-coupled, three-dimensional rotation suggests a need for more than one small gyro to achieve controlled stabilization and precession. A unit meeting these requirements is being developed.

Stabilization and self-rotation force requirements have been computed for a 250-pound rigid weightless man and these data will serve as base lines for future studies.

REFERENCE

Simons, J. C., and Gardner, M. S., Self-Maneuvering for the Orbital Worker. WADD Technical Report 60-728, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, December 1960.

PERFORMANCE OF THE TETHERED WORKER

Dr. Duane F. Kasten

Behavioral Sciences Laboratory

For reasons of safety or orientation, a member of a spacecrew may be attached to his vehicle while performing maintenance tasks under weightless conditions. Several possible means of attachment have been suggested: one of these is tethering, or attachment by one or more slack or taut lines fastened to the interior or exterior of his vehicle. Such an attachment is expected to inhibit the tendency of a free-floating worker to tumble or spin as a result of reaction to his work movements.

Figure 21. A tethered subject floating through the cabin area. An observer holds the tethering lines.

Three factors are involved in the investigation of work performance of the tethered subject. First, the best means of harnessing a tethered subject and the best points to attach the tethering lines on the subject are being determined. A parachute harness is being used as a device for providing anchor points on the subject; single, double, and triple points of attachment and single and double lines are being investigated. Second, subjects' performances on standard motor performance tests are serving as the criteria for selecting the best tethering arrangements. Subjects are performing work-sample tests under 1- and zero-g conditions. Comparisons of test performance under the two levels of gravity will permit estimates of capability decrement under the weightless condition. The third factor will be investigation of the reaction of the tethered worker to sudden accelerations. Two types of sudden acceleration are causing problems. Accelerations may be self-induced or they may be caused by direction or velocity changes of the vehicle. The effects of such accelerations upon the subject are being plotted. Observations are being made on the worker's ability to remain tethered, to reorient himself, and to return to the performance of useful work.

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MAGNETIC AND ADHESIVE SHOES

Earl D. Sharp and Capt. John C. Simons

Behavioral Sciences Laboratory

In the normal environment, the vertical motions involved in walking behavior are counteracted by gravity. However, the tractionless space traveler will have difficulty walking with normal gait along a surface. Unless he is firmly anchored, the slightest force he applies against the floor will push him from the walkway.

This study investigated self-locomotion in magnetic and adhesive shoes that could permit the wearer to walk with an earth-oriented gait.

In the first experimental effort, magnetic shoes were made by loosely bolting 12 Alnico magnets through rubber shims to aluminum soles. Although the soles were rigid, the shims allowed a $\pm 3°$ ankle rotation transverse to the walking surface. A plantar flexion of $8°$-$10°$ was sufficient to introduce an airgap between the magnets in the sandal and the floor and to eliminate the 21- to 22-pound inductive force.

A soft iron plate, 18 inches by 1/8-inch by 13 feet, was bolted to the ceiling of the aircraft cabin to serve as the walkway.

Tests of the magnetic sandals showed that shoes with too narrow an area of contact led to a pendulum effect, i.e., with insufficient anchoring for the subject to rotate his mass, he was incapable of self-locomotion. Other difficulties were those of counteracting momentum and performing the necessary stepping movements. When one subject tried to walk with magnetic sandals, he found that any force applied to move the body forward resulted instead in a movement of the foot backward. This skating effect forced an early consideration of factors other than static holding forces.

Need was revealed for flexibility in the soles to allow normal plantar flexion and for information about the holding forces required in the magnets. To meet these needs, new, variable-power, electromagnetic shoes are being developed to allow a closer investigation of idiosyncrasies of the zero-g gait. An analysis of gait with continuous force applications will be recorded from the electromagnetic shoes.

Another approach has been the use of Velcro adhesive, a nylon material composed of minute hooks and eyes. When two surfaces of this material are pressed together, the hooks engage the eyes and develop a tensile attraction strength of about 8 pounds per square inch.

A walkway of "hook" material was installed in the C-131, and the "eye" material was cemented to the bottoms of a pair of tennis shoes. About eight subjects tested the shoes, and motion pictures of their walking behavior are being studied to discover the problems encountered while walking, stooping, turning, and performing other gross motor responses during weightlessness.

Results of walking with the first pair of Velcro shoes showed that greater adhesion would be necessary for greater confidence of the wearer. The shoe soles were modified to flat bottoms, which gave a larger area of contact and improved performance. The shear quality of this material is sufficient to eliminate virtually all skating or sliding action.

The ceiling of the aircraft cabin was used as a walkway because of its obvious value for observing reorientation. An apparently universal phenomenon has been noted by the subjects: that of an immediate spatial orientation with the direction of their feet perceived as "down," regardless of actual position. The development of orbital crew compartments designed for single-floor observer positions is considered unnecessary for space vehicles.

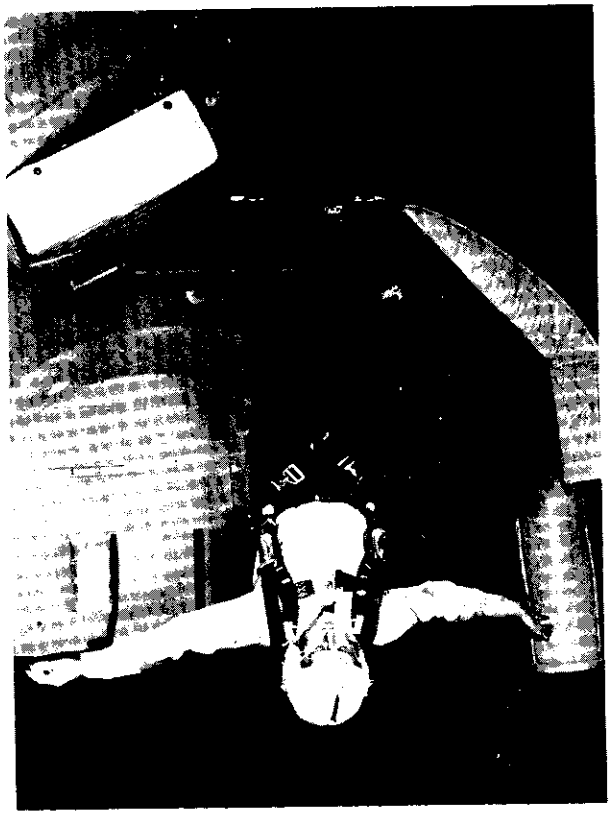

Figure 22. Subject attempts to walk on aircraft ceiling with magnetic shoes

Figure 23. Tennis shoes with Velcro soles are tested on overhead walkway. Weightless observer floats in the background.

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FLEXIBLE ACCESS PORT CONTAINER ASSEMBLY

Elizabeth Comfort

Biomedical Laboratory

The inadequacy of open containers during zero g and the tendency of weightless objects to float about the aircraft cabin have been noted. A container was developed to retain small items securely and to make them readily accessible during zero g. The container cover is fabricated of overlapping leaves of flexible material, which allow the hand to be inserted easily, but which prevent the contained items from floating out into the cabin.

Hook tape (Velcro) is provided to attach the container to the flight coveralls, aircraft seat, or bulkhead.

The assembly was evaluated during zero-g as an inflight food container and as a container for small electronic components or other repair parts and tools. The device has met many of the requirements for a compact, portable parts container for use under weightless conditions.

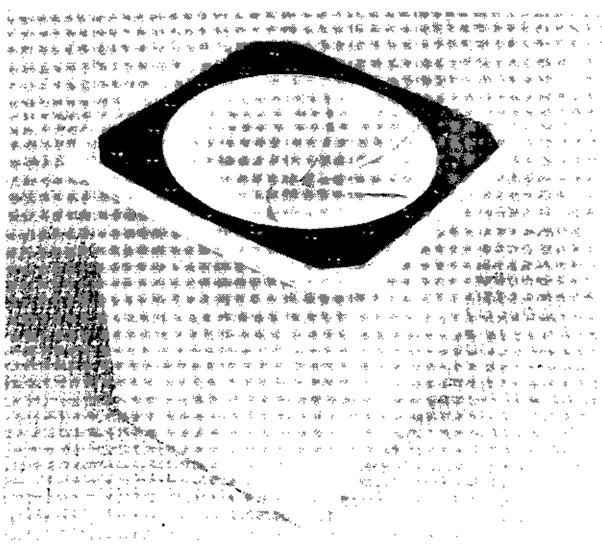

Figure 24. Flexible access port container assembly

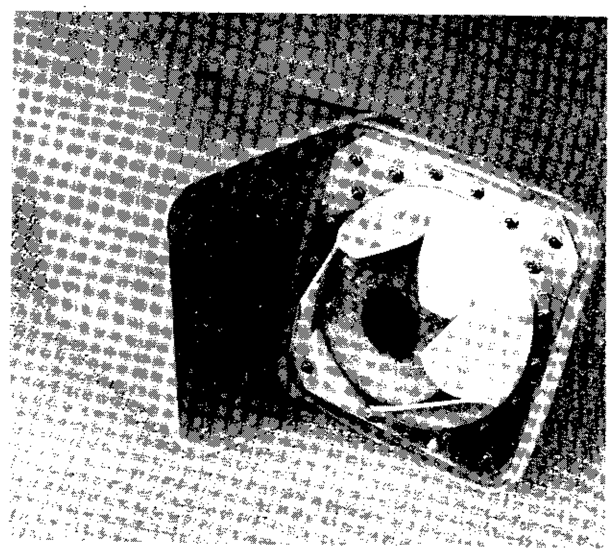

Figure 25. Container with object inserted to show operation

FREE-FLOATING SENSATIONS AND PERFORMANCE

Capt. John C. Simons and Capt. Melvin S. Gardner

Behavioral Sciences Laboratory

This study summarizes free-floating sensory and performance factors experienced by unencumbered personnel in a weightless state. Free-floating personnel are being interviewed during parabolas in the C-131B aircraft while performing gross motor activities in a lighted cabin and in an unstructured visual field (dark cabin). Potential applications of these factors to hardware development and crew training and selection are discussed, and significant areas for future research proposed. Minimum performance profiles for single-impulse, free-soaring trajectories outside the vehicle were computed for the orbital situation.

The following sensations and performance factors were investigated, in particular:

1. Exhilaration
2. Comfort of Nontactual Support
3. Lack of Falling Sensation
4. Knowledge and Control of Limb Position
5. Knowledge of Body Position
6. Knowledge of Rotation
7. Knowledge of Surface Location
8. Concern over Collision Difficulty in Absorbing Inertia
9. Illusions (Target Motion)
10. Sense of Zero, Partial g and Excessive g
11. Sense of Heaviness after Zero-g Period
12. Decrease of Clothing Pressures
13. Nausea and Motion Sickness
14. Decrease in Span of Attention
15. Harness Restraints
16. Body Resilience Motions
17. Cross-Coupled Motions
18. Sloppy Pendulous Motions

19. Ease of Self-Propulsion

20. Difficulty in Walking

21. Helplessness Between Surfaces

22. Rigidity of Powered Tools

23. Suspension of Dust and Objects - Inadequacy of Open Containers

24. Change of Relaxed Posture

25. Physiological Factors

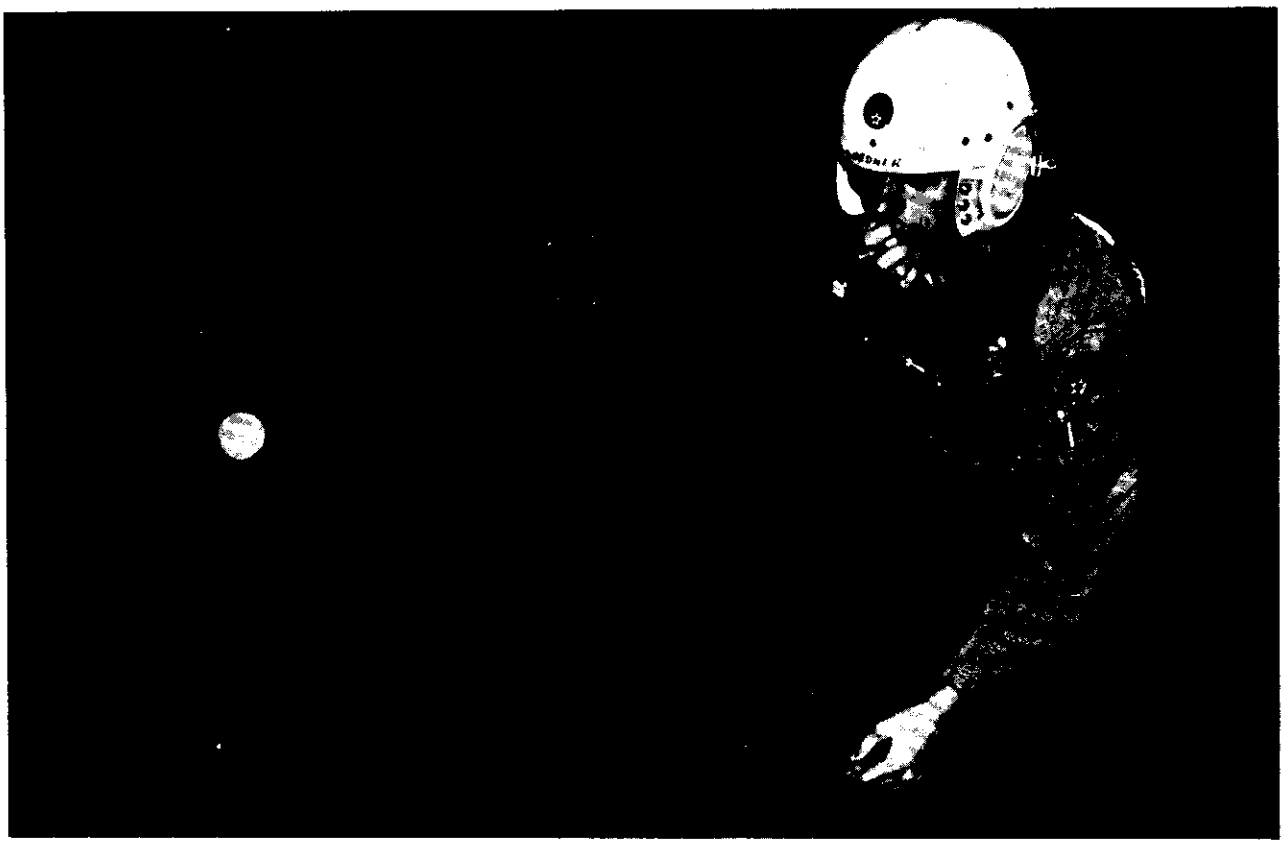

Figure 26. Moon display and subject in darkened cabin

It has become apparent during preliminary tests that descriptive base lines are required to describe the physical characteristics of surface-free (weightless) man. Definitive studies of man at rest, man in angular motion, and man in linear motion were completed.

5. FINE MOTOR BEHAVIOR

USE OF HAND TOOLS

Maj. Leroy D. Pigg

Behavioral Sciences Laboratory

Following the law of conservation of momentum, the force a weightless man attempts to exert on a fixed object, as in performing maintenance or construction work in space, will, by the resulting reaction, move him away from the object; or the force will rotate his body about his point of contact with the object when he attempts to apply torque.

A theoretical analysis and an experimental test of this situation were made, using frictionless platforms to simulate the weightless condition. Qualitative and quantitative results show the need for a handhold to enable the worker to maintain his position at his workplace.

Qualitative observations have also been made in the aircraft during weightlessness. In this condition, six degrees of freedom are possible to the free-floating man, in contrast to the three degrees of movement possible on a frictionless platform. Work was found to be impossible without a handhold. Because of the body's inertia and leverage factors, the strength of a man's wrist is not sufficient to compensate for the reaction to the force that he exerts.

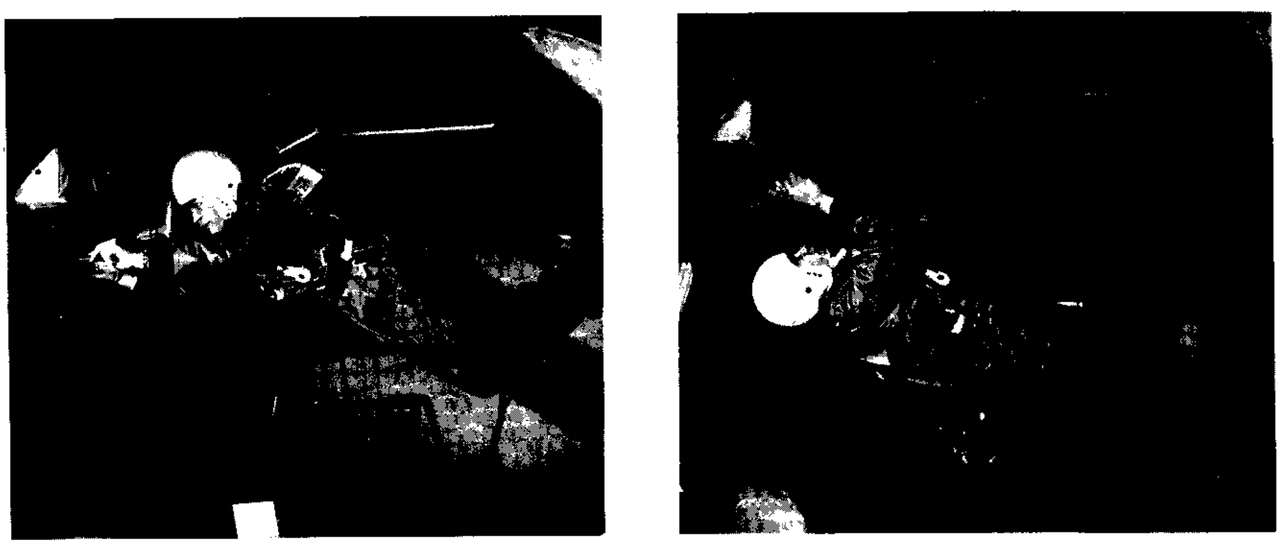

Figure 27. Attempt to use a conventional screwdriver while weightless results in rotation of the body

Besides providing rigid attachments for the man, tools could be designed with closed force systems. Such tools may themselves serve as firm points of attachment for the man using them. A more extensive investigation of this problem is being carried out by North American Aviation, Inc.

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MASS DISCRIMINATION VALIDATION STUDY

Lt. Joseph P. Loftus, Jr., and Nola K. Barnes

Behavioral Sciences Laboratory

The air-bearing table, used to simulate the frictionless aspects of weightlessness, has many advantages for experimental purposes, if its validity can be determined. The extent to which results of performance tests found by this means can be generalized to the weightless state depends upon the similarity of the stimulating conditions.

Determination of the ability to discriminate masses handled on a frictionless table revealed a difference threshold greater than twice as large as in the discrimination of weights under normal circumstances. It is reasonable to ask whether the same relations would hold in a truly weightless state. Since this type of experiment can also be carried out in weightless flight, a validation study is being conducted to check the generality of this and similar laboratory results for predicting performance in space flight.

The classical lifted weights experiment is being carried out during the zero-g portion of the weightless maneuver in the KC-135. Identical capsules containing varying "weight" are presented to the subject for his judgments of difference in mass. Although weightless, the stimulus objects differ with respect to mass and thus their inertial characteristics; the discrimination of these differences will be determined. Three series of masses are being used, with standard stimuli of 500, 1000, and 3000 grams and comparison stimuli varying around these standards. The difference threshold will be determined for each by the customary methods.

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SPEED AND ACCURACY OF POSITIONING WEIGHTLESS OBJECTS

William N. Kama

Behavioral Sciences Laboratory

An experiment, the first in a series of two using the frictionless table, was undertaken to investigate the ability of man to position weightless objects rapidly and accurately. The task involved moving four different masses over a frictionless table through three distances and in two directions in the horizontal plane: left to right and near to far. Results were analyzed in terms of constant error, absolute error, and response time.

Major results of the study:

1. In general, subjects tended to undershoot the mark, although some overshooting was detected at two distances in the left-right direction.

2. Accuracy, in terms of absolute error, decreased as distance increased. In terms of percent error, however, accuracy increased with increase in distance.

3. Accuracy increased as response time increased.

4. Response time for both directions increased as distance increased; however, response time for the left-right direction of movement averaged 0.37 seconds longer than for the near-far direction.

5. Variability, somewhat larger in the near-far than in the left-right direction of movement, increased as distance increased.

PSYCHOMOTOR PERFORMANCE: OPERATION OF SWITCHES

Capt. James E. Wade

Behavioral Sciences Laboratory

The role of the pilot in a manned space craft may be largely one of monitoring automatically-controlled functions and of performing emergency operations. This study investigated the possible decrement in one kind of emergency response, that of sequentially operating switches during a period of weightlessness.

Each of twelve volunatary subjects was flown through three double parabolas in the C-131. They were instructed to operate continuously one of three sets of switches, as fast as possible, to turn an indicator light on and off.

A push button, toggle, and rotary switch were coupled with a master-push button switch to form the three sets used. A different set was employed during each double trajectory flown. The comparison data were the same subjects' response times in straight-and-level flight.

Figure 28. Psychomotor panel containing recording apparatus and switches operated by subject as described

The fastest response was achieved with the push button switch under both normal and weightless conditions. All three types of switching motions showed a small but significant decrease in speed during weightlessness. There were also indications of differences in the decrements of the three types of switching motions, with the toggle-switch motion showing the largest decrement.

The subjects must have a solid position from which to work in order to maintain their performance. A normal seat with a tight safety belt proved quite adequate in this respect.

Possible implications for the design of manually operated switches in space craft may be drawn from these results.

OPERATOR DYNAMIC RESPONSE

Lt. Joseph P. Loftus, Jr., and Lt. Stuart N. Mapes, Jr.

Behavioral Sciences Laboratory

Changes in acceleration will probably bring about changes in muscle tension (myotaxis). If this is true, the dynamic characteristics of human control movements are very likely to be different under weightlessness. This, in turn, suggests that the dynamic characteristics of an optimum controller system for use in a weightless environment may be different from those of optimum controllers for use under other gravitational conditions.

The present study is concerned with the influence of weightlessness on continuous control performance of the human operator. Some assessment may also be made of the relative suitability of various controller configurations under conditions of weightlessness and during periods of transistion to and from weightlessness.

The data are being collected by means of a compensatory tracking task. The experimental equipment consists of a step function programmer, a DC amplifier, and an operator seat with center- and side-mounted sticks. This equipment is mounted on a pallet as a self-contained unit, compatible with mounting requirements in both the KC-135 and the C-131 aircraft.

Continuous traces of the stimulus, the operator's response, and the acceleration profile of the aircraft are recorded on a Heiland photo-oscillograph, indicating real time in 0.01 seconds by background markings. From the continuous trace, lag time, rise time, damping, and time on target will be determined.

Subjects are Air Force pilots. Ten subjects will be used in the initial study, which is organized for analysis-of-variance treatment with acceleration, controller configuration, and practice level as variables.

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PRESSURIZED SUIT MOBILITY

Dr. Edwin G. Vail

Dyna-Soar Engineering Office

Types of movement, ease of movement, and mobility achieved by the wearer of a full-pressure suit in a weightless environment were studied, while an attempt was made to determine mobility requirements for man in space suits.

An XMC-2 full-pressure suit equipped with a bottled gas supply is being used for this study. Weightless subjects observe their own performance and note restrictions of movement with suits inflated to 3 and 5 PSI. Motion pictures are also obtained for later examination.

Figure 29. Observers note ease of movement and stability in XMC-2 full-pressure suit, uninflated

Results have not yet been analyzed, but experience of subjects thus far has shown no major mobility problems with pressurized or unpressurized suits of this type.

Later investigations will evaluate performance in discrete motor tasks, including tool manipulations.

IV. AEROMECHANICS STUDIES

1. POWER GENERATION HEAT TRANSFER PROBLEMS

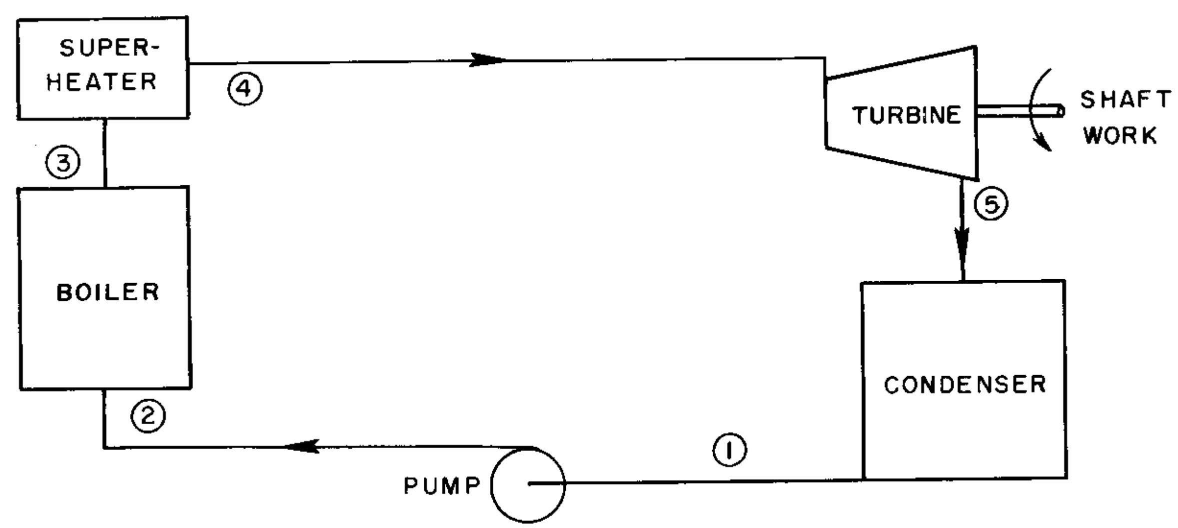
INTRODUCTION

One of the most important phases of energy conversion cycles is the efficient acceptance, transfer, and rejection of heat. The size and weight of all thermal-power generating systems will be profoundly affected by the heat transfer characteristics of each component.

The most efficient, reliable, and versatile thermal cycle for long periods of space operation at high power output requirements is the Rankine cycle.

The basic Rankine cycle consists of a boiler, superheater, turbine, condenser, and pump. The Rankine cycle flow diagram, depicted in figure 30, illustrates the various steps through which heat is added, work removed, and heat rejected from the working fluid during one complete cycle.

Figure 31 depicts the temperature entropy curve. The inherent problem associated with operation of a Rankine cycle in space is the attainment of a stable liquid-vapor interface in the boiler and condenser. The stable liquid-vapor interface in the boiler assures a constant flow of vapor to the turbine, and in the condenser it assures a constant flow of liquid to the boiler pump inlet. This necessitates the efficient change of state at high heat transfer rates, from liquid to vapor in the boiler, and from vapor to liquid in the condenser.



Rankine cycle flow diagram ; 1 to 2, the working fluid is pumped into the boiler ; 2 to 3, the working fluid is heated at constant pressure and converted from a liquid to a vapor ; 3 to 4, the vapor is superheated at constant pressure ; 4 to 5, work is removed by the turbine ; 5 to 1, the condenser removes heat at constant pressure and changes the working fluid back into a liquid, thus completing the cycle.

Figure 30. Rankine cycle flow diagram

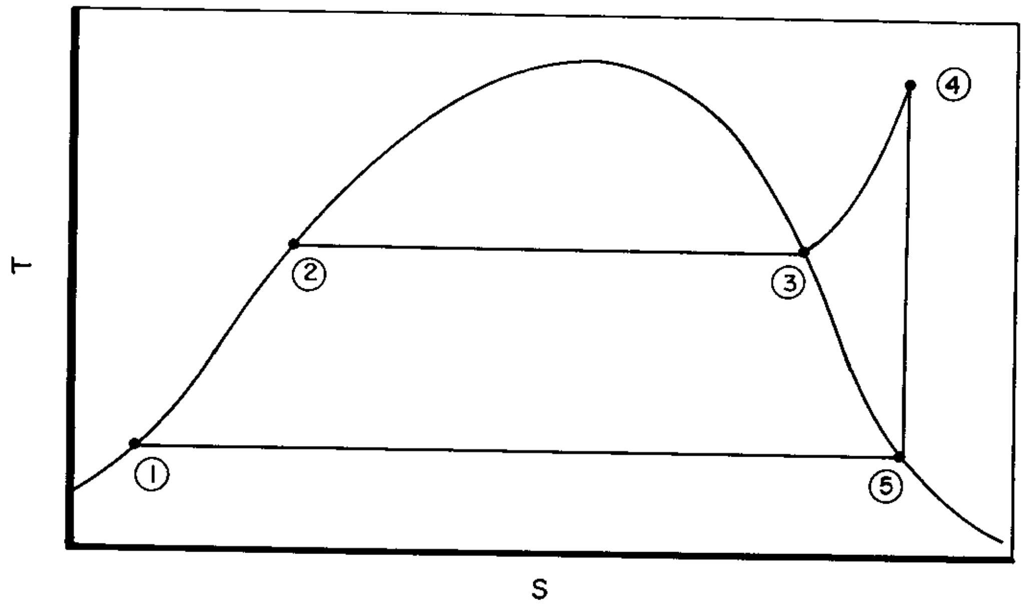


Figure 31. Temperature entropy curve

The boiling process which affords the highest heat transfer rates for reasonable temperature differences between the heat transfer surface and the working fluid is nucleate boiling (figure 32). Nucleate boiling occurs through the action of tiny cells of air or other gases that adhere to the heating surface and form the nuclei of vapor bubbles which rapidly leave the heating surface to allow more bubbles to form. The bubbles on a heated, easily wetted surface are smaller and will more promptly disengage themselves from the surface, thereby providing a better heat transfer medium, as opposed to a surface that is coated and, therefore, not easily wetted. An increase in temperature of the heating surface results in the formation of a continuous film of vapor covering it; this is called film boiling. The vapor film formed during film boiling presents such an effective barrier to heat transfer that it causes a rapid rise in the temperature of the heated surface. Nucleate boiling, therefore, provides the best heat transfer rate without a large increase in the heated surface temperature.

The major problem in predicting nucleate boiling heat transfer coefficients in a zero gravity environment stems from the lack of information concerning the importance of the g term in Rohsenow's equation, which predicts nucleate boiling heat transfer coefficients.

$$\frac{q}{A} = \left[\left(\frac{C_1}{C_{sf}} \right) \cdot \left(\frac{\Delta T}{P_{r_1}^{1.7}} \right) \right]^3 \cdot \sqrt{\left(\frac{g}{g_C} \right) \cdot \left(\frac{\rho_1 \ \rho_v}{\sigma} \right)} \cdot \left(\frac{\mu}{h_{fg}^{\ 2}} \right).$$

Theoretically, if the g term on the right-hand side of the equation goes to zero, the heat transfer to the fluid drops to zero. However, since this is not completely true, the effect of a reduced or zero-g field on the nucleate boiling process must be determined.

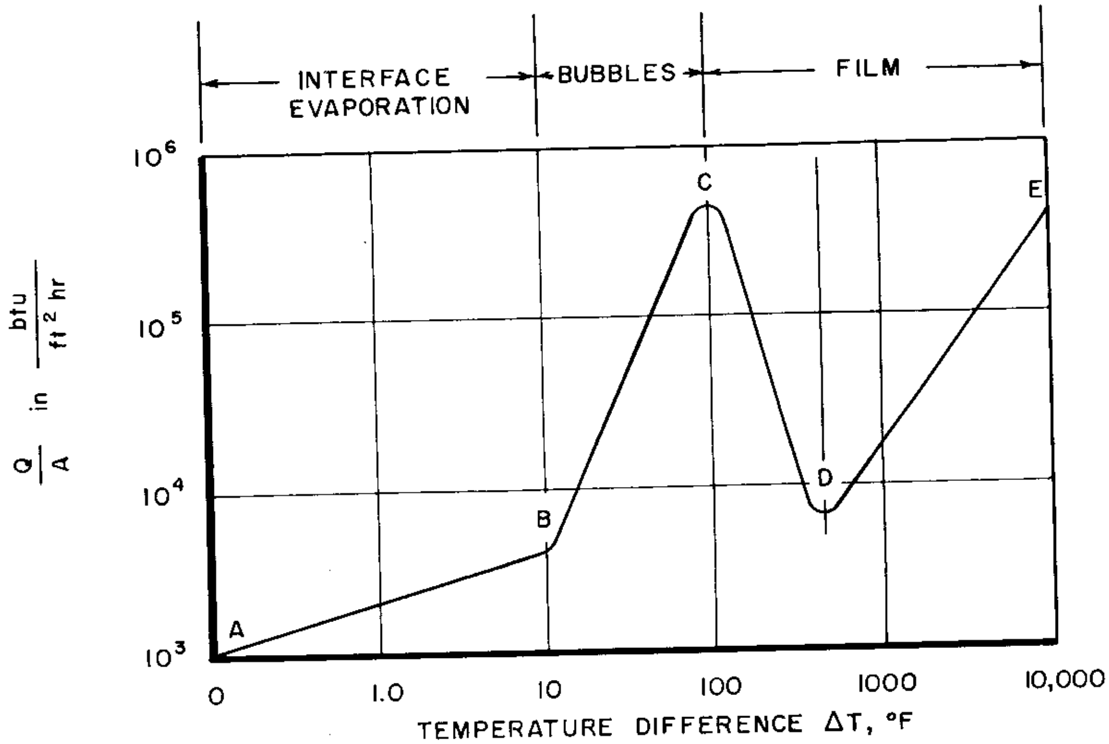


Figure 32. Heat transfer curve

In the normal process of heating a liquid, the heat transfer process is governed by the laws of convection, and the heat transfer coefficients can be predicted quite accurately. Since the convection process is dependent on a gravity field, the above laws may no longer be applicable. In a zero-gravity environment, one might expect that the fluid adjacent to the heat transfer surface will experience a rapid increase in temperature due to the lack of convection forces, and pass quickly from nucleate to film boiling with correspondingly lower heat transfer rates.

The condensation of vapor liberates a considerable amount of heat, but at the same time forms a film of liquid; if the liquid is wetting, it acts as a barrier covering the cooler surface. Under conditions of one g the film could be drained off by gravity flow and therefore, not affect the rate of heat transfer. Observations of the manner in which heat from condensation of vapors is transmitted were developed in mathematical form by Nusselt in 1916. He assumed, if it is a wetting fluid, the vapor condenses in a continuous film flowing in streamline motion down the cooling surface. Gravity alone was considered responsible for the downward movement, and no allowance was made for the possible effect of the velocity of the vapor flowing over the surface of the film. Nusselt's equation for conductance of a continuous film on the outside of horizontal tubes is

$$h_c = 0.725 \left(\frac{K^3 \rho^3 \; gr}{D \mu \Delta T} \right)^{1/4}$$

and on vertical and inclined surfaces

$$h_c = 0.943 \left[\frac{K^3 \rho^2 rg (\sin x)}{L \mu \Delta T}\right]^{1/4} .$$

Upon examining both equations it can be seen that if g is zero, h_c will be zero. Therefore, once a condensing surface is covered with film its conductance will be zero or at least negligible. Again, we know that some condensation will occur. To what extent the condensation process is slowed down must be determined by evaluating the magnitude of the effect of the g term on the condensation process.

MERCURY BOILER-CONDENSER UNIT

Paul Grevstad, Thompson Ramo Wooldridge, Inc., Cleveland, Ohio

Eugene Zara, Flight Accessories Laboratory

The first Thompson Ramo Wooldridge mercury boiler-condenser unit tested in the C-131 aircraft is shown in figure 33. The unit consisted of a pool boiler with immersion heaters, a fine mesh screen located at the boiler outlet to prevent liquid mercury spillage into the condenser, a condenser tube, and a blower to draw air across dry ice and pass it over the condenser tube. Gravity flow was used to return the liquid mercury to the boiler. The results obtained from this unit were qualitative because the unit was not instrumented.

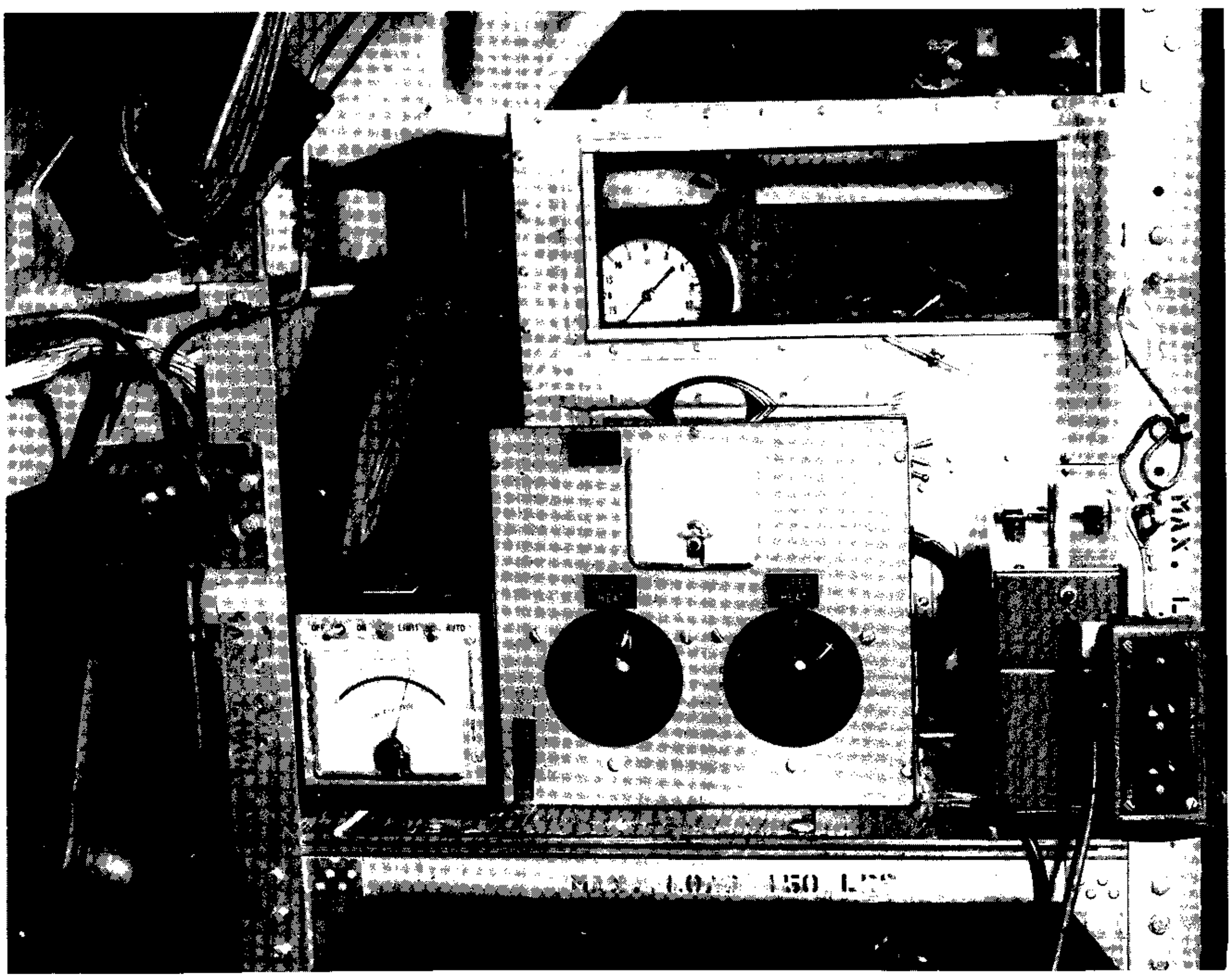


Figure 33. Thompson Ramo Wooldridge Mercury Boiler-Condenser Test Unit

The major parameters investigated were stability of the liquid-vapor interface in the condenser and the ability of vapor-liquid shear forces to carry condensed droplets of mercury to the interface. A completely satisfactory stable liquid vapor interface was not obtained; however, the feasibility of using liquid vapor shear forces to move condensate along a heat transfer surface was demonstrated.

BOILING AND CONDENSING HEAT TRANSFER

Lt. Lloyd Hedgepeth, Charles Delaney, and Eugene Zara

Flight Accessories Laboratory

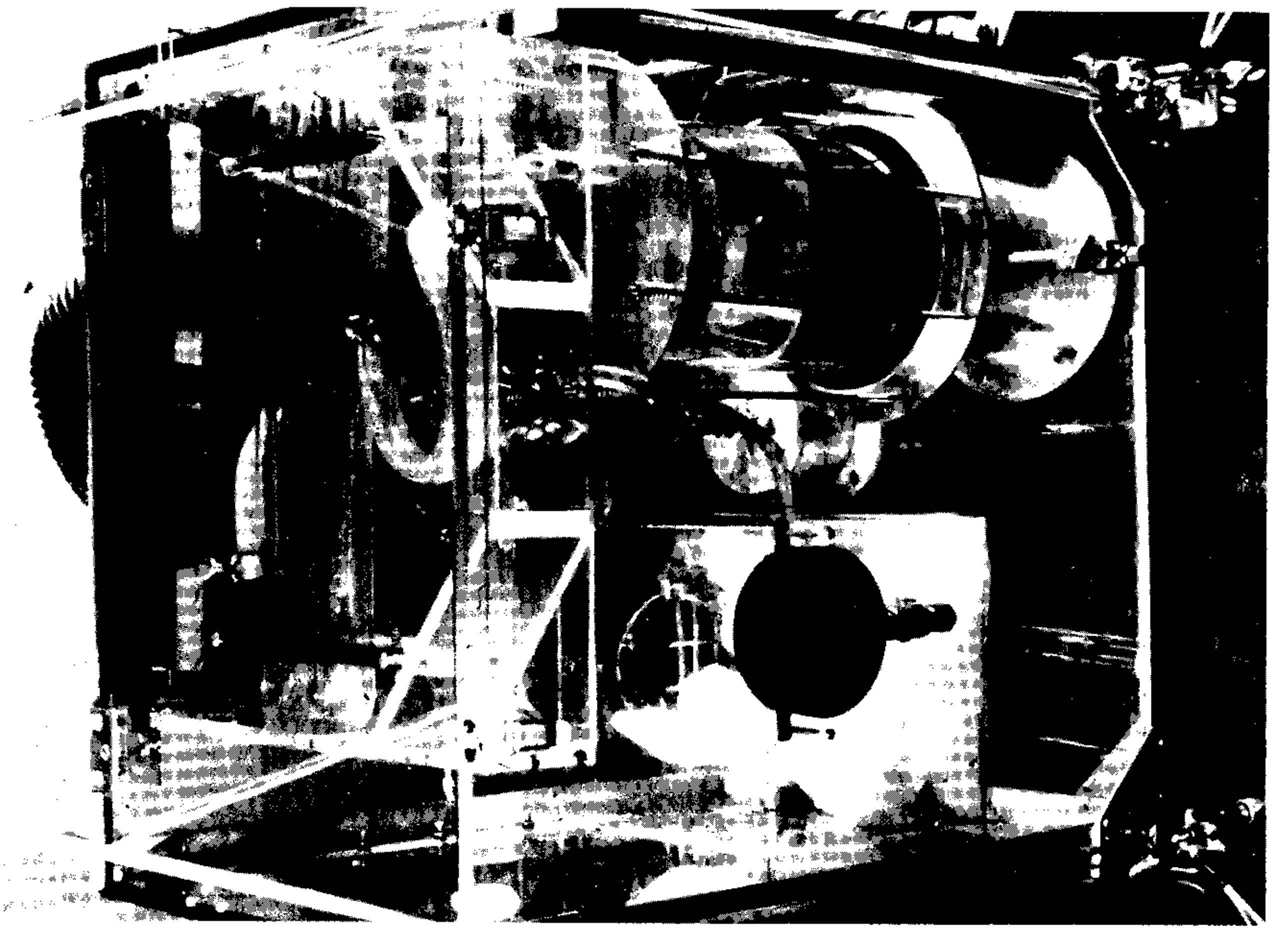


Figure 34. Optically transparent boiler test unit

Figure 34 shows the ASD boiler-condenser unit, which was completely transparent, allowing observation, both visual and photographic, of all the components in the system.

The unit consists of a pyrex boiler with an immersion heater, a pyrex condenser, a graduated cylinder to measure rate of condensation, a receiver, and a blower which draws air through dry ice and passes it over the condenser tubes. The condensed liquid is returned to the boiler by a hand pump.

Difficulties in maintaining a pure weightless condition for test rigs bolted to the framework of the aircraft led to the development of the suspension system that has been described elsewhere in this report. After becoming familiar with the rig's behavior in a free-floating condition, the experimental crew abandoned all suspension lines and permitted the rig to float freely.

Preliminary findings with the pyrex boiler and condenser have shown the following peculiarities:

1. Boiling takes the appearance of foaming while the vapor bubbles cling together as a mass of spheres.

2. Vapor bubbles increase in size with increased zero g time.

3. Surface tension is predominant and the vapor bubbles do not break.

4. Condenser flow stops and in some instances flows the wrong way.

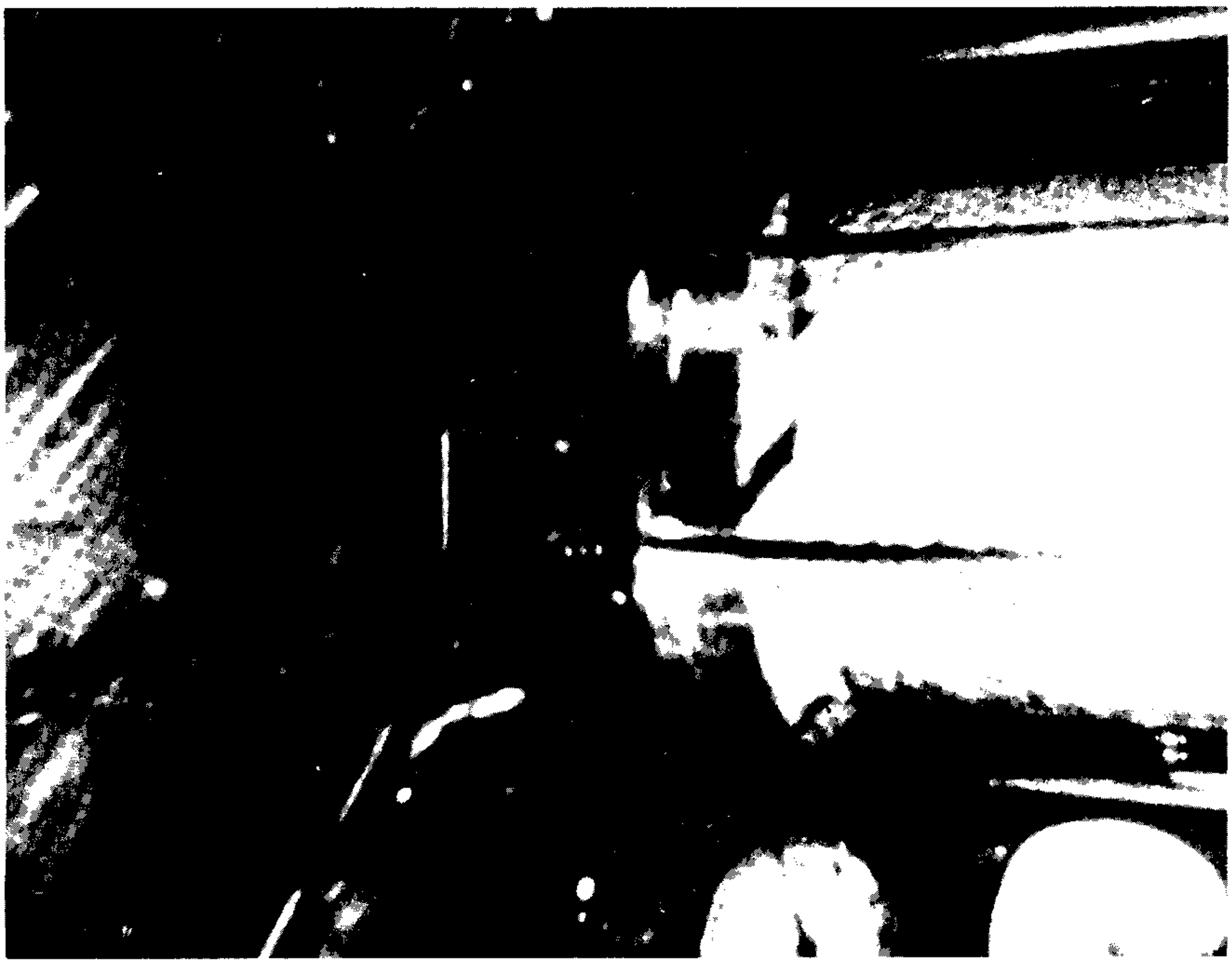


Figure 35. Boiler test unit free floated

MERCURY RANKINE CYCLE TEST UNIT

Paul Grevstad, Thompson Ramo Wooldridge, Inc., Cleveland, Ohio

Eugene Zara, Flight Accessories Laboratory

Thompson Ramo Wooldridge (TRW), Inc., designed and built a complete Rankine cycle system to fly on the ASD KC-135 aircraft. The OFFB AEC unit was built by TRW acting as a subcontractor to Atomics International, the prime contractor to Atomic Energy Commission in support of the SNAP II system.

The system consisted of a forced convection boiler and superheater, a nozzle, and desuperheater to simulate a turbine, a condenser, and a pump. The boiler and superheater converted liquid mercury to a superheater vapor at a pressure of 100 psia and a temperature of 1150°F. The superheated vapor passes through a nozzle and desuperheater that results in a pressure and temperature drop corresponding to a turbine. The vapor passes on through the condenser and is converted to a liquid at a temperature of 550°F, and a pressure of 3-6 psia. The liquid-vapor interface was adjusted to prevent pump cavitation. The pump returns the liquid to the boiler, thus completing the cycle.

In the first flights, the instrumentation and the stability of the system were checked.

Results of the test on the aircraft indicate that a stable interface was established in the condenser tubes, and cavitation in the pump was avoided.

Thompson Ramo Wooldridge plans to free float the test unit after the initial check-out flights have been completed. This will give quantitative data from which more definite conclusions can be drawn.

Figure 36. Thompson Ramo Wooldridge Rankine cycle test unit

FLAME TESTS AND COMBUSTION CHARACTERISTICS

Robert G. Clodfelter

Propulsion Laboratory

G. T. Beery

Flight Accessories Laboratory

In theory, all convection will disappear under zero-g conditions, since convection currents are a function of the gravitational field. After a system enters zero g, there will be a time interval before all residual motion subsides. Once all convection motion has ceased, the availability of oxygen for combustion is dependent on the rate of diffusion of air into the CO_2 accumulated around a flame.

To test this effect, a glass funnel was inverted over a burning candle during flight to prevent outside disturbances from acting on the flame. On entering zero g, the flame was reduced to a small ball around the wick. Oxygen starvation was apparent, but in only a few cases was the flame extinguished before pullout from the weightless parabola.

Further study will determine the effect of zero g upon combustion of certain liquid and solid materials. Initially, observation will be made of flame behavior of burning solids. For these tests, a transparent (Plexiglas) chamber of approximately 2 to 2-1/2 cubic feet will be used, with provisions for mounting lights and a movie camera. The test material will be ignited in the center of the chamber. Comparisons will be made between combustion characteristics at zero g during flight and at one g at the same pressure, altitude, and temperature on the ground.

A second phase will concern combustion of fluids by using a specially constructed spherical chamber capable of withstanding high internal pressures. Provisions will be made for variation of chamber pressures and entrance of fluids and air, as well as ignition source, lighting, and photography through a transparent window.

2. FLUID ORIENTATION

Robert G. Clodfelter

Propulsion Laboratory

Problems of fluid transfer and the venting of open cycle systems make the investigation of fluid orientation in the weightless environment of prime importance. The results of studies conducted under zero g indicate that fluid orientation is affected primarily by the relationship between the cohesive and adhesive forces of the fluid for the container. If the cohesive force is greater than the adhesive force, the fluid will not wet the surface of the container. The number of gas bubbles that form for any given fluid is a function of the mode of formation. Surface tension will cause the bubbles to remain independently suspended unless acted upon by an external force.

Vapor bubble behavior in a fluid was simulated by inserting a tube into a Plexiglas container approximately 95% full of water and introducing air through the tube (figure 37). Repeat zero-g tests showed the following results: The air space in the top of the tank intermixed with the fluid and formed a large bubble that floated randomly about the tank throughout the duration of the run. The smaller bubbles formed by air passing through the tube also floated randomly about the tank, rather than rising to the top of the tank, as would happen under normal gravitation. The most interesting result of this test was that the bubbles did not collide, burst, and form a larger bubble, as expected. Instead, the bubbles bounced off each other and continued on their random paths. This latter effect was attributed, in part, to the high surface tension value of water (approximately 73 dynes/cm at room temperature).

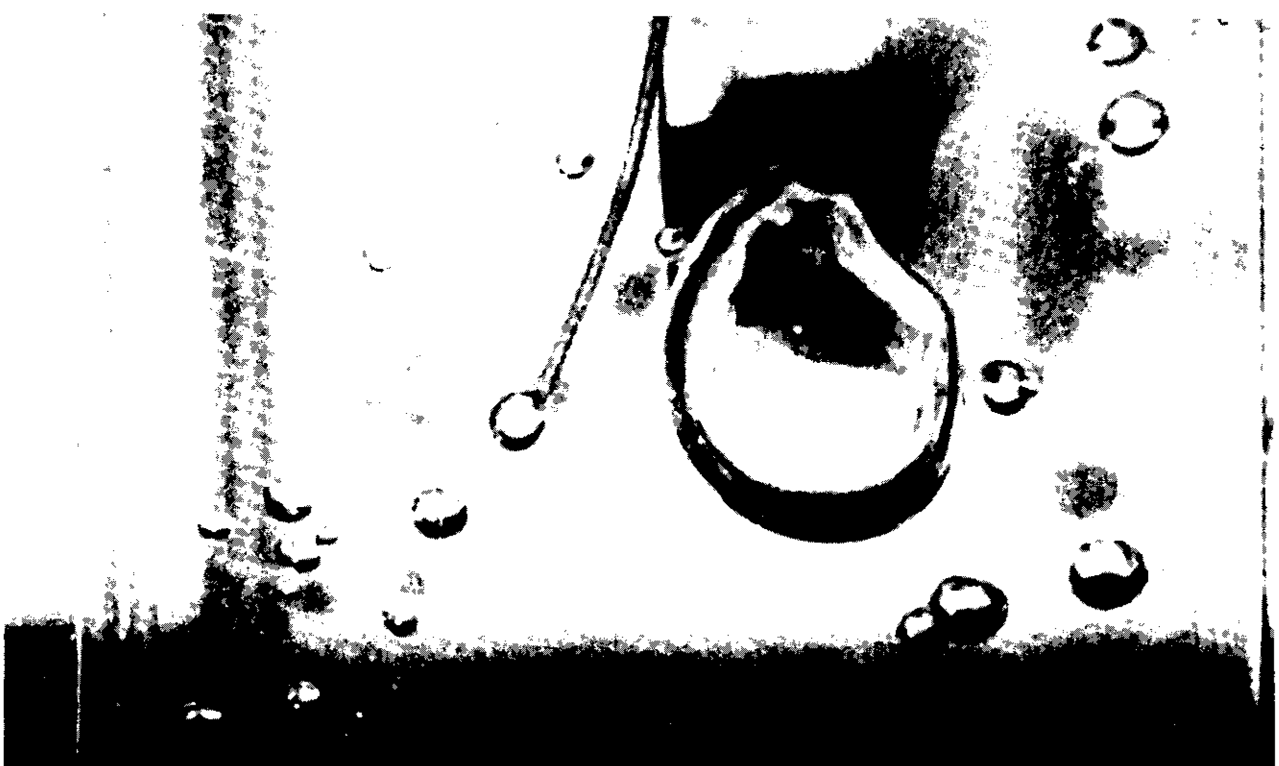


Figure 37. Vapor behavior in a fluid under zero g

Fluids of lower surface tensions were simulated by the addition of aerosol to water. Results of these tests showed that, although the bubbles formed were considerably reduced in size, they did not burst upon contact to form larger bubbles. The small bubbles tended to cluster together in groups, which floated randomly about the tank.

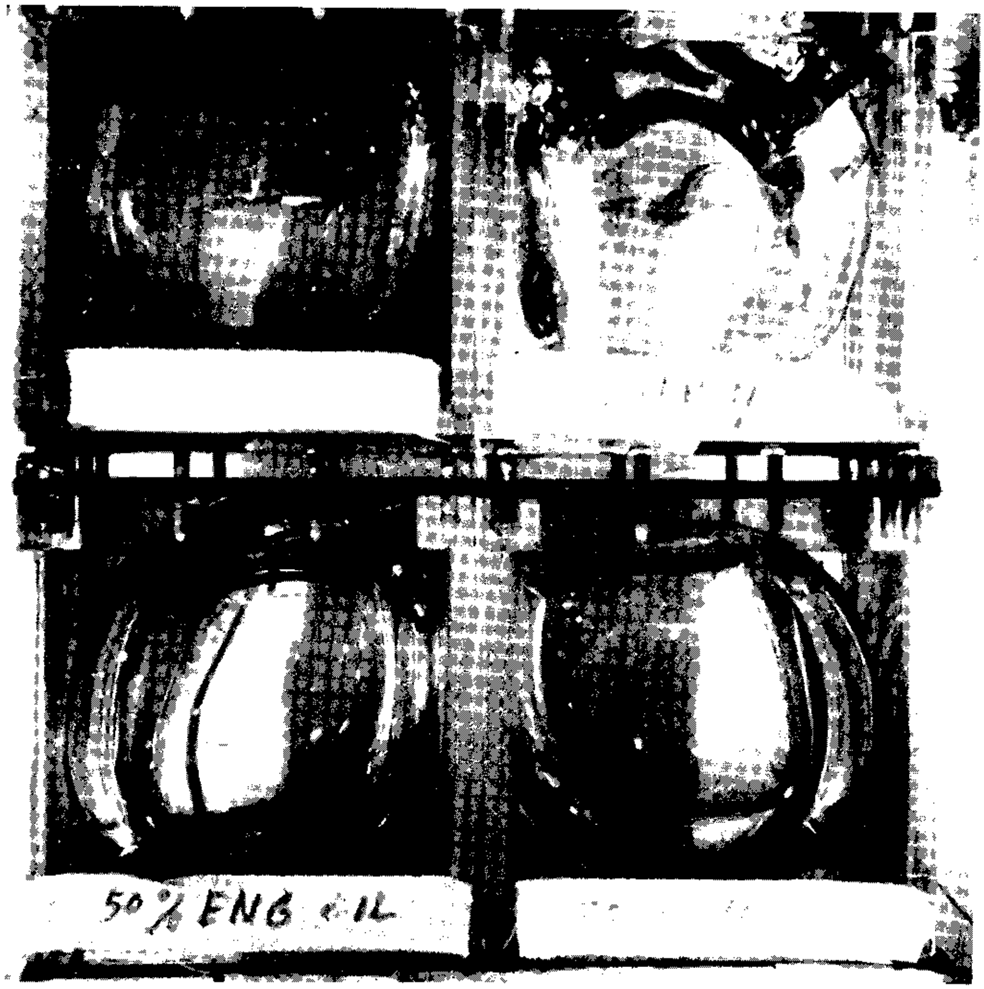


Figure 38. Orientation of fluids with varying surface tensions

Figure 38 shows a fluid orientation test using samples representing a wide range in surface tension values. The upper right-hand cell contains JP-4 fuel, with the lowest surface tension, and lower right, distilled water with the highest; left, hydraulic fluid above, and grade 1100 engine oil below. These tests indicated that surface tension had little effect upon relative orientation for these fluids, although further studies on fluids with varying surface tensions will be conducted.

The results thus far show that the location of a fluid in a container cannot be predicted. The practical significance of this problem was demonstrated in the attempt to transfer freon from one tank to another by means of a small centrifugal pump (figure 39). This method of fluid transfer is inadequate since it does not insure the presence of the fluid at the inlet to the pump. Therefore, conventional methods of fluid transfer and venting cannot be used successfully while the fluid is in a weightless state. Positive expulsion bladder pumps now appear to be the most practical methods of fluid transfer tested. Future research will include tests of other methods.

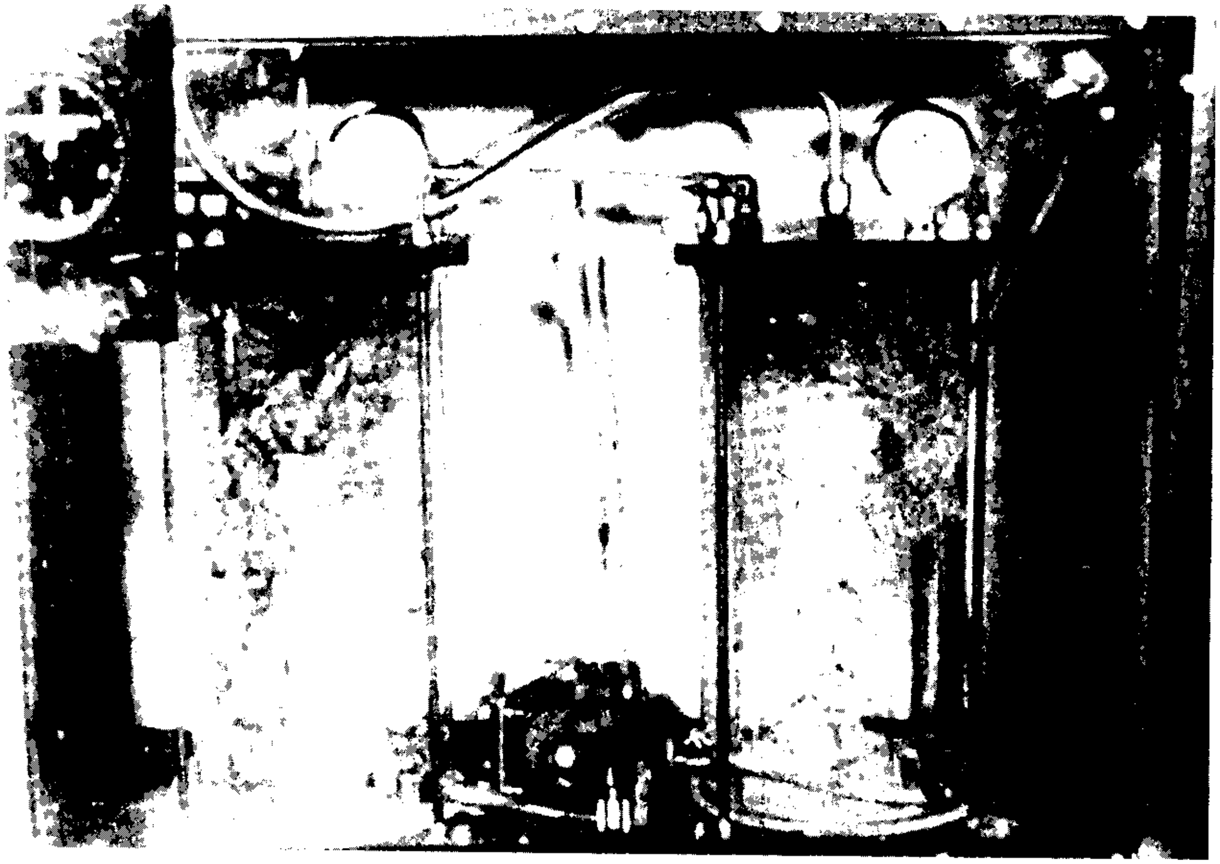


Figure 39. Centrifugal pump arranged to transfer fluid from right to left tank

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FREE-FLOATING WATER SPHERE

Robert G. Clodfelter

Propulsion Laboratory

A thin-walled Plexiglas sphere approximately 12 inches in diameter and half-filled with water has been used to observe fluid motion and orientation in another aspect during transition to weightlessness and during the weightless period. The procedure followed was to enter the parabola with the sphere resting on the floor of the aircraft. The transition to the weightless state was preceded by slight negative g in order to lift the container into the free area of the cabin.

The major fluid distortions resulted from the sphere's receiving small accelerations upon leaving the floor. This tended to cause it to rotate. In only a few runs did the sphere lift off with little or no rotation.

As was expected, adhesive force caused the water to begin to climb the walls of the container during weightlessness. When the sphere was rotating, centrifugal force increased this effect. During one trajectory, the water oriented itself around the inside of the container, forming an almost perfect vapor bubble in the center. Another phenomenon observed was the tendency for small bubbles not to break but rather to remain intact throughout the parabola. This effect might be attributed to the high surface tension of water. The same phenomenon, however, has been observed in other tests when using fluids of lower surface tensions, as reported in the preceding pages.

ADHESION AND COHESION

Lt. R. C. Lewis

Propulsion Laboratory

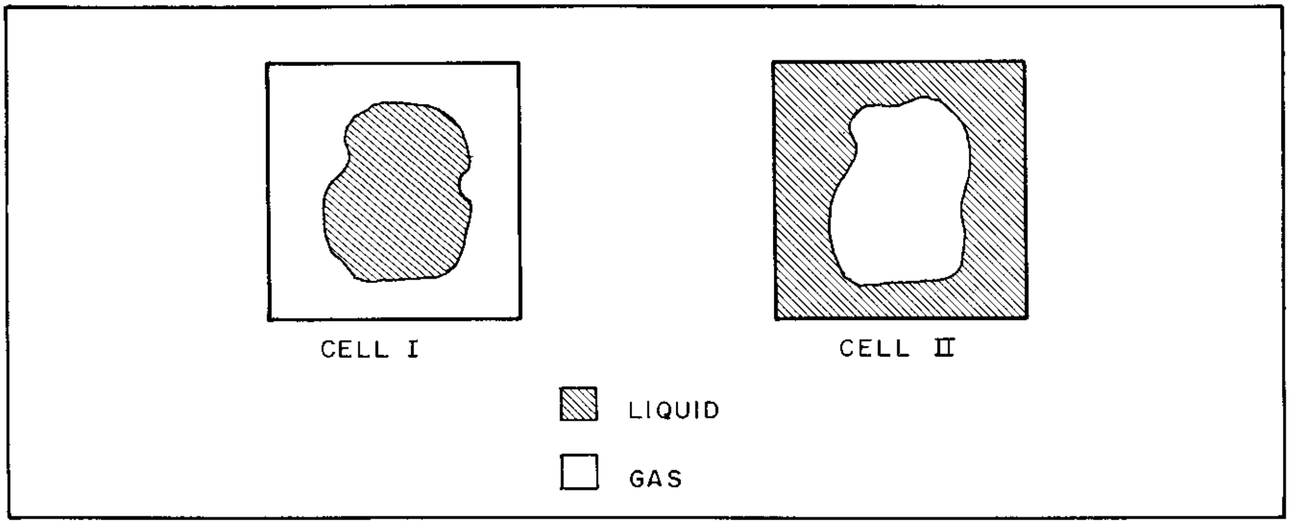

Figure 40. Expected orientation of fluid in the cells

To better understand the adhesive and cohesive forces of fluids under weightless conditions, a test was made using two Plexiglas containers. One cell was coated on the inside with wax to lower the fluid adhesion, while the second cell was left uncoated. It was expected that the colored water in the first cell would tend to pull away from the cell walls, forming a mass in the center with airspace around the walls. In the second cell, with a higher adhesion, the water should form around the walls, with an airspace forming somewhere in the center of the cell.

During the test flight, the cells were rigidly attached to the aircraft, and therefore received foreign accelerations from vibration, yaw, and pitch of the aircraft. Because of these uncontrolled factors, results can be expressed only in terms of trends in the fluids. In the cell with the low-adhesion wax coating, the water had a definite tendency to pull away from the wall, but did not form the single mass in the center. In the second cell, as predicted, the liquid tended to climb the walls leaving the air bubble to form in the center. Further testing will be conducted under more ideal zero-gravity and with better non-wetting coatings on the container walls. More precise results should be attained under these conditions.

USE OF SMALL ACCELERATION FOR FLUID AND VEHICLE ORIENTATION

Lt. R. C. Lewis

Propulsion Laboratory

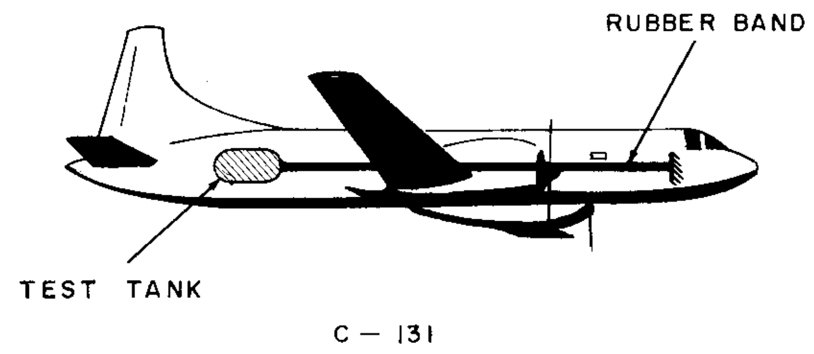

Figure 41. Location of test tank in aircraft

Using a small acceleration to orient fluid in a propellant tank is one approach to the problem of providing a space vehicle with restart capability. However, considering the weight penalty associated with such a system, a better understanding of the effects of acceleration is necessary. Vehicle orientation is also a problem when using this technique, owing to the shifting of the center of mass that results from fluid movement and orientation.

In conjunction with Convair Astronautics, a series of tests was run on a model Centaur tank using small g forces to orient the fluid. The acceleration was applied by a long rubber band stretching almost the length of the C-131 aircraft. Because of the length of the rubber, its force of approximately 0.01 g changed very little during the course of a run.

Positive results were not obtained; however, the observers stated that there was a definite tendency for the fluid to "bottom" in the model propellant tank. In the future, this program will be expanded to include study of orientation in relation to acceleration, time, and propellant tank shape.

ROTATING TANK FOR VENTING AND TRANSFER

Robert G. Clodfelter

Propulsion Laboratory

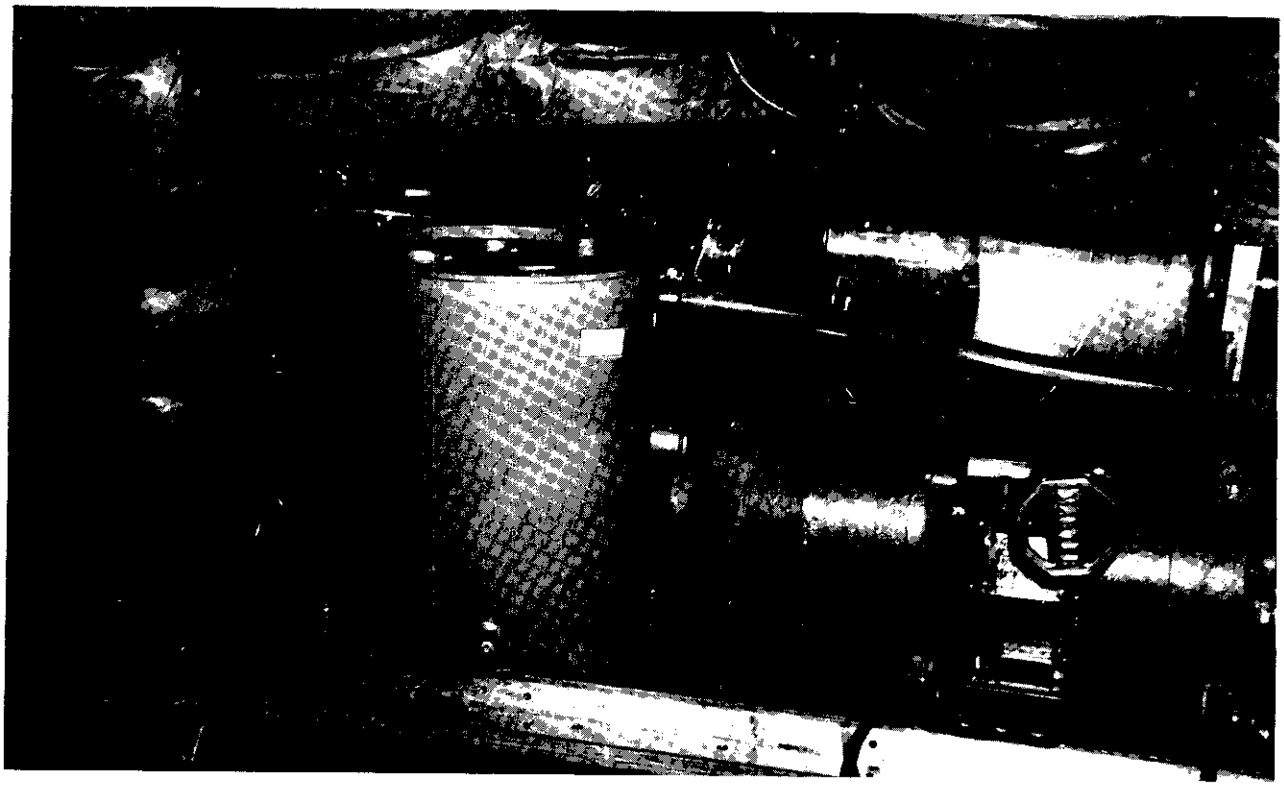

Figure 42. Rotating tank test equipment

In order to test the possibility of using a rotating tank for venting and transfer of fluids, a test tank was fabricated from Plexiglas. The unit, as shown in the picture, consists of a tank whose walls taper from the ends to the center of the tank, away from its axis of rotation. By means of centrifugal force and with the aid of the baffle, the fluid tends to travel toward the farthest point from the axis of rotation. The tank outlet is located at this point, with the outlet line running to a discharge line in the center of the right end plate. Gas fed from the center of the left end plate under pressure provides the differential required to cause fluid flow. This tank is rotated by a variable RPM motor.

Since this system is too heavy to be safely free floated, and since it can be used for tests in environments other than weightlessness, it was mounted rigidly in the aircraft. The purpose of the test is to find the rate of rotation and the pressure necessary for fluid transfer under varying conditions. For more accurate interpretation of the results, the aircraft oscillograph record of accelerations will be used.

While the system works satisfactorily, insufficient data have been obtained to present results.

3. ABLE-5 VEHICLE STABILITY

G. S. Reiter and D. A. Lee, Space Technology Laboratories, Los Angeles, California

The third stage and payload of the Able-5 Lunar satellite vehicle constitute a spin-stabilized, rigid body having a cavity partially filled with fluid. This project investigated the stability of this vehicle during the fre-fall phase of the vehicle's trajectory.

A dynamic model was constructed, similar in dimensions and inertial characteristics to the actual vehicle. It was spun on a turn table, then released while spinning and floated in the KC-135 cabin during weightlessness.

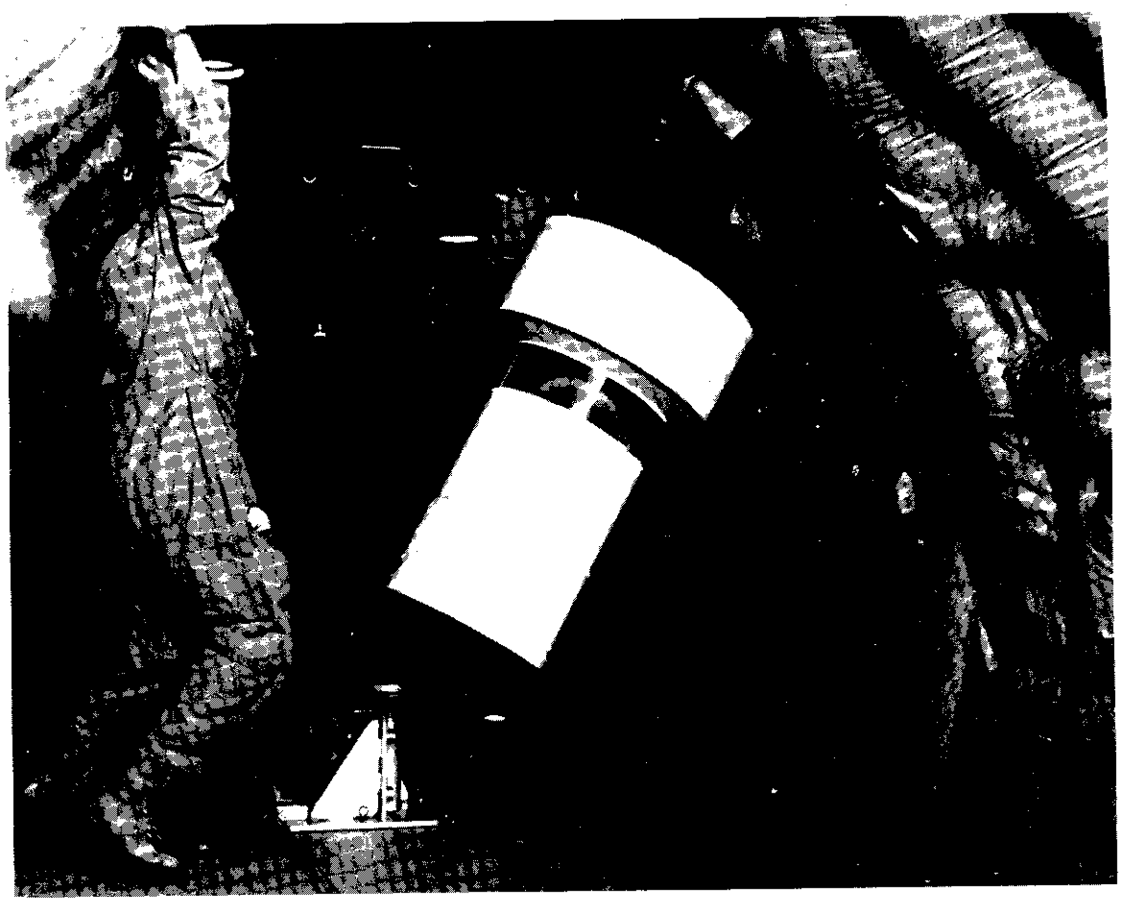

Figure 43. The test model spinning during weightlessness

An angular accelerometer in the model telemetered data on the motion of the capsule to a receiver-recorder in the cabin. The parameters that were varied were (1) spinup time before release, (2) spin rate, (3) amount of fluid intake, and (4) presence or absence of baffles. The motion of the capsule was observed for a tendency to tumble, or, more precisely, the time constant of the exponential growth of precession angle. Fourteen flights were made, with a total of about 280 parabolas.

Detailed data reduction has not been completed. A difficulty encountered was failure to obtain a sufficiently long period of impact-free weightlessness; it was difficult to keep the capsule floating freely without contact with other objects. Only about 63 percent of the parabolas yielded usable data.

APPENDIX

A message from Hq AFSC dated 25 March 1960 advised ASD of the formation of a joint AFSC/NASA study group which was to insure a coordinated and integrated program for investigations of zero-g effects. As its initial step, the study group at ASD undertook the task of identifying NASA and AFSC weightlessness research requirements and the planned programs or those now being carried out to satisfy these requirements. The following listing of AFSC test programs in weightlessness results and was reported to AFSC on 2 May 1960.

APPENDIX I

CURRENT AND FUTURE AFSC WEIGHTLESS TEST PROGRAMS

This zero g study survey includes the following assumptions and factors:

A. Condition time duration is infinite.

B. AFSC, NASA, other government agencies, and contractors are included.

C. Reduced gravity, decaying gravity (-1 to 0-g), and minus gravity conditions are included in order to cover turbulence, vibration, emergency maneuvers and re-entry profiles.

D. The C (current) symbol in the status column includes completed projects and the F (future) symbol includes potential problem areas that are not specific requirements.

E. The "test agency" category lists agencies actually conducting the tests and the "sponsor" category lists requesting agencies.

F. The studies are listed under three major headings of

I. Physics

II. Physiology

III. Psychology

only for convenience of reference and do not intend any organizational functions.

PHYSICAL PROPERTIES AND/OR EQUIPMENT

I. PHYSICS (Materials and Processes) - This area should include an initial theoretical survey of all physical processes that include g in their basic equations. The emphasis in this area is on fluid (liquid or gas) behavior, internal, and external vibration and the resistance characteristics of moving mechanics.

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Fluid orienta-tion		30273	Formation of gas bubbles	C & F	ASD(PL)		C131B & KC135	Advance state of the art in fluid systems
		30273	Formation of liquid bubbles	C & F	ASD(PL)		C131B & KC135	Advance state of the art in fluid systems
	Delta	30273	Vernier rocket operation	F	ASD (PL)	Douglas	KC135	Vehicle orienta-tion
	Delta	30273	Small accelera-tion	F	ASD (PL)	Douglas AFBMD	KC135	Vehicle staging
	Centaur	30273	Liquid level indicator design	C & F	ASD (PL)	Convair Astronautics NASA	C131B & KC135	Tank displays
		30273	Vortex	C	ASD (PL)		C131B	Advance state of the art
		30273	Tank & fluid vibration characteristics	F	ASD (PL)		C131B & KC135	Tanks
	Centaur	497A	1/100 g accelera-tion	C	ASD (PL)	NASA Convair	C131B	Vehicle staging
	Centaur	497A	Orientation	C	ASD (PL)	NASA Convair	C131B	Tanks

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Fluid orientation (cont'd)	Agena		Orientation	F	ASD	AFFTC	KC135	Tank & valve feasibility & design data
		30273	Vibration frequency study	F	ASD (PL)		KC135	
			Liquid-gas interface	C	SSD	Air Research	Atlas Spacer RVX-2A	LOX converter
			Liquid-gas interface	C	SSD	STL	Piggy-Back RVX-2A	Basic study device
Phase separation of liquids & gases	Centaur	497 A	Propeller venting of tanks	C	ASD (PL)	NASA Convair	C131B	Cryogenic tanks
	Centaur	497 A	Filter 200 mesh	C & F	ASD (PL)	NASA Convair	C131B	Cryogenic tanks
	Centaur	497A	Radial inflow	C & F	ASD (PL)	NASA Convair	C131B	Cryogenic tanks
	Centaur	497A	Radial out flow	C & F	ASD (PL)	NASA Convair	C131B	Cryogenic tanks
	Centaur	497A	Venting type of heat exchanger	C & F	ASD (PL)	NASA Convair	C131B	Cryogenic tanks
		30273	Rotating tank	F	ASD (PL)		KC135	Vehicle tanks
		30273	Selective location of vent outlet	F	ASD (PL)		KC135	Vehicle tanks

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
		30273	Material coatings	F	ASD (PL)		KC135	Vehicle tanks
		30273	F100 all attitude tank	F	ASD (PL)		KC135	Vehicle tanks
Fluid transfer		30273	Water transfer	C	ASD (PL)		C131B	Expulsion systems
		6753	Liquid hydrogen transfer	F	ASD	AFFTC	KC135	Expulsion bladder
	X-15	6753	Nitrogen transfer	F	ASD (PL)	AFBMD	KC135	Expulsion systems
		6753	Hydrogen or oxygen transfer	F	ASD (PL)	AFBMD	KC135	Expulsion systems
	X-15	3116	H_2O_2 transfer	F	ASD	AFFTC	KC135	Expulsion bladder
	33(616)-7219	30273	Feed ION engine	F	ASD (PL)		KC135	ION engine
		3143	Engine compart-ment drainage	F	ASD	AFFTC	KC135	Fluid systems & rocket engines
	Test KC135	30273	Oil transfer	C	ASD (PL)		KC135	Expulsion systems
	Test KC135	30273	JP 4 transfer	F	ASD (PL)		KC135	Expulsion systems
	X-15	3116	LN 2 transfer	F	ASD		KC135	Baffle tank
		30273	Freon transfer	C	ASD (PL)		C131B	Pumps
		30273	Pressure transfer	F	ASD (PL)		KC135	Rotating tank

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Fluid transfer (cont'd)		3780	Fluid passage designs	F	ASD	AFSWC	KC135	Airborne reactor
Liquid surface tension		30273	Capillary action	F	ASD (PL)		KC135	Advance state of the art
		30273	Comparison test orientation	C	ASD (PL)		C131B	Formation orientation
		30273	Adhesion cohesion	C & F	ASD (PL)		C131B & KC135	Surface wettability
		30273	Material coatings	F	ASD (PL)		KC135	Surface wettability
			Lubrication film analyses	F	ASD (ML)		KC135	Lubrication requirements
Gases			Heat dissipation	F	ASD (ETL)		KC135 & M	Module cooling filter development, tables of diffusion rates
Mechanics	Test KC135		Inertial relationships within electro-mechanical devices	F	ASD (ETL)		KC135	KC135 instrumentation check
		6220		F	ASD (ARL)		KC135	Adequacy of vertical seeking stabilized camera system

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Mechanics (Cont'd)				F	ASD (FCL)		KC135	Relays, servo mechanisms checks
Photo-graphy		6220	Optical characteristics	F	ASD (ARL)		KC135	Designs of high quality large diameter lenses
		6220	Wet film processing	F	ASD (ARL)		KC135	Photo reproducer
Vibration			Frequency study of standard mounts	F	ASD (ETL)		C131B	Vibration mounts
			Frequency study of standard masses	F	ASD (AML)		C131B	Dampening coefficients
		6220	Camera drift rates	F	ASD (ARL)		KC135	Balance of internal vibrating cameras
Chemical processes		30273	Rates of reaction	F	ASD (PL)		KC135	State of art
			Survey of g terms	F	ASD (ARL)		N/A	All sciences
H-T: boiling liquids	Centaur	30273	Nucleate boiling	C & F	ASD (PL)	NASA Convair	C131B & KC135	Boiler development
	Centaur	497A	"	"	"	"	"	"
		30273	Film boiling	F	ASD (PL)		KC135	"
		30273	Translation	F	ASD (PL)		KC135	"

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
H-T: boiling liquids (Cont'd)		3145	Pool boiling	C & F	ASD (AAL)		C131B & KC135	Boiler development, boiling theory under zero g
		3145	Forced convection boiling	C & F	ASD (AAL)		C131B & KC135	Boiler development, boiling theory under zero g
		3145	Novel boiler design	F	"		"	"
		3145	Basic H-T capsule	F	SSD	ASD	609A	Heat transfer data
		3145	Boiler test capsule	F	"	"	"	Boiling H-T data, test of boiler design
H-T: liquid condensation		3145	Curved tube	F	ASD (AAL)	EOS	KC135	Condenser development
		30273	Rotating plate	F	ASD (PL)		KC135	"
	Snap	3145	Mercury condensing rig	C & F	ASD (AAL)	AEC-TRW	C131B & KC135	Mercury condensers development
		3145	Pyrex tubes	C & F	ASD (AAL)		C131B & KC135	Condensation data, condenser development
		3145	Spray conditions	F	ASD (AAL)	EOS	KC135	Condensation data, condenser development

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
H-T: liquid condensation (Cont'd)		3145	Taper tubes	F	ASD (AAL)	EOS	KC135	Condensation data, condenser development
		3145	Basic orbital capsule	F	SSD	ASD (AAL)	609A	"
		3145	Specific orbital radiator designs	F	SSD	ASD (AAL)	609A	"
			Complete system operation	F	"	"	"	Rankine cycle orbital system
			Collector development	F	"	"	"	Solar collector
		3145	Fuel cell operation	F	"	"	"	Fuel cell
H-T: convection tion			Flame pattern	C & F	ASD (PL)		C131B & KC135	Convection data
		3780	H-T to reactor coolant	F	ASD	AFSWC	KC135	Airborne reactor
		7340	Convective H-T	C	ASD (ML)		N/A	Free convection in g fields
Scale factors			Testing methods time and size	F	ASD (PL)		C131B & KC135	State of the art

II. PHYSIOLOGY The emphasis in this area is on the determination of space crew selection criteria, crew performance limits and evaluation of environmental support systems for all manned space vehicles.

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Cardiac	*Dyn 1 WS-464L SR 182 SR 192 SR 79814 Mercury	71746	Protective reflexes	F	ASD (AML)		KC135 & M	Crew selection & performance tolerances
		71745	Chemical analyses	F	"		"	Circulation data
		71745	Serum and parotid fluid	F	"		KC135	G suits, vehicle envelope criteria
		71746	Direct and indirect blood pressure	F	"		"	Blood pooling indices
		71746	Coagulation rates	F	"		"	First aid processes
		71745	Bioelectric telemetry	F	"		"	Evaluate telemetry gear biophysical
Eating	*	71833	Eating	C	"		F-104	Food & water dispensers
		71833	Swallowing	C	"		"	Food development
		68930	Food delivery	F	ASD (AML)	AMFL (AFMDC)	C131 KC135	Primate food & water dispensers
Sensory deprivation	*	71749	Muscle tonus	F	"			Development of measurement & telemetry techniques

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Sensory deprivation (cont'd)		71745	Muscle atrophy	F	ASD (AML)			Massage & motion equipment
		71745	Galvanic skin response	C	"		KC135 C131B	Alertness warning display
Vibration	*	71582	Body resonance	C	"		KC135 C131B	Re-entry turbulence limits, seat suspension
Breathing	*	63215	Vent separation techniques	F	ASD (AML)		KC135 C131B	LOX coverter OX regenerators (algae)
		71821	Respirator Behavior	F	"		KC135 & M	Lung dynamics & telemetry development
			Gas-liquid interface	C	SSD	Martin	Atlas Spacer	Photo-synthetic gas exchanger
Vision	*	71586	Monocular & binocular acuity	C	ASD (AML)		C131B	Acuity decrements, lighting
		71586	Depth perception	C	"		C131B	Perceptual decrements
		71834	Retinal deformation	C	"		C131B	Visual field - displacement, display design
		71585	Oculogravic, oculogyral illusions	C	"		"	Acceleration profiles, vertigo limits

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Viscera	*	71821	Organ shape & displacement	C	ASD (AML)		KC135	Illness problems
Vestibular canal	*	71585	Pigeon orientation	C	ASD (AML)		C131B	Otolith behavior orientation criteria
Motion sickness	*	71585		C	"		"	Crew selection, anti-g suits, drugs
Brain	*	71830	Brain waves	F	"		KC135	Operator performance
Waste disposal	*	63159	Urine and solid waste disposal	F	"		"	Closed cycle collection and regeneration system
Clothing	*	63389	Fabric comfort	F	"		C131B	Fabric selection and design
Biological system interactions			Encapsulated Mouse	C	SSD	SAM	Atlas Piggy-back RVX-2A	Psychophysiological data obtained from simultaneous study of several systems
			Encapsulated Primate	C	SSD	SAM	Discoveror	Psychophysiological data
Biological system integration	X-15	7758	Reaction to 60 seconds zero g	C & F	AFFTC	SAM	F100F	Physiology data package

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Biological system integration		7758	Telemetry	C & F	AFFTC	SAM	F100F	Aircraft and physiological ground readout console
		7758	Instrumentation	C & F	AFFTC	SAM	F100F	Sensors for air-borne physio-logical measure-ments
		68921	FKG, resp. g skin tem. GSR	F	ASD	AMFL (AFMDC)	C131 KC135	Physiological responses

III. PSYCHOLOGY The emphasis in this area is on the unrestrained orbital worker outside a space ship in an anthropomorphic suit or the vehicle driver in a shirt sleeve environment or pressure suit.

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Training	*Dyn 1 SR 464L SR 182 SR 192 SR 79814 Mercury	71586	Free-floating orientation	C	ASD (AML)		C131B	Astronauts' weightless familiarization program
		1710	Individual difference	F	ASD (AML)		KC135	Inflight maintenance, orientation and disorientation performance
Gross motor performance	*	71585	Self-propulsion	C	ASD (AML)		C131B	Orbital transfer, deceleration indices
	*	71585	Self-stabilization	C	ASD (AML)		C131B	Tumble recovery attitude control
	*	PR92012	Tool handling	C	ASD(AAL)	N. A. A.	C131B	Space tools design criteria
	*	71586	Mass discrimination	C	ASD (AML)		C131B	Material design & handling data
	*	71585	Self locomotion	C	ASD (AML)		C131B	Work position, performance limits, crew-station design, adhesive shoes and walkways

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Gross motor performance (cont' d)	*	71585	Mass-inertial relationships	F	ASD (AML) (AAL)		KC135	Hand held take-up reels, hand holds, hand lines
		71749	Moments of inertia of limbs	F	ASD (AML, ARL)		C131B	Operator stabilizing requirements
		71749	Limb rotation	C	ASD (AML)		KC135	Cockpit layout, seat design, tool handling
	*	13529	Material handling	F	ASD (AL)		KC135	Grappling devices
	*	13983	Const & maint hardware	F	ASD (AL)		KC135	Design criteria for fasteners
Discrete psycho-motor	*	71586	Handwriting	C	ASD (AML)		C131B	Written records & communications
	*	71585	Reaction time	C	ASD (AML)		C131B	Controls layout, design data
	*	71831	Suit mobility	C	ASD (AML)		C131B	Suit design data
		71749	Muscle forces	F	ASD (AML)		C131B	Operator capabilities to exert forces
	Mercury	68931	Cardiovascular, respiratory responses	F	ASD (AML)	AMFL/ NASA (AFMDC)	KC135	Performance decrements
		71749	Reflected surface area	F	ASD (AML)		C131B	Suit design data

STUDY AREA	PROGRAM AREA	PROJECT OR TASK	PHENOMENA INVESTIGATED	STATUS	TEST AGENCY	SPONSOR	TEST VEHICLE	APPLICATION
Discrete psycho-motor (Cont'd)		71749	Limb restraints	C	ASD (AML)	Boeing	C131B KC135	Study restraint rig
	*	13529	Tethering behavior	F	ASD (AL)			Tethering devices
	*	71585	Unconscious movement	F	ASD (AML)			Data on unde-sirable motion, during sleep
		71585	Reflexes	F	ASD (AML)			Effects upon performance capabilities
Vestibular functions		71586	Subjective rotation responses	C	ASD (AML)		C131B	Performance capabilities and emotion data sensory adaption rates, spin limits, coupled rotation effects
		71585	Perception of gravity	F	ASD (AML)		KC135	Decay of foot-down orientation
Audition		71786	Verbal intel-ligibility	C	ASD (AML)		C131B	Intercom and phonetic alphabet data
Time per-ception		71585	Subjective time	C	ASD (AML)		C131B	Performance limitations
		71585	Span of attention	F	ASD (AML)			Duty analyses

APPENDIX II

CURRENT NASA PROGRAM ON EFFECTS OF WEIGHTLESSNESS ON VEHICLE SYSTEMS

STUDY AREA	PHENOMENA INVESTIGATED	*STATUS	TEST VEHICLE	APPLICATION
A. Heat transfer to cryogenic propellants in tanks	1. Heat transfer process to liquid hydrogen at solar flux rates	C	AJ-2 and Aerobee	Centaur
	2. Heat transfer process to liquid hydrogen at earth albedo rates and less	F	Atlas rocket	Centaur
	3. Flash heating of hydrogen upon wall contact during collecting and engine starting	C	AJ-2 airplane	Centaur
	4. Expulsion of gas bubbles from hydrogen during collection of fuel, and cavitation limits of fuel pump during this process	C	AJ-2 airplane	Centaur
	5. Effect of activity of attitude control on heat transfer into liquid hydrogen	C	Aerobee rocket	Centaur
B. Motional dynamics of vehicles	1. Angular motion of cylindrical tanks partially filled with fluid (small disturbance)	C	AJ-2 airplane	Space vehicles with large propellant load
	2. Control of attitude of a cylindrical tank containing non-cryogenic fluid	C	AJ-2 airplane	Space vehicles with large propellant load

*C = current

F = future

APPENDIX II (CONT' D)

STUDY AREA	PHENOMENA INVESTIGATED	*STATUS	TEST VEHICLE	APPLICATION
	3. Yaw-pitch instability in control of attitude	F	AJ-2 airplane	Centaur
	4. Some large disturbance dynamics	F	AJ-2 airplane	Space vehicles with large propellant load
C. Fluid processes in evaporators, condensers, and closed 2-phase thermodynamic cycles	1. Heat transfer and burnout of electrically heated wires in liquid	C	Drop tower	Power generation
	2. Heat transfer and fluid flow in a tube type evaporator	F	AJ-2 airplane	Power generation
	3. Heat transfer in an evaporator of a solar heater	F	AJ-2 airplane or KC-135	Power generation
	4. Fluid process in a lithium hydride closed cycle power generator	F	AJ-2 airplane	Power generation
D. Basic fluid	1. Natural frequency of drops of liquid (check of theory)	F	AJ-2 airplane	
	2. Collision of a drop against a wall (heated)	C	Tank, also AJ-2 airplane	
	3. Collision of drops	F	AJ-2 airplane	
	4. Equilibrium configuration of a viscous fluid wetting the tank walls (no heat transfer)	C	AJ-2 airplane	
	5. Drop dispersion processes in cryogenic liquid inside a hot tank	F	AJ-2 airplane	

APPENDIX II (CONT' D)

STUDY AREA	PHENOMENA INVESTIGATED	*STATUS	TEST VEHICLE	APPLICATION
	6. Capillary pumping	C	Drop tower	
	7. Dynamics of a large drop inside of which circulation is important	F		
E. Pressurization	1. Gas-liquid separator, motor driven centrifugal type	F	AJ-2 airplane	Saturn
	2. Test of bladder type expulsion for starting	C	Ground tests AJ-2 airplane	Space vehicle starting
F. Structure	1. Dynamics of inflation of thin plastic spheres	F	AJ-2 airplane or KC-135	
	2. Erection of solar collector of light weight	F	AJ-2 airplane or KC-135	
	3. Dynamics and orientation control of solar collector	F	AJ-2 airplane KC-135	
	4. Erectable deflated structures incapable of withstanding 1g	F	AJ-2 airplane KC-135	