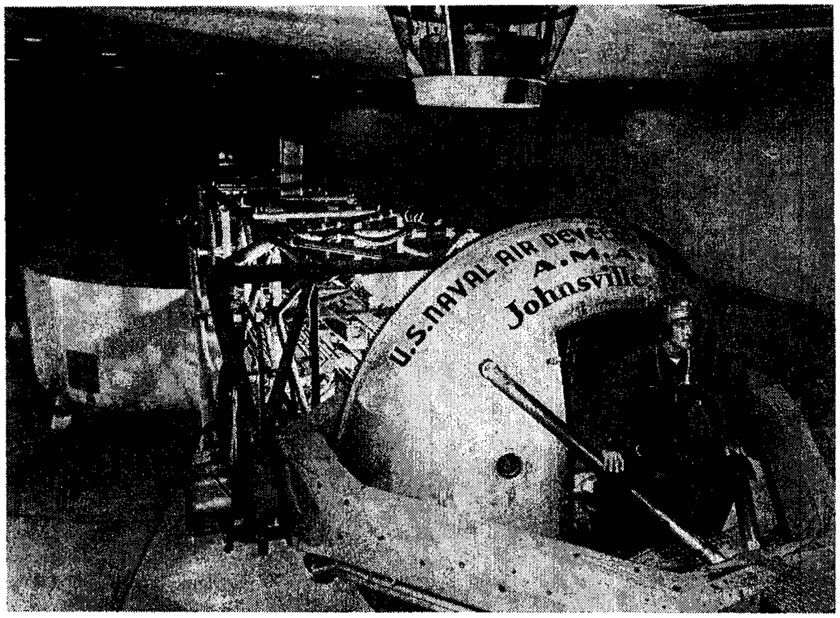

This unique 50-ft radius centrifuge is the most versatile machine existing for testing human acceleration tolerance, prime factor in setting the performance of manned space craft.

Preparing man for space flight

Acceleration studies with the Navy's huge, unique centrifuge at Johnsville probe man's resources as a space pilot, and prepare him **for** fateful days to come

By *Carl C. Clark and James D. Hardy*

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Clark

Hardy

Carl C. Clark is head of AMAL's Biophysics Div. He received a B.S. degree in physics from Worcester Polytechnic Institute in 1944 and a doctorate in zoology from Columbia Univ. in 1950. He assumed his present position in 1954, after serving as a research associate in physiology at Cornell Univ. Medical College and as assistant professor of zoology at the Univ. of Illinois. Dr. Clark is also an associate in physiology at the Univ. of Pennsylvania School of Medicine.

James D. Hardy is research director of AMAL. After receiving a doctorate in physics and mathematics from Johns Hopkins in 1930, he was a National Research Council Fellow in physics at the Univ. of Michigan until 1932, when he was appointed Research Fellow at the Russell Sage Institute of Pathology in New York City, During WW 11, he served on mine sweepers in the European theater, and for this duty was decorated with the Purple Heart and the Legion of Merit. Following the war, he was a professor of physiology at Cornell Univ. Medical College until 1953, when he was appointed professor of physiology at the Univ. of Pennsylvania and director of AMAL. Dr. Hardy's chief studies have concerned body temperature regulation and physiological effects of acceleration.

OUR TASK of preparing man for space flight is, first, to insure that he has adequate physiological and psychological ranges, including the desired performance capabilities, and, second, to provide a local environment which keeps him within these ranges.

Selection of a seemingly suitable man is the first step. Selection will be based on an examination of the candidate's physiological and psychological tolerance ranges. This involves measuring the candidate's bodily and mental responses in altered and generally stressful environments. We emphasize the importance of performance capabilities, The space pioneer presumably will not only be healthy but also have mature and experienced responses, probably evidenced by technical and graduate degrees. The popular conception of the space pilot as a vigorous 18-year-old athlete may miss this point.

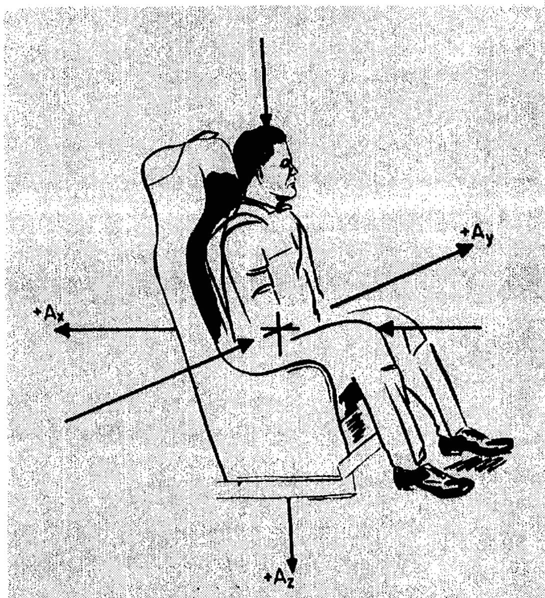
Once the pilot is selected, we may modify him by training, particularly with regard to his performance ranges. There are, in addition, procedures not yet well worked out which may alter our pilot physiologically and biochemically to increase his tolerances and comfort, These may include such simple means as giving him pure oxygen to breathe and diets of low solid waste (to reduce the body waste problem on flights of short duration) and complex means, greatly in need of further research, such as the administration of drugs.

However, regardless of efforts to prepare man for space flight, it is certain that man's body and perfprmance ranges will be inadequate; it will be necessary to greatly modify the local environment to protect and sustain his life. The scientific community must give man in space a pressure capsule to retain his respiratory gases, a chemical and temperature conditioning system to maintain his oxygen and thermal balance, and radiation and meteor shields; must design him instruments, restraints, and controls to optimize the critical aspects of pilot read-in, decision making, and read-out; and may need to give him computers to speed his decisions.

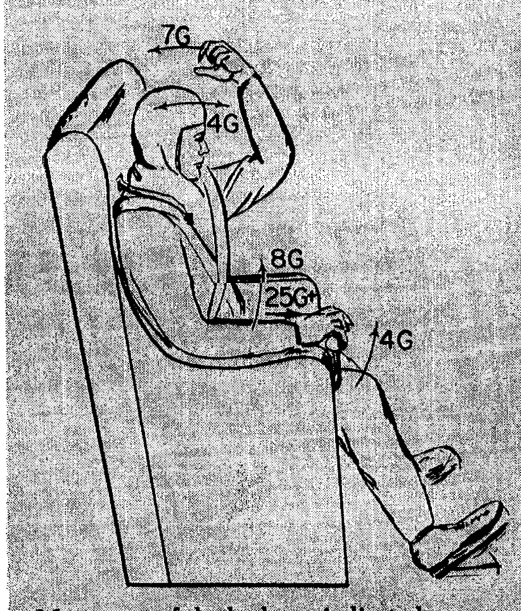
So far, there is little experience with the operation of the body for long periods near the limits of its ranges, so that, as a point of view, one should attempt to provide local environments as near to "normal" conditions as possible, and to utilize the extreme tolerance ranges only under emergency conditions. There are many problems to be considered. Attention must be directed to the morale aspects of the space environment, for example, with respect to crew personalities, number, sexes, and motivations, and with respect to amusements and communication. It may be possible, for instance, to send to the space crew commercial television and radio broadcasts. To reduce the sense of isolation, it will be desirable to augment in every possible way the feedback from the crew to the world behind. Exercise is also important in maintaining a sense of well being. With the absence of aerodynamic drag in space, it may be feasible for the spaceman to assemble a bar-mesh "jungle gym" on the back of his vehicle, and take his exercise away from the confinement of his cockpit. But these are almost byways compared with the problem of acceleration.

Long-duration acceleration is one aspect of space flight which cannot be filtered out or attenuated. Human acceleration tolerance sets a limit to manned vehicle performance. The determination of acceleration tolerance has thus led to major studies with huge centrifuges, such as the human centrifuge, with its 50-ft radius, at the Naval Air Development Center,

This centrifuge, shown on the opposite page, is designed to reach **40** g in **7** sec, and is provided with a power-driven double gimbal system, unique for human centrifuges, by which it is possible to program continuously the direction of the subject with respect to the resultant acceleration vector.



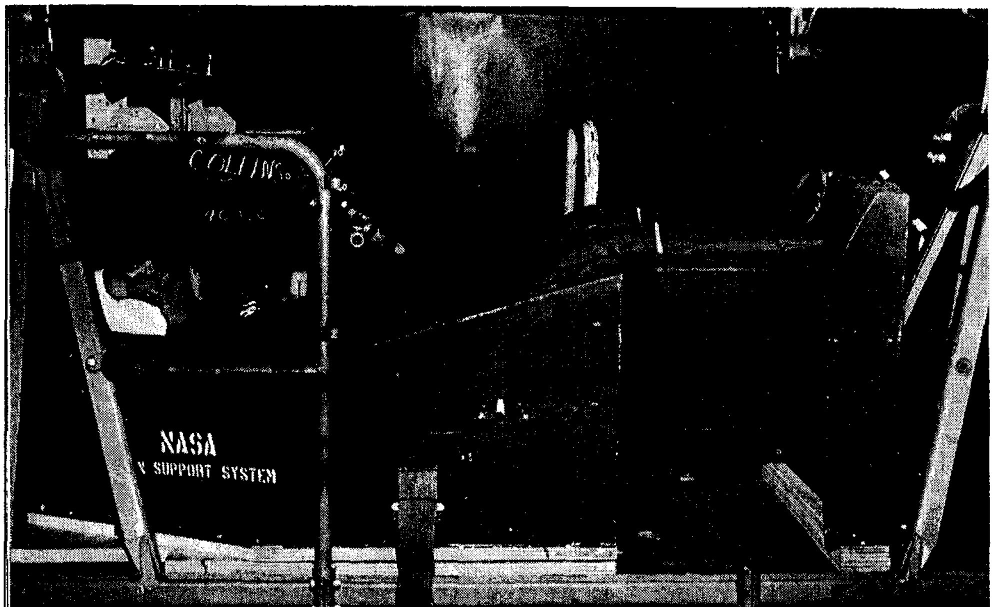
Physiological Acceleration Vectors



Movement of the body, as indicated by the arrows, is just possible at the accelerations listed.

Defining Accelerations of Aircraft or Vehicle

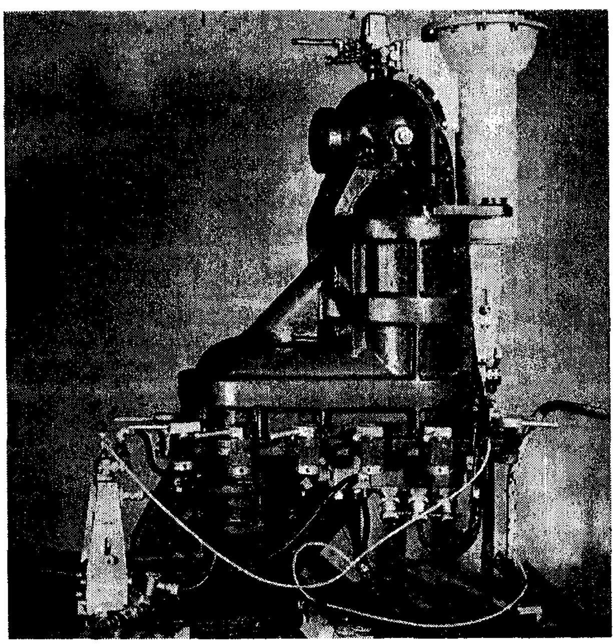
Here we should pause a moment and define acceleration. The figure at top right shows the right-hand orthogonal physiological acceleration vectors in use by AMAL, and indicates the direction of movement of the heart relative to the skeletal frame. The standard NASA terminology for accelerations of an aircraft or vehicle is a right-hand orthogonal set with vehicle a_x positive and forward, vehicle a_y positive to the right, and vehicle a_z positive downward. With these definitions, physiological and vehicle accelerations have the same signs for the pilot sitting upright except for a_z: it is thus necessary to note that a positive vehicle a_z produces a physiologically negative a_z acceleration, as in an outside loop. Thus, for clarity, it is recommended that accelerations



The NASA Contour Couch

always be specified as *vehicle accelerations* or *physiological accelerations.* The accelerations referred to hereafter are physiological ones.

To have pilot read-out, it is necessary that the pilot move. The figure on page 19 summarizes motion capabilities while under acceleration. For vehicle accelerations of the magnitudes and directions shown, limb motions in the same directions are marginally possible. The ability to drag the heel along the floor depends critically on the friction between these surfaces. Drawing the foot back at an a_x of -5 g is difficult but still possible. Note the ability to operate wrist and finger controls to an a_x of +25 g. It seems likely that the distal part of the foot would have a similar capability. Speech is intelligible at a physiological a_z of $+6$ g; at higher levels of acceleration the pilot is generally straining, which prevents clear enunciation.



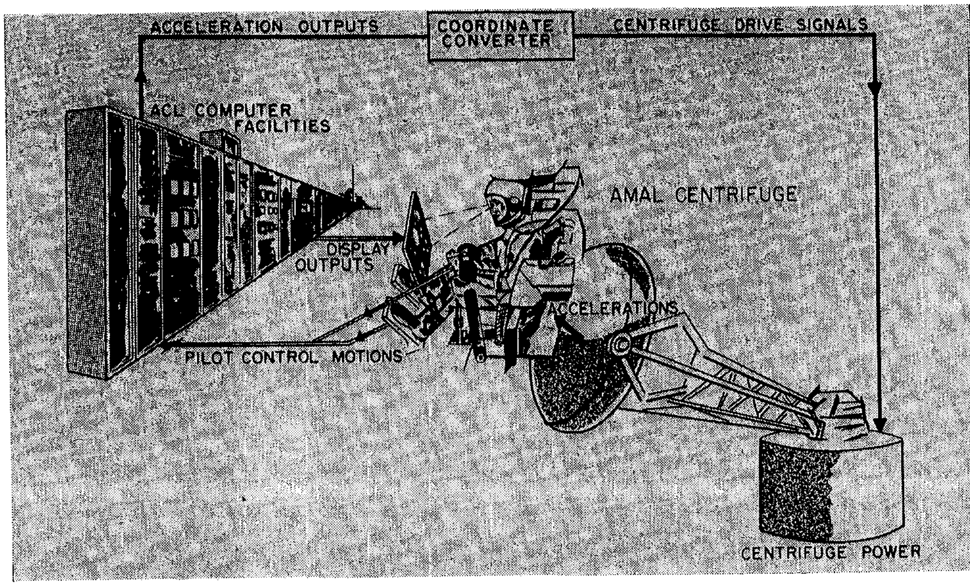
In this water-filled g-capsule, which he designed in 1956, R. Flanagan Gray, riding the Navy centrifuge, withstood 31 g for 5 sec—a record for human tolerance to acceleration (back to chest).

Determining Tolerance to Acceleration

Human tolerance to acceleration is determined not so much by the force produced (divers can withstand the force of 20 atm of pressure) as by body distortion, particularly blood displacements, produced by the force. Tolerance is increased by preventing such displacement. For physiological positive a_z acceleration, the greyout tolerance level of $+3$ to $+5$ g when relaxed may be increased 1 to 2 g by straining and 1 to 2 g by an antiblackout suit or immersion in water up to the chest, and up to 4 g if both straining and a g-suit are used. Other means to reduce body distortion will presumably increase g-tolerance.

Recent work at our laboratory in testing and development of an NASA idea has shown that by supporting the body in a contoured or body-mold couch, as shown in the photo at top left, a man in the slightly inclined chest-to-back position can reach an a_x of $+25$ g without greyout, with a (1-cosine) waveform with a period of 40 sec. An important aspect in the attainment of this record was selection of back and head angles large enough to prevent chest pain, small enough to avoid blackout.

A re-evaluation of body distortion from acceleration was made by R. Flanagan Gray of this laboratory in 1955. He suggested that a principal site of blood pooling, particularly when the lower limbs and abdomen are compressed by a g-suit, is the lungs, and that air pressure within the lungs would prevent such pooling. To minimize body surface distortions, he chose to immerse himself in water,



Dynamic control simulation with the Navy Centrifuge

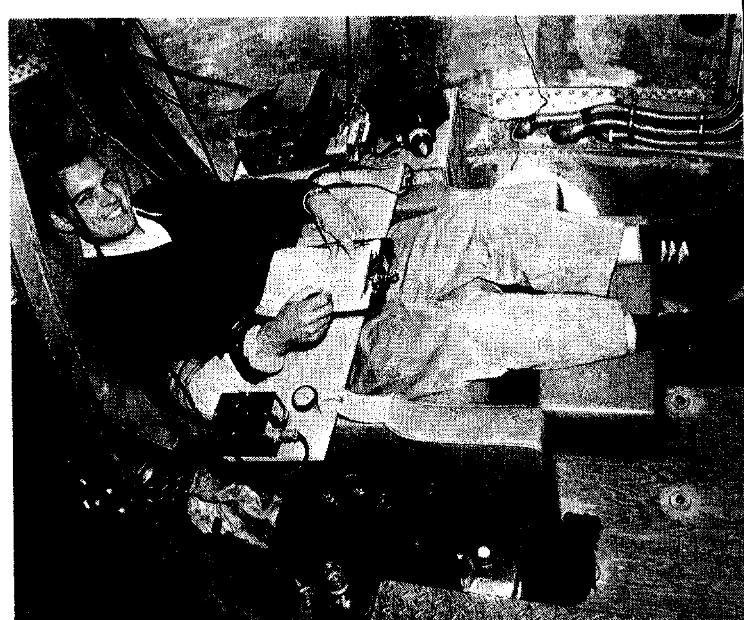
but with the vital addition (over work done during WW II by E. H. Wood, et al.; see OSR Report No. 207, Nov. **12,** 1943) of complete immersion and lung pressurization. By the simple technique of complete immersion and holding his breath to attain lung pressurization as the chest compressed during acceleration, Gray set **a** new centrifuge record in April **1958** for ***a,*** tolerance of $+16$ g with a (1-cosine) waveform with a period of **25** sec. The physiological limit at **16** g was not greyout but the inability to voluntarily hold air in the lungs.

Gray had recognized that higher lung pressures would be necessary. For this reason, in 1956, he designed a seated-body-form aluminum g-capsule, subsequently built by the David Clark Co., as shown at the bottom of the opposite page. Gray's capsule has a closed respiratory system and is filled with water. The rigid container, when sealed, insures that the body maintains a constant volume. The respiratory system pressurizes the lungs enough to prevent them from distorting under forces of acceleration. Oscillation of pressure above the applicable base line maintains oxygen transport at constant volume.

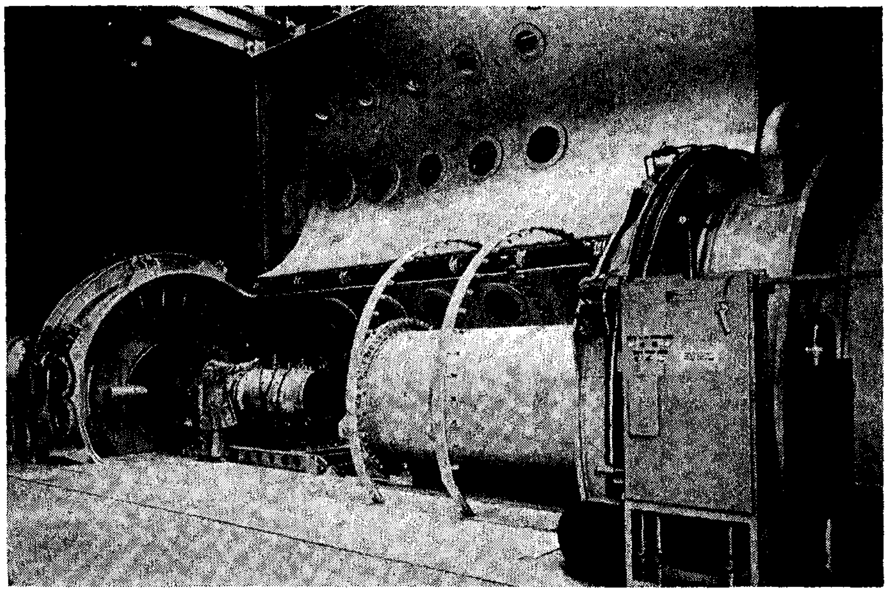
Thus far, the water capsule has only been tested with the subject facing away from the center of rotation of the centrifuge. The acceleration in this position is back to chest, or $-a_x$. In this position, Lt. Comdr. Martin G. Webb, USN-MC, has reached a level of 28 **g** with a 1-cosine acceleration pattern of 28-sec total duration. More recently, Gray in this position has reached a peak level of 31 g, which was maintained for a period of 5 sec—a record for centrifuge acceleration tolerance for humans in this orientation.

During the run, Gray experienced a moderate amount of abdominal pain, which may have been due to compression of intestinal gases. Gray's arm and leg movements were free and he suffered little disturbance of vision. Due to the difference in density between the water and the thorax, the subject was moved strongly against the back of the capsule. This contact may have been the cause of minor back pain which he felt a day after the experiment. **A** complete physical examination revealed no apparent physical damage which could be attributed to the tests.

The high degree of protection Gray's capsule gives can be appreciated by a comparison of the condition of one of Col. John Stapp's subjects in the pioneering tests of accelerations of this magnitude carried out on the high-speed sleds at Holloman AFB (See *J. Aviation* **(CONTINUED ON PAGE 88)**



Medical researchers are taking up the challenge of preparing man for space flight. Here, author Clark cheerfully takes a 2-g "trip to Mars" in 42 hr, in a first study of longduration acceleration.



Hypersonic Ramjet Engine Test Stand at Marquardt

This stand at Marquardt's modernized Jet Lab in Van Nuys, Calif., will test 6 ft diam ramjet engines with up to 5000 lb thrust at simulated altitudes approaching the limit for air-breathing power plants. Stand cell is 14 ft in diam and 80 ft long.

Preparing Man for Space Flight

(CONTINUED FROM PAGE 21)

Medicine, **26:** 268–288, 1955). Hospitalization of several days was not uncommon for men sled-tested. It is now a valid point of view that, given suitable protection, man may tolerate higher levels of acceleration and for periods much longer than had been thought possible.

For the success of man in space, the crew should be as familiar as possible with all the stresses and emergencies which they might meet. Some of these situations may require rapid and precise reactions for survival. There may be, for instance, an overreaction to anything unexpected.

The mental environment of the spaceman, moreover, focuses down on what we, in the presumably calm atmosphere of our offices, consider to be but a small part of the total environment. Recently a test pilot "crashed" the X-15 centrifuge simulator on one of his first few dynamic flights, to later comment "I was concentrating on the g-meter." This was only one of several important instruments for proper control during part of the re-entry, as he knew from hours of static-simulator practice.

It is a primary requirement that the space pilot will be provided local environments which, if properly utilized, isolate him from the greater part of his hazards. By training it will be possible to make situations seem routine which at first are extremely stressful.

There are two approaches to training for space flight. One is the older method, illustrated by the early NACA aircraft-research program of moving higher and faster in small steps, repeated with respect to all aspects that are different by each pilot. The other approach to training is by simulation, a method of increasing importance now that the cost of simulating a flight has become significantly less than the cost of the actual flight, even if the latter involves no aocidents.

Simulation Must Be Very Good

Although one can say that there is no substitute for reality, one must also admit that there is no substitute for being prepared for this reality. With the simulation technique, crews could maintain proficiency on the ground throughout the experimental envelope of the vehicle. Any crew could be used to extend the envelope, perhaps still in small steps, bringing back information which, added to the simulator, would extend the envelope for all. For this to be possible, the simulation must be very good. Thousands of ground "flights" would be made for each actual flight.

Simulation techniques have developed initially for each of the hazards of space separately. At present, there are available pressure chambers, thermal chambers, noise chambers centrifuges, linear tracks, shake tables, aircraft ballistic trajectories for zero-g studies, "fixed base" cockpit computer simulators for the study of controls, adequacy of controllability, displays, and ,control .techniques, tracking and landing simulators as refinements of the last, etc. The need is to combine these separate devices to provide, with as much reality as possible, the total experience of crew sensory read-in, decision making, and read-out.

"When In Doubt Add Parameter"

Certain parameters of the environment seem less significant than others in affecting the crew facilities, and these might receive less emphasis in the simulation. But the point of view in simulation work should be "when in doubt add the parameter" for "desk' evaluation of importance may be quite different from flight evaluation. Biologists, for instance, are just beginning to work on responses of the body to combined stresses; it cannot be predicted whether a man who can perform adequately during two separate stresses will do the same when the stresses are combined. Perhaps the quickest approach is the detailed simulation of the particular local environment of concern. Finally, at every opportunity a simulation shauld receive flight comparison with subsequent validation or improvement.

To simulate the flight aocelerations of a particular aircraft, one can use either a human centrifuge or a variable-stability aircraft. Linear track devices thus far do not have the power and length for long-duration accelerations. Aircraft motion has six degrees of freedom; the detailed reproduction of the time histories of its three linear acceleration components and three angular acceleration components would require the full displacement and speed capabilities of the aircraft itself. For slower vehicles, the variable-stability aircraft can carry out an essentially perfect simulation. For faster vehicles, the variable-stability aircraft has generally been flown (particularly by NASA and Cornell Aeronautical Lab) to simulate the linear accelerations, with some sacrifice of accuracy in simulating angular accelerations. Available power and the strength of the variable-stability aircraft limit the durations and magnitudes of accelerations which can be simulated with them.

Human centrifuges are constrained in motion, yet can have the power and strength to simulate accelerations well beyond those of present vehicles. For experiments fixed on the centrifuge arm or mounted in free-swinging carriages, these centrifuges have but one degree of freedom of control; the other five parameters of the vehicle motion are generally incorrectly matched during the simulation.

The AMAL centrifuge, shown on page 18, is an exception. The only human centrifuge with a powered double gimbal system, it has three degrees of freedom of control. Up to the .present time, tests with this centrifuge have emphasized simulation of the three linear acceleration components, at a sacrifice of angular acceleration matching.

New Technique

For earlier work, the centrifuge was remotely controlled, to give to the subject specified accelerations unaffected by his actions, as if he were a passenger in the vehicle. In July 1957, the new technique of centrifuge dynamic control simulation—with pilot-oomputer closed-loop control, as illustrated on page 21—was first put into operation, following its development in cooperation with the NADC Aeronautical Computer Lab and Univ. of Pennsylvania consultants.

In this technique, the pilot makes the mission flight control motions, and a computer determines the three linear acceleration components which would have been generated had the pilot made the same ,control motions in actual flight and drives the centrifuge to deliver these accelerations to the pilot. At the same time, the computer drives the pilot's display instruments, to show the changing conditions of the flight. The pilot then receives all the maneuver loads of flying the vehicle under his own control. Unfortunately, a ground-based centrifuge is unable to provide accelerations of magnitude less than 1 g; for the simulation of outside loops or ballistic flight, the centrifuge is stopped until 1 g is again exceeded.

Three programs of centrifuge simulation of the **X-15** research aircraft have been carried out, two using this technique of dynamic control simulation. Some 601 dynamic flights and 991 static flights of the X-15 have been made with the centrifuge simulator during these three programs.

With the centrifuge simulator, it is now possible to examine simulataneously both flight-control performance and acceleration tolerance and determine their interactions. It is proposed for future work *to* add at least the horizon aspects of the "view out the windows" to provide the peripheral field visual cues important in pilot control orientation. Pressure, temperature, and sound simulation may eventually be added. By providing the pilot with the exact displays, controls, vehicle responses as represented by display changes and linear acceleration components, and with as many of the other sensory cues of the actual flights as possible, the pilot can be trained in the procedures for normal flight and for emergencies. Ideally, it would be desirable to so perfect the flight simulator that a blindfolded pilot could not tell it from the real thing. The expense and hazard of space flight is such that this ***is*** the necessary trend in the simulation art.

Space-medicine research cannot wait for the engineers to provide a vehicle to be simulated. This research will probe ahead, determining human limitations of body and performance, and means of obviating these limitations. The high-acceleration work at AMAL and in other laboratories falls in this catagory and is of basic importance to the engineers who will design a vehicle to utilize human capabilities.

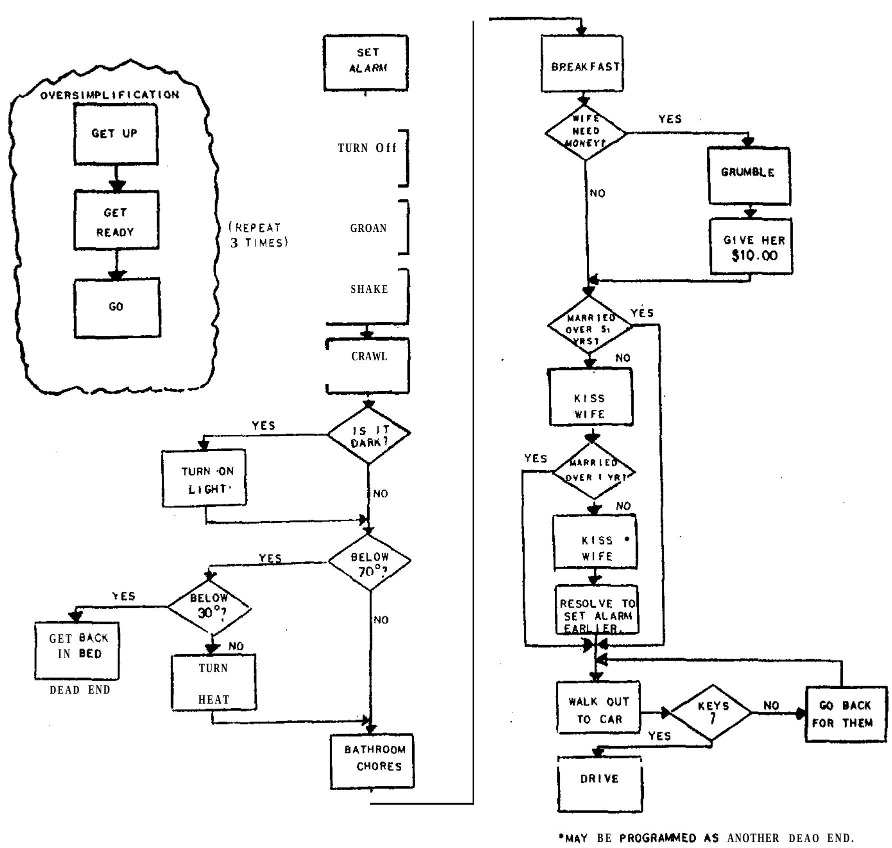
long Duration Acceleration

As an example of the kind of research which can be done, one of the authors recently rode the Johnsville centrifuge at 2 g for 24 hr to study the consequences of long duration acceleration, which had not been determined before. To avoid nausea, he made only slow head motions. He cooked, ate, slept, stood up, made medical observations on himself, wrote and typed, and generally carried out living activities. However, he lost interest in these activities while under stress and passed most of the time listening to the radio and napping.

If this 2-g acceleration had been in a straight line, in **24** hr he would have traveled 45 million miles and reached a speed of **3.8** million mph. If he accelerated at 2 g half way and decelerated the other half, he would have reached Mars in **42** hr, made the moon in **3.5** hr, and gone across the country in 15 min.

Through such studies man is evaluating his capacity for space flight, and it is hoped that man will be prepared for space when the engineers are prepared to let him start.

Program: How to Get Up in the Morning



Foote Mineral ***Co.,*** Philadelphia, prepared this diagram **to** show how programmers have to instruct a computer to work. The step-by-step procedure is patterned after the way in which **a** function is actually set up on a computer.