NASA TECHNICAL NOTE

NASA TN D-2195

NASA TN D-2195

SOME OBSERVATIONS DURING WEIGHTLESSNESS SIMULATION WITH SUBJECT IMMERSED IN A ROTATING WATER TANK

by Ralph W. Stone, Jr., and William Letko

Langley Research Center

Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • SEPTEMBER 1964

SOME OBSERVATIONS DURING WEIGHTLESSNESS SIMULATION WITH SUBJECT IMMERSED IN A ROTATING WATER TANK

By Ralph W. Stone, Jr., and William Letko

Langley Research Center
Langley Station, Hampton, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

For sale by the Office of Technical Services, Department of Commerce, Washington, D.C. 20230 -- Price $0.50

SOME OBSERVATIONS DURING WEIGHTLESSNESS SIMULATION WITH SUBJECT IMMERSED IN A ROTATING WATER TANK

By Ralph W. Stone, Jr., and William Letko

SUMMARY

An investigation was made with a rotating water tank to determine the feasibilty of the water-immersion technique for weightlessness simulation, including an attempted elimination of the otolith cues by rotation. Because of the early orbital flights the experiments were not continued and the technique was not fully evaluated; however, the experiences encountered are believed to be of general interest and of some possible physiological consequence.

INTRODUCTION

Before the flights of the American and Russian astronauts no data were available concerning the effects of weightlessness for periods longer than about 1 minute. Since there was considerable speculation about the effects of longer exposure to weightlessness, water immersion was suggested by several investigators (for example, ref. 1) as a possible means of simulation of weightlessness for relatively long periods. Immersion of the human body in a fluid of the same relative density is one way, long recognized, of eliminating to a great extent the cues from the kinesthetic sense. (See refs. 1 and 2.) This sense is one of the three primary senses by which people tend to orient themselves with respect to the gravity vector. The other two primary senses used for orientation are the visual and the vestibular (otolith). The visual sense can be readily voided by limiting the vision to the inside of a container or capsule as it would be in a spacecraft. Rotation of the container was suggested in reference 1 as a possible means to void the otolith sense. A tank was designed and built at the Langley Research Center (LRC), based on these concepts, to investigate the effectiveness of water immersion with rotation as a technique for weightlessness study. Although this immersion tank has been abandoned as a means of weightlessness simulation, the experiences encountered in this attempted simulation are believed to be of interest and are presented herein.

APPARATUS

The immersion tank at LRC consisted of a water tank in which the subject could be completely immersed and his vision restricted to the inside of the tank. The immersion tank could be rotated by means of an air motor at rates of rotation up to about $1\frac{1}{2}$ cycles per second. Figure 1 is a photograph of the exterior of the immersion tank and some associated equipment. Figure 2 is a sketch showing pertinent dimensions of the tank. Provision was made for the subject to be loosely strapped in a chair in the tank as indicated in figure 2; his angular orientation about the long axis of the tank could be arbitrarily chosen. Also, the vertical location of the subject could be chosen so that the axis of rotation would pass through any level between the subject's buttocks and ears. In addition, the chair could be replaced by a couch so that the subject could lie in such a position that the long body axis coincided with the axis of rotation. Since the maximum dimension of the immersion tank along the axis of rotation is only $5\frac{1}{2}$ feet the subject was required to flex his knees so that the lower part of the legs and the feet were about 1 foot from the axis of rotation.

The subject wore a skin diver's suit (wet type) which gave positive buoyancy and therefore required ballasting of the torso and extremities. This ballasting was done by thin lead bands which were affixed where required for neutral buoyancy. Some of these bands can be seen in figure 3 which is a photograph (overhead view) of the subject seated in the simulator.

Measurements of heart rate, respiration rate, and galvanic skin resistance were made for the subject. However, no records of galvanic skin resistance were obtained in the investigation reported herein because of water seepage into the electrode area. Figure 4 shows a subject with test equipment, and figure 5 presents some of the instruments used. Continuous two-way communication was provided by incorporating a microphone in the full face mask which can be seen in figure 4. For some of the experiments a conventional-type face mask was used with the microphone contained in a portion of the mouthpiece to provide adequate communication. The air supply was provided by a conventional self-contained underwater breathing apparatus which was located in the water tank.

The regulator was a two-stage demand type and, for the seated subject, was located in the tank to one side of the subject about level with his neck. The pressure at the regulator location was about 2.5 lb/sq in. For the subject in the horizontal position, the regulator was located on the rotational axis of the tank near the subject's feet, and the pressure was essentially the same as that for the seated position. The expired air was exhausted to the atmosphere through a special rubber valve in the exhaust line. Two small cylinders of about 8 inches in diameter and 4 inches in depth, one end of which was covered by a rubber diaphragm, containing air at atmospheric pressure were provided to allow for chest expansion when the tank was completely filled with water. Some of these features can be seen in figure 3.

Provision was made to empty the water tank in an emergency. Generally, about 15 seconds were required for the water level to be below the subject's head, and decompression at the subject's position was prevented during this process by the admittance of air into the tank through four air valves.

Some auxiliary experiments, which are described in the section "Tests" were conducted with the simple centrifuge shown in figure 6. This centrifuge had a chair mounted on one arm 19 feet from the centrifuge axis. The chair could be rotated independently of the centrifuge rotation by means of an air motor. The rate of chair rotation could be controlled by the subject, who was seated in the chair and whose vision was restricted to the interior of the box. The interior of the box was lighted and contained a rotational rate meter and a simple display which consisted of a vertical line and some diagonal lines intersecting at their midlengths. The relationship of the chair and centrifuge is indicated in figure 7(a) and the interior arrangement of the vision-restricting box is shown in figure 7(b).

TESTS

Tests were made in the immersion tank for two conditions: one in which the subject was seated so that the axis of rotation passed through both his ears (fig. 3) and one in which the subject was lying on a couch with knees flexed so that the axis of rotation passed through the long axis of his body.

With the subject seated, tests were made at rates of rotation up to a maximum of 60 rpm; with the subject supine, tests were made at rates of rotation up to a maximum of 75 rpm. These limits of rotational rates were established by an auxiliary experiment, in which the "oculogravic illusion" as suggested by the Aviation Medical Acceleration Laboratory, Johnsville, Pennsylvania, was used as a means of determining the rates of rotation at which otolith nullification might be presumed to have taken place, thus voiding the cues of the otolith organs. These experiments were performed at LRC on a small centrifuge (fig. 6). A similar study made at Johnsville is discussed in reference 3.

A description of the occurrence and use of the oculogravic illusion is as follows: A person seated at the end of a centrifuge and facing opposite the direction of rotation is subjected to a resultant force which is composed of a centrifugal force and the normal gravitational force, as indicated in figure 8(a). The schematic of the otolith organs indicates a deflection of the otoliths relative to the body, corresponding to the resulting force acting on it. Figure 8(a) is a factual representation of what the subject is actually experiencing. However, when the subject's view is restricted, say, to the interior of a box as it is in the present investigation, the subject accepts the direction of the resultant force as the direction of the gravity vector. (See fig. 8(b).) This cue is so strong that the subject experiences a visual illusion which makes vertical lines in the box appear to tilt with him. This illusion is called the oculogravic illusion. When the subject changes his orientation on the centrifuge so that he is facing the direction of rotation, the direction of the tilt of the lines is reversed. Therefore, when the subject is rotated at the end of an independently rotating centrifuge, he experiences an illusion of a wobbling or conical motion. It was expected that the rotational rate at which the conical motion disappeared was the rate at which an effective nullification of the response from the otolith organs occurred. The cues of the otolith organs were no longer associated by the brain. The rate of rotation at which nullification occurred was expected to be somewhat different for different people.

For these tests 14 people rode the device. The rate of rotation of the centrifuge was arbitrarily chosen to provide about 1g centrifugal acceleration at the subject's location which was 19 feet from the axis of centrifuge rotation. The axis of chair rotation passed through the subject's long body axis. The rate of chair rotation at which the wobble disappeared was in the range from 55 to 75 rpm. These values of rotational rates represent the upper limits of the water-tank rotational rates used in the simulation. The intent was that the otolith cues would be suppressed by rotating the water tank at those rotational rates at which a loss, or at least an attenuation, of the oculogravic illusion occurred on the centrifuge. In this connection it should be mentioned that although the apparent wobble disappeared, there remained an illusion of a small-radius cylindrical motion of the vertical line in the box. The reason for this sensation is not evident at this time.

RESULTS AND DISCUSSION

In the water-tank weightlessness-simulation tests, the total immersion time of the subject was of the order of 1 hour so that time at a particular rate of rotation was quite short. As was mentioned previously, the subject in the seated position was rotated at rates up to 60 rpm. The subject felt that he experienced motions such as those illustrated in figure 9. At low rotational rates from 0 to 20 rpm, the subject experienced a motion which he described as being similar to the motion one experiences on a Ferris wheel (fig. 9(a)). With an increase in rotational rate the motion appeared to be more elliptical and became even more elliptical with further increases in rate until the subject felt he was in a plunging motion with no rotation, as indicated in figure 9(c). This sensation occurred at around 55 rpm which was near the rate at which otolith nullification was expected on the basis of the oculogravic illusion experiment. As the rate of rotation was increased from 55 to 60 rpm, the subject still felt the plunging motion but his impression was that there was some decrease in amplitude. This decrease was as expected on the basis of the following considerations: If in the most rudimentary sense the mechanical aspects of the otolith organ system (exclusive of the nervous system) acted as a highly damped mechanism, as it seems to be, and if the otolith organ system could be represented by a second-order differential equation, the mechanism would have a cyclic response to constant rotation equal to the frequency of that rotation. Furthermore, the magnitude of this response would diminish with increasing frequency of rotation. The further complication of such a system with the nervous system, which has its own characteristics superimposed on those of the mechanical system, would alter the ultimate mental recognition of the response. A precise specification of this entire system and the ultimate response to high-speed rotation is not possible at this time. The results, however, substantiate in part the response characteristics just noted in that a frequency of the rotation was sensed and the magnitude was apparently diminishing with rate of rotation. Complete elimination of response was of course not obtained.

Although it was expected that a further increase in rotational rate would cause a further decrease in the apparent plunging motion, it was decided to try some experiments with the subject supine with the long torso axis along the axis of rotation. The subject for this experiment was the same as for the seated experiment. In the supine position, of course, the various parts of the body were closer to the axis of rotation than they were with the subject seated. However, it should be pointed out that for the supine subject the axis of rotation passed between the otolith organs of the left and right ears, thus resulting in a nonsymmetrical stimulation of the left and right otolith organ systems during rotation. From this consideration, at least, it would appear more desirable to rotate the subject about an axis through both his ears, as described previously, since this condition results in an equal stimulation of the otolith organs of both ears. Nevertheless, a test was made with the subject supine, and the sensations of motion experienced by the subject are illustrated in figure 10. The subject felt as if he were on a Ferris wheel with his long body axis parallel to the axis of rotation. This sensed motion became elliptical with an increase in rotational rate, as for the seated test, but the elliptical motion persisted even when the rate of rotation was increased to 75 rpm, which was the highest value attained. Although complete time histories of the rotational rate were not obtained for the two test conditions, the records show that in proceeding from one rate of rotation to the next, the tank acceleration was $1.5^{\circ}/\text{sec}^2$ or less. Although the subject sensed motions of substantially large magnitude either seated or supine, the subject indicated that he did not feel any actual motion of his body relative to the support system. Therefore, either the cues from the otolith organ system were not completely nullified in these situations or the cues were obtained from other sources.

Recent studies of Dr. Ashton Graybiel at the U.S. Naval Aviation Medical Center, Pensacola, Florida, indicated that in the slow-rotating room, labyrinth defective subjects perceived similar rotations or motions. This strongly suggests that the sensations reported herein may be of nonotolith gravi receptor origin. Movements of the internal organs (heart, lungs, etc.), which are suspended in cavities that contain some air spaces, are possible sources of motion cues. The tissues by which these organs are suspended in the body would be subjected to loads caused by the centrifugal forces on the organ due to tank rotation. It should be pointed out, however, that acceleration on those parts of the body that are completely surrounded by water is compensated for by a corresponding increase in the water pressure gradient due to tank rotation. The subject may have obtained some cues from the changing pressure gradient; however, this was not indicated by the subject. The subject was not required to make any bodily movements in the tank and, therefore, the Coriolis forces from this source can be eliminated as a cause of the motion sensation. Differences in motion experienced for the different orientations of the subject indicate that there may be a difference in sensitivities or a difference in nullification frequencies of the cueing mechanism for the two conditions.

Even though the seated subject sensed a decrease in amplitude of motion with an increase in rate of rotation, it is not certain that the sensation of motion would be entirely eliminated even if the rates of rotation were further increased. No additional tests were made to check whether this motion would be eliminated, since orbital flights of up to several days' duration were made and the results indicated that weightlessness could be tolerated for periods of time beyond the practical limits of the water tank.

Figure 11 shows the respiration rate and heart rate recorded during the different events taking place during the two types of water-tank experiments. The approximate time between events is also shown in the figure. (It was also planned to present records of galvanic skin resistance but, as has been mentioned, data could not be obtained because of water seepage into the probe area.) It should be pointed out that the rates plotted are the maximum for the event shown and that considerable variation occurred during the different phases, especially of the heart rate. The respiration rate for the seated subject was generally higher than it was for the supine subject except during rotation when the respiration rate for the supine subject was sometimes the same or slightly higher than for the seated subject. Respiration rates from 14 to 21 breaths per minute were recorded during the tests and are within reasonable limits for the test conditions.

The heart rate was higher for the supine subject than it was for the seated subject throughout the experiment (fig. 11). For the seated subject the heart-rate range was from about 80 to 114 beats per minute, whereas for the supine subject the heart-rate range was from about 80 to 130 beats per minute. In each test the heart rate measured a few minutes after the subject merely entered the tank (tank dry) was considerably higher than the heart rate measured outside the tank. This increase in heart rate was about 30 beats per minute for the seated subject and about 40 beats per minute for the supine subject. The increase was obviously due to anxiety. In each test a further increase of less than 10 beats per minute occurred at the initiation of tank rotation and it decreased as the rate of tank rotation increased above 30 rpm and continued to decrease until test termination.

Although the heart rate decreased with an increase in tank rotation, an electrocardiogram or EKG (axillary) of abnormal appearance was obtained at 60 rpm and above for the supine subject. Heart-rate records obtained at rotational rates of 65, 55, and 0 rpm are shown in figure 12 for comparison purposes. It should be remembered that these heart records were obtained under unusual conditions - that is, the subject was immersed in water and the signals were obtained through slip rings. It is therefore believed that the unusual undulations obtained above 60 rpm are artifacts; this is substantiated to some degree by the fact that the undulations have a frequency equal to the rotational frequency of the simulator. Indeed, some experiments outside the simulator indicated that contact pressure changes of the electrodes, such as those due to body movements, could result in abnormalities similar to those observed; for example, see the electrocardiograms presented in figure 13, one of which was obtained while intermittently pressing the upper arm against the electrode (fig. 13(c)) and one was obtained while gently patting over an electrode with the fingertips (fig. 13(b)).

Despite these results it should be pointed out that the source of the irregularities has not been definitely established and proper precautions should be taken for the subject's safety in tests of this nature. Additional instrumentation, especially more EKG electrodes, would be useful in this respect.

CONCLUDING REMARKS

The water immersion technique of weightlessness simulation used herein was not fully evaluated because orbital flights were made with no apparent ill effects for periods of time beyond the practical limits of the present water tank. It is believed, however, that immersion is still a useful tool in studies which require elimination or at least a diminution of the cues from the kinesthetic sense.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., April 9, 1964.

REFERENCES

1. Muller, H. J.: Approximation to a Gravity-Free Situation for the Human Organism Achievable at Moderate Expense. Science, vol. 128, no. 3327, Oct. 3, 1958, p. 772.

2. Knight, Leon A.: An Approach to the Physiologic Simulation of the Null-Gravity State. Jour. Aviation Medicine, vol. 29, no. 4, Apr. 1958, pp. 283-286.

3. Gray, R. F., and Morway, D. M.: Preliminary Study of Damping of the Otolith Organ System by Epicyclic Rotation. MA-5919, Aviation Medical Acceleration Lab., U.S. Naval Air Dev. Center (Johnsville, Pa.), Dec. 28, 1959.

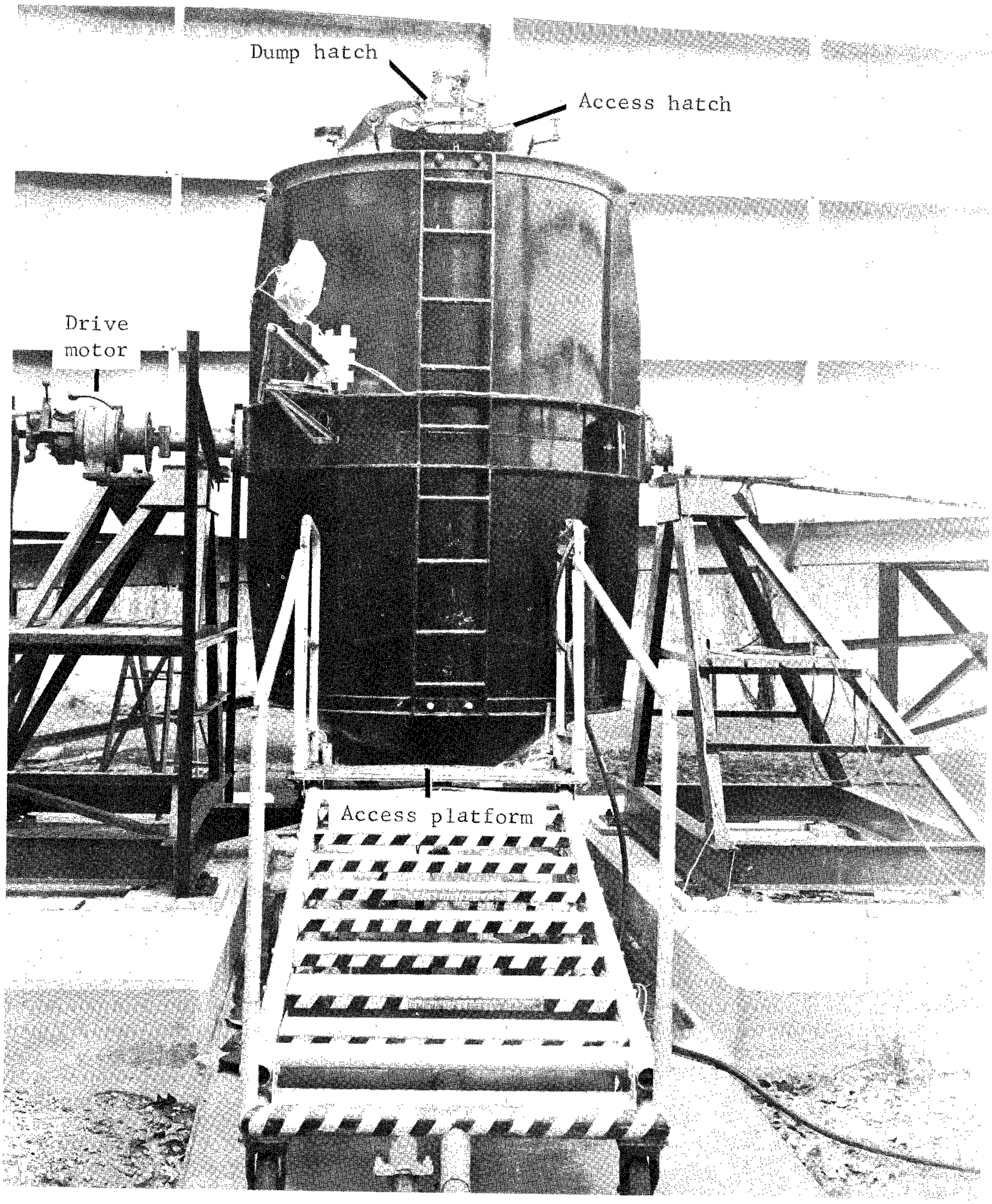


Figure 1.- Immersion tank at LRC with lowered access platform. L-60-4.1

 L-3841

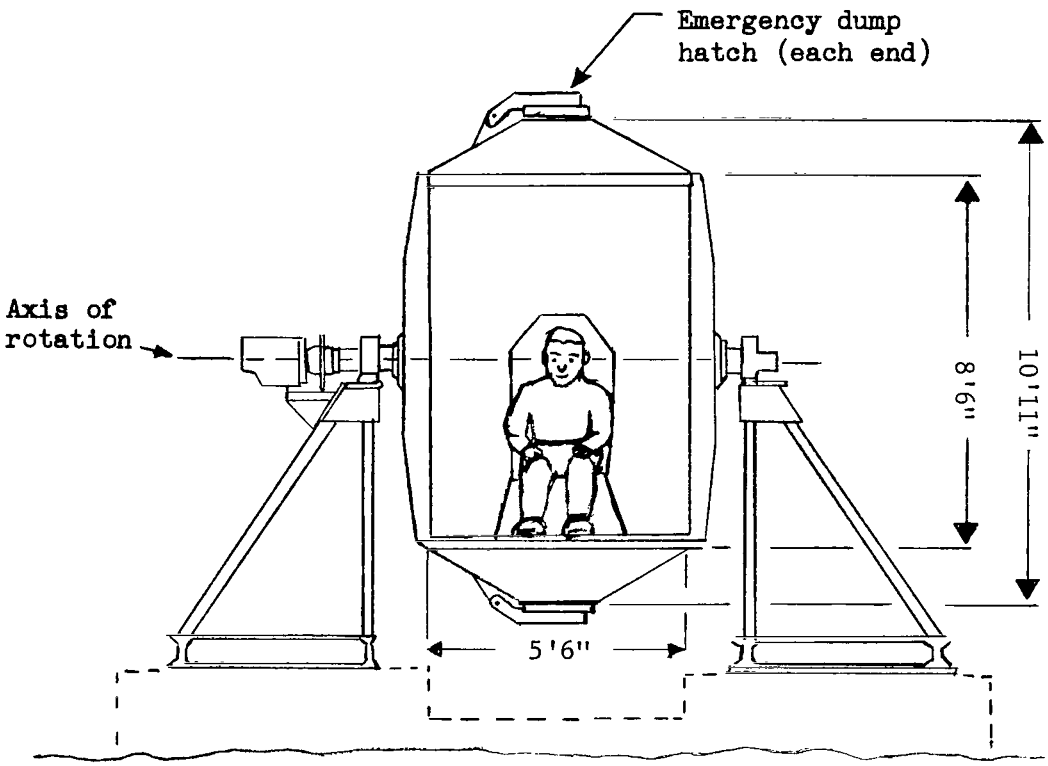


Figure 2.- Sketch showing dimensions of immersion tank and position of subject.

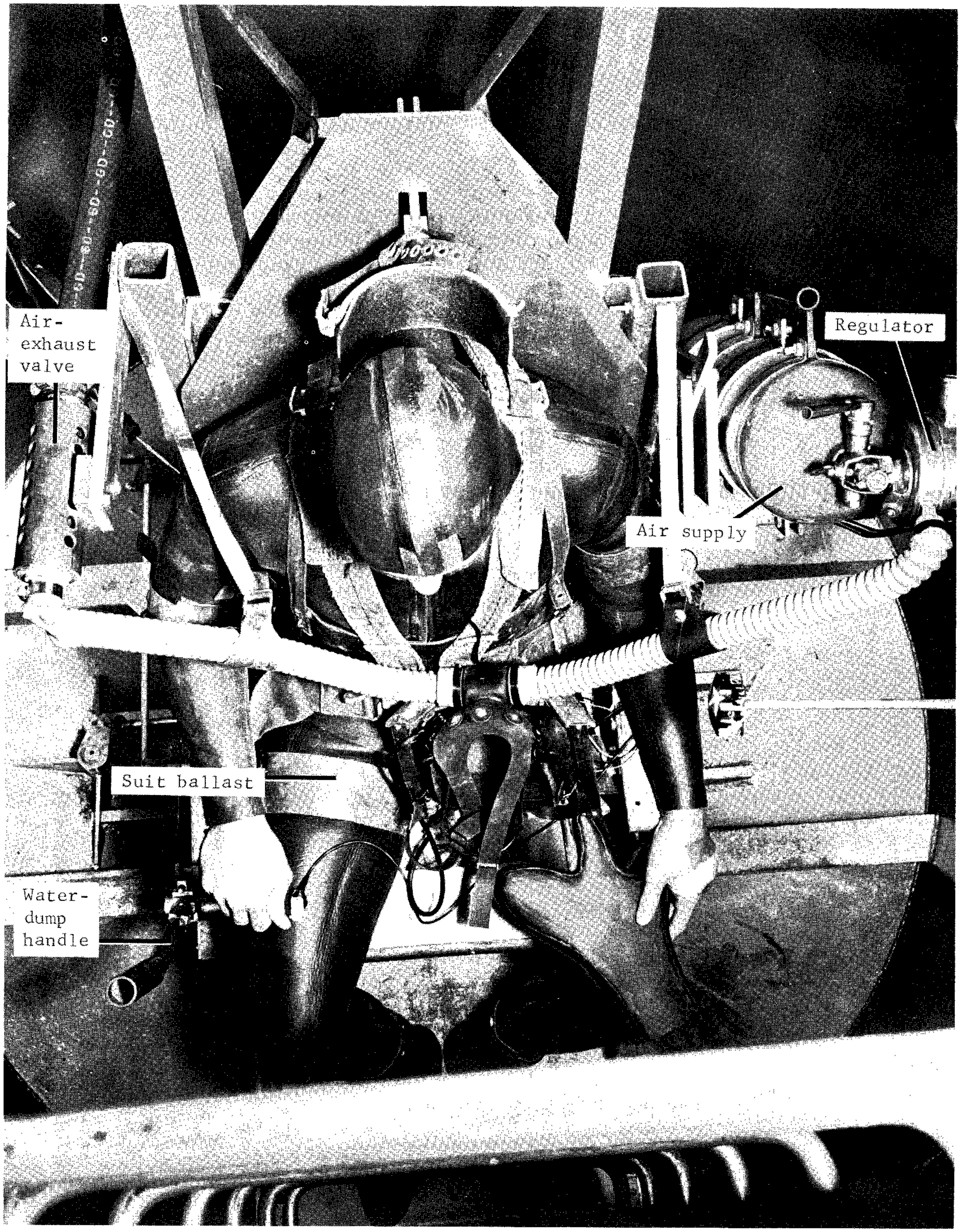


Figure 3.- Internal features of immersion tank with seated subject. L-60-916.1

Figure 4.- Subject with test equipment in wet-type skin-diver's outfit. L-60-919.1

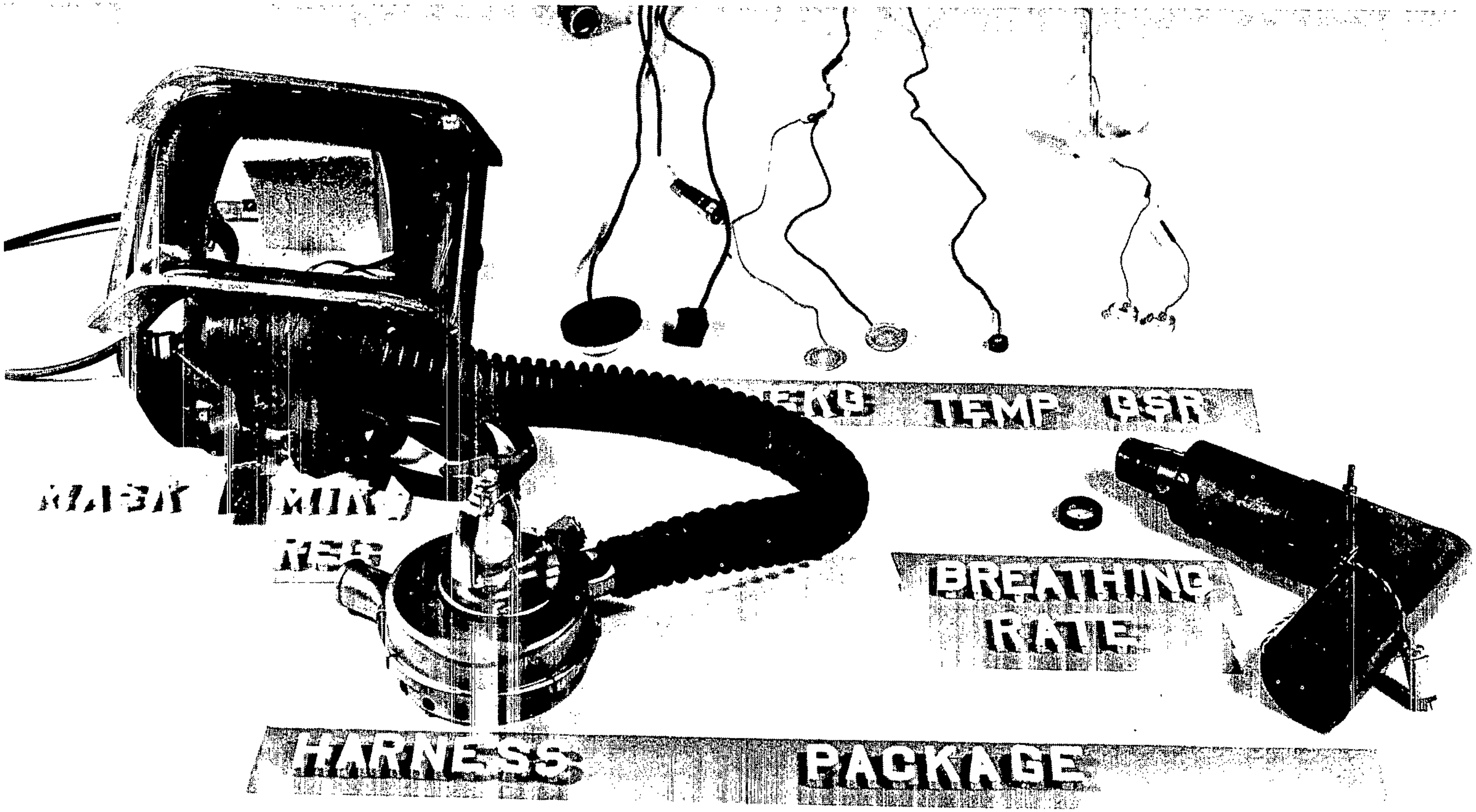


Figure 5.- Instrumentation used in immersion-tank experiments. L-60-5746

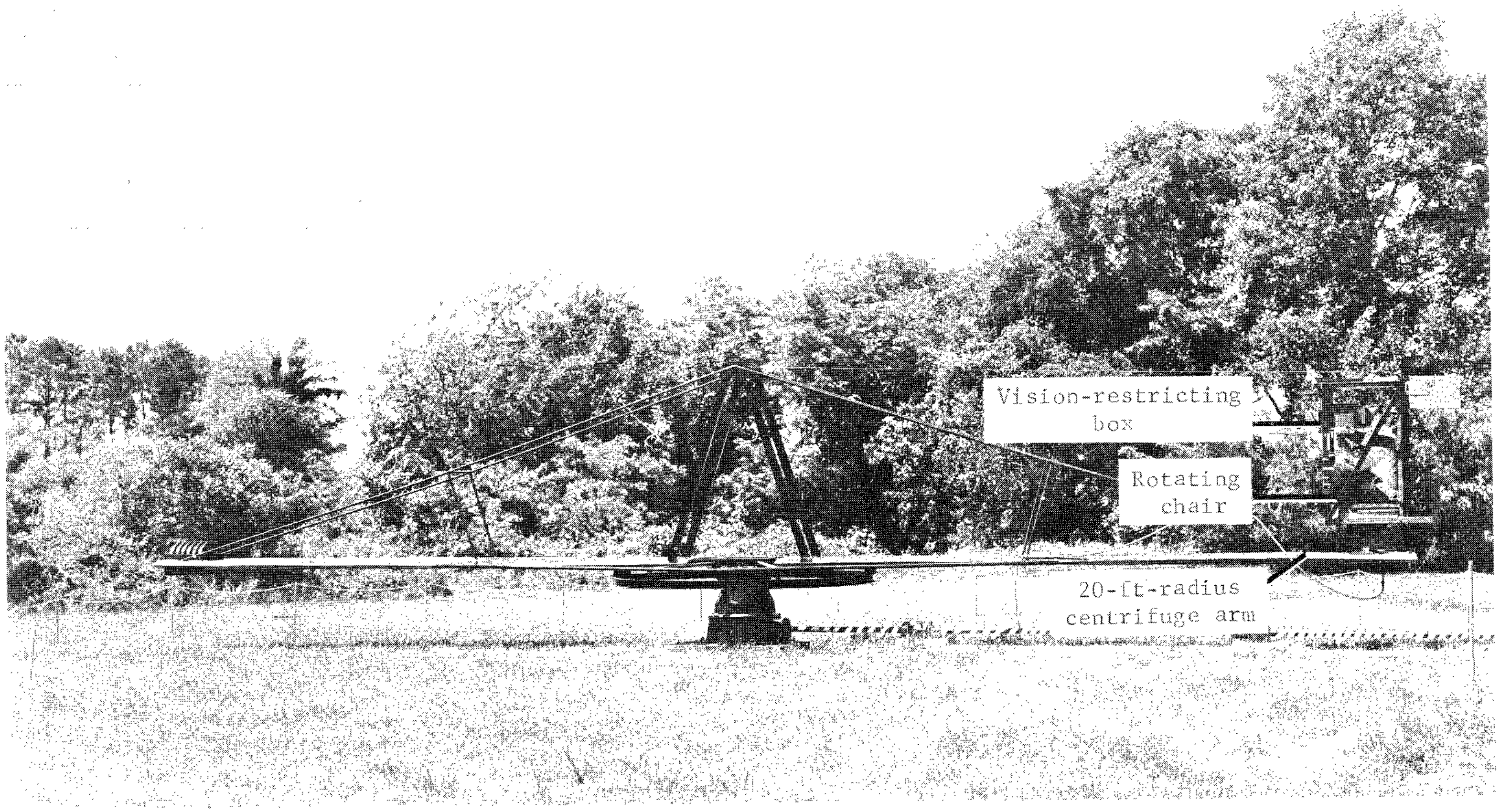
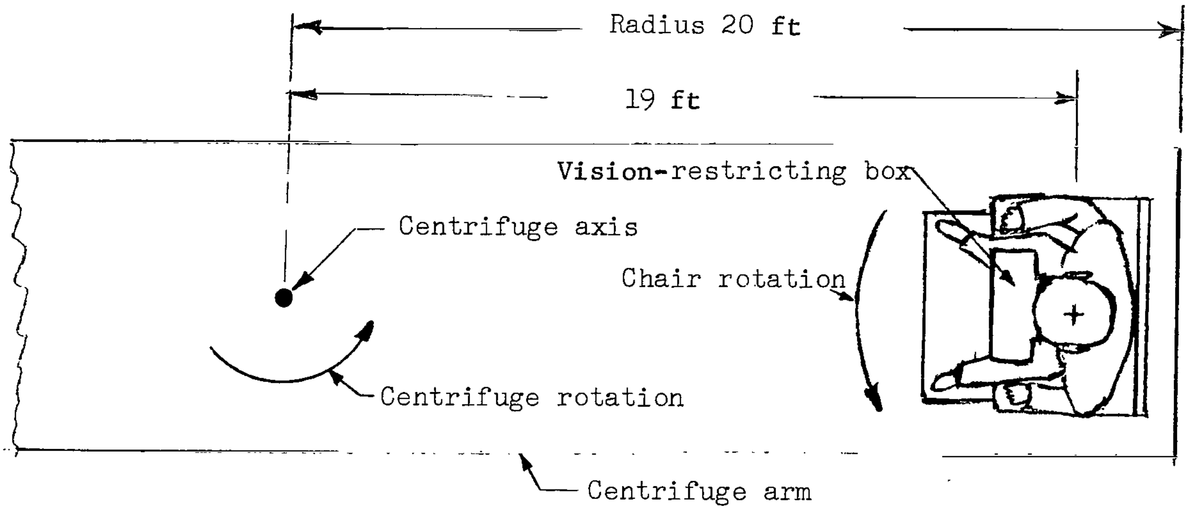
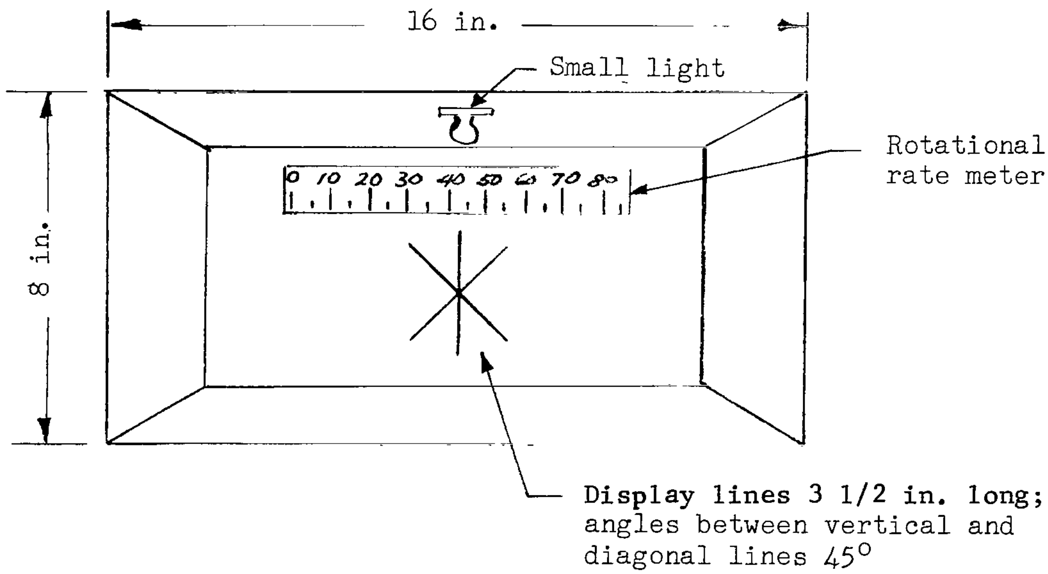


Figure 6.- Centrifuge with rotating chair used in oculogravic illusion tests. L-60-3231.1

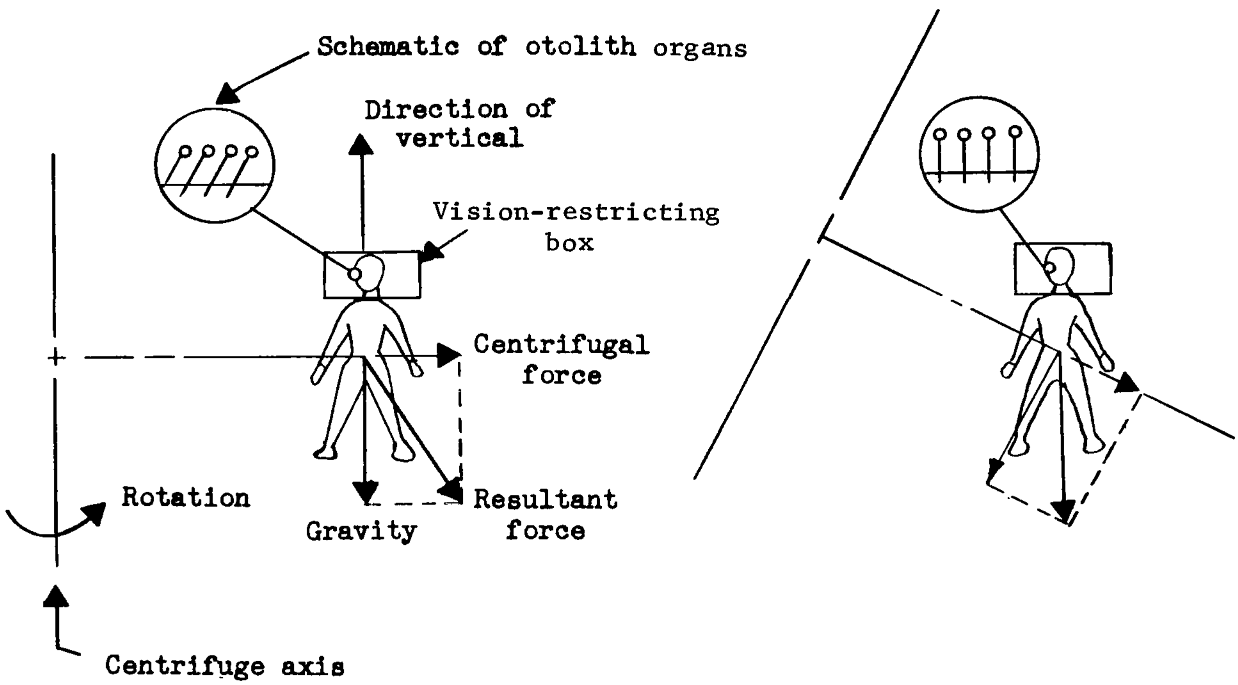


(a) Relationship of chair and centrifuge.



(b) Interior arrangement of vision-restricting box.

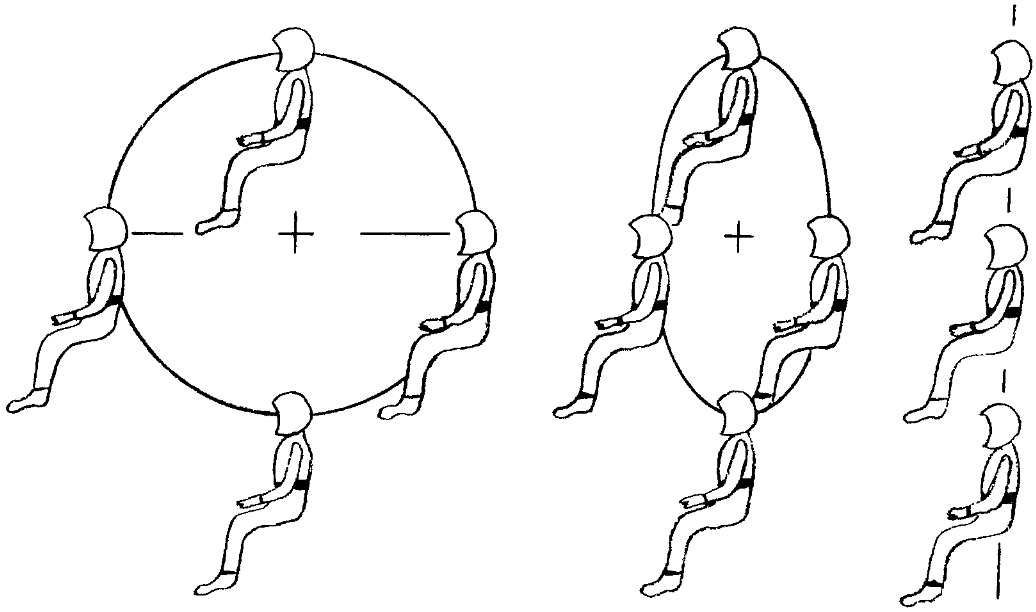
Figure 7.- Sketch showing some details of centrifuge and rotating chair.



(a) Actual experience.

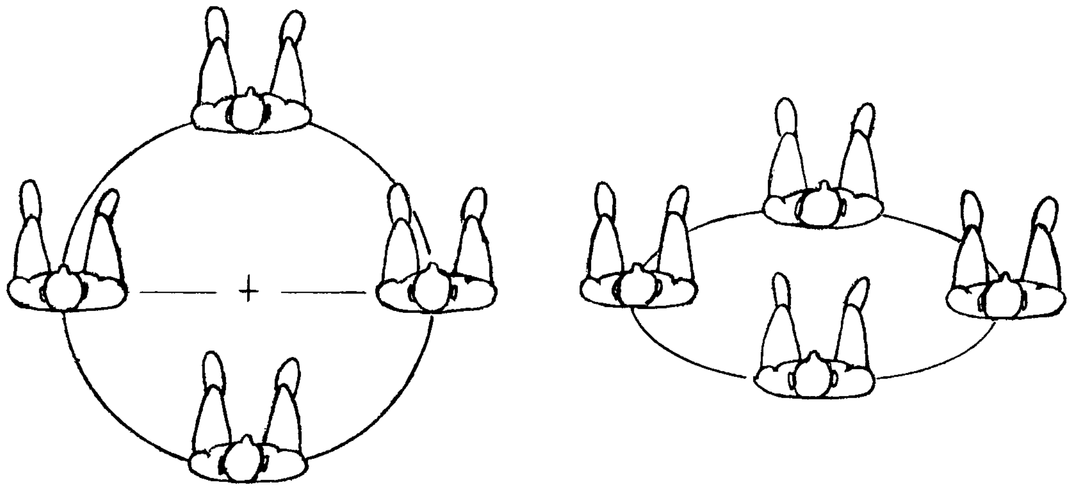
(b) Oculogravic illusion.

Figure 8.- Illustration of oculogravic illusion which occurs on centrifuge with subject facing opposite the direction of rotation. Subject's vision is restricted to the small box and the subject is essentially unaware that the centrifuge is rotating.



(a) 0 to 20 rpm. (b) 20 to 55 rpm. (c) 55 to 60 rpm.

Figure 9.- Illustration of motions sensed by seated subject.



(a) 0 to 20 rpm. (b) 20 to 75 rpm.

Figure 10.- Illustration of motions sensed by supine subject.

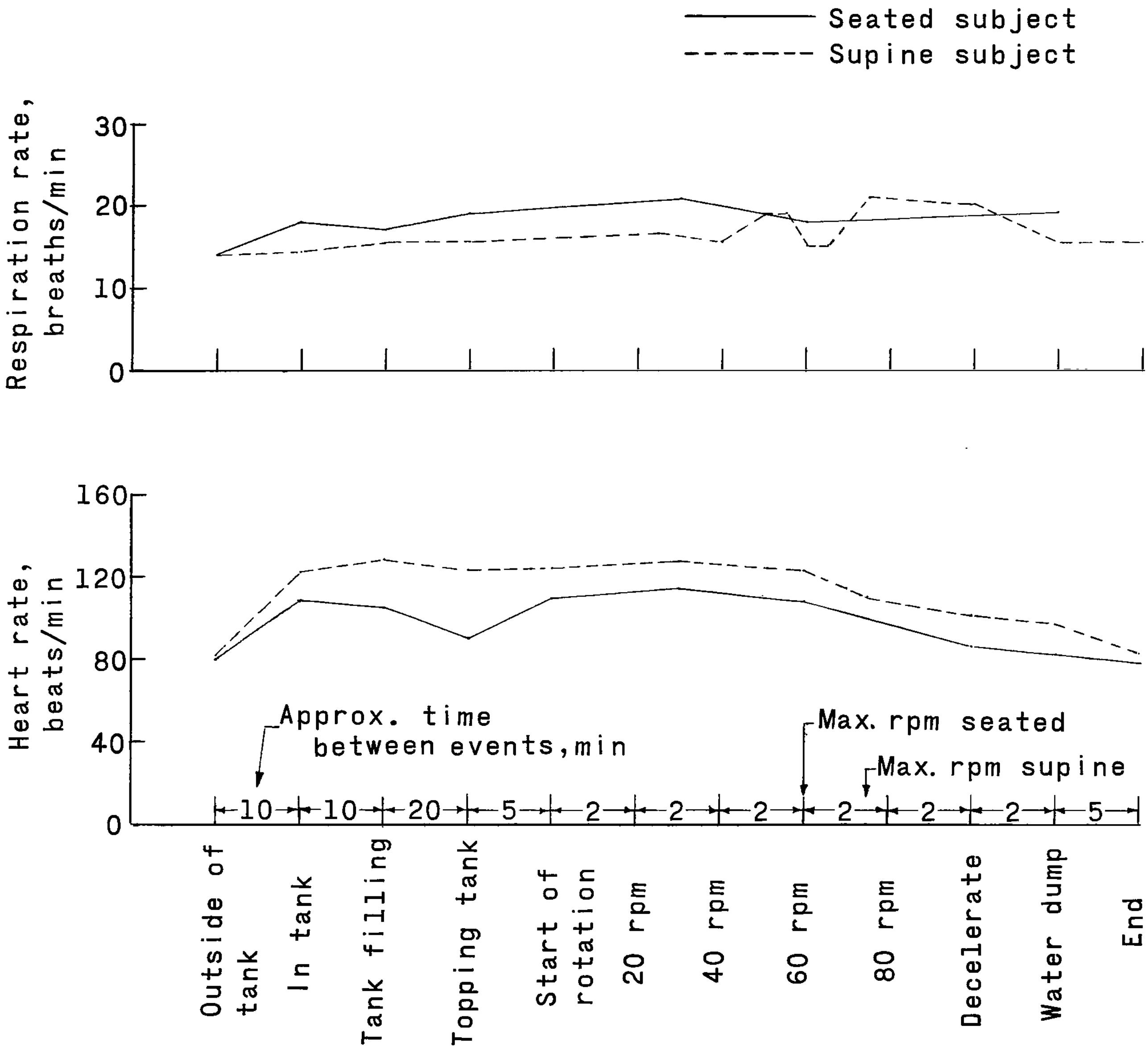
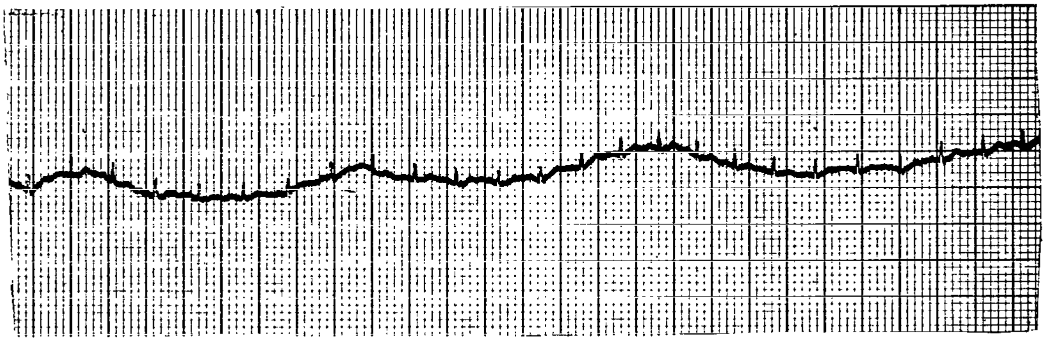
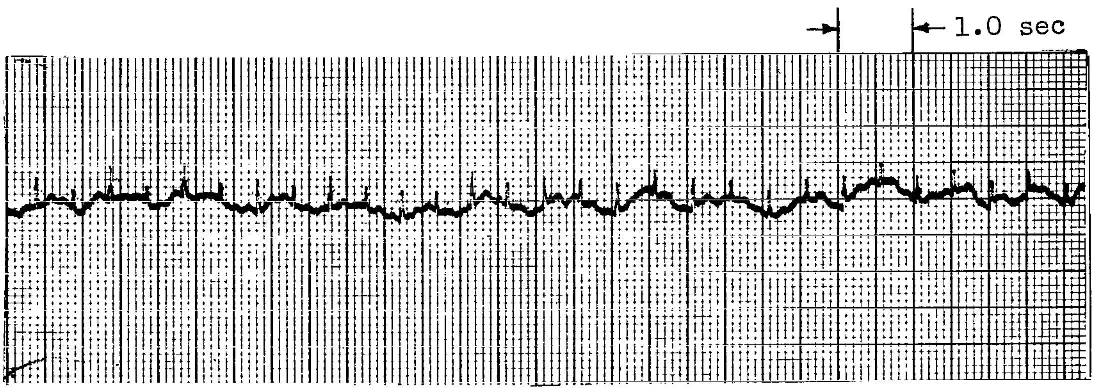


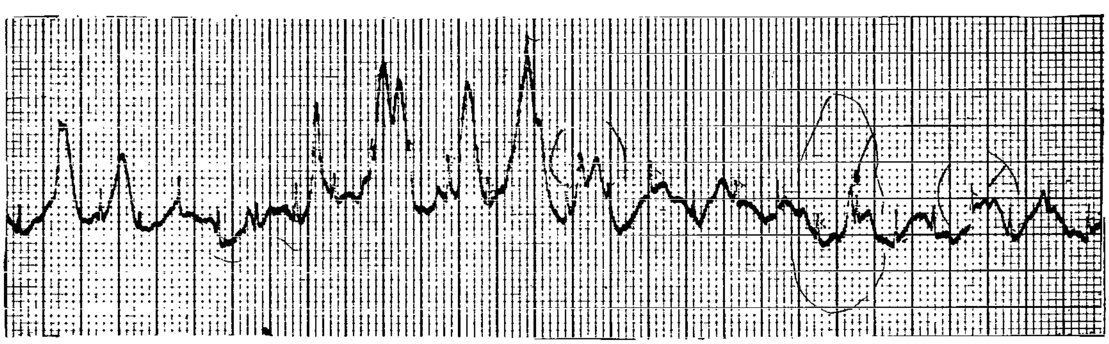
Figure 11.- Maximum respiration and heart rates recorded during the different test events for subject seated and supine.



(a) 0 rpm.

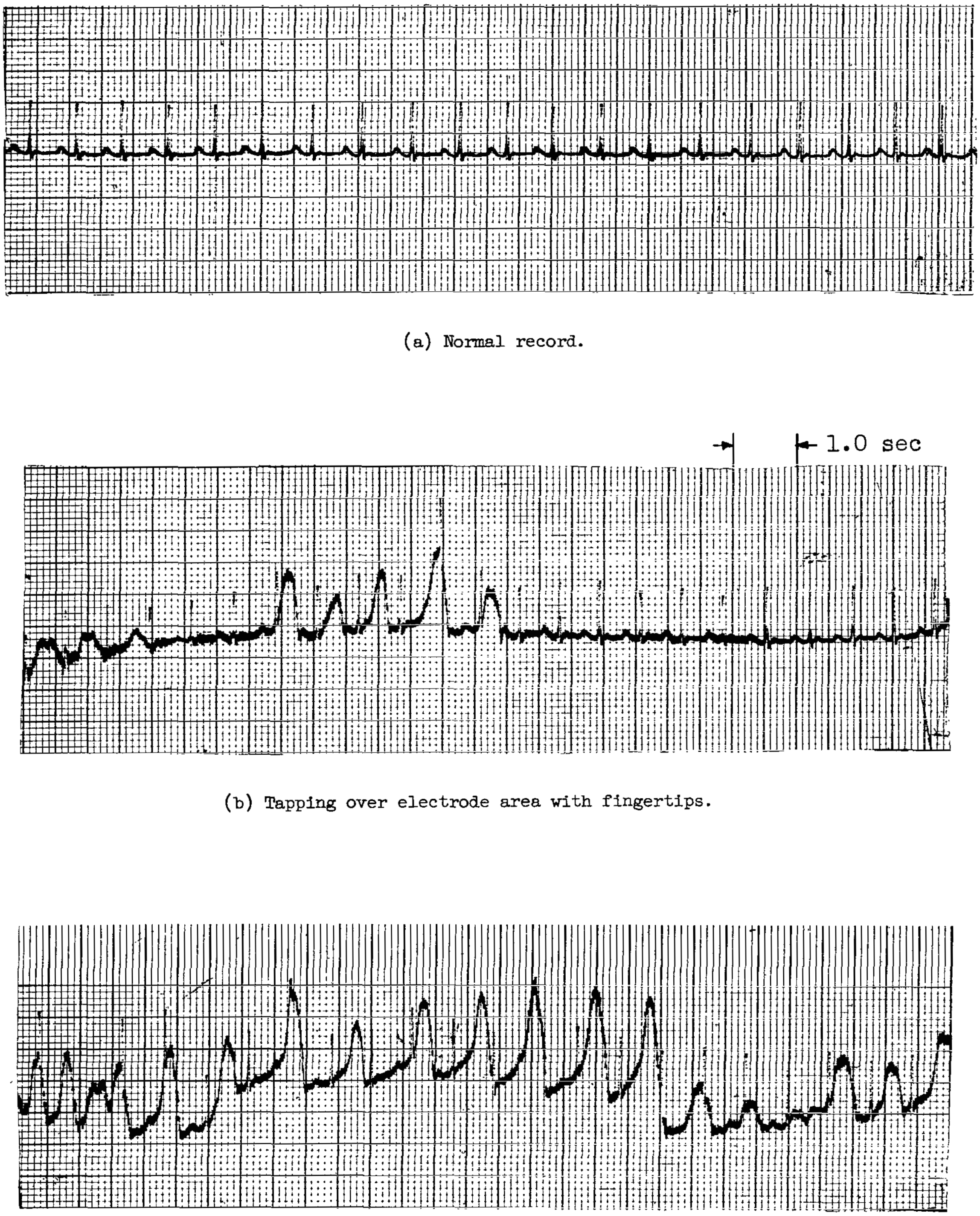


(b) 55 rpm.



(c) 65 rpm.

Figure 12.- Comparison of electrocardiograms obtained in the water tank at rotational rates of 0, 55, and 65 rpm. Record at 0 rpm was obtained just prior to topping the tank.



(a) Normal record.

(b) Tapping over electrode area with fingertips.

(c) Upper-arm pressure against electrode.

Figure 13.- Changes in electrocardiograms obtained by applying intermittent pressure on electrodes. Records were obtained outside immersion tank.

NASA-Langley, 1964 L-3841

2/7/85

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Technical information generated in connection with a NASA contract or grant and released under NASA auspices.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

TECHNICAL REPRINTS: Information derived from NASA activities and initially published in the form of journal articles.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities but not necessarily reporting the results of individual NASA-programmed scientific efforts. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION DIVISION

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546