

Medical Experiment M008

INFLIGHT SLEEP ANALYSIS

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MEDICAL EXPERIMENT MO08

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SUMMARY

The electroencephalogram of Command Pilot Frank Borman was recorded continuously during the first two days of the Gemini VII flight in December, 1965. This first U.S. attempt to record EEG during orbital flight was designed to study sleep cycles during flight and to assess the effect of "weightlessness" upon the electrical activity of the brain. This report gives the technique used and the preliminary results of visual interpretation of the record.

The recording was of good technical quality. The two sleep periods which occurred during the record were evaluated visually for depth of sleep versus time on a minute-to-minute basis. The first sleep period was found to be inadequate in terms of depth and length, but the second sleep period was normal. The tracing during the alert state, including ascent and orbital flight, showed no pathological changes and no definite alterations which could be attributed to "weightlessness." It is concluded that these preliminary results confirm the view that orbital flight has no apparent deleterious effect on cerebral function.

OBJECTIVES

Recordings of the electroencephalogram (EEG) on a pilot during orbital flight were made for the first time in the U.S. space program on the Gemini VII flight. The immediate goal of this project (called the M-8 experiment) was to obtain an objective evaluation of the pilot's sleep pattern in order to discover any deviation from patterns recorded on earth and to assist in revealing factors which may interfere with sleep in an orbiting spacecraft, since some difficulty sleeping has been reported by several astronauts. In addition to this practical goal, the experiment was also intended to determine the effects, if any, of "weightlessness" on the electrical activity of the brain.

This report gives the technique of EEG recording used in the Gemini VII flight and presents the results of visual interpretation of the data. Computer analysis of the same data will be reported by others.

METHODS

Two channels of EEG data from Command Pilot Frank Borman were recorded on an onboard tape recorder. The electrodes were chlorided silver discs imbedded in a lucite cup. These were filled with NASA electrolyte jelly and attached to the scalp with Eastman 910^R adhesive over sites which had been denuded with depilatory cream and drilled

with a high-speed dental burr. EEG channel No. 1 was derived from the left central and left occipital electrodes; EEG channel No. 2, from the midline central and midline occipital electrodes. The lining material of the astronaut's helmet was designed with indentations over each electrode position in order to avoid pressure on the electrodes. Transistorized signal conditioners were worn in pockets of the astronaut's underwear.

The onboard tape recorder was capable of recording 100 hours of data on one reel of magnetic tape. After recovery of the spacecraft, the data was re-recorded onto another tape having a standard IRIG format. This tape was written out on an ink-writing oscillograph at an equivalent real-time paper speed of 15 mm/sec for visual interpretation.

RESULTS

Quality and Quantity of Data--Most of the EEG data recorded was of excellent quality from the standpoint of visual interpretation. During rest and sleep, the tracings were as good as any obtained on earth, even in carefully-controlled laboratory situations. When the astronaut was alert and active, the record contained electrode movement and muscle potential artifacts which tended to obscure the normal low voltage wakeful pattern. Except during meals, however, the artifacts in active periods were not of such

magnitude as to have prevented detection of pathological changes, since the latter are almost always characterized by an increase in voltage and a decrease in frequency.

Figure 1 is a bar graph representing quantity of data recorded. A total of 54 hours and 43 minutes of interpretable EEG data was obtained, starting from 15 minutes prior to lift-off. EEG derivation No. 1 (left central to occipital) became noisy after 25 hours, 50 minutes of flight (point B in Figure 1) and it ceased to function after 28 hours, 50 minutes (point C). EEG derivation No. 2 (midline central to occipital) gave artifact-free data up to 43 hours, 55 minutes (point D), and ceased to function after 54 hours, 28 minutes.

Also indicated in Figure 1 are the two sleep periods (shaded areas) which occurred during the recording, one period during which the astronaut closed his eyes for the greater part of two hours (between dotted lines), and meals (black rectangles). The sleep periods are discussed below. The meals (or periods of gum chewing) are noted because they represent temporary interruptions in the interpretability of the EEG data due to artifacts produced by rhythmic chewing motions.

EEG Pattern in the Active State--Examples of the EEG pattern in the active state are shown in Figures 2B, 3A, and 3B. Before liftoff (Figure 2B) the record showed occasional

astronauts' report that they were able to exclude sunlight from the spacecraft completely, the shadow history is the only factor showing a suggestive relationship with arousal. Of the total one-minute epochs in the two sleep periods, 26.4 per cent contained some arousal-type EEG activity (EO and stage 0 on Figure 8). Of the sleep minutes recorded while the spacecraft was in sunlight, 35.2 per cent showed some arousal, whereas only 9.3 per cent showed arousal while the spacecraft was in the earth's shadow.

DISCUSSION

The Russians began inflight EEG recording with the flight of Nikolayev and Popovich and have continued to monitor EEG in all subsequent flights. Judging from the few available English translations of their reports,^{1,3} the Russians use only one EEG channel, which can be telemetered to earth or recorded on board. The two electrodes (mid-occipital and mid-frontal) are held in place by an elastic cap or band. The quantity of EEG data obtained on earlier flights is not mentioned, but on the recent three-man flight (Komarov, Feoktistov, and Yegorov), only brief (about 40 second) intervals of EEG data were recorded periodically during the flight while the crew members were performing hand and eye coordination tests. No mention has been made of EEG recordings while the cosmonauts were asleep in orbit.

second) activity in the alert state, but this could not be evaluated quantitatively by visual means.

EEG Pattern During Sleep--As shown in Figure 1, two sleep periods occurred during the recording. The first sleep period occurred at 14:07 hours (flight time) and lasted only 1 hour, 28 minutes. The second sleep period began at 33:10 hours and lasted 8 hours, 46 minutes.

The EEG patterns during sleep are very distinctive and, since the astronaut is quiet, no artifact obscures the record. Figures 5, 6, and 7 illustrate the EEG patterns at various stages or levels of sleep. Stage 0 consists of a full alpha rhythm, and is interpreted as the resting, eyes-closed pattern. In the transition from stage 0 to stage 1 sleep (Figure 5A and B), the alpha rhythm decreases in voltage and is gradually replaced by low voltage theta activity, mixed with some low voltage faster components; this is the first EEG sign of drowsiness. Stage 2 sleep, or light sleep, is characterized by moderately high voltage, semi-rhythmic and rhythmic theta activity and sharp transient waves. This activity is a mixture of occipital and central sleep characters (Figure 5C). Stage 3 sleep, or moderate sleep (Figure 6A), is characterized by sigma activity (14 cps), mixed with vertex transients and some low voltage delta activity (1-3 cps). Stage 4 sleep, or deep sleep, is distinguished by almost continuous high voltage delta activity, as shown in

Figure 6B. When the subject arouses, or is aroused, from sleep (Figure 6C), the record quickly reverts to stage 0, or the resting, awake pattern.

The recently-described "paradoxical" phase of sleep is difficult to recognize without simultaneous recordings of eye movement (electro-oculogram). The sample in Figure 7, which resembles a mixture of stages 1 and 2 sleep, shows some of the EEG characteristics observed during "paradoxical" sleep with rapid eye movements: runs of 3 per second "saw-tooth" waves, runs of low voltage alpha activity and theta activity, low voltage fast activity without spindles of sigma activity, and occasional very slow transients having a period of more than one second. This type of pattern, which might represent "paradoxical" sleep, occurred for two fairly long sections during the second sleep period in flight--beginning at 11:05 hours and 14:20 hours.

The sleep periods were located by visually scanning the write-out of the tape. Each minute of sleep was classified as to stage of sleep according to the above criteria, and plotted graphically versus time, as shown in Figure 8 which illustrates the sleep pattern of both flight sleep periods, as well as a control sleep period recorded prior to flight. The uppermost level on the vertical axis represents the eye-open, alert pattern. The next level is the eyes-closed, resting pattern, or stage 0. The heavy horizontal line in the center of

stage 0 represents the division between waking and sleeping EEG patterns. The next four levels represent the four stages of sleep from light sleep down to deep sleep. When, as is the usual case, more than one EEG sleep stage was seen during a one-minute epoch, the vertical line for that epoch was drawn to overlap the two or more stages seen during that minute. The horizontal axis of these graphs is marked in elapsed flight time. The control sleep period (upper left graph in Figure 8) was similarly analyzed for comparison of rate of falling to sleep and depth, but the overall pattern cannot be compared to the flight periods since the subject was not allowed to complete a spontaneous sleep period.

The depth of sleep pattern in the second sleep period clearly shows the normal cyclical variations in level of sleep described by Dement and Kleitman.² The transient arousals within the period, however, seem to be slightly more frequent, and fully alert patterns (levels above the horizontal black bar in Figure 8) are seen more often in this period than were found in Dement and Kleitman's laboratory studies of normal individuals.

An attempt was made to correlate the transient arousals from sleep with various environmental factors, such as suit and cabin temperature variations, cabin pressure variations, and the shadow history of the spacecraft. In spite of the

runs of low voltage alpha rhythm superimposed upon a somewhat unsteady baseline and mixed with eye-blink potentials (transient downward deflections). Occasional runs of low voltage 5-7 cycle per second activity also appeared in the record; these resemble theta activity but are difficult to distinguish with certainty from rapid ocular or eyelid movement potentials. During ascent (Figure 3A) continuous high frequency muscle potentials were superimposed upon the trace. After 24 hours in orbit (Figure 3B) the record showed a more "relaxed" pattern, with more rhythmic alpha activity and less muscle potential artifact.

During meals, or when the astronaut chewed gum (Figure 4A), the record consists of high voltage 1.5-2.0 cycle per second waves mixed with muscle potentials. These artifacts, produced by rhythmic chewing motions, obscure cerebral potentials entirely.

When the astronaut closed his eyes, such as illustrated in Figure 4B, the record shows a strong alpha rhythm and is free of artifact. This sample is from a two-hour period in the first day of flight during which the astronaut apparently tried to sleep but was unable to do so.

The entire wakeful record (which constituted 77.5 per cent of the total recording) was visually scanned for evidence of EEG changes of clinical significance; none were found, either during ascent or in orbit. By comparison with the preflight baseline study, there seemed to be slightly more theta (4-7 cycles per second) activity.

The EEG recording on Gemini VII is, therefore, probably the most complete study yet made during orbital flight in terms of number of channels, length of recording, and variety of subject activity and states of consciousness. Two channels of EEG data were recorded continuously from before lift-off through the first day of flight. The recording thus covers ascent, three working periods of orbital flight, and two sleep periods. It is hoped that a longer-lasting electrode system can be developed in the near future so that a recording can be made throughout an entire flight, including re-entry and recovery.

From a medical point of view, the results of the current study were essentially negative in that no pathological EEG changes were observed, and visual inspection of the tracing revealed no changes which could be attributed to the "weightless" state. Furthermore, it is difficult to draw conclusions from the two recorded sleep cycles. The first sleep period was definitely inadequate in terms of length and depth of sleep, but the pattern was typical of ordinary insomnia or disturbed sleep, which can easily be explained on the basis of the understandable anxiety of the situation and the unique conditions of orbital flight. The second sleep period was adequate in terms of depth and length, but this cannot be used as definite evidence against orbital sleep disturbance since

the pilot was probably quite fatigued due to loss of sleep in the first sleep period. Sleep patterns in subsequent sleep periods later in the flight will have to be obtained in order to arrive at any definite conclusions as to whether orbital flight per se tends to disturb sleep.

The EEG's of the cosmonauts were analyzed in terms of alpha, beta, and theta indices. In general, most showed an initial decrease in alpha index (per cent time alpha) early in the flight, followed by a progressive increase in alpha index. These changes, the Russian authors opine, are indicative of a "poorly defined fatigability of the cosmonauts," but are not pathological. The EEG recordings from Tereshkova were somewhat different in that she showed an augmentation of theta index during weightlessness.³ Since we have not found such index determinations to be useful clinically, this type of analysis has not been carried out on EEG records from Gemini VII. Other investigators will employ computer analysis of the EEG data from Gemini VII in order to search for any changes which are not evident in visual interpretation.

CONCLUSIONS

(1) The first U. S. attempt to record the electroencephalogram during orbital flight was successful. It demonstrated that it is possible to obtain good-quality EEG

tracings for a relatively long period from an astronaut during ascent, while operating the vehicle in orbit, and during sleep.

(2) Visual interpretation of the EEG tracing revealed no abnormalities and no obvious changes attributable to "weightlessness."

(3) Depth of sleep patterns of the first two sleep periods during the flight were not unusual. The first sleep period was inadequate in terms of depth and length, but the second sleep period was normal.

(4) The results of this preliminary EEG study confirm the view that orbital flight has no apparent deleterious effect on the activity of the brain.

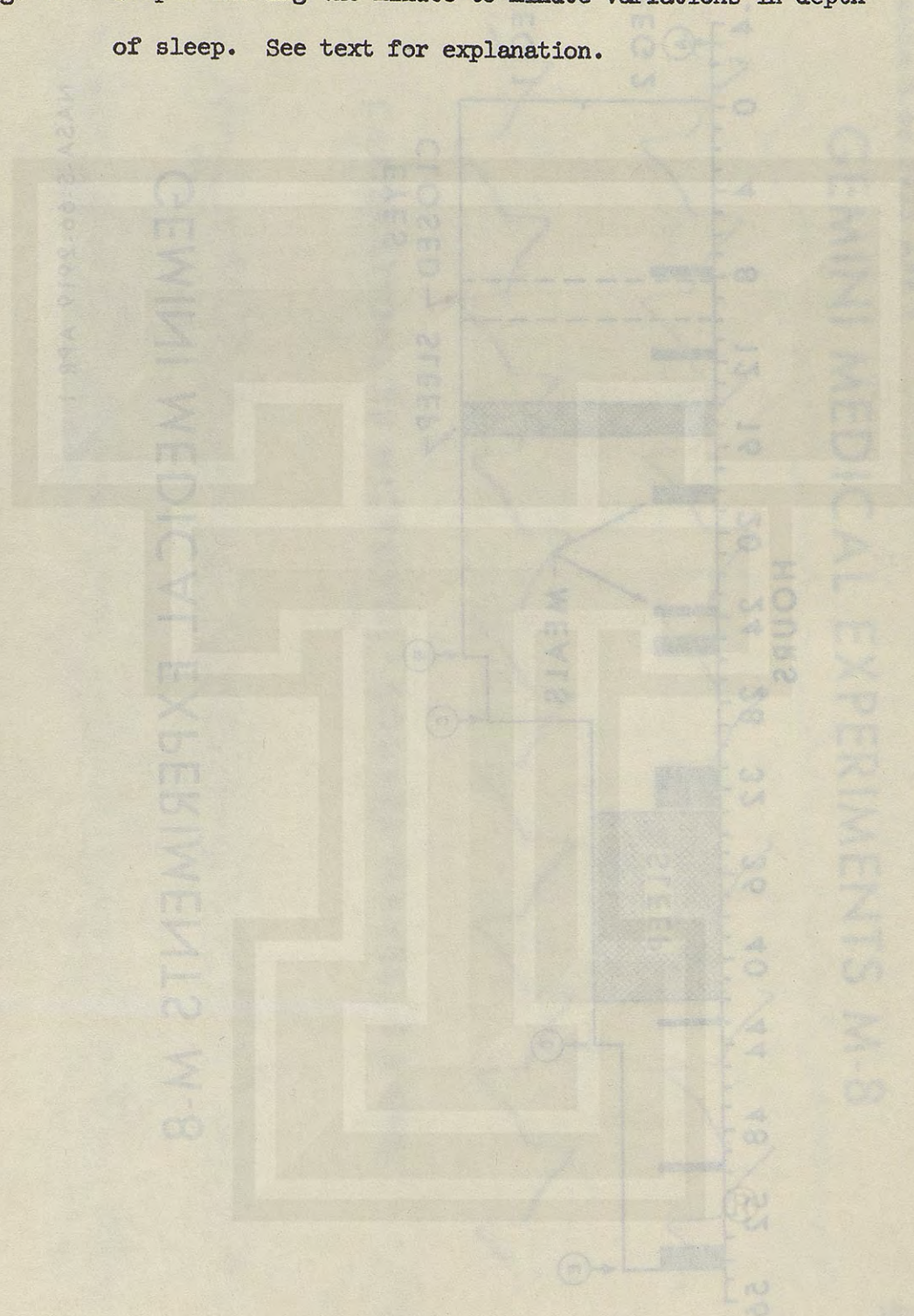
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2. Dement, W., and Kleitman, N.: Cyclic Variations in EEG During Sleep and Their Relation to Eye Movements, Body Motility and Dreaming. Electroenceph. Clin. Neurophysiol., 9:673, 1957.
3. Parin, V. V., Volynkin, Y. U. M., and Vassilyev, P. V.: Manned Space Flight--Some Scientific Results. In Florkin, M.: Life Sciences and Space Research, Vol. III. North Holland Pub. Co., Amsterdam, 1965.
4. Shackel, B.: Skin-drilling: A Method of Diminishing Galvanic Skin Potentials. Amer. J. Psychol., 72:114, 1959.

FIGURE LEGEND

- Fig. 1 Bar graph representing quantity of EEG data obtained.
See text for explanation.
- Fig. 2 A. (Upper two tracings): Write-out of calibration signals which were applied to the data tape prior to liftoff. All EEG illustrations in this paper used this gain and chart speed.
B. (Lower two tracings): EEG pattern prior to liftoff.
- Fig. 3 A. (Upper two tracings): EEG pattern during ascent, near peak acceleration.
B. (Lower two tracings): EEG pattern during orbital flight.¹/₂
- Fig. 4 A. (Upper two tracings): Artifacts produced in EEG pattern by rhythmic chewing motions.
B. (Lower two tracings): Fully expressed alpha rhythm present when eyes are closed while pilot is alert.
- Fig. 5 A and B. (Upper two tracings): Illustration of the transition from the alert, resting pattern to drowsiness, or stage 1 sleep.
C. (Lower trace): Light sleep pattern, or stage 2 sleep.
- Fig. 6 A. (Upper trace): Stage 3 sleep, or moderate sleep.
B. (Middle trace): Deep sleep, or stage 4.
C. (Illustration of a transient arousal from Stage 4 sleep to stage 0.
- Fig. 7 Continuous tracings showing a mixture of sleep stages 1 and 2. This pattern occurred for long intervals and resembles the EEG seen during the rapid eye movement phase of sleep, or "paradoxial sleep."

Fig. 8 Graphs showing the minute-to-minute variations in depth of sleep. See text for explanation.



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GEMINI MEDICAL EXPERIMENTS M-8

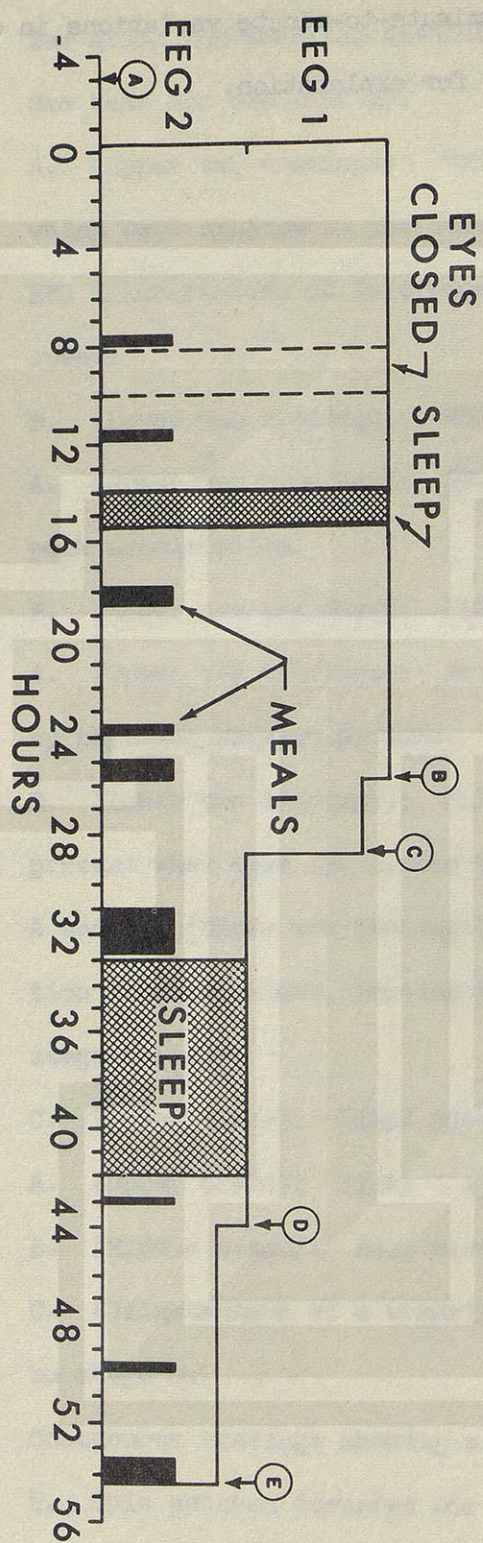
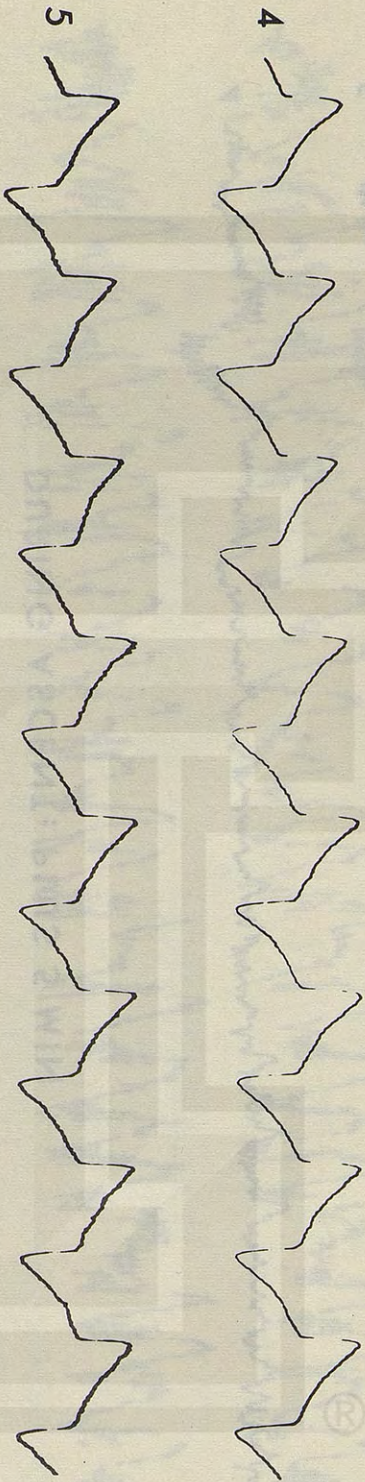


Fig. 1

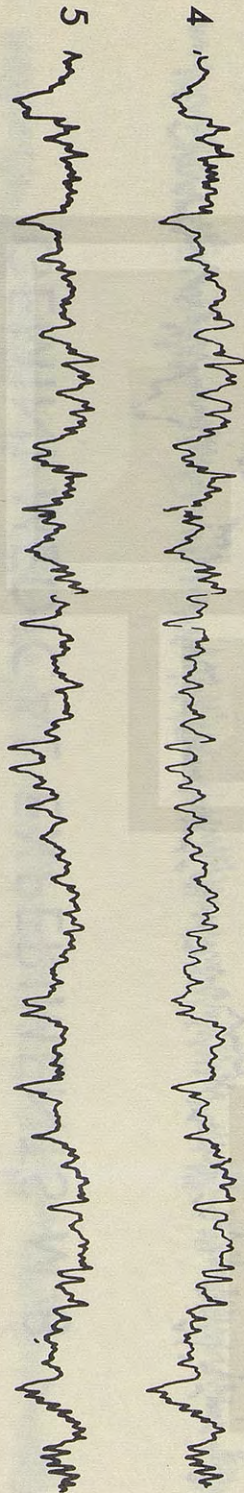
GEMINI MEDICAL EXPERIMENTS M-8

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CALIBRATION: 50 MICROVOLT SQUARE WAVES, 0.5 CPS

Fig. 2

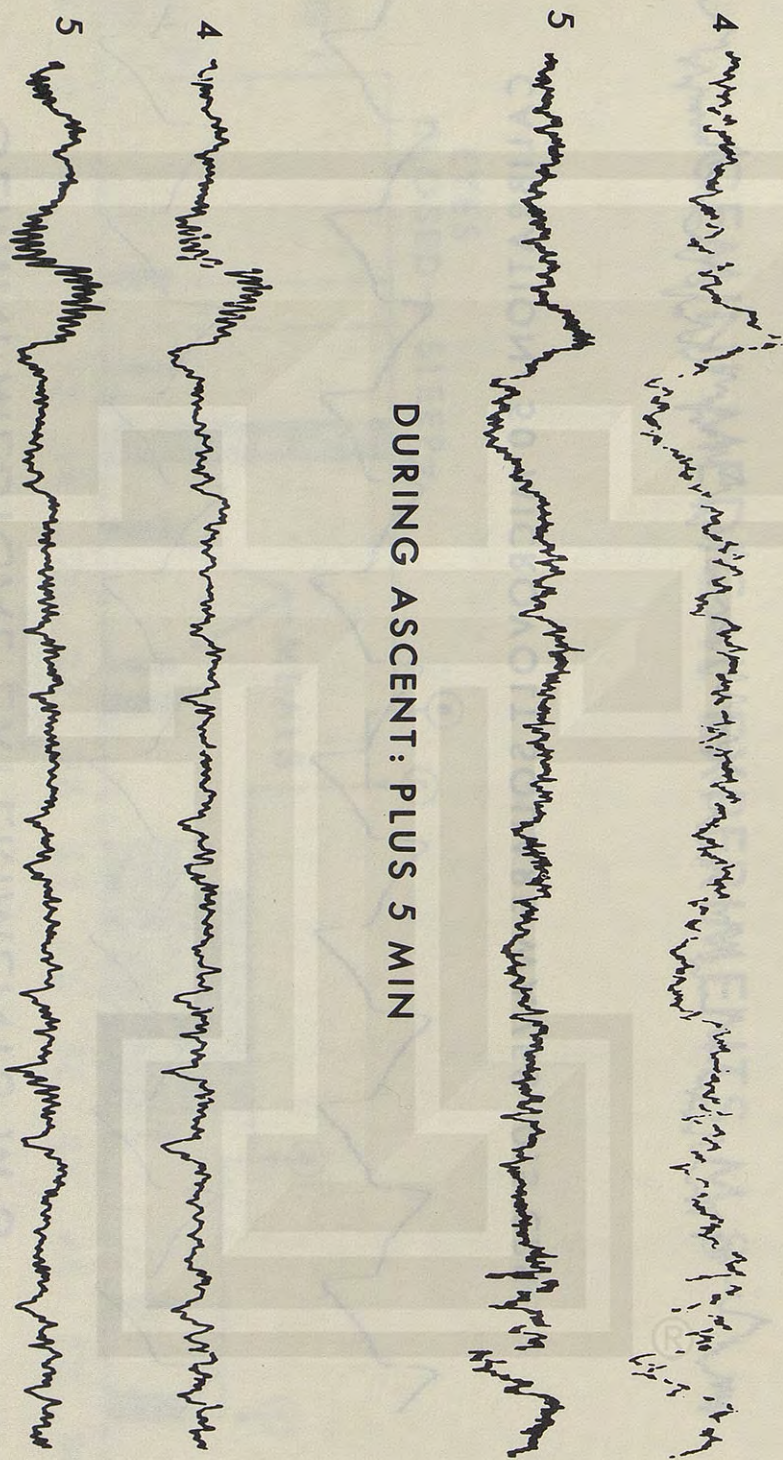


BEFORE LIFT OFF: MINUS 10 MIN

RESTING, EYES CLOSED: 8 HR, 16 MIN

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GEMINI MEDICAL EXPERIMENTS M-8

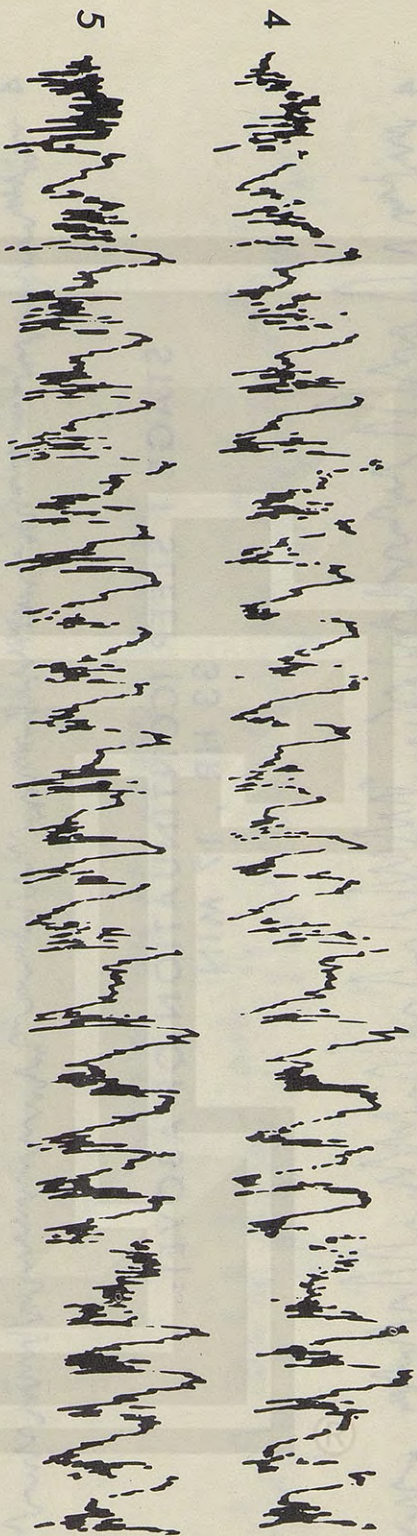


DURING ASCENT: PLUS 5 MIN

IN ORBIT: 24 HR, 27 MIN

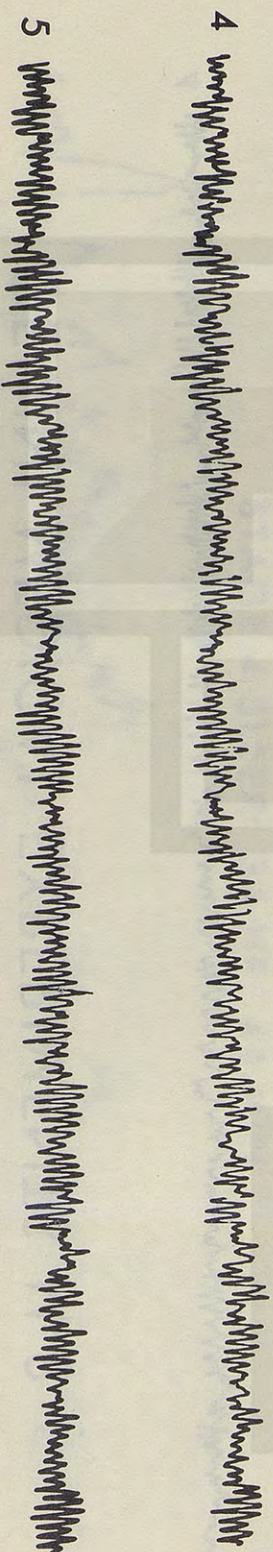
Fig.
3

GEMINI MEDICAL EXPERIMENTS M-8



DURING MEAL: 7 HR, 49 MIN

Fig.
4



RESTING, EYES CLOSED: 8 HR, 16 MIN

PARTIAL AROUSAL: 36 HR, 53 MIN

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GEMINI MEDICAL EXPERIMENTS M-8

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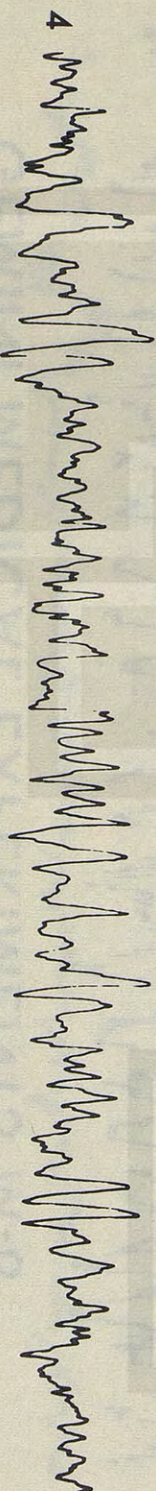


TRANSITION TO STAGE 1 SLEEP: 33HR, 17 MIN



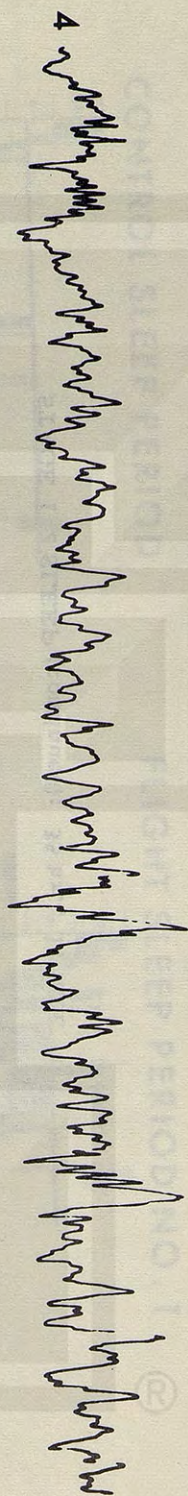
Fig. 5

STAGE 1 SLEEP (CONTINUATION OF ABOVE):
33 HR, 17 MIN

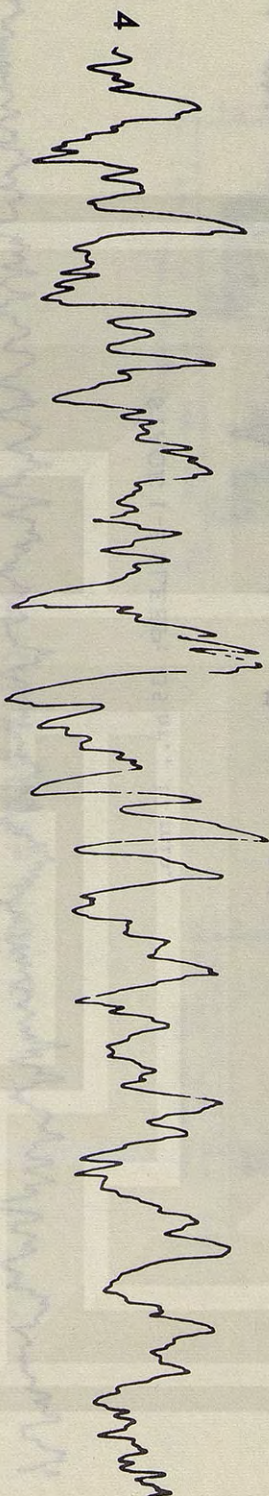


STAGE 2 SLEEP: 33HR, 24 MIN

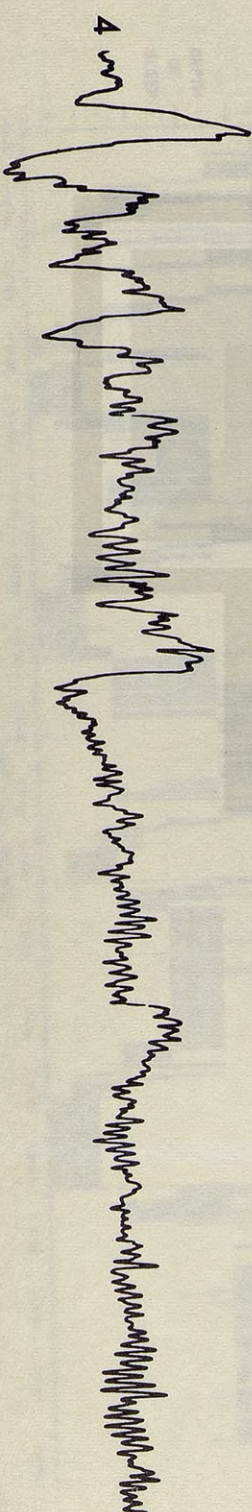
GEMINI MEDICAL EXPERIMENTS M-8



STAGE 3 SLEEP: 34 HR, 16 MIN



STAGE 4 SLEEP: 34 HR, 44 MIN



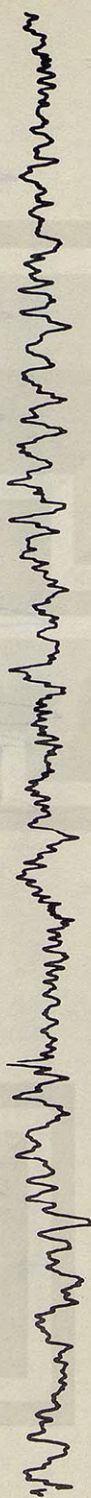
PARTIAL AROUSAL: 36 HR, 53 MIN

Fig.
6

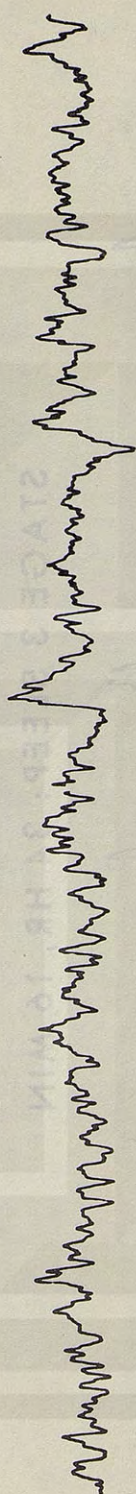
1:3:00 1:3:30 1:4:00 1:4:30 1:5:00 1:5:30 1:6:00 1:6:30 1:7:00 1:7:30 1:8:00
TIME (DAY:HR:MIN.)

PARTIAL AROUSAL: 36 HR., 53 MIN

STAGE 4 SLEEP: 34 HR., 44 MIN



STAGE 1-2 SLEEP: 35 hr., 11 min.

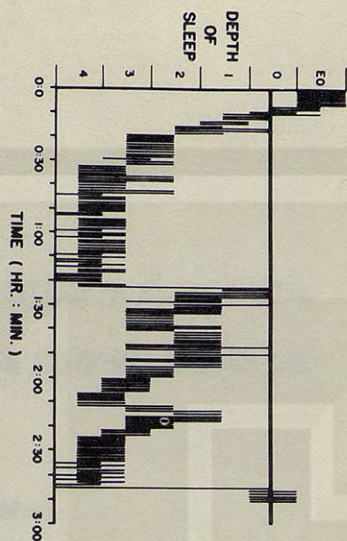


STAGE 1-2 SLEEP (continued): 35 hr., 11 min.

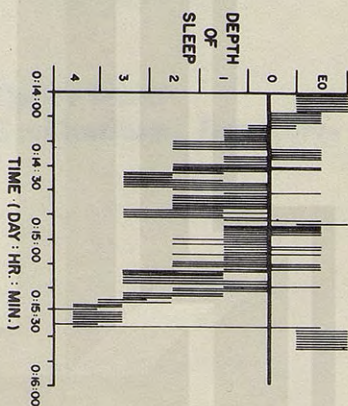
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GEMINI MEDICAL EXPERIMENTS M-8

CONTROL SLEEP PERIOD



FLIGHT SLEEP PERIOD NO. 1



FLIGHT SLEEP NO. 2

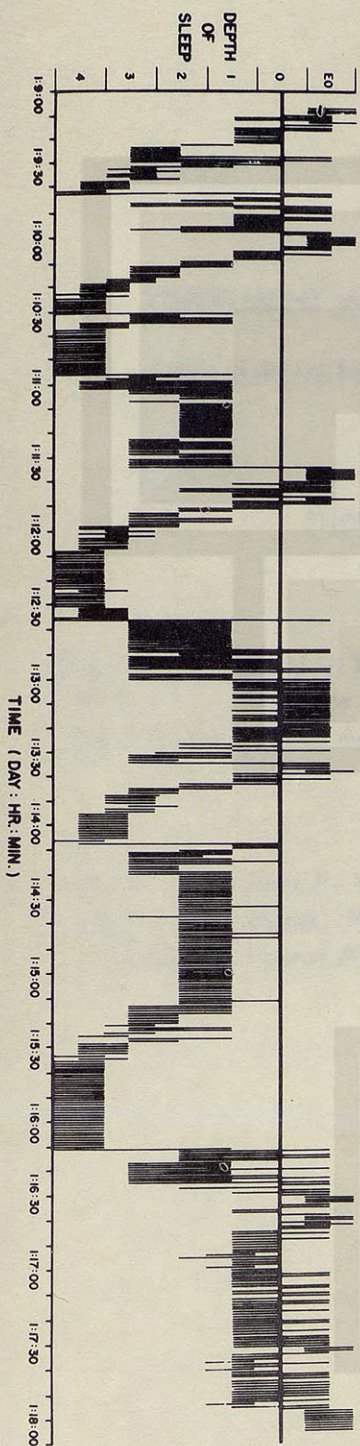


Fig.
8

EXPERIMENT M-9, HUMAN OTOLITH FUNCTION:

MEASUREMENTS IN GEMINI FLIGHTS V AND VII

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EXPERIMENT M-9, HUMAN OTOLITH FUNCTION:

MEASUREMENTS IN GEMINI FLIGHTS V AND VII*

The otolith organs and semicircular canals which comprise the nonacoustic labyrinth in man contain the only sensory receptors which specifically react to gravito-inertial forces. Many investigators refer to them collectively as the vestibular organs, which emphasizes the difficulties under many circumstances of distinguishing between these two closely related sensory systems. Under ordinary conditions, the physiological stimulus to the otoliths is linear and to the canals, angular acceleration. Thus, the canals are stimulated by the inertial forces generated by the rotary movements of the head (body) and subserve such normal functions as sensing rotation and aiding in visual tracking and in maintaining postural equilibrium. The otolith organs are stimulated by gravity, by changes in the gravito-inertial force vector with respect to the head, and by changes in position of the head with respect of this vector; they contribute to such useful functions

*Answers to questions raised at the time of this presentation have been incorporated in the text.

as the perception of linear motions, orientation to the upright, and maintenance of postural equilibrium. Loss of the semicircular canals in man under terrestrial conditions results in qualitative loss of certain functions whereas loss of otolith function results mainly in quantitative deficiencies; the receptor organs responding to mechanical forces including the direct and indirect effects of weight often act in a complimentary or synergistic fashion.

The vestibular organs are affected quite differently in weightlessness, and their individuality is emphasized. At rest there is "physiological deafferentation" of the otolith apparatus, but there is no corresponding effect on the canals. With movement of the body (head) the angular accelerations generated would stimulate the canals much the same as under terrestrial conditions, but the small linear accelerations might not always constitute an adequate stimulus to the otoliths and, when they did, would not provide a cue to the upright of the spacecraft. Stated differently, when a person makes his first transition into weightlessness, the normal stimulus to the otolith apparatus is lost for the first time in his life. It is analogous to closing the eyes, with the important difference that we are habituated to eyes closed as well as open. In the absence of linear accelerations, cues provided by contact with the environment are in response to mechanical force.

Although a unique and remarkable opportunity exists in orbital space flight to investigate many aspects pertaining to the role of the otoliths and canals, such experimentation is difficult and only limited possibilities were afforded in the Gemini flights. The experiment agreed upon comprised two distinct but not wholly unrelated parts. One consisted of the pre- and post-flight measurement of ocular counterrolling, a measurement of otolith function (1). The other was concerned with the influence of nonvisual cues on spatial localization. Here the astronauts' task was to set a luminous line to the horizontal in an otherwise dark visual field; pre- and post-flight it was set to the Earth horizontal, and in flight, to an element in the spacecraft horizontal with respect to the astronaut. The data were collected under the immediate supervision of Dr. Earl F. Miller; the Center investigator in GT V was Dr. John Billingham, and in GT VII, Mr. Richard Waite.

SPATIAL LOCALIZATION

The purpose of this experimental probe was to compare the influence of nonvisual sensory information under terrestrial and weightless conditions on the visually perceived direction of space. Data

obtained from earlier experiments not only are relevant for comparative purposes but also serve as a necessary introduction.

SENSORY SYSTEMS

It is generally held that physical space is not provided by a specific quality of sensations themselves but by a construct placed upon them. It is acquired as man becomes aware of the external environment in relation to himself. Under natural living conditions the most important cues for the perceived direction of space are furnished by the visual and gravito-inertial force environments. The best concordance between the two is manifested with man upright, and its achievement represents one of the most dramatic manifestations of man's adaptation to his outer environment. In the course of his primitive sense experiences, man's perception of the visual world underwent a reversal to conform with the gravitational upright, and the central nervous system integrative mechanisms, continuously ensuring spatial orientation, constitute an elegant example of homeostasis. It is necessary to keep in mind the evolutionary manner in which orientational homeostasis was acquired to appreciate properly how and why it is disturbed when man extends his natural abilities by artificial means. In adjusting to these new force environments man at once reflects his habituation to specific natural terrestrial conditions and the plasticity of his central nervous system.

In Figure 1 is shown a simplified analysis of cues to space perception provided under terrestrial conditions and some of the possibilities for interaction among them. The great concordance between cues from the gravitational and visual environments is obvious in natural environments and yet more so in artificial ones which are based on the gravitational coordinate system.

Some of the possibilities for interaction can be artificially contrived, not only by manipulations of the visual and force environments but also by the use of subjects with or without labyrinthine function. In general, manipulations are far easier to accomplish in the visual than in the force environment; moreover, with vision a unique situation exists in which one can study nonvisual influences on visual space localization in the absence of visual cues to space. This is represented by the broken lines in Figure 1. It is important to emphasize that in the articulation between sensory information from the visual and force environments, visual cues are inadequate and only a very slight influence is demonstrable.

Examples of Interactions Between Cues From Visual and Force Environments

In Figure 2 (top) is shown a naive normal subject on an open centrifuge and facing the center of rotation. When he is exposed

to a centripetal force of 1.0 g unit, the centrifuge appears to slope upward away from him and the room appears similarly sloped (2).

This is at once a demonstration of preternatural control over the force environment and a partial conformity of the visually perceived upright to the gravito-inertial upright. This has been termed the oculogravic illusion (3) based on the Earth reference.

In Figure 2 (below) he is exposed to 2.0 g units, and, some persons at least, soon feel as if they are stationary and on their back and perceive the room rotating around them. This is probably analogous to experiences of aviators in certain types of spin (4). Not only are visual cues overwhelmed but also there is over-compensation with reference to the gravito-inertial upright. The curious reversal with regard to relative motion between centrifuge and room might have its genesis in the fact that the force environment is static in the sense that the force pattern with reference to the subject is unchanging at constant velocity and is supernormal in magnitude.

In Figure 3a the subject is seated in a closed lighted room on a human centrifuge and facing in the direction of rotation. When exposed to a centripetal force of 1.0 g unit, he perceives the room

as sloped with down on his right side. When visual cues are greatly reduced (Figure 3b), the slope increases, and there may be good concordance between the visual and force upright. This orientation of the subject creates a more favorable opportunity for him to indicate horizontality by clockwise or counterclockwise rotation of a visual target or rod than when he faces the center where estimates would be made as deviations above or below an imaginary horizon.

Examples of the Influence of Nonvisual Cues on the Visually Perceived Direction of Space

A large body of information has been obtained by having subjects set a visual target or rod in an otherwise uniform visual field either to internal or external spatial coordinates (5-9). Many investigators since Aubert (10) have explored the effects of tilting their subjects in the gravitational field, and with the introduction of the human centrifuge (11, 12) it became possible to change the direction of the gravito-inertial force vector with respect to the subject. There are interesting and important differences between the responses obtained with tilt and on the centrifuge, not all of which have been satisfactorily explained.

THE OCULOGRAPHIC ILLUSION

In Figure 4 a subject is shown seated facing the direction of rotation while exposed to a centripetal force of 1.0 g unit (13). The

sketch depicts the arrangement of physical objects as viewed by closed circuit television. Note the free swinging plumb bob which is the only indication of the gravito-inertial vertical.

Figure 5 shows how a naive subject perceives the situation with eyes closed; he feels as if he is tilted to the right in an upright room. A sophisticated subject is also aware of the tilt but will realize his position has not changed with reference to the room.

Both subjects, if viewing a luminous line in the dark while suddenly subjected to a centripetal force of 1.0 g unit, would perceive the line as rotating slowly clockwise from the horizontal position through an arc usually greater than 45° . This is an illusory or apparent motion representing influences of cues from the force environment on visual spatial localization. If the subject is requested to set the line to the Earth horizontal, he rotates it counterclockwise from its original setting toward the gravito-inertial horizontal, usually overcompensating at this level of force; grasping a swivel rod with eyes closed, he also sets this near the gravito-inertial horizontal. The results are scored in terms of correspondence of the settings to the gravito-inertial horizontal. With the visual target the threshold* of perception for perceiving the

*75 per cent (or greater) correct responses.

illusory rotation with the subject upright is 1.0003 g units, about equivalent to an angle ϕ of 1.5° (14).

The settings by normal subjects and by persons with bilateral labyrinthine defects (L-D subjects) (13) who were requested to maintain the line at the horizontal continuously throughout an experimental trial in which they were subjected to a change in direction of gravito-inertial force of about 20° are shown in Figure 6. Note the delay or lag between the change in force vector and the apparent rotation of the line, indicating, presumably, the complex nature of this integrative mechanism (15).

The effects of having the subject delay in opening his eyes are shown in Figure 7. This demonstrates that visual perception is not essential for the integrative action, although it tends to favor it slightly. Vision is essential only to display the effects.

In Figure 8 is shown a comparison between the settings of naive normal and L-D subjects exposed to gravito-inertial forces corresponding to deviations from the gravitational vertical (angle ϕ) of 10° , 20° , 30° , and 40° (13). The variance was great in the case of the ten L-Ds, but not in the normal subjects. The group differences were attributed to the presence and absence of vestibular, and more likely otolith, function.

The L-D subjects over a period of time demonstrated "improvement" in the correspondence of their settings with the gravito-inertial horizontal. In addition to a possible practice effect, although the means of monitoring was not evident, the settings were greatly improved with prolonged exposure (16) and by encasing the subjects in Fiberglas molds. Some of these factors were evident in the experimental findings upon comparing the settings of the luminous line between normal and L-D subjects when exposed to identical changes in the gravito-inertial upright, once when submerged to the neck, and again under dry conditions (17). In the latter circumstance the use of Fiberglas molds tended to maximize the area of good contact with the centrifuge while under water these contacts were minimal.

The curves in Figure 9 summarize the findings. Three normal subjects manifested little difference in setting the line to the gravito-inertial horizontal under dry and wet conditions. On the other hand, the L-D subjects manifested a great difference; submerged they set the line very close to the Earth horizontal which coincided closely with their internal horizontal coordinate; when dry, the settings were qualitatively similar but quantitatively about half the value indicated by the normal subjects.

Put in other terms, the loss of cues from the receptor organs responding to mechanical force had only a slight effect in the normal subjects inasmuch as the distance receptors in the otolith organs were functioning normally; the quantitatively slight decrease might be said to represent the contribution of the non-otolith receptors under dry conditions. The L-D subjects under dry and favorable conditions demonstrated that the nonotolith receptor organs provided good cues to the force environment despite the absence of distance receptors, and their settings were a measure of these cues alone. Underwater, the cues were greatly diminished, and in the absence of distance receptors there was shown to be little influence from gravito-inertial cues.

Certain Effects of Lateral Tilt in the Gravitational and Gravito-inertial Fields

Seated upright in a tilt chair normal subjects set a luminous line approximately to the gravitational horizontal but manifest a characteristic bias as they are tilted leftward or rightward through 90°. Initially, the bias appears as an over- and later as an under-compensation termed, respectively, the E- and A-phenomenon, as

shown in Figure 10 (18). The bias is greater and the consistency less in L-D subjects.

This bias as a function of increasing G load was measured on the centrifuge by controlling the deviation of a freely swinging platform from the gravito-inertial upright (19). In Figure 11 the family of curves obtained from eight normal subjects shows the increase in bias with increasing magnitude of force, and in Figure 12 are the findings under similar conditions in two subjects without vestibular function. Note that the change from the E- to A-phenomenon occurs with smaller angles of tilt in L-D subjects compared with normal subjects and that the bias tends to be greater and the variance in the settings far greater.

When fixating the luminous line while lying on the side as depicted in Figure 13 not only is the A-phenomenon prominent but also, for some subjects, the line appears slowly to rotate clockwise and counter-clockwise, a form of apparent motion (20). The estimations of a Mercury astronaut, of a normal, and of an L-D subject are shown in Figure 14 (21). The estimations of the astronaut were typical for two subjects while those of the normal and L-D subjects represented the modes for both groups who manifested great individual variance.

THE IN-FLIGHT EXPERIMENT

These findings indicate that the best concordance between nonvisual and visual cues to the gravitational vertical is provided with man upright or nearly upright. Presumably this is the result of much practice with excellent monitoring possibilities. A constancy bias with regard to nonvisual cues can be demonstrated with increasing angles of tilt and with increasing g load for the same angle of tilt in normal persons. To persons without vestibular (otolith) function the bias and its variance are greater, and under gravitational conditions the angle at which E to A reversal occurs is smaller than in normals.

Insofar as these findings may be extrapolated to weightlessness, it would appear that agravic touch, pressure, and kinesthetic cues representing an unusual pattern would increase the tendency toward bias while lifting the g load would reduce it. The poverty of cues from the several sensory systems is summarized in Table I.

Important questions were whether a person in weightlessness would perceive a line of light in the dark as stationary with respect to clockwise or counterclockwise rotation, and how readily it would be influenced by agravic touch, pressure, and kinesthetic cues. It was with these considerations in mind that we suggested the experiment now to be described.

THE IN-FLIGHT EXPERIMENT

Methodology

Subjects. The medical findings on the four astronauts who participated in GT V and VII flights are available elsewhere in NASA publications.

Equipment. The goggle device used represented a modification and miniaturization of a target-device previously described (22). It consisted essentially of a collimated line of light in an otherwise dark field. This "line" could be rotated about its center by means of a knurled knob. A digital readout of "line" position was easily seen and was accurate within $\pm 0.25^\circ$.

The goggle device was monocular and fabricated in duplicate so that the astronaut in the lefthand seat used the right eye with the readout visible to the astronaut on his right, and vice versa. The readout was adjusted for each flight so that the instrument's zero was represented by a value other than zero or 180° to eliminate or reduce the possible influence of knowledge of the settings upon subsequent judgments. Horizontality with respect to the apparatus was 61.3° for the astronaut on the left and 98.8° for the astronaut on the right in the Gemini V, and 76.6° and 101.6° for the left and right Gemini VII astronauts.

It was necessary to incorporate the device with the Vision Tester which was used in another experiment (Figure 15). The device was held at the proper position, with the lines of sight coincident with the optic axes of the instrument, by means of a bite-board individually fitted to the subject. A head brace, as shown in Figure 15, was provided to connect the bite-board of the instrument to the map board slot of the spacecraft and thereby eliminate any rolling movement or displacement of the zero target setting for horizontal with respect to the spacecraft; a limited amount of freedom around its pitch axis was permitted by the folding configuration of the brace as designed for storage purposes. This method of fixing the Vision Tester to the spacecraft was not used in the GT V mission, but a similar positioning of the instrument was achieved by having the subject sit erect in his seat with his head aligned with the head rest.

Procedure. The pre-flight testing of the Gemini V crew was accomplished sixteen days prior to their flight. The Gemini VII crew were similarly tested on two different occasions, nineteen and six weeks prior to their flight.

Pre- and post-flight, the measurements were made with the subject rigidly secured in the upright position. The experimenter offset the line clockwise or counterclockwise in variable amounts, then the subject set it to what he regarded as vertical. This was repeated five or more times.

The method in-flight was as follows: Immediately after completion of the Visual Acuity Experiment, and without removing the instrument from his face, the subject prepared for making his judgments of horizontality by occluding the left eyepiece and turning on the luminous target before the opposite eye. The target appeared against a completely dark background. The observer astronaut offset the line, and the subject's task was to set it parallel to an element of the spacecraft panel horizontal with respect to himself. When satisfied with the setting, he closed his eyes and removed his hand from the knurled knob. This served as a signal to the observer to record the setting and offset the target. This procedure was scheduled to be repeated five times during each of the daily test sessions. In the interest of conserving vital spacecraft power during the early part of the Gemini V flight, no settings were made; for the same reason during revolution 24, 39,

and 54 only one judgment of horizontality was made by each subject. Upon completion of a test session by the first subject the Vision Tester was handed to the other pilot, and the same sequence was carried out after completion of the visual acuity test. Finally, the readings for each pilot were tape-recorded by voice.

RESULTS

In Figure 16 is shown the measurements obtained in GT V. The striking feature is the difference in estimations of horizontality in the case of Pilot A obtained in-flight as compared with pre- and post-flight. Post-flight variance was significantly greater than the variances for each of the in-flight measurement groups and was also significantly greater than pre-flight variance. The estimates of Pilot B revealed no systematic differences except that the post-flight variance was greater than pre-flight.

The findings obtained on the two astronauts in GT VII are shown in Figure 17. For Pilot C there is no systematic variance differences among the pre-, post- and in-flight measurement. For Pilot D variance of pre-flight measurements was significantly greater than variances for all other sets of measurements including post-flight. Post-flight variance was significantly greater than the variances

of in-flight measurement and for 9 of the 14 sets of measurements obtained during orbital flight.

Two findings deserve further comment, namely, the small intra-test variance in a single series of inflight settings and the apparent bias manifested by astronaut A.

The finding that the intratest variance of in-flight settings never exceeded and often was smaller than the pre- and post-flight settings becomes even more significant when account is taken of the unfavorable conditions aloft, especially in GT V, where it was not feasible to use a "biting board." It is a safe prediction that if the in-flight settings had been made under terrestrial gravitational conditions, the intratest variance would have been far greater than pre-flight and probably greater than post-flight measurements aboard the carrier.

As pointed out above, in attempting to anticipate the influence of agravic cues on spatial localization the loss of G loading might be expected, by extrapolation, to reduce the tendency toward a bias while the unusual patterning of sensory cues, especially in the absence of otolith function, might tend to increase this tendency. The small intra- and inter-test variance in setting the line during exposure to weightlessness strongly suggests that agravic cues exert a weak influence on central intergravitational processes underlying

visual spatial localization. Stated in another way, the loss of sensory information from the otolith organs and other receptor organs stimulated by gravity following transition into weightlessness did not appear to influence visual mechanisms concerned with the perceived direction of space. Under these circumstances the sensory information is so meager and the pattern so unusual that it would hardly serve as adequate primitive sense experience out of which to construct a concept of physical space. Once this concept has been established, however, meager postural cues may suffice for spatial orientation even in darkness.

These findings have important implications for the interpretation of ground-based experiments using essentially the same procedure. They strongly suggest that the A- and E-phenomena and their variants and the oculogravic illusion and its variants are the positive results of sensory inputs and that the differences observed between normal and L-D subjects imply either a greater or modulating influence or both. Lifting the gravitational load did not lead to rotary autokinesis, for example, implying, in turn, possible influences via the extra-ocular muscles.

The question arises whether the in-flight settings would have revealed less variance if the astronauts' task had involved setting the line to the horizontal body coordinate representing personal space rather than to an external reference. Although this question cannot be answered, it would seem that the variance might have been less inasmuch as setting the line to an external reference involved an extra step dependent on memory of the relation between the two frames of reference.

With regard to the in-flight settings of astronaut A, they differed from those of the other three in that they were approximately 30° clockwise with respect to the external horizontal reference but were similar in that the intra- and inter-trial variance were small. The question arises whether the settings near 30° represent a systematic procedural error, a bias, or settings with reference to independent symbolic cues. The same goggle device was used post-flight; hence, a mechanical error is ruled out. Inasmuch as the task involved setting the line to a horizontal cabin reference coinciding with the astronaut's body horizontal, it did not matter if the body reference

was chosen, thereby eliminating any confusion between the two.

Our experience is so limited that we cannot even answer the question whether a bias of this magnitude based on nonvisual sensory inputs under agravic conditions is possible. The phenomenon does not seem typical of the characteristics of biases manifested under terrestrial conditions, but this does not rule out the possibility. This can of course be put to the test whenever it becomes feasible in weightlessness to manipulate sensory cues and investigate the effects on spatial localization. There is too the possibility that the settings were made using a cue other than the internal coordinates of the body. This of course can be controlled in the future.

subject's head with respect to the tilt device. This method has been used in parabolic flight, and some of the findings are depicted in Figures 19 and 20.

It would have been of interest to determine any changes in roll as a function of exposure aloft in the Gemini flight, but for obvious reasons this was out of the question. Measurements were made, however, pre- and post-flight.

APPARATUS AND PROCEDURE

The apparatus used for measuring ocular counterrolling is essentially a tilt device on which a camera system is mounted (25). The main supporting part of this device acts as a carrier for the stretcher-like section. This section contains Velcro straps and a saddle mount to secure the subject in a standing position within the device and can be rotated laterally to $\pm 90^\circ$ about the optic axis of the camera system and, when the subject is properly adjusted, also about the visual axis of his right or left eye. A custom fitted bite-board was also used in counterrolling testing to fix the subject's head with respect to the camera recording system.

The camera system used to photograph the natural iris landmarks includes a motor driven 35 mm camera with bellows extension and an electronic flash unit (25). A console located at the base of the tilt device contains a bank of power packs which supply the electronic

flash, a timer control mechanism, and controls for the flashing, round-fixation light which surrounds the camera lens. A triaxial accelerometer unit which senses and relays signals of linear acceleration to a Consolidated Electrodynamics Corporation galvanometer recorder was mounted to the head portion of the device for shipboard use.

A test cubicle 12' x 16' x 10' insulated against outside sounds, light, and temperature was constructed for carrying out the post-flight tests of spatial localization and counterrolling onboard the recovery carrier.

Immediately prior to the pre- and post-flight testing one drop of 1% pilocarpine hydrochloride ophthalmic solution was instilled in the subject's eye which was opposite to the one he used for making visual orientation judgments. These judgments were made first. Then the subject remained in the upright position in the tilt device, the Vision Tester and its bite-board were removed, and preparations were made for photographically recording the eye position associated with a given position of body tilt. The counterrolling bite-board was inserted in the subject's mouth, and the position of his appropriate eye was adjusted so that it coincided with the optic axis of the camera system when he fixated the center of the flashing red ring of light. Six photographic recordings were made at this position; then the subject was slowly tilted in his lateral plane to each of four other positions ($\pm 25^\circ$, $\pm 50^\circ$), and the same photographic procedure was repeated.

of g loading, which should tend to reduce it. Although one astronaut consistently set the line approximately 30 degrees from the external reference while in-flight, it remains to be verified whether these settings represented the internal (body) reference, which, under the experimental conditions, should have been the case.

Stated differently, the results demonstrate the possibility of investigating the influence, if any, of agravic sensory information on perceived spatial visual localization.

If our conclusion is correct that the influence of agravic cues on visually perceived direction in space is small, this influence should be even less discernable when visual cues are present. Thus, in weightlessness the interaction between visual and non-visual cues should favor the former to a greater degree than under terrestrial conditions.

OTOLITH FUNCTION AS DETERMINED

BY OCULAR COUNTERROLLING

Direct testing of the function of the otolith organs as in the case of the semicircular canals, vision or hearing is not done routinely because of the great difficulties involved and the limited clinical interest in these organs. The difficulties include manipulating the physiological stimulus and lack of a specific, accurate indicator. Among the methods used, estimation of the oculogravic illusion with the subject submerged to reduce nonotolith sensory inputs and ocular counterrolling with head fixed to reduce influences from "cervical reflexes" are in all likelihood the most accurate. Only the latter is practical, and the most accurate measurements of the roll or ocular torsion have been made using "landmarks" in the fundus (23) or artificial or natural external markings (1). In Figure 18 is shown the change in position of the eye as a function of lateral tilt from the upright; the measurements were made from photographs of the face obtained in the upright and tilt positions (24). The reliability of the method was established using normal and L-D subjects. Moreover, when these same subjects were exposed to changes in direction and magnitude of force on a human centrifuge, the amount of the roll in the normal subjects was found to be a function of the laterally-acting (shearing) force. Dr. Miller introduced a photographic procedure which depends on matching crypts in the iris between photographs taken with the subject upright and in lateral tilt (25) which eliminates the need for sutures but requires absolute fixation of the

The accelerometer system was used post-flight during all testing to continuously record motions of the recovery ship around its roll, pitch, and yaw axes.

Post-flight examinations were begun for pilots A, B, C, D, approximately six, five, six, and four and one-half hours, respectively, following their recovery at sea.

RESULTS

The counterrolling measurements are summarized in Figures 21 and 22. The values for pilots A and B were in the lower range of a large random group of normal persons while the values for pilots C and D were in the mid-range. No significant differences were found pre- and post-flight in any of the four astronauts. The slight difference in the counterrolling curves can be accounted for by the small rotary oscillations (physiological unrest) of the eye and the fact that an average of several recordings is used to define the position of the eyes associated with any given body tilt.

DISCUSSION

The failure to find any significant changes was not unexpected but it remained to be done. The only feature worthy of comment is the relatively small roll in the case of astronauts A and B. Inquiry has not disclosed any common factor associated with the flight which might account for the findings.

SUMMARY AND CONCLUSIONS

Two experimental probes were carried out involving the astronauts in the Gemini V and VII flights.

One was concerned with the influence of nonvisual cues on spatial localization. The astronauts' task was to set a dim line of light in an otherwise dark field to an external horizontal reference; the Earth's horizontal was used pre- and post-flight and an element in the spacecraft, horizontal with respect to the astronaut, was used in-flight.

The second experiment consisted in the pre- and post-flight measurement of ocular counterrolling which depended, for the greater part at least, on a reflex response having its genesis in the otolith apparatus. No significant pre- and post-flight differences in response were demonstrated.

The outstanding finding was the small intratest variance in the settings made in-flight and relatively small bias in three of the four astronauts. These results suggested that the unusual patterning of tactile cues, which would tend to induce a bias, was more than offset by the loss

ACKNOWLEDGMENTS

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TABLE LEGEND

1. Contribution to the perception of extrapersonal space of various sensory cues derived from natural and weightless conditions.

SENSORY SYSTEMS	NATURAL COND	WEIGHTLESS SPACECRAFT
	WEIGHTLESS SPACECRAFT	WEIGHTLESS SPACECRAFT
AUDITORY	SOUND	WEIGHTLESS SPACECRAFT
KINESTHETIC	FORCE	WEIGHTLESS SPACECRAFT
TACTILE	TOUCH	WEIGHTLESS SPACECRAFT
VESTIBULAR	FORCE	WEIGHTLESS SPACECRAFT
VISUAL	VISION	WEIGHTLESS SPACECRAFT
SYSTEMS	WEIGHTLESS SPACECRAFT	WEIGHTLESS SPACECRAFT
SENSORY	WEIGHTLESS SPACECRAFT	WEIGHTLESS SPACECRAFT

PERCEPTION Extrapersonal Space (EPS)

SENSORY SYSTEMS	NATURAL COND.		WEIGHTLESS SPACECRAFT ★	
	PHYSIOL. STIMULUS	PHYS STIM.	CONTRIB. TO EPS	
VISUAL	VISUAL ENVIRONMENT	TARGET	INADEQUATE ★★	
VESTIB- ULAR	CANAL.	INERT. ANG. ACC. FORCES	I. F. > THRES.	? NIL
	OTOLITH	GRAVITY INERTIAL LINEAR ACC. F.	I. F. > THRES.	NIL
TACTILE	TOUCH	MECH. FORCES	GRAV. WEIGHT	AGRAVIC T
	PRESS.	AGRAVIC T. P. & Jt. C&D†	AGRAVIC P	AGRAVIC P
KINESTHETIC				POSTURE SHAPE COUCH
AUDITORY	SOUND	PRESSURE	AMBIENT	? INADEQUATE

★ Astronaut secured in couch; fixates line in dark ★ Visual memory a factor
† Joint Capsule Compression & Displacement

Table 1

FIGURE LEGENDS

- Figure 1 - Extrapersonal Space
- Figure 2 - Interaction Between Cues From Visual and Gravito-inertial Force Environments.
- Figure 3 - Depicting the Illusory Tilt of a Physically Upright Room Perceived by a Subject on a Human Centrifuge.
- Figure 4 - Physical conditions as perceived by closed circuit television with subject fixed during exposure on human centrifuge. Plumb bob only indication of change.
- Figure 5 - Naive subject facing away from direction of rotation fixating a luminous line in the dark regards himself as tilted in an upright room.
- Figure 6 - Change in setting of star as function of time compared with change in direction of resultant force of 20° . Curves depict mean values.
- Figure 7 - Mean values for the oculogravic illusion in five normal subjects with progressively longer delay time in presenting the target.
- Figure 8 - Estimates of the oculogravic illusion by normal and L-D subjects. Single settings of star.
- Figure 9 - Change in direction of gravito-inertial vertical with respect to subject (Angle Φ).
- Figure 10 - Mean curves represent E & A phenomena of individual test sessions of one subject.
- Figure 11 - Change in E-phenomenon as a function of increasing G level in normal subjects.

Figure 12 - Change in E- and A-phenomena as a function of increasing G level in L-D subjects.

Figure 13 - Diagram of apparatus used to determine location of visual horizontal with subject in upright or recumbent position.

Figure 14 - Localization of a dim line of light in the dark to the horizontal by three subjects lying on their left side.

Figure 15 - Photograph illustrating the Vision Tester and its use within the spacecraft. Note head brace connecting the biteboard of the Vision Tester to the instrument panel.

Figure 16 - Estimations of visual horizontality made by crew of Gemini V pre-, in-, and post-flight.

Figure 17 - Estimations of visual horizontality made by crew of Gemini VII pre-, in-, and post-flight.

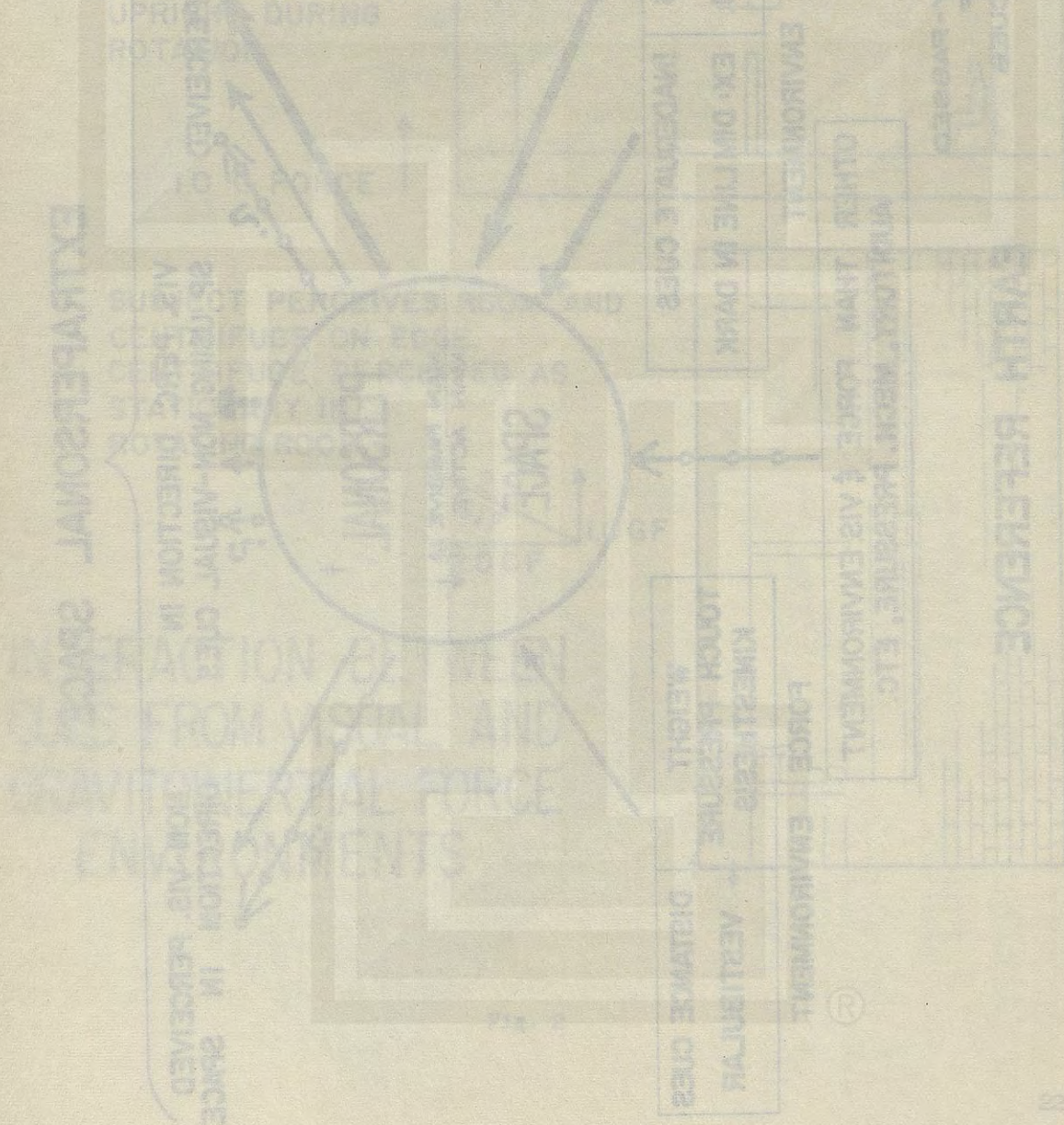
Figure 18 - a) Showing sutures in conjunctiva and markers at outer canthi; b) Demonstrating counterroll of eye with lateral tilt.

Figure 19 - Counterrolling as a function of magnitude of gravitational force (Zero G, 1/2 G, 1 G) and body position with respect to direction of force in normal and labyrinthine-defective subjects.

Figure 20 - Relative otolith activity (mean counterrolling response of three subjects) as a function of the logarithm of the gravitational stimulus.

Figure 21 - Ocular counterrolling measurements of the Gemini V crew obtained pre- and post-flight.

Figure 22 - Ocular counterrolling measurements of the Gemini VII crew obtained pre- and post-flight.



INTER
CUES
GRAV
E

EXTRAPERSONAL SPACE

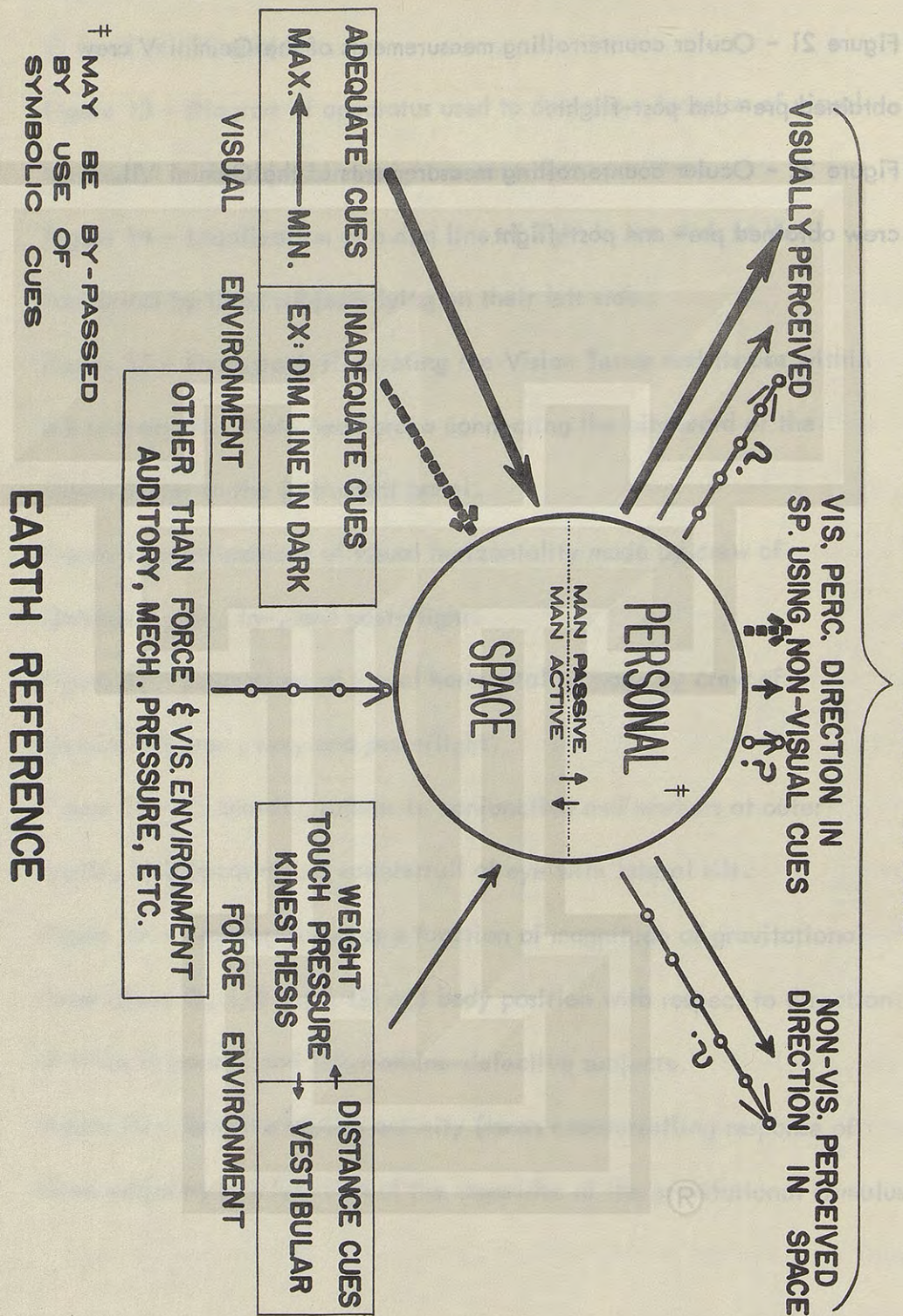
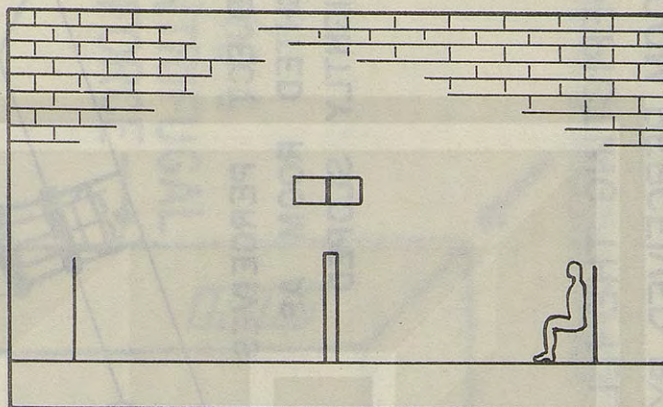


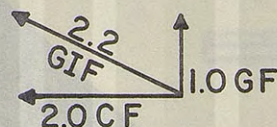
Fig. 1

PHYSICAL OBJECTS
UNCHANGED WITH
RESPECT TO
GRAVITATIONAL
UPRIGHT DURING
ROTATION

1.0 G FORCE



SUBJECT PERCEIVES ROOM AND
CENTRIFUGE ON EDGE.
CENTRIFUGE PERCEIVED AS
STATIONARY IN A
ROTATING ROOM



INTERACTION BETWEEN
CUES FROM VISUAL AND
GRAVITOINERTIAL FORCE
ENVIRONMENTS

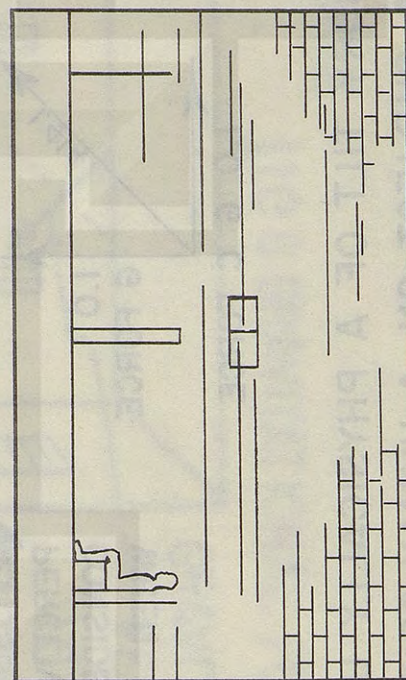
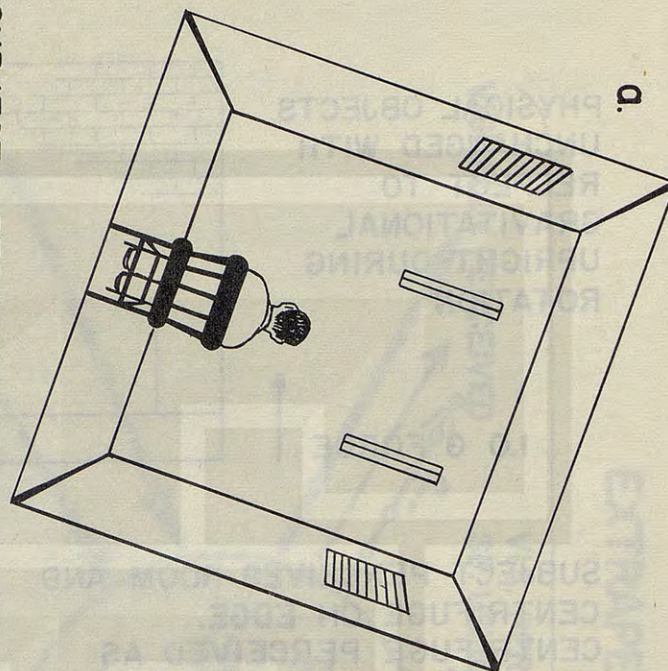
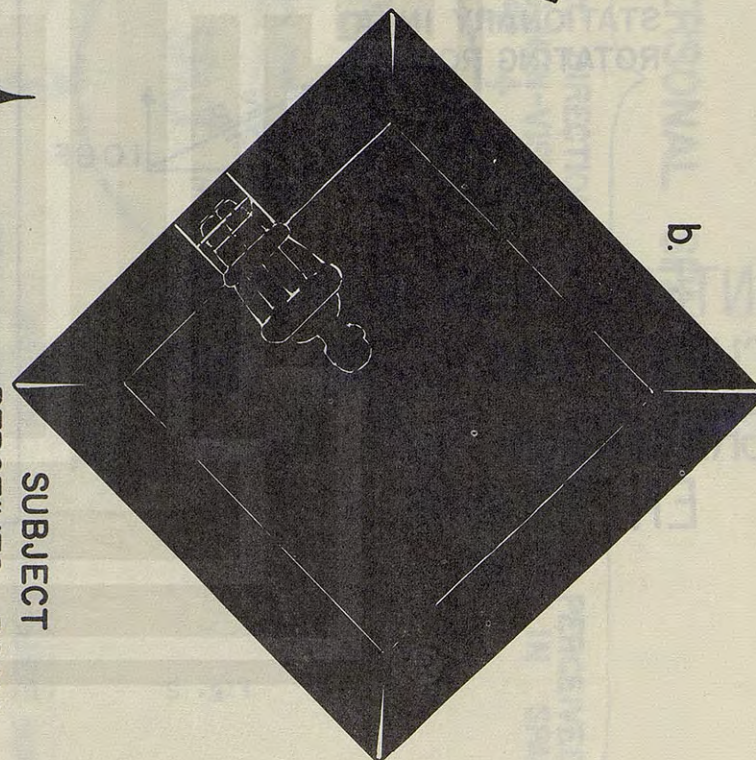


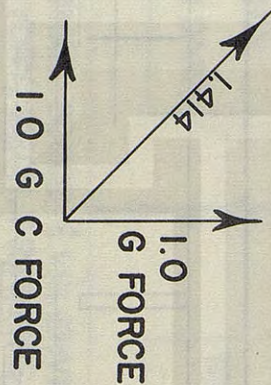
Fig. 2



SUBJECT PERCEIVES
LIGHTED ROOM AS
SLIGHTLY SLOPED



SUBJECT
PERCEIVES ROOM
CONSIDERABLY SLOPED
WHEN DARKENED



DEPICTING THE ILLUSORY TILT OF A PHYSICALLY UPRIGHT
ROOM PERCEIVED BY A SUBJECT ON A HUMAN CENTRIFUGE

Fig. 3

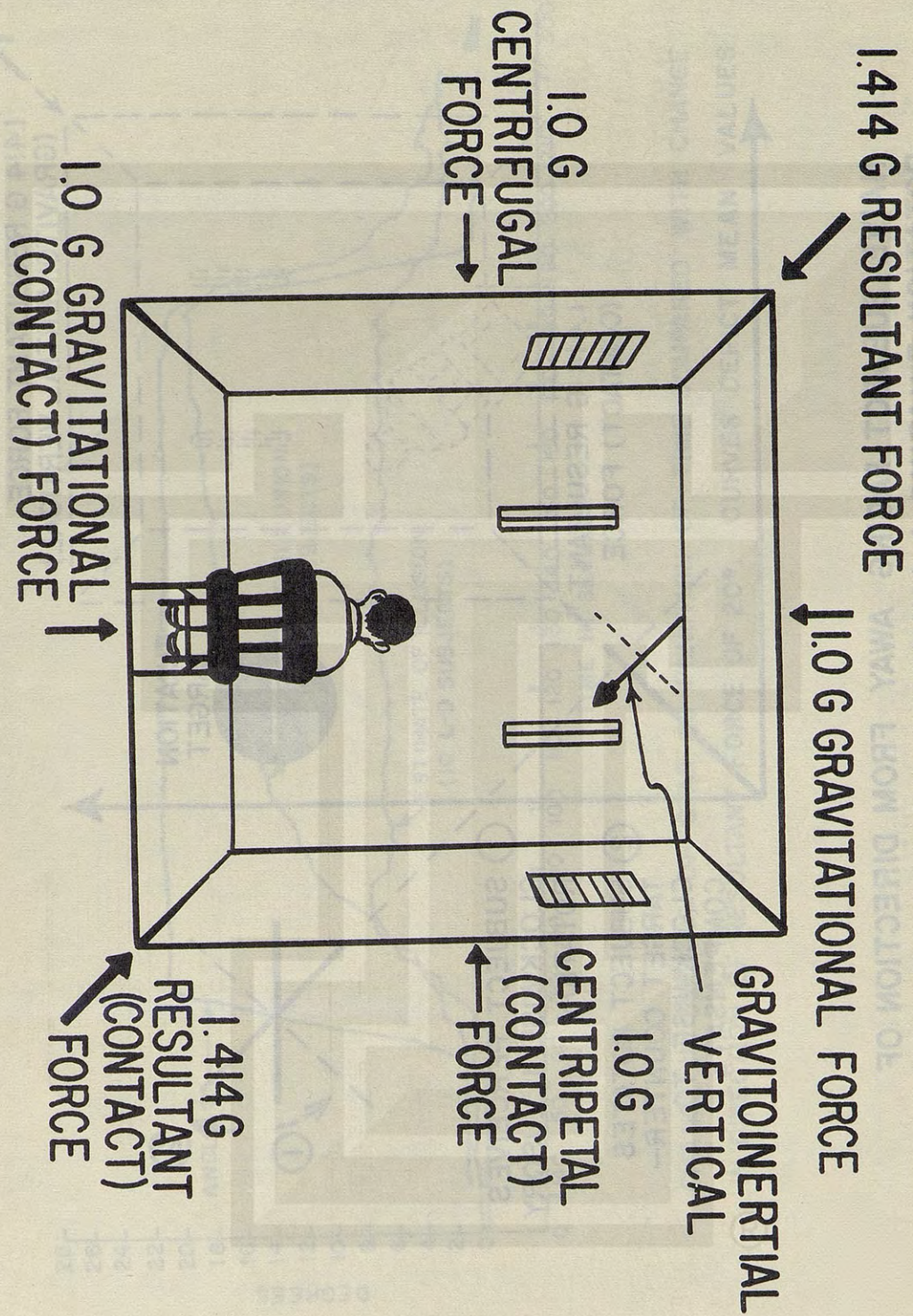
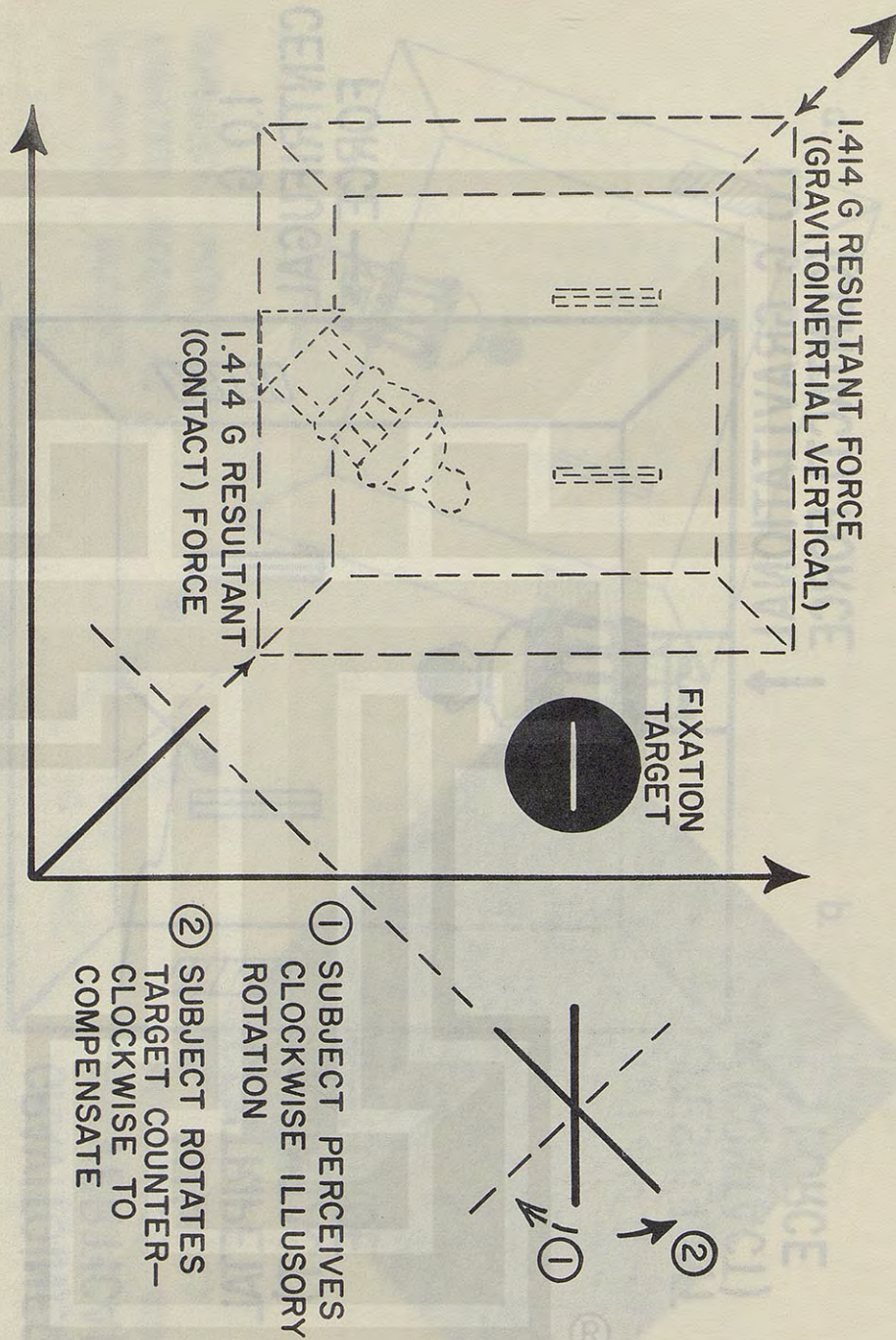


Fig. 4

d.

b.



NAIVE SUBJECT FACING AWAY FROM DIRECTION OF
 ROTATION FIXATING A LUMINOUS LINE IN THE DARK
 REGARDS HIMSELF AS TILTED IN AN UPRIGHT ROOM

Fig. 5

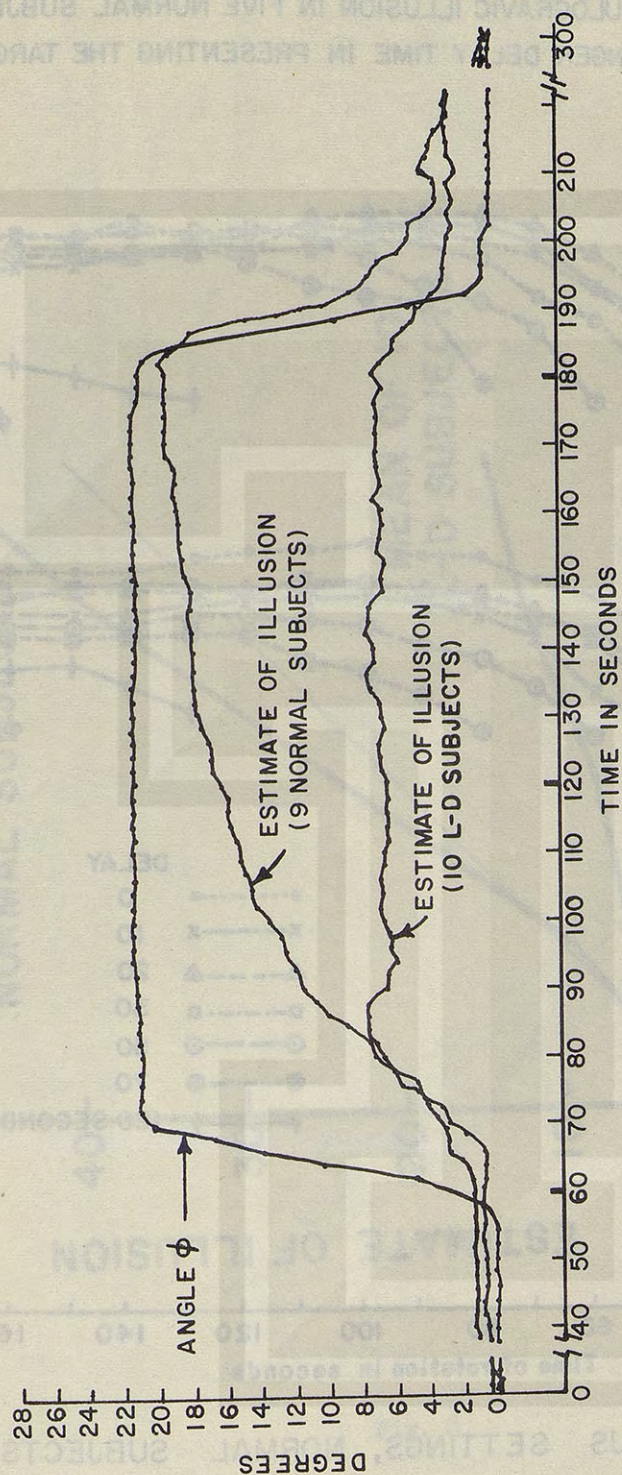
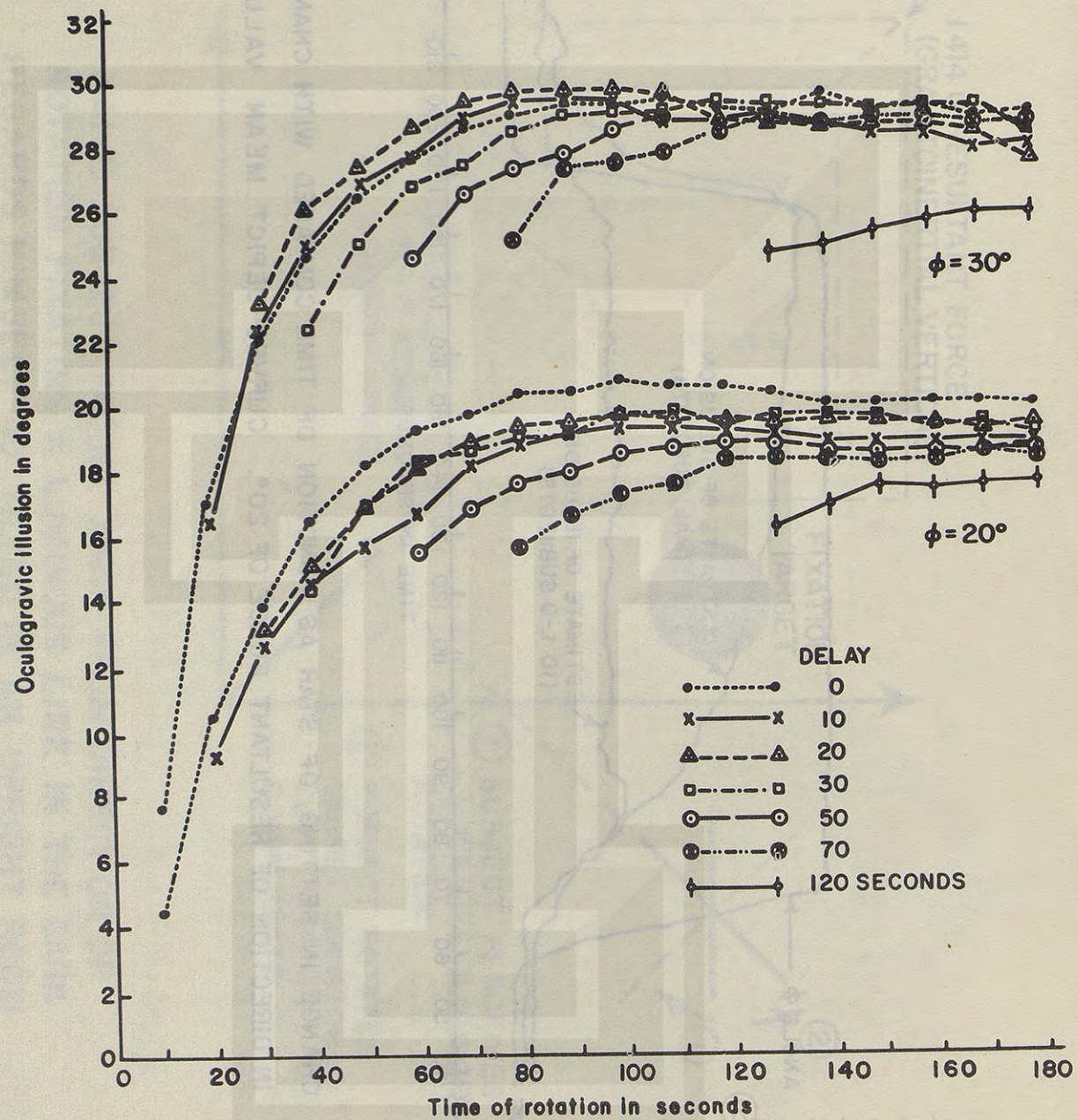


Fig. 6

CHANGE IN SETTING OF STAR AS FUNCTION OF TIME COMPARED WITH CHANGE
IN DIRECTION OF RESULTANT FORCE OF 20°. CURVES DEPICT MEAN VALUES

MEAN VALUES FOR THE OCULOGRATIC ILLUSION IN FIVE NORMAL SUBJECTS
WITH PROGRESSIVELY LONGER DELAY TIME IN PRESENTING THE TARGET



CONTINUOUS SETTINGS, NORMAL SUBJECTS

Fig. 7

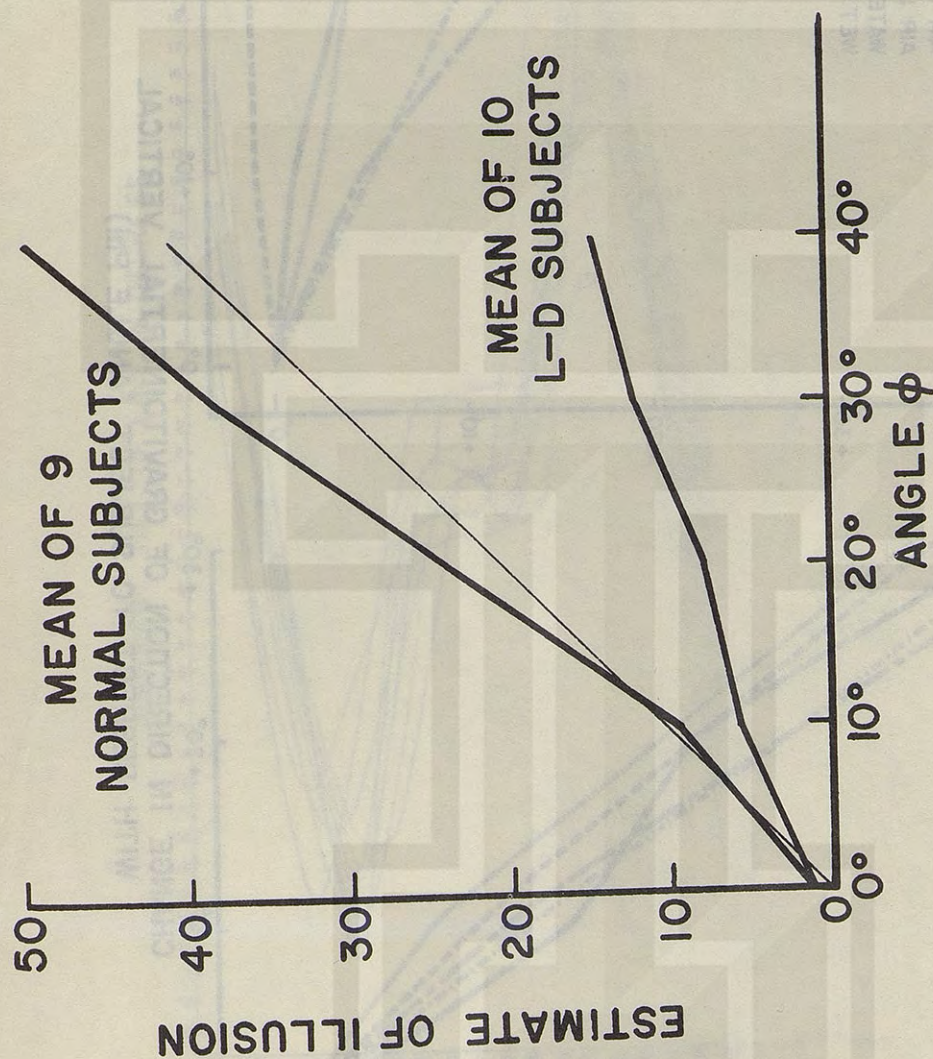


Fig. 8

ESTIMATES OF THE OCULOGRAPHIC ILLUSION BY NORMAL
AND L-D SUBJECTS. SINGLE SETTINGS OF STAR.

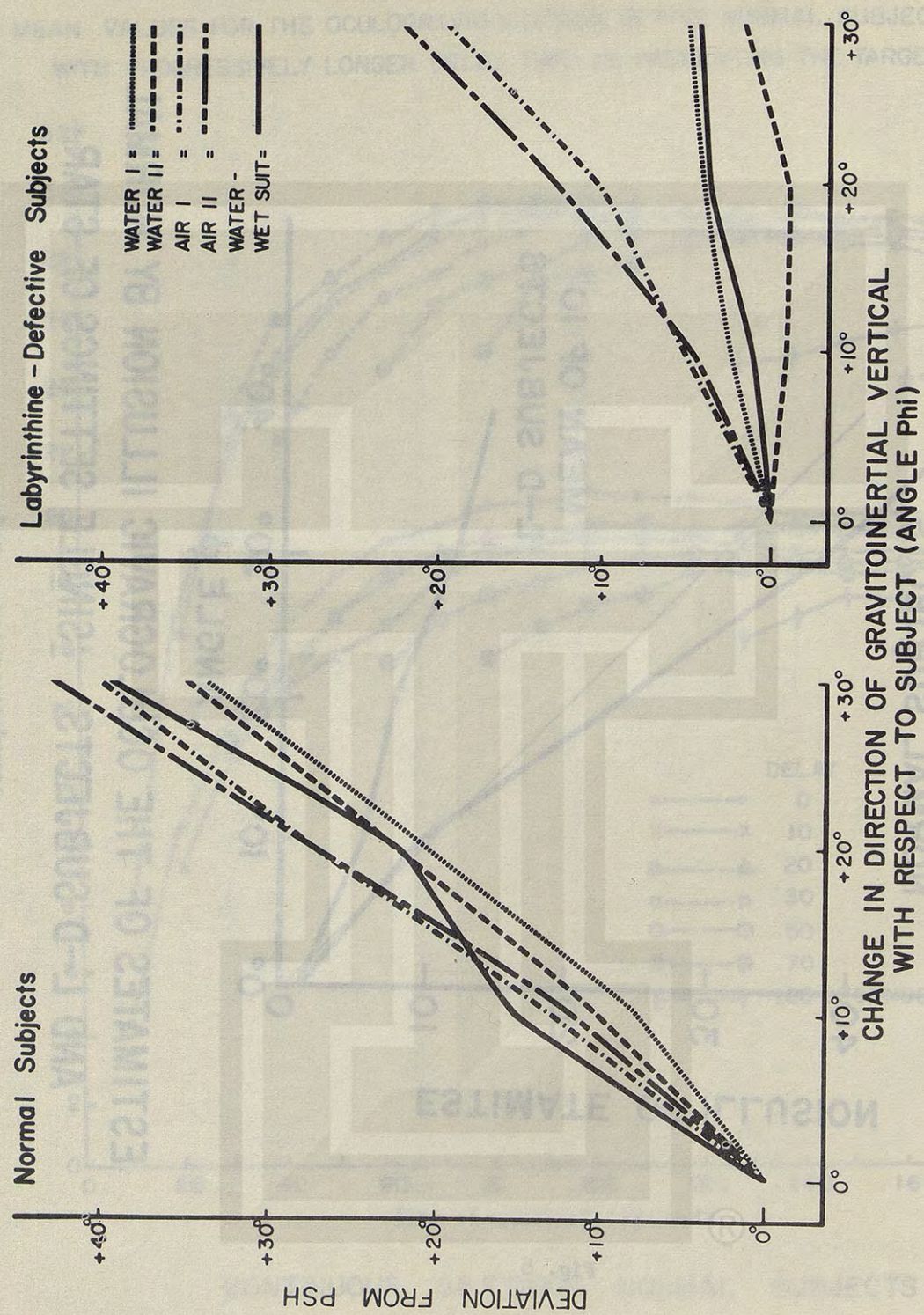
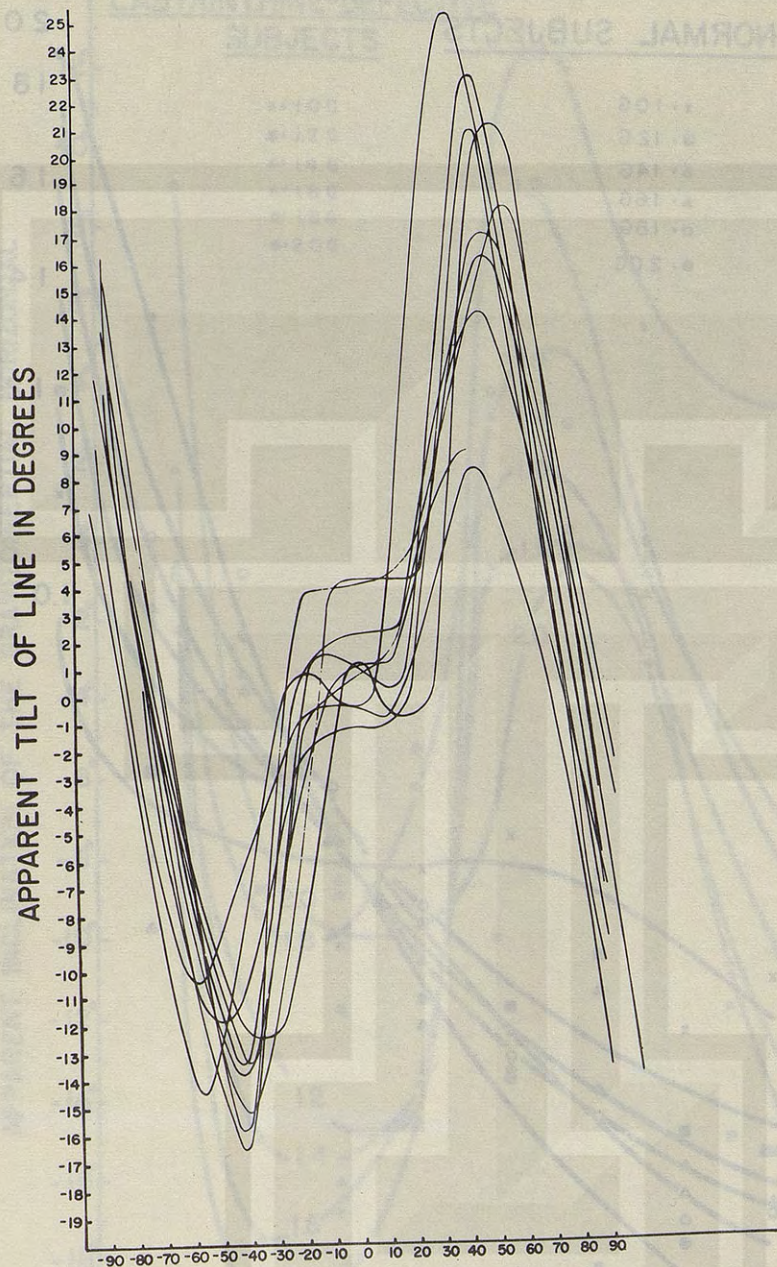


Fig. 9



MEAN CURVES REPRESENT $E \xi A$ PHENOMENA OF
INDIVIDUAL TEST SESSIONS OF ONE SUBJECT

Fig. 10

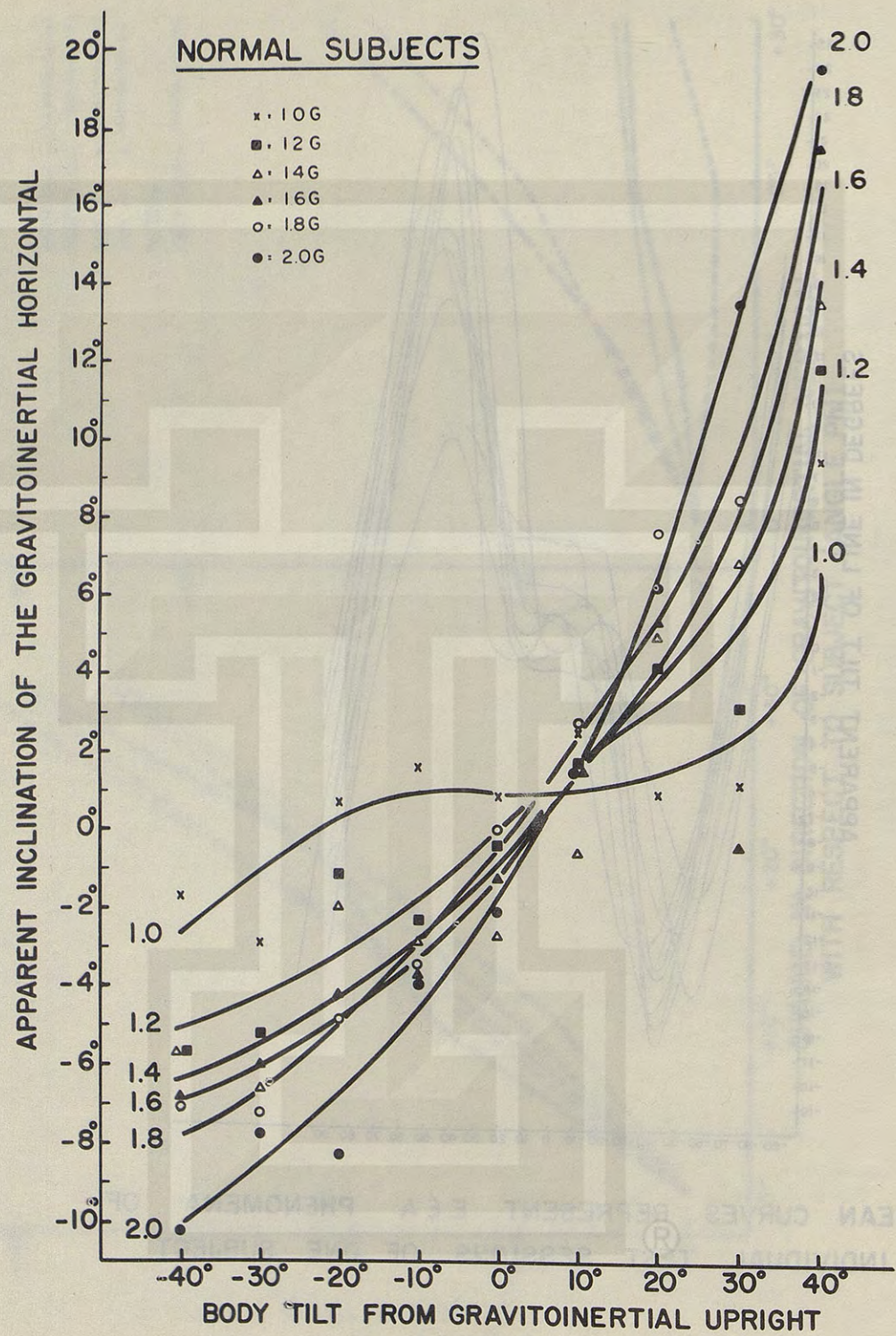


Fig. 11

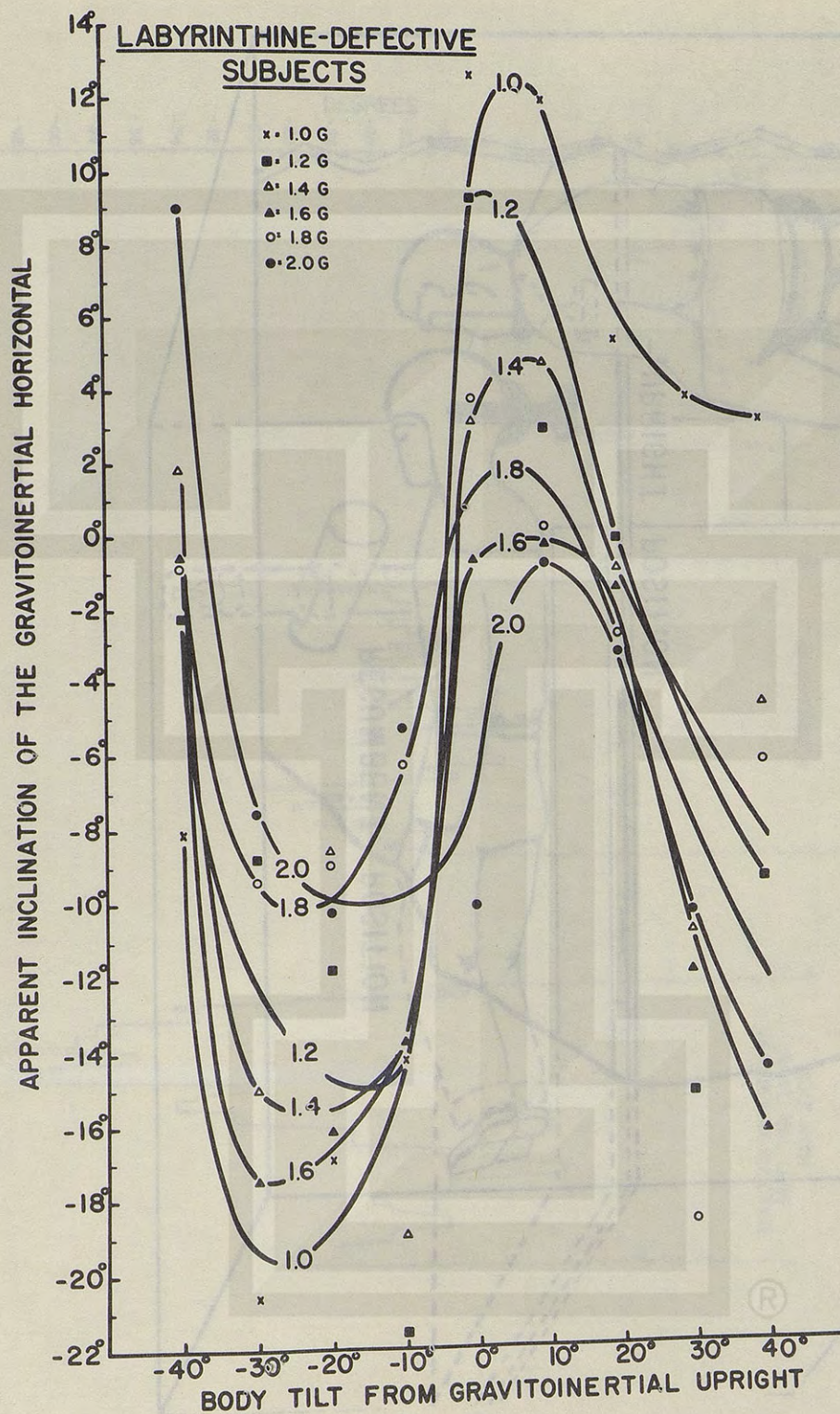


Fig. 12

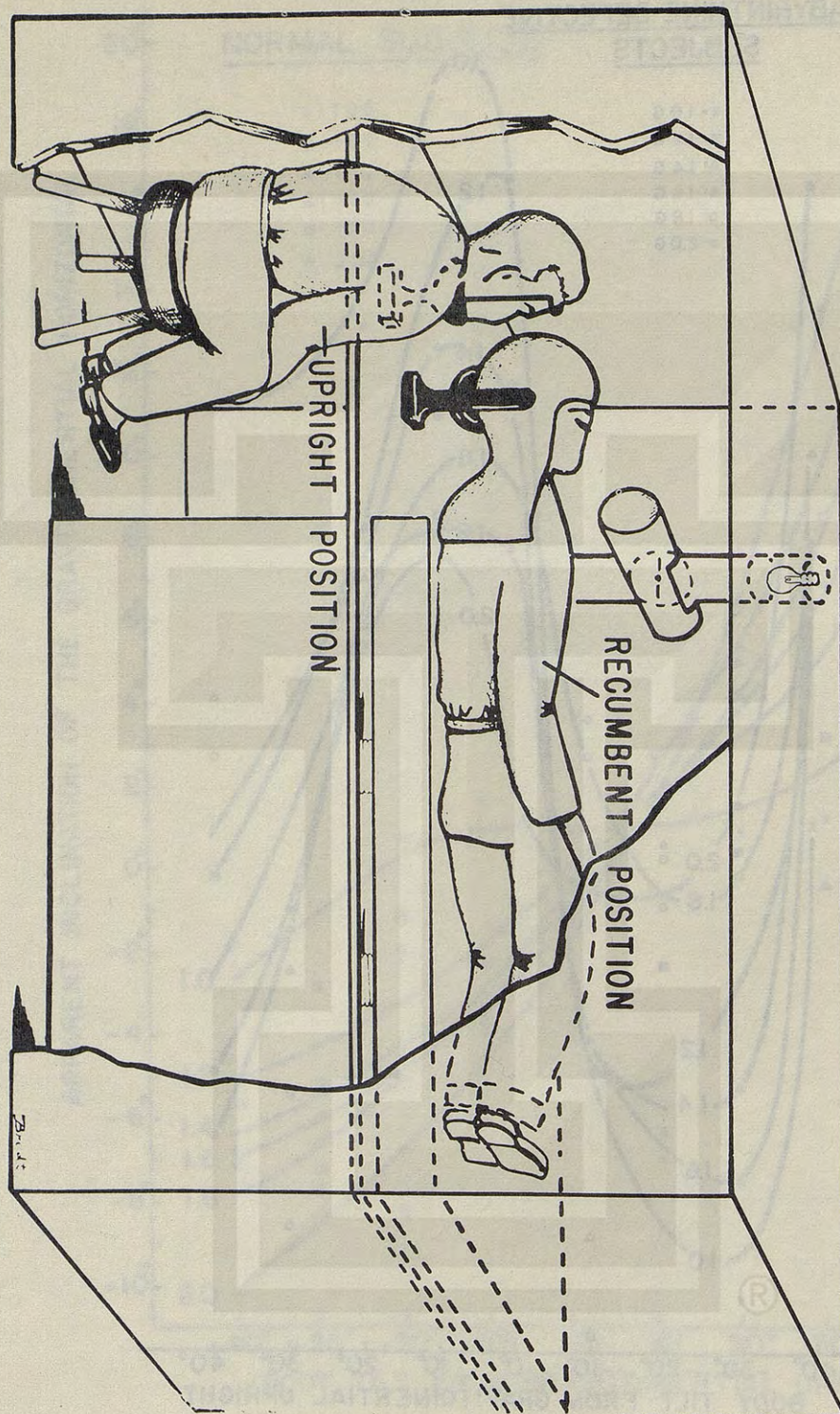


Fig. 13

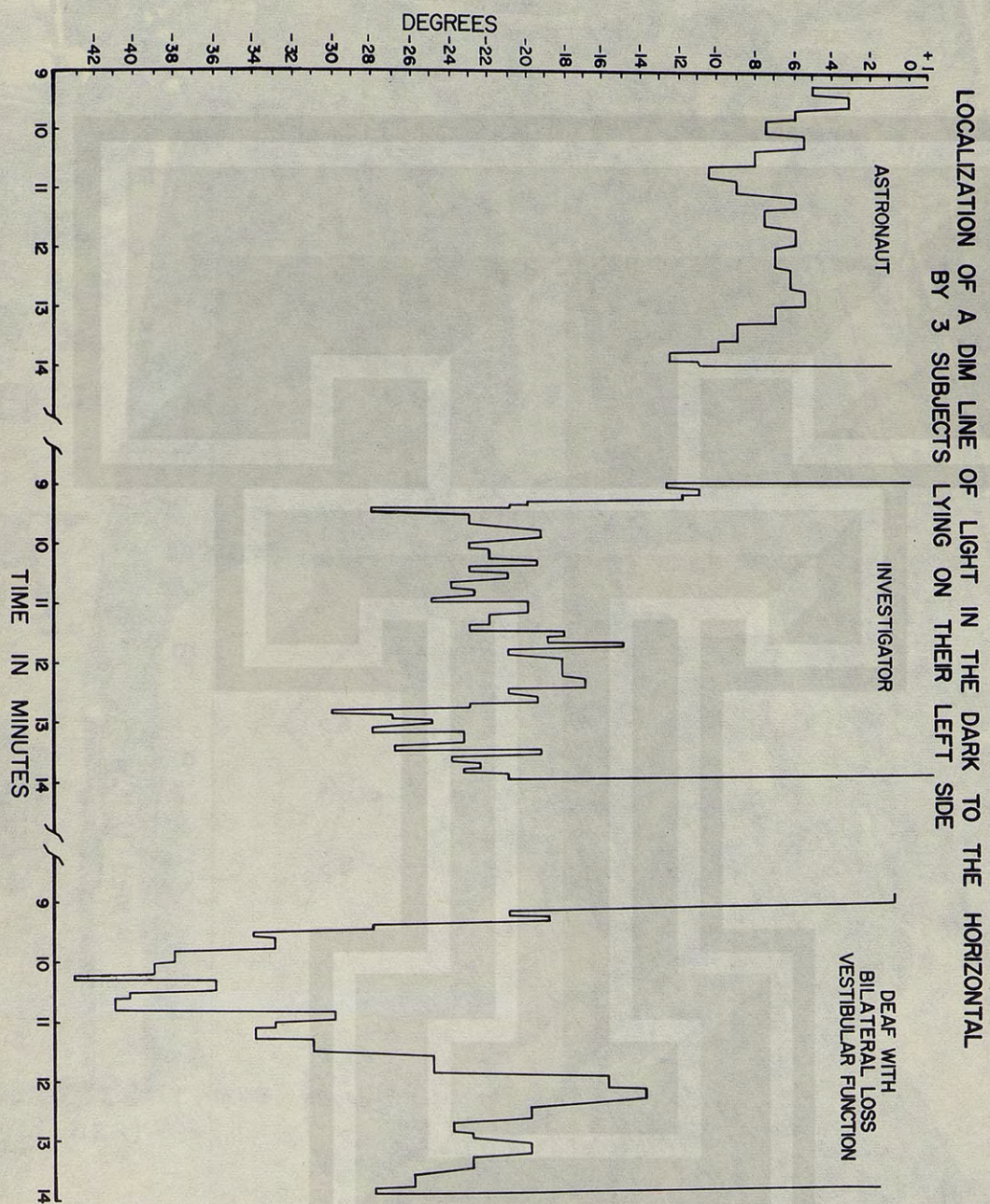
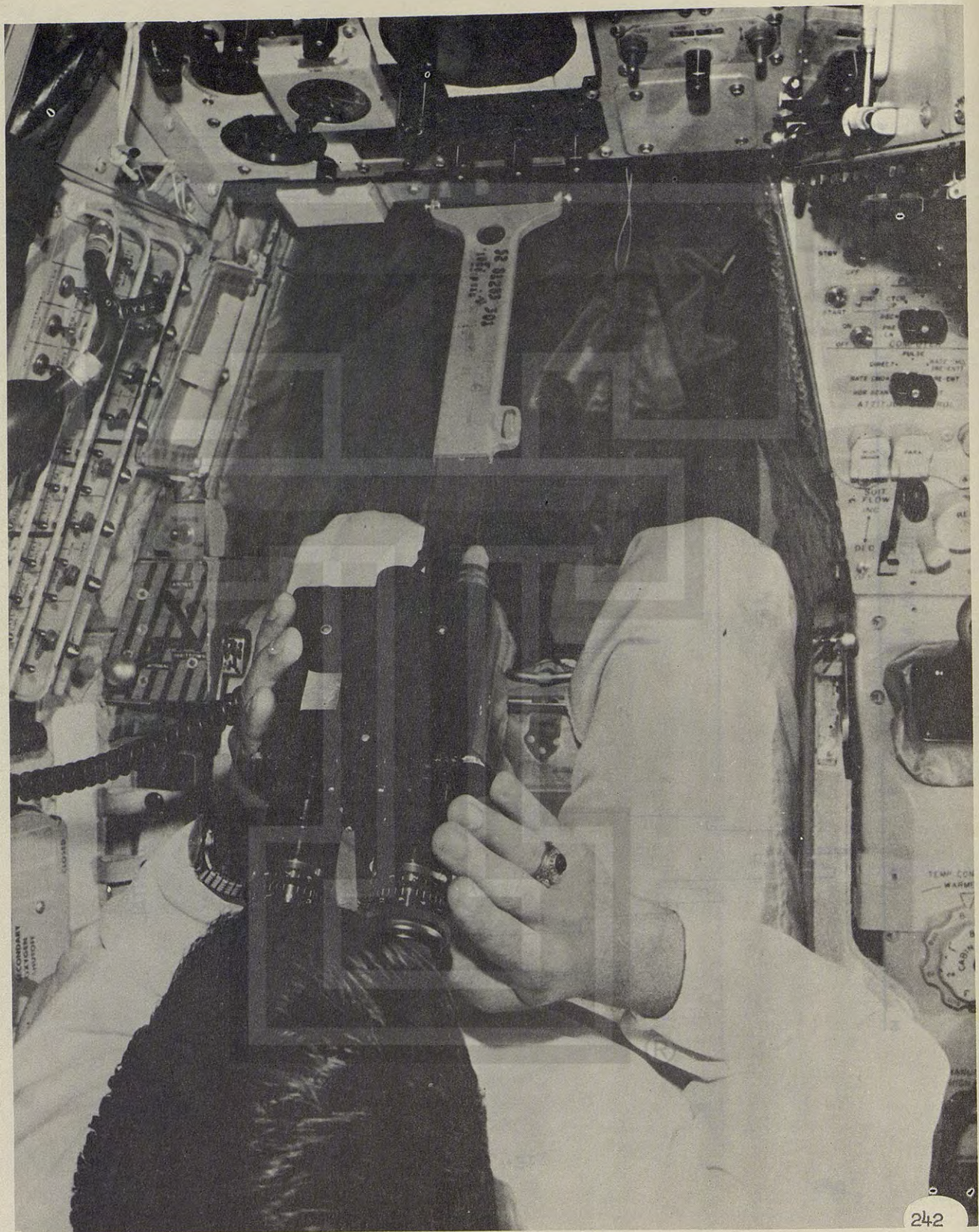


Fig. 14



PRE-F

POST-F
(CARRI

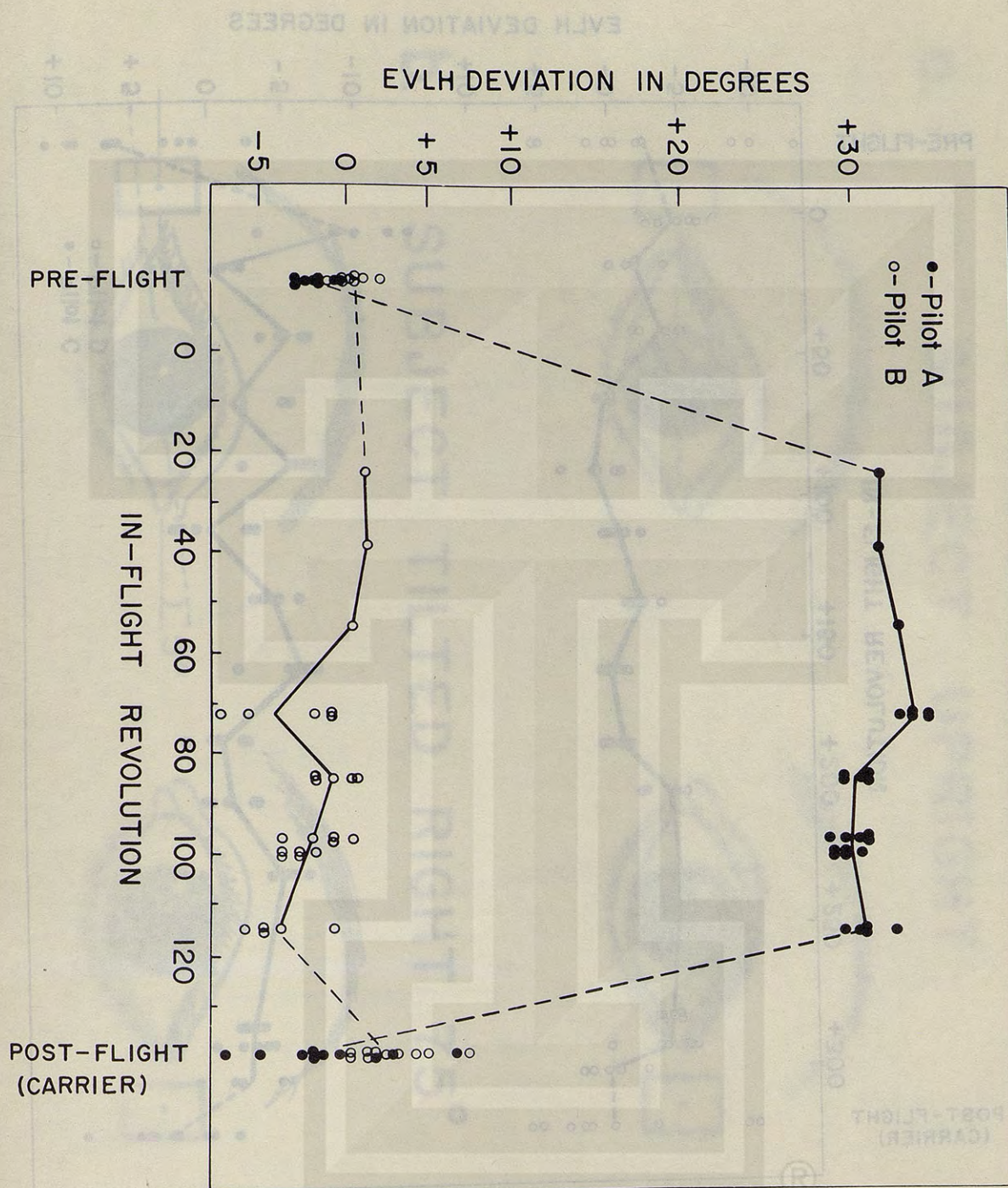


Fig. 16

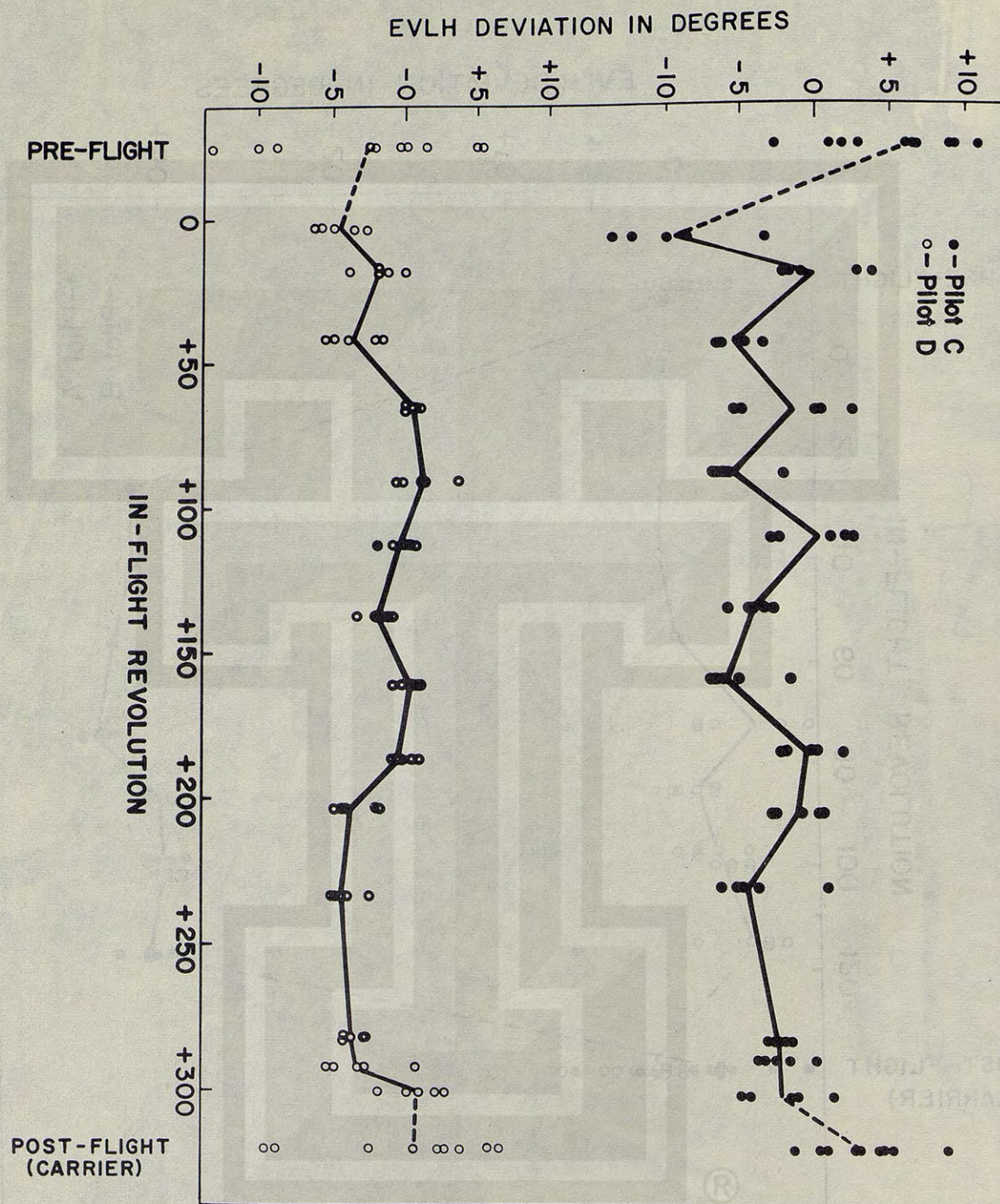
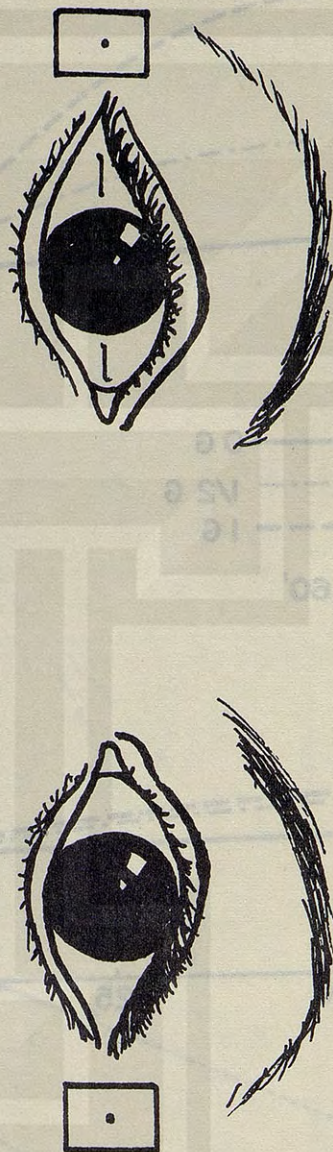


Fig. 17

a. SUBJECT UPRIGHT



b. SUBJECT TILTED RIGHT 75°

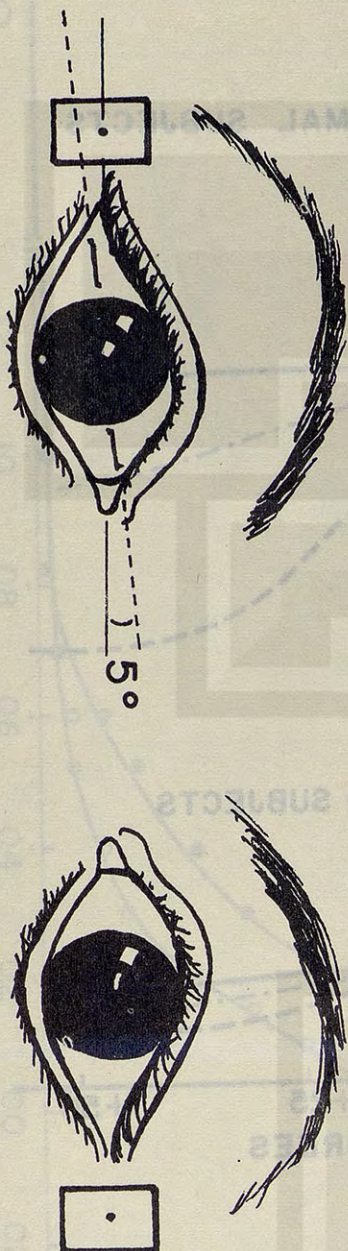


Fig. 18

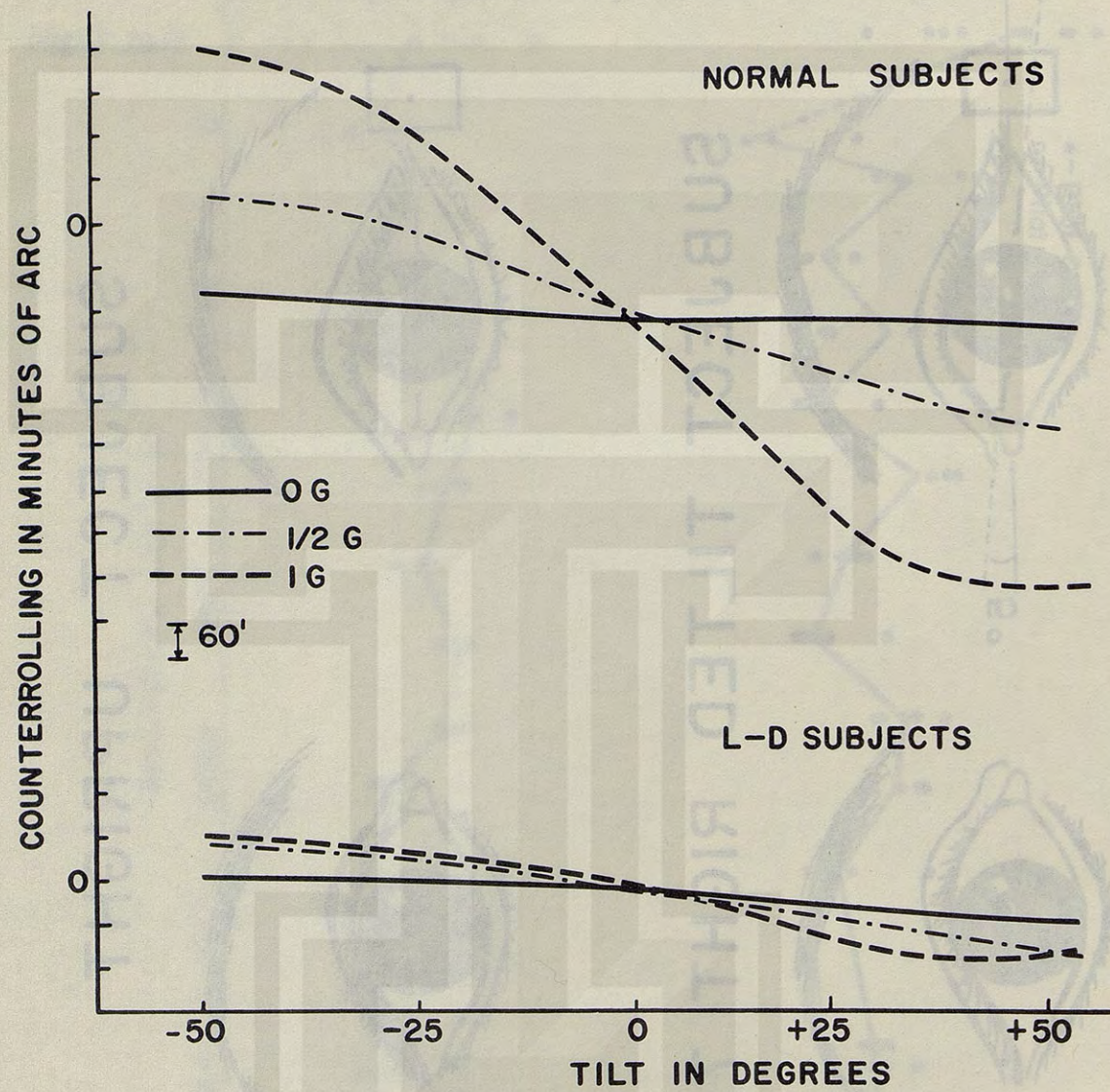


Fig. 19

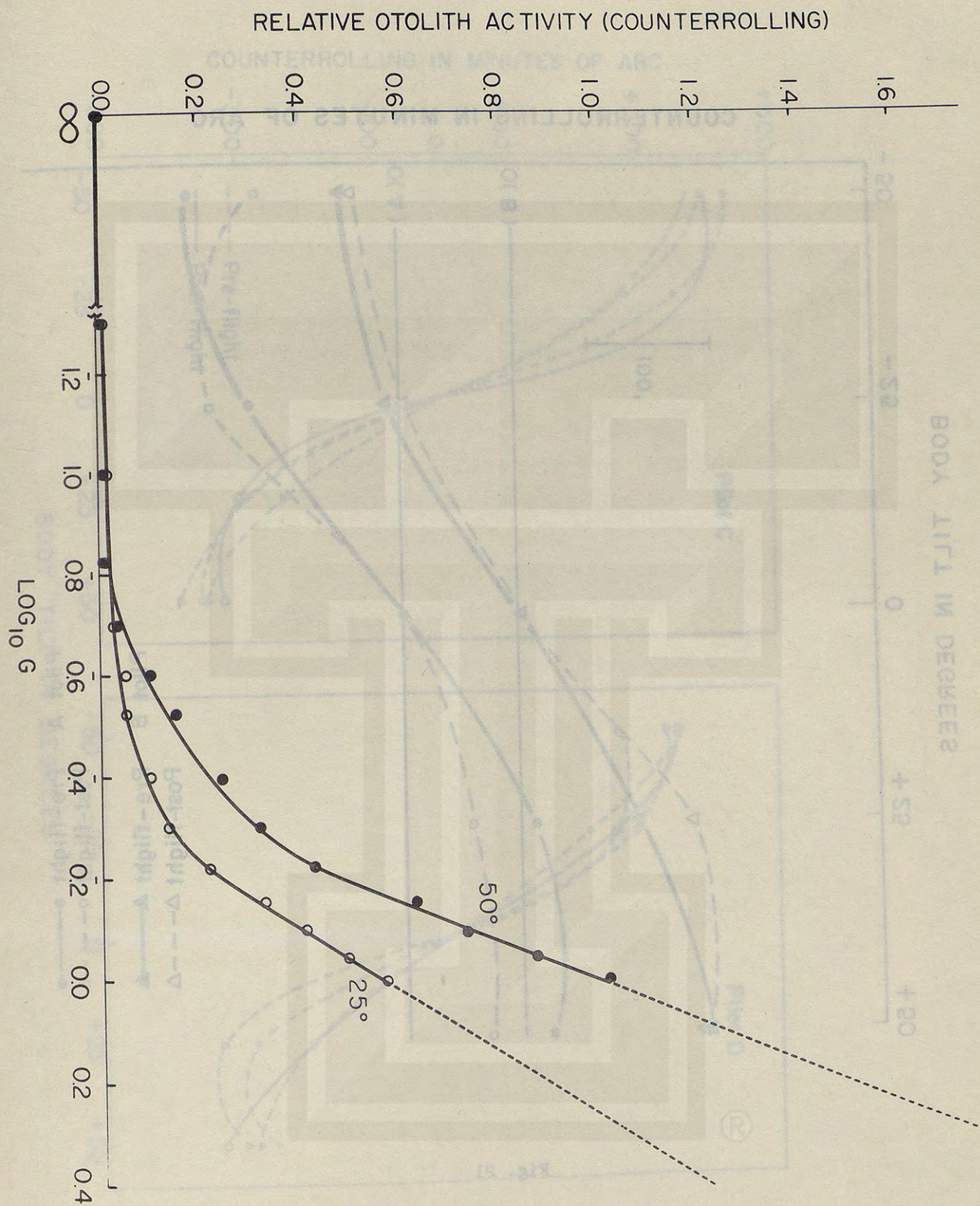


Fig. 20

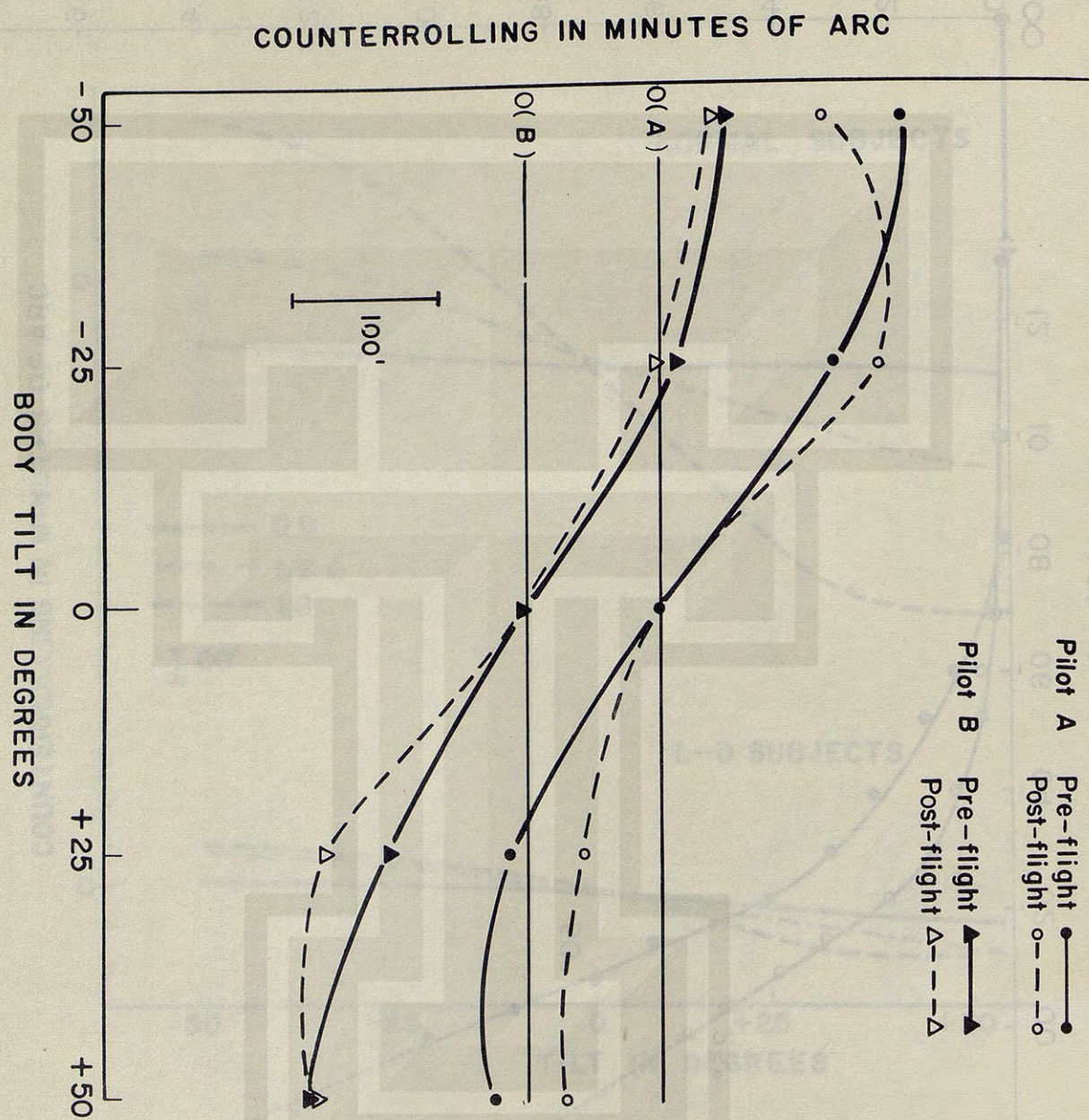


Fig. 21

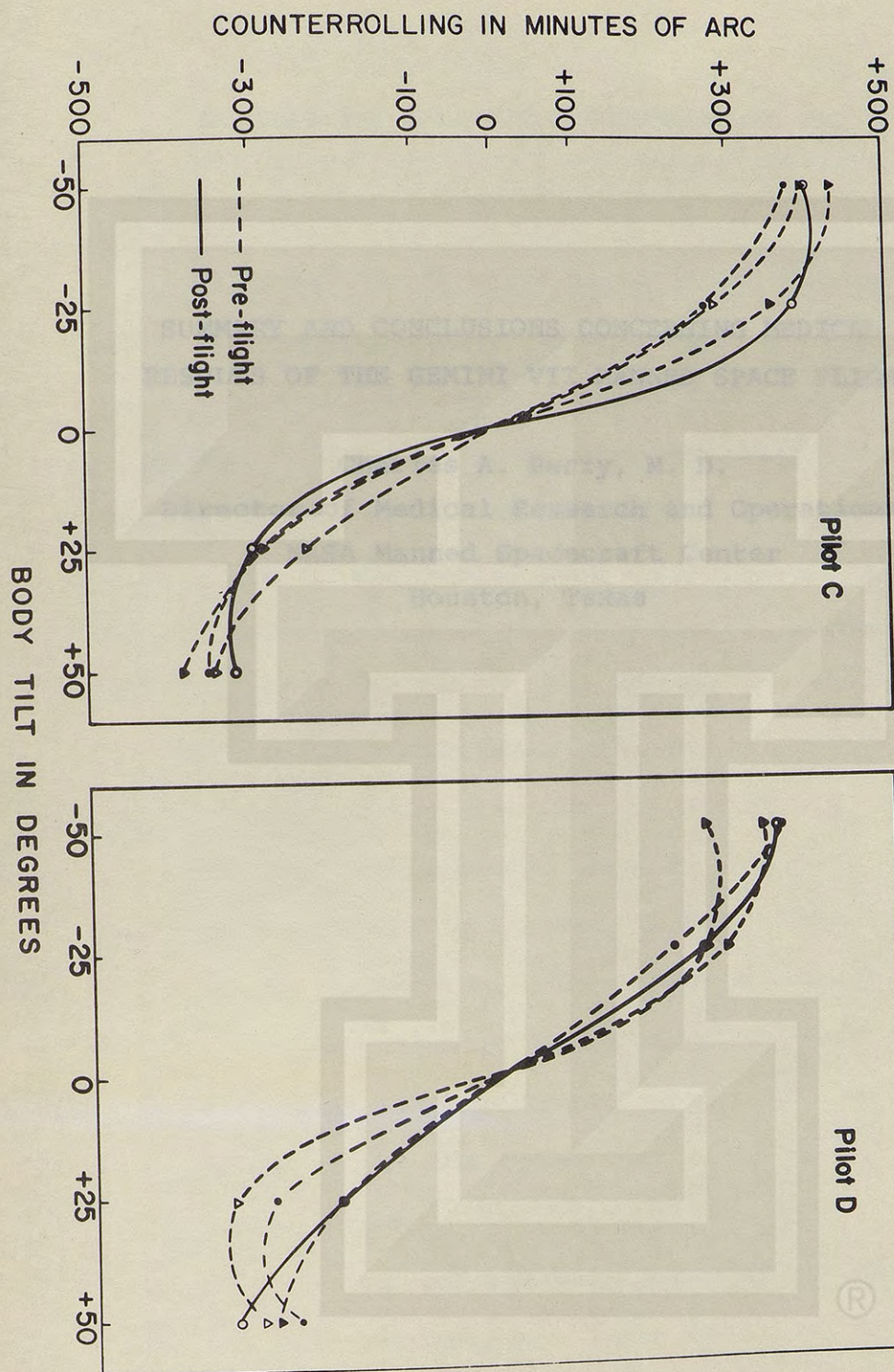


Fig. 22

SUMMARY AND CONCLUSIONS CONCERNING MEDICAL
RESULTS OF THE GEMINI VII MANNED SPACE FLIGHT

Charles A. Berry, M. D.

Director of Medical Research and Operations

NASA Manned Spacecraft Center

Houston, Texas

I think you are right. I think the medical
position prior to the flight was not
adequate. I think the medical
community was not prepared for the
flight. I think the medical
community was not prepared for the
flight. I think the medical
community was not prepared for the
flight.

BODY TILT IN DEGREE

SUMMARY AND CONCLUSIONS CONCERNING MEDICAL
RESULTS OF THE GEMINI VII MANNED SPACE FLIGHT

In summation, I think it is quite obvious that there are two principal tasks we must accomplish if we are to evaluate man's response to the space environment. The first task requires realistic answers to the questions of whether it is safe to expose man to the environment anticipated and if so, a determination of how long you can expose him without encountering significant physiological or performance decrements. The second task relates more closely to the previous discussion. It requires a search for the causes of some of the changes which have been seen and an attempt to learn more about man's basic system functions in the space environment. In accomplishing these tasks, we have used a rather false separation into what might be called operational tasks and those that could be called experimental tasks.

I think you are all well aware of our medical position prior to Gemini. There were many predictions about what man could and could not do and indeed many people felt that man was the limiting

factor as far as our space activities were concerned. Our primary job then became one of obtaining information enabling us to commit man to longer periods of time in the space environment. Our immediate goal was to qualify him if possible for the lunar mission.

The operational activities accomplished in attaining this goal have included routine pre- and postflight medical studies consisting of physical examination, blood, urine, and x-rays studies, supplemented by inflight observations made by real-time physiological monitoring and adequate reporting of the crews inflight. Additional critical information was obtained from debriefing the crews postflight. The purpose of all of these activities was to secure information allowing us to assess the physical and mental status of the crew and their capability to perform their particular mission. I would like to summarize some of the data obtained from these operational medical activities.

The tilts have been previously discussed by Dr. Dietlein. A comparison of pre- and postflight

a. tilts has provided us an assessment of the cardiovascular response to the total spaceflight environment. The typical postflight tilt response of increased pulse rate and decreased blood pressure has been seen on each of our missions. Figure 1 summarizes the increase in heart rate during the tilt from a comparison of the preflight with the first postflight and second postflight tilts. The percentage increase in heart rate appears to increase in virtually a linear fashion through the eight-day flight and the theoretical projection of this curve to 14 days caused some concern prior to the 14-day flight. You will note that the 14-day data are more like the four-day data. It is our feeling that many factors are involved in this less severe response, some of them being the three 10-minute exercise periods per day, the diet, the removal of the suits for a considerable period of time and perhaps the longer period of time for adaption to the spaceflight environment. We have noted a return to normal preflight values within a 50-hour period regardless of the duration of the spaceflight. Some individual variation was seen and was expected. There was a near syncopal

affair in one instance following the 14-day flight and one instance during a preflight tilt on an earlier mission.

The next major group of observations conducted as operational procedures involved the blood studies. In addition to the normal routine of blood counts pre- and postflight, blood volume studies were conducted on the four- eight- and 14-day flights. Figure 2 graphically represents the absolute neutrophilia observed. It has returned to normal in 24 hours. Figure 3 summarizes the blood volume results obtained, the most noteworthy being a decrease in red blood cell mass which like the tilt data appeared to be increasing through the eight-day flight. We had expected to see most of the change in plasma volume studied by the RISA technique. The data reveal a normal vascular or blood volume maintained by an increase in plasma volume of the 14-day flight. A decrease in red cell mass is still noted, but it does not appear to increase with increasing duration of flight. The RISA and chromium-51 studies have not been done since the 14-day flight and we look to the Apollo flights to provide additional data in this area. An

example of the Cr-51 data is seen in Figure 4. Continued study of the red cells has shown that there is an increased hemolysis noted postflight. This may be seen graphically in the case of the command pilot on the 14-day flight in Figure 5. This increased tendency to hemolysis had disappeared by 48 hours postflight. The increased hemolysis has also been demonstrated on flights as short as the one day Gemini VI mission. It appears that we have cells that are increased in size, more fragile and thus easily destroyed by some mechanism requiring further investigation. The routine count and fragility determinations can be made on every mission.

One of the important points I would like to make is the flexibility we have retained by conducting this procedure as an operational one rather than as a numbered experiment. When it was obvious that we were obtaining some interesting data concerning the red cell mass, our procedure was modified without a requirement for making large paperwork changes in protocols and staffing them through a number of channels. We did the modification in a timely fashion in order to acquire the best

information possible and take advantage of the situation as it arose.

We plan to continue the study of this red cell mass phenomenon in chamber studies in the hopes of determining the mechanism. We do feel that our 100% oxygen environment may be involved in the changes noted and, therefore, we feel that further chamber work is mandatory. An early report from the chamber study conducted at the School of Aerospace Medicine during which we had our people conduct the same blood study has revealed some decrease in the red cell mass, but apparently not of the same magnitude noticed in flight. We are unable at the present time to say how long this decreased red cell mass persists postflight. It has been followed on only one occasion when the determinations were repeated on the 18th postflight day after the 14-day mission. At that time, the blood volume had returned to normal as had the plasma volume and red cell mass. We are unable to state how long before the 18th day they had returned to normal.

Bicycyle ergometry was accomplished as an operational procedure pre- and postflight on the Gemini VII

mission. Previous investigations have shown that cardiovascular and respiratory functions are not optimal when a heart rate of 180 beats per minute is observed as a response to a gradually increased work load. The bicycle ergometry was used as an exercise capacity test pre- and postflight in order to determine whether changes occur in crewmen's physiologic reaction to work. The results on Gemini VII were tentative only due to some equipment problems. They appear to indicate a decrease in exercise capacity and a reduction in oxygen consumption. (See Figures 6 and 7)

Though there was an experiment (M-5) which required a number of biochemical determinations on Gemini VII, we have routinely obtained some biochemical measures on both blood and urine pre- and postflight. No significant changes have been noted, though the electrolyte and protein determinations have been helpful in our assessment of dehydration.

Our routine physiological monitoring has given us voluminous information on heart rate, both from ground-based studies for comparison with flight data and from the missions themselves. We have noted peak heart rates at launch and re-entry on each of our flights. (See Figure 8)

These increased heart rates are the result of the tension at these two critical periods and the physiologic response to the increased G loads encountered. The heart rate during orbital flight has usually settled at an average resting rate and has shown adequate response to any work loads imposed. On the long duration missions, and in particular on Gemini VII, we were impressed by the fact that the plotting of high, mean, and low heart rates (See Figures 9 and 10) allowed us to follow the sleep state of the crewmen in a very effective manner. The periods of waking can be easily noted and our assessments of the total sleep periods in this manner matched fairly accurately with the reports of the crew and with the determination of sleep time through the use of the EEG on Gemini VII.

Blood pressures have been obtained on all of our missions through Gemini VII and at several critical points during the re-entry and landing activities. The pressures have been generally within what would be considered a normal envelope and some peak pressures were obtained at the time of increased heart rate due to various stresses. (See Figure 11)

We have used a crew reporting system in order to follow the intake of food and water during flight. This is an important crew procedure if we are to have any real-time assessment of this physiologic state. There are problems in obtaining accurate information of this sort, because it requires some meticulous observation and recording on the part of the crew during very active portions of the mission. The water gun has a counter which records a count for every half-ounce dispensed. This requires noting the gun reading prior to obtaining water, recording the reading at the conclusion, and subtracting to obtain the difference in count. This must then be converted to ounces and recorded. There are obviously several possible sources of error in such a method. We have obtained some most helpful information on the state of hydration by this method, however.

It would seem appropriate to look at the medical data obtained thus far by either operational or experimental processes and to assess their implication as far as future flights are concerned. This sort of a summary lends itself to the format of a system review with which physicians are familiar.

SKIN

We have been concerned with the response of the skin in a situation, where it has been moist a good deal of the time and there has been only minimal opportunity to do any sort of cleansing. We have been very pleased with the capability of the skin to maintain a state of normalcy even with the lack of adequate hygiene which is present. We have seen no infections and have had only minimal reaction around sensor sites following 14 days of flight. Following the eight-day flight, the crew did have some drying of the skin which responded to the use of a lotion. This same crew had some difficulty with excess dandruff during the eight-day mission.

THE CENTRAL NERVOUS SYSTEM

With the exception of the EEG used in only one instance to evaluate the depth of sleep, our best assessment of central nervous system function comes from the overall crew response during these missions. As we relate the ability of the crew to respond to the demands placed upon them, it is obvious that the central nervous system must have functioned in a very normal manner. They have

responded to many normal and emergency demands through the various flight phases some of which are summarized in Figure 12.

THE SPECIAL SENSES

Dr. Graybiel has discussed the results of the vestibular experiment and in addition, we have questioned the crew carefully following each mission, including the Gemini IV extravehicular activity. We have had no instance of disorientation during any of our flights and we have observed no remarkable findings in this area.

Visual acuity has been measured preflight and postflight without evidence of change. We have also measured visual acuity inflight and have seen no decrement caused by the weightless flight. We are convinced that the pilot's reports of ground and inflight findings are accurate.

EAR NOSE AND THROAT

We have had no change in hearing and no other difficulties except for some drying of the nasal mucous membranes and the throat. We feel that this is related to our 100% oxygen environment and such findings have also been noted in some of our long-

term chamber studies.

THE CARDIOVASCULAR SYSTEM

Many of the findings in this area result from operational procedures already discussed and in summary we may say that the responses to massive tilt are self-limited and return to normal within a 50 hour period postflight, regardless of mission duration through 14 days. We are not sure how long a period is required for the blood volume to return to normal, but we assume it to be a matter of days.

THE RESPIRATORY SYSTEM

We have seen no respiratory problems to date.

THE GASTROINTESTINAL SYSTEM

There has been no difficulty with ingestion of food if it is properly packaged, nor have we seen any difficulties with the passage of food through the normally functioning gastrointestinal tract. The use of the low residue diet, preflight and inflight, has caused no difficulty.

THE GENITO-URINARY SYSTEM

We have seen no abnormalities in the function of this system, either inflight or postflight. The handling of either liquid or solid waste still remains as a problem requiring further effort.

THE MUSCULOSKELETAL SYSTEM

The x-ray densitometry and calcium balance studies have been covered in detail. In summary, we may state that we are seeing less evidence of loss of muscle or bone constituents than was originally predicted. It would appear at this time that the changes noted are certainly within an acceptable range.

In evaluating the response of man as a system thus far, it would appear that he has functioned in a very acceptable manner and has shown himself to be capable of conducting prolonged missions in space. We certainly expect to see some physiologic change but expect that the changes noted will be within the ranges which we have seen to date. In retrospect, our doubling of man's exposure has been demonstrated to be an acceptable approach in obtaining data allowing us to commit man for

longer duration flight. Therefore, I feel that we may confidently commit man to a 30-day flight if he is given the proper environmental support.

I am sure that we are all aware of the adaptive physiology being noted in man's response to the flights. It is most important that we document these changes and evaluate them in relation to the adaptation. We must exert some effort to determine the mechanism involved. We are seeing man adapt to a new environment characterized by the zero-G state, and then readapt to a 1-G environment here on earth. We must study both of these adaptations. The stress on the individual is of interest here, for we are asking him to adapt to the weightless state to which he is exposed within a short period of time; and then to do what appears to be a more difficult adaptation back to the 1-G environment on earth in a period of time dependent upon flight duration.

There are some important points I would like to note as a result of these studies. The first is that the conduct of an inflight experiment is a very difficult field operation and this is particularly true in the medical area. I think

there is no better example of this than the M-7 Calcium Balance Experiment. This is a difficult task in isolated patients. In the case of these missions, we are asking investigators to conduct these studies in an operational situation which is not in any sense like the hospital laboratory. There are a number of complicated operational interfaces and many of these cannot be rigidly structured because they vary with the mission demands. It is necessary to carefully select the flight upon which we are to do any given medical experiment. In other words, you cannot arbitrarily state that we would like to run a calcium study, for instance, and place it on the nearest available flight. The flight program must be carefully evaluated and the experiments which are to be done must be integrated with a number of operational procedures. There are many of these activities which may conflict with each other if they are not properly programmed.

The second point relates to the need to have some operational flexibility in conducting an assessment of man's responses through operational measures rather than necessarily by the laborious experiment

route. Many of the things that have been called medical experiments are not experiments at all; but are merely measures of a particular function of a body system. You could put a number of these together and say that you have one large experiment. For instance, the large number of studies which have been conducted on the cardiovascular system are indeed a series of measures which, when put together, could be called an experiment or at least an evaluation of the cardiovascular system.

We are tasked with the job of determining man's response to the space flight environment and it is an ongoing process which is planned for each flight, no matter what its duration. We must record even the minimal changes noted, evaluate their effect upon the flight, establish an adequate hypothesis concerning these effects, and hopefully establish a system of measurement which will allow us to elucidate the mechanisms involved. Our future flight programs rely upon basic missions whose duration is as long as our longest mission to date. We must continue our evaluation of man if we are to properly support this flight program.

SUMMARY AND CONCLUSIONS CONCERNING MEDICAL
RESULTS OF THE GEMINI VII MANNEED SPACE FLIGHT

We are dealing with very small numbers of people,
and we find that we must make sweeping conclusions
from very little information at the present time.
I think, however, that in viewing the overall
situation, we can all take pride in the fact that
there has been a large amount of medical infor-
mation obtained by working in a difficult space
"laboratory."

SUMMARY AND CONCLUSIONS CONCERNING MEDICAL RESULTS OF THE GEMINI VII MANNED SPACE FLIGHT

Figure 1	-	NASA-S-66-11665	Heart Rate Tilt Response Compared with Mission Duration
Figure 2	-	66-11534	Gemini Pilots' White Blood Cell Response
Figure 3	-	66-1715	Gemini Blood Volume Studies
Figure 4	-	65-8969	Gemini V Blood Volume Determinations (Command Pilot)
Figure 5	-	66-1140	Hemolysis-Gemini VII (Command Pilot)
Figure 6	-	66-5463	Gemini VII Ergometry Studies (Borman)
Figure 7	-	66-5464	Gemini VII Ergometry Studies (Lovell)
Figure 8	-	66-11663	Gemini Peak Heart Rates, Beats/Min
Figure 9	-	66-1765	Pilot Heart Rate - 4 hour intervals
Figure 10	-	65-12599A	Pilot Heart Rate - 4 hour intervals (Continued)
Figure 11	-	65-12592A	Gemini VII Command Pilot Blood Pressure
Figure 12	-	66-5820	Evidence of Normal Central Nervous System Function

HEART RATE TILT RESPONSE COMPARED WITH MISSION DURATION

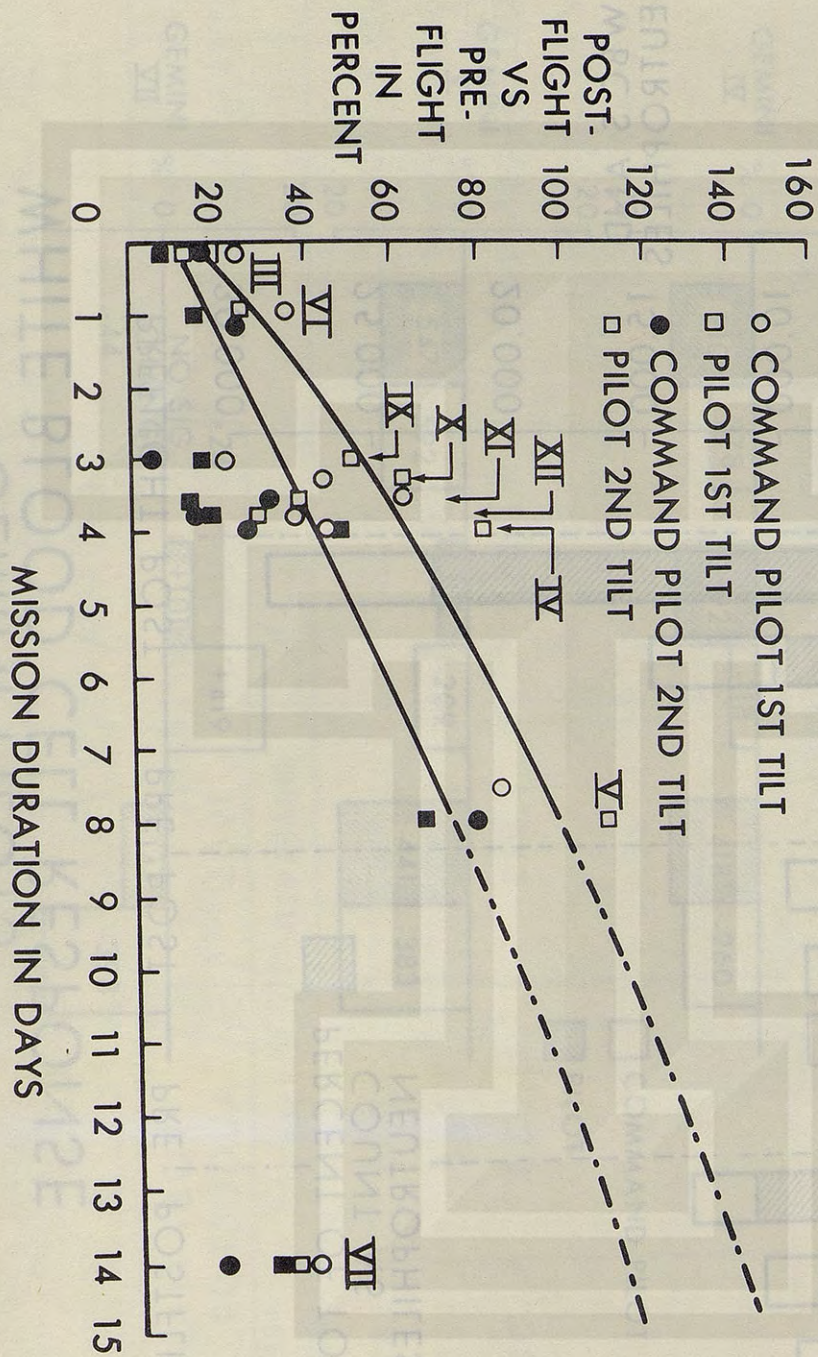


Fig 1

GEMINI PILOTS' WHITE BLOOD CELL RESPONSE

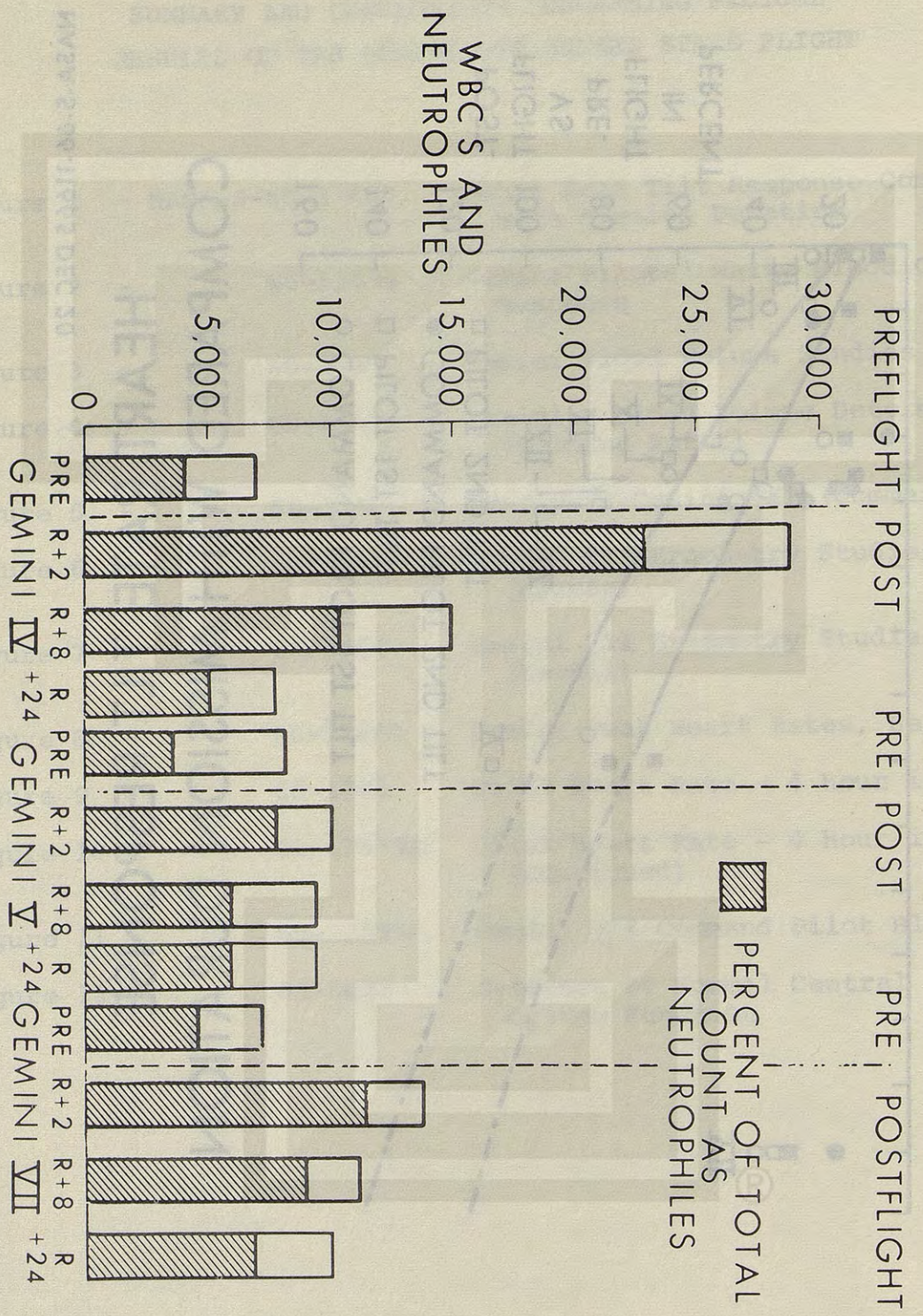


Fig 2

GEMINI BLOOD VOLUME STUDIES

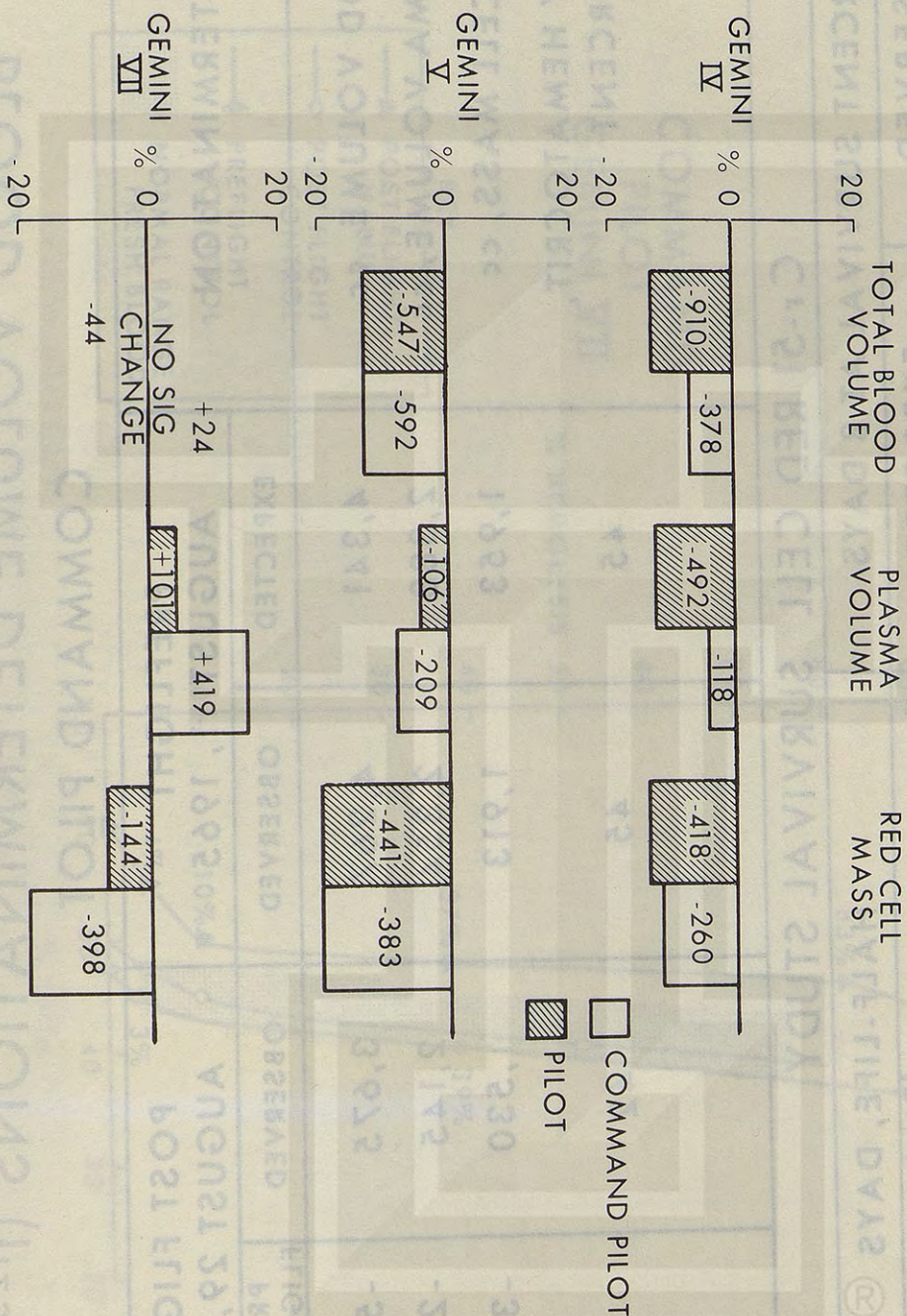


Fig. 3

GEMINI PILOTS'

WHITE BLOOD CELL RESPONSE

BLOOD VOLUME DETERMINATIONS (1125) COMMAND PILOT

DETERMINATION	PREFLIGHT AUGUST 11, 1965		POST FLIGHT AUGUST 29, 1965	
	EXPECTED	OBSERVED	OBSERVED	PRE-TO POST FLIGHT CHANGE
BLOOD VOLUME, cc	4,341	4,267	3,675	-592(13%)
PLASMA VOLUME, cc	2,388	2,354	2,145	-209(8%)
RED CELL MASS, cc	1,953	1,913	1,530	-383(20%)
BODY HEMATOCRIT, PERCENT	45	45	42	-3

Fig. 4

Cr-51 RED CELL SURVIVAL STUDY

PERCENT SURVIVAL AT 8 DAYS		HALF-LIFE, DAYS	
OBSERVED	EXPECTED	OBSERVED	EXPECTED
70	82-83	18	22-29

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COMMAND PILOT GEMINI VII

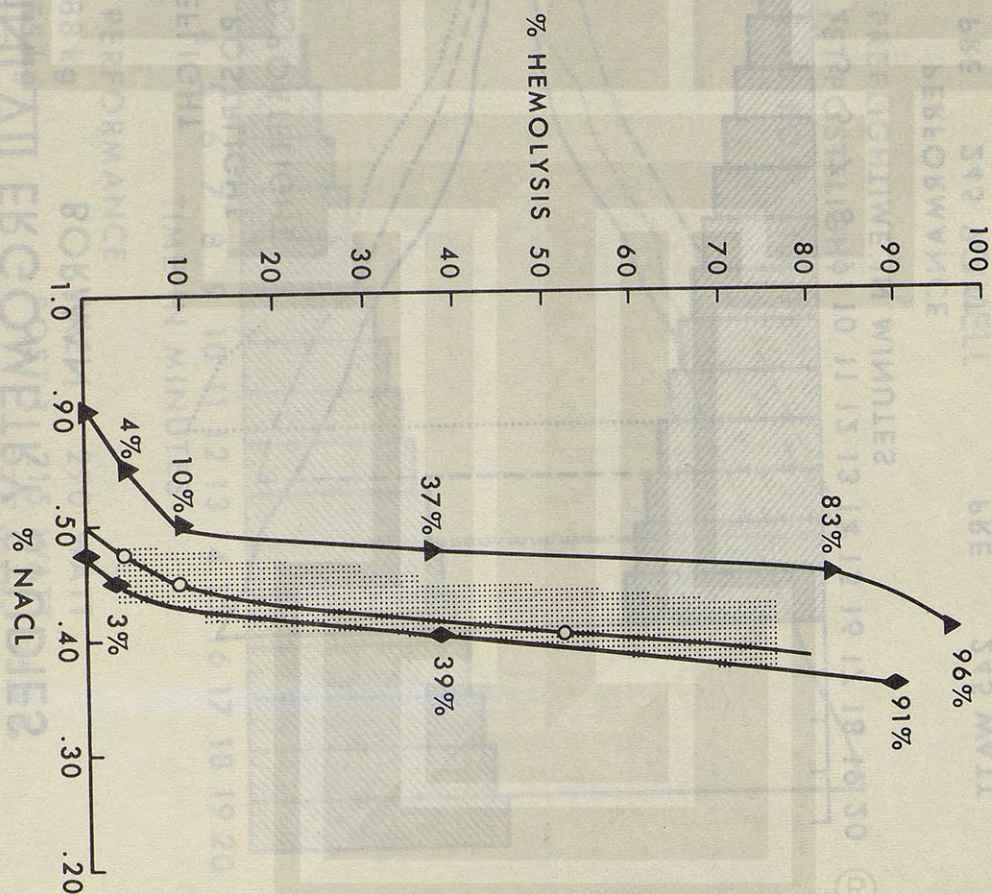
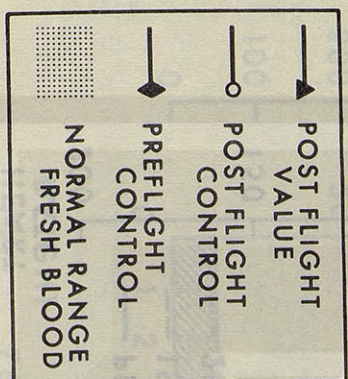


Fig. 5

PRE 70.00 kg
POST 74.55 kg
 $\Delta 2.33$ kg

POST I 215 WATT
 $\Delta 75$ WATT 25.9%

GEMINI VII ERGOMETRY STUDIES

BORMAN

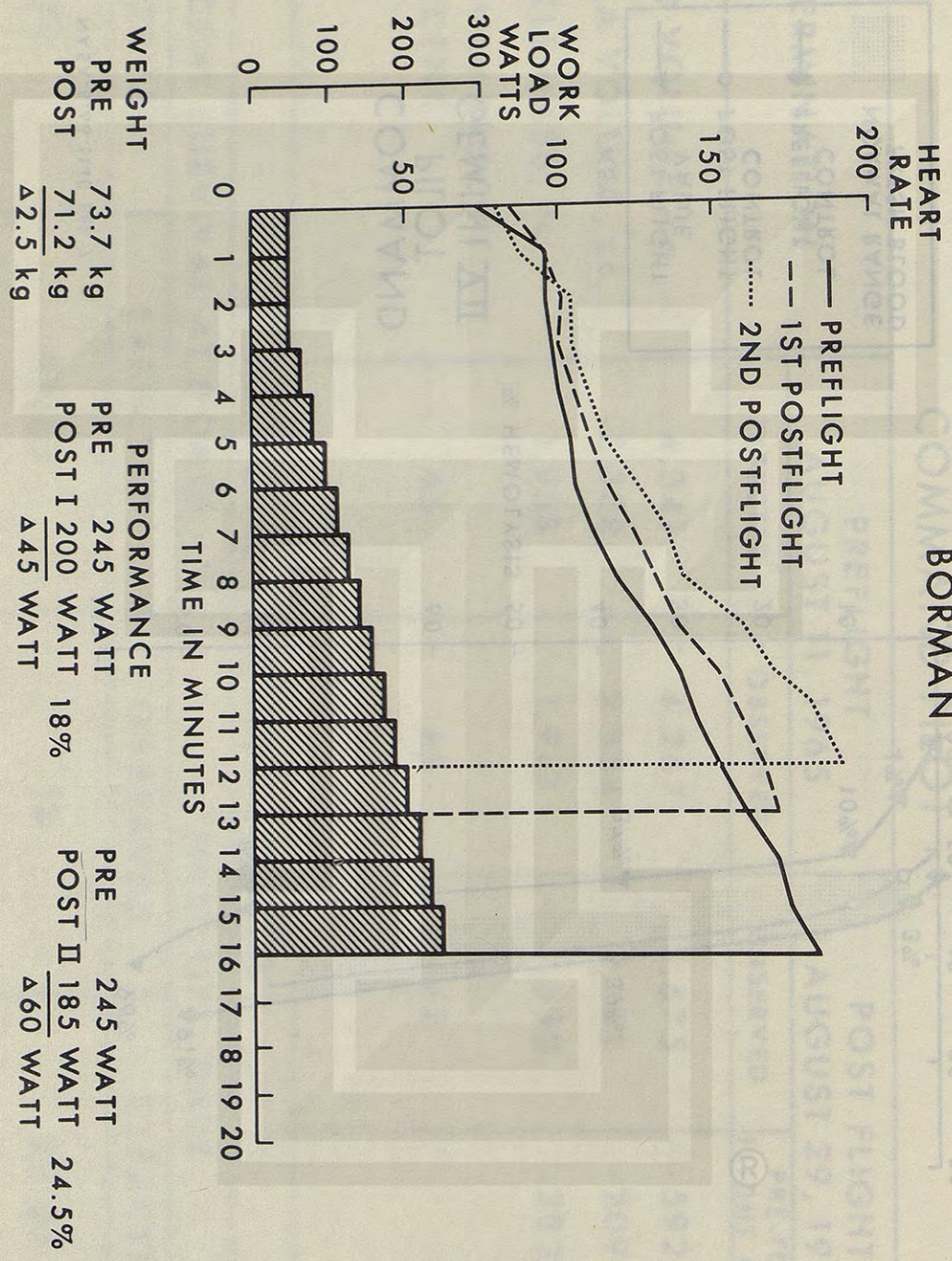


Fig. 6

GEMINI VII ERGOMETRY STUDIES

LOVELL

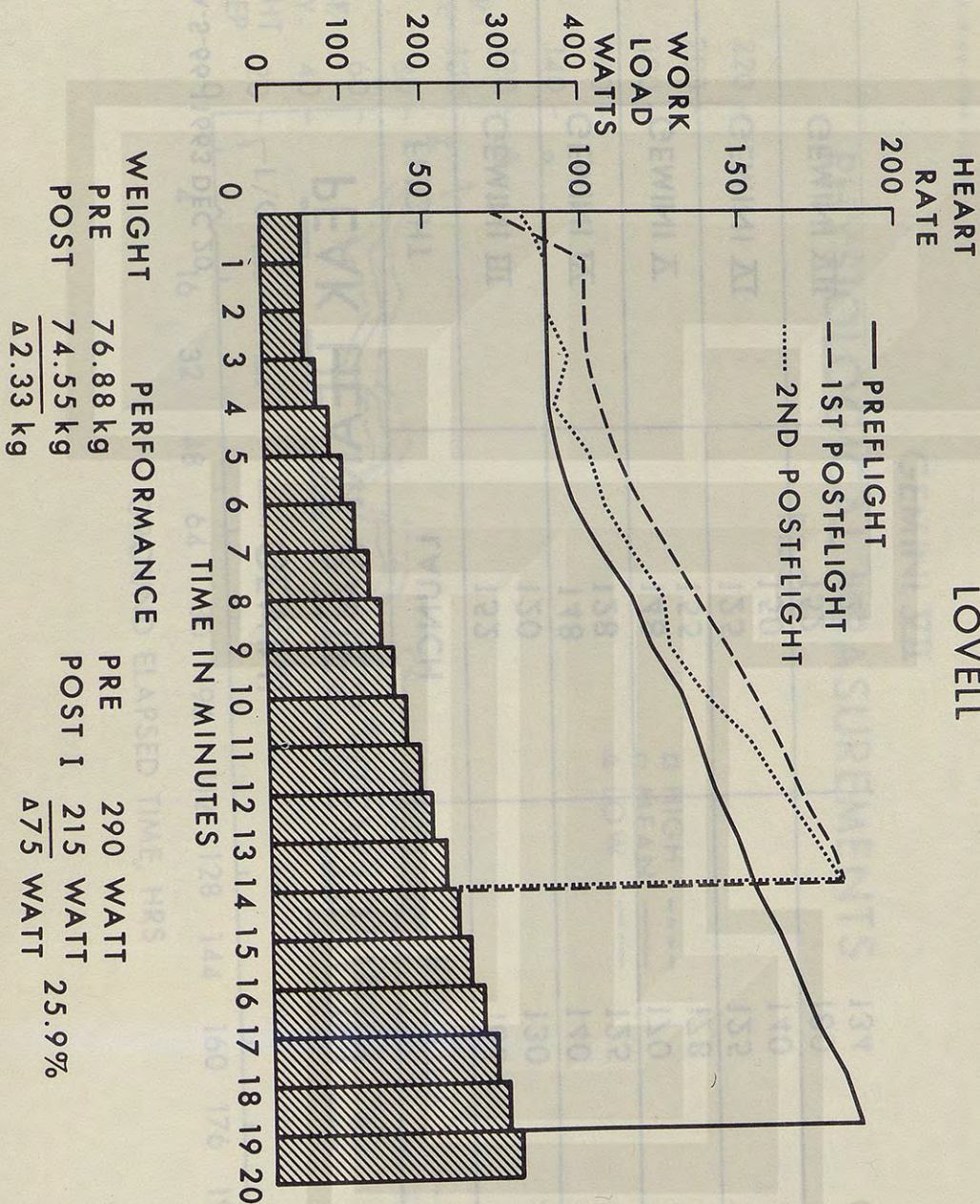


Fig. 7

GEMINI VII ERGOMETRY STUDIES

WEIGHT		PERFORMANCE	
PRE	76.88 kg	PRE	290 WATT
POST	74.55 kg	POST 1	215 WATT
	$\Delta 2.33$ kg		$\Delta 75$ WATT

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GEMINI

PEAK HEART RATES, BEATS/MIN

FLIGHT	LAUNCH	REENTRY
GEMINI III	152 120	165 130
GEMINI IV	148 128	140 125
GEMINI V	148 155	170 178
GEMINI VI	125 150	125 140
GEMINI VII	152 125	180 134

Fig. 8

GEMINI VII PILOT PHYSIOLOGICAL MEASUREMENTS

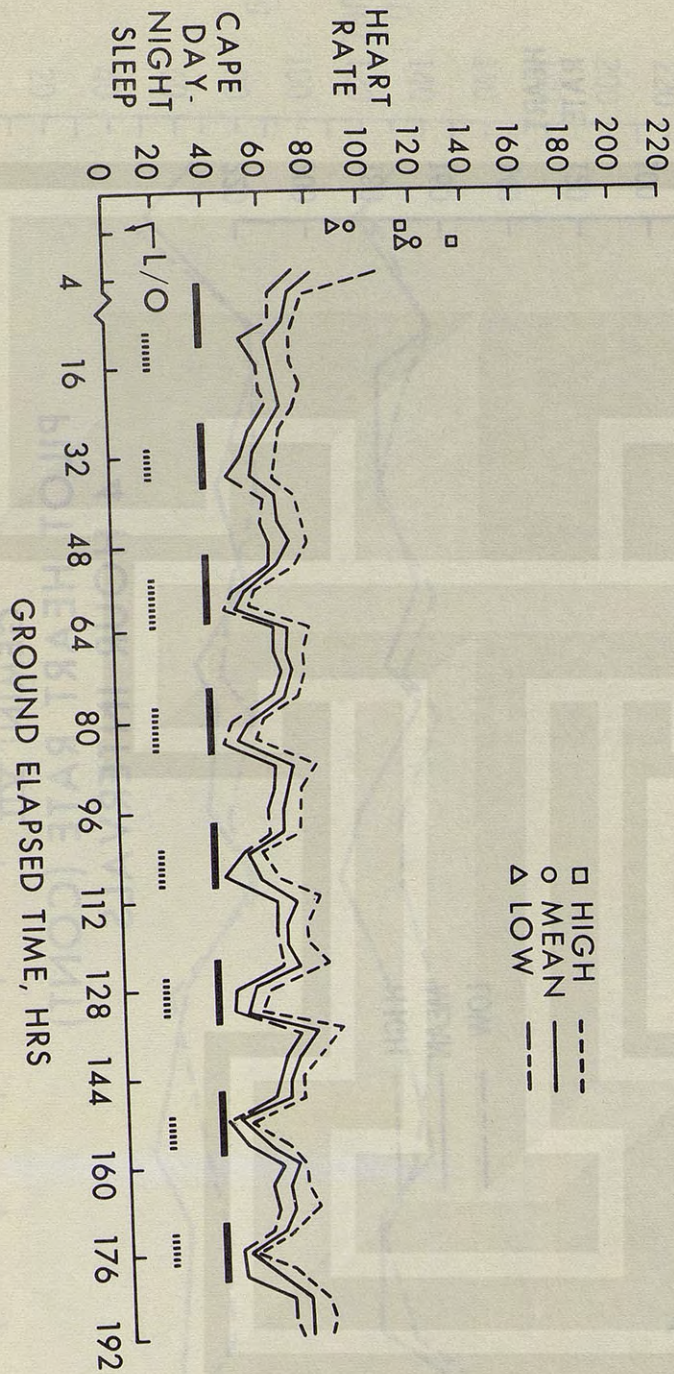


Fig. 9

0 16 32 48 64 80 96 112 128 144 160 175 192
 PRE-LAUNCH GET

GEMINI VII PILOT HEART RATE (CONT) 4 HOUR INTERVALS

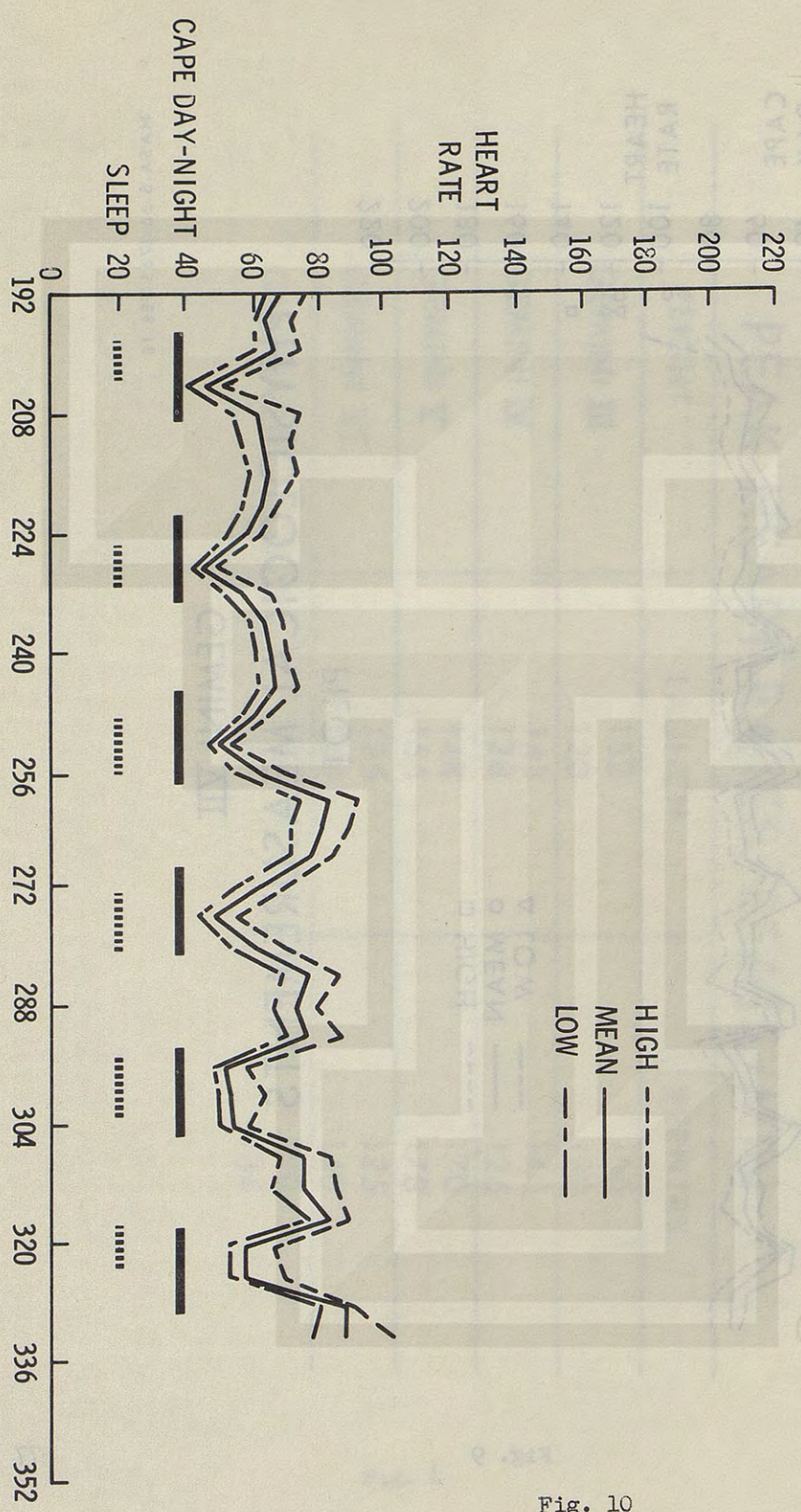


Fig. 10

GEMINI VII COMMAND PILOT BLOOD PRESSURE

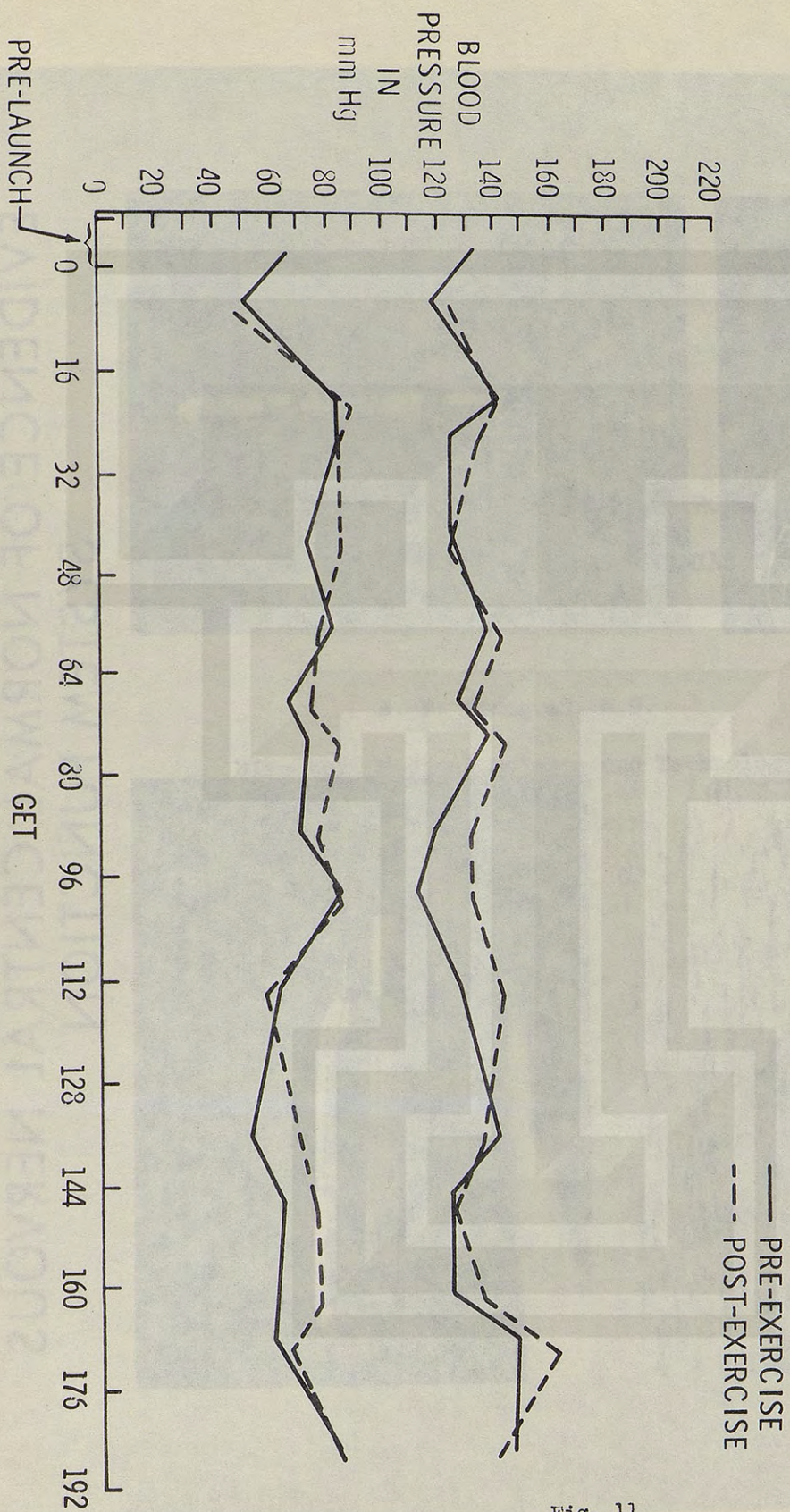


Fig. 11

NASA-S-66-5820 JUN 20

EVIDENCE OF NORMAL CENTRAL NERVOUS SYSTEM FUNCTION

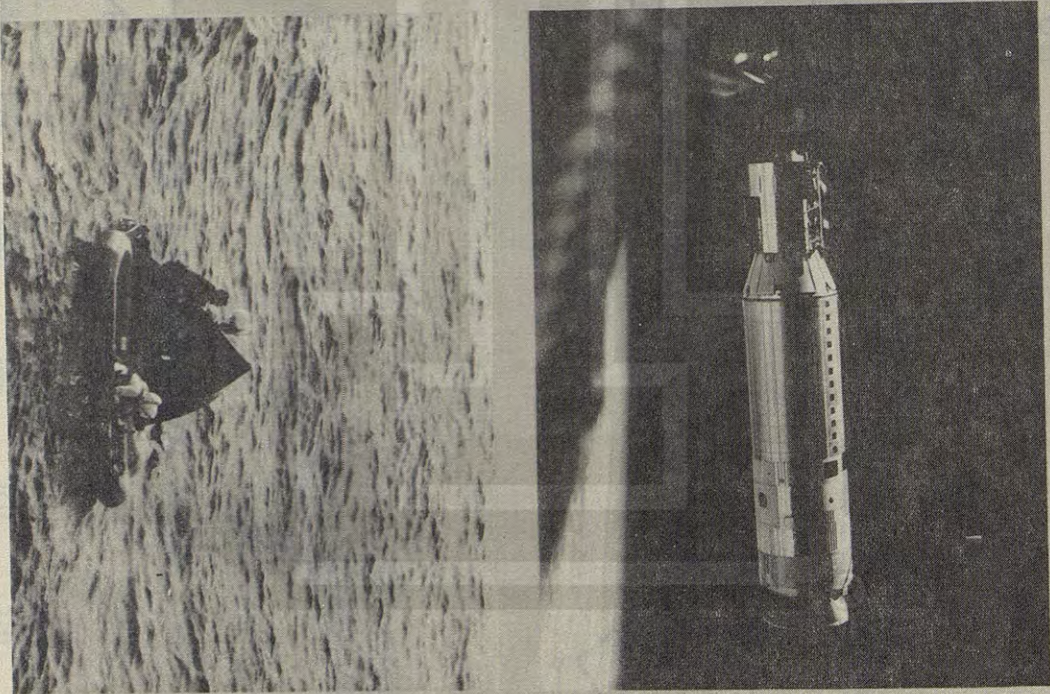
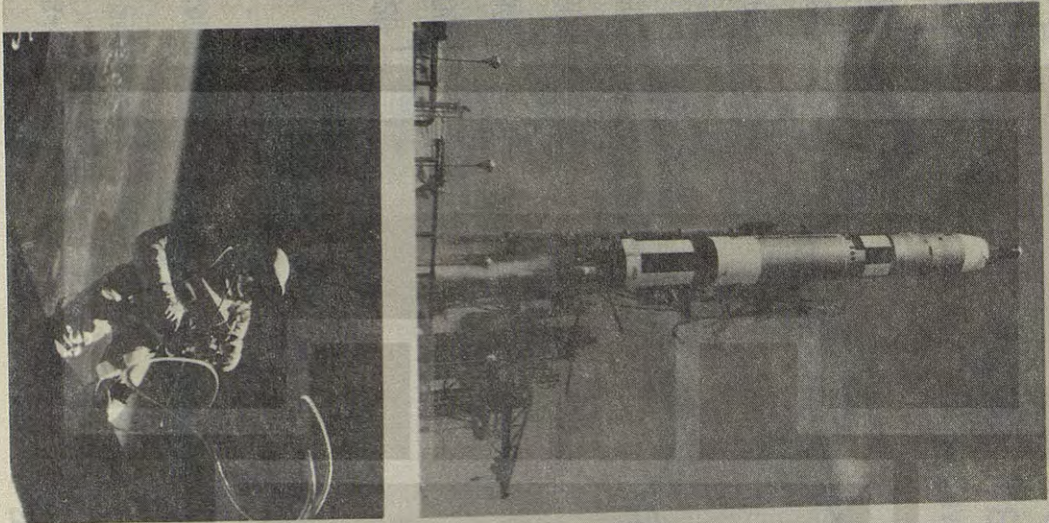


Fig. 12

SUMMARY OF MEDICAL EXPERIMENTS PROGRAM
REVIEW OF FINDINGS THROUGH GEMINI 7

S. P. Vinograd, M.D.

Director, Medical Science and Technology

NASA Headquarters

Washington, D. C.

SUMMARY OF MEDICAL EXPERIMENTS PROGRAM
REVIEW OF FINDINGS THROUGH GEMINI 7

The operational objective of the Medical Experiments Program looks well beyond the Apollo missions to prognosticate, validate, and protect man's welfare on very long duration missions of the future. The foregoing series of reports on our progress to date indicates that a small, but significant advancement has been made by virtue of negative as well as positive findings.

From MO01, the Cardiovascular Reflex Experiment, we have learned that a preventive measure against circulatory de-adaptation which has proven valid on the ground has not been successful in flight. This has led to the scheduling of a new and more promising therapeutic measure for trial aboard Apollo. The tilt table studies have confirmed the tendency toward cardiovascular deconditioning and show some evidence that a semblance of a trend pattern may be emerging. The need for determining specific causal relationships will require the repetition of these studies during space flight missions and the extension of associated ground-based studies. The clear-cut evidence of individual variation in these as well as other findings further emphasizes this need.

The reduction of red cell mass was clearly demonstrated during the Gemini 4, 5, and 7 missions. Ground-based studies suggest that this was due, at least in part, to the 100% oxygen atmosphere. Further highly sophisticated ramifications of this study into the field of red cell enzymology are currently being carried out. They show promise of data which may prove to be of importance to clinical medicine as well as space medicine, thanks to the problem definitions brought out by this investigation.

The fact that total blood volume was reduced in shorter duration flights and unchanged at the end of the 14-day flight may support the concept that the Gauer and Henry reflex, which reduces plasma volume, predominates early and for a relatively short time to be superseded later by a compensatory rise in plasma volume. On the other hand, this finding may be a reflection of lessened thermal stress, improved food and fluid intake, and increased exercise which characterized the 14-day flight. The fact that there was evidence of dehydration concurrently with an unaltered blood volume and even an increased plasma volume after the 14-day flight may prove to be a very significant contribution to our knowledge of the basic physiological mechanisms of dehydration and circulating blood volume control.

The Exercise Tolerance Experiment, MO03, has shown us that a heavier exercise regimen will be required for its successful accomplishment in the future. By virtue of its relatively low

sensitivity, a provocative exercise regimen of this sort may lend itself to calibration as a specific predictive index of significant cardiovascular change on future flights.

M004, the Phonoelectrocardiographic Experiment, brought forth no evidence of change relatable to the space environment. This would seem to refute the Soviet interpretations of their seismocardiographic data. The validity of these negative findings is given some support by the absence of evidence of myocardial disturbance by any other method of measurement utilized.

Experiment M005, the Bioassay of Body Fluids, has provided a beginning insight into the mechanisms of several physiological responses of man to space flight. Urinary aldosterone changes, never before measured, have been identified which can be linked to corresponding changes observed in fluid and electrolyte balance. The determination of epinephrine, norepinephrine, and 17-hydroxycorticosteroid output levels has raised questions and given some speculative clues to their relative roles in human environmental physiology. The continuation of this effort on future missions will be followed with very close interest by those who have a responsibility in flight crew support in manned space flight.

The Bone Densitometry Experiment, M006, has demonstrated what has long been anticipated; that there is, indeed, a reduction

of bone density during space flight. Although these changes have not been severe, this experiment has further shown that bone density reduction in the non-weightbearing bones (upper extremities) was clearly more pronounced than that seen in the same areas during equivalent periods of bed rest on earth. Paradoxically, bone density was seemingly less affected by the 14-day flight than by either the 4- or 8-day flights. The reasons for this are not clear, but here again, individual variation must be separated from the favorable influences of diminished thermal stress, increased food and water intake, and increased exercise program which characterized the environment and events of the 14-day flight.

Data from M007, the Mineral Balance Experiment, has shown a moderately elevated calcium output and a greater than anticipated output of nitrogen and phosphorus. The need for a simple and accurate urinary sampling system is apparent as is the value of this investigative effort to prognostications of flight crew support for protracted manned flights of the future.

The Electroencephalographic Analysis of Sleep, M008, has accurately portrayed the sleep patterns which actually did occur during flight. It also raised a question, as is frequently the case during the progress of any research; the question of the significance of the slightly increased theta wave activity observed.

Experiment M009, Human Otolith Function, elicited little or no evidence to suggest a change in otolith function during flights of up to 14 days in the Gemini configuration. This would tend either to contradict Soviet findings or to verify our crew selection criteria and training procedures as compared with those employed by the Soviets. While our total data points are still too few to establish the absolute absence of otolith effect, we can now assume with reasonable confidence that there probably will be no untoward otolith effect of practical significance within 14 days. The pursuit of this investigation in Apollo flight crews who, like the Soviet cosmonauts, will not be restrained within the spacecraft will add further clarifying data. Repetition during longer flights of the future will be necessary to extend the time line since the possibility of the later occurrence of otolith changes cannot be ruled out. The investigation of semicircular canal effects is planned for the AAP program.

The four major objectives of the Medical Experiments Program, as has been illustrated by today's progress report, are being pursued. In quick review, they are to determine effects, mechanisms, predictive means, and most effective preventive or corrective measures. All of the Gemini experiments are directed toward the first objective, the determination of the effects of space flight on man and the time courses of these effects.

Experiments MO04 (the Phonoelectrocardiogram), MO05 (Bioassay of Body Fluids), MO07 (Mineral Balance), MO09 (Human Otolith Function), and the red cell mass and blood volume studies are all contributing data on mechanisms by which these effects are manifested. MO03 (In-Flight Exerciser) may prove to be of value as an in-flight predictive index of circulatory changes as they might unfavorably affect post-flight activities. Finally, Experiment MO01 (Cardiovascular Reflex) is the evaluation of a technique to prevent circulatory de-adaptation during space flight. The Medical Experiments Program is designed to enable us to effectively plan and carry out long duration manned missions of the future. Our data appear to have confirmed, from a medical viewpoint, the feasibility of the Apollo lunar landing mission, and they support the practicality of currently planning a 28-30-day mission. Although the program is very young, it has also yielded data which promises to contribute to our knowledge of basic physiology, particularly in the areas of red cell enzymology, and dehydration and fluid balance.

Finally, it should be noted that the program's successes to date reflect the ability, diligence, and teamwork of the participating outside scientific community, NASA center medical community, and astronauts. The individuals are all deserving of unstinting credit.