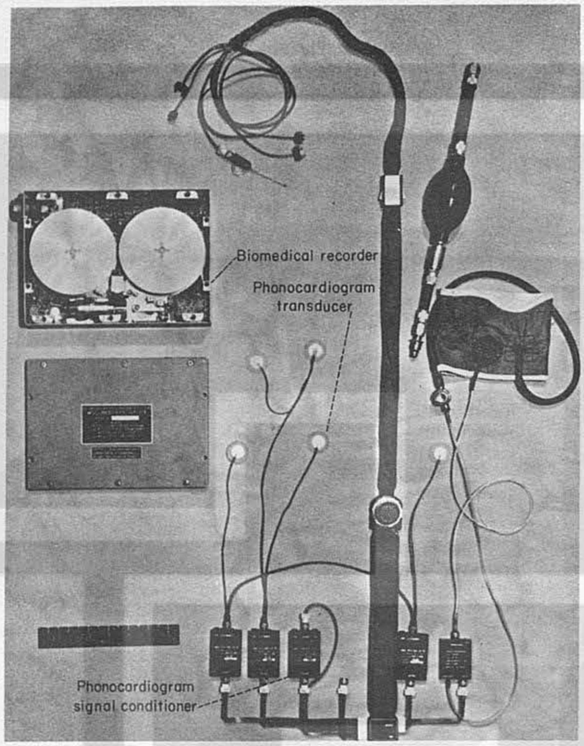

FIGURE 40-3.—Biomedical and communications harness used during Gemini IV mission.

inches. Exercise periods lasted for 30 seconds, during which time the astronaut stretched the bungee cords through a full excursion once per second. Exercise periods (crew status reports) were scheduled twice daily for each crewmember. Additional isometric-isotonic exercises were performed by each astronaut approximately three times daily. Blood pressure measurements were obtained before and after each exercise period (crew status report).

Results

The flight crew performed the exercises as scheduled. Heart rates were determined by counting 15-second periods for 2 minutes before and following exercise, as well as the first and last 15-second periods during each exercise. Comparison of 1-g preflight exercise periods with succeeding periods also revealed little difference in heart-rate response. Inflight responses to exercise are graphically illustrated in figure 40-4. Heart rates are plotted for the command pilot and pilot before, during, and following exercise. Both astronauts exhibited a moderate rise in pulse rate during exercise, with a rapid return to near preexercise levels within 1 minute following exercise. Similar M-3 results have been previously reported for the Gemini IV and Gemini V crews (refs. 1 and 2).

Representative preexercise and postexercise blood pressures are illustrated in figures 40-5 and 40-6 for the command pilot. The systolic values tended to be slightly higher following exercise. Diastolic values were more variable, but generally tended to be slightly higher following exercise. Samples of telemetered physiological data obtained during a typical inflight exercise are illustrated in figure 40-7.

Conclusions

The M-3 experiment on Gemini VII was successfully performed. On the basis of the data obtained during this mission, the following conclusions appear warranted:

(1) The response of the cardiovascular system to a calibrated workload is relatively constant for a given individual during space flights lasting 14 days.

(2) The crewmembers are able to perform mild-to-moderate amounts of work under the conditions of space flight and within the confines of the Gemini spacecraft. This ability continues essentially unchanged for missions up to 14 days.

(3) Using a variant of the Harvard Step Test as an index, no decrement in the physical condition of the crew was apparent during the 14-day missions, at least under the stress of the relatively mild workloads imposed in this experiment.

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2. DIETLEIN, L. F.; AND RAPP, R. M.: Experiment M-3, Inflight Exerciser. Manned Space-Flight Experiments Interim Report, Gemini V Mission, Washington, D.C., January 1966.

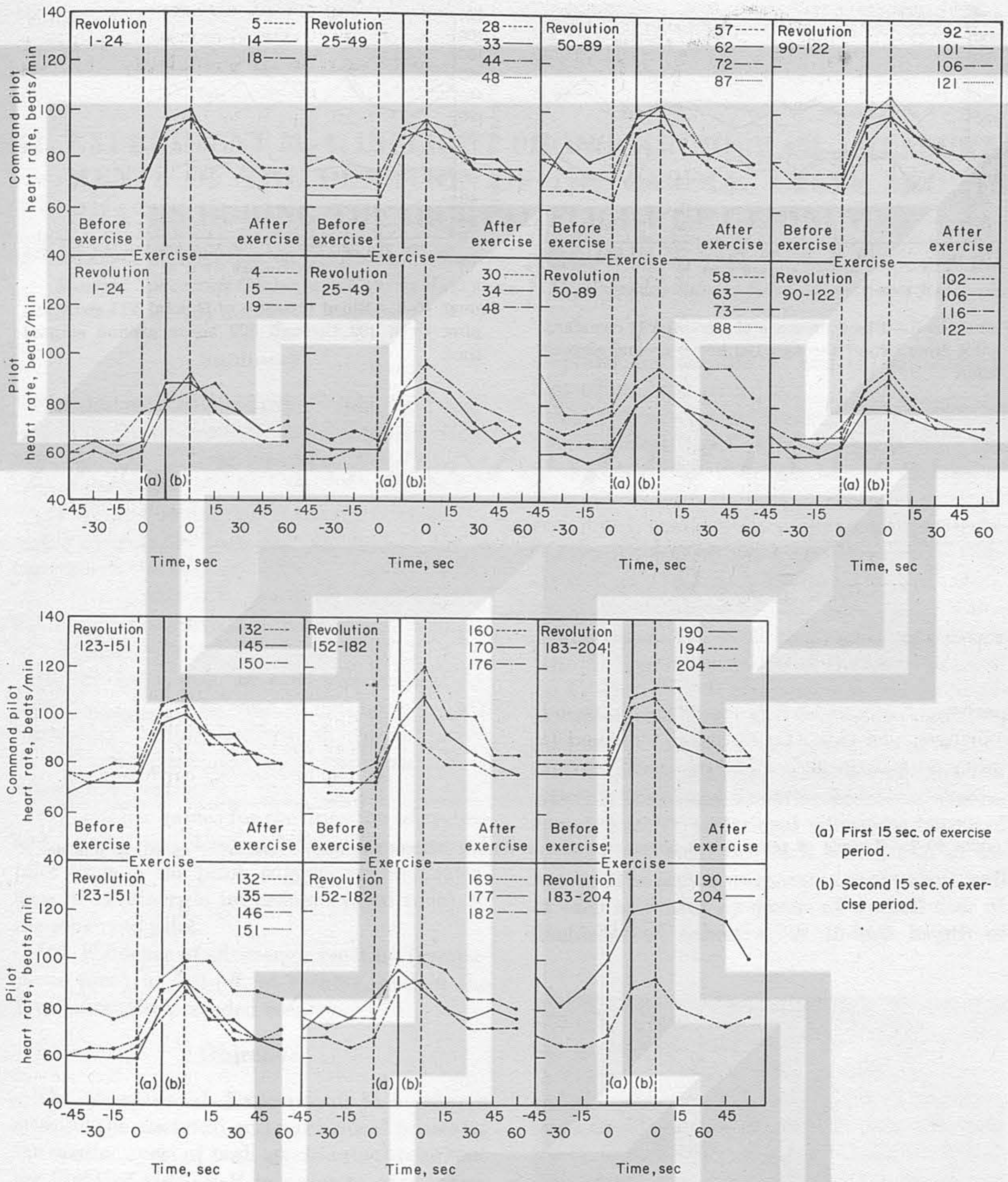

FIGURE 40-4.—Inflight responses to exercise.

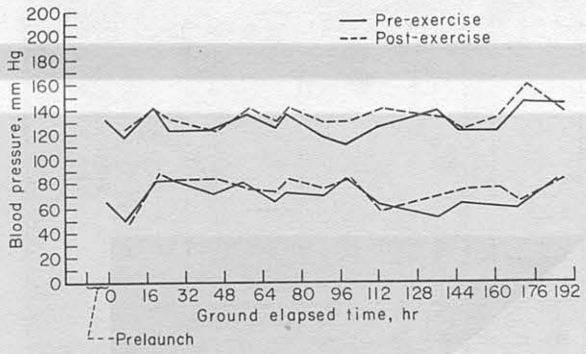

FIGURE 40–5.—Blood pressure of Gemini VII command pilot from lift-off through 192 hours ground elapsed time.

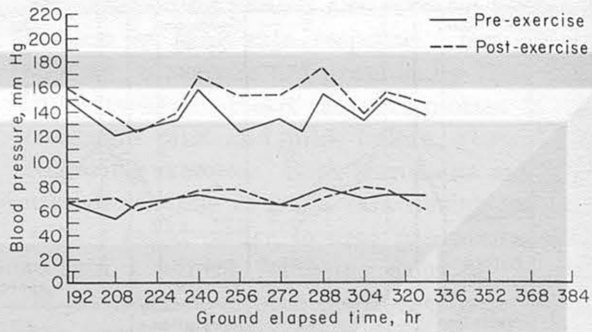

FIGURE 40–6.—Blood pressure of Gemini VII command pilot from 192 through 322 hours ground elapsed time.

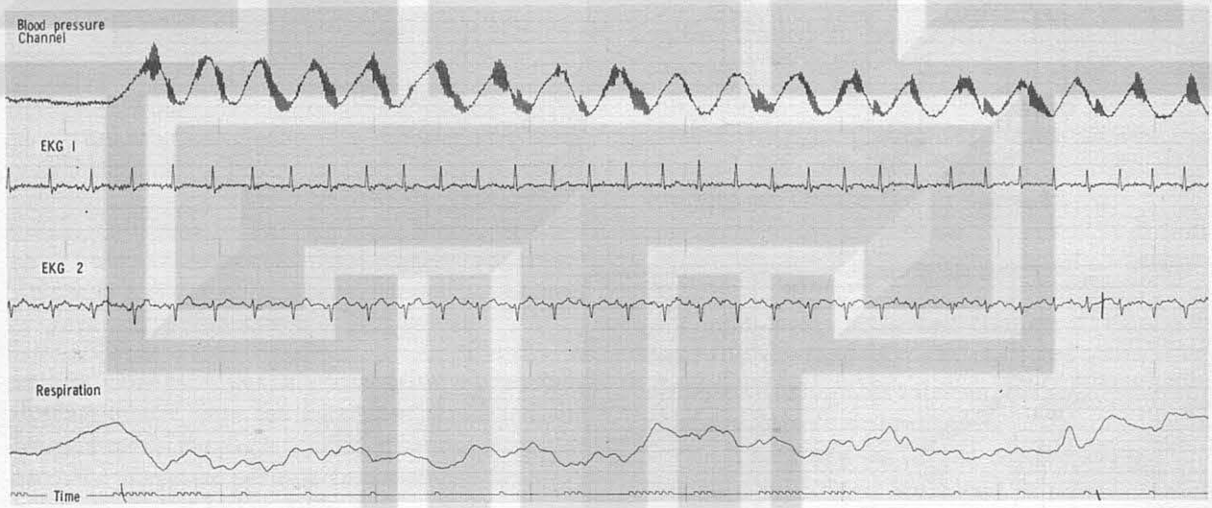

FIGURE 40–7.—Sample of telemetered physiological data during inflight exercise. (Recorder speed, 25 mm/sec.)

41. EXPERIMENT M-4, INFLIGHT PHONOCARDIOGRAM—MEASUREMENTS OF THE DURATION OF THE CARDIAC CYCLE AND ITS PHASES DURING THE ORBITAL FLIGHT OF GEMINI V

By LAWRENCE F. DIETLEIN, M.D., *Assistant Chief for Medical Support, Crew Systems Division, NASA Manned Spacecraft Center, and* CARLOS VALLBONA, M.D., *Texas Institute of Rehabilitation and Research, Baylor University College of Medicine*

Summary

Simultaneous electrocardiographic and phonocardiographic records were obtained from both Gemini V crewmembers. Analysis of these data revealed:

(1) Wide fluctuations of the duration of the cardiac cycle within physiological limits throughout the mission.

(2) Fluctuations in the duration of electromechanical systole that correlated with changes in heart rate.

(3) Stable values for electromechanical delay (onset of QRS to onset of first heart sound) throughout the mission, with shorter values observed at the peak heart rates recorded during lift-off and reentry.

(4) Higher values for the duration of systole and for electromechanical delay in the command pilot than in the pilot, suggesting preponderance of cholinergic influences (vagal tone) in the command pilot.

(5) Evidence of adrenergic reaction (sympathetic tone) at lift-off, at reentry, and in the few hours that preceded reentry.

Objective

The objective of Experiment M-4 was to measure the electrical and mechanical phases of the cardiac cycle of both astronauts throughout the flight of Gemini V in order to gain information on the functional cardiac status of flight crewmembers during prolonged space flights.

Equipment

The experimental equipment system consisted of three distinct parts, including the following: (1) a phonocardiographic transducer; (2) an electrocardiographic signal conditioner (preamplifier and amplifier); and (3) an onboard biomedical tape recorder.

The transducers and signal conditioners were housed within the Gemini pressure suit. The phonocardiographic sensor was applied parasternally in the left-fourth intercostal space of each flight crewmember. Electrodes for the detection of the electrocardiographic signals were applied in the usual location for the manubrium-xiphoid (MX) lead.

The phonocardiographic transducer used on Gemini V was identical with that used in Gemini IV (ref. 1). It consisted of a 7-gram piezoelectric microphone 1 inch in diameter and 0.200 inch in thickness (fig. 41-1), and was developed by the Bioinstrumentation Section of the Crew Systems Division. The transducer or sensor responds to the translational vibrations imparted to the chest wall with each contraction of the heart. The sensor was secured to the chest wall of each astronaut by means of a small disk of doublebacked adhesive. A 10-inch length of

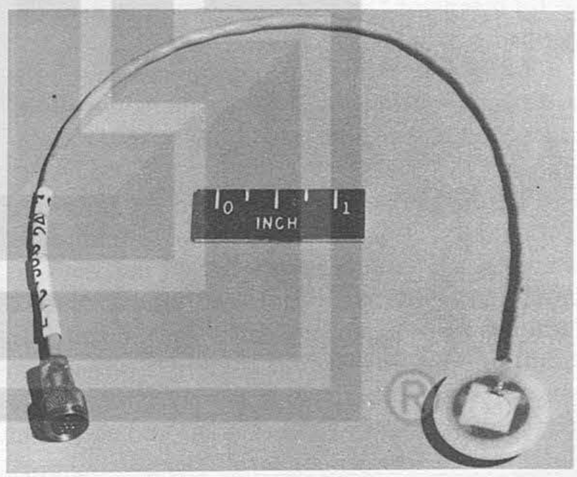

FIGURE 41-1.—Phonocardiogram transducer.

flexible 0.10-inch-diameter shielded cable transmitted the phonocardiographic signal to the Gemini signal conditioner (fig. 41–2) housed in a pocket of the undergarment. The phonocardiographic signal was then relayed from the signal conditioner output to the suit bioplug and thence to the biomedical magnetic tape recorder (fig. 41–3).

The electrocardiogram and the phonocardiogram of each astronaut were recorded simultaneously throughout the mission. The recording procedure was entirely passive and did not require active participation on the part of the flight crewmembers.

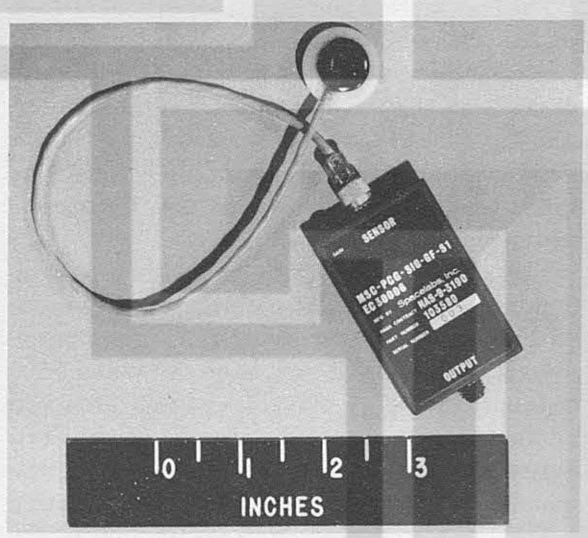

FIGURE 41–2.—Phonocardiograph system.

Procedure

Experiment M–4 was accomplished in Gemini V by means of the instrumentation system described above.

The analog data from the biomedical tape recording were played back in real time, digitized, and then analyzed by computer techniques.

The playback protocol included the following periods: (1) Initial: continuous for 9 minutes, starting at 1 minute before lift-off until orbital insertion; and (2) Final: continuous from 5 minutes before reentry until touchdown. In addition, records approximately 1 minute in duration were obtained at hourly intervals for the first 24 hours of the mission and at 4-hour intervals for the remainder of the mission until 5 minutes before reentry.

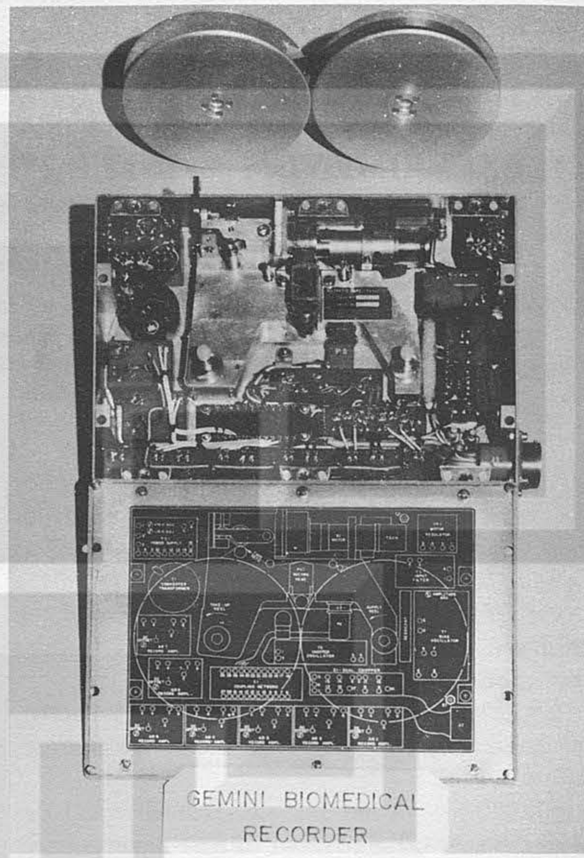

FIGURE 41–3.—Biomedical recorder.

The analog records of electrocardiogram and phonocardiogram were semiautomatically digitized with a Telecordex analog-to-digital converter. Digital readings were obtained at each of the following points: (1) at the onset of a QRS complex; (2) at the onset of the first heart sound; (3) at the onset of the second heart sound; and (4) at the onset of the next QRS complex. A computer program provided calculations of the duration of each RR interval, the duration of the mechanical systole (plus excitation time), the duration of diastole, the interval between the onset of QRS and the first heart sound (electromechanical delay), and the interval between the first and second heart sounds. The same program computed the means and standard deviations of these variables after each 15 consecutive beats.

Results and Discussion

Both astronauts had similar patterns of change in the duration of the cardiac cycle and of its several phases throughout the mission, but quantitative differences between the two subjects warrant separate discussions.

Results on the Command Pilot

Figure 41–4 indicates the serial plot of measurements throughout the mission. In the records that were obtained just before lift-off, the total duration of the cardiac cycle was 455 milliseconds (equivalent to a heart rate of 132 beats per minute). Electromechanical systole (mechanical systole plus excitation time) lasted 345 milliseconds; electromechanical delay (onset of QRS to first heart sound) was 100 milliseconds; and the interval between the onset of the first and second heart sound was 245 milliseconds. At lift-off, the duration of the cardiac cycle was 345 milliseconds (equivalent to a heart rate of 173 beats per minute). The cardiac cycle gradually increased in duration (cardiac deceleration) after orbital insertion, and a stabilization occurred at approximately 14 hours after lift-off. A significant shortening of the cardiac cycle, with shortening of systole and slight shortening of the electromechanical delay, occurred during a period of exercise at 9 hours 13 minutes after lift-off when the heart rate rose from a value of 75 to 125 per minute. Throughout the mission, there were wide fluctuations in the cardiac cycle (plot R of fig. 41–4), which seemed to correlate with concomitant changes in the duration of electromechanical systole (plot S of fig. 41–4) and the time interval between the first and second heart sounds (plot X of fig. 41–4). The electromechanical delay (time interval between the onset of QRS and of the first heart sound) remained relatively constant throughout the mission, although, as discussed later, the values were higher at lower heart rates. It is noteworthy that the electromechanical delay became slightly shorter approximately 12 hours before reentry, at which time the peak heart rate was recorded at 137 beats per minute. The duration of systole also became considerably shorter at this time.

Figure 41–5 reveals the fluctuations of the heart rate observed throughout the mission. From the tenth hour after lift-off to approximately 7 hours before reentry, Command Pilot Cooper had consistently low heart rates, with an overall average of approximately 68 beats per minute. The lowest values were recorded on the fourth and fifth days of the mission (50 beats per minute). It is interesting that the highest values of heart rate were recorded usually a few hours before midnight, eastern standard time. This was particularly evident during the last 3 days of the mission and suggests persistence of the circadian rhythmicity of heart rate based on the normal Cape Kennedy day-night cycle. Similar observations had been previously made in the command pilot of Gemini IV (ref. 1).

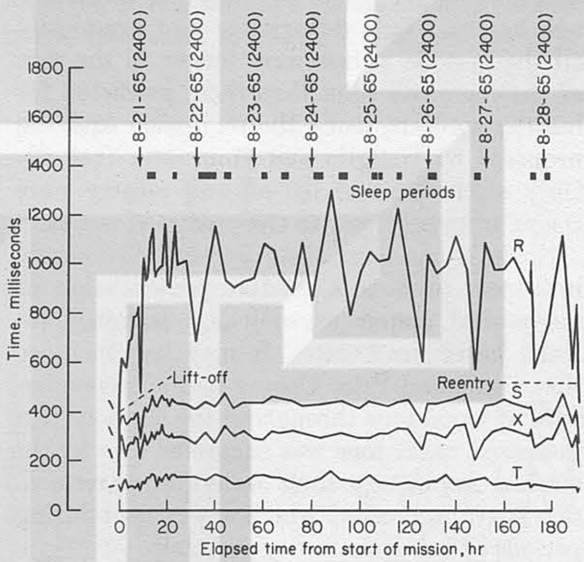

FIGURE 41–4.—Cardiac measurements for Gemini V command pilot.

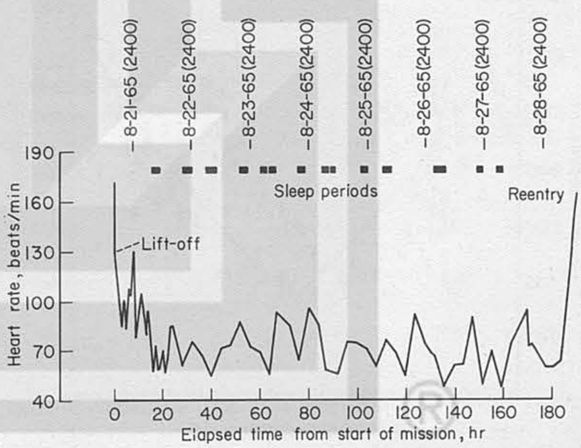

FIGURE 41–5.—Heart rates for Gemini V command pilot.

Figure 41–6 illustrates the correlation between heart rate and the duration of electromechanical systole and electromechanical delay. The average values for the duration of the cardiac cycle (R) at different time periods are plotted along the ordinate. The corresponding average values for the duration of electromechanical systole (S), for electromechanical delay (T), and for the time interval between the first and second heart sounds (X) are plotted along the abscissa. It is clear that in general the values of S, X, and T were longer when the total duration of the cardiac cycle was also longer (that is, when the heart rate was lower). It is remarkable that practically all the systolic values were longer in the case of the command pilot than those predicted for healthy subjects, using the regression equation proposed by Hegglin and Holzmann (ref. 2). Only at the time of lift-off and reentry were the values of S closer to the predicted norms.

Since it has been observed that cholinergic influences produce a relative prolongation of mechanical systole as well as a tendency toward lower heart rates, it may be concluded that Command Pilot Cooper had a preponderance of vagal tone throughout the mission. An increased vagal tone was suggested also by the marked respiratory sinus arrhythmia (respiration heart rate reflex) which was evident during periods of reduced activity and sleep.

Scant information is available on the relationship between electromechanical delay and heart rate. In general, the value of T remains almost constant at about 100 milliseconds when the heart rate varies between 60 and 120 per minute. The T values for the command pilot were greater, and the longest duration observed was 150 to 160 milliseconds during the fourth and fifth days of the mission. It must be emphasized, however, that the longest delays occurred at the lowest heart rates, suggesting that a preponderance of vagal tone also influenced the delay. It is likely that the stressful circumstances of lift-off and reentry accounted for the observed adrenergic effects on the heart. An increased heart rate and an absolute and relative shortening of mechanical systole and of electromechanical delay were the result of these adrenergic influences.

A prolongation of the electromechanical delay had been reported by Baevskii and Gazenko (ref. 3) during the flight of Cosmonaut Titov. The observations made of Astronaut Cooper suggest that increased vagal tone accounted for this prolongation, but since, in the case of Astronaut Cooper, manifestations of nausea or other untoward signs of vagal preponderance did not occur, we may conclude that the finding of prolonged electromechanical delay did not have any pathological significance, and was perhaps only a manifestation of superb physical conditioning.

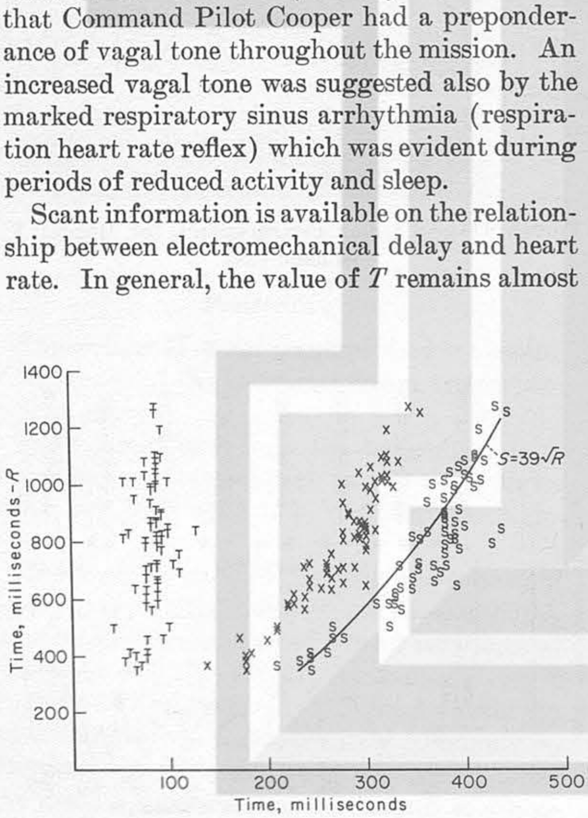

FIGURE 41–6.—Correlation of cardiac measurements for Gemini V command pilot.

Results on the Pilot

The responses observed in Pilot Conrad were similar to those observed in Command Pilot Cooper, but there were quantitative differences (fig. 41–7). The duration of Conrad's cardiac cycle just before lift-off averaged 460 milliseconds (equivalent to a heart rate of 130 beats per minute). The average duration of electromechanical systole was 305 milliseconds; that of electromechanical delay, 70 milliseconds; and that of the time interval between the first and second heart sounds, 235 milliseconds. At lift-off, the shortest cardiac cycle corresponded to a heart rate of 171 beats per minute. There was a gradual deceleration after insertion into orbit, and the values became stable at approximately 16 hours from the onset of the mission. Throughout the mission, the duration of the cardiac cycle varied considerably, with concomitant changes in the duration of systole (S) and of the time interval between the first and second heart sounds (X). The electromechanical delay (T) remained relatively constant, but there was a significant shortening that began approximately 20 hours before reentry. Low values for the duration of the cardiac cycle and its various components were observed at the time of reentry when the duration of the cardiac cycle was 365 milliseconds (equivalent to a heart rate of 164 beats a minute). At that time, mechanical systole reached its lowest value (220 milliseconds), and electromechanical delay was measured at 75 milliseconds.

The heart rate fluctuated throughout the mission, but in general the average values were somewhat higher than those of the command pilot (fig. 41–8). In addition to the peak values at lift-off and at reentry, there was also a high value shortly after the ninth hour when the flight schedule called for a period of physical exercise. At that time the heart rate peaked at 130 beats per minute. Circadian fluctuations of the heart rate were not so evident in the case of the pilot as compared with the command pilot, although peaks of heart rate were also recorded in the evening hours of the last 3 days of the mission.

In contrast to what was observed in the case of the command pilot, the values of the duration of electromechanical systole (S) for Pilot Conrad were closer to normal throughout the mission (fig. 41–9). Values of systole shorter than those predicted were measured at the time of reentry. A correlation between the electromechanical delay (T) and the duration of the cardiac cycle (R) was not as evident in the pilot as in the command pilot, but in general the lowest values were measured at the peak heart rates recorded at lift-off and at reentry. These findings suggest that vagal preponderance in Pilot Conrad was less prominent than that observed in the command pilot, and that adrenergic influences may have prevailed occasionally during the mission. These observations correlate well with findings of numerous extrasystoles during the first hours of the mission and at the time of reentry. Extrasystoles occurred at random throughout the mission but not so frequently as during lift-off and reentry.

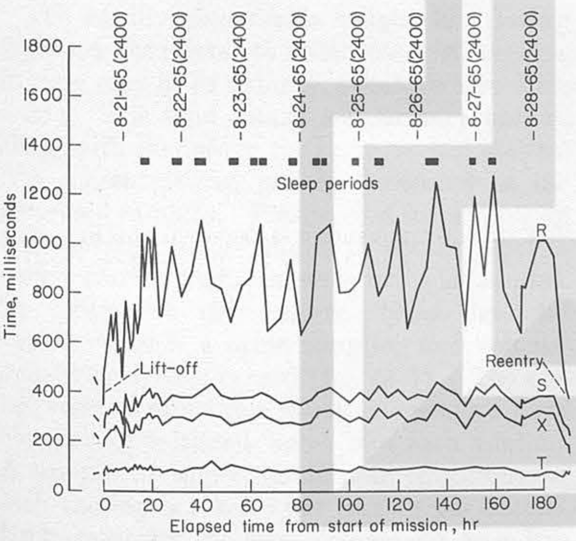

FIGURE 41–7.—Cardiac measurements for Gemini V pilot.

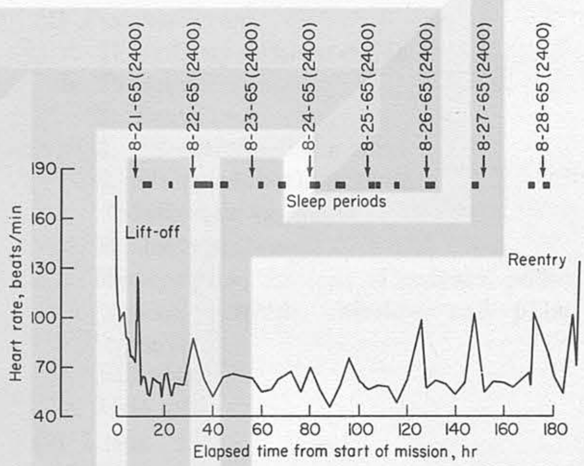

FIGURE 41–8.—Heart rates for Gemini V pilot.

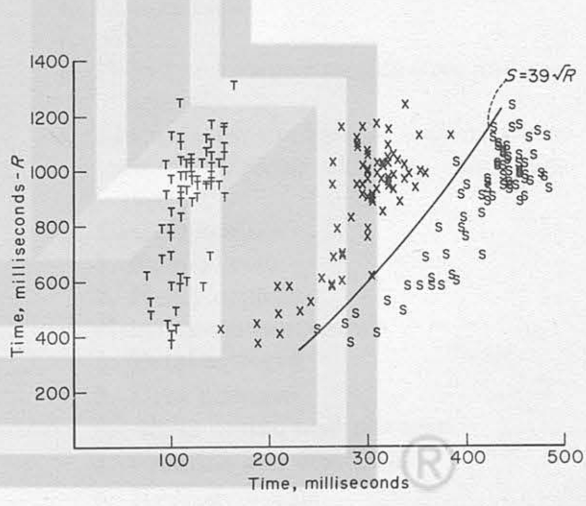

FIGURE 41–9.—Correlation of cardiac measurements for Gemini V pilot.

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42. EXPERIMENT M–5, BIOASSAYS OF BODY FLUIDS

By LAWRENCE F. DIETLEIN, M.D., *Assistant Chief for Medical Support, Crew Systems Division, NASA Manned Spacecraft Center, and* E. HARRIS, Ph. D., *Crew Systems Division, NASA Manned Spacecraft Center*

Objective

Medical Experiment M–5 is designed to obtain objective data concerning the effect of space flight on several of the systems of the human body. This experiment, as part of an overall evaluation, addresses itself to those areas where effects can be observed by alterations in the chemistries of body fluids.

Procedures

Inflight and postflight steroid and catecholamine values provide a means for assessing the extent of the stresses to which the crewman is subjected, and provide a measurement of the physiological cost to the crewman in maintaining a given level of performance during space flight.

To assess the effects of space flight upon the electrolyte and water metabolism of the crewman, plasma and urinary electrolytes and urine output values are determined along with the antidiuretic hormone (ADH) and the aldosterone.

The readily recoverable weight loss during flight may be related to water loss. Water loss, in turn, may be of urinary, sweat, or insensible origin. The fluid intake and urinary output, along with changes in the hormone and electrolyte concentrations, can be measured in the recovered samples. Plasma and urine samples are analyzed before flight to obtain baseline data. During flight, only the urine is sampled. To accomplish this and to obtain the total voided volumes, a urine-sampling and volume-measuring system is used (fig. 42–1). The system consists of a valve which introduces a fixed quantity of tritiated water into each voiding. A sample of approximately 75 milliliters of each voiding is taken after adding the isotope. Upon recovery, the total volume can be calculated by measuring the dilution of the tritium in the sample. Benzoic acid is used as the preservative.

Immediately upon recovery, the first postflight plasma sample is obtained. Samples are taken at 6, 24, and 72 hours after flight. Urine is collected continuously for 48 hours after flight. Each sample is frozen and returned to the Manned Spacecraft Center for analysis.

The following analyses are performed:

(1) Plasma/Serum
- a. 17-hydroxycorticosteroids
- b. Proteins
  1. Total
  2. Albumin/globulin ratio
  3. Electrophoretic pattern
- c. Antidiuretic hormone
- d. Hydroxyproline
- e. Electrolytes, the ions of sodium, potassium, calcium, chlorine, and phosphate
- f. Bilirubin
- g. Uric acid

(2) Urine
- a. Volume
- b. Specific gravity
- c. Osmolality
- d. pH
- e. 17-hydroxycorticosteroids (free and conjugated)
- f. Electrolytes, the ions of sodium, potassium, calcium, chlorine, and phosphate
- g. Catecholamines
  1. Epinephrine
  2. Norepinephrine
- h. Nitrogenous compounds
  1. Total nitrogen
  2. Urea nitrogen
  3. Alpha amino acid nitrogen
  4. Creatine and creatinine
  5. Hydroxyproline
- i. Antidiuretic hormone
- j. Aldosterone (preflight and postflight only)

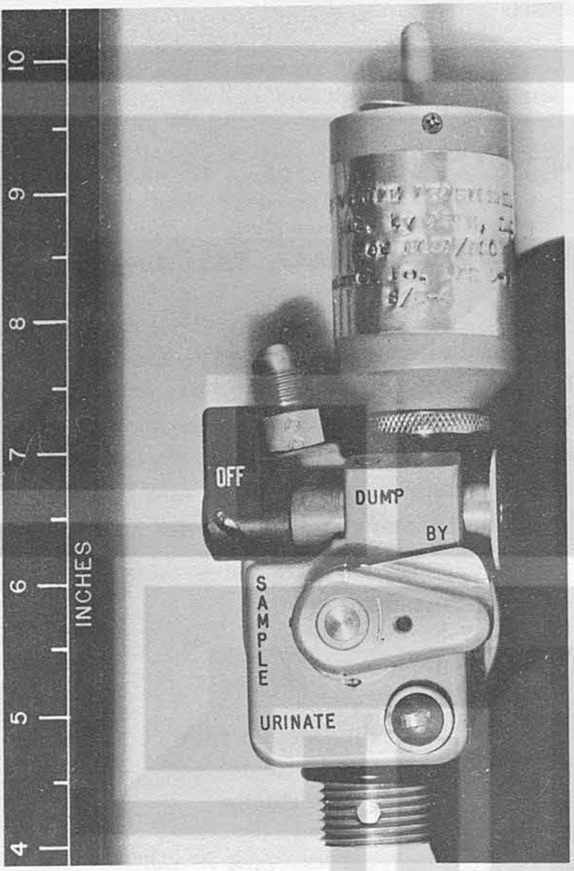

FIGURE 42-1.—Urine sampling and volume measuring system.

Results

Experiment M-5 was first scheduled for flight on Gemini VII. However, preflight and postflight plasma samples were obtained from the crewmen of Gemini IV through VI-A. No values out of the normal range were observed, nor were any trends evident in the Gemini IV through VI-A samples.

Analysis of the Gemini VII samples is still underway. The preflight and postflight plasma samples have been analyzed, and the results are presented in tables 42-I and 42-II. Electrophoretic patterns were normal. The values were all in the normal range, except for an anticipated increased 17-hydroxycorticosteroids in the first sample drawn following recovery. These returned to essentially preflight levels within 6 hours.

Hydroxyproline, which was determined because of its presence in collagen and its possible relationship to the decalcification process, did not change sufficiently to be interpreted in terms of bone density changes.

The drop in plasma uric acid immediately postflight must be examined further. A likely cause of the drop could be low purine intake. This possibility is being examined.

TABLE 42-I.—*Gemini VII Command Pilot Plasma Analysis*

[All dates 1965]

Components	Preflight		Postflight			
	Nov. 25	Dec. 2	Dec. 18 (1130 hr)	Dec. 18 (1820 hr)	Dec. 19	Dec. 21
Sodium, meq/liter	147	146	138	140	144	143
Potassium, meq/liter	4.7	5.4	4.1	4.7	4.7	4.9
Chlorine, meq/liter	103	103	100	102	103	106
Phosphate, mg, percent	3.2	3.7	4.0	4.2	3.1	3.6
Calcium, mg, percent	9.0	9.2	8.6	9.2	9.0	9.2
Urea nitrogen, mg, percent	19	16	16	20	25	18
Uric acid, mg, percent	6.8	6.6	4.6	6.0	5.9	6.0
Total protein, g, percent	7.3	7.4	6.8	7.6	7.0	7.1
Albumin, g, percent	4.7	4.9	4.2	QNS	4.5	4.6
17-OH corticosteroids, micrograms per 100 ml	18.8	----------	28.3	16.0	----------	----------
Hydroxyproline, micromilligrams per ml:						
Free	.008	.007	.010	.011	----------	----------
Bound	.131	.146	1.51	.185	----------	----------
Total	.139	.153	.161	.196	----------	----------

Plasma ADH was elevated enough for determination only in Pilot Lovell's first postflight plasma sample, although, as can be seen in tables 42–II and 42–IV, marked water retention was exhibited by both crewmembers immediately postflight. The water retention and the rapid weight gain after flight are consistent with the assumption that the weight lost during flight was the result of water loss.

Tables 42–III and 42–IV are comparisons of preflight and postflight 24-hour urine samples.

The retention of elecrolytes and water following reentry is consistent with the hypothesis that atrial and thoracic stretch receptors are of physiological importance in the change from a condition of 1 gravity to null gravity, and vice versa. A change from null gravity to an erect position in 1 gravity would result in a pooling of blood in the lower extremities and an apparent decrease in blood volume as experienced in

TABLE 42–II.—*Gemini VII Pilot Plasma Analysis*
[All dates 1965]

Components	Preflight		Postflight			
	Nov. 25	Dec. 2	Dec. 18 (1230 hr)	Dec. 18 (1800 hr)	Dec. 19	Dec. 21
Sodium, meq/liter	149	146	139	144	143	144
Potassium, meq/liter	4.9	5.1	4.1	5.0	5.5	5.0
Chlorine, meq/liter	104	103	97	101	100	104
Phosphate, mg, percent	3.1	3.3	3.9	3.9	3.4	3.4
Calcium, mg, percent	9.6	9.6	9.2	9.4	10.0	9.6
Urea nitrogen, mg, percent	23	22	21	28	27	24
Uric acid, mg, percent	6.1	5.8	3.8	5.3	5.0	5.0
Total protein, g, percent	7.8	7.8	7.2	7.9	8.1	7.2
Albumin, g, percent	4.8	4.7	4.3	----	----	----
17-OH corticosteroids, micrograms per 100 ml	13.3	----	26.2	8.9	----	----
Hydroxyproline, micromilligrams per ml:						
Free	.017	.010	.010	.005	----	----
Bound	.161	.167	.182	.187	----	----
Total	.178	.177	.192	.192	----	----

TABLE 42–III.—*Gemini VII Command Pilot Urinalysis*
[All dates 1965]

Components	Preflight		Postflight	
	Nov. 23	Dec. 1	Dec. 18	Dec. 21
Chlorine, meq	144	148	61	145
Calcium, mg	254	266	310	268
Uric acid, g	.96	.95	1.20	1.07
Total volume, ml	2920	3235	2160	3690
Sodium, meq	141	146	64	133
Potassium, meq	93.0	79	73	106
Phosphate, g	1.13	1.16	1.72	1.12
17-hydroxycorticosteroids	6.9	8.76	13.69	9.28
Total nitrogen, g	19.2	22.6	30.9	20.5
Urea nitrogen, g	18.1	18.5	26.6	18.7
Hydroxyproline, mg	48.74	37.0	65.4	39.9
Creatinine, g	2.11	2.11	2.86	1.80

TABLE 42–IV.—*Gemini VII Pilot Urinalysis*

[All dates 1965]

Components	Preflight		Postflight	
	Nov. 23	Nov. 30	Dec. 18	Dec. 19
Chlorine, meq	177	139	40	45
Calcium, mg	182	126	115	207
Uric acid, g	. 91	1. 14	. 45	. 92
Total volume, ml	1912	1737	735	1405
Sodium, meq	162	145	35	58
Potassium, meq	76	93. 0	44	58
Phosphate, g	1. 12	1. 27	. 80	1. 07
17-hydroxycorticosteroids	8. 0	9. 07	7. 83	8. 33
Total nitrogen, g	19. 94	21. 6	12. 81	22. 8
Urea nitrogen, g	17. 19	17. 06	11. 75	21. 51
Hydroxyproline, mg	39. 39	43. 1	31. 8	37. 4
Creatinine, g	2. 27	2. 25	1. 75	2. 16

the atria and thorax. This would produce an increased output of ADH and aldosterone, and a consequent water and electrolyte retention would occur. In null gravity, the increased volume of blood in the thorax and atria would produce a diuresis by a reversal of the above mechanism, and weight loss equivalent to the water loss would occur. Other mechanisms such as alterations or changes of water and electrolyte distributions in the various body compartments may also contribute to the observed results. Resolution of the mechanism still awaits results of the aldosterone and the inflight sample analyses.

Conclusions

Preflight and postflight urine and plasma samples from the Gemini VII crew were analyzed. Electrolyte and water retention observed immediately postflight are consistent with the assumption that the Gauer-Henry atrial reflex is responsive to a change from the weightless to the 1-gravity environment. Alterations in electrolyte and water distribution during flight may also be contributory.

Immediately postflight, plasma 17-hydroxycorticosteroid levels were elevated. Plasma uric acid was reduced. The cause of the reduction is unknown, but presumed to be dietary.

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43. EXPERIMENT M–6, BONE DEMINERALIZATION

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Summary

Experiment M–6 of this series of investigations on bone demineralization was designed to find the effect upon the human skeletal system of prolonged weightlessness and immobilization associated with confinement for a period of days in the Gemini spacecraft. This investigation was conducted both on the primary and backup crews of the 14-day Gemini VII mission, using the same method of radiographic bone densitometry as that employed in the Gemini IV and Gemini V studies. Radiographs were made preflight and postflight of the left foot in lateral projection and of the left hand in posterior-anterior projection of each crewman:

(1) At 10 days and at 3 days preflight and on the day of launch at Cape Kennedy.

(2) On the aircraft carrier U.S.S. *Wasp* immediately after recovery and again 24 hours later.

(3) At the Manned Spacecraft Center at 11 days and at 47 days following recovery.

In the laboratories of the Texas Woman's University Research Institute, sections of the os calcis, the talus, and hand phalanges 4–2 and 5–2 were evaluated for changes in skeletal mineralization. The method used was radiographic bone densitometry. The percentages of decrease in X-ray-equivalent calibration wedge mass found between radiographs made immediately preflight and postflight are shown in the table which follows.

Losses of this magnitude do not denote skeletal pathology, since all of the astronauts met or closely approached their preflight status before the respective studies closed.

The crewmen of Gemini VII, as seen in the table, experienced far lower losses in the os calcis than were found in the crews of Gemini IV and Gemini V. Losses in the finger were less than were found in the crewmen of these two previous flights, for whom bone densitometry measurements were made, although the differences were not so wide as in the case of the os calcis changes.

	Command pilot	Pilot
Conventional os calcis scanning section	−2. 91	−2. 84
Overall os calcis involving multiple traces over 60 percent of the bone	−2. 46	−2. 54
Section through the distal end of the talus	−7. 06	−4. 00
Multiple traces covering hand phalanx 4–2	−6. 55	−3. 82
Multiple traces covering hand phalanx 5–2	−6. 78	−7. 83
Greatest change in any section of the os calcis	−5. 17	−7. 66
Greatest change in hand phalanx 4–2	−9. 11	−8. 00
Greatest change in hand phalanx 5–2	−12. 07	−14. 86

The crewmen in the backup crew experienced only those changes in bone density found in healthy men pursuing their everyday activities.

The results of this study cannot be evaluated fully until further data are available, especially with respect to the difference in skeletal changes in the heel bone and the finger bone. Factors which probably contributed to the superior findings in the os calcis were these:

(1) The crewmembers of this mission ate a far higher proportion of the diet prepared for them than did those of Gemini IV and particularly of Gemini V.

(2) The crew had isometric and isotonic exercise for prespecified periods of time daily.

(3) An exerciser was used routinely.

(4) The crewmen slept for longer periods of time.

Methods

Densitometer Assembly

The instrumentation employed for the photometric evaluation of bone density from radiographs is a special analog computer consisting of a series of subassemblies, all designed to operate together as a completely integrated system. The basic units of the overall assembly, the theoretical aspects of the technique, and the history of the development of the method have been reported in references 1 through 4. Certain applications of the use of the bone densitometric employed in this study have been described in references 5 through 9.

Standard Radiographic Exposure Technique

Because different X-ray units were used at the three locations, the radiographs employed for densitometric measurements at different sites were standardized by three methods:

(1) An aluminum-alloy wedge exposed on the film adjacent to the bone was used.

(2) A roentgen meter to determine the calibrated kilovoltage which would produce identical beam qualities in each of the three X-ray units was used.

(3) A specially prepared phantom which was shaped like an os calcis and contained a standard quantity of ash enclosed in a tissue-simulating absorber to detect possible technique variations, was exposed at each testing site.

The X-ray machines were calibrated before each group of exposures by means of Victoreen roentgen meters in order to relate kilovoltage to X-ray transmittance in milliroentgens through a standard 2-millimeter aluminum filter under a specific X-ray intensity. Under the exposure conditions utilized, all units yielded a beam quality of 60 kilovolts, comparable with the central unit at the Texas Woman's University.

The X-ray film used in this investigation was Eastman Type AA film, which was exposed in cardboard holders.

Interpretation of the Term "X-Ray Absorbence"

As used in this report, the term "X-ray absorbence" by bone refers to the beam attenuation resulting from the hydroxyapatite and water-organic contents in their relative molecular weight concentrations, together with the overlying and underlying soft tissue. The results are reported in terms of wedge mass equivalency of the bone sites evaluated. Although changes in composition or thickness of the extrabone tissue could account for slight changes in total X-ray absorption, our tests have shown that, in the case of the os calcis, errors accountable to changes in soft tissue mass are slight.

Evaluation of Wedge Mass Equivalency in the Bones Evaluated

As noted, radiographs were made preflight and postflight of the left foot in lateral projection, and of the left hand in posterior-anterior projection of each crewman in the Gemini VII study. In previous investigations of bone mass changes before, during, and after orbital flight, the same radiographic exposures were made for the Gemini IV and the Gemini V crews.

In the Gemini IV study, the os calcis or heel bone was investigated, as was phalanx 5–2 of the left hand. In the Gemini V investigation, the same bones were examined, with the addition of phalanx 4–2, the distal end of the left radius, and the left talus. In the current study, the os calcis, the talus, and phalanges 5–2 and 4–2 of the left hand were included.

Central os calcis section.—This anatomical site was used in the M–6 Experiment in the Gemini IV and Gemini V flights and was repeated in the Gemini VII mission. The tracing path across the left os calcis in lateral projection runs diagonally between conspicuous posterior and anterior landmarks which, by superimposing successive radiographs, can be reproduced accurately in serial films of the same individual. This single path (1.3 millimeters in width) is known as the "conventional scan." (See fig. 43–1.)

Multiple parallel os calcis evaluations.—Approximately 60 percent of the total os calcis mass is evaluated in the parallel path system. After making the conventional scan, a series of parallel paths, 1.0 millimeter apart, were scanned, beginning 1 millimeter above the conventional path and continuing to the lowest

FIGURE 43-1.—Positive print of lateral foot radiograph showing location of the central section of the os calcis ("convention" section) which is evaluated for bone density changes, as well as the location of the section of the talus which is scanned.

portion of the bone. The total number of paths scanned is, therefore, proportional to the size of the bone which, of course, has individual variations. For the command pilot, 38 paths were required to cover the os calcis portion examined, while 42 parallel scans were needed for the pilot. Figure 43-2 illustrates the alinement of parallel paths through the os calcis portion examined (every path is not shown in the illustration).

The talus.—A single scanning path was made through the talus of the left foot, originating at the interior surface and projecting anteriorly to the conspicuous landmark, shown in figure 43-1.

Sections of the phalanges 4-2 and 5-2.—The second phalanx of the fourth and the fifth fingers of the left hand was scanned by parallel cross-sectional paths 1 millimeter apart alined tangentially with the longitudinal axis and covering the entire bone area (fig. 43-3).

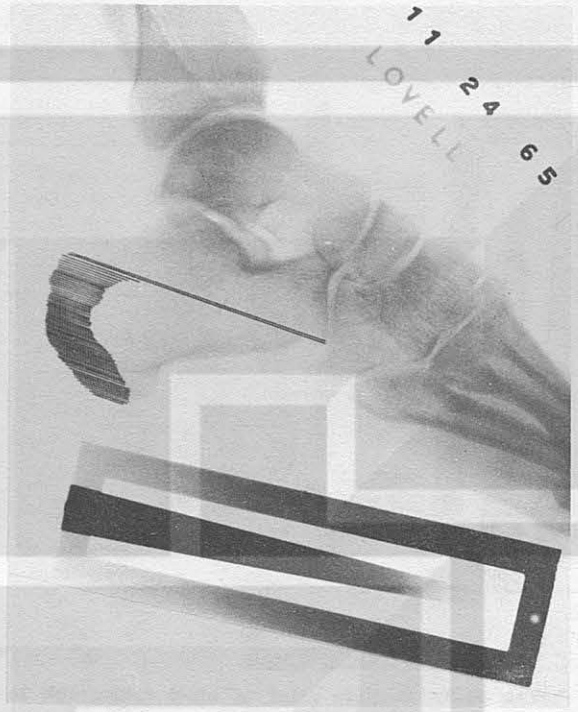

FIGURE 43-2.—Positive print of radiograph of os calcis showing location of the multiple sections which are evaluated. These scans are made entirely across the bone, parallel with the conventional section. They are 1 millimeter wide from the center of one scan to the center of the next scan, and hence they cover all of the 60 percent of this bone which is involved in this evaluation.

Results

X-Ray Absorption Changes in Central Os Calcis Section ("Conventional" Path)

The X-ray absorption values (in terms of calibration wedge equivalency) which were obtained from the central os calcis section throughout the Gemini VII mission are given in table 43-I and in figure 43-4. Based on a comparison of the calibration wedge equivalency of the immediate postflight radiograph with that made immediately before the launch, this central or "conventional" segment of the os calcis exhibited a change during the flight of only -2.91 percent for the command pilot and of -2.84 percent for the pilot.

It should be noted that there was an increase in bone mass of this anatomical site before the orbital flight and for 11 days after the flight in both crewmen. The postflight increase was more pronounced in the pilot. At the time the

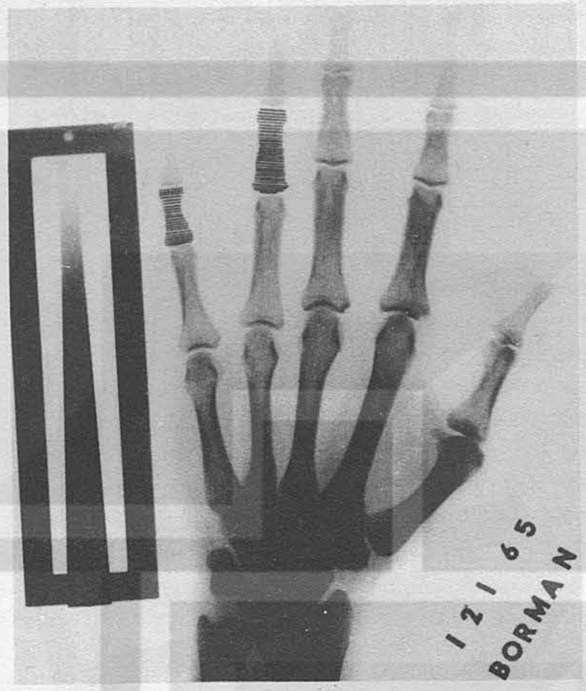

FIGURE 43–3.—Positive print of hand radiograph in posterior-anterior projection, showing position of parallel traces on phalanges 5–2 and 4–2. The scans slightly overlap each other and cover the entire bone in each case.

last radiograph of the series was made, 70 days after the study had begun, the command pilot had leveled off in calibration wedge equivalency of this section of the os calcis at a value higher than any preflight result. The pilot, on the other hand, had a value in the last radiograph which was higher than that of any of his previous films except the next to the last measurement.

Table 43–II shows that the decrease in the overall sum of the sectional values obtained from the parallel scans made in the radiograph taken of the command pilot on the aircraft carrier immediately after his recovery was only −2.46 percent of the value made immediately before launch. The comparable change in values for the pilot was −2.54 percent. The table shows also that the greatest change during flight in bone mass in any of the multiple sections of the os calcis of the command pilot was −5.17 percent, while that of the pilot was −7.66 percent.

A graph of the sums of the calibration wedge equivalency values for the multiple os calcis sections for each of the preflight and postflight

TABLE 43–I.—*Bone Densitometric Values Obtained From Scanning the Central Section of the Os Calcis of Gemini VII Crewmen at Intervals Throughout the Preflight, Orbital Flight, and Postflight Periods*

[Based on integrator counts]

(a) Command pilot [a]

Film	Date	Integrator counts obtained during densitometric scanning of X-rays		
		Evaluation 1	Evaluation 2	Average, both evaluations
1	11/24/65	12 012	11 933	11 973
2	12/01/65	12 625	12 567	12 596
3	12/04/65	12 407	12 411	12 409
4	12/18/65	11 994	12 103	12 049
5	12/19/65	12 314	12 465	12 390
6	12/29/65	12 985	13 155	13 070
7	02/03/66	12 901	12 745	12 823

(b) Pilot [b]

Film	Date	Evaluation 1	Evaluation 2	Average, both evaluations
1	11/24/65	13 438	12 296	13 367
2	12/01/65	13 253	13 243	13 248
3	12/04/65	13 724	13 713	13 718. 5
4	12/18/65	13 306	13 351	13 328. 5
5	12/19/65	13 523	13 305	13 414
6	12/29/65	14 750	14 614	14 682
7	02/03/66	14 001	13 968	13 984

[a] Difference between immediate preflight and carrier postflight values=2.91 percent.

[b] Difference between immediate preflight and carrier postflight values=2.84 percent.

radiographs is shown for both crewmen in figure 43–5. A general similarity between the graph of the conventional trace and that of the overall os calcis sections for the serial radiographs of the pilot is seen in figures 43–4 and 43–5. The two graphs of the command pilot also bear some resemblance to each other.

Although there is some inconsistency in the magnitude of changes from section to section in the multiple scans of the os calcis, it is apparent that bone mass decreased somewhat more in the superior sections than in the inferior sections in both astronauts from the beginning to the close of the flight. The effect undoubtedly is attributable in major part to the greater pro-

TABLE 43-II.—*Comparison of Bone Changes During Flight in Total Os Calcis From Multiple Sections of the Os Calcis of the Crewmen in the Gemini VII Mission*

Position of tracing	Command pilot			Pilot		
	Integrator counts from densitometer 12/4/65 (average)	Integrator counts from densitometer 12/18/65 (average)	Percent change from 12/4 to 12/18/65	Integrator counts from densitometer 12/4/65 (average)	Integrator counts from densitometer 12/18/65 (average)	Percent change from 12/4 to 12/18/65
1 mm above	12 136	11 652	−3. 99	13 791	13 359	−3. 13
Conventional	12 409	12 049	−2. 91	13 719	13 329	−2. 84
1 mm below	11 468	11 124	−3. 00	12 592	12 239	−2. 81
2 mm below	11 229	10 836	−3. 50	11 937	11 689	−2. 08
3 mm below	10 988	10 648	−3. 09	11 838	11 550	−2. 43
4 mm below	10 956	10 628	−2. 99	11 928	11 465	−3. 88
5 mm below	10 726	10 418	−2. 87	11 613	11 306	−2. 64
6 mm below	10 460	10 142	−3. 04	11 314	11 186	−1. 13
7 mm below	10 332	9 934	−3. 85	11 214	11 013	−1. 79
8 mm below	10 238	9 709	−5. 17	11 122	10 898	−2. 01
9 mm below	9 978	9 597	−3. 82	10 799	10 591	−1. 93
10 mm below	9 690	9 415	−2. 84	10 630	10 275	−3. 34
11 mm below	9 630	9 248	−3. 97	10 394	10 046	−3. 35
12 mm below	9 294	8 964	−3. 55	10 126	9 890	−2. 33
13 mm below	8 968	8 690	−3. 10	9 790	9 562	−2. 33
14 mm below	8 694	8 568	−1. 45	9 536	9 276	−2. 73
15 mm below	8 557	8 381	−2. 06	9 280	9 186	−1. 01
16 mm below	8 090	7 996	−1. 53	9 056	8 866	−2. 10
17 mm below	7 795	7 578	−2. 78	8 979	8 586	−4. 38
18 mm below	7 570	7 451	−1. 57	8 960	8 274	−7. 66
19 mm below	7 470	7 328	−1. 90	8 222	7 892	−4. 01
20 mm below	7 403	7 268	−1. 82	7 452	7 432	−0. 27
21 mm below	7 295	7 209	−1. 18	7 331	7 290	−0. 56
22 mm below	7 221	7 184	−0. 51	7 241	7 168	−1. 01
23 mm be,ow	7 176	7 141	−0. 49	6 893	6 989	+1. 39
24 mm below	7 192	7 130	−0. 86	6 890	6 843	−0. 68
25 mm below	7 172	7 103	−0. 96	6 843	6 702	−2. 05
26 mm below	7 097	7 002	−1. 34	6 829	6 503	−4. 77
27 mm bleow	6 914	6 838	−1. 10	6 645	6 400	−3. 69
28 mm below	6 845	6 740	−1. 53	6 451	6 243	−3. 23
29 mm below	6 801	6 684	−1. 72	6 312	6 180	−2. 09
30 mm below	6 319	6 210	−1. 72	6 218	6 128	−1. 45
31 mm below	6 022	5 965	−0. 95	6 090	5 910	−2. 95
32 mm below	5 694	5 608	−1. 51	6 033	5 748	−4. 72
33 mm below	4 989	4 962	−0. 54	5 764	5 631	−2. 30
34 mm below	4 448	4 382	−1. 48	5 769	5 549	−3. 81
35 mm below	3 750	3 767	−1. 97	5 452	5 319	−2. 44
36 mm below	2 896	2 816	−2. 76	5 391	5 088	−5. 63
37 mm below	X	X	X	4 804	4 614	−3. 96
38 mm below	X	X	X	4 362	4 253	−2. 51
39 mm below	X	X	X	3 714	3 637	−2. 06
40 mm below	X	X	X	3 070	3 322	+8. 22
Total	311 912	304 244	X	352 394	343 427	X
Mean change	X	X	−2. 46	X	X	−2. 54

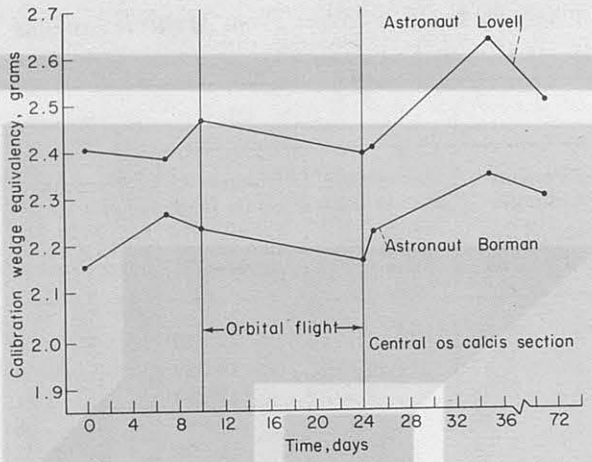

FIGURE 43-4.—Graph of the calibration wedge mass equivalency data on the "conventional" os calcis section which were evaluated for the Gemini VII flight crew.

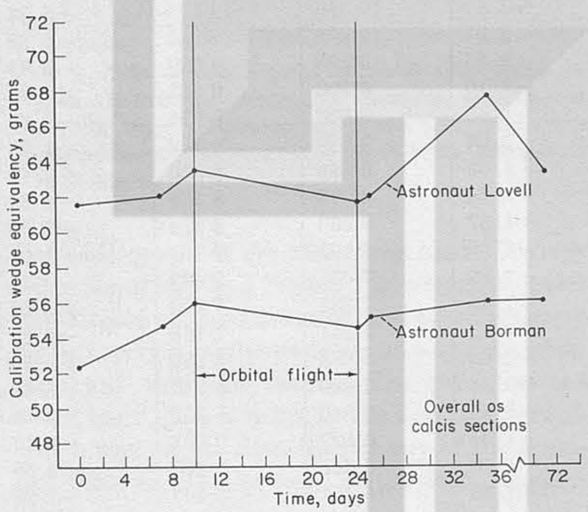

FIGURE 43-5.—Graph of the calibration wedge mass equivalency data on the total parallel sections of the os calcis which were evaluated for the Gemini VII flight crew.

portion of trabecular or cancelous tissue in the central and superior parts of this bone, with greater proportions of compact or cortical tissue in the distal sections.

Changes in the Talus

The calibration wedge mass equivalency at the talus scanning site obtained from the radiograph made immediately postflight was 7.06 percent lower than the final preflight value for the command pilot and 4.00 percent lower for the pilot. Prior to the flight the talus value first increased and then decreased for the command pilot, with a value at the time of launch which was slightly higher than the initial preflight level. The pilot showed a slight decrease in this site preflight. Both crewmen exhibited a marked increase for 11 days, after which there was a slight decrease, but with final values not markedly different from the initial levels. (See fig. 43-6.)

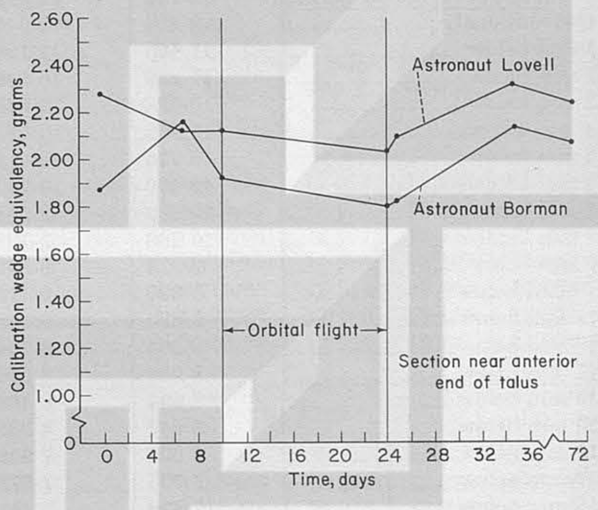

FIGURE 43-6.—Graph of the calibration wedge mass equivalency data on the section of the talus which were evaluated for the Gemini VII flight crew.

Bone Mass Changes in Hand Phalanges 4-2 and 5-2

As in the case of the os calcis, multiple parallel scans were made across hand phalanges 4-2 and 5-2, with distances of 1 millimeter from the center of one scan to that of the next scan. In this matter, the entire area of each phalanx was evaluated in posterior-anterior projection. (See fig. 43-3 for the positions of the sections scanned.)

Phalanx 4-2.—From the time the radiograph was made immediately before launch until the one which was made 14 days later, immediately after recovery on the carrier, the command pilot sustained an overall change of −6.55 percent in the 25 scans required to cover phalanx 4-2. The change in this anatomical site for the pilot during the same period was −3.82 percent, with 25 scans required to cover this bone. The greatest change in any section of phalanx 4-2 was −9.11 percent for the command pilot and −8.00 percent for the pilot.

Figure 43–7 consists of graphs of the calibration wedge equivalency values for hand phalanges 4–2 for the serial radiographs of the two Gemini VII crewmen. The graph of the command pilot shows that the value for phalanx 4–2 was higher at the beginning of the orbital flight than the first preflight value, with a decline by the close of the flight. This was followed by a gradual increase after the flight.

The graph for phalanx 4–2 for the pilot shows a marked increase in X-ray absorbence during the first 7 preflight days, followed by a decrease during the last 4 preflight days. Following the decrease during the flight, there was a sharp and then a gradual postflight increase.

Phalanx 5–2.—From the beginning to the close of the orbital flight, the command pilot sustained an overall change of −6.78 percent in the 18 parallel sections of phalanx 5–2. In the 17 scans required to cover hand phalanx 5–2 of the pilot, an overall change of −7.83 percent in bone mass was found. The greatest change in this bone for the command pilot was −12.07 percent, and for the pilot, −14.86 percent. As in the case of the crewmen of Gemini V, the losses in phalanx 5–2 tended to be greater than that of phalanx 4–2.

Figure 43–8 shows graphically the overall changes in the bone mass of the sections of the hand phalanges of the crewmen throughout the study. The values for the command pilot did not experience as marked preflight and postflight changes as those for the pilot. The values for the pilot took a sharp upward trend during the first 7 days of the preflight period, followed by a decline during the next 3 days. The last preflight value, however, was higher than the initial level. After the decline in X-ray mass equivalency shown during the flight, there was a sharp increase during the first 24 hours after the flight, with a continued moderate increase through the next 11 days, followed by a final decrease. However, the value 47 days after the flight was higher than the initial value found when the study began.

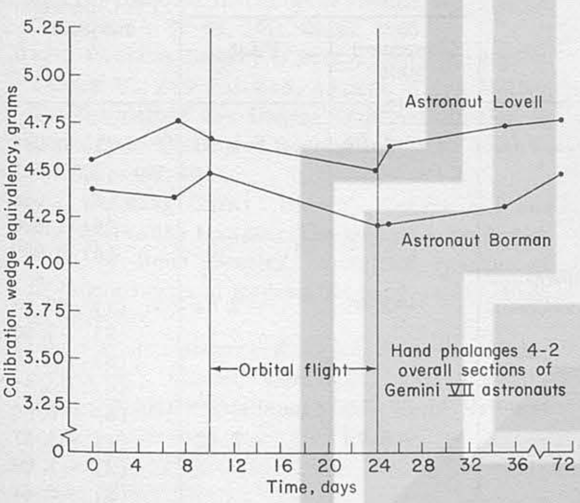

FIGURE 43–7.—Graph of the calibration wedge mass equivalency data on hand phalanx 4–2 for the Gemini VII flight crew.

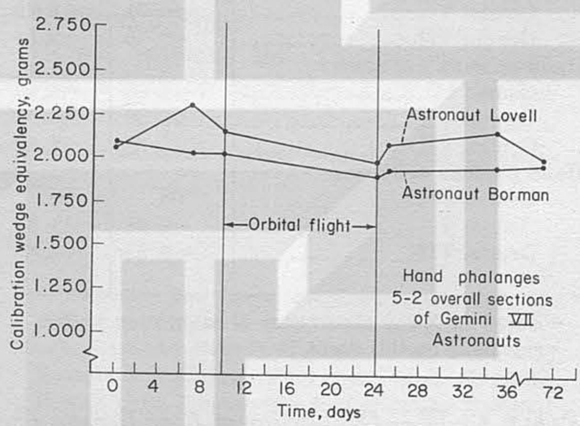

FIGURE 43–8.—Graph of the calibration wedge mass equivalency data on hand phalanx 5–2 for the Gemini VII flight crew.

Discussion

Comparison of Bone Density Changes in Crewmen of Gemini IV, Gemini V, and Gemini VII During Space Flight

It is interesting to note how the crewmembers of Gemini IV, Gemini V, and Gemini VII have compared with each other as to skeletal changes in three major anatomical sites with respect to changes in skeletal density during space flight. The bone mass changes in table 43–III (in terms of calibration wedge equivalency) have been found for the command pilot and the pilot in the "conventional" os calcis section, in the combined sections covering 60 percent of the os calcis, and in hand phalanges 5–2 and 4–2, both for the command pilot and the pilot for the three orbital flights.

TABLE 43–III.—*Comparison of Bone Density Changes in Crewmen of Gemini IV, Gemini V, and Gemini VII During Space Flight*

Position of anatomical site evaluated	Change in bone mass,[a] percent	
	Command pilot	Pilot
Conventional os calcis scan:		
Gemini IV	−7. 80	−10. 27
Gemini V	−15. 10	−8. 90
Gemini VII	−2. 91	−2. 84
Multiple os calcis scans:		
Gemini IV	−6. 82	−9. 25
Gemini V	−10. 31	−8. 90
Gemini VII	−2. 46	−2. 54
Hand phalanx 5–2 scans:		
Gemini IV	−11. 85	−6. 24
Gemini V	−23. 20	−16. 97
Gemini VII	−6. 78	−7. 83
Hand phalanx 4–2 scans:		
Gemini IV	(b)	(b)
Gemini V	−9. 98	−11. 37
Gemini VII	−6. 55	−3. 82

[a] Based on X-ray absorbency of calibration wedge.
[b] Not done on this flight.

Comparison of Bone Density Changes in the Gemini VII Crew With Bedrest Subjects on Similar Diets for 14 Days

On the basis of the tentative evaluation of food intake based on the residue removed from the spacecraft postflight, it is estimated that 1.00 gram of calcium was consumed by the Gemini VII crewmen during their orbital flight. On this basis, the os calcis and hand phalanx 5–2 were compared with subjects at supine bedrest for 14 days in the Texas Woman's University (TWU) bedrest units. Bedrest men on comparable diets lost slightly more in the os calcis and considerably less in phalanx 5–2 than did the crewmen on this mission, as seen by the data in table 43–IV.

Comparison of Bone Density Changes in Crew and in Backup Crew of Gemini VII

The backup crew of Gemini VII, which included Edward White and Michael Collins, had four radiographs made in connection with this mission on the following dates: November 24, 1965; December 1, 1965; January 3, 1966; and February 3, 1966.

TABLE 43–IV.—*Comparison of Bone Density Changes in the Gemini VII Crew With Bedrest Subjects on Similar Diets for 14 Days*

	Gemini VII crew		TWU bedrest subjects
	Command pilot	Pilot	
Mean calcium daily intake (estimated), grams	1. 00	1. 00	(1) 0. 931 (2) 1. 021 (3) 1. 034 (4) 1. 020 (5) 0. 930
Change in conventional section of os calcis in bone mass (calibration wedge equivalency), percent	−2. 91	−2. 84	(1) −3. 46 (2) −3. 56 (3) −5. 79 (4) −5. 11 (5) −5. 86
Change in bone mass of hand phalanx 5–2, percent	−6. 78	−7. 83	(1) −1. 57 (2) −1. 00 (3) −0. 44 (4) −0. 96 (5) −1. 27

The spread from the highest to the lowest X-ray absorbency value in the os calcis for White was 2.5 percent covering a period of 3 months and 10 days. The spread for Collins was 3.2 percent over the same period. On comparable dates, not involving any aspect of the orbital flight, the spread in os calcis absorbency values was 6.6 percent for Frank Borman and 9.8 percent for James Lovell. This indicates that the maximum spread was less in the backup crew than in the flight crew.

No exact dietary records for the backup crew were kept during this period.

Conclusion

The Gemini VII flight crew activities were calculated in part to support a metabolic study. Hence, tasks not related to this objective were minimized, with the result that time could be spent on isometric and isotonic exercise, on exercise with a mechanical device, and on sleep. Also there was more time available for eating. By consuming a larger proportion of the diet provided for them, the crewmen not only increased the amount of calcium which they consumed, but also the quantity of total energy and of other essential nutrients. Furthermore, various foods supplied for this mission were provided with supplementary calcium.

The results of the study show decreased loss of X-ray density of the largest bone in the foot, but with far less dramatic results obtained with the hand. This would indicate to the authors the need for further attention to the development of exercise routines which would involve the hands and fingers.

Without reducing the emphasis on dietary calcium, a probable need also exists for further research in which other nutrients known to be related to skeletal status would serve as variables.

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44. EXPERIMENT M–7, CALCIUM AND NITROGEN BALANCE

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Introduction

The primary objective of Experiment M–7 was to obtain data on the effects of space flight of up to 14 days' duration on two of the largest metabolically active tissue masses of the human body, the bones and muscles, and thus on the functional integrity of the skeletal and muscular systems.

From prior ground-based studies on the effects of bedrest or immobilization on normal human subjects, it has been predicted that the confinement of the Gemini space vehicle, in association with the lack of physical stress and strain on muscles and bones due to weightlessness, would result in substantial losses of calcium, nitrogen, and related elements. Bedrest studies have shown, for example, that in 2 weeks of immobile rest, the amount of calcium excreted in the urine was doubled, and, over longer periods, substantial negative balances or losses of calcium, nitrogen, and other elements occurred. Significant losses in a space flight continuing over a period of several weeks theoretically could lead to a serious weakness of the bones and muscles.

By use of the metabolic-balance method, which involves precise control of the dietary intake and the collection and analysis of all excreta, it is possible to obtain a quantitative determination of the extent of change in the principal inorganic constituents of these systems, the degree of loss thereof being generally proportional to the degree of deterioration in function. Biomedical data on this problem using this quantitative method have not been obtained on previous American or Russian space flights. X-ray films taken before and after the Gemini IV and V flights indicated changes in the equivalent aluminum density of two bones, the heel, and a finger, but these findings cannot yet be equated with calcium losses from the whole skeleton.

Realistic consideration of this metabolic-balance study indicates that it was not, in any true sense, an experiment on the effects of weightlessness on body metabolism, but was rather an observation of biochemical changes occurring as a result of several complex, interrelated influences—principally weightlessness, confinement, moderate physical movement, slight hyperoxia, and low atmospheric pressure.

Because of the tremendous number of analyses to be carried out, specific analytical results are not available at the time of this preliminary report. However, an account can be given of the detailed and intricate protocol and of the generally successful accomplishment of a very difficult study.

Procedure

The general plan of a metabolic study requires continuous procurement of data during a control phase at normal activity on earth for as long a time as is feasible before flight. Complete inflight data and a postflight control phase are also required. In view of the numerous other requirements of the Gemini VII mission, the preflight control phase was limited to 9 days, beginning 14 days before launch. The postflight control phase was even more brief, lasting only 4 days.

The method employed in obtaining quantitative information on a metabolic system requires complete and continuous data on the dietary intake of each constituent under study and continuous collection of all urine and stool specimens before, during, and after the flight. Since under certain circumstances the skin may be an important avenue of excretion of various elements, particularly calcium, perspiration also had to be collected during representative periods before and after flight, and continuously during flight.

Dietary Intake

Not only must the content and composition of all food and water intakes be known, but, insofar as possible, the amounts must be kept as constant as possible. To the extent that the intake of each constituent can be kept constant from day to day and from control-to-experimental phase, the changes in the amounts of these constituents excreted can be safely attributed to the influences of the experiment itself—in this case, the flight. If the intake is not kept relatively constant, then changes in excretory levels will be difficult or impossible to interpret because of their change with the change in intake.

In this particular study, what was essentially necessary for diet control during the preflight and postflight control phases was establishment of metabolic kitchen facilities and techniques for food preparation, weighing, storage, cooking, and serving in the kitchen of the astronauts quarters in the Manned Space Operations Building at Cape Kennedy.

Standard metabolic-study techniques were used for minimizing variations from day to day in the composition of individual food items. All food items were weighed to a precision of 0.1 gram, and liquids were measured to less than 2 milliliters. A sample menu is shown in table 44–I. Variety was made possible by rotation of three daily menus. Table 44–II lists the actual composition (from diet tables) of the nitrogen and calcium consumed day by day during the preflight control phase. The extent to which the values varied from day to day, particularly during the first several days, is due to the fact that no time was available for a precontrol trial of the diets with the four crewmen in the control phase of the study, and also because there was need for adjustments during the study to fit the crewmembers' needs with respect to total calories and bulk. The extent to which the values remained constant from day to day was attributable not only to dietetic skill in menu planning under difficult circumstances, but also to the rapid understanding by the crewmembers of the principles and requirements of constant dietary intake in a metabolic study. The nearly constant diet control was also attempted for phosphorus, magnesium, potassium, sodium, fat, carbohydrate, and total calories.

TABLE 44–I.—*Menu 2 (Sample)*

Meal	Food [a]	Weight, grams
Breakfast	Eggs (2)	100
	Canadian bacon	50
	Bread (toast)	50
	Butter	70
	Puffed rice	20
	Grape jelly	25
	Orange juice	175
	Milk	340
	Coffee or tea	
Lunch	Baked ham	120
	Mashed potatoes	150
	Frozen baby lima beans	95
	Hot rolls	50
	Peach halves, canned	100
	Coffee or tea	
Dinner	Beef tenderloin steak	180
	Onions, Bermuda	30
	Baked Idaho potatoes	150
	Carrots, canned or frozen	100
	Hot rolls	50
	Lettuce	30
	Tomatoes, fresh sliced	75
	Mayonnaise	10
	Apricot halves	100
	Coffee or tea	
	Vanilla ice cream	150

[a] Salt: as desired; sugar: 10 grams.

An important point in overall dietary intake planning was the necessity to impose some degree of constancy of intake, particularly with respect to calcium, long before the control phase actually began, so that the excretory values during this relatively brief phase would not be merely a reflection of adjustment to a change in the customary level of intake. To provide this necessary element of control, the four crewmembers drank two glasses of milk daily for 5 months prior to the beginning of the study.

During the flight phase Edward White and Michael Collins dropped out of the study, while Frank Borman and James Lovell in the Gemini vehicle consumed the prepackaged, solid, bite-sized foods and the freeze-dried foods reconstituted with water which had been prepared on contract for the Crew Systems Division of NASA. Although the food items taken on

TABLE 44-II.—*Experiment M-7, Nitrogen and Calcium Dietary Intake*

[All data in grams per 24 hours]

(a) Preflight control days

Crewman	Element	12	11	10	9	8	7	6	5	4	Mean	Standard deviation
Frank Borman	Nitrogen	27.36	27.54	29.84	25.17	31.02	29.65	23.39	30.50	29.90	28.26	
	Calcium	.973	.982	.986	1.002	1.002	.986	1.000	.980	.999	.990	±0.011
James Lovell	Nitrogen	23.58	23.87	26.26	23.57	26.70	25.87	23.58	26.70	25.87	25.11	
	Calcium	.984	1.010	.992	1.001	.999	.958	.991	1.000	.958	.988	±.109
Edward White	Nitrogen	22.05	24.93	27.82	27.76	32.34	27.62	27.68	30.22	27.09	27.50	
	Calcium	.892	1.006	.985	.980	1.047	1.007	.972	.924	.977	.977	±.046
Michael Collins	Nitrogen	24.50	24.67	27.84	27.86	31.30	30.05	27.97	31.30	30.21	28.41	
	Calcium	.998	.998	.979	.981	1.001	.967	.997	1.001	1.003	.992	±.012

(b) Postflight control days

Crewman	Element	1	2	3	4	Mean	Standard deviation
Frank Borman	Nitrogen	24.54	31.01	22.00	23.66	25.30	
	Calcium	.941	1.045	.871	1.055	.978	±0.088
James Lovell	Nitrogen	22.42	26.08	26.45	24.00	24.74	
	Calcium	.953	.993	.901	1.071	.980	±.072

Gemini VII were generally similar to those on prior flights, certain foods—notably fruit drinks and puddings—were supplemented with calcium lactate in order to provide as closely as possible a mineral intake of the same level as was taken during the control phase. In addition, the flight food was packaged in specific meal-packs to be taken in a definite time sequence so that the day-to-day dietary intake would also remain as constant as possible under these difficult-to-control circumstances. For reasons which are not presently known, the crewmen did not follow the prescribed meal sequence; thus, when the inflight intake data from a combination of log information and diet analyses have been assembled, there will certainly be day-to-day fluctuations. It is possible that calcium fluctuations will turn out to be modest in view of the number of calcium-supplemented food items in nearly all the meals. In any case, since the crewmen consumed the various food items fairly consistently almost in their entirety, the intake of calcium and nitrogen for the block flight period will be closely similar to that of the control phase.

During the first day of the 4-day postflight control phase, the crewmen (onboard the carrier) consumed foods previously prepared at Cape Kennedy. They returned to their quarters at the Cape for the remaining 3 days, and ate the same diet as they did during the preflight control phase.

Collection of Specimens

Bottles, a commode adaptation of toilet seats, and a small refrigerator setup were used in the astronauts' quarters for the collection of all urine and stool specimens during the preflight and postflight control phases. This setup was similar to that used in hospital metabolic research wards. All specimens were labeled by the crewmembers with the initial of their last name, the date, and the time of passage. They were placed immediately in the refrigerator. Specimen collection stations were also set up at the Gemini Mission Simulator and at two other locations at Cape Kennedy. Specimens were picked up by the staff at regular intervals and returned to a laboratory in the Manned Space Operations Building where they were prepared for shipment to Cornell University for analysis.

On 2 days prior to the flight and on 2 days after the flight, perspiration collections were made separately for each crewman. The somewhat involved procedure included an initial washing of the subject's body with distilled water, the wearing of cotton long underwear for 24 hours, and a second body washing. The underwear was rinsed, and the water from this rinse, along with the water from the body washes, was collected and analyzed for minerals and electrolytes.

For the flight phase, collection of perspiration and its analysis were accomplished using the cotton undergarments, which were worn throughout the flight, and the distilled water from the skin wash performed shortly after arrival on the carrier.

Collection of urine and stool specimens during flight was a complex procedure in the weightless state, and it required development of special equipment. It was essential to have stool-specimen collection made with relative ease to assure that fecal material would be well formed. Apparently helpful in this process was the moderately-low-residue character of the metabolic diet which was continued until the morning of the launch. Stool specimens were wrapped securely (with preservative added) in plastic collection devices labeled with the crewman's name and the time. They were stowed in the locker for specimens.

Development of the urine collection device involved a great deal of effort and ingenuity, not merely because of the problem of collecting fluids in the weightless state but also because of lack of space for storage of the total volume of all specimens. It was necessary to devise a method of determining the volume of each voided specimen and then taking an aliquot for storage for later analysis. Several systems were tried, but the one used involved the introduction of a tracer quantity of tritium into an 800-milliliter plastic collection bag which received the urine voiding. After the tracer was well mixed with the full voiding, part was transferred to a 75-milliliter bag for storage and later analysis and the remainder was expelled from the spacecraft.

In actual experience the urine collection device worked well but with some leakage inconvenience at the point of connection between the subject and the device. The more serious problems were as follows:

(1) Since there was considerable concern about adequate stowage space and about whether the volume of each specimen saved could be controlled by the astronauts, one of the astronauts, during the early part of the flight, provided aliquots which were much too small.

(2) One sample bag broke.

(3) Four of the specimen bags were not labeled with either the crewman's name or the time.

Aside from the deficiencies noted above, most of the urine specimens were properly collected and labeled.

This brief summary barely hints at the considerable problems in planning and the tremendous detail involved in specimen collection, labeling, recording, and shipment. A 10-day full runthrough of the methods was conducted in September 1965 at the 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Members of the group involved in that exercise came to Cape Kennedy in November and December to assist in this study.

Analytical Problem

The principal reason that results are not yet available lies in the magnitude of the analytical problem in this study. Analyses are being done on specimens from a total of 76 man-days of study, involving approximately 300 urine specimens, 60 stool specimens, 14 perspiration samples, and an indefinite but large number of diet samples. Each of these specimens is being analyzed for nitrogen, calcium, phosphorus, magnesium, sodium, and potassium. In addition, the urine specimens are being analyzed for creatine, creatinine, sulfate, chloride, and hydroxyproline. Stool specimens are also being analyzed for fat. Added to the number of analyses to be accomplished and correlated, the problem is further complicated in the inflight phase by the irregular time periods from one voiding to the next. Because of this, some difficulty is anticipated in relating the analytical values to a regular 24-hour pattern.

Relationship to Other Experiments

A close working relationship was necessary between Experiments M–7 and M–5, the analysis of body fluids. Blood specimens were collected before and after flight as part of the M–5 protocol for serum calcium, phosphorus, and alkaline phosphatase. In bedrest studies involving extreme immobilization over several weeks, elevations in serum calcium have been noted. M–5 analyses of urine for electrolytes, corticosteroids, and catecholamines require urine collected in both Experiments M–5 and M–7, and aliquots of the urine specimens now at Cornell University are being sent to the Manned Spacecraft Center for the planned M–5 analyses.

Great interest will be focused on the correlation between the degree of apparent mineral loss from the os calcis and metacarpal bones in the M–6 Experiment and the total mineral loss from the whole skeleton, which will be indicated from the balance study. Since the skeleton varies considerably from bone to bone in the relative availability of calcium, the correlation between the two methods, if possible, will not be simple.

Interpretation and Significance of the Study

As indicated initially, during the space flight several influences in addition to weightlessness were present which could have had varying and conflicting influences on calcium metabolism. These included confinement, moderate physical movement, slight hyperoxia, and low atmospheric pressure. In interpreting the results, it may be necessary to deal with the possible interfering effects of the bungee exercise procedure (M–3 Experiment) for both astronauts and the M–1 alternating pneumatic cuff experiment for Lovell. The need is evident for careful selection of studies in future flights to assure as clear-cut answers as possible. In any case, there is a very important need for further ground-based studies to enable sorting out the kind and degree of effect of a number of the possible influences currently imposed on this experiment by various engineering constraints, such as low atmospheric pressure, high oxygen tension, confinement, and exercise. Regardless of these considerations, if significant changes in any of the various aspects of metabolism are found, they will serve as a basis for predicting what derangements of more serious degree are likely to occur on longer flights or in an orbiting laboratory, if well substantiated, effective protective procedures are not developed.

Conclusion

This preliminary report has attempted to describe the difficult and detailed planning, the rather prodigious management effort required by both the investigators and the NASA staff, and the tremendous and perceptive cooperation on the part of the crewmembers and their office that are required for completion of the calcium and nitrogen balance study. Considering the complexity of the study, it was conducted exceptionally well.

45. EXPERIMENT M–8, INFLIGHT SLEEP ANALYSIS

By PETER KELLOWAY, Ph. D., *Chief, Neurophysics, Methodist Hospital, Texas Medical Center, Houston, Tex.*

Introduction

The necessity of monitoring the cardiovascular function during space flight has been recognized and implemented since the inception of the manned space-flight program. More recently, attention has been directed to the possibility of monitoring the brain function during space flight.

A cooperative research program at the Baylor University College of Medicine, at the University of California at Los Angeles Medical School, and at the Manned Spacecraft Center has been directed to the following practical and scientific questions:

(1) Can the electrical activity of the brain, as it is revealed in the electroencephalogram (EEG) recorded from the scalp, provide important and useful information concerning such factors as the sleep-wakefulness cycle, degree of alertness, and readiness to perform?

(2) Is it feasible and practical to record the EEG (brain waves), which is an electrical signal measured in microvolts, under the unique and difficult conditions which prevail during space flight?

The special conditions which exist during space flight consist of such factors as—

(a) Possible electrical interference from the many electrical devices near each other aboard the spacecraft.

(b) The necessity for recording during the routine activity of the subjects with attendant artifacts produced by muscle action, movements, sweating, skin resistance changes, and so forth.

(c) The requirement for miniaturization of the necessary instrumentation to a point sufficiently small and light in weight to justify its existence as part of the payload of the space vehicle.

(d) Provision of scalp electrodes and a method of attachment which would permit prolonged artifact-free recordings without producing significant discomfort or irritation to the scalp. (In clinical practice, electrodes are generally not required to remain in place for longer than 1.5 hours.)

(3) What are the minimal number of brain areas and, hence, of channels of electrical data which are necessary to provide EEG information adequate to identify and differentiate all levels of sleep and wakefulness?

(4) Can computer or other forms of automatic analysis be effectively employed to analyze the EEG data in order to yield the required information, thus avoiding the necessity of having EEG experts constantly at hand to read and analyze the records?

(5) Finally, can highly sophisticated techniques of computer analysis reveal important correlations between EEG activity and higher brain functions having to do with such states as vigilance and attention which are not evident on simple visual analysis of the EEG record?

These are the practical problems which are being studied. In addition, the following scientific questions are under investigation:

(1) Possible influences of weightlessness, and so forth, upon brain function and particularly upon the sleep-wakefulness cycle as evidenced by EEG changes.

(2) The application of computer analysis techniques to the analysis of the EEG under various controlled conditions; for example, sensory stimulation, heightened affective states, mental computation, as well as other similar factors.

Objectives

A major part of this research program has already been completed, but the present report is concerned only with the preflight and inflight data obtained in carrying out the specific experiment, Inflight Sleep Analysis, in connection with the Gemini VII flight.

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The primary purpose of this experiment was to obtain objective and precise information concerning the number, duration, and depth of sleep periods of one of the members of the crew (Command Pilot Borman).

The importance of precise information concerning the sleep (hence, rest) of the crew, especially during prolonged flights, is obvious. The electroencephalogram is capable of providing this information, as the electrical activity of the brain undergoes clearly established and consistent variations with different levels of sleep. Using the EEG, it is possible to distinguish four levels of sleep ranging from drifting or drowsiness to profound sleep, and a special state sometimes called paradoxical sleep or the rapid eye movement stage of sleep, which is believed by many investigators to be important for the psychoaffective well-being of the individual.

Approach and Technique

Baseline Data

Baseline, multichannel EEG, and other psychophysiological data were recorded on Borman and the backup command pilot, White, at the Laboratory of Space Neurobiology at the Methodist Hospital during all stages of sleep and during the waking state. These recordings were used as a baseline for comparison with recordings made in the altitude chamber runs at St. Louis and finally with the inflight records.

Electrodes and Recording System

Preliminary studies of 200 control subjects, and specifically of White's and Borman's preflight EEG's, had shown that all of these stages of sleep could be differentiated and identified in records obtained from a single pair of electrodes placed on the scalp—one in the central, and one in the occipital region. It was also found that if these electrodes were placed in the midline of the head, the least possible artifact from muscle activity was attained. As weight and space limitations permitted only one more EEG recording channel, what was essentially a duplicate of the first electrode pair was used but displaced a few centimeters to the left of the midline. Such electrode placements reveal essentially the same information as the midline pair, but this choice was made (rather than obtaining data from another brain area) to provide for the possibility that one or more of the electrodes of one pair might be dislodged or become defective.

The recording system consisted of two miniature transistorized amplifiers, carried by the astronaut in pockets of his underwear, and a small magnetic tape recorder inside the spacecraft. The tape recorder, running at a very slow speed, was capable of recording 100 hours of data continuously.

Preflight Tests

Preliminary tests of the electrode system, amplifiers, and tape recorder under flight conditions were made first in the altitude chamber at McDonnell Aircraft Corp. and subsequently at the Manned Spacecraft Center.

Another dry-run test was made at Cape Kennedy the day before the flight, and recordings were made at the launch pad prior to lift-off.

All of these preflight runs yielded good recordings, clean of all artifact except that engendered by the movements of the subjects themselves.

Inflight Test

Recording of the EEG was to be continuous throughout the first 4 days of the Gemini VII flight. During these 4 days, the command pilot was to keep his helmet on unless marked discomfort or other factors necessitated its removal. The electrode system was, therefore, designed for a helmet-on arrangement.

Results

The events (as determined from the medical recorder data) from 15 minutes before lift-off to the time one of the second electrode pair was dislodged are shown graphically in figure 45–1. A total of 54 hours and 43 minutes of interpretable EEG data was obtained. Most of these data were of excellent quality from the viewpoint of visual interpretation.

EEG channel 1 became noisy after 25 hours and 50 minutes of flight (indicated by point B), and no interpretable data appeared in this channel after 28 hours and 50 minutes (indicated by point C). EEG channel 2 gave good, artifact-free data up to 43 hours and 55 minutes (point D), at which time it became intermittently noisy. No interpretable data were recorded after 54 hours and 28 minutes of flight (point E), at which time the electrodes for this channel were inadvertently dislodged. The sleep periods (shaded areas) will be discussed later in detail. The meals are indicated in the illustration because they represent periods of temporary interruption of the interpretability of the EEG data due to muscle and movement artifacts produced by rhythmic chewing (fig. 45–2).

As indicated in figure 45–1, 8 hours after lift-off, the command pilot closed his eyes and remained quiet for almost 2 hours—8:12:00 to 10:19:00 ground elapsed time (g.e.t.)—without showing signs of drowsiness or sleep. A portion of the record during this period is shown in figure 45–2.

Sleep is very easy to detect in the EEG records. Figures 45–3 and 45–4 show the distinc-

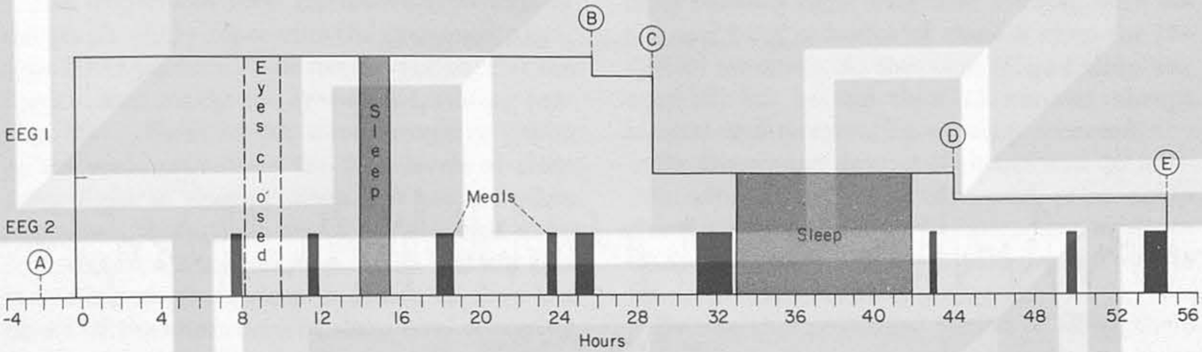

FIGURE 45–1.—EEG data flow.

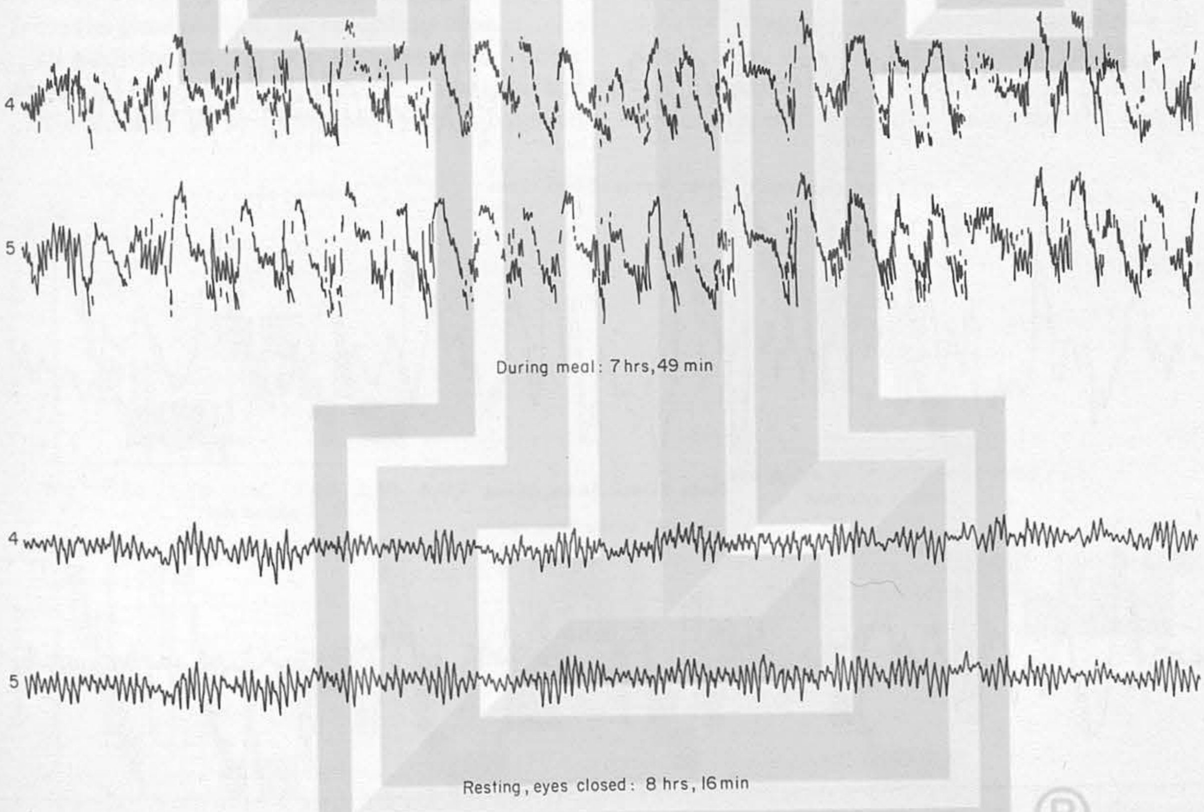

FIGURE 45–2.—EEG recordings taken during rhythmic chewing (upper) and during eyes-closed resting condition (lower).

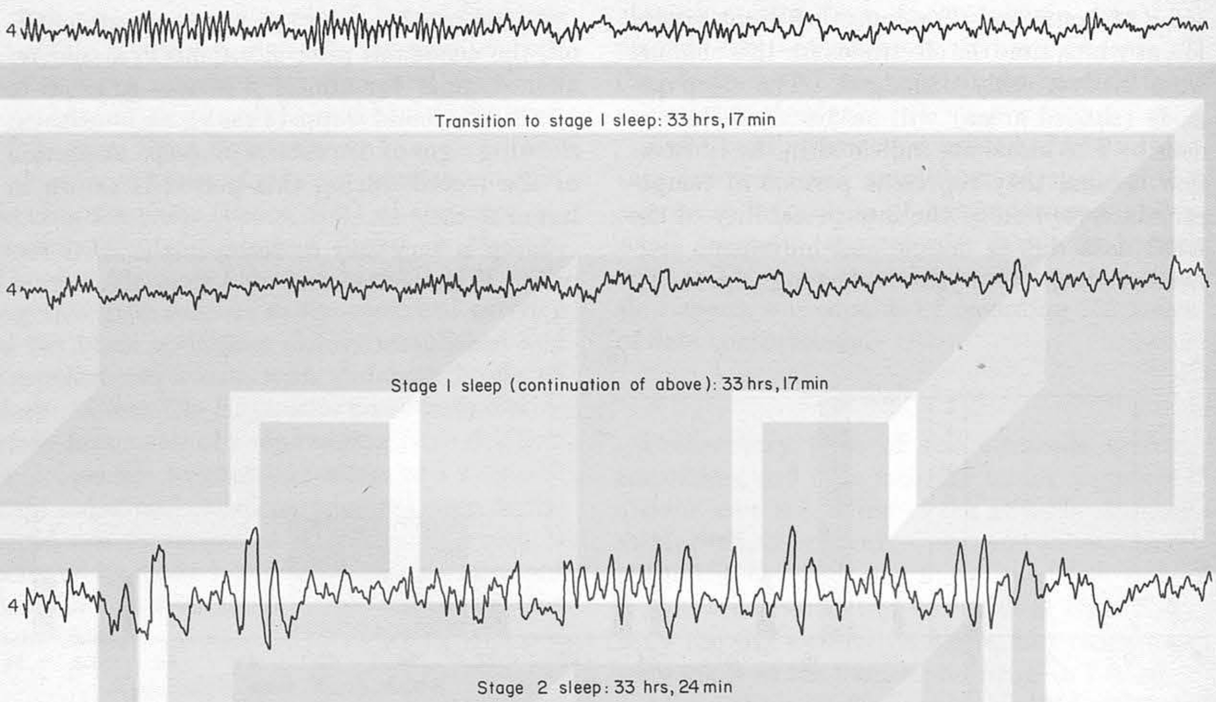

FIGURE 45-3.—EEG recordings showing progression from awake to light sleep.

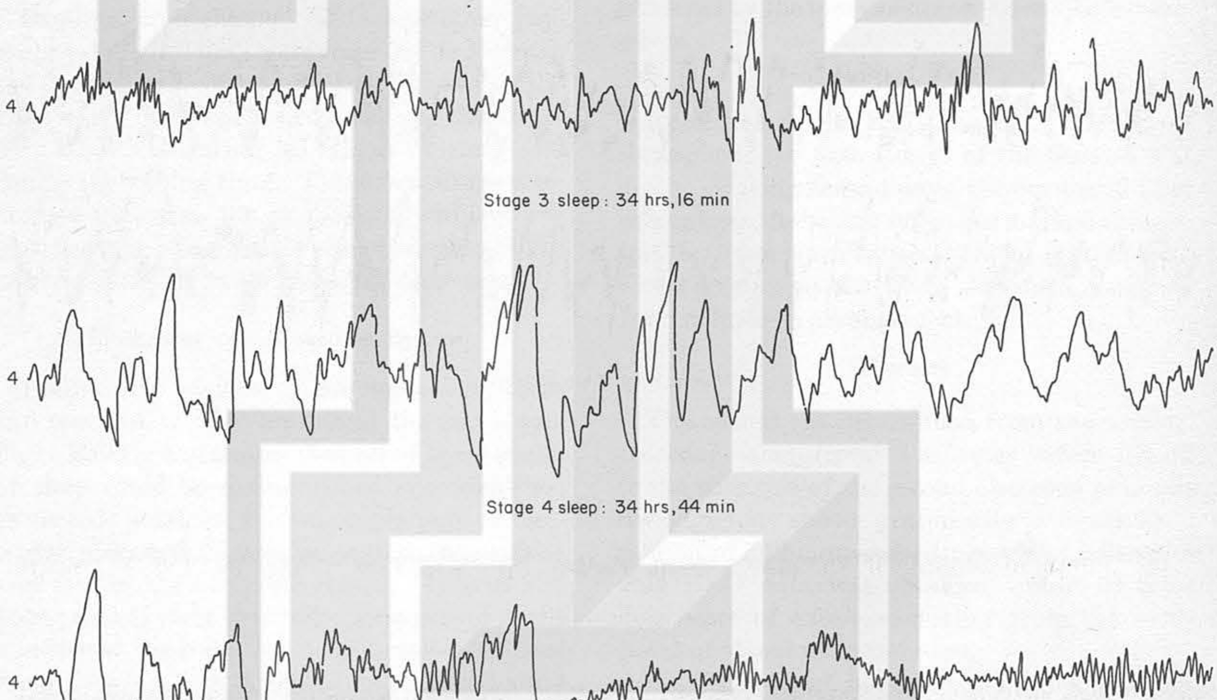

FIGURE 45-4.—Example of EEG recordings of moderate sleep (stage 3), deep sleep (stage 4), and partial arousal.

tive patterns found at each level of sleep. These illustrations were taken from the second sleep period during flight.

The total sleep periods are graphically represented in figure 45–5. For ease of representation, each period of sleep is divided into 1-minute epochs, and these are illustrated by the vertical lines. The length of this line represents the range of sleep level variation during the minute it represents.

The uppermost level on the vertical axis of the graph (EO) represents the eyes-open, alert-type EEG pattern. The next lower part of the vertical axis marks the eyes-closed, resting pattern (O). Each of the next successive points on the scale represents the four levels of sleep from light to deepest sleep. When, as often happened, more than one EEG stage of sleep occurred in a 1-minute epoch, the vertical line indicating stage of sleep is drawn to show the extent of the alterations of sleep level occurring during this time.

The horizontal axis of these graphs represents the flight time in hours and minutes, translated from the time code on the recording tape.

In addition to the two sleep periods during flight, a similar graphic representation is shown of the control or baseline sleep period made in the laboratory in September 1965. This is shown in order to compare the rate and character of the "falling-to-sleep" pattern, but it cannot be used to compare the cyclic alterations occurring in a full night's sleep because the subject was awakened after 2 hours and 45 minutes. The first part of the characteristic cyclic changes of level can, however, be seen.

The first inflight sleep period shown on the right side of the graph showed marked fluctuations between light sleep and arousal, with occasional brief episodes of stage 3 sleep for the first 80 minutes. At that time stage 4 sleep was reached, but in less than 15 minutes abrupt arousal and termination of sleep occurred.

On the second day, at 33 hours and 10 minutes after lift-off, the command pilot again closed his eyes and showed immediate evidence of drowsiness. Within 34 minutes he was in the deepest level of sleep (stage 4).

During this prolonged period of sleep, there were cyclic alterations in level similar to those which occur during a full night of sleep under normal conditions. Such cyclic changes are usually irregular and aperiodic, as shown in figure 45–6, which is taken from a normal control series studied by Dement and Kleitman. Generally, each successive swing toward deeper

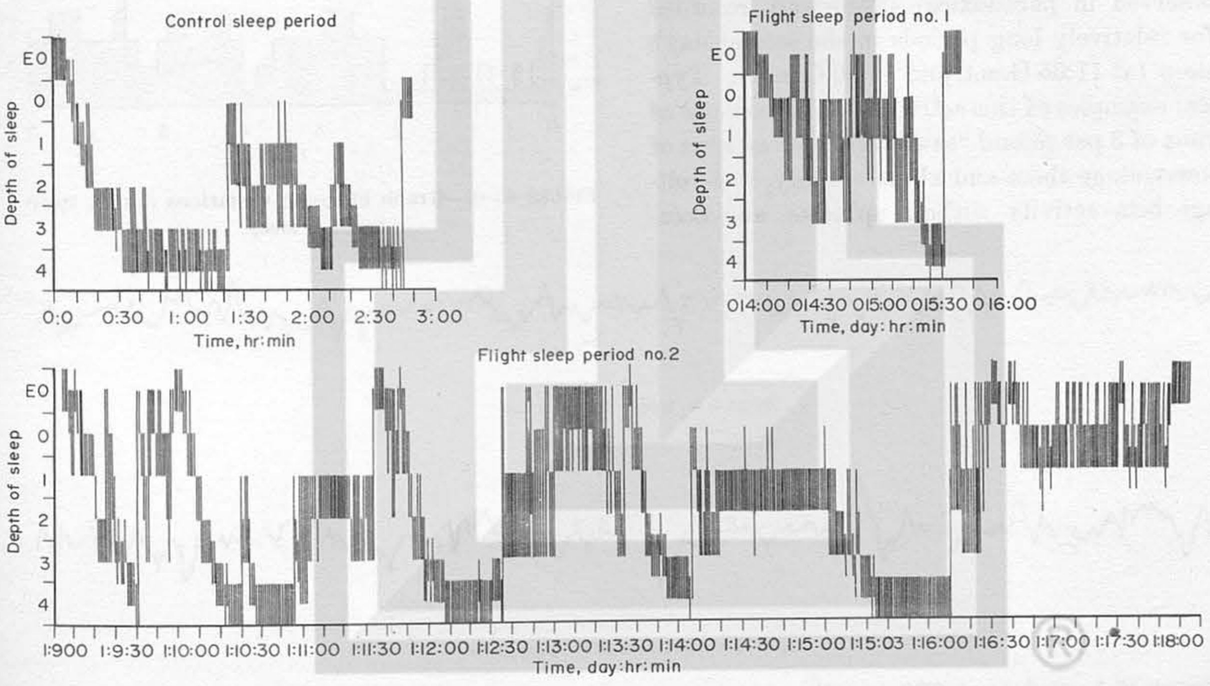

FIGURE 45–5.—Analysis of control sleep period and two flight sleep periods.

sleep, after the first period of stage 4 has been obtained, only reaches successively lighter levels; but, in Borman's second night of sleep, stage 4 was reached and maintained for 20 minutes or more at three different times after the first episode. It is interesting to speculate as to whether this increase in the number of stage 4 periods reflected an effect of deprivation of sleep during the first 24 hours.

After approximately 7 hours of sleep, a partial arousal from stage 4 sleep occurred, and, after a brief period (12 minutes) of fluctuating between stages 2 and 3, Borman remained in a state fluctuating between drowsiness and stage 1 sleep until finally fully roused about 1.5 hours later. Whether any periods of the so-called "paradoxical" sleep, rapid eye movement sleep, or dreaming sleep occurred during this oscitant period cannot be determined with certainty from our records because of the absence of eye movement records and because paradoxical sleep is generally very similar in its character to ordinary stage 1 sleep. However, two periods of a pattern which resemble an admixture of certain characteristics of stage 1 and stage 2 sleep, and which resemble some of the activity which this group and other investigators have observed in paradoxical sleep, were recorded for relatively long periods in the second day's sleep (at 11:05 G.m.t. and 14:20 G.m.t.). Typical examples of this activity (which consists of runs of 3 per second "saw-tooth" waves, runs of low-voltage theta and alpha activity, low-voltage beta activity without spindles, and occasional slow transients with a time course of about 1 second are shown in figure 45-7.

Conclusions

This experiment has clearly demonstrated the feasibility of recording the EEG during space flight. Refinement of technique and the development of more comfortable and efficient electrode systems will soon permit recording throughout prolonged space flights.

The precise information which the EEG can afford concerning the duration, depth, and number of sleep periods suggests that EEG monitoring should be considered for routine use in the prolonged space flights contemplated in the Apollo and other programs.

The importance of such information in the direction and execution of the flight, both to the medical monitors on the ground and to the crew, is evident.

In the meantime, EEG studies presently planned in the Gemini and Apollo programs, correlated in time with activity and events aboard the space vehicle, should provide important information for the formulation of future flight plans in relationship to scheduling of sleep periods.

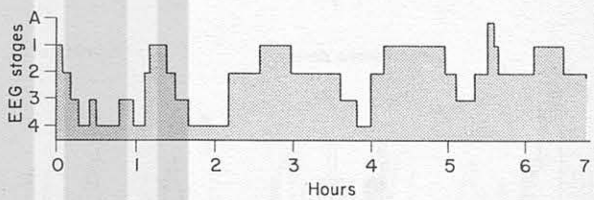

FIGURE 45-6.—Graph of cyclic variations during spontaneous sleep.

FIGURE 45-7.—Sample of EEG recording showing a mixture of stage 1 and stage 2 sleep (possibly representing "paradoxical" sleep phase).

The analysis of sleep by EEG is a very elementary exercise at the present state of the art. The possibility that monitoring electrical brain activity may yield important information concerning higher brain functions during flight has yet to be fully explored. It is to be hoped that the full exploration of the potentiality of electroencephalography as an analytic tool in brain function can be realized through the intense efforts catalyzed by the space program.

46. EXPERIMENT M–9, HUMAN OTOLITH FUNCTION

By Earl Miller, M.D., *U.S. Navy School of Aviation Medicine*

Objective

The purpose of the M–9 Experiment for the Gemini VII flight was identical to the experiment carried out in conjunction with the fifth flight of the Gemini series. In these flights, two kinds of information were sought:

(1) The ability of the astronauts to estimate horizontality with reference to the spacecraft in the absence of vision and primary gravitational cues.

(2) The possible effect of prolonged weightlessness on otolith function.

Preliminary results obtained during the Gemini V mission are contained in reference 1. In this report comparisons will be made among the results of the four pilots (A, B, C, D) involved in the Gemini V and VII missions.

Egocentric visual localization of the horizontal (EVLH) was the test chosen to measure "horizontality," inflight as well as preflight and postflight. It may best be described by means of an illustration (fig. 46–1). If an observer, while seated upright under ordinary conditions, regards a dim line of light in darkness, he is able to set a line in the dark to the horizontal with great accuracy (ref. 2). If, under proper conditions, he is exposed to a change in the gravitoinertial vertical with respect to himself, he is able to set the line approximately perpendicular to the changing direction of the mass acceleration (ref. 3). This indicates that in the absence of visual cues (the line itself is an inadequate cue), the ability of the observer to estimate the vertical and horizontal is due to the influence of primary and secondary gravitational cues. Persons with bilateral loss of the organs of equilibrium (otolith apparatus) are inaccurate in carrying out this task, indicating the important role of the otolith apparatus in signaling the upright. In weightlessness, primary gravitational cues are lost, and the otolith apparatus is physiologically deafferentated (ref. 4); that is to say, it has lost its normal stimulus. This creates a unique opportunity to investigate the role of secondary gravitational cues in orientation to the environment with which a person is in contact. The crewman in orbital flight is cued to his spacecraft, even with eyes closed, by virtue of tactile cues. Consequently, as a first step in exploring the loss of primary gravitational cues in space flight, it was deemed worthwhile to obtain serial EVLH measurements.

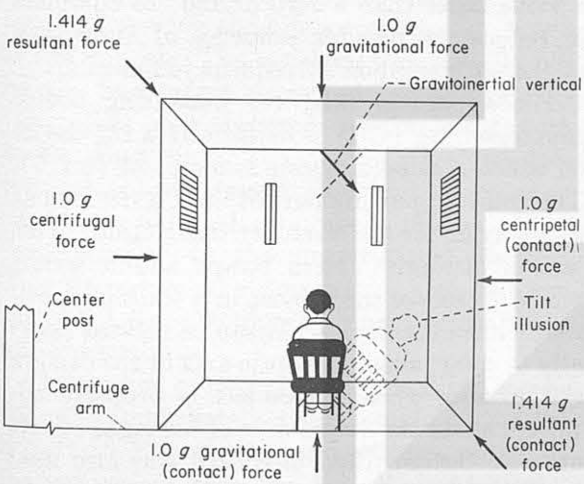

Figure 46–1.—Diagram illustrating egocentric visual localization of the horizontal in response to and in accordance with the direction of the active gravitational or gravitoinertial force.

Otolith function was measured by means of ocular counterrolling (ref. 5) during preflight and postflight periods. It depends on the observation that, when a person is tilted rightward or leftward, the eyes tend to rotate in the opposite sense. If proper technique is used (ref. 5), the amount of counterroll can be measured accurately. Persons with bilateral loss of otolith function either do not manifest counterrolling or the roll is minimal, possibly indicating a slight residual function (ref. 6). In its present form this test cannot be carried out in a small spacecraft; hence, the limitation exists for preflight and postflight measurements. The object of the test was to determine whether prolonged physiological deafferentation of the otolith apparatus had changed its sensitivity of response.

Apparatus and Procedure

The apparatus for measuring the EVLH of the spacecraft was incorporated into the onboard vision tester which was part of the S-8/D-13 Experiment. This incorporation was made to save weight and space and represented only a physical interface; in all other respects the two experiments were completely separate entities. The inflight vision tester is a binocular instrument (fig. 46-2) with an adjustable interpupillary distance (IPD) but without any focusing adjustment. The instrument device is held at the proper position, with the lines of sight coincident with the optic axes of the instrument, by means of a biteboard individually fitted to the subject. This insured that at each use the instrument was similarly located with respect to the subject's axes, if he had made the proper IPD adjustment. In this position the eyecups attached to the eyepieces of the instrument excluded all extraneous light from the visual field.

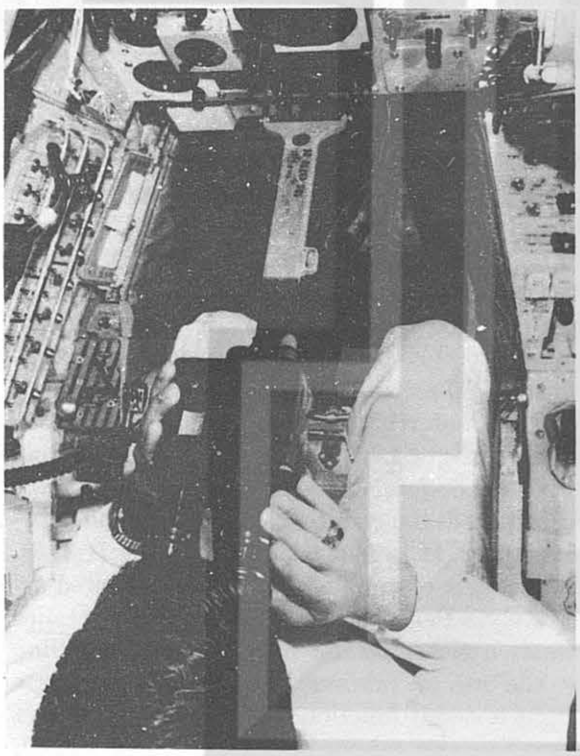

FIGURE 46-2.—Subject using vision tester with head brace attached to the instrument panel of the spacecraft.

Direct-current power regulated by the instrument was supplied by the spacecraft.

A headbrace, as shown in figure 46-2, was provided to connect the biteboard 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 Gemini V mission, but a similar positioning of the instrument was achieved by having the subject sit erect in his seat with his head alined with the headrest.

The apparatus used represented a modification and miniaturization of a target device previously described (ref. 3). 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 digit readout of line position was easily seen and was accurate within ±0.25°.

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

The apparatus used for measuring ocular counterrolling (CR) is essentially a tilt device on which a camera system is mounted (ref. 7). The main supporting part of the CR 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. It can be rotated laterally to ±90° about the optic axis of the camera system and, when the subject is properly adjusted, about the visual axis of his right or left eye. A custom fitted biteboard was also used in CR 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-millimeter camera with bellows extension and an electronic flash unit. 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 galvanometer recorder was mounted to the head portion of the device for shipboard use.

A test cubicle 12 feet by 16 feet by 10 feet (height) insulated against outside sounds, light, and temperature was constructed for carrying out the postflight tests of EVLH and CR onboard the recovery carrier.

Method

The preflight testing of CR and EVLH for both subjects was accomplished at Pensacola, Fla., and Cape Kennedy at 19 and 6 weeks, respectively, prior to the flight.

Immediately prior to the preflight and postflight testing of EVLH, one drop of 1 percent pilocarpine hydrochloride ophthalmic solution was instilled in the subject's eye which was opposite to the eye used for making visual orientation judgments. The subject was then placed in the CR tilt device, properly adjusted, and secured. The method of conducting the preflight and postflight EVLH test was as follows: The IPD of the vision tester was adjusted and the device was brought into its proper position by inserting the biteboard into the mouth of the subject. The experimenter initially offset the line target presented to one eye only (the other eye observed a completely dark field). By means of the knurled wheel, the subject rotated the target clockwise or counterclockwise until it appeared to be alined perpendicular to the gravitational vertical. This procedure was repeated in each test session until eight settings had been made in the upright position.

The method of testing EVLH in flight was as follows: Immediately after completion of the S-8/D-13 Experiment, and without removing the instrument from his face, the subject prepared for EVLH testing by occluding the left eyepiece (command pilot) or right eyepiece (pilot) by means of the ring of the eyepiece, and turning on the luminous target before the opposite eye. The target appearing against a completely dark background was initially offset at random by the observer pilot. The subject pilot's experimental task was to adjust the target until it appeared horizontal with respect to his immediate spacecraft environment. The subject, when satisfied with each setting, closed his eyes and removed his hand from the knurled ring. This served as a signal to the observer pilot to record the setting and offset the target. This procedure was repeated five times during each of the daily test sessions. The vision tester was then 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. The subjects were instructed to apply the same amount of tension on their seat belts during the EVLH test in an attempt to keep the influence of secondary gravitational cues upon these judgments as constant as possible.

The preflight and postflight measurements of ocular CR were accomplished according to the standard procedure used at the U.S. Naval Aerospace Medical Institute. Following the EVLH test, the subject remained in the upright position in the tilt device. The vision tester and its biteboard were removed, and preparations were made for photographically recording the eye position associated with a given position of body tilt. The CR biteboard 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 ($\pm 25°$, $\pm 50°$) and the same photographic procedure was repeated.

The accelerometer system was used during the postflight EVLH and CR tests to record continuously the motions of the recovery ship around its roll, pitch, and yaw axes.

During the EVLH and CR tests, readings of blood pressure, pulse rate, and electrocardiogram were monitored by NASA Manned Spacecraft Center medical personnel. Postflight examinations were begun for pilot D and pilot C approximately 4.5 and 6 hours, respectively, following their recovery at sea.

Results

Ocular Counterrolling

Preflight.—Three separate preflight measurements of ocular CR (fig. 46–3) made on the same day indicated that basic otolithic function of pilot C and pilot D were well within the range of counterrolling response found among a random population of 100 normal subjects (represented in fig. 46–4 by the shaded area). This CR response of each member of Gemini VII crew is markedly different from that found for the crew pilots (CP, CN) but similar to other crewmen who have been tested (fig. 46–4).

Postflight.—As seen in figure 46–3, postflight measurements (solid line) revealed no significant change in the mean CR response from that manifested before the flight (broken line). The slight differences in the CR 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.

Egocentric Visual Localization of the Horizontal (EVLH)

Preflight and postflight.—The deviations from the instrument's zero of the pilot's discrete EVLH settings are summarized in figure 46–5. The judgments of each pilot in an upright body position as to the location of the horizontal under normal gravitational conditions were somewhat unstable prior to the flight. In approximately one-half the settings, deviations greater than 5° were recorded, and one setting of each pilot exceeded 10°. On the day of recovery, the pattern of response was similar to that of preflight in spite of the fact that the judgments were made under unstable, though relatively calm, sea conditions. The accelerometer tracings are being analyzed to determine the magnitude of linear and angular acceleration that occurred during the postflight test.

Inflight.—The EVLH judgment throughout the flight showed no trends with respect to longitudinal changes in the stability or absolute position of horizontal within the spacecraft. However, it should be noted that, on the initial day of testing, pilot C revealed somewhat more deviation on the average than during succeeding test sessions. In general, comparison of estimations of horizontality under weightless conditions were substantially more closely oriented to the immediate physical environment and more consistent than comparable EVLH settings under standard gravitational conditions.

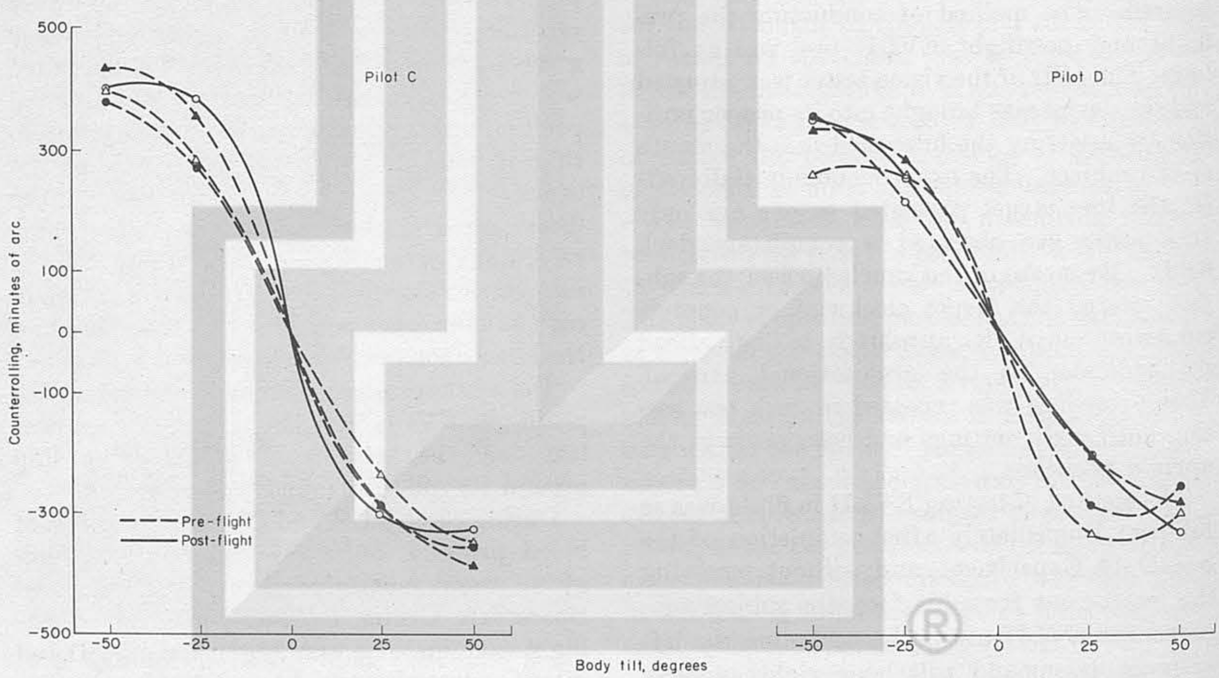

FIGURE 46–3.—Mean counterrolling response of each pilot subject.

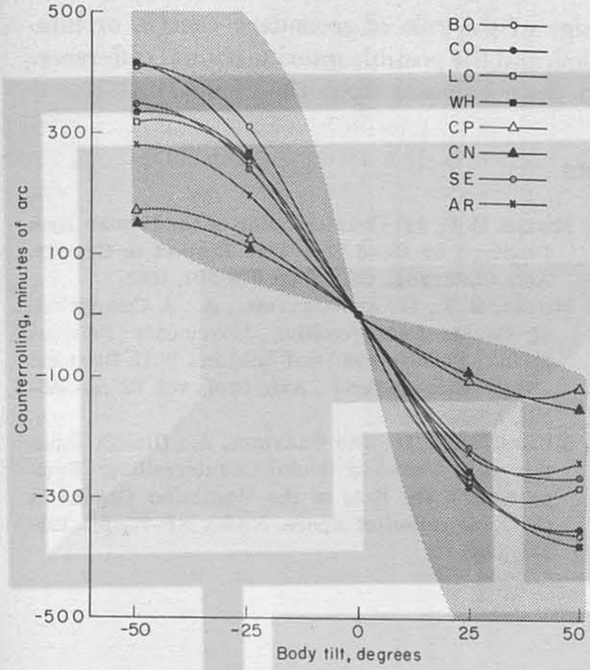

FIGURE 46-4.—Counterrolling response curves of eight astronauts (shaded area represents range of response of 100 randomly selected subjects).

Discussion

The completion of the M-9 Human Otolith Function Experiment carried out in conjunction with the Gemini V and VII flights has provided quantitative information concerning otolithic sensitivity and orientation of four subjects exposed to an orbiting spacecraft environment for prolonged periods of time.

Preflight counterrolling measurements revealed marked differences between the Gemini V and VII crews with regard to the magnitude of their basic response; however, after the flight, each pilot maintained his respective preflight level of response, which indicated that no significant change in otolithic sensitivity occurred as a result of the flight, or at least no change persisted long enough to be recorded several hours after recovery.

The EVLH data recorded for each subject confirmed the observation made repeatedly in parabolic flight experiments that a coordinate space sense exists even in weightlessness if contact cues are adequate; however, it was found that the apparent location of the horizontal within the spacecraft may not necessarily agree

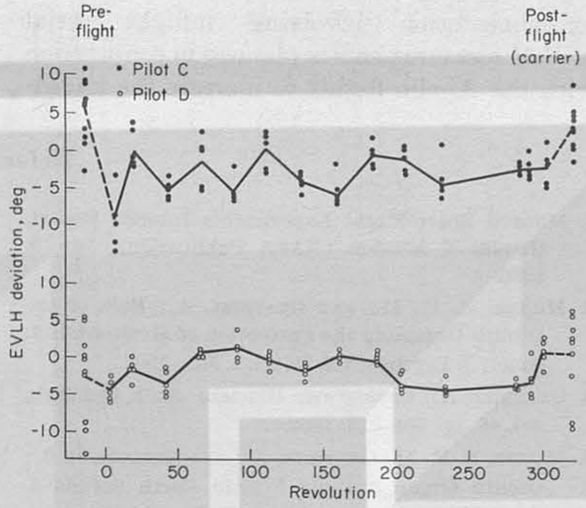

FIGURE 46-5.—Deviation from instrument's absolute zero of individual settings of EVLH.

with its physical correlate in the spacecraft (a line parallel to the vehicle's pitch axis). The data taken of pilot A, for example, revealed greater than 30° deviation from the absolute horizontal, indicating that with eyes closed the cues furnished by virtue of contact with the spacecraft did not allow correct perception of the cabin vertical. The uniformity of his settings throughout the flight suggested, furthermore, that "learning" did not occur in the absence of any knowledge of the accuracy of these estimates. With one possible exception already noted on pilot C in his first inflight test session, EVLH judgments were relatively accurate and more stable than under normal gravitational conditions. These data show that relatively accurate and consistent nonvisual orientation is possible throughout a prolonged period of weightless exposure so long as secondary cues are adequate. These same cues, however, may, in certain individuals, contribute to rather large errors in the perception of the principal coordinates of the spacecraft.

The potential influence of sensory cues on orientation is well known to the aviator who has experienced the "leans," that is, the tendency either to fly with one wing low, or, in straight and level flight using instruments, to feel inclined away from the "upright." This not uncommon illusion occurs in spite of the relative abundance of cues in this situation compared with those in a spacecraft. Further experimentation involving inflight serial EVLH measurements is planned in conjunction with the Apollo flights to increase the knowledge of the role of secondary cues in orientation, and the possible interindividual differences in their influence upon the crewman.

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APPENDIXES

APPENDIX A

NASA CENTERS AND OTHER GOVERNMENT AGENCIES

This appendix contains a list of Government agencies participating in the Gemini Program.

NASA Headquarters, Washington, D.C., and the following NASA centers:
- Ames Research Center, Moffett Field, Calif.
- Electronics Research Center, Cambridge, Mass.
- Flight Research Center, Edwards, Calif.
- Goddard Space Flight Center, Greenbelt, Md.
- Kennedy Space Center, Cocoa Beach, Fla.
- Langley Research Center, Langley Station, Hampton, Va.
- Lewis Research Center, Cleveland, Ohio
- Manned Spacecraft Center, Houston, Tex.
- Marshall Space Flight Center, Huntsville, Ala.

Department of Defense, Washington, D.C.:
- Department of the Army
- Department of the Navy
- Department of the Air Force

Department of State, Washington, D.C.

Department of Commerce, Washington, D.C.

Department of the Interior, Washington, D.C.

Department of Health, Education, and Welfare, Washington, D.C.

Department of the Treasury, Washington, D.C.
- U.S. Coast Guard

Atomic Energy Commission, Washington, D.C.

Environmental Science Services Administration

U.S. Information Agency, Washington, D.C.

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APPENDIX B

CONTRACTORS, SUBCONTRACTORS, AND VENDORS

This appendix contains a listing of contractors, subcontractors, and vendors that have Gemini contracts totaling more than $100 000. It represents the best effort possible to obtain a complete listing; however, it is possible that some are missing, such as those supporting activities not directly concerned with Manned Spacecraft Center activities. These contractors, subcontractors, and vendors are recognized as a group.

Contractors

Acoustica Associates, Inc., Los Angeles, Calif.
Aerojet-General Corp., Downey, Calif.
Aerospace Corp., El Segundo, Calif.
Arde Portland, Inc., Paramus, N.J.
AVCO Corp., Stratford, Conn.
Burroughs Corp., Paoli, Pa.
Bechtel Corp., Los Angeles, Calif.
Bell Aerosystems Co., division of Bell Aerospace, Buffalo, N.Y.
CBS Labs Inc., Stamford, Conn.
Cook Electric Co., Skokie, Ill.
David Clark Co., Inc., Worcester, Mass.
Evans Construction Co., Houston, Tex.
Farrand Optical Co., Inc., Bronx, N.Y.
Federal Electric Corp., Paramus, N.J.
Garrett Corp., The, AiResearch Mfg. Co. Division, Los Angeles, Calif.
General Dynamics/Astronautics Division, San Diego, Calif.
General Dynamics/Convair Division, San Diego, Calif.
General Electric Co., Syracuse, N.Y.
General Electric Co., West Lynn, Mass.
General Precision, Inc., Binghamton, N.Y.
Honeywell, Inc., Minneapolis, Minn.
International Business Machines Corp., Owego, N.Y.
J. A. Maurer, Inc., Long Island City, N.Y.
Ling-Temco-Vought Aerospace Corp., Dallas, Tex.
Lockheed Missiles & Space Co., Sunnyvale, Calif.
Martin Co., Division of Martin-Marietta Corp., Baltimore, Md.
Martin Co., Division of Martin-Marietta Corp., Denver, Colo.
McDonnell Aircraft Corp., St. Louis, Mo.
Melpar, Inc., Falls Church, Va.
North American Aviation, Inc., Rocketdyne Division, Canoga Park, Calif.
Philco Corp., Philadelphia, Pa.
Philco Corp., WDL Division, Palo Alto, Calif.
Space Labs, Inc., Van Nuys, Calif.
TRW Systems, Inc., Redondo Beach, Calif.
Sperry Rand Corp., Sperry Phoenix Co. Division, Phoenix, Ariz.
Western Gear Corp., Pasadena, Calif.
Whirlpool Corp., St. Joseph, Mich.

Subcontractors and Vendors

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ACR Electronics Corp., New York, N.Y.
Advanced Communications, Inc., Chatsworth, Calif.
Advanced Technology Laboratories, Inc., Mountain View, Calif.
Aeronca Manufacturing Corp., Baltimore, Md.
Aeroquip Corp., Jackson, Mich.
American Machine & Foundry Co., Springdale, Conn.
American Radiator & Standard Sanitary Corp., Mountain View, Calif.
Astro Metallic, Inc., Chicago, Ill.
Autronics Corp., Pasadena, Calif.
Avionics Research Corp., West Hempstead, N.Y.
Barnes Engineering Co., Stamford, Conn.
Beech Aircraft Corp., Boulder, Colo.
Bell Aerosystems Co., Buffalo, N.Y.
Bendix Corp., Eatontown, N.J.
Brodie, Inc., San Leandro, Calif.
Brush Beryllium Co., Cleveland, Ohio

Brush Instrument Corp., Los Angeles, Calif.
Burtek, Inc., Tulsa, Okla.
Cadillac Gage Co., Costa Mesa, Calif.
Cannon Electric Co., Brentwood, Mo.
Cannon Electric Co., Phoenix, Ariz.
Calcor Space Facility, Whittier, Calif.
Captive Seal, Inc., Caldwell, N.J.
Central Technology Corp., Herrin, Ill.
Clevite Corp., Cleveland, Ohio
Clifton Precision Co., Clifton Heights, Pa.
Collins Radio Co., Cedar Rapids, Iowa
Computer Controls Corp., Framingham, Mass.
Comprehensive Designers, Inc., Philadelphia, Pa.
Consolidated Electrodynamics Corp., Monrovia, Calif.
Cosmodyne Corp., Hawthorne, Calif.
Custom Printing Co., Ferguson, Mo.
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Douglas Aircraft Co., Inc., Tulsa, Okla., and Santa Monica, Calif.
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Edgerton, Germeshausen & Grier, Inc., Boston, Mass.
Electro-Mechanical Research, Inc., Sarasota, Fla.
Electronic Associates, Inc., Long Branch, N.J.
Emerson Electric Co., St. Louis, Mo.
Emertron Information and Control Division, Litton Systems, Inc., Newark, N.J.
Engineered Magnetics Division, Hawthorne, Calif.
Epsco, Inc., Westwood, Mass.
Explosive Technology, Inc., Santa Clara, Calif.
Fairchild Camera & Instrument Corp., El Cajon, Calif.
Fairchild Camera & Instrument Corp., Cable Division, Joplin, Mo.
Fairchild Controls, Inc., Division of Fairchild Camera & Instrument Corp., Hicksville, N.Y.
Fairchild Hiller Corp., Bayshore, N.Y.
Fairchild Stratos Corp., Long Island, N.Y.
Garrett Corp., The, AiResearch Manufacturing Co. Division, Los Angeles, Calif.
General Electric Co., West Lynn, Mass.
General Precision, Inc., Binghamton, N.Y.
General Precision Aerospace, Little Falls, N.Y.
Genistron, Inc., Bensenville, Ill.
Giannini Controls Corp., Duarte, Calif.
Goodyear Aerospace Corp., Akron, Ohio
Gulton Industries, Hawthorne, Calif.
Hamilton-Standard, Division of United Aircraft Corp., Windsor Locks, Conn.
Hexcel Products, Inc., Berkeley, Calif.
H. L. Yoh Co., Philadelphia, Pa.
Honeywell, Inc., Minneapolis, Minn.
Honeywell, Inc., St. Petersburg, Fla.
Hurletron Corp., Wheaton, Ill.
Hydra Electric Co., Burbank, Calif.
International Business Machines Corp., Owego, N.Y., and New York, N.Y.
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Sperry Rand Corp., Torrance, Calif.
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Union Carbide Corp., Whiting, Ind.
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Western Gear Corp., Lynwood, Calif.
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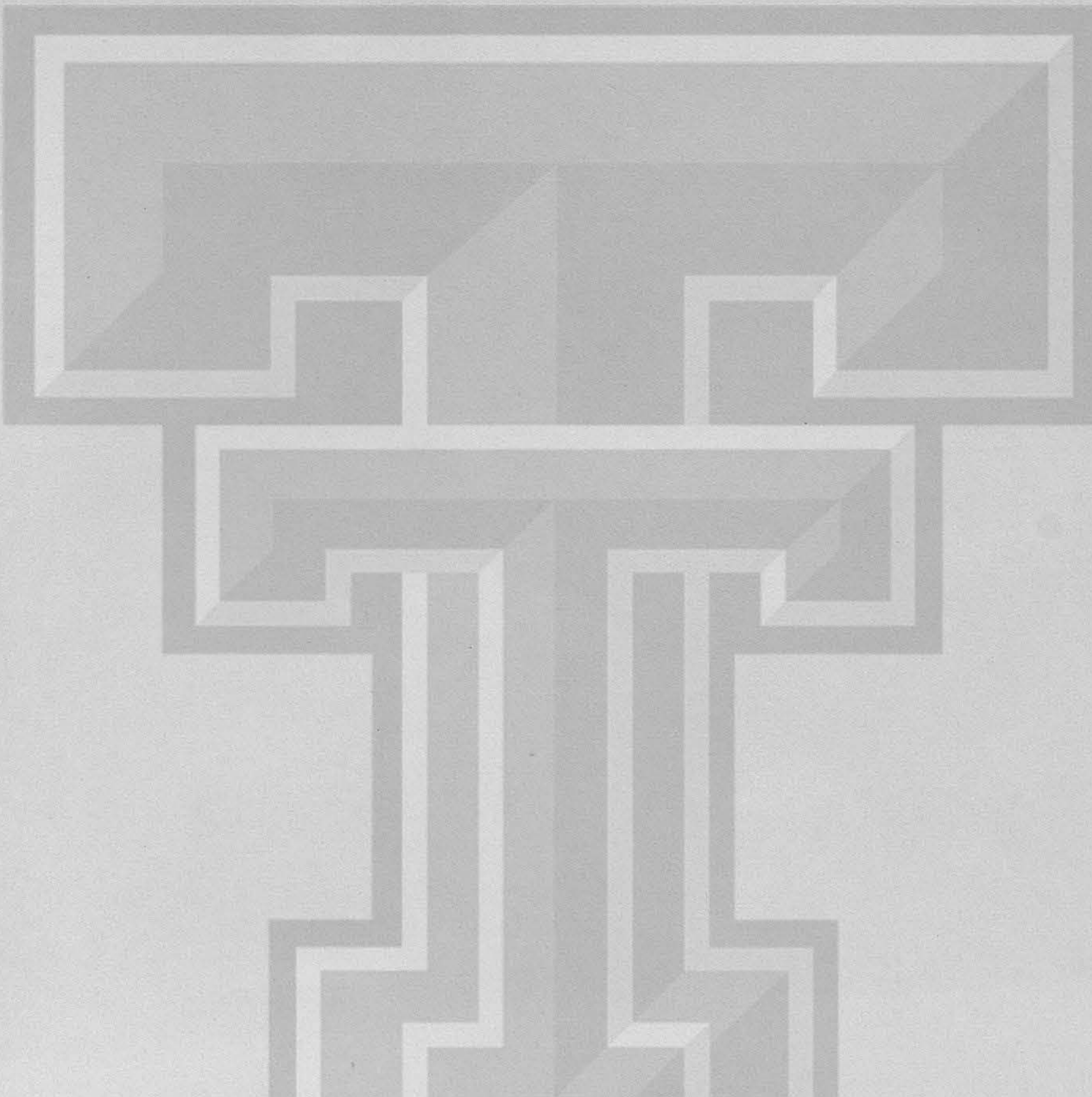

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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