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NASA TECHNICAL MEMORANDUM

THE GEMINI PROGRAM

BIOMEDICAL SCIENCES EXPERIMENTS SUMMARY

Compiled by Edward O. Zeitler and Thomas G. Rogers
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September 1971

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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FOREWORD

The Gemini Program Experiments Summaries are a compilation of the experiments that were performed on the Gemini III to XII missions. These results have been amended and annotated to include updated information. Therefore, this summary is not just a rewrite of the original information. The summaries are arranged according to experiment, rather than according to mission.

Fundamentally, two major divisions have been established: biomedical sciences experiments and physical sciences experiments. Within these major divisions, several subdivisions have been established, and, within these subdivisions, the individual experiments have been arranged in an order that emphasizes the interrelationships of many of the experiments. No rank of importance is expressed or implied by the sequence of the experiments.

Just as the Gemini Program was amplified by the knowledge and techniques that were developed during Project Mercury, the Apollo Program is being augmented by the achievements that were made during the Gemini Program. It is hoped that this document results in an augmented awareness of the tremendous importance of the Gemini Program Experiments and the effect of these experiments on the manned space-flight program.

THE GEMINI PROGRAM EXPERIMENTS

By Robert O. Piland* and Paul R. Penrod*

INTRODUCTION

During Project Mercury, it was proven that man can function as a pilot-engineer-experimenter for as many as 34 hours in weightless flight. Therefore, it was a primary objective of the Gemini Program to explore the capabilities of man in situations of longer duration and more complex missions. The proven effectiveness of man as a scientific observer in orbital flight was supported by the capabilities of the Gemini spacecraft with respect to scientific-equipment accommodation, fuel budget, attitude-control system, and habitability for extended missions. All of these factors, in context with the planned mission profiles, afforded an unprecedented opportunity for the performance of a comprehensive program of inflight experiments. Therefore, from the beginning of the Gemini Program, there was a parallel and concerted effort by NASA to support the generation of suitable experiments from all sources. Among others, these sources included educational institutions, U.S. Government agencies, NASA field centers, the Department of Defense, and industrial laboratories. Experiments of significance to the life sciences and the physical sciences were developed.

It is apparent that the concentration of experiments has been on the long-duration missions. This was done because of the inherent influence of time, which facilitates a larger data yield for time-sensitive parameters, repetitious contacts with selected subjects, and increased potential for objects of opportunity. However, the increased crew time that was available for the operation of equipment and participation in experimental protocol was of great significance. Also, it should be emphasized that planning on a programwide basis permitted the scheduling of experiments on multiple flights if these additional data points (with the associated continuity in time and procedures) were significant. Finally, more ambitious mission objectives (such as crewmember extravehicular activities and rendezvous and docking) facilitated the programing of experiments that extended beyond the confines of a single spacecraft, and even beyond the limitations of a single mission.

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PROCEDURES

To take most effective advantage of the capabilities that have been described, the following procedures were used. Experiment proposals were evaluated by NASA personnel within the framework of the following major considerations.

1. Life-science or physical-science merit
2. Effect on flight safety
3. Extent of spacecraft changes required
4. Mission compatibility
5. Readiness and qualification of equipment
6. Extent of crewmember participation
7. Attitude-control fuel budget
8. Weight and volume
9. Instrumentation and electrical power

After the selection of experiments that were in concert with these criteria, the principal investigators for the proposed experiments were contracted by NASA to design, develop, qualify, and deliver flight equipment in accordance with the Gemini Program management and design criteria. Also included was the requirement to establish the necessary experimental protocol and support the preflight, inflight, and postflight activities that were associated with the particular experiment.

Activities in the immediate preflight interval were variable and were unique to each experiment. Crewmember familiarization with objectives and training in procedures were the responsibility of the principal investigators, and each principal investigator was required to define and to assist as required in procedure implementation. Similarly, when base-line data on crewmember physiological parameters were required, the principal investigator had an equivalent responsibility. Preparation and the state of readiness of special ground-based targets or ground-located participating equipment was a principal investigator task. Participation in final crewmember briefings, equipment checks, and NASA-sponsored press conferences was required.

During the mission, availability of the principal investigator for consultation on real-time adjustment of experimental procedures was essential. Also, the manning and operation of ground-based targets and participating equipment sites were required.

Postflight activities included participation in the scientific debriefing of the crewmen. A summary compilation of experimental results was required for incorporation in the mission report during the immediate postflight interval. It is NASA policy to sponsor, within 90 days after a mission, a public report of the experimental results to

the extent of reduction and analysis that exists at the time. A final publication of results is required when data analysis is complete and when conclusions are established firmly.

CONCLUSION

The inflight experiments that were completed were successful, and these experiments are indicative of the desirability of full use of the capabilities of subsequent spacecraft designs and missions for the performance of an experiments program. The results of these experiments and similar experimental programs should contribute immeasurably to the related technologies and to the basic and applied sciences.

CONTENTS

INTRODUCTION TO THE GEMINI PROGRAM BIOMEDICAL SCIENCES EXPERIMENTS

By Thomas G. Rogers*

The capability of man to function in space was demonstrated during Project Mercury. A major objective during the Gemini Program was to acquire operational proficiency for manned space flight. As has been noted elsewhere (ref. 1), the experiments of the Gemini Program "have been of a nature that required or exploited man's capability to discriminate for the collection of data, and then retrieve the data for postflight evaluation." A significant portion of this information not only was collected by man for the benefit of man, but was collected from man in the role of an experimental subject. Those experiments that did not involve the use of a human subject did involve the use of biological systems that could be used to make inferences regarding the biological safety of man in space. A flight summary of the experiments is given in table I.

At the end of Project Mercury, there were no problems regarding launch and reentry acceleration, spacecraft control, psychomotor performance, eating and drinking, orientation, and urination; however, problems remained regarding defecation, sleep, and orthostatic hypotension (ref. 2). This situation had a great influence on mission-duration planning during the Gemini Program. The following statements provide perspective regarding the experiment program (ref. 2). "Certain procedures have been considered of such importance that they have been designated operationally necessary and have been performed in the same manner on every mission. Other activities have been put into the realm of specific medical experiments in order to answer a particular question or to provide a particular bit of information. These investigations have been programed for specific flights. An attempt has been made to aim all of the medical investigations at those body systems which have indicated some change as a result of our earlier investigations."

From the operational and experimental observations, sufficient biomedical knowledge was gained that it could be stated (ref. 3) that "Although much remains to be learned, it appears that if man is properly supported, his limitations will not be a barrier to the exploration of the universe." The biomedical experiments that formed a large part of the evidence upon which that statement was based are the subject of the Gemini Program Biomedical Sciences Experiments Summary.

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TABLE I.- THE GEMINI PROGRAM BIOMEDICAL SCIENCES EXPERIMENTS

FLIGHT SUMMARY

Experiment number	Gemini mission										Experiment title
	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
M001			X		X						Cardiovascular Conditioning
M004		X	X		X						Inflight Phonocardiogram
M006		X	X		X						Bone Demineralization
M007					X						Calcium Balance
M005					X	X	X				Body-Fluids Bioassay
M003		X	X		X						Inflight Exerciser
M008					X						Inflight-Sleep Analysis
M009			X		X						Human Otolith Function
S008 and D013			X		X						Visibility and Visual Acuity
S004	X								X		Radiation at Zero Gravity
S003						X				X	Frog Egg Growth
S002	X										Sea Urchin Egg Growth

EXPERIMENT M001

CARDIOVASCULAR CONDITIONING

By Lawerence F. Dietlein* and William V. Judy*

INTRODUCTION

Base-line studies performed in support of Experiment M001 resulted in data that were indicative that the leg cuffs, when inflated to 70 to 75 mm Hg for 2 out of every 6 minutes, provided protection against the cardiovascular deconditioning produced by water immersion for 6 hours (ref. 1). Four healthy male subjects were immersed in water to the neck level for a 6-hour period on two separate occasions (2 days apart). Six hours of water immersion resulted in cardiovascular deconditioning, as was evidenced by cardioacceleration in excess of the rate observed during the control tilt and by the occurrence of syncope in two of the four subjects. These data are shown in figures 1 to 4. The tilt-response data collected after the second period of water immersion, during which leg cuffs were used, were indicative that a protective effect was achieved. Cardioacceleration was less extensive and syncope did not occur.

The physiological mechanisms responsible for the observed efficacy of the cuff technique remain obscure (ref. 2). It may be postulated that cuffs prevent thoracic blood-volume overload, with the consequent inhibition of the Gauer-Henry reflex and with the resultant diuresis and diminished effective circulating blood volume. Alternatively, or perhaps additionally, it might be postulated that cuffs induce an intermittent artificial hydrostatic gradient (by increase of venous pressure distal to the cuffs during inflation) across the walls of the leg veins, mimicking the situation that results from standing erect in a unit-gravity environment and thereby preventing the deterioration of the normal venomotor reflexes. Theoretically, this action should lessen the pooling of blood in the lower extremities and should increase the effective circulating blood volume upon return to a unit-gravity environment after weightlessness or its simulation. The precise mechanism, or mechanisms, of action have not been defined.

EQUIPMENT AND METHODS

The equipment consisted of a pneumatic timing or cycling system and a pair of venous pressure cuffs (figs. 5 and 6). The cycling system was entirely pneumatic and

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alternately inflated and deflated the cuffs attached to the thighs of the pilot. Three basic components comprised the system as flown on the Gemini V mission (fig. 7).

1. A pressurized storage vessel charged to 3500 psig with oxygen

2. A pneumatic control system for monitoring the pressurized storage vessel

3. A penumatic oscillator system for periodic inflation and deflation of the cuffs

The equipment that was flown on the Gemini VII mission was almost identical to that used on the Gemini V mission, and it was supplied with oxygen pressure from the spacecraft environmental control system. The pneumatic venous-pressure cuffs were formfitted to the proximal thigh region of the pilot. The cuffs consisted of a 3- by 6-inch bladder enclosed in a soft nonstretchable fabric. The bladder portion of each cuff was positioned on the dorsomedial aspect of each thigh. The lateral surface of the cuffs consisted of a lace adjuster that was used to ensure proper fit.

RESULTS

The pilots for the Gemini V and VII missions were experimental subjects; the command pilots were control subjects. The experiment was operative for the first 4 days of the 8-day Gemini V mission and for the first 13.5 days of the 14-day Gemini VII mission.

Preflight and Postflight Tilts

Prior to these missions, each crewmember was given a series of tilt-table tests. Data from these control tilts have been summarized in table I, the numerical values being mean values for the three control tilts. Gemini V crewmember cardiovascular responses to preflight +70° tilts are shown in table II. The results of six consecutive postflight tilts for the Gemini V command pilot and pilot are summarized in figures 8 and 9. Heart-rate change during the initial postflight tilt has been expressed as a percentage of the preflight value for all the Gemini flights to date; these data are shown in figure 10. The results of four consecutive postflight tilts for the Gemini VII command pilot are indicated in figures 11 to 14 and for the Gemini VII pilot in figures 15 to 18. The Gemini VII tilt-table data are shown in figure 19.

Data Summary

Postflight pulse rates. - The crewmembers for both the Gemini V and VII missions had increased resting pulse rates during the first 12 to 24 hours after recovery. Resting pulse-rate changes for the members of both crews are indicated as deviations from the preflight mean values in table II. Changes in the tilt mean heart rate of the members of the two crews during the postflight recovery period are shown in table III. The Gemini V crewmen had a higher postflight mean resting pulse rate than did the Gemini VII crewmen, with a maximum difference of twelvefold (pilot) occurring 2 to 4 hours after recovery. This increased resting pulse rate gradually returned to preflight levels. The Gemini VII crewmen had a slight increase in postflight mean resting

pulse rate compared with preflight levels; these values had returned to preflight levels approximately 24 hours after recovery. The crewmembers for both the Gemini V and VII missions had changes in their resting systolic and diastolic blood pressures after the missions. These values have been indicated as deviations from the preflight mean values in table IV. The Gemini V crewmen had a twofold greater increase in pulse rate than did the Gemini VII crewmen during the first two postflight tilts. Although the Gemini VII crew had a smaller increase in pulse rate during the tilt procedures, the Gemini VII pilot had to be returned to the supine position at the end of 12 minutes during the first tilt. This syncopal response was of the vasodepressor type and has been illustrated in figure 15. This experience on the first tilt procedure may account for his increased pulse rate during the second and third tilts. The pulse rates of all crewmembers decreased during succeeding tilts to approximately preflight values (figs. 8 and 19).

Postflight systolic pressure. - All crewmembers had decreased resting systolic blood pressure 2 to 4 hours after recovery. The Gemini V command pilot and the Gemini VII pilot maintained systolic pressures that were lower than the preflight values throughout the postflight test period. All crewmembers had a decreased resting diastolic blood pressure during each postflight tilt test except during the first and last tilts of the Gemini V command pilot and during the second tilt of the Gemini VII pilot. Daily changes in resting blood pressures have been indicated in figures 9 and 19 as deviations from the preflight mean values.

Postflight pulse pressure. - All crewmembers had narrowed pulse pressures during the first postflight tilt (compared with the preflight tilt and the postflight resting values). The Gemini V crewmen also had a significant pulse-pressure narrowing during the second (8 to 12 hours) postflight tilt. The Gemini V command pilot maintained a low systolic pressure during the third and fourth tilts, whereas the systolic pressure of the Gemini V pilot returned to normal preflight levels after the second postflight tilt. The Gemini VII crewmen had no significant pulse-pressure narrowing during their second, third, or fourth postflight tilts. The changes in systolic and diastolic pressures for members of both crews have been indicated in table V as deviations from the preflight mean values.

Postflight blood pressure. - During the postflight recovery phase, blood pressure values for the Gemini V and VII crewmembers returned to approximately pretilt resting levels (figs. 8 and 19).

Postflight leg-volume changes. - Leg-volume changes during the postflight tilts were indicative that the pilots, who wore the pneumatic cuffs, pooled significantly less blood in their legs during the tilts than did the command pilots. Postflight legpletnysmographic values for the Gemini V crewmen are shown in table VI. These values have been indicated as percent increase in excess of the preflight control values in table VII. Although the Gemini VII pilot had a vasodepressor-type syncope during his first postflight tilt, he did not pool an excessive amount of blood in his legs (2 percent more than the preflight control value). Also, despite the fact that the Gemini V and VII command pilots pooled similar quantities of blood in their legs during the first postflight tilt, the men differed considerably in the volume pooled during the remaining tilts. Primarily, these differences, and those of the Gemini V pilot, may be a reflection of differences in the extent of hydration.

Blood volume, plasma volume, and red-cell-mass variation. - Changes in blood volume, plasma volume, and red-cell mass were determined before and after flight. Radioactive isotope (I^{125}, Cr^{51}) techniques were used to make these measurements. The results have been shown in table VIII as percent changes.

The Gemini VII crewmen sustained a 4- to 15-percent increase in plasma volume during the 14-day mission, whereas the Gemini V crewmen lost 4 to 8 percent of their plasma volume during the 8-day mission. All crewmen lost 7 to 20 percent of their red-cell mass. However, the Gemini VII pilot sustained only a 7-percent decrease as compared with the 19- to 20-percent decrease sustained by the other crewmembers. The decrease in red-cell mass and the increase in plasma volume of the Gemini VII crewmen offset each other to result in a net zero-percent change in blood volume, whereas the reduction in plasma volume and red-cell mass of the Gemini V crewmen contributed to the measured 13-percent decrease in blood volume. These changes in blood volume may reflect, in part, the extent of hydration of the Gemini V crewmen, but this is not true for the Gemini VII crewmen.

Body-weight changes. - Postflight changes in body weight have been indicated in table IX. The Gemini V command pilot and pilot sustained a 7.5- and 8.5-pound loss in body weight, respectively. The Gemini VII command pilot and pilot lost 10.0 and 6.5 pounds, respectively. These values are similar to those observed after other missions that were of shorter duration.

DISCUSSION

Flight Conditions

Flight conditions that were operative during the Gemini VII mission were notably different from those that were operative during the Gemini V mission. These differences were of sufficient magnitude that a comparison of the experiment results on the two missions is difficult, if not impossible. The Gemini VII mission was different from previous Gemini missions in that the Gemini VII crewmen did not wear their suits during an extensive portion of the 14-day flight. Their food and water intake more closely approximated the optimum than it did on previous flights; this assured better hydration and electrolyte balance. Also, the Gemini VII exercise regimen was more rigorous than that used on previous flights. These variables, in addition to the individual variability that is always present, precluded any direct comparison of results on the two missions. Further, the pulsatile cuffs were operative during only the first half of the 8-day Gemini V mission.

Physiological Responses

The postflight physiological responses of the Gemini VII crewmen were different from, and generally improved in comparison with, those observed for the Gemini V crewmen. However, it was difficult to determine which of the mentioned variables were responsible for the observed improvement. Perhaps this improvement is best shown in figure 8; change in heart rate during the initial postflight tilts is expressed

as a percentage change with respect to the preflight value. The responses of the Gemini VII crewmen were far superior to the responses observed for the Gemini IV and V crewmen, and the responses were almost comparable to those observed subsequent to 14 days of recumbency. The physiological measurements of the Gemini VII pilot should be compared only with those of the command pilot (who served as the control subject).

Response Comparison

Additional comparisons between the Gemini VII and V crewmen may be summarized as follows.

1. The Gemini VII crewmen had a smaller increase in postflight mean resting pulse rate (4 and 10 beats per minute compared with 21 and 59 beats per minute).

2. The Gemini VII crewmen had signs of orthostatic intolerance for only 24 hours postflight; the Gemini V crewmen had these signs for 24 to 48 hours postflight.

3. The Gemini VII crewmen pooled less blood in their lower extremities during all postflight tilts than did the Gemini V crewmen.

4. The Gemini VII crewmen had less significant changes in intravascular-fluid volumes during the postflight period, shown as follows.

a. Total blood volume: 0 percent compared with 13 percent

b. Plasma volume: +15 percent and +4 percent compared with -8 percent and -4 percent

c. Red-cell mass: -19 percent and -7 percent compared with -20 percent and -20 percent

5. The Gemini VII crewmen lost 10.0 pounds (command pilot) and 6.5 pounds (pilot) during flight. The Gemini V crewmen lost 7.5 pounds (command pilot) and 8.5 pounds (pilot) during flight.

6. The Gemini VII crewmen regained less body weight during the first 24 hours postflight than did the Gemini V crewmen (40 percent and 25 percent compared with 50 percent).

Only physiological findings for the Gemini V crewmen will be summarized here.

1. The resting pulse rate and blood pressure of the pilot returned to preflight resting levels within 48 hours after recovery; the command pilot required a somewhat longer period.

2. The pulse pressure of the pilot narrowed during tilt and was less at rest than that of the command pilot.

3. The plasma volume of the pilot decreased 4 percent; that of the command pilot decreased 8 percent.

4. The body weight loss of the pilot was 7.5 pounds and that of the command pilot was 8.5 pounds.

5. Generally, pooling of blood in the legs of the pilot was less than that observed in the command pilot.

The observed differences between the Gemini V command pilot and pilot probably reflect only individual variability and cannot be construed as a demonstration of any protective effect of the pulsatile thigh cuffs. The Gemini V tilt-table data have been summarized in figures 9 and 10.

Gemini VII tilt-table data have been presented in figures 11 to 14 for the command pilot and in figures 15 to 18 for the pilot. All the Gemini VII tilt-table data have been summarized in figure 19. During the first postflight tilt, the pilot had signs of vasodepressor syncope; the tilt was interrupted and the pilot was returned to the supine position. This episode occurred despite the absence of evidence of increased pooling of blood in the lower extremities. During subsequent tilts, the pilot had shown no signs of syncope or of impending syncope. It is of significance that this episode of syncope occurred despite the fact that the measured blood volume of both crewmembers was unchanged from preflight values. It is possible that this syncopal episode was the result of sudden vasodilation, resulting in pooling of blood in the splanchnic region, diminished venous return, diminished cardiac output, and a decrease in cerebral blood flow.

As has been mentioned, there was no diminution in the blood volume of either Gemini VII crewmember after the mission. The plasma volume of the pilot increased 4 percent, whereas the plasma volume of the command pilot increased 15 percent. The red-cell mass of the pilot decreased 7 percent, whereas the red-cell mass of the command pilot decreased 19 percent. The pilot lost 6.5 pounds (nude body weights) during the mission and replaced 25 percent of this loss during the first 24 hours after recovery. The command pilot lost 10.0 pounds and replaced 40 percent of this loss within the first 24 hours after recovery. Additional tilts resulted in data that represented a moderate cardioacceleration in the pilot during tilts 2 and 3, with normal pulse pressure and insignificant pooling of blood in the legs (figs. 16 to 18). The command pilot sustained moderate cardioacceleration, significant pulse-pressure narrowing, and increased pooling of blood in the legs during the first postflight tilt. Subsequent tilts resulted in data that represented a rather rapid return of heart rate and pulse pressure to normal; however, the command pilot had a greater tendency to pool blood in the legs than was observed for the pilot.

CONCLUSIONS

Based on preflight and postflight data, it has been concluded that pulsatile cuffs were not effective in lessening postflight orthostatic intolerance. This conclusion was not based on the occurrence of syncope during the first tilt of the pilot, but was based on the higher heart rates observed (as compared with the control subject) during

subsequent tilts. It is well established that syncope itself is a poor indicator of the extent of cardiovascular deconditioning. Pulsatile cuffs did lessen the extent of post-flight pooling of blood in the legs (as determined by the strain-gage technique).

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TABLE I. - SUMMARY OF GEMINI V AND VII PREFLIGHT TILT-TABLE TESTS

Subject	Gemini mission	Pretilt		+70° tilt			Posttilt		
		Pulse rate, beats/min	Blood pressure, mm Hg	Pulse rate, beats/min	Blood pressure, mm Hg	Leg-volume change, percent	Pulse rate, beats/min	Blood pressure, mm Hg	Leg-volume change, percent
Command pilot	V	58	109/72	75	111/79	+3.0	55	108/62	+0.3
	VII	59	117/68	78	120/79	+2.7	56	115/64	+.2
Pilot	V	73	110/72	87	114/81	+4.5	70	113/76	+.4
	VII	72	131/75	84	126/84	+4.4	70	123/73	+.5

TABLE II. - CHANGE IN RESTING MEAN HEART RATE

[Data are in beats/min[a]]

Subject	Gemini mission	Hours after recovery					
		2 to 4	8 to 12	24 to 30	48 to 56	72 to 80	90 to 104
Command pilot	V	+21	+32	+10	+6	+6	+9
	VII	+10	+8	-2	-1	--	--
Pilot	V	+59	+41	+18	0	+12	+19
	VII	+4	+9	+5	-5	--	--

[a]Positive values are greater than the preflight mean; negative values are less than the preflight mean.

TABLE III. - CHANGE IN TILT MEAN HEART RATE

[Data are in beats/min[a]]

Subject	Gemini mission	Hours after recovery					
		2 to 4	8 to 12	24 to 30	48 to 56	72 to 80	90 to 104
Command pilot	V	+79	+69	+35	+14	+13	+21
	VII	+40	+19	+2	+4	-	--
Pilot	V	+86	+55	+21	+4	+11	+32
	VII	+28	+33	+34	+2	--	--

[a]Positive values are greater than the preflight means; negative values are less than the preflight means.

TABLE IV. - CHANGE IN RESTING MEAN BLOOD PRESSURE

[Data are in mm Hg[a]]

Subject	Gemini mission	Hours after recovery											
		2 to 4 (b)		8 to 12 (b)		24 to 30 (b)		48 to 56 (b)		72 to 80 (b)		96 to 104 (b)	
Command pilot	V	-9	+10	-10	-8	-10	-3	-13	-9	-3	-3	-5	+6
	VII	-3	-3	+11	+9	+2	-3	+5	-5	--	--	--	--
Pilot	V	-3	-8	0	-9	+1	-8	+4	-9	+3	-3	+1	-6
	VII	-8	-4	-7	-2	-4	-4	-14	-5	--	--	--	--

[a]Positive values are greater than the preflight mean; negative values are less than the preflight mean.

[b]Left-hand value is systolic; right-hand value is diastolic.

TABLE V. - CHANGES IN TILT MEAN BLOOD PRESSURE

[Data are in mm Hg[a]]

Subject	Gemini mission	Hours after recovery											
		2 to 4 (b)		8 to 12 (b)		24 to 30 (b)		48 to 56 (b)		72 to 80 (b)		96 tc 104 (b)	
Command pilot	V	-16	+6	-13	+6	-6	+2	-9	-7	+11	+7	-8	+9
	VII	-27	-8	+5	+4	-3	-6	-4	-5	--	--	--	--
Pilot	V	-20	-3	-12	+11	+6	+9	+8	+2	+8	+4	+7	+3
	VII	-33	-11	+2	-2	+6	+1	-12	-11	--	--	--	--

[a]Positive values are greater than the preflight mean; negative values are less than the preflight mean.

[b]Left-hand value is systolic; right-hand value is diastolic.

TABLE VI. - POSTFLIGHT LEG-PLETHYSMOGRAPHIC VALUES

Days postrecovery	Postflight change in volume, per min percent[a, b]			
	Gemini IV		Gemini V	
	Command pilot	Pilot	Command pilot	Pilot
1	+22	+131	+119	+80
2	+27	+61	+44	+25
3	-38	+126	+73	+57
4	--	--	+78	+117
5	--	--	+111	+97

[a]Percent change in volume = cc/100 cc tissue/min.

[b]Positive values are greater than the preflight mean; negative values are less than the preflight mean.

TABLE VII. - CHANGE IN LEG-BLOOD VOLUME

[Data are in percentage change in excess of preflight mean (cc/100 cc tissue/min)]

Subject	Gemini mission	Hours after recovery					
		2 to 4	8 to 12	24 to 30	48 to 56	72 to 80	96 to 104
Command pilot	V	89	149	44	73	78	111
	VII	71	31	47	33	--	--
Pilot	V	87	73	25	57	117	97
	VII	2	36	9	15	--	--

TABLE VIII. - CHANGE IN INTRAVASCULAR VOLUME

[Data are in percent[a]]

Subject	Gemini mission	Change in total blood volume	Plasma-volume change	Red-cell-mass change
Command pilot	V	-13	-8	-20
	VII	0	+15	-19
Pilot	V	-12	-4	-20
	VII	0	+4	-7

[a]Positive values are greater than the preflight mean; negative values are less than the preflight mean.

TABLE IX. - NUDE BODY-WEIGHT CHANGES

Subject	Gemini mission	Weight change, lb (a)
Command pilot	V	-7.5
	VII	-10.0
Pilot	V	-8.5
	VII	-6.5

[a]Negative values indicate weight loss.

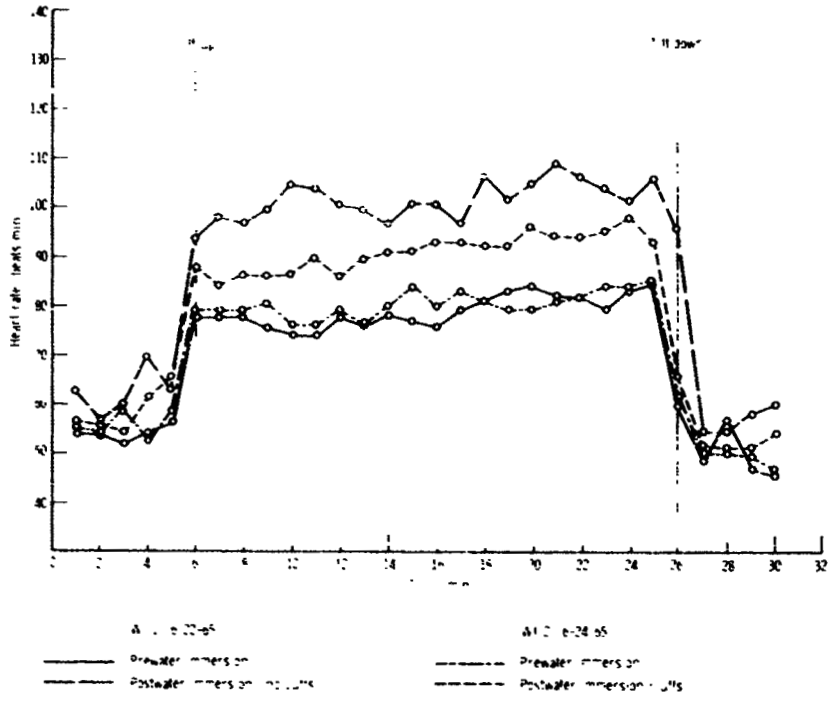


Figure 1. - Six-hour water-immersion-study data on subject M.

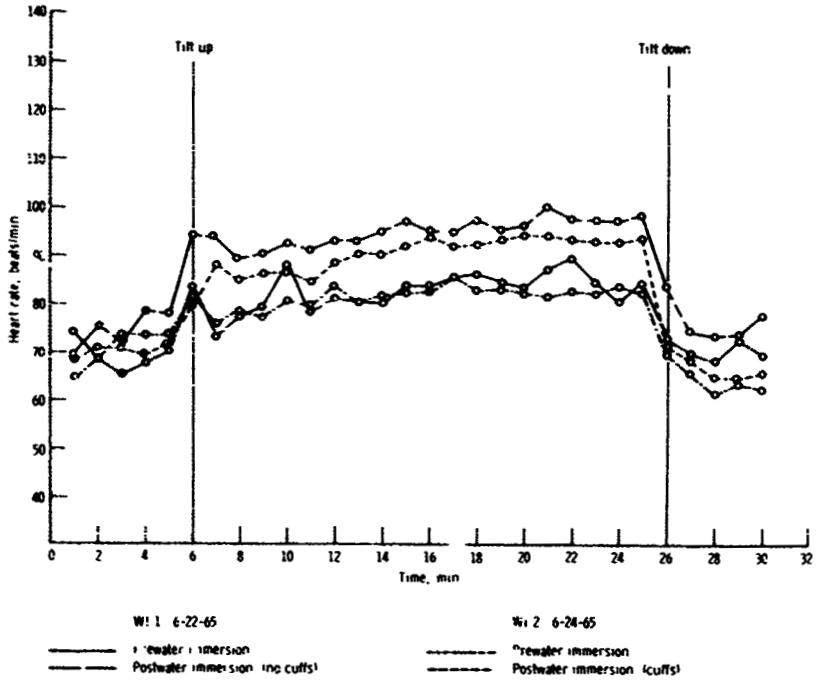


Figure 2. - Six-hour water-immersion-study data on subject L.

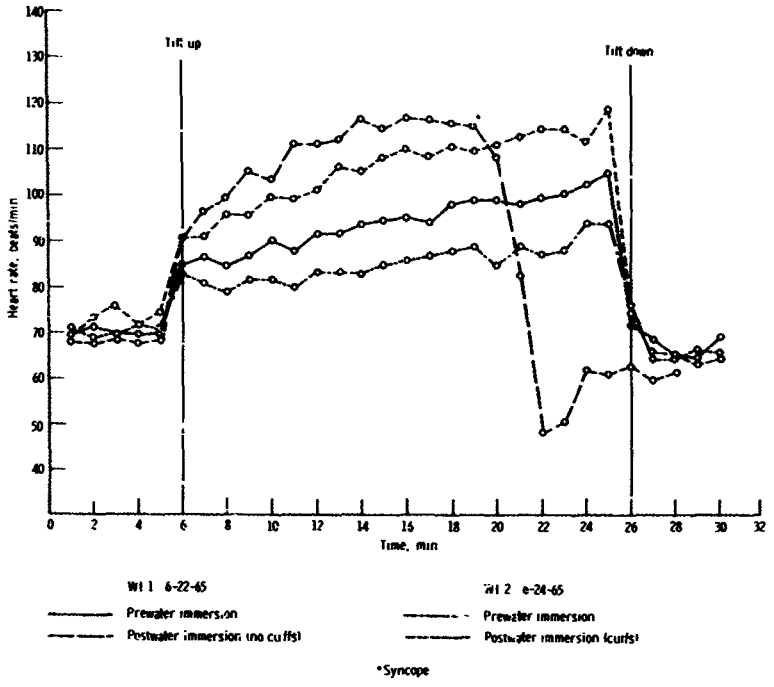


Figure 3. - Six-hour water-immersion-study data on subject D.

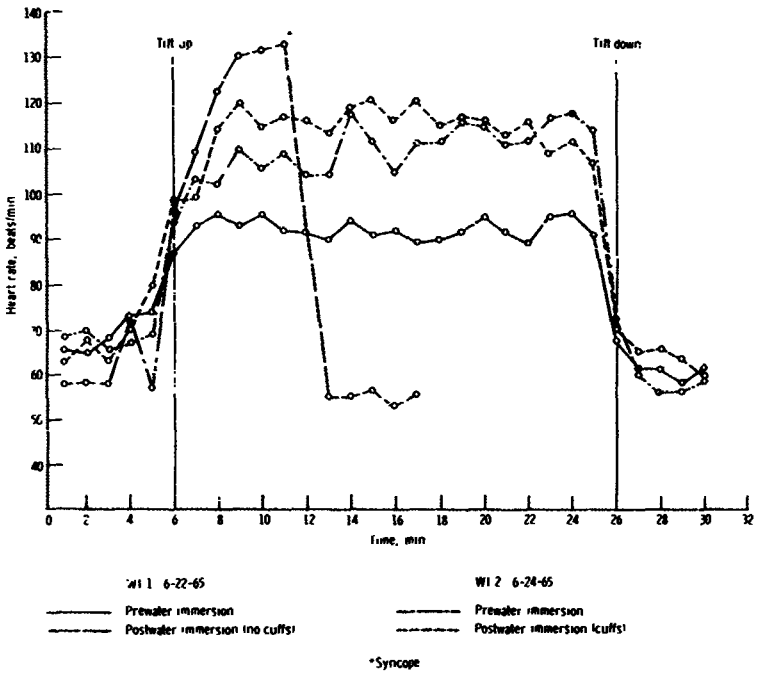


Figure 4. - Six-hour water-immersion-study data on subject C.

Figure 5 - The cardiovascular-reflex-conditioning system.

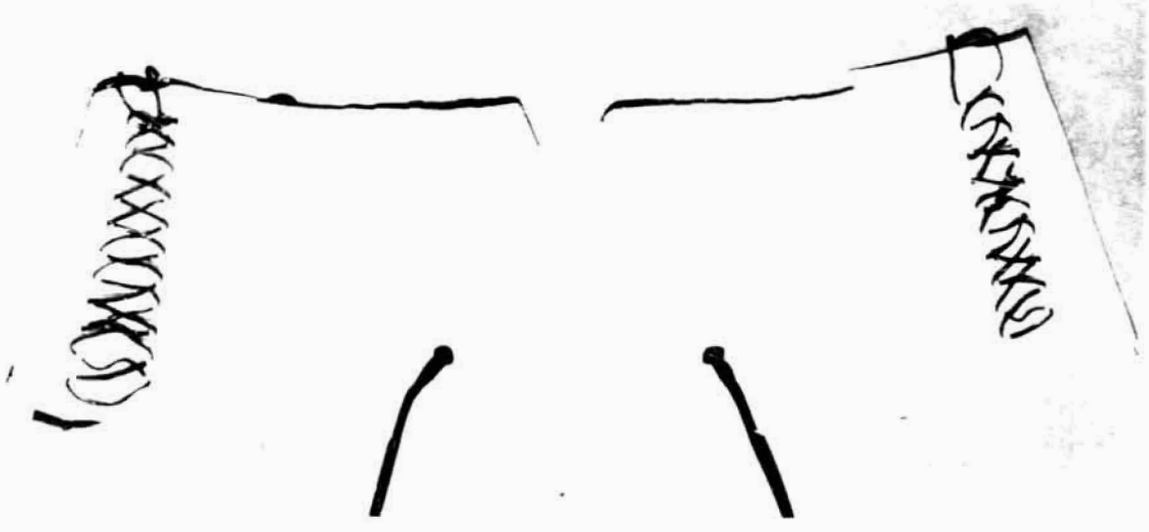


Figure 6. - Pneumatic cuffs that were used in Experiment M001.

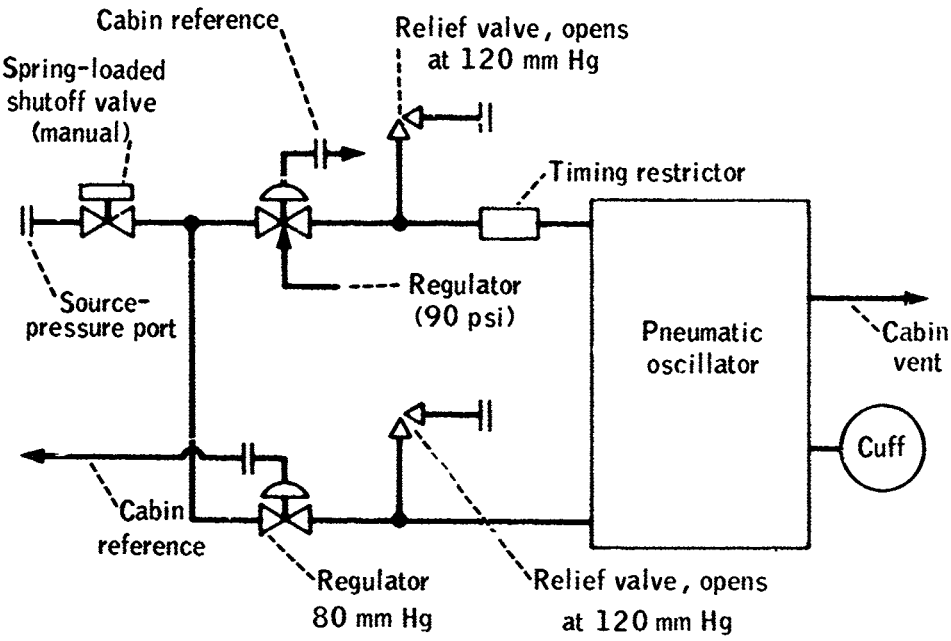


Figure 7. - Components of the cycling system that were flown on the Gemini V mission.

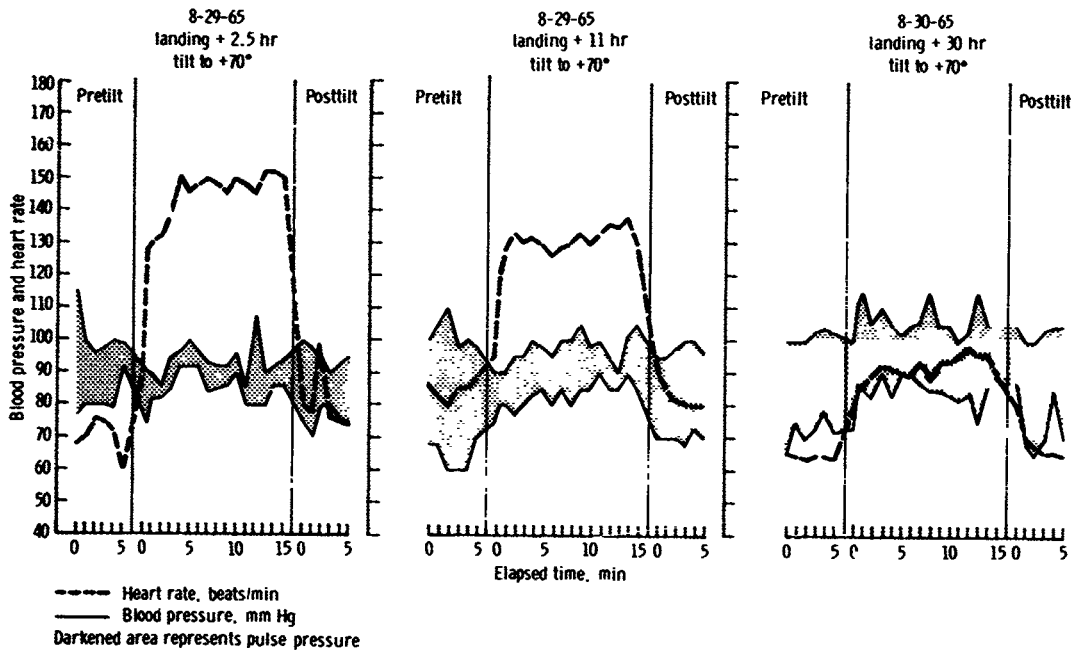


Figure 8. - Tilt-table data on the Gemini V command pilot.

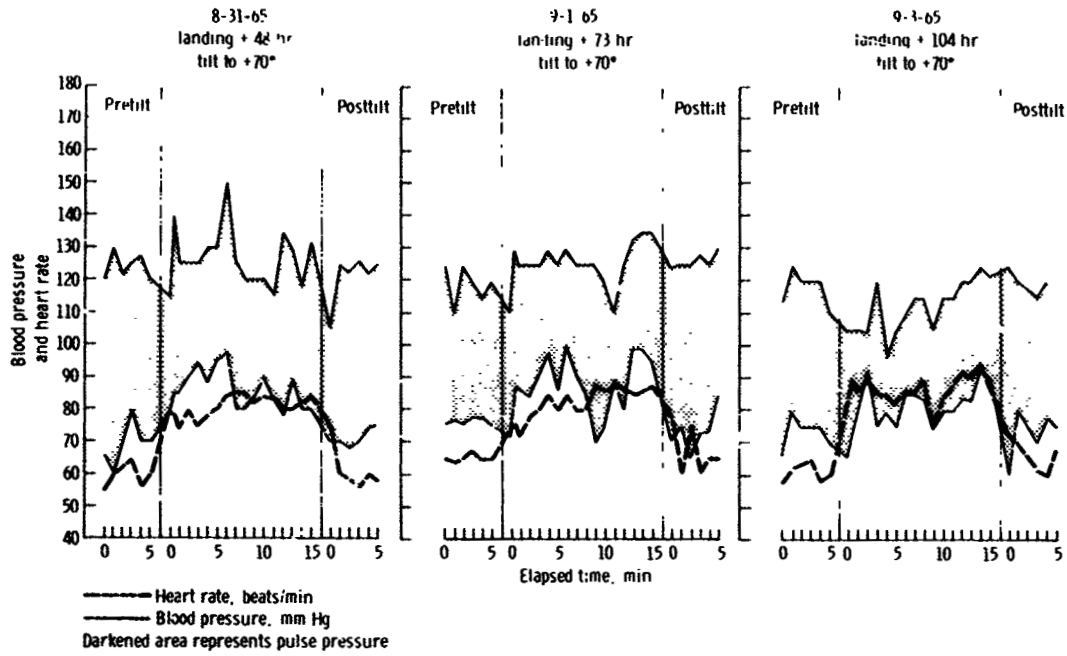


Figure 9. - Tilt-table data on the Gemini V pilot.

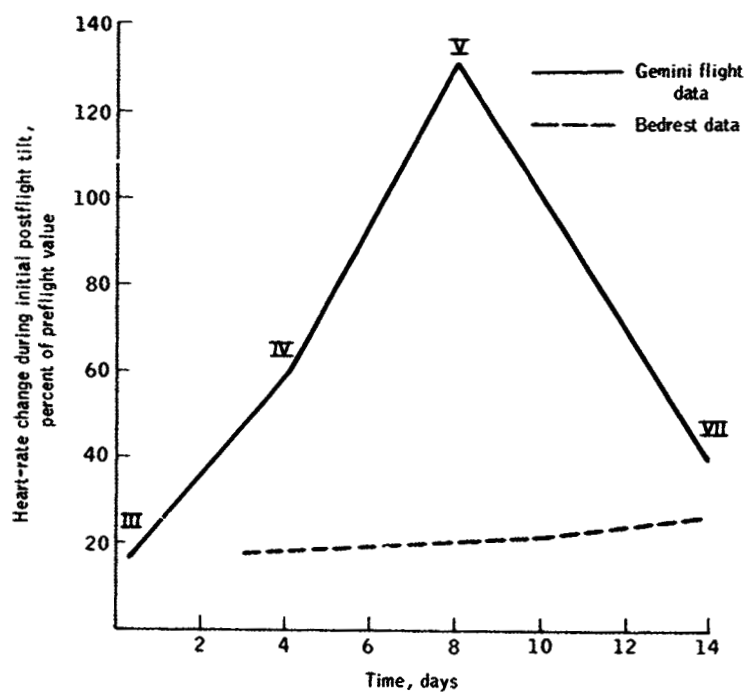


Figure 10. - Data on heart-rate changes during the initial postflight tilt.

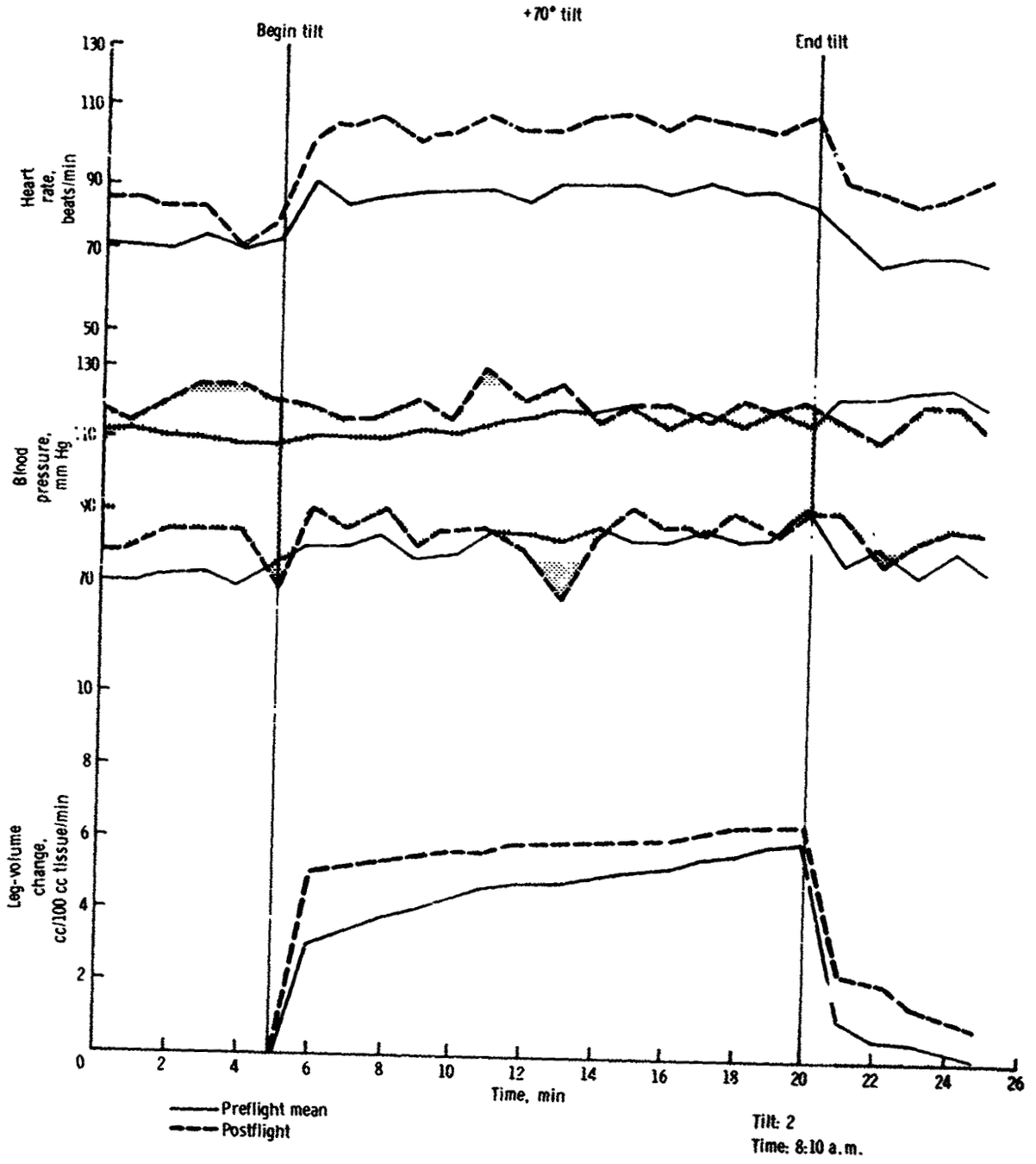


Figure 11. - Postflight tilt-table data on the Gemini VII command pilot, December 18, 1965.

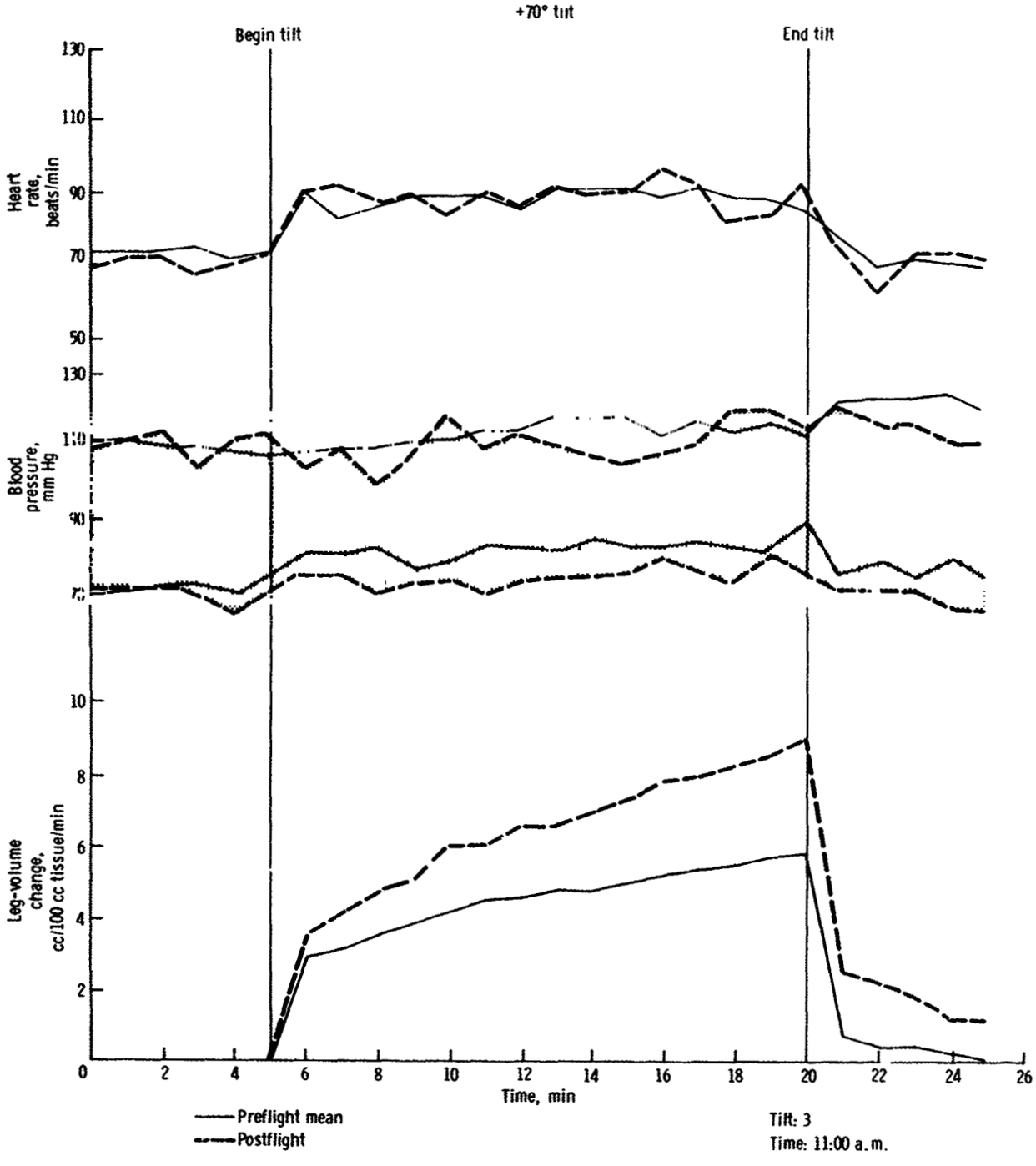


Figure 12. - Postfight tilt-table data on the Gemini VII command pilct, December 19, 1965.

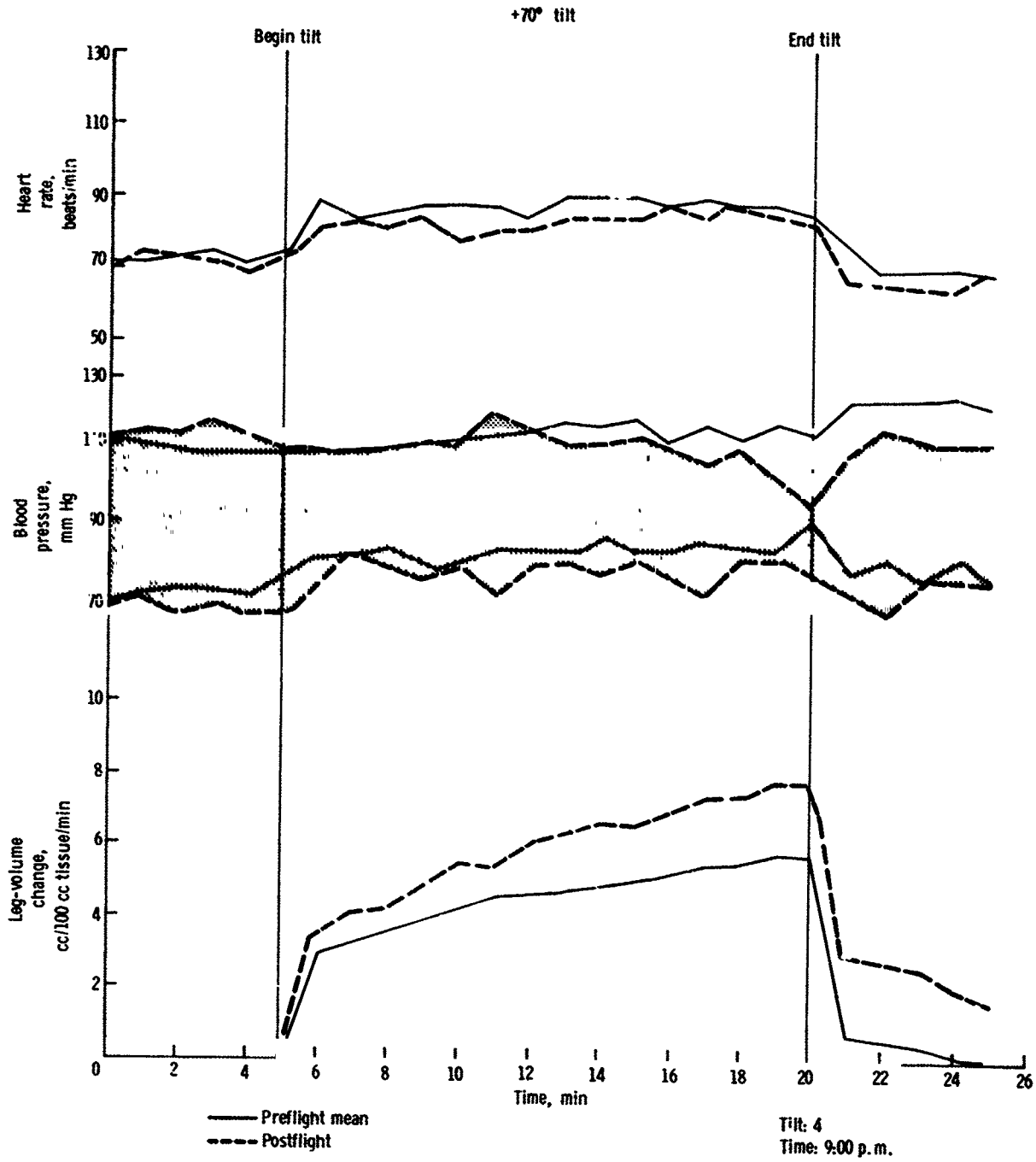


Figure 13. - Postflight tilt-table data on the Gemini VII command pilot, December 20, 1965.

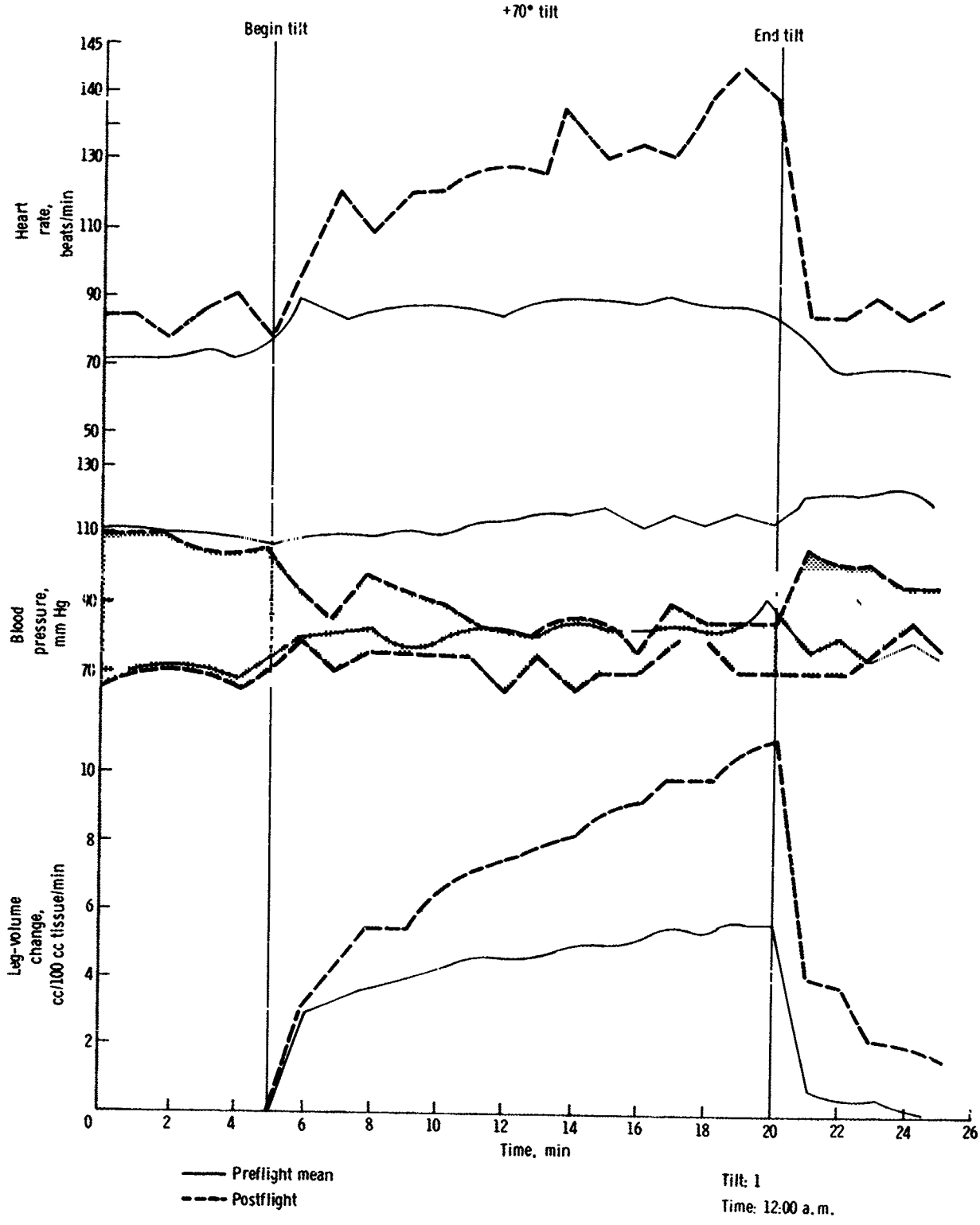


Figure 14. - Postflight tilt-table data on the Gemini VII comman : pilot, December 28, 1965.

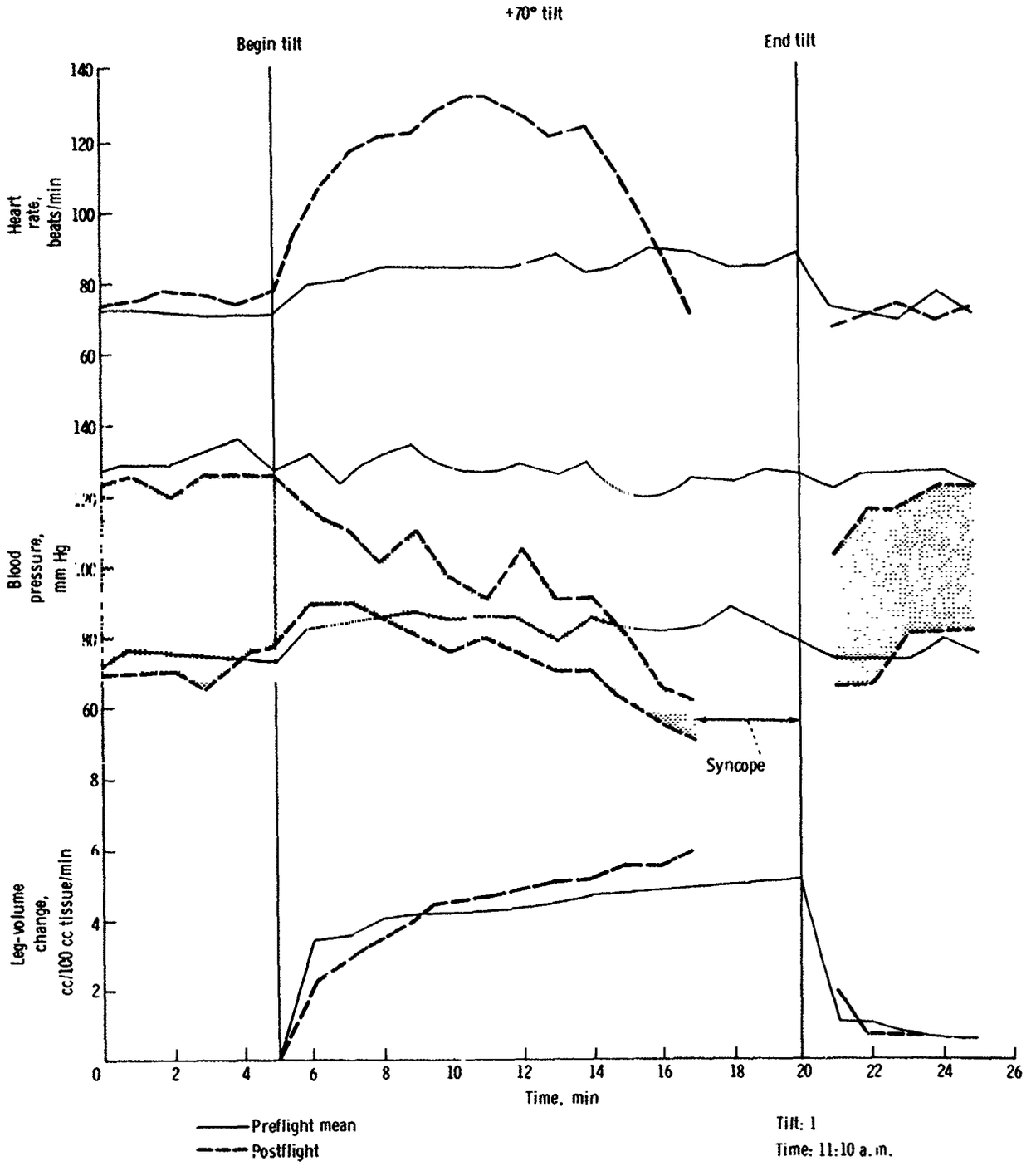


Figure 15. - Postflight tilt-table data on the Gemini VII pilot, December 18, 1965.

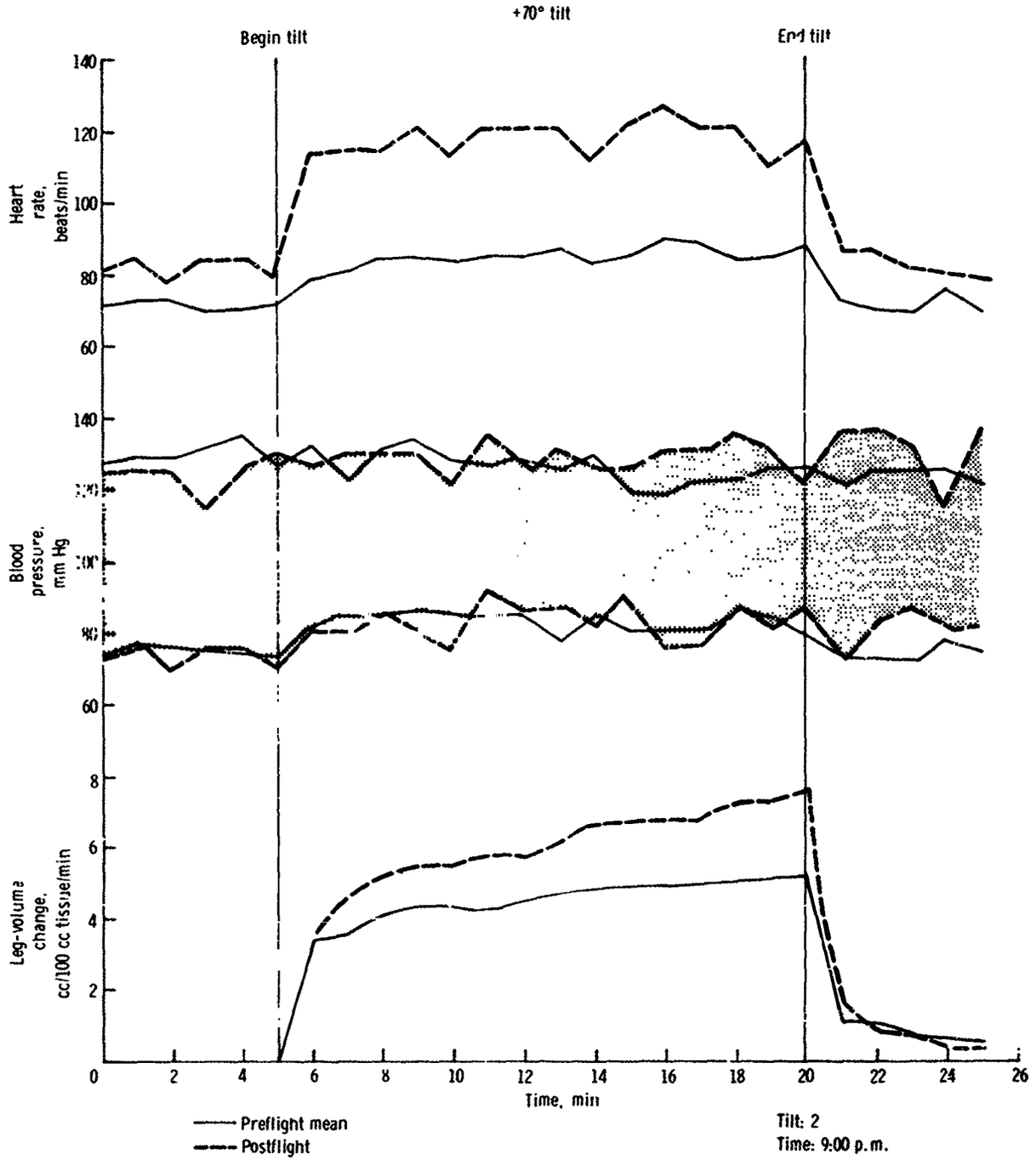


Figure 16. - Second set of postflight tilt-table data on the Gemini VII pilot, December 18, 1965.

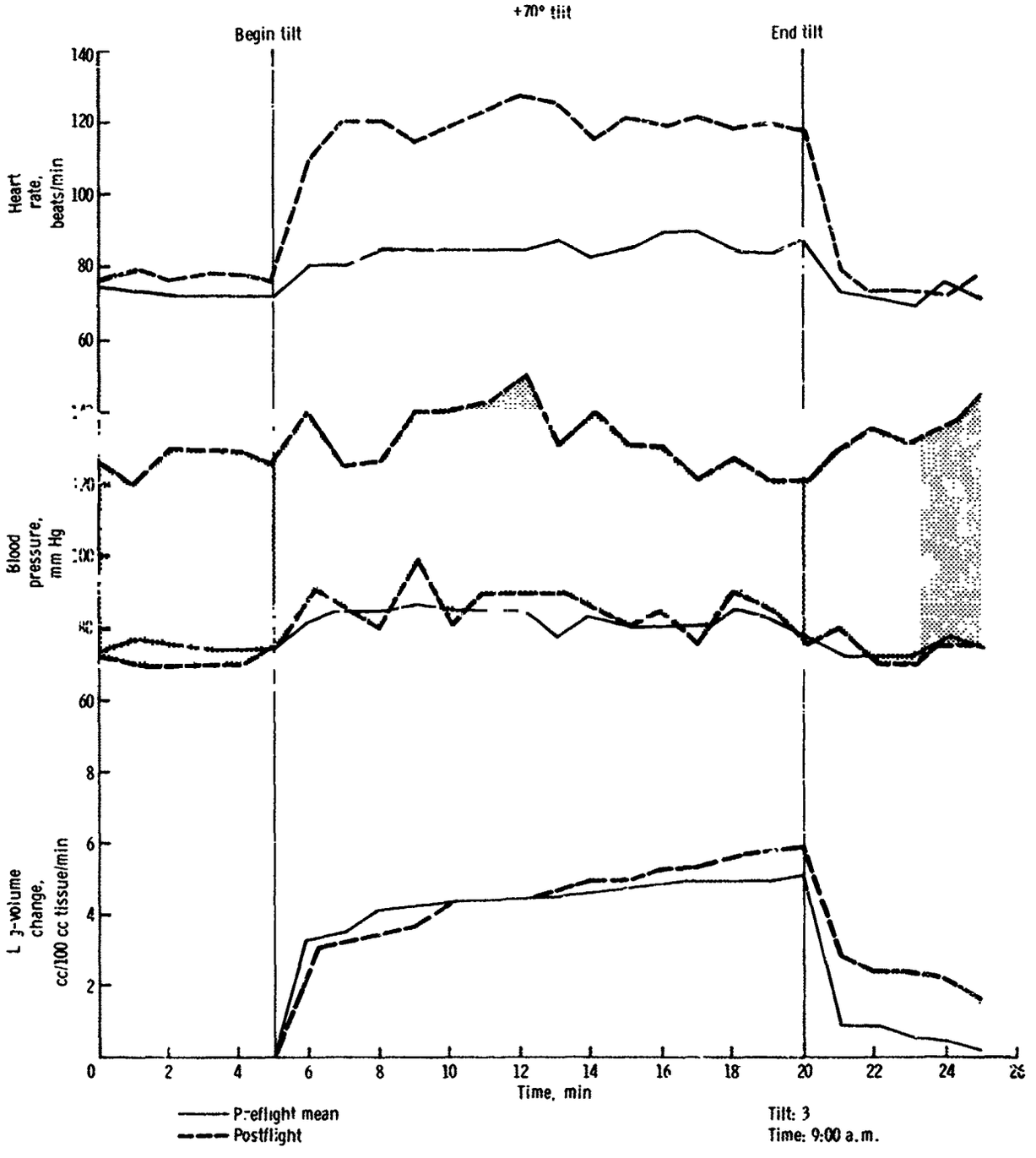


Figure 17. - Postflight tilt-table data on the Gemini VII pilot, December 19, 1965.

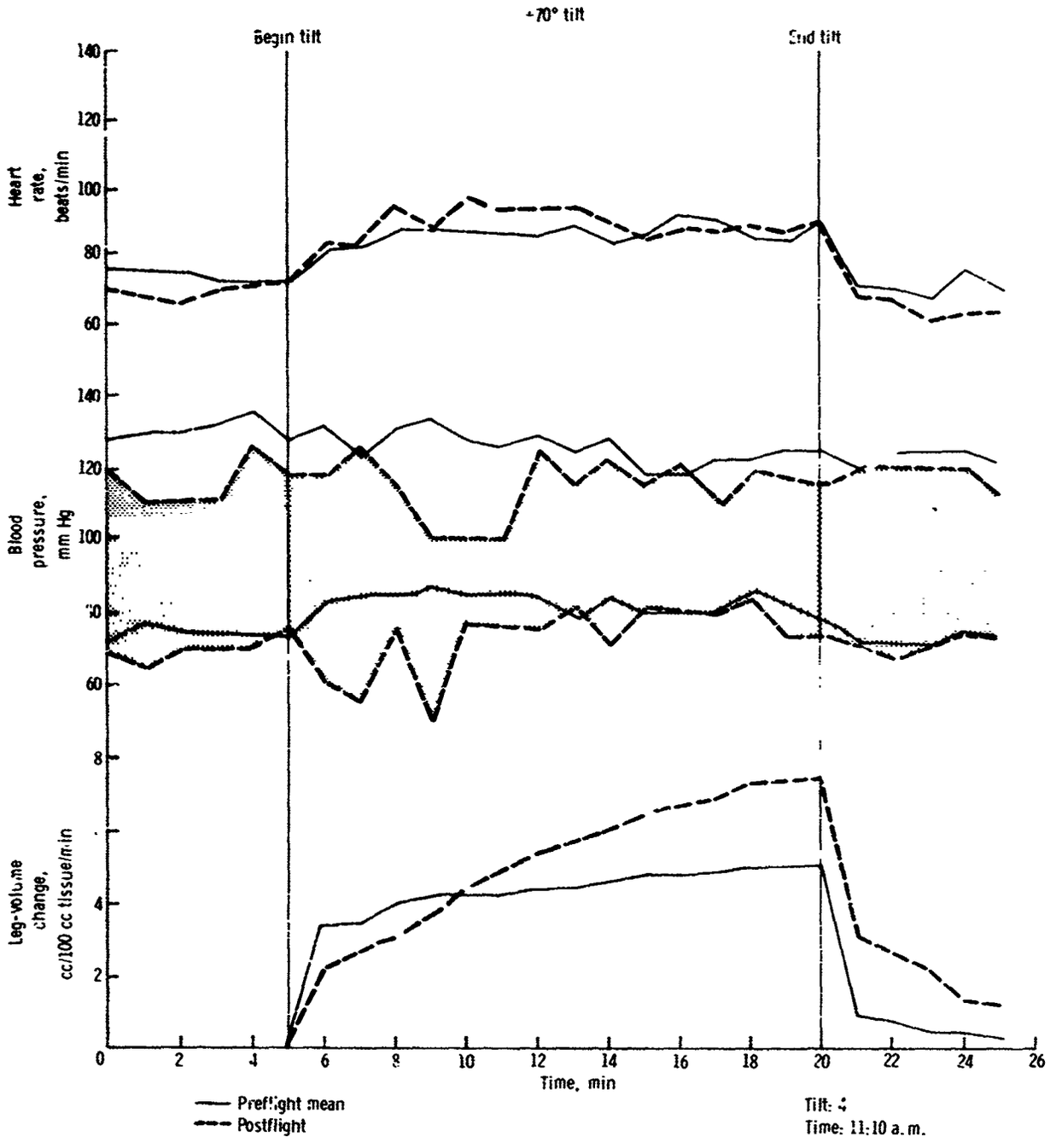
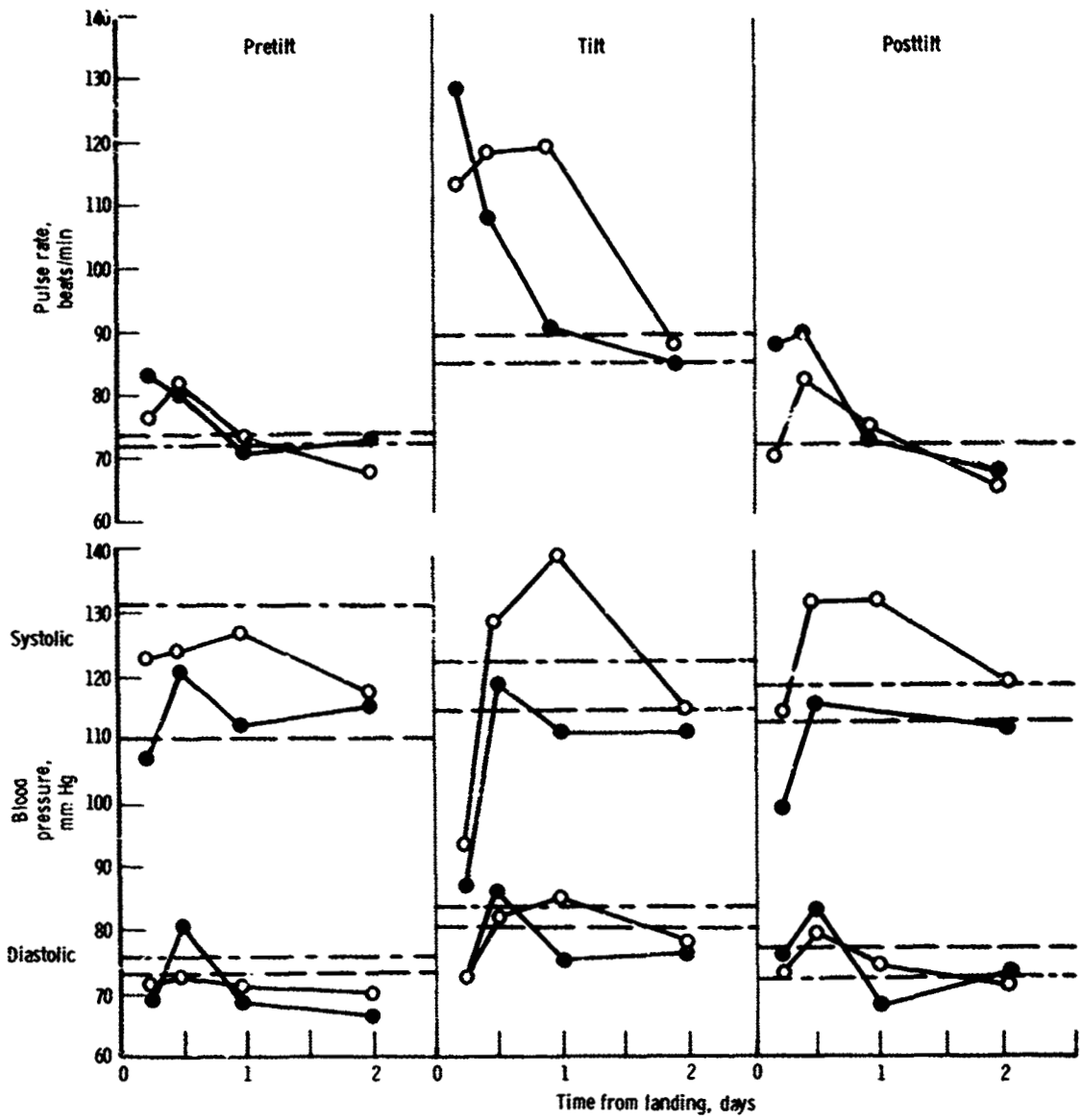


Figure 18. - Postflight tilt-table data on the Gemini VII pilot, December 20, 1965.



Note: Pilot postflight tilt 1 is the mean of a 12-min tilt; the subject was tilted to the supine after a tendency to faint.

Figure 19. - Tilt-table data from the Gemini VII mission.

EXPERIMENT M004

INFLIGHT PHONOCARDIOGRAM

By Lawerence F. Dietlein*

INTRODUCTION

Electrocardiographic and phonocardiographic data were obtained from both the Gemini IV and V crewmembers. The objective of Experiment M004 was the measurement and correlation of the various phases of the electrical and mechanical activity of the cardiac cycle, in an effort to gain insight into the cardiac functional status of crewmembers during long-duration space flight.

EQUIPMENT

The equipment consisted of three parts: a phonocardiographic transducer, an electrocardiographic signal conditioner (preamplifier and amplifier), and an onboard biomedical tape recorder. The signal conditioner was identical with that used to make electrocardiographic measurements. Both the transducer and signal conditioner were worn inside the Gemini pressure suit. The phonocardographic sensor was applied parasternally over the left fourth intercostal space of each crewmember. The phonocardiographic transducer used on the Gemini IV and V missions was a 7-gram piezoelectric microphone that was 1 inch in diameter and 0.200 inch in thickness. The transducer was applied to the thoracic wall of the subject by means of a small colostomy seal made of double-backed adhesive. A 10-inch length of flexible (0.10-inch diameter) shielded cable conducted the phonocardiographic signal to the Gemini electrocardiographic signal conditioner (fig. 1) which was housed in a pocket of the undergarment. The phonocardiographic signal was conducted from the signal conditioner output to the suit bioplug, and subsequently to the biomedical recorder (figs. 2 and 3).

PROCEDURE

The electrocardiogram and the phonocardiogram of each crewmember were recorded throughout the missions. The recording procedure was entirely passive and required no active participation by the crewmembers.

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The transducer or sensor responded to the translational vibrations imparted to the chest wall during each contraction of the heart. Phonocardiographic signals were recorded simultaneously with electrocardiographic signals derived from the manubrium-xiphoid (M-X) lead. Then, analog data from the biomedical tape recorder were played back in real time, were semiautomatically digitized, and were analyzed by the use of computer techniques. 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
4. At the onset of the next QRS complex

The playback protocol included the following periods.

1. Initial; continuous for 9 minutes, starting 1 minute before lift-off and lasting until orbital insertion
2. Final: continuous from 5 minutes before entry until touchdown

Also, records of approximately 1-minute 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 entry. A computer program was used to calculate the duration of each R-R interval, the duration of the mechanical systole (plus excitation time), the duration of diastole, the interval between the onset of the QRS wave and the first heart sound (electromechanical delay), and the interval between the first and second heart sounds. The same program was used to compute the means and the standard deviations of these variables after each group of 15 consecutive beats.

RESULTS

Gemini IV Mission

The lowest plot in figure 4 is indicative that the interval between the Q wave and the first heart sound for the command pilot was relatively constant; that is, the interval did not increase as inflight time increased. The same was true of the pilot (fig. 5, lowest plot). The duration of systole is shown in the middle plot of figure 4. The interval between the Q wave and the second heart sound also remained constant during the 4-day mission.

Heart rates (figs. 4 and 5, top plots) were greatest at lift-off, during entry, and during extravehicular activity (pilot). The interval from the Q wave to the first sound and the interval from the Q wave to the second sound (duration of systole) from the pilot (fig. 4, lowest and middle plots) remained essentially constant during the mission. The heart-rate plot for the command pilot revealed definite circadian rhythmicity

based on the Cape Kennedy 24-hour day-night cycle. The command pilot had a low heart rate during periods coinciding with midnight, Cape Kennedy time.

The Q wave to first sound intervals for the command pilot and the pilot were shortened during flight relative to preflight base-line values. This is interpreted as an adrenergic response of the cardiovascular system to mild stress.

Plots of the duration of systole (lower curve) and the systolic ratio (upper curve) from the command pilot are shown in figure 6. Corresponding measurements from the pilot are shown in figure 7. The systolic ratio is the observed systolic duration divided by the predicted duration of systole. The proposed regression equation (refs. 1 and 2) was used to predict the values of the duration of systole.

Generally, a heart-rate increase results in a shortening of systole, with a proportional shortening of isotonic and isometric phases, and a shortening of diastole. However, a shortening of the mechanical-systole duration in excess of that predicted for the rate increase occurs under the influence of adrenergic agents (sympathetic discharge) or of digitalis. In addition to a positive inotropic effect, it is likely that these agents hasten the metabolic reactions of the myocardium during systole. Cholinergic agents produce the opposite effect, resulting in an increase in the ratio of observed systole to predicted systole. A ratio lower than 1.0 is suggestive of the influence of adrenergic factors Both crewmembers had systolic-ratio values between 0.9 and 1.0, indicating a mild adrenergic influence throughout the mission (figs. 6 and 7).

Gemini V Mission

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

Command pilot. - The serial plot of measurements throughout the mission is shown in figure 8. 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). Gradually, the cardiac cycle increased in duration (cardiac deceleration) after orbital insertion, and 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 increased from a value of 75 to 125 beats per minute. Throughout the mission, there were great fluctuations in the cardiac cycle (plot R of fig. 8) which seemed to correlate with concomitant changes in the duration of electromechanical systole (plot S of fig. 8) and the time interval between the first and second heart sounds (plot X of fig. 8). The electromechanical delay (the time interval between the onset of the QRS wave and the onset of the first heart sound) remained relatively constant throughout the mission; although, as will be discussed, the values were greater at lower heart rates. It is noteworthy that the electromechanical delay became slightly

shorter approximately 12 hours before entry, at which time the peak heart rate was recorded (137 beats per minute). Also, the duration of systole became considerably shorter at this time.

The fluctuations of the heart rate observed throughout the mission are shown in figure 9. From the 10th hour after lift-off to approximately 7 hours before entry, the command pilot 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 noteworthy that the highest heart-rate values were recorded (usually) a few hours before midnight, eastern standard time. This was particularly evident during the last 3 days of the mission and is suggestive of persistence of the circadian rhythmicity of heart rate based on the normal (Cape Kennedy) day-night cycle. Similar observations had been made regarding the command pilot of the Gemini IV mission (ref. 3).

The correlation between heart rate and the duration of electromechanical systole and electromechanical delay is shown in figure 10. 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 larger when the total duration of the cardiac cycle was longer (when the heart rate was lower). It is remarkable that practically all the systolic values were longer for the command pilot than those predicted for healthy subjects, using the regression equation proposed elsewhere (ref. 1). Only at lift-off and entry were the values of S closer to the predicted norms.

Because it has been observed that cholinergic influences result in a relative prolongation of mechanical systole and a tendency toward lower heart rates, it may be concluded that the command pilot had a preponderance of vagal tone throughout the mission. An increased vagal tone also was suggested by the significant respiratory sinus arrhythmia (respiration and heart-rate reflex) that was evident during periods of reduced activity and sleep.

Little information is available on the relationship between electromechanical delay and heart rate. Generally, the value of T remains almost constant at approximately 100 milliseconds when the heart rate varies between 60 and 120 beats per minute. The T values for the command pilot were greater than 100 milliseconds, and the longest duration that was observed was 150 to 160 milliseconds during the fourth and fifth days of the mission. However, it must be emphasized that the longest delays occurred at the lowest heart rates, which is suggestive that a preponderance of vagal tone also influenced the delay. It is likely that the stress of lift-off and entry was responsible 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 (ref. 4) during the flight of Cosmonaut Titov. Observations of the command pilot are suggestive that increased vagal tone accounted for this prolongation. However, because in the case of the command pilot, manifestations of nausea or other peculiar signs of vagal

preponderance did not occur, it may be concluded that the finding of prolonged electromechanical delay did not have any pathological significance and perhaps was only a manifestation of excellent physical conditioning.

Pilot. - The observed responses of the pilot were similar to those of the command pilot, but there were quantitative differences (fig. 11). The duration of the cardiac cycle of the pilot 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 was 70 milliseconds, and that of the time interval between the first and second heart sounds was 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 stabilized 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 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 entry. Low values for the duration of the cardiac cycle and its various components were observed at the time of entry when the duration of the cardiac cycle was 365 milliseconds (equivalent to a heart rate of 164 beats per minute). At that time, mechanical systole was at its lowest value (220 milliseconds), and electromechanical delay was 75 milliseconds.

The heart rate of the pilot fluctuated throughout the mission, but generally the average values were somewhat higher than those of the command pilot (fig. 12). In addition to the peak values at lift-off and at entry, there also was 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 for the pilot as compared with the heart rates of the command pilot, although peaks of heart rate also were recorded in the evening hours of the last 3 days of the mission.

In contrast to what was observed for the command pilot, the values of the duration of electromechanical systole (S) for the pilot were closer to normal throughout the mission (fig. 13). Values of systole shorter than those predicted were measured at the time of entry. A correlation between the electromechanical delay (T) and the duration of the cardiac cycle (R) was not evident for the pilot as for the command pilot, but generally the lowest values were measured at the peak heart rates recorded at lift-off and at entry. These findings are suggestive that vagal preponderance for the pilot was less prominent than that observed for the command pilot and that adrenergic influences may have prevailed occasionally during the mission. These observations correlate closely with findings of numerous extrasystoles during the first hours of the mission and at the time of entry. Extrasystoles occurred at random throughout the mission but not so frequently as they did during lift-off and entry.

CONCLUSIONS

Gemini IV Mission

The command pilot had a circadian rhythmicity of pulse rate (based on Cape Kennedy time reference). Phonoelectrocardiographic data on both crewmen reveal no significant decrease in duration of systole (Q wave to second heart-sound interval) or in the Q wave to first heart-sound interval. The systolic ratios of both crewmembers are suggestive of a mild adrenergic response throughout most of the 4-day mission.

There was no prolongation of the time interval between the onset of electrical systole (Q wave) and the onset of mechanical systole (first heart sound). Also, there was no prolongation of systole (the interval between Q wave and second heart sound), and there was a significant diurnal rhythmicity in the pulse rate of the command pilot based on the 24-hour Cape Kennedy time cycle.

Gemini V Mission

Wide fluctuations (within physiologically normal limits) of the duration of the cardiac cycle were noted throughout the mission. Fluctuations in the duration of electromechanical systole that correlated with changes in heart rate were also observed. Stable values for electromechanical delay (onset of the QRS wave to the onset of the first heart sound) were noted throughout the mission; shorter values were observed at the peak heart rates recorded during lift-off and entry. Larger values for the duration of systole and for electromechanical delay were observed for the command pilot than for the pilot; these values were suggestive of a preponderance of cholinergic influences (vagal tone) in the command pilot. Evidence of adrenergic reaction (sympathetic tone) was observed at lift-off, during entry, and in the few hours that preceded entry.

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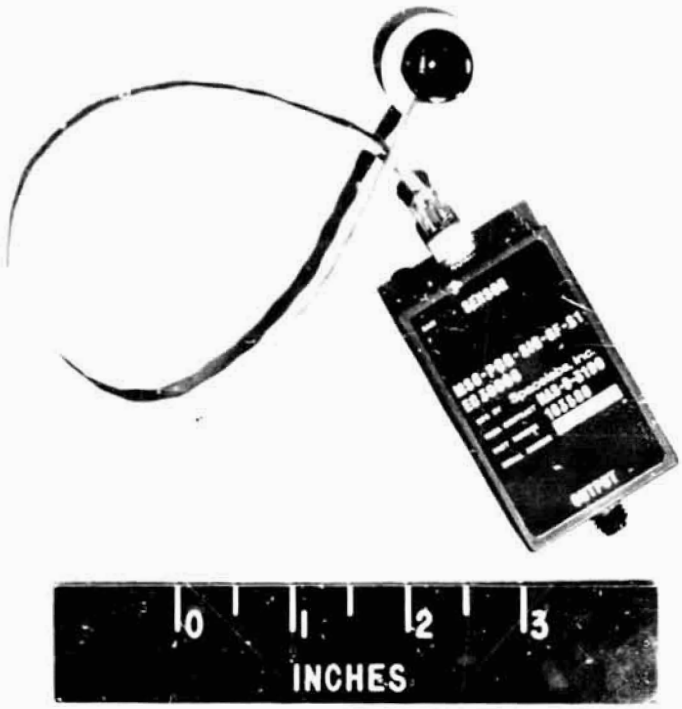

Figure 1. - Phonocardiographic system.

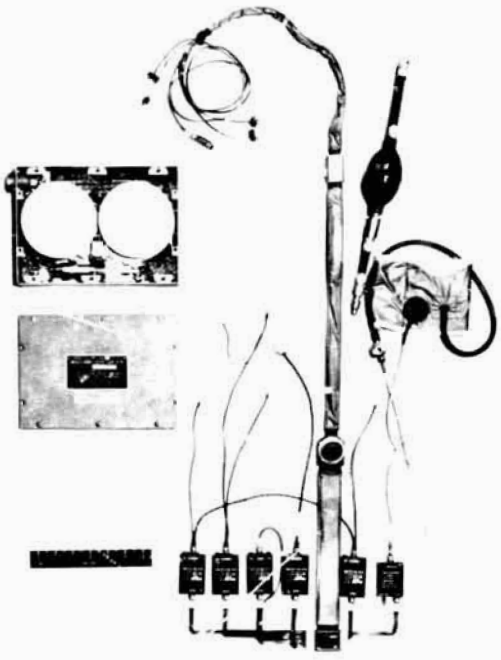

Figure 2. - Bioinstrumentation system.

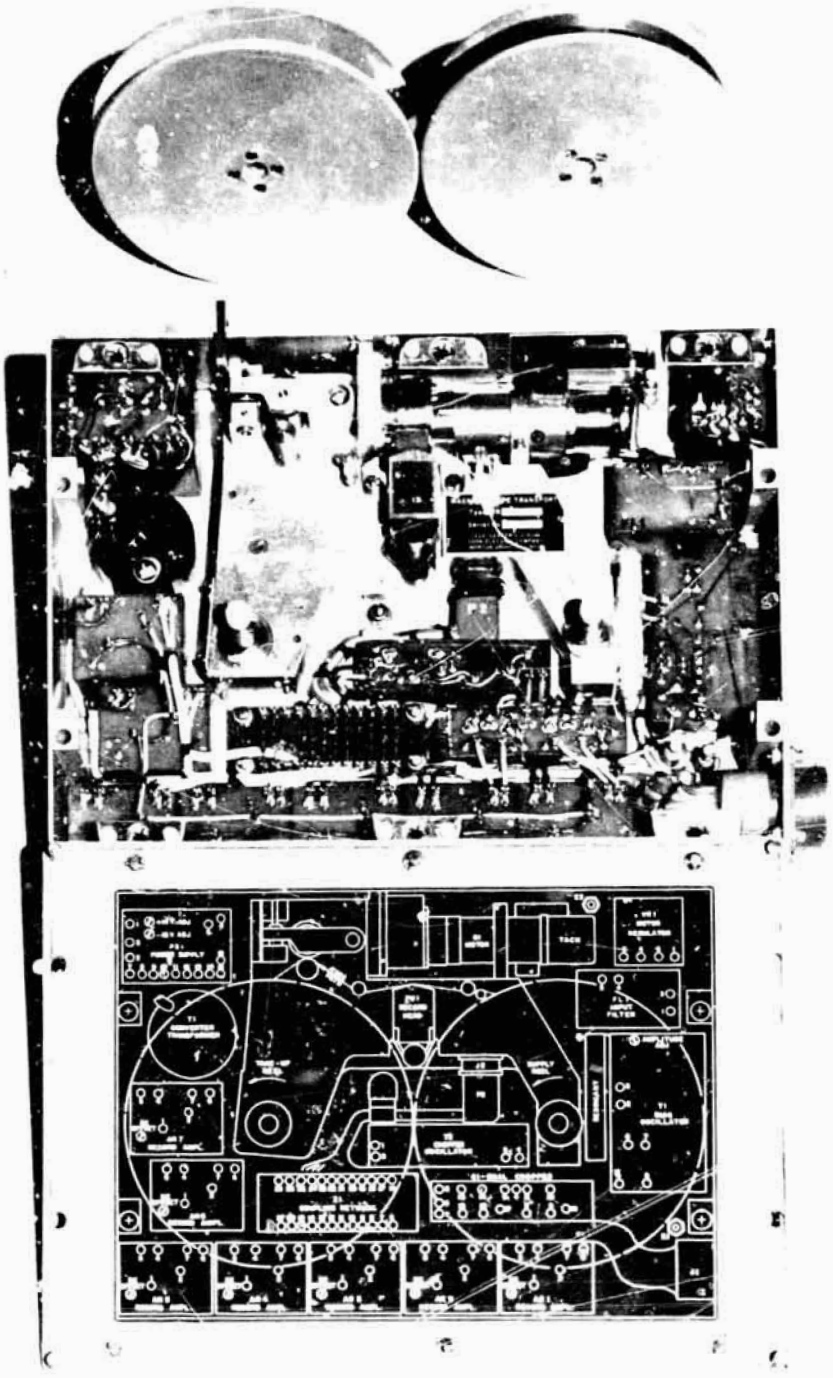

Figure 3. - Biomedical recorder.

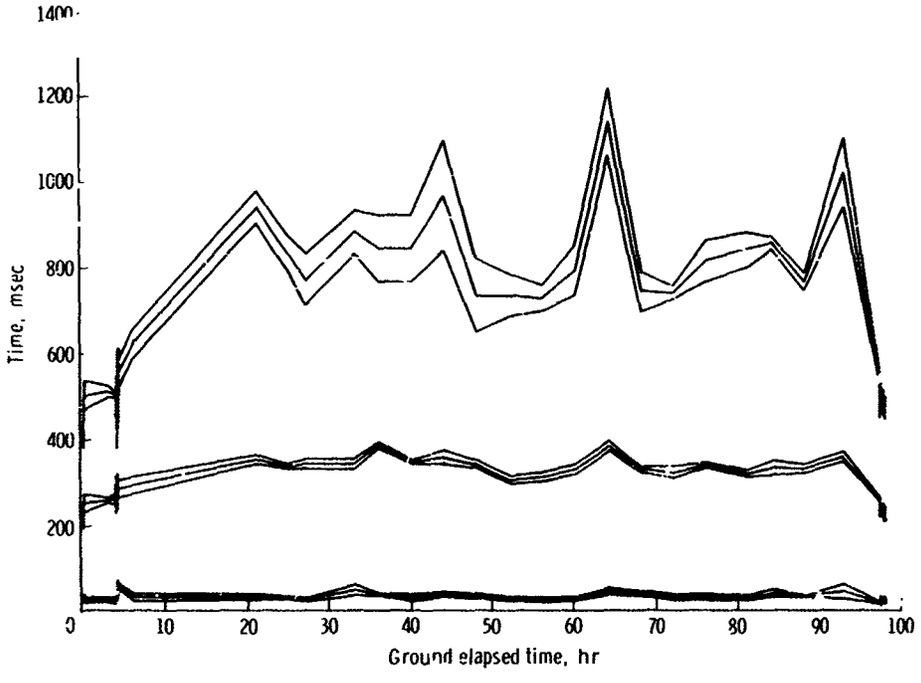

Figure 4. - Electrocardiographic data for the Gemini IV command pilot.

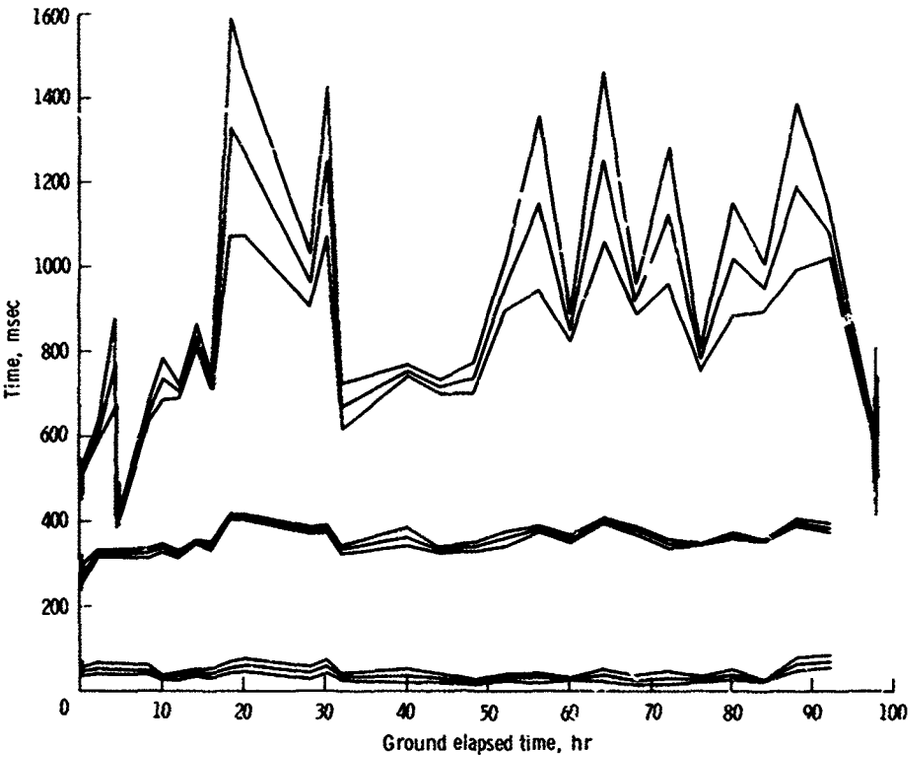

Figure 5. - Electrocardiographic data for the Gemini IV pilot.

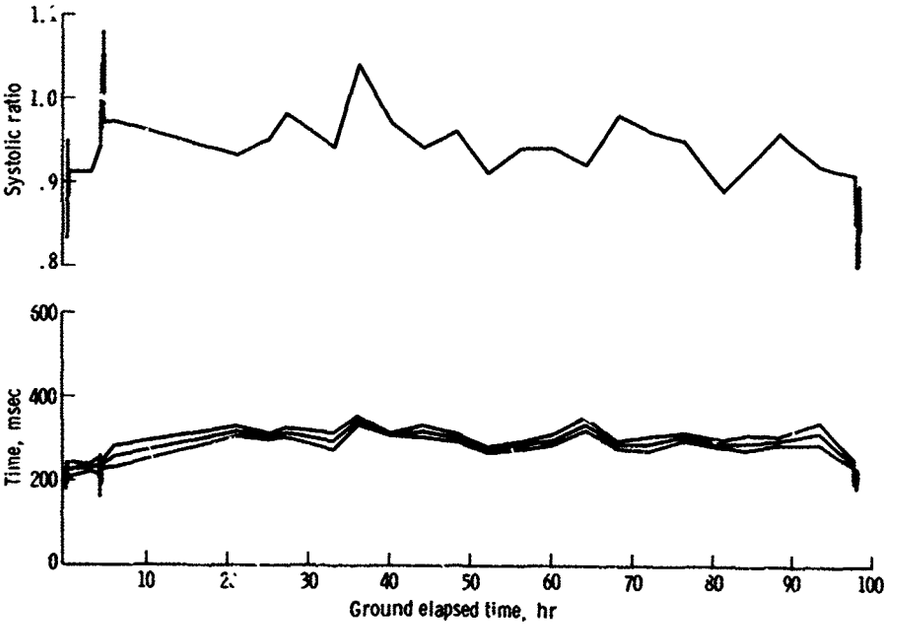

Figure 6. - Systolic-ratio data for the Gemini IV command pilot.

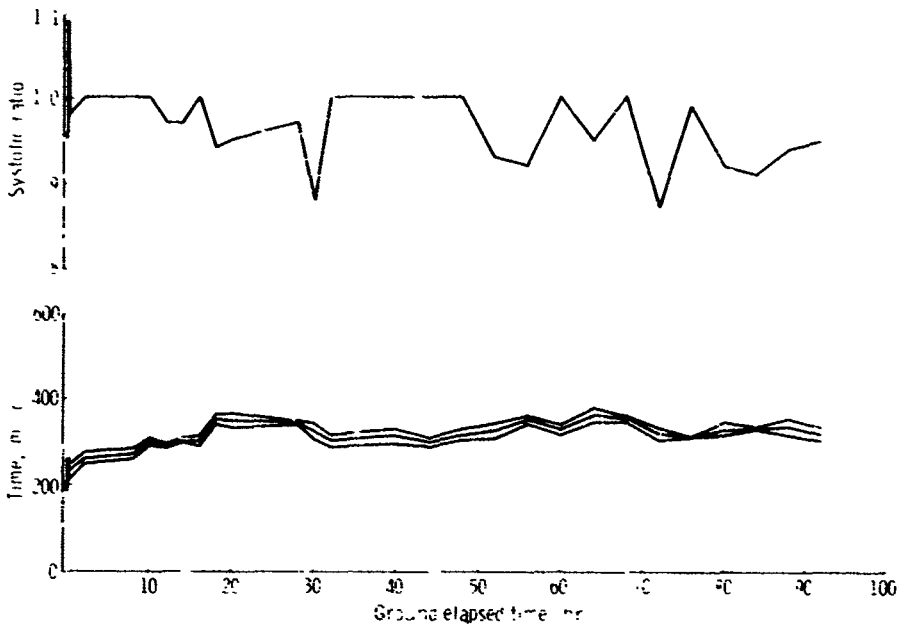

Figure 7. - Systolic-ratio data for the Gemini IV pilot.

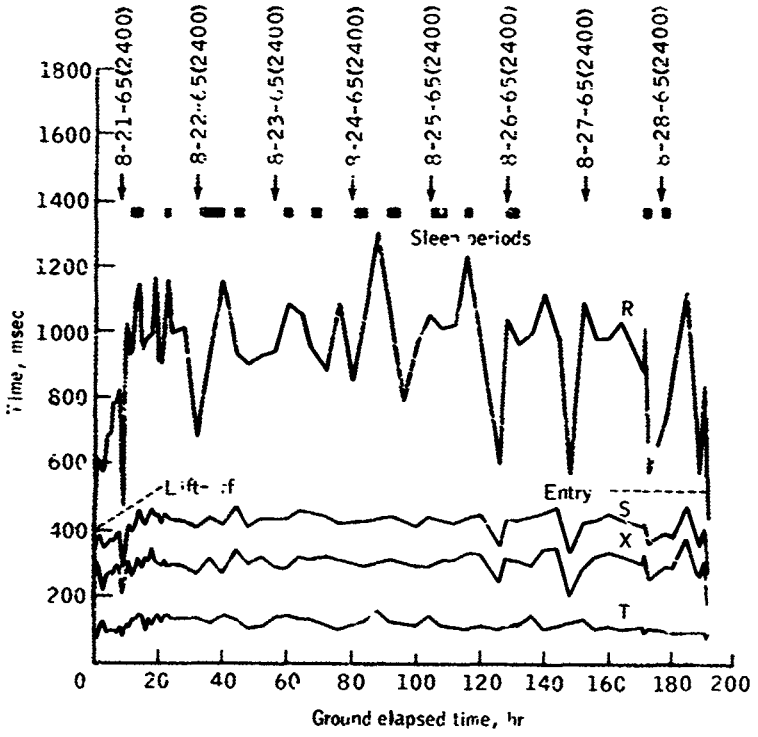

Figure 8. - Cardiac measurements for the Gemini V command pilot.

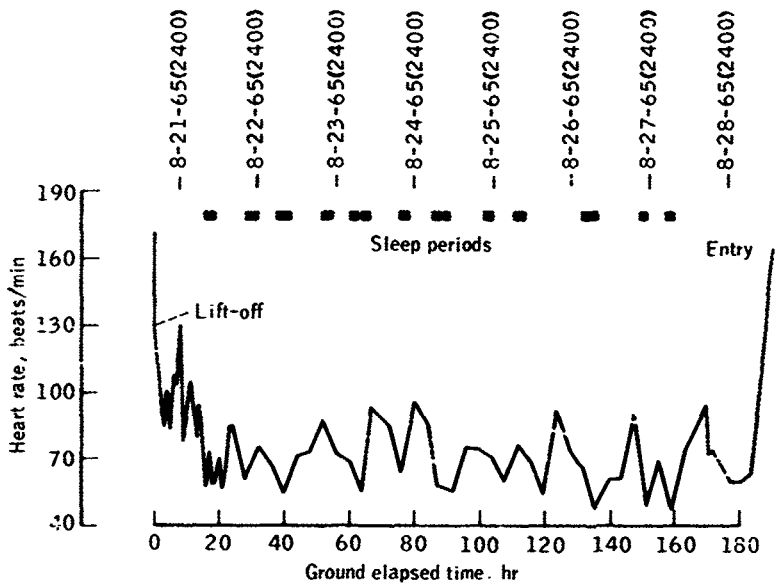

Figure 9. - Heart rates for the Gemini V command pilot.

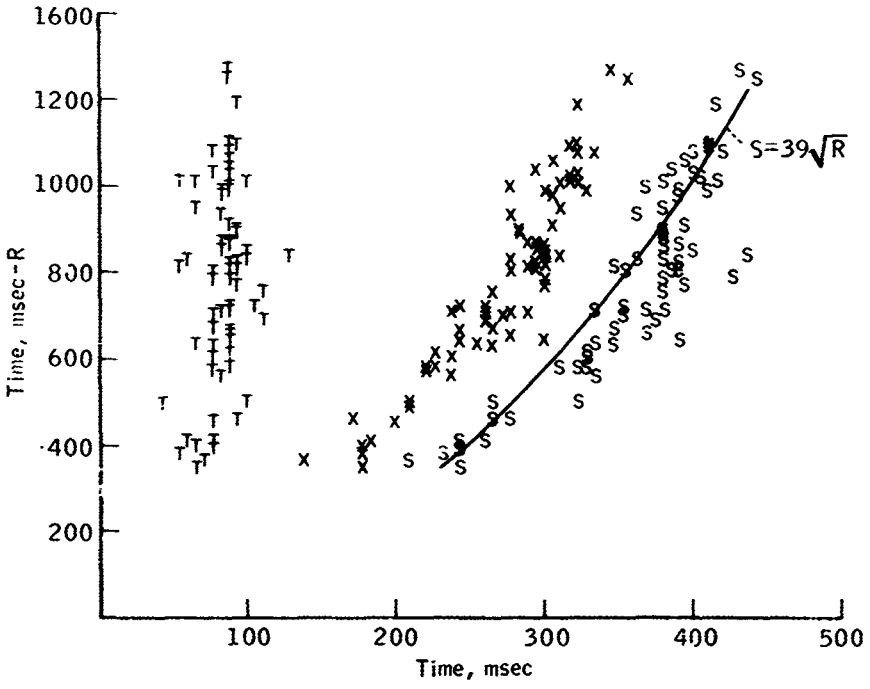

Figure 10. - Correlation of cardiac measurements for the Gemini V command pilot.

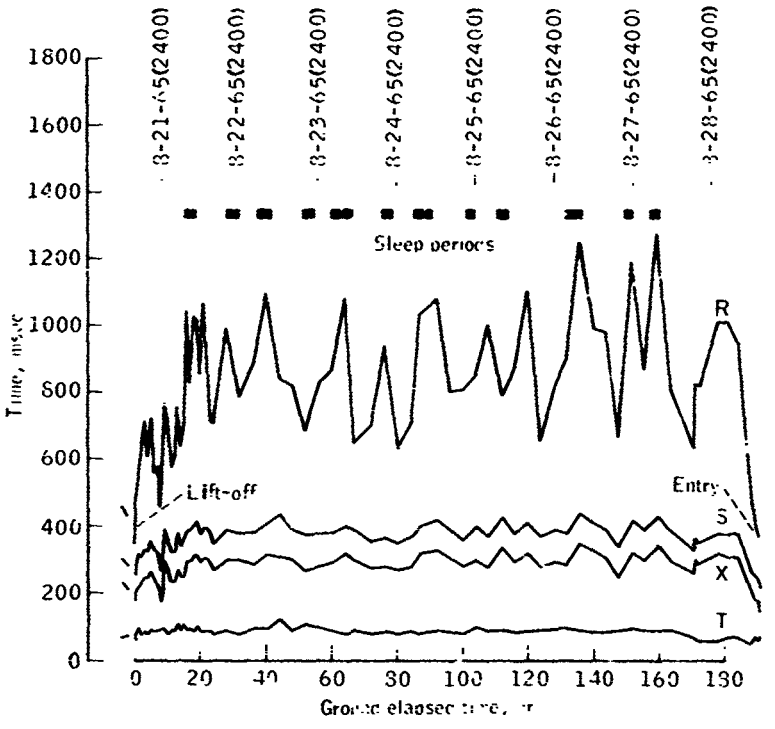

Figure 11.- Cardiac measurements for the Gemini V pilot.

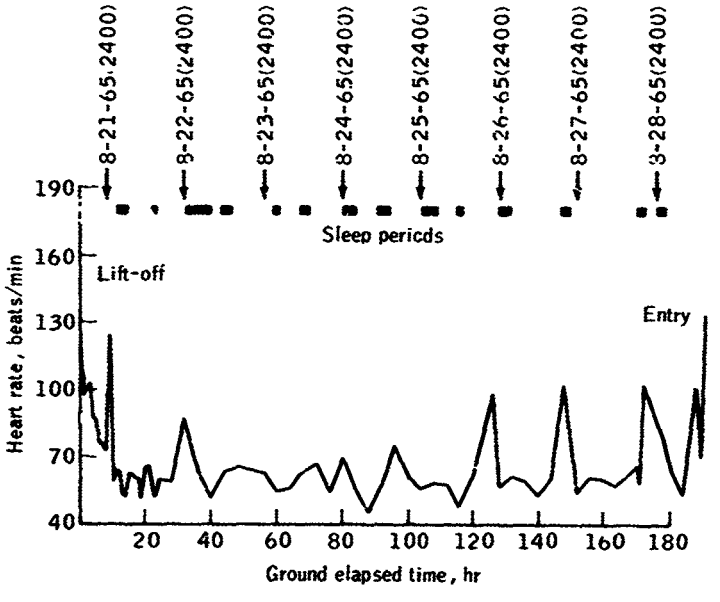

Figure 12.- Heart rates for the Gemini V pilot.

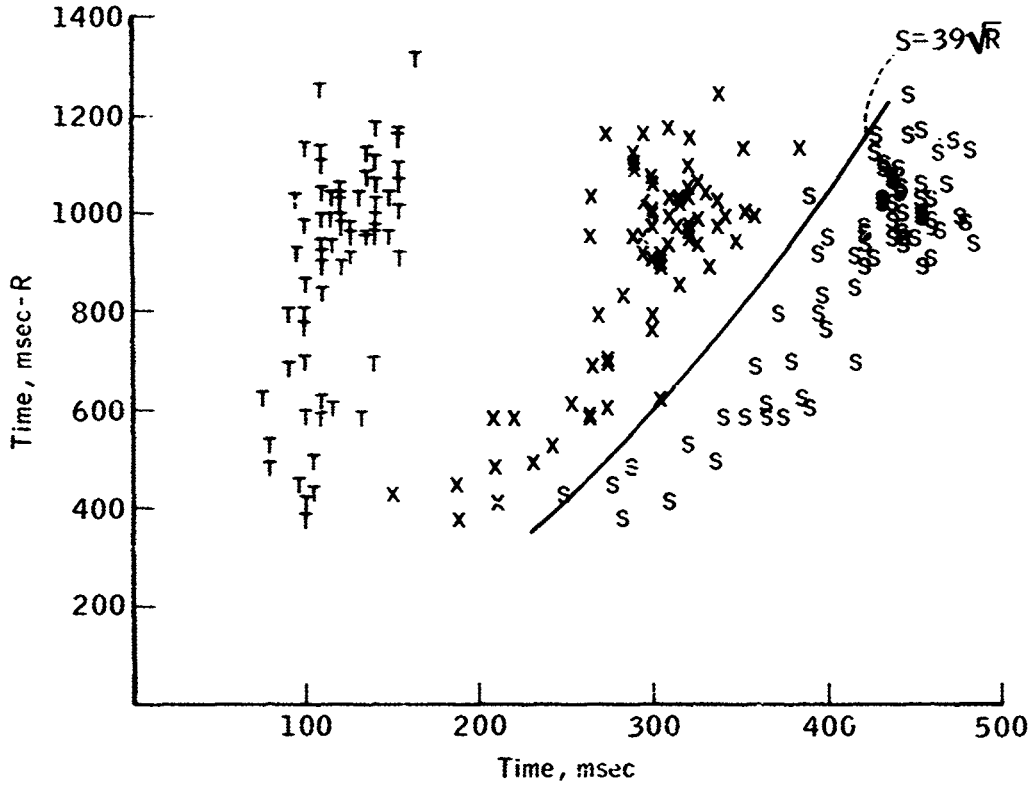

Figure 13. - Correlation of cardiac measurements for the Gemini V pilot.

EXPERIMENT M006

BONE DEMINERALIZATION

By Pauline B. Mack,* George P. Vose,*
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INTRODUCTION

A bone-demineralization study, based on radiographic bone densitometry, was performed on the crewmembers of the Gemini IV, V, and VII missions. Radiographs were made from the lateral aspect of one foot and from the posterior-anterior aspect of one hand of each crewmember on each of the three missions.

EXPERIMENTAL METHODS

Gemini IV

Radiographs were made according to the following schedule.

1. Nine days and 3 days before lift-off at Cape Kennedy

2. On the morning of lift-off at Cape Kennedy

3. Immediately after recovery on board the U.S.S. Wasp

4. At the Manned Spacecraft Center (MSC) 16 days and 50 days after recovery

During the flight, members of the research team were stationed not only on the U.S.S. Wasp in the Atlantic Ocean, but also in the Hawaiian Islands in preparation for a possible descent into either ocean.

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Gemini V

A bone-demineralization study was conducted on both the primary and backup crewmembers of the 8-day Gemini V mission. The same method of radiographic bone densitometry was used as that used on the Gemini IV mission. Radiographs were made preflight and postflight of the left foot (lateral projection) and of the left hand (posterior-anterior projection) of each crewman according to the following schedule.

1. Ten days, 4 days, and 2 days preflight, and on the morning of lift-off at Cape Kennedy, Florida

2. On the U. S. S. Lake Champlain immediately after recovery and again after 24 hours

3. At the MSC 10 days and 58 days after recovery

Because different X-ray units were used at the separate locales, the radiographs prepared for densitometry were standardized by three methods; these are as follows.

1. By use of an aluminum alloy wedge exposed adjacent to the bone

2. By use of a roentgenometer to determine the calibrated kilovoltage producing identical beam qualities in each of the three X-ray units

3. By exposure of a standard absorber (at each test site) composed of bone ash in an organic matrix (casein) and enclosed in a tissue-simulating absorber (plexiglass) to detect possible technique variations at the three locations involved

Gemini VII

The same method of radiographic bone densitometry was used as that used in the Gemini IV and Gemini V studies. Preflight and postflight radiographs were made of the left foot (lateral projection) and of the left hand (posterior-anterior projection) of each crewman according to the following schedule.

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

2. On board the U. S. S. Wasp immediately after recovery and 24 hours after recovery

3. At the MSC 11 days and 47 days after recovery

EQUIPMENT

The instrumentation used for the photometric evaluation of bone density from radiographs was a special analog computer, consisting of a series of subassemblies, all

designed to operate as an 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 elsewhere (refs. 1 to 4). Certain applications of the use of the bone densitometry used in this study also have been described (refs. 5 to 9). The X-ray film used was Type AA industrial film and was exposed in cardboard holders.

RADIOGRAPHIC EXPOSURE TECHNIQUE

Because different X-ray units were used at the three locations, the radiographs used for densitometric measurements at different sites were standardized by three methods. These methods were as follows.

1. An aluminum alloy wedge exposed on the film adjacent to the bone.

2. A roentgenometer was used to determine the calibrated kilovoltage which would result in identical beam qualities in each of the three X-ray units.

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

The X-ray machines were calibrated before each group of exposures with roentgenometers 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 used, all units had a beam quality of 60 kilovolts, comparable with the unit at the laboratory of the senior author. Milliamperage, kilovoltage, and time were set to give an exposure of 0.167 ± 0.001 roentgen. This procedure helped assume a constant relationship among the mass-absorption coefficients of hydroxyapatite, water, protein, fat, and aluminum alloy.

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, including the overlying and underlying soft tissue. The results are reported in terms of the wedge-mass equivalency of the bone sites evaluated. Although changes in composition or thickness of the tissue other than bone could be responsible for slight changes in total X-ray absorption, it has been proven that, in the case of the os calcis, errors caused by changes in soft-tissue mass are sli .

BONE-MASS EVALUATIONS

Central Os Calcis Section

Because of the anterior and posterior landmarks on the central os calcis, a trace the width (1.3 millimeters) of the scanning beam, referred to as the conventional scan,

was made on successive films of this longitudinal series. Each radiograph was made with extreme care so that the image of the os calcis on each film could be superimposed exactly over that of the initial film. With a small steel needle, the initial film was punctured at each end of the bone image; this defined the limits of the central or conventional trace. The two needle pricks could be identified by means of the magnification unit in the densitometer, which makes possible exact positioning of the film prior to scanning. The same technique was applied to the image of the calibration wedge on the same film. Before tracing the bone segments on each successive film, each film was superimposed over the first film with the needle pricks made in exactly the same positions. The anatomical location of the scan by which the central os calcis section was evaluated is shown in figure 1.

Multiple Parallel Os Calcis Evaluations

Approximately 60 percent of the total os calcis mass was evaluated by use of the parallel-path system. Without removal of the film from the densitometer after making a conventional scan, parallel scans 1.0 millimeter apart were made, beginning with a scan 1.0 millimeter above the conventional position and continuing to the bottom of the os calcis image. Thirty-seven scans were used to cover this sector on the os calcis of the Gemini IV command pilot. Forty parallel scans were used to cover this sector on the radiograph of the Gemini IV pilot (fig. 2). For the Gemini V command pilot (fig. 3), 34 paths were required to scan the os calcis portion, whereas 35 parallel scans were needed for the pilot. The alinement of parallel paths through the portion of the os calcis of the Gemini V pilot is shown in figure 4 (not every path is shown, however). For the Gemini VII command pilot, 38 paths were required to scan the os calcis portion; 42 parallel scans were needed for the pilot. The alinement of parallel paths through the portion of the os calcis that was examined is shown in figure 5 (every path is not shown).

Values of bone X-ray absorption were recorded from the data secured from the multiple scans. These values are reported in four groups covering approximately one-fourth of the total area scanned. These values are also reported as an overall value.

Control of scan widths. - For both the os calcis and the phalanx scans, the measured width of each individual bone segment was used to define the length of the scan for the specific segment for each film in the series on each crewmember.

Sections of phalanx 4-2 and 5-2. - The second phalanx of the fourth and the fifth finger of the left hand was scanned by parallel cross-sectional paths 1 millimeter apart tangentially alined with the longitudinal axis and covering the entire bone (fig. 6). Only phalanx 5-2 was evaluated on the Gemini IV crewmen.

Distal end of radius. - A single scan path was made through the diaphysis of the left radius (parallel to the distal surface) as shown in figure 7 for the Gemini V crewmen.

The talus. - For the Gemini V and VII crewmembers, a single scan path was made through the talus of the left foot, originating at the inferior surface and projecting anteriorly to the conspicuous landmark shown in figure 8.

RESULTS

Gemini IV

Results of the tests performed on the Gemini IV crewmen are as follows.

Central os calcis section X-ray absorption changes. - The X-ray absorption values (in terms of calibration-wedge equivalency) obtained from the central os calcis section throughout the study are shown in figure 9 and table I. Based on an average of preflight wedge-equivalancy values, the command pilot had a change of -9.53 percent in this section of the bone, with a -7.80-percent change when the immediate postflight value was compared with the immediate preflight bone mass. The corresponding values for the pilot were -6.20 and -10.27 percent.

Changes in muliple sections of the os calcis. - As noted, thirty-seven 1-millimeter scans were made on each of the os calcis films of the command pilot, all parallel to the conventional or central os calcis section. The first scan was made 1 millimeter above the conventional scan, with 35 successive scans below the scan of this central os calcis site.

On the os calcis series of the pilot, 40 scans were made in each case because the bone was larger. The first scan was made 1 millimeter above the scan of the conventional section and 38 parallel scans below this section (figs. 2 and 3).

In the series of multiple os calcis scans for both crewmembers, the values immediately after flight were lower than those before flight. There were no exceptions to this. An example is given in table II. The integrator counts from the densitometer assembly are given for 40 parallel segments of the os calcis of the pilot made immediately before and immediately after the 4-day orbital flight.

Comparison of four groups of os calcis parallel sections. - To compare different regions of the os calcis regarding changes in bone-mass equivalency during flight, each multiple scan was divided into four groups, and the sums of the values for each group were compared. An example of the findings, in which the wedge-mass equivalency values for the pilot are given for the four os calcis sections, is shown in figure 10. The first quarter represents the proximal section and the fourth quarter represents the distal section of the combined scans. The graph is based on a comparison of the immediate preflight radiograph with the immediate postflight radiograph.

The four plots begin with the mean wedge-mass equivalency values for the preflight films (zero time on the graph), followed, in succession, by the values obtained from the individual postflight radiographs. The changes in the four os calcis sections of the radiograph of the pilot, from the averages of the preflight values to the values obtained from the radiographs which were taken immediately after the orbital flight, were as follows.

1. Proximal section (segments 1 millimeter above the conventional scan through segment 8 below the conventional scan), -7.88 percent

2. Second section (segments 9 through 18 below the conventional scan), -7.69 percent

3. Third section (segments 19 through 27 below the conventional scan), -7.05 percent

4. Distal section (segments 28 to the bottom of the bone), -2.52 percent

Comparison of overall series of segments. - Plots of a summation of wedge-mass equivalency values for the respective multiple segments of the os calcis of the crewmembers are shown in figure 11. The plot for the command pilot is based on the 37 segments shown in the radiograph (fig. 2), and the plot for the pilot is based on the 40 segments indicated in figure 3. The value shown at zero time in both plots represents the value of the first of the three preflight films; the remaining series of radiographs follow in sequence. When the value for the immediate preflight radiograph is compared with the immediate postflight value, the command pilot had a total loss in the os calcia of 6.82 percent and the pilot had a loss of -9.25 percent.

Bone-mass changes in phalanx 5-2. - It is remarkable that the phalanx of the fifth digit sustained some losses in X-ray absorption in as short a time as 4 days. In the bedrest series, no changes of noteworthy magnitude in bone absorption by the phalanx 5-2 site were noted, except during the last half of 30-day bedrest periods.

As for the os calcis, multiple scans were made across finger phalanx 5-2 for the wedge-mass equivalency values obtained from evaluations of the films taken during this study. The scans were made across the posterior-anterior view of the finger.

For assistance in the interpretation of the data, the phalanx scans were combined into five groups, from the proximal to the distal end of the phalanx. A plot of the wedge-mass equivalency data from one of the five groups of scans of the phalanx of the command pilot is shown in figure 12. The change in wedge-mass equivalency of this section of the bone for this subject was -10.74 percent; this was calculated from a comparison of the values obtained from the radiograph taken immediately before liftoff to that obtained immediately after the crewmembers were on board the U.S.S. Wasp.

Gemini V

X-ray absorption changes of central os calcis section. - Values of X-ray absorption (in terms of calibration-wedge equivalency expressed in grams) obtained from the central os calcis section during the Gemini V study are shown in figure 13 and in table III. Based on an average of all four preflight wedge-equivalency values, the command pilot had a change of 19.3 percent in this section of bone, with a 15.1-percent change when the film exposed immediately postflight was compared with the film exposed immediately before launch. The corresponding values for the pilot were 9.0 and 8.2 percent. Recovery was substantially complete for both crewmen on the 25th day (10 days postflight); full recovery had occurred by the 75th day (58 days postflight).

Changes in multiple sections of the os calcis. - Thirty-four parallel scans were made of each os calcis radiograph of the command pilot and 35 scans were made of the

radiograph of the pilot, representing approximately 60 percent of the total bone mass in each crewman (fig. 4).

The values immediately after the flight and 24 hours after the flight were lower than any of the preflight values, with a 10.3-percent decrease for the command pilot and an 8.6-percent decrease for the pilot (fig. 14). Complete recovery had occurred by the 75th day (58 days postflight).

Comparison of four groups of os calcis scans. - In an effort to determine which regions of the os calcis were the most sensitive reflectors of bone-mass changes, the multiple scans were divided into four groups, each group represented by a longitudinal section of bone approximately 9 to 10 millimeters wide. The changes between the preflight and postflight values of four sections for each crewman are summarized as follows.

1. Superior section (segments 1 millimeter above the scan through segment 3 below)

Command pilot, percent	-12.8
Pilot, percent	-8.5

2. Second section (segments 9 through 18 below the conventional scan)

Command pilot, percent	-11.8
Pilot, percent	-9.1

3. Third section (segments 9 through 18 below the conventional scan)

Command pilot, percent	-4.4
Pilot, percent	-7.5

4. Inferior section (segments 28 to inferior surface of os calcis)

Command pilot, percent	-4.7
Pilot, percent	-7.5

As was expected, there was some inconsistency in the magnitude of changes among sections. However, it was apparent that the bone mass decreased slightly more in the superior sections than in the inferior sections of both crewmembers. This effect may be attributed to the greater proportion of cancellous bone than cortical bone in the superior regions compared with the inferior regions of the os calcis. This may help to explain the fact that changes of greater magnitude often have been observed in the conventional scan path than have been observed in multiple scans of the entire bone.

Changes in the distal region of the radius. - During the 8-day Gemini V mission the X-ray wedge-mass equivalency of the distal end of the left radius decreased 25.3 percent in the command pilot and decreased 22.3 percent in the pilot. The preflight values were regained by both crewmembers by the 75th day (fig 15).

Changes in the talus. - The X-ray wedge-mass equivalencies at the talus scanning site made immediately postflight were 13.2 percent lower than the final preflight value for the command pilot and 9.8 percent lower for the pilot (fig. 16). Recovery was faster in the talus than in the radius; however, both crewmen were almost fully recovered on the 27th day (18 days postflight) and were fully recovered by the 75th day (58 days postflight).

Bone-mass changes in 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 so that each phalanx in posterior-anterior projection was evaluated entirely (fig. 6). Decreases in wedge-mass equivalency were noted in both phalanges during the 8-day orbital phase of the study, although in both crewmen the decreases in phalanx 5-2 was greater than in phalanx 4-2. In the command pilot, a 22.6-percent decrease in wedge-mass equivalency occurred when the value determined immediately postflight was compared with the average value of the four preflight films; the pilot wedge-mass equivalency decreased by 24.5 percent. In hand phalanx 4-2, decrements of 6.2 and 6.4 percent occurred in the command pilot and pilot, respectively (figs. 17 and 18).

Relationship of inflight results to results from bedrest studies. - In the study, 845 milligrams of calcium per day were provided for each crewman during the flight. However, only 373 milligrams (mean value) were consumed daily by the command pilot and 333 milligrams (mean value) were consumed by the pilot.

In the bedrest study, one group of men was placed on an extremely low level of calcium; mean daily levels consumed tended to be even slightly less than those of the Gemini V crewmen. The comparative wedge-mass equivalency changes in the central os calcis section for both crewmen and for four bedrest subjects (on similar average calcium intakes for similar periods of time) are summarized in table IV.

Gemini VII

X-ray absorption changes of central os calcis section. - The X-ray absorption values (in terms of calibration-wedge equivalency) obtained from the central os calcis section throughout the Gemini VII mission are given in table V and figure 19. Based on a comparison of the calibration-wedge equivalency of the radiograph exposed immediately postflight with that exposed immediately before the launch, the conventional segment of the os calcis changed only -2.91 percent (command pilot) and -3.84 percent (pilot) during the flight.

It should be noted that there was an increase in bone mass of this anatomic site in both crewmen before the orbital flight and for 11 days after the flight. The postflight increase was more significant for the pilot than for the command pilot. At the time the last radiograph of the series was exposed, 70 days after the study had begun, the command pilot had leveled off in calibration-wedge equivalency of this os calcis section at a value higher than any preflight value. However, in the last radiograph, the pilot had a value which was higher than for any of his previous films except the next to the last measurement. The decrease in the overall sum of the sectional values obtained from the parallel scans made of the radiograph taken of the command pilot on the aircraft carrier immediately after his recovery was only 2.46 percent of the value determined from a radiograph exposed immediately before launch (table VI). The comparable

change in values for the pilot was -2.54 percent. The table also contains data which prove that the greatest change in bone mass during flight in any of the os calcis multiple sections of the command pilot was -5.17 percent, whereas the change for the pilot was -7.66 percent. A graph of the sums of calibration-wedge equivalency values for the multiple os calcis sections for each of the preflight and postflight radiographs is shown for both crewmen in figure 20. A general similarity between the graph of the conventional trace and the graph of the overall os calcis sections for the serial radiographs of the pilot may be seen in figures 19 and 20. The two graphs of the command pilot also have 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 of both crewmen from the beginning to the end of the flight. The effect undoubtedly is attributable, in major part, to the greater proportion of trabecular or cancellous tissue in the central and superior parts of this bone and to the relatively 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 exposed immediately postflight was 7.06 percent lower than the final preflight value for the command pilot and was 4.00 percent lower for the pilot. Prior to the flight, the talus wedge-mass equivalency value increased and then decreased for the command pilot; the value at launch time was slightly higher than the initial preflight value. The pilot had a slight mass decrease at this site preflight. Both crewmen had a significant mass increase for 11 days, after which there was a slight decrease; but final values were not significantly different from initial values (fig. 21).

Bone-mass changes in phalanges 4-2 and 5-2. - As in the case of the os calcis, multiple parallel scans were made across radiographs of hand phalanges 4-2 and 5-2. These scans were 1 millimeter apart (center to center). In this manner, each entire phalanx was evaluated in posterior-anterior projection (fig. 22).

From the time the radiograph was made immediately before launch until the radiograph made 14 days later (on the carrier immediately after recovery), the command pilot had an overall change of -6.55 percent in the 25 scans required to scan phalanx 4-2. The change in this anatomic site for the pilot during the same period was -3.82 percent; 25 scans were needed to monitor this bone. The greatest change in any section of phalanx 4-2 was -9.11 percent (command pilot) and -8.00 percent (pilot).

Graphs of the calibration-wedge equivalency values for hand phalanges 4-2 for the serial radiographs of the two Gemini VII crewmen are shown in figure 23. For the command pilot, the value for phalanx 4-2 was higher at the beginning of the orbital flight than was the first preflight value, and decreased before the end of the flight. This decrease was succeeded by a gradual increase after the flight. For phalanx 4-2, the pilot had a significant increase in X-ray absorbence during the first 7 preflight days, then had a decrease during the last 4 preflight days. After the inflight decrease, there was a sharp, and then a gradual, increase.

During the orbital flight, the command pilot had an overall bone-mass change of -6.78 percent in the 18 parallel sections of phalanx 5-2. In the 17 scans that were used

to scan hand phalanx 5-2 of the pilot, an overall change of -7.83 percent in bone mass was noted. The greatest change in this bone of the command pilot was -12.07 percent and -14.86 percent for the pilot. As in the case of the crewmen of Gemini V, the losses from phalanx 5-2 tended to be greater than the losses from phalanx 4-2. The overall bone-mass changes in the sections of hand phalanges throughout the study are shown in figure 24. The values for the command pilot did not undergo preflight and postflight changes as great as those for the pilot. The values for the pilot took a sharp upward trend during the first 7 days of the preflight period, and declined during the next 3 days. However, the last preflight value was higher than the initial value. After the decline in mass equivalency shown during the flight, there was a sharp increase during the first 24 hours after the flight, a continued moderate increase during the next 11 days, and finally a decrease. However, the value 47 days postflight was greater than the value measured at the beginning of the study.

DISCUSSION

Gemini IV

In the first venture into measurement of changes in skeletal mass during space flight, an entirely new environment is being explored. In extensive studies, the level of dietary calcium consumed during and previous to bedrest immobilization was noted to affect calcium loss from the body and to cause changes in bone mass. These dietary relationships have been reported (refs. 5 and 6). Also, exercise was shown to be effective in reduction of bone-mass losses (ref. 7). The possibility of stress as a factor in bone-mass loss has been discussed elsewhere (ref. 7). In this study, bone-mass losses were experienced by the crewmembers, and these losses were greater in the central os calcis section than were the losses of the bedrest subjects, on a similar daily level of dietary calcium, during the same time interval. In finger phalanx 5-2, distinct losses in bone mass were evident compared with only minor losses in the bedrest subjects, except in the case of prolonged bedrest immobilization, as has been noted. The losses in bone mass from the central os calcis sections of the crewmembers during the 4-day flight, compared with those of bedrest subjects on similar dietary calcium levels for the same length of time, are shown in table VII.

The loss of bone mass observed in the bedrest immobilization studies was accompanied by urinary and fecal losses of calcium, phosphorus, and nitrogen; these losses were greater during bedrest than during ambulation. The loss of bone mass does not represent only a calcium loss, but was based on losses of all the mineral components of bone, including small amounts of protein.

Because spacecraft parameters change, it was not possible to formulate definite conclusions concerning all of the variables which were involved in this study. More data, on a larger number of subjects, are needed for a more thorough interpretation of the results. However, one result has been demonstrated. Of every anatomic site investigated, densitometric values underwent a negative change in 4 days, and the change was greater than the losses incurred by healthy men in bedrest during the same period of time and on the same dietary level of calcium. Further evidence that bone-mass loss had occurred during space flight was demonstrated by increased bone-mass levels when the crewmen returned to their regular activities after the flight.

Densitometric evaluations of serial radiographs of control subjects often have shown rather frequent changes in bone mass within relatively short time periods. For this reason, it was decided to make two preflight and two postflight radiographs of the Gemini V backup crewmen. In comparison of the changes observed preflight and postflight (conventional os calcis scanning site) between the two crews, it was found that no changes greater than 4 percent were evident in either member of the backup crew. This was in contrast to the 15.1- and 8.9-percent losses observed for the flight crew.

It is known that the skeletal system undergoes a general loss of minerals during immobilization or long-duration bedrest. However, in both the Gemini IV and the Gemini V studies, bone-mass losses were greater in both the os calcis and the phalanx than were noted for the bedrest subjects during the same time period. Although the bone-mass losses on the 8-day Gemini V flight were generally greater than on the 4-day Gemini IV flight, the information to date is still insufficient to conclude that the losses tend to progress linearly with time, or whether a form of physiological adaptation may occur in space flights of longer duration.

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 the Gemini IV, Gemini V, and Gemini VII missions have compared regarding skeletal changes in three major anatomic sites with respect to changes in skeletal density during space flight. The bone-mass changes shown in table VIII (in terms of calibration-wedge equivalency) have been found for the command pilot and the pilot of each mission 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.

Comparison of Bone-Density Changes in the Gemini VII Crewmen 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 was estimated that 1.00 gram of calcium was consumed by the Gemini VII crewmen during orbital flight. On this basis, the os calcis and hand phalanx 5-2 were compared with those sites of subjects in bedrest for 14 days. Bedrest subjects, on comparable diets, lost slightly more from the os calcis and considerably less from phalanx 5-2 than did the crewmen on this mission (table IX).

Comparison of Bone-Density Changes in Crewmen and in Backup Crewmen of the Gemini VII Mission

The backup crew of the Gemini VII mission had four radiographs made according to the following schedule: November 24, 1965; December 1, 1965; January 3, 1966; and February 3, 1966. The range, from the highest to the lowest absorbency value in the os calcis, was 2.5 and 3.2 percent, during a period of 3 months and 10 days for the backup crewman. On comparable dates, not involving any aspect of the orbital flight,

the spread in os calcis absorbency values was 6.6 and 9.8 percent for the crewmen. This indicated that the maximum spread was less in the backup crewmen than it was in the flight crewmen. Exact dietary records for the backup crewmen were not kept during this period. The summary of scans on the flight crewmen in shown in table X.

The Gemini VII flight-crew activities were calculated in part to complement a metabolic study. Therefore, tasks not related to this objective were minimized so that time could be spent in isometric and isotonic exercise, in exercise with a mechanical device, and in sleep. Also, more time was available for meals. By consumption of a larger proportion of the provided diet, the crewmen not only increased the amount of calcium consumed but also increased the total energy and the quantity of other essential nutrients. Furthermore, various foods supplied for this mission were supplemented with calcium lactate.

The results of the study proved a decreased loss of X-ray density of the heel bone, but the results were far less dramatic than the results obtained for the hand. This indicated the need for further attention to the development of exercise routines which would involve the hands and fingers. Without reduction of the emphasis on dietary calcium, it is probable that a need also exists for further research in which other nutrients, known to be related to the status of skeletal mineralization, would be variables.

SUMMARY

Gemini IV

Losses in absorbence (in terms of X-ray equivalent aluminum alloy mass) in different sites in the os calcis, ranging from 6.20 to 13.42 percent, were noted for the crewmembers of the Gemini IV mission. Losses from finger phalanx 5-2 were within a comparable range. Radiographs, made of the crewmembers at two postflight times, revealed progressive increases in X-ray absorbence by these anatomic sites; postflight values approximated preflight values. It should be emphasized that changes of 6.20 to 13.42 percent in X-ray absorbence do not imply that elemental calcium changes of this magnitude occurred.

For comparative purposes, the radiographically determined losses in X-ray absorbence were compared with X-ray absorbence losses in healthy young men in bedrest. These subjects had undergone bedrest immobilization for the same length of time and had consumed daily a similar quantity of calcium. In all cases, the absorbence losses for the crewmembers exceeded losses for the bedrest subjects, an indication that restriction of body movement did not represent the only factor involved.

An important finding of the study was that the absorption losses from bone are recoverable within comparatively short time periods.

Gemini V

Losses in X-ray absorbence (in terms of X-ray equivalent aluminum alloy mass) between radiographs made immediately preflight and postflight at the conventional os calcis tracing path were 15.1 percent for the command pilot and 8.2 percent for the pilot. When the immediate postflight value was compared with the average of the four preflight values, the losses were 19.3 percent for the command pilot and 9.0 percent for the pilot.

Losses in X-ray wedge-mass equivalency of the distal radius, a bone not examined in Gemini IV, were 25.3 percent and 22.3 percent for the command pilot and pilot, respectively. The left talus, not examined in previous flights, had a bone-mass decrease of 13.2 percent in the command pilot and 9.8 percent in the pilot.

In interpreting these data, it should be understood that changes in X-ray absorbency of bone involve not only calcium, but also involve other mineral constituents of calcium hydroxyapatite, interstitial protein, and overlying and underlying protein.

Gemini VII

The percentages of decrease in X-ray equivalent calibration-wedge mass noted between radiographs made immediately preflight and postflight have been noted Losses of this magnitude do not denote skeletal pathology, because all crewmembers equaled or closely approximated their preflight skeletal status before the termination of the studies.

The crewmen of the Gemini VII mission experienced far smaller losses from the os calcis than were found for the crewmembers of the Gemini IV and Gemini V missions. Finger mineral losses were less than those found in the crewmen of these two previous flights. Bone-densitometric measurements were made on the Gemini IV and V crewmembers, but the differences were not as great as in the os calcis mineral changes. The backup crewmen of the Gemini VII mission experienced only those changes in bone density noted for healthy men pursuing their everyday activities.

The results of this study cannot be evaluated completely 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 findings of better quality in the os calcis were as follows.

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

2. The crewmen had isometric and isotonic exercises for prespecified periods of time each day.

3. An exerciser was used routinely.

4. The crewmen slept longer.

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TABLE I. - EVALUATION OF CENTRAL OS CALCIS, POSTERIOR-ANTERIOR ASPECT OF CONVENTIONAL SEGMENT, GEMINI IV MISSION

Radiographs	X-ray absorption values, calibration-wedge equivalency, g
Command pilot	
Mean of values from preflight radiographs	2.397
Radiograph taken immediately before lift-off	2.353
Radiograph taken immediately after end of flight	2.169
Radiograph taken 16 days after end of flight	2.216
Radiograph taken 50 days after end of flight	2.274
Pilot	
Mean of values from preflight radiographs	2.642
Radiograph taken immediately before lift-off	2.762
Radiograph taken immediately after end of flight	2.479
Radiograph taken 16 days after end of flight	2.419
Radiograph taken 50 days after end of flight	2.593

TABLE II. - COMPARISON OF CALIBRATION WEDGE-MASS EQUIVALENCY VALUES BASED ON INTEGRATOR READINGS FROM 40 PARALLEL SEGMENTS OF THE OS CALCIS FROM RADIOGRAPHS MADE ON THE GEMINI PILOT IMMEDIATELY BEFORE AND IMMEDIATELY AFTER THE 4-DAY MISSION

Position of scan, mm (a)	Integrator counts from densitometer computer		Change from film A to film B, percent
	Film taken immediately preflight	Film taken immediately postflight	
+1	15 162	13 675	-9.80
Conventional scan	15 346	13 770	-10.27
-1	14 404	12 920	-10.30
-2	13 752	12 508	-9.04
-3	13 286	11 921	-10.27
-4	13 198	11 753	-10.95
-5	13 139	11 524	-12.29
-6	12 984	11 558	-10.98
-7	12 889	11 530	-10.54
-8	12 692	11 368	-10.43
-9	12 542	11 414	-8.99
-10	12 104	10 516	-13.12
-11	11 673	10 282	-11.92
-12	11 136	10 094	-9.36
-13	10 791	9 871	-8.52
-14	10 407	9 336	-10.29
-15	10 266	9 118	-11.18
-16	9 961	8 784	-11.82
-17	9 734	8 428	-13.42
-18	9 562	8 448	-11.65
-19	9 032	8 168	-9.56
-20	8 684	7 846	-9.65
-21	8 358	7 539	-9.80
-22	8 168	7 478	-8.45
-23	7 997	7 351	-8.08
-24	7 784	6 980	-10.33
-25	7 594	6 963	-8.31
-26	7 336	6 881	-7.16
-27	7 138	6 834	-4.26
-28	7 046	6 612	-6.16
-29	6 801	6 595	-3.03
-30	6 667	6 528	-2.08
-31	6 583	6 388	-2.96
-32	6 508	6 286	-3.41
-33	6 442	6 130	-4.55
-34	6 271	6 106	-2.63
-35	6 136	5 964	-2.08
-36	5 783	5 354	-7.57
-37	5 517	4 920	-10.82
-38	4 923	4 442	-10.18
Total	385 774	350 084	9.25

[a]The + indicates above the conventional scan; the - indicates below the conventional scan.

TABLE III. - EVALUATION OF CENTRAL OS CALCIS, POSTERIOR-ANTERIOR ASPECT OF CONVENTIONAL SEGMENT, GEMINI V MISSION

Radiographs	X-ray absorption values in terms of aluminum-wedge equivalency, g
Command pilot	
Mean of values from preflight radiographs	2.0205
Radiograph taken immediately before lift-off	1.9193
Radiograph taken immediately after end of flight	1.6235
Radiograph taken 10 days after end of flight	1.9215
Radiograph taken 58 days after end of flight	2.0101
Pilot	
Mean of values from preflight radiographs	1.8214
Radiograph taken immediately before lift-off	1.8169
Radiograph taken immediately after end of flight	1.6574
Radiograph taken 10 days after end of flight	1.7762
Radiograph taken 58 days after end of flight	1.8160

TABLE IV. - COMPARISON OF WEDGE-MASS EQUIVALENCY LOSSES IN CENTRAL OS CALCIS OF GEMINI V CREWMEN AND BEDREST SUBJECTS ON SIMILAR DAILY INTAKES OF DIETARY CALCIUM FOR SIMILAR PERIODS OF TIME (8 DAYS)

Subjects	Average calcium consumed per day, mg	Central os calcis wedge-mass equivalency change, percent	
		Based on mean of preflight values	Based on last value before launch
Command pilot	373	-19.3	-15.1
Pilot	333	-9.0	-8.2
Bedrest subject 1	307	--	[a]-8.65
Bedrest subject 2	292	--	[a]-5.06
Bedrest subject 3	303	--	[a]-7.89
Bedrest subject 4	308	--	[a]-8.06

[a]Based on value before bedrest.

TABLE V.- 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]

Film	Date	Integrator counts obtained during densitometric scanning of X-rays		
		Evaluation 1	Evaluation 2	Average of both evaluations
Command pilot[a]				
1	11/24/65	12 012	11 932	11 973
2	12/01/65	12 652	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
Pilot[b]				
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.

TABLE VI. - COMPARISON OF BONE-MASS CHANGES DURING FLIGHT IN TOTAL OS CALCIS FROM MULTIPLE SECTIONS OF THE OS CALCIS OF THE CREWMEN ON THE GEMINI VII MISSION

[All dates are in 1965]

Position of scan, mm (a)	Command pilot			Pilot		
	Integrator counts from densitometer Dec. 4 (average)	Integrator counts from densitometer Dec. 18 (average)	Percent change from Dec. 4 to Dec. 18	Integrator counts from densitometer Dec. 4 (average)	Integrator counts from densitometer Dec. 18 (average)	Percent change from Dec. 4 to Dec. 18
+1	12 136	11 632	-3.98	13 791	13 359	-3.13
Conventional scan	12 409	12 049	-2.91	13 719	13 329	-2.84
-1	11 468	11 124	-3.00	12 592	12 239	-2.81
-2	11 229	10 836	-3.50	11 937	11 689	-2.08
-3	10 985	10 648	-3.09	11 838	11 550	-2.43
-4	10 956	10 628	-2.99	11 928	11 465	-3.88
-5	10 726	10 418	-2.87	11 613	11 306	-2.64
-6	10 460	10 142	-3.04	11 314	11 186	-1.13
-7	10 332	9 934	-3.85	11 214	11 013	-1.79
-8	10 238	9 709	-5.17	11 122	10 898	-2.01
-9	9 978	9 597	3.82	10 799	10 591	-1.93
-10	9 690	9 415	-2.84	10 630	10 275	-3.34
-11	9 630	9 248	-3.97	10 394	10 046	-3.35
-12	9 294	8 964	-3.55	10 126	9 890	-2.33
-13	8 960	8 690	-3.10	9 790	9 562	-2.33
-14	8 694	8 568	-1 45	9 536	9 276	-2.73
-15	8 567	8 381	-2.06	9 280	9 186	-1.01
--	8 090	7 996	-1.53	9 056	8 866	-2.10
-17	7 795	7 578	-2.78	8 979	8 586	-4.38
-18	7 570	7 451	-1.57	8 960	8 274	-7.66
-19	7 470	7 328	-1.90	8 222	7 892	-4.01
-20	7 403	7 268	-1.82	7 452	7 432	-.27
-21	7 295	7 209	-1.18	7 331	7 290	-.56
-22	7 221	7 184	-.51	7 241	7 168	-1.01
-23	7 176	7 141	-.49	6 893	6 989	+1.39
-24	7 192	7 130	-.86	6 890	6 843	-.68
-25	7 172	7 103	-.96	6 843	6 702	-2.05
-26	7 097	7 002	-1.34	6 829	6 503	-4.77
-27	6 914	6 838	-1.10	6 645	6 400	-3.69
-28	6 845	6 740	-1.53	6 451	6 243	-3.23
-29	6 801	6 684	-1.72	6 312	6 180	-2.09
-30	6 319	6 210	-1.72	6 218	6 128	-1.45
-31	6 022	5 965	-.95	6 090	5 910	-2.95
-32	5 694	5 608	-1.51	6 033	5 743	-4.72
-33	4 989	4 962	-.54	5 764	5 631	-2.30
-34	4 448	4 382	-1.48	5 769	5 549	-3.81
-35	3 750	3 767	-1.97	5 452	5 319	-2.44
-36	2 896	2 816	-2.76	5 391	5 088	-5.63
-37				4 804	4 614	-3.96
-38				4 362	4 253	-2.51
-39				3 714	3 637	-2.06
-40				3 070	3 322	+8.22
Total	311 912	304		352 394	343 427	
Mean change			-2.46			-2.54

[a]The + indicates above the conventional scan; the - indicates below the conventional scan.

TABLE VII. - COMPARISON OF WEDGE-MASS EQUIVALENCY LOSSES IN CENTRAL OS CALCIS OF GEMINI IV CREWMEN AND BEDREST SUBJECTS ON SIMILAR DAILY INTAKES OF DIETARY CALCIUM AND FOR SIMILAR PERIODS OF TIME (4 DAYS)

Subjects	Average calcium consumed per day, mg	Central os calcis wedge-mass equivalency change, percent	
		Based on mean of preflight values	Based on last value before launch
Command pilot	679	-9.53	-7.80
Pilot	739	-6.20	-10.27
Bedrest subject 1	675	--	[a]-2.67
Bedrest subject 2	659	--	[a]-4.25
Bedrest subject 3	636	--	[a]-3.39
Bedrest subject 4	636	--	[a]-3.59

[a]Based on value before bedrest.

TABLE VIII. - COMPARISON OF BONE-DENSITY CHANGES IN CREWMEN OF THE GEMINI IV, GEMINI V, AND GEMINI VII MISSIONS, DURING SPACE FLIGHT

Anatomic 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.

TABLE IX. - COMPARISON OF BONE-DENSITY CHANGES IN THE GEMINI VII CREWMEN WITH BEDREST SUBJECTS ON SIMILAR DIETS FOR 14 DAYS

Item	Gemini VII crewmen		Bedrest subjects
	Command pilot	Pilot	
Mean daily intake of calcium (estimated), g	1.00	1.00	0.931 1.021 1.034 1.020 .930
Change in conventional section of os calcis in bone mass (calibration-wedge equivalency), percent	-2.91	-2.84	-3.46 -3.56 -5.79 -5.11 -5.86
Change in bone mass of hand phalanx 5-2, percent	-6.78	-7.83	-1.57 -1.00 -.44 -.96 -1.27

TABLE X. - SUMMARY OF SCANS MADE FOR GEMINI VII CREWMEMBERS

Scan site	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

Figure 1. - Roentgenogram of the os calcis with the conventional scan path indicated.

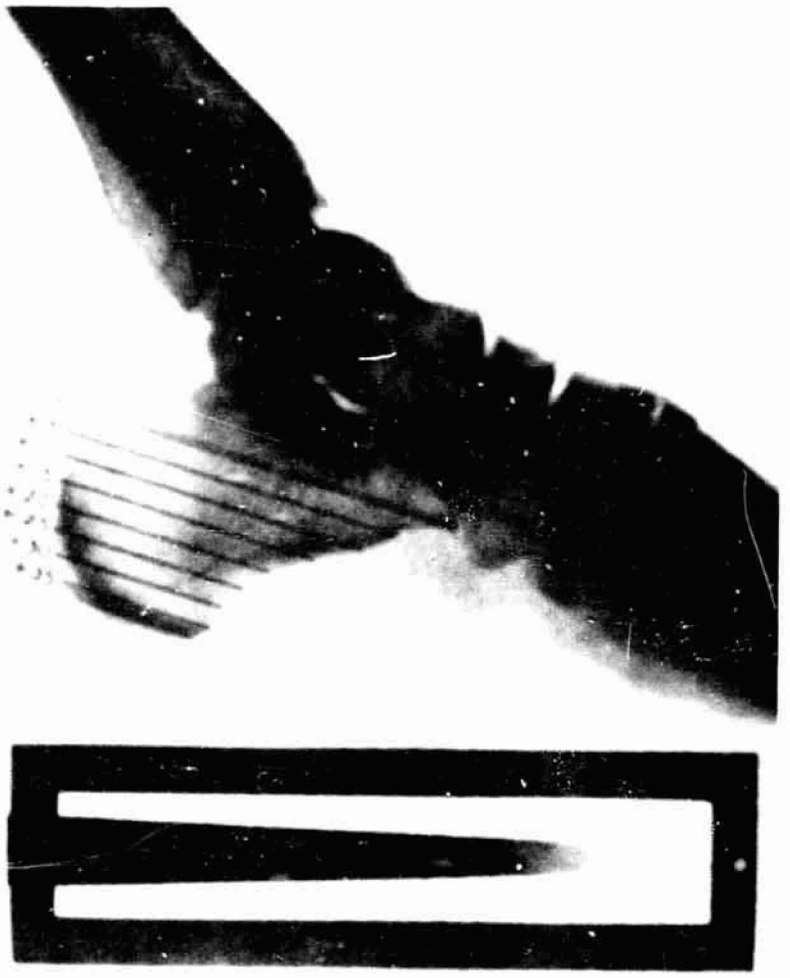

Figure 2. - Roentgenogram of the os calcis of the Gemini IV pilot with parallel scan paths indicated.

Figure 3. - Os calcis of the Gemini V command pilot.

Figure 4. - Roentgenogram of the os calcis of the Gemini V pilot with some of the multiple parallel scan paths indicated.

Figure 5. - Roentgenogram of the os calcis
of the Gemini VII command pilot.

Figure 6. - Roentgenogram of the hand of the Gemini V pilot with parallel scan paths indicated.

Figure 7. - Roentgenogram of the hand of the Gemini V command pilot with the distal radius scan path indicated.

Figure 8. - Roentgenogram of the foot of the Gemini V command pilot with conventional scan paths indicated on the os calcis and talus.

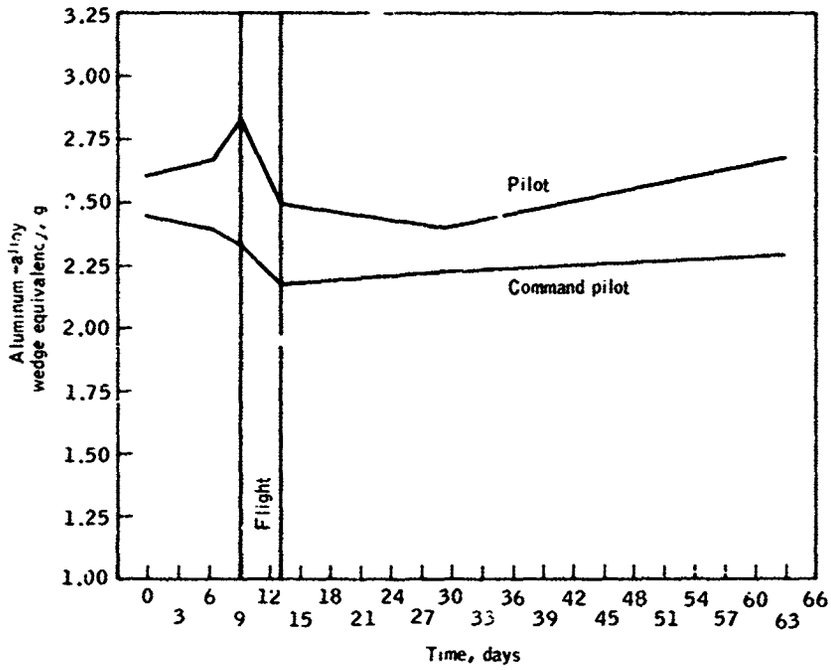

Figure 9. - Wedge-equivalency changes of the central segment of the os calcia of the Gemini IV crewmembers throughout the program.

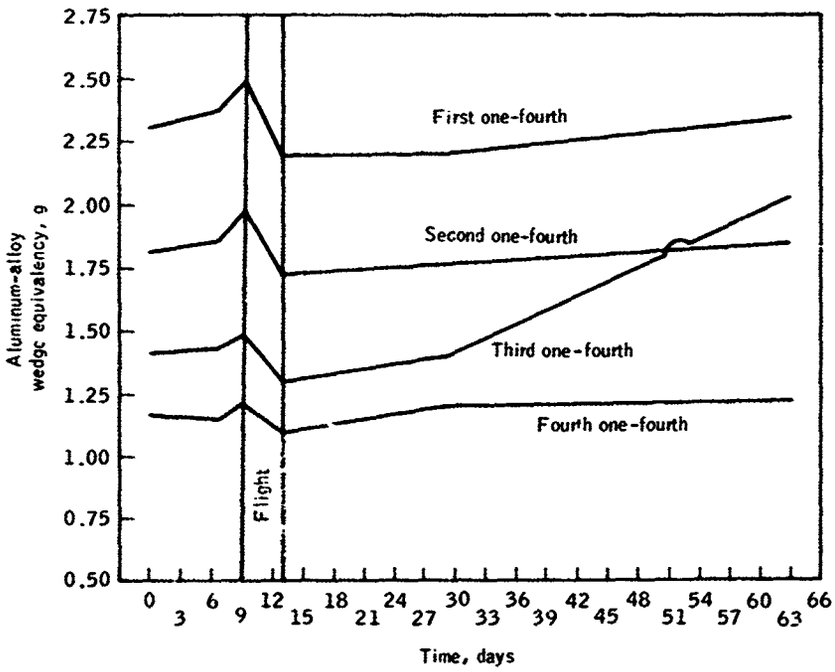

Figure 10. - Mean wedge-equivalency changes for four groups of parallel segments of the os calcis of the Gemini IV pilot.

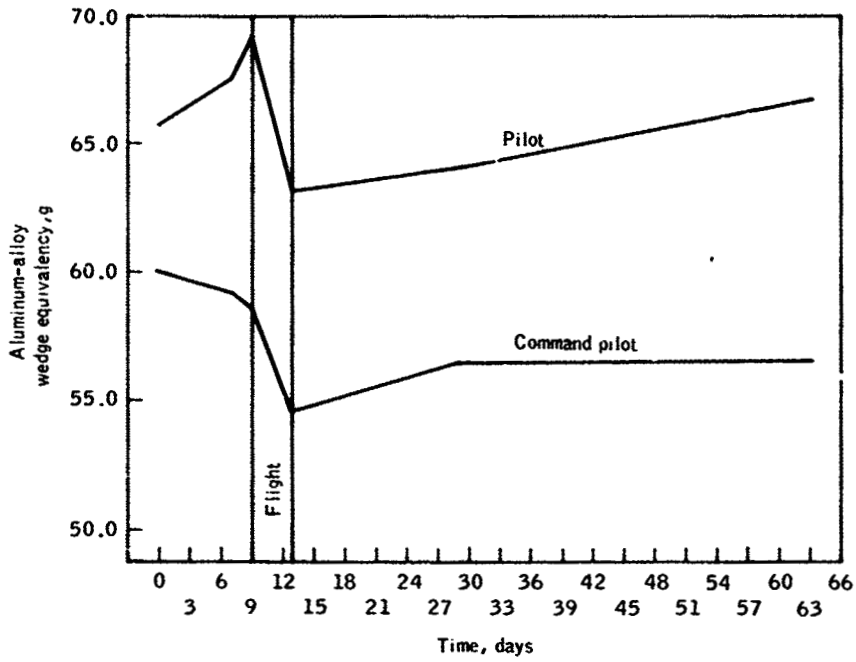

Figure 11. - Overall wedge-equivalency changes of the entire series of os calcia parallel segments for the Gemini IV crewmen.

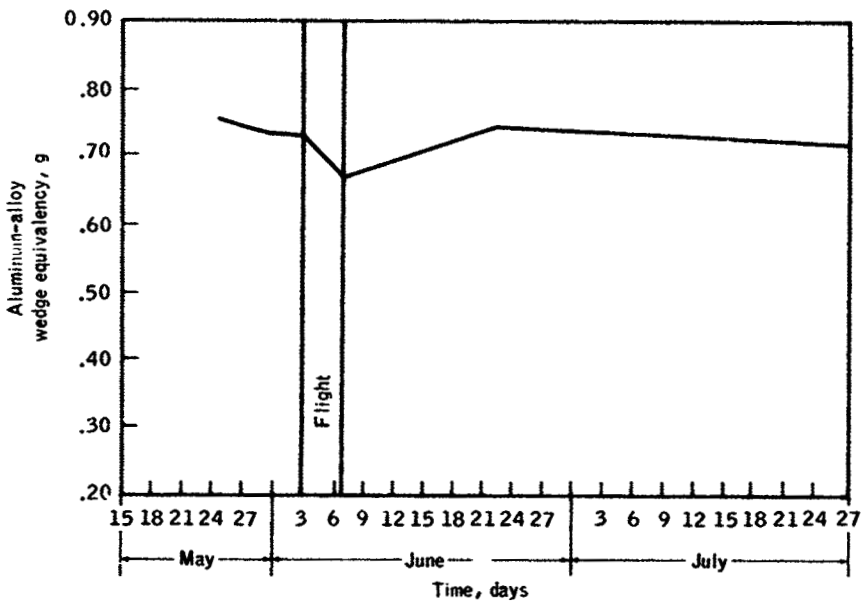

Figure 12. - Wedge-equivalency changes of a band of segments across hand phalanx 5-2 for the Gemini IV command pilot; the band represents one-fifth of the length of this digit.

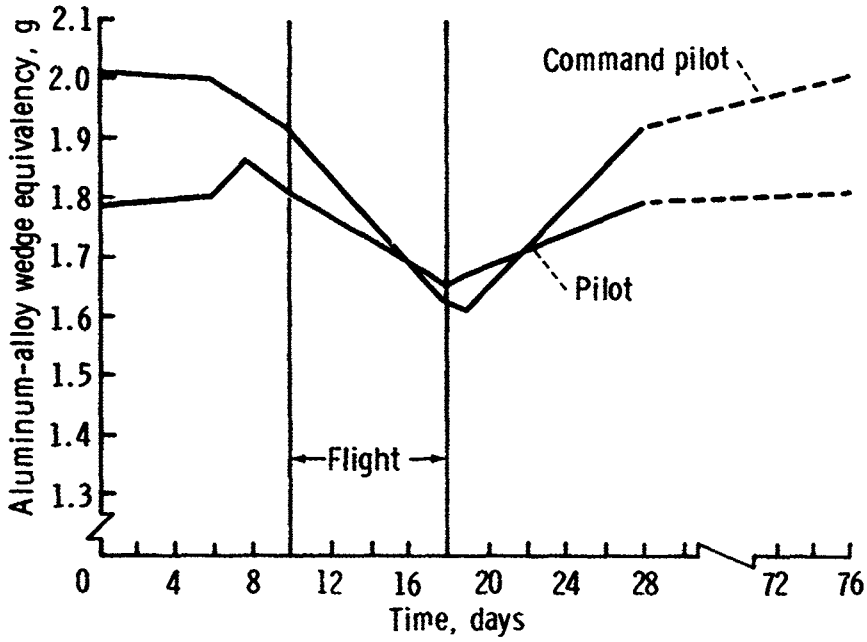

Figure 13. - Os calcia central segment wedge-equivalency changes for the Gemini V crewmen throughout the program.

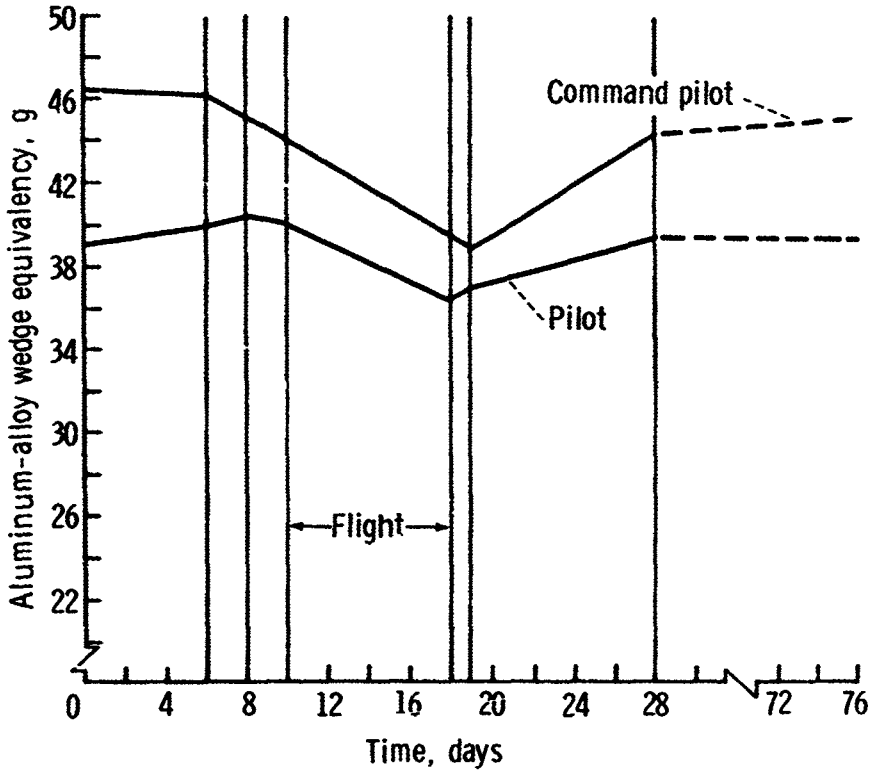

Figure 14. - Changes in wedge equivalency of the entire series of parallel scans of the os calcia of the Gemini V crewmen.

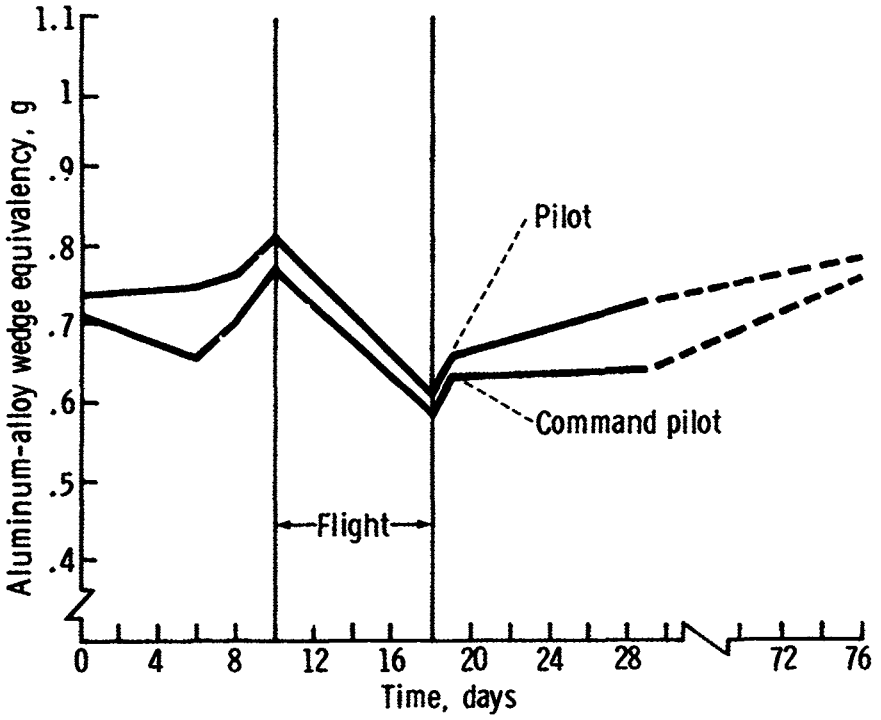

Figure 15. - Wedge-equivalency changes in the distal radii of the Gemini V crewmen.

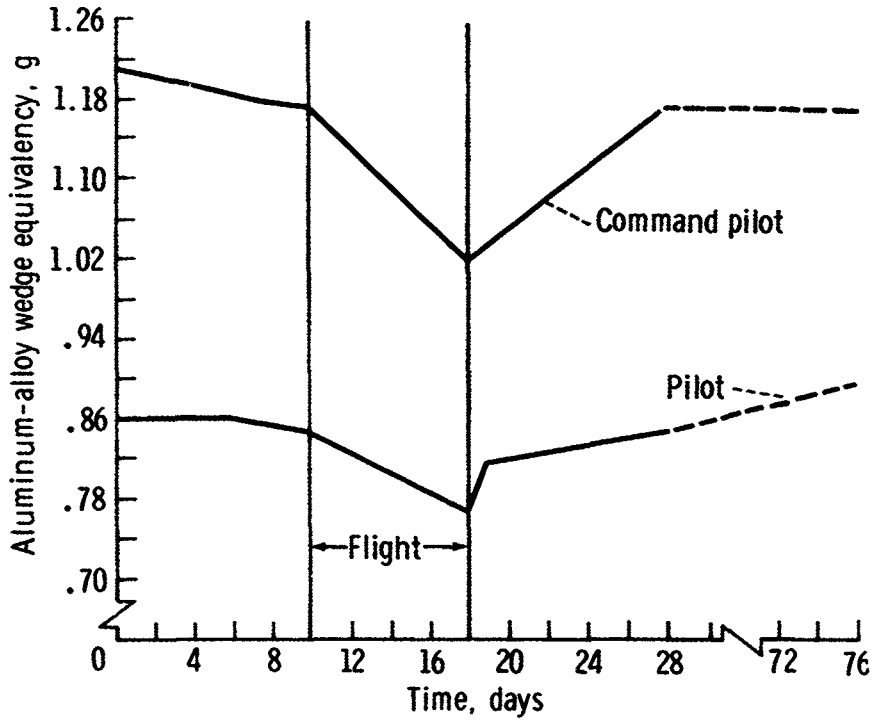

Figure 16. - Wedge-equivalency changes in the talus of the Gemini V crewmen.

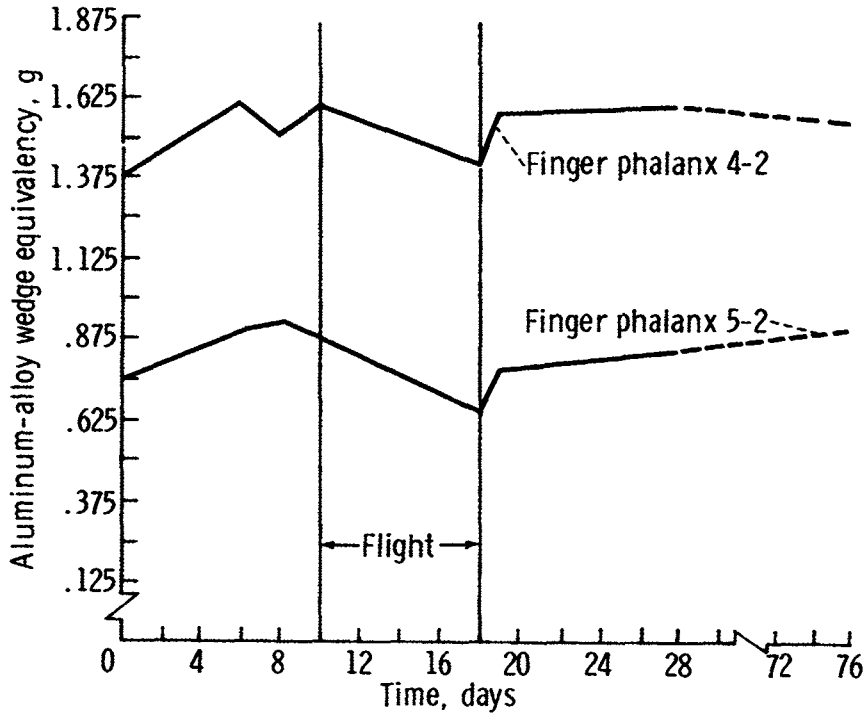

Figure 17. - Changes in wedge equivalency of hand phlanges 4-2 and 5-2 of the Gemini V command pilot.

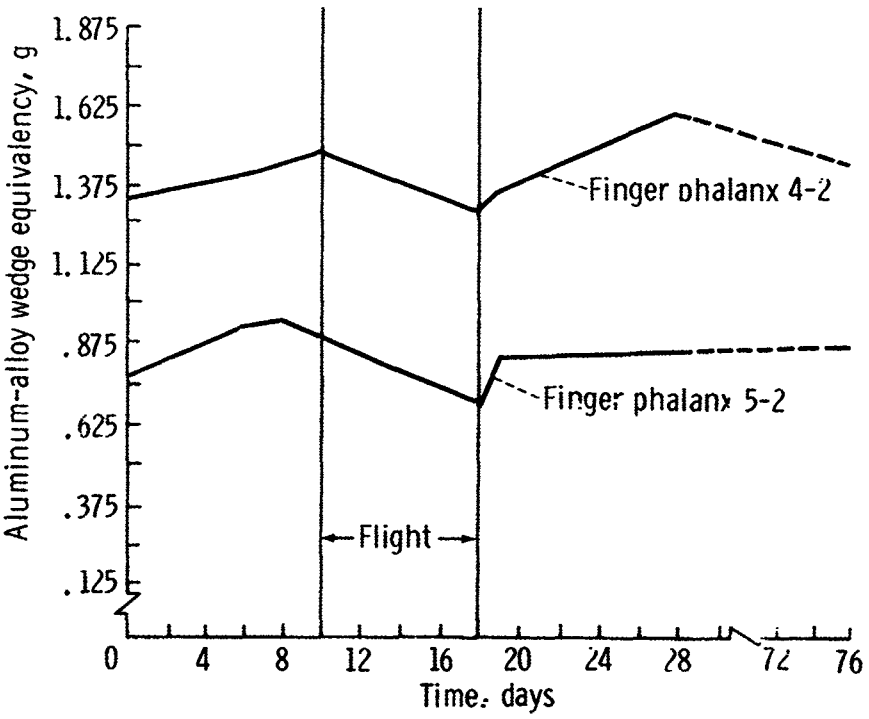

Figure 18. - Wedge-equivalency changes in hand phlanges 4-2 and 5-2 of the Gemini V pilot.

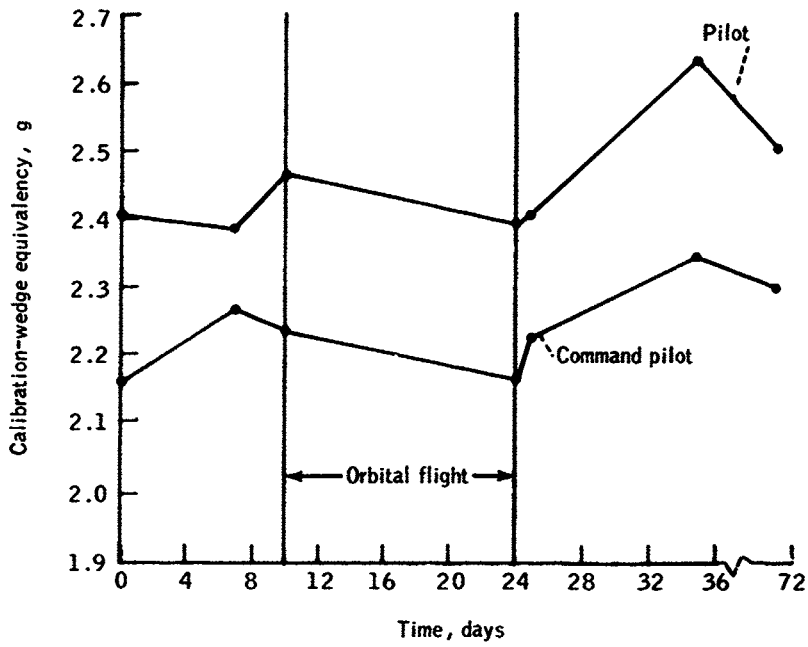

Figure 19. - Calibration-wedge mass-equivalency data on the conventional os calcia sections evaluated for the Gemini VII crewmen.

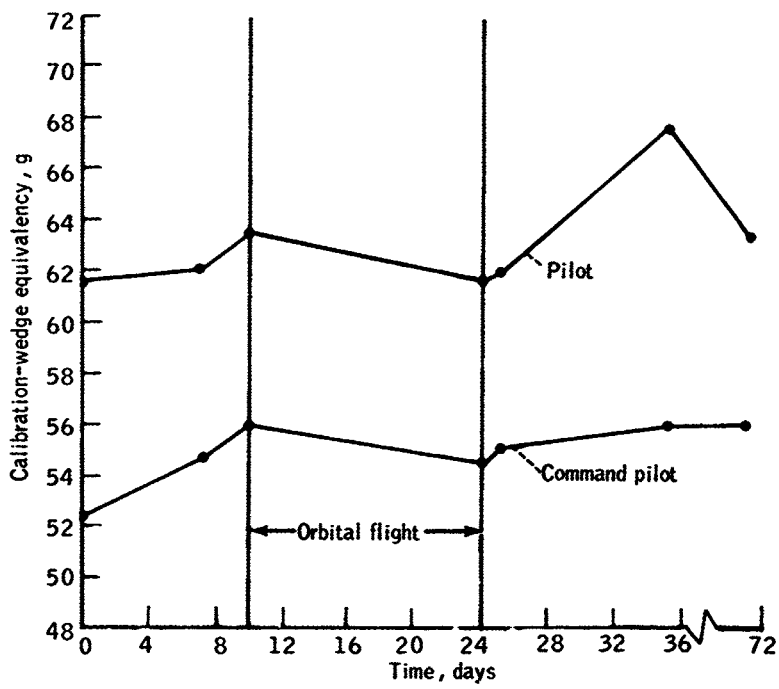

Figure 20. - Calibration-wedge mass-equivalency data on all the parallel sections of the os calcia evaluated for the Gemini VII crewmen.

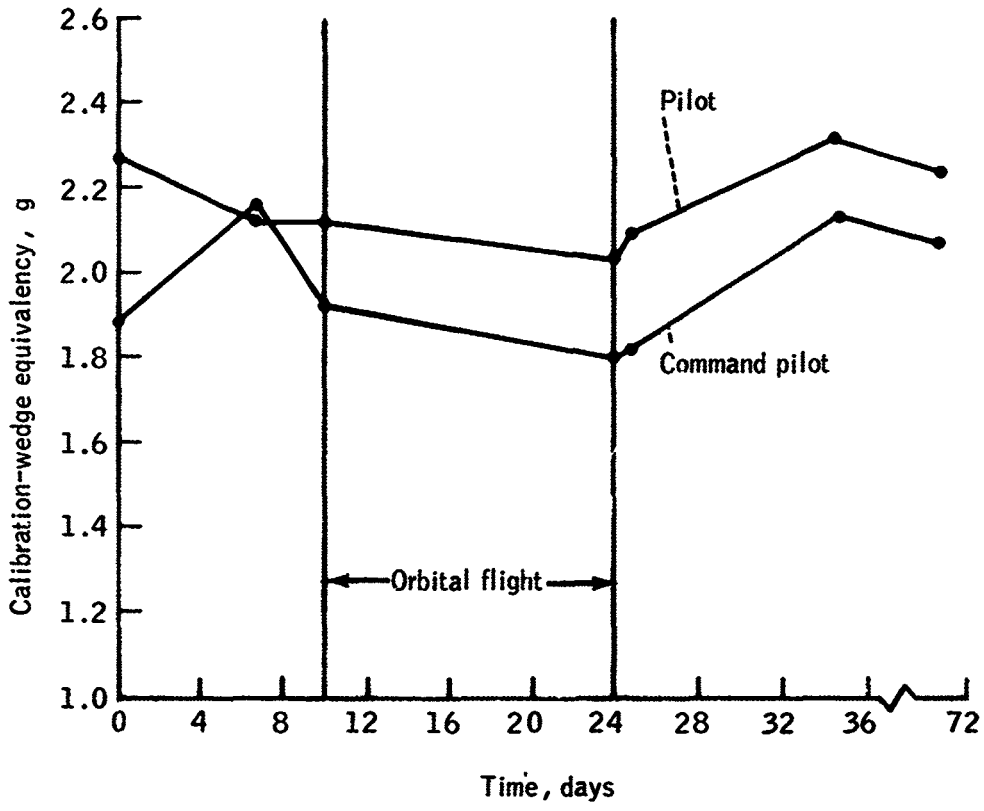

Figure 21. - Calibration-wedge mass-equivalency data on the section of the talus evaluated for the Gemini VII crewmen.

Figure 22. - Roentgenogram of the hand of the Gemini VII command pilot; the position of the parallel traces is shown overlapping and covering the entire digit.

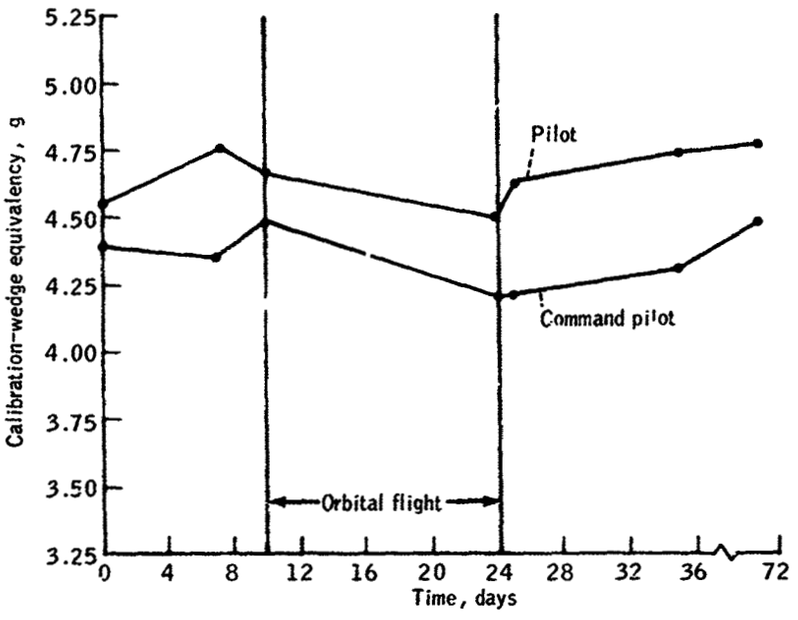

Figure 23. - Calibration-wedge mass-equivalency data on hand phalanx 4-2 for the Gemini VII crewmen.

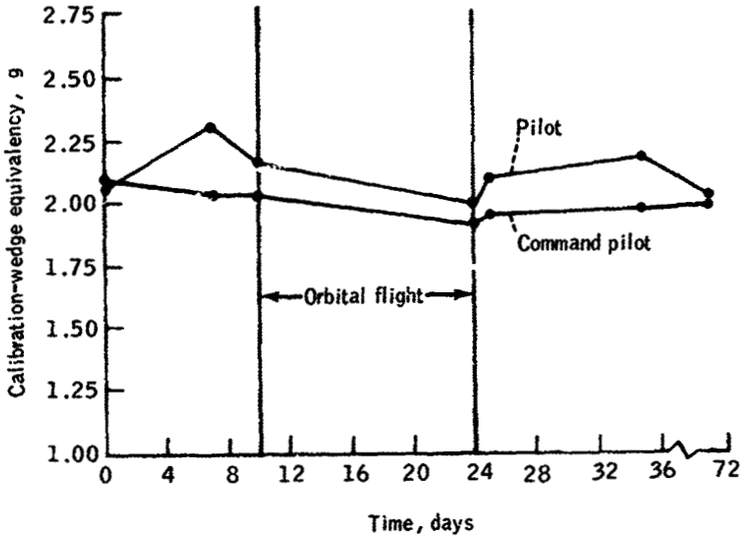

Figure 24. - Calibration-wedge mass-equivalency data on hand phalanx 5-2 for the Gemini VII crewmen.

EXPERIMENT M007

CALCIUM AND NITROGEN BALANCE

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INTRODUCTION

The objective of Experiment M007, which was performed on the Gemini VII mission, was to collect data on the effects of a 14-day space flight on two of the largest metabolically active tissue masses of the human body — the bones and the muscles. Thus, knowledge could be acquired regarding the functional integrity of the skeletal and muscular systems.

PERSPECTIVE

From the results of ground-based studies on the effects of bedrest or immobilization on normal human subjects, it had been predicted that confinement in the Gemini spacecraft, associated with the weightlessness-related lack of physical stress and strain on muscles and bones, would result in significant loss of calcium, nitrogen, and metabolically related elements. It has been proven in bedrest studies (ref. 1) that in 2 weeks of immobile rest, urinary calcium was doubled; and when measured over longer periods, substantial negative balances (or losses) of calcium, nitrogen, and other elements occurred (fig. 1). Significant losses of these elements during a space flight that continued over a period of several weeks theoretically could lead to serious skeletal and muscular weakness.

By use of the metabolic-balance method, which involves precise control of dietary intake and 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 the skeletal and the muscular systems. The extent of loss of inorganic constituents generally is proportional to the extent of functional deterioration. Roentgenograms

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taken before and after the Gemini IV and V flights indicated changes in the aluminum-equivalent density of two bones (the heel and one finger); however, these findings cannot be equated with calcium loss from the entire skeleton.

Realistic consideration of this metabolic-balance study is indicative that it was not, in any sense, an experiment on the effects of weightlessness on body metabolism; rather, it was an observation of biochemical changes that occurred as a result of several complex and interrelated influences. Principally, these influences were weightlessness, confinement, moderate physical movement, slight hyperoxia, and low atmospheric pressure. A detailed report of this study is given elsewhere (ref. 2).

PROCEDURE

The general plan of a metabolic study involves continuous collection of data during a normal-activity control phase on Earth for as long a time as is feasible before flight. Also, complete inflight data and a postflight control phase are required. In consideration of the numerous other requirements of the Gemini VII mission, the preflight control phase began 12 days before launch and was limited to 10 days. The postflight control phase was of only 4 days duration.

The method used to obtain quantitative information on a metabolic system has two requirements: collection of complete and continuous data on the dietary intake of each constituent under study and the continuous collection of all urine and feces excreted before, during, and after the flight. Because, under certain circumstances, the skin may be an important route of excretion of various elements (particularly calcium), perspiration also was collected during representative periods before and after flight. During flight, perspiration was collected continuously.

Dietary Intake

Not only must the qualitative and quantitative composition of all food and liquid intakes be known, but, insofar as possible, the amounts ingested 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 can be kept constant from control phase to experimental phase, the changes in the amounts of these constituents excreted can be attributed confidently to the influences of the experiment itself. If the intake is not kept relatively constant, changes in excreted quantities will be difficult or impossible to interpret because of change as a consequence of intake alteration.

The establishment of metabolic kitchen facilities and techniques for food preparation, weighing, storage, cooking, and serving in the kitchen of the crew quarters in the NASA Manned Space Operations Building at Cape Kennedy, Florida, was an essential factor in this study. Standard metabolic-study techniques were used to minimize day-to-day variations in the composition of individual food items. All food items were weighed to an accuracy of ±0.1 gram, and liquids were measured to an accuracy of ±2 milliliters. A sample menu is shown in table I. Variety was made possible by rotation of three daily menus. The quantities of nitrogen and calcium consumed (taken from diet tables) day by day during the preflight control phase are listed in table II.

The extent to which the values varied from day to day, particularly during the first several days, was because time was not available for a precontrol trial of the diets with the four crewmen in the control phase of the study. Also, variation was caused by a need for adjustments during the study to fit the needs of the crewmembers 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 adjustment of the crewmembers to the principles and requirements of constant dietary intake. The near-constant diet control was attempted for phosphorus, magnesium, potassium, sodium, fat, carbohydrate, and total calories (ref. 3).

An important aspect in overall dietary intake planning was the necessity to impose some constancy of intake (particularly of calcium) long before the control phase 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, each of the four crewmembers was requested to drink two glasses of milk daily for 5 months prior to the beginning of the study.

During the flight phase, the backup crewmen dropped out of the study, whereas the prime crewmen consumed Gemini prepackaged, solid, bite-size foods and freeze-dried foods that were reconstituted by the use of water (ref. 4). Although the food items taken on the Gemini VII mission were similar to those on prior missions, certain foods (notably fruit drinks and puddings) were supplemented with calcium lactate to provide a mineral intake as similar as possible to the same level as was taken during the control phase. Also, 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 remain as constant as possible under these difficult-to-control circumstances. Because of difficulty in handling equipment in the extremely small volume of the cabin, the crewmen did not follow the prescribed meal sequence; thus, there were day-to-day fluctuations. It is possible that calcium fluctuations were minor because of the number of calcium-supplemented food items in almost all meals. In any case, because the crewmen consumed almost all the various food items fairly consistently, the average intake of calcium for the total flight period was similar to the intake during the control phase. During the first day of the 4-day postflight control phase, the crewmen (on board the carrier) consumed foods prepared at Cape Kennedy. The crewmen returned to their quarters at Cape Kennedy for the remaining 3 days and ate a diet that was similar to that which was eaten during the preflight control phase.

Specimen Collection

Bottles, a commode adaptation of toilet seats, and a small refrigerator were used in the astronaut quarters for the collection of all urine and feces during the preflight and postflight control phases. This apparatus 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 excretion. Then, specimens were placed in the refrigerator immediately. Specimen-collection stations were established at the Gemini mission simulator and at two other locations at Cape Kennedy. Specimens were picked up at regular intervals and were returned to a laboratory in the Manned Space Operations Building, where they were prepared for shipment to Cornell University for analysis.

Two days prior to the flight and 2 days after the flight, perspiration collections were made from each crewman. The somewhat complicated procedure included washing the body with distilled water, the wearing of cotton long underwear for 24 hours, and another body washing. The underwear was rinsed, and the water from this rinse, combined with the water from the body washes, was analyzed for minerals and electrolytes.

For the flight phase, collection of perspiration was accomplished by the use of the cotton undergarments which were worn throughout the flight. Distilled water from the skin wash that was performed shortly after arrival on the carrier was included in the specimen to be analyzed.

Collection of urine and feces in the weightless environment was a complex procedure and it required the development of special equipment. It was essential for feces to be well formed to assure that stool collection would be made with relative ease. Apparently, the moderately low residue of the metabolic diet was helpful in this process. This diet was continued until the morning of the launch. Fecal specimens were wrapped securely in plastic collection devices (preservative already added), which were labeled with the name of the crewmember and the time of excretion; then, the specimens were stowed in the locker.

Development of the urine-collection device involved a great deal of effort and ingenuity, not merely because of the problem of collecting fluids in a weightless environment, but also because of lack of space for storage of the total volume of all specimens. It was necessary to devise a method for determination of the volume of each specimen and then take an aliquot for storage (for analysis). Several systems were tested on the ground, but the one that was used in flight involved the introduction of a tracer quantity of tritium into an 800-milliliter plastic collection bag into which the urine was excreted. After the tracer was mixed thoroughly with the specimen, an aliquot was transferred to a 75-milliliter bag for storage and analysis; the remainder was expelled from the spacecraft.

The urine collection device did not work well in flight, mainly because of leakage at the point of connection between the subject and the device. The more serious problems with the aliquot bags that were saved for analysis are summarized in the following list.

1. Because there was considerable concern about adequate stowage space and about whether the volume of each specimen saved could be controlled by the crewmen, one of the crewmen, during the early part of the flight, made aliquots that were much too small.

2. One aliquot bag was broken.

3. Four of the aliquot bags were not labeled (no name, no time).

Other than the deficiencies just mentioned, most of the urine specimens were properly collected and labeled.

This summary is not an adequate account of the numerous problems that were involved in planning and the tremendous detail that was involved in specimen collection, labeling, recording, and shipment. A 10-day rehearsal of the methods was conducted

in September 1965 at the 6570th Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Dayton, Ohio. Members of the group involved in the exercise came to Cape Kennedy in November and December 1965 to assist in this inflight study.

ANALYTICAL PROBLEM

Analyses were performed on specimens that represented 76 man-days of study and that involved approximately 300 urine specimens, 60 fecal specimens, 14 perspiration samples, and an indefinite (but large) number of diet samples. Each specimen was analyzed for nitrogen, calcium, phosphorus, magnesium, sodium, and potassium. Also, the urine specimens were analyzed for creatine, creatinine, sulfate, chloride, and hydroxyproline. In addition to these components, fecal specimens were analyzed for fat. In addition to the number of analyses that were performed and correlated, the problem was complicated further in the inflight phase by the irregular time periods from one urination to the next. Because of this irregularity, some difficulty occurred when an attempt was made to relate the analytical values to a regular 24-hour pattern.

RELATIONSHIP TO OTHER EXPERIMENTS

A close-working relationship between the design of Experiments M007 and M005 (the analysis of body fluids) was necessary. Blood specimens were collected before and after flight as a part of the Experiment M005 protocol for the determination of serum calcium, phosphorus, and alkaline phosphatase. In bedrest studies that involved immobilization for several weeks, slight increases in serum calcium have been noted. Experiment M005 analyses of urine for electrolytes, corticosteroids, and catecholamines were based upon urine that was collected during Experiments M005 and M007. Aliquots of the urine specimens at Cornell University were sent to the Manned Spacecraft Center for the Experiment M005 analyses just mentioned.

Great interest will be focused on the correlation between the extent of apparent mineral loss from the os calcis and metacarpal bones (Experiment M006) and the total mineral loss from the entire skeleton. This correlation will be indicated by the results of the balance study. Because the skeleton varies considerably from bone to bone in the relative availability of calcium, the correlation between the two methods, if at all possible, will not be simple.

RESULTS

The validity of any metabolic study rests heavily on the completeness of collection of specimens, for which investigators rely mainly on the expertness of their collection techniques and the faithfulness with which they are carried out. For 24-hour urines, investigators have long had the aid of the 24-hour excretion of creatinine; although not infallible, it is certainly a useful guide. Preflight, except for the first 2 days for the pilot, the values for 24-hour excretion of urinary creatinine were constant for each individual, indicating good collection procedures. However, during the

orbital or inflight phase, the creatinine values were erratic (variance inflight was significantly greater than preflight variance for both men). Primarily, this erratic variance was caused by difficulty in the use of the inflight urine collection and transport system. As was stated, leakage occurred during collection of many specimens; some aliquots were lost and possibly some aliquots were inadequately mixed with tritium. It was decided that inflight urine volumes were not reliable as a basis for calculation. Therefore, to provide data more indicative of the true state of metabolic indices (with acknowledgment of possible error and with the necessary assumption that renal clearance was not altered significantly by the space environment), it was decided to correct all inflight urinary excretion values on the basis of presumed unchanged urinary creatinine excretion. Creatinine excretion was calculated as being the mean of urinary creatinine excretion [illegible] the preflight control 10 days plus the postflight control 4 days for each of the two [illegible] nauts who were studied in flight. Thus, the urinary metabolic data of the inflight phase of this study are reported as corrected on the basis of measured excretion compared with expected 24-hour creatinine excretion.

Mineral-Metabolism Data

Metabolic-balance data are shown in tables III and IV. Urinary excretion of calcium did not change significantly during the first 7 days of space flight in either man. However, a definite increase started on approximately the eighth day for astronaut F. B. : this increase persisted during the 4 days of observation after flight. The mean increase in urinary calcium during the second week in flight was 23 percent for F.B. and 9 percent for J. L. (fig. 2). The 9-percent increase was not significant.

The phosphate data that were obtained for the astronauts were indicative of an increase in urinary phosphate over the first 9 days of space flight. This increase occurred during a time when dietary phosphate was half that of the control values. Thereafter, urinary excretion dropped approximately to control values despite relatively constant dietary intake.

The net balance of calcium (fig. 3) during flight was less positive for both men. In the case of J. L., this was because of an increase in fecal calcium. Dermal losses of calcium, listed as "sweat," were low for both men in all phases and were slightly higher during the relatively inactive postflight recovery days. Despite decreased fecal excretion, the phosphate balances became more negative during the flight, but returned to control levels during the recovery phase.

Urinary nitrogen decreased during flight and returned to preflight values during the postflight phase for both astronauts. Dietary nitrogen was less during the flight, and, as a result, nitrogen balance became negative during this phase. Sulfate-excretion data tended to resemble nitrogen-excretion data. Changes in magnesium balance and urinary excretion were similar to those factors for calcium (fig. 4). The data in figures 3 and 4 were plotted according to the method given in reference 5.

Electrolyte Data

For potassium metabolism, the response varied between the two astronauts (fig. 4). Astronaut F.B. sustained an initial decrease in urinary potassium in the presence of a significant decrease in dietary potassium in flight. During the second week of

flight, urinary potassium increased, a change that was correlated with a simultaneous slight decrease in urinary sodium. Immediately postflight in astronaut F. B., potassium excretion decreased to preflight values as the dietary intake was increased. However, astronaut J. L. underwent only a slight decrease in urinary potassium in the first week of flight. despite a significant intake restriction. During the second week, potassium excretion decreased further and then increased to preflight values during the recovery phase.

The two astronauts studied had different patterns of urinary-sodium excretion (fig. 5). For astronaut F. B., despite a slight decrease in dietary sodium, there was natriuresis during the first week of flight, a return to control values during the second week of flight, and a significant retention in the early postflight period. Conversely, astronaut J. L. underwent no change in sodium excretion during the first part of the space flight, an increase in excretion thereafter, and then (in a manner similar to astronaut F. B.) a significant retention postflight. The salient features of urinary chloride excretion were: for astronaut F. B., a significant reduction during the first 10 days of flight; and for astronaut J. L., a reduction during the recovery phase.

Hormone Excretion

The urinary excretion of metabolites of adrenal hormones underwent definite changes in relation to the flight (figs. 6, 7, and 8). For astronaut J. L., epinephrine excretion and, more variably, norepinephrine excretion were greatest on the 2 days of greatest predicted stress — the day of lift-off and the day of splashdown. For astronaut F. B., catecholamine excretion approximated this pattern, but the values were not different significantly from the control preflight phase. The excretion of 17-hydroxycorticosteroids, which is regarded as representing chronic adaptation to stress, was surprisingly low during the entire orbital-flight phase. For both subjects, this measurement was increased on the day of splashdown. The few values that were obtained for urinary aldosterone were increased during and immediately after flight.

Blood-chemistry results have been reported by Dietlein and Harris (ref. 6). Analyses of preflight and postflight serum and plasma for calcium, phosphorus, sodium, potassium, chlorine, urea nitrogen, total protein, and albumin were indicative of no changes as the result of the flight. Immediately postflight, plasma 17-hydroxycorticosteroids were increased and plasma uric acid was decreased slightly.

DISCUSSION

The principal goal of these studies was to measure any changes that may have been produced by the period of zero gravity in the total body metabolism related to the musculoskeletal system. The presence of stresses in addition to weightlessness has been indicated clearly. There were many problems, both foreseeable and unforseeable, that were associated with this experiment; possibly, these problems account in part for some of the differences in metabolic responses between the two subjects. However, despite these inadequacies, the experiment was of distinct value because it represented the first attempt to obtain information on possible metabolic changes in man during space flight.

With reference to the relative validity of the data, a crucial point is the necessity to correct the inflight urinary excretion values on the basis of the assumption of unaltered 24-hour renal clearance and urinary excretion of creatinine, ascribing the low and variable urinary creatinine values mainly to the known incomplete and variable urine collections in flight. This correction procedure cannot be validated short of a repeat study with accurate collections; only in this way could the possibility of decreased renal clearance be ruled out. The lowered inflight creatinine value cannot be explained, even partly, on the basis of muscle waste, because, during the several weeks of the extreme immobilization of bedrest in casts (ref. 1), urinary creatinine values did not decline. This finding also may be cited as some reassurance that glomerular filtration rate (GFR) and creatinine clearance do not change greatly, if at all, in weightlessness. The GFR increases briefly after a shift of body position from vertical to horizontal on Earth, and it may decrease slightly during sleep, but a characteristic of the GFR is the capability to adjust promptly to the initiation of stresses and to return to the original level. In a bedrest study that has been completed recently, creatinine clearances have been measured weekly in three normal subjects before, during, and after 30 weeks of bedrest; the clearance values have not changed (ref. 7). The likelihood that the correction was reasonable was supported by the pattern of urinary calcium. The intake of calcium was changed least between control and experimental phases, and the urinary excretion of calcium is only alterable sluggishly by most influences (including dietary). The corrected inflight values for urinary calcium during the first few days of flight were very similar to preflight values; values for specimens that were collected near the end of flight were at the same level as, and were certainly no higher than, the recovery-phase values. Recovery-phase values were virtually the same as preflight for astronaut J. L. and were increased with respect to preflight values for astronaut F. B. Finally, correction on the basis of urinary creatinine was the only method available in this situation by which meaningful data could be obtained. The conclusions that are described obviously must be tempered by consideration of this reservation.

Calcium Metabolism

The trend in urinary calcium excretion during flight was similar to that during immobilization, but was much less extensive. Mean urinary calcium increase during the second week of bedrest in the Cornell Study (ref. 1) over control levels was 10 percent (ranging from 53 to 130 percent among the four subjects), whereas the increase for the same period was 23 percent for astronaut F. B. and 9 percent for astronaut J. L. (the latter was not significant). However, the changes in calcium balance were appreciable, resulting in the assumption, supported by fecal nitrogen values, that fecal period separations between preflight control and in flight were accurate.

However, interpretation of this moderate negative shift involves consideration of the influences of various interacting factors in this study. The bases are evident for the prediction that weightlessness would increase losses of calcium. With regard to the gaseous atmosphere of the spacecraft (100 percent oxygen at 5 psi), it has been shown in tissue-culture studies that high oxygen atmosphere leads to increased bone resorption; therefore, hyperoxia might contribute further to losses of calcium. However, as a possible partial explanation for the slight extent of calcium loss that was noted in this study, high altitude has been proven to decrease or suppress the losses of calcium at bedrest (ref. 8). This fact is suggestive that decreased atmospheric pressure may

have been protective. In addition, the isometric-exercise program and the continuous activity in the flight work by the subjects may have acted further to decrease calcium losses. Finally, the recently observed direct relationship between calcinuria and dietary protein intake raises the possibility of another protective influence against urinary calcium loss — the inadvertent sharp reduction in protein intake in flight in this study. Because considerable individual variability of response to each of these influences (weightlessness, high-oxygen-content atmosphere, high altitude, exercise, and dietary protein reduction) may be expected, the differences that were observed between astronauts F. B. and J. L. may not be surprising. Clearly, many additional ground-based clinical and animal studies are needed to sort out the validity and relative importance of the various possible influences on calcium metabolism.

Phosphate and Nitrogen Excretion in Relation to Muscle Integrity

The significant increase in urinary phosphate excretion was one of the more striking changes that were observed, particularly because it occurred in spite of an approximate 1 gram per day decrease in phosphate intake during flight. This change was reminiscent of the early peak of urinary phosphate excretion with nitrogen excretion in immobilization (ref. 1) and must have reflected some significant metabolic derangement. Because the loss of calcium was moderate, attention turned from bone to muscle. Although urinary sulfate and nitrogen excretion were less during the inflight phase than in the control phase, these elements did not decrease as much as would have been expected from the uncontrollable decrease in dietary intake of these two elements. This observation is suggestive of the loss of substantial muscle tissue, which was corroborated subjectively by one of the astronauts who commented on the "flabbiness" of his leg muscles upon his return to Cape Kennedy.

Electrolyte Metabolism

Urinary sodium is a function of dietary intake, aldosterone activity, and glucocorticoid secretion; usually, fecal losses of sodium are very small and are relatively constant. Correlation of the observations of urinary sodium excretion with measurements of urinary adrenocortical metabolites was suggestive of a relationship to 17-hydroxycorticosteroid excretion but not to aldosterone excretion.

Urinary excretion of potassium may reflect protein metabolism, aldosterone secretion, and glucocorticoid action. The variability in response to potassium excretion that was noted for the two astronauts has no ready explanation.

Astronaut J. L. had a pattern of chloride excretion that was parallel to that of sodium excretion. However, astronaut F. B. excreted chloride in parallel with potassium. The reason for this discrepancy was not apparent. Balances of chloride were not calculated because of technical difficulties in the measurement of dietary chloride.

Hormone Excretion

One of the most striking findings in the study was the consistently low urinary 17-hydroxycorticosteroid values during flight. High values were expected and were seen on the first postflight day. Because deterioration of corticosteroids in unrefrigerated urine (with or without benzoic acid crystals) generally is less than 1 milligram per 24 hours over a 2-week period, the observation regarding the inflight results appears to be valid. This point was checked by E. M. Cotlove, D. Young, and D. Dorow of the Department of Clinical Pathology, Clinical Center, National Institutes of Health, Bethesda, Maryland. In this check, a very similar method was used. Urinary sodium excretion was well correlated with 17-hydroxycorticosteroid excretion for both crewmen, and sodium retention occurred with increased excretion of these hormonal metabolites, as would be expected. Various physiological bases for the low inflight values of corticosteroids may be among the following items: suppression of the hypothalamo-pituitary-adrenal axis (unlikely in view of the quick increase in urinary values for both crewmen immediately upon reentry); in vivo steroid interconversions, either enzymatic or mechanistic and related to altered transcortin levels (not measured); alterations in renal tubular function (not measured); a defect in erythrocyte membranes, caused by an oxygen partial pressure (pO_2), that facilitated steroid entrapment within red blood cells (a speculative possibility, because erythrocyte fragility was increased); and losses of steroids in sweat (even in induced sweating such losses are minimal, rarely exceeding 4 to 8 micrograms per 100 milliliters of eccrine sweat). Of these possible causes, two are unlikely, and the others have not been studied in sufficient depth to explain the experimental findings.

The pattern of catecholamine excretion was correlated reasonably well for astronaut J. L. with the times of greatest stress — the beginning and end of the flight. Also, data for astronaut J. L. contained a correlation between the corticosteroids and both potassium excretion and the ratio of urinary sodium to potassium. The urinary excretion of aldosterone did not correlate with electrolyte excretion.

SUMMARY

The collection of data on the response of the skeletal and muscular systems to 14-day space flights was the goal of Experiment M007. It had been predicted that space flights of such duration would result in a significant loss of calcium, nitrogen, and other metabolically related elements. A metabolic-balance method was used to assess this metabolic problem. This experiment was complementary to the analysis of the effects of space flight on body fluids (Experiment M005). In addition to weightlessness, the various influences present during this experiment could have exerted varying and conflicting influences on calcium metabolism.

Technical or engineering constraints on biomedical observations during the flight prevented optimal performance during the inflight phase, which resulted in variations in dietary control (except for calcium, which was reasonably constant) and in losses of urine samples. Considerable interindividual variability was demonstrated in all experimental factors that were measured. In one crewman, significant increases in urinary calcium occurred during the second week of flight. These increases persisted during

the recovery phase, and calcium balance became less positive in flight for both subjects. Urinary phosphate excretion increased substantially in flight for both subjects despite a reduction of phosphate intake. Urinary nitrogen and sulfate excretion decreased in flight but to a lesser extent than would be expected from the reduction in intake. Patterns of excretion of magnesium, sodium, potassium, and chloride were different for each subject, and, in part, could be correlated with changes in adrenocortical steroid production. The principal hormonal change was a striking decrease during flight in the urinary excretion of 17-hydroxycorticosteroids. Dermal losses of calcium, magnesium, sulfate, nitrogen, and phosphate were insignificant during all three phases.

CONCLUSION

Because of the numerous influences in space flight of many kinds, notably 100-percent-oxygen atmosphere, one-third atmospheric pressure, and relatively uncontrolled physical activity in addition to weightlessness, the metabolic effects of weightlessness per se could not be determined in this experiment. Undoubtedly, the various metabolic changes that were observed represented the net effect of several different concurrent and counteracting factors that were predominantly physical in nature. Determination of the true effects of weightlessness will necessitate careful sorting out of the effects of these other factors in appropriate, well-controlled, ground-based studies.

Within the rather broad limits of precision of this first metabolic study in space, the changes in calcium metabolism and in other factors were moderate enough to support (from the metabolic viewpoint) the decision that a voyage to and from the Moon would be safe medically, because the time involved would be no more (in fact, less) than was involved on the Gemini VII mission. However, for assessment of the physiological safety and performance of astronauts on future, much longer flights, the necessity is evident for additional in-space metabolic observations; these observations must be planned with better control, despite operational constraints. Such studies will result in more reliable information for accurate prediction of the extent of mineral and other metabolic changes to be expected in long-duration space flight and will result in the establishment of a basis for judgment of the necessity for development and assessment of corrective or protective measures.

This report represents an attempt to describe the difficult and detailed planning, the great management effort required both by the investigators and the NASA staff, and the tremendous and perceptive cooperation of the crewmembers that were required for completion of the calcium and nitrogen balance study. Considering the complexity of the experiment, it was conducted with exceptional quality.

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TABLE I. - PREFLIGHT MENU I[a]

Meal	Food	Weight, g
Breakfast	Beef patty	120
	Egg	50
	Bread	50
	Butter	80
	Honey	30
	Orange juice	175
	Milk	165
	Coffee	2
Lunch	Beef patty	240
	American cheese	20
	Onion slice	30
	Green peas	95
	Rolls	40
	Lettuce	80
	Italian dressing	20
	Orange sherbet	100
	Milk	160
	Tea	.5
	Lemon juice	5
Dinner	Chicken breast	180
	Rice	60
	Green beans	100
	Rolls	60
	Lettuce	80
	Tomatoes	75
	Italian dressing	20
	Pineapple	100
	Milk	25
	Tea	.5
	Lemon juice	5
8:00 p.m.	Vanilla ice cream	150

[a]For astronaut F. B.

TABLE II. - NITROGEN AND CALCIUM INTAKE

Crewman	Element	Preflight control days										Mean	S. D.
		12	11	10	9	8	7	6	5	4	3		
F. B.	N	24.72	23.46	27.41	23.57	26.03	27.20	21.27	25.39	27.50	21.25	24.78	±2.36
	Ca	1.108	1.110	1.041	1.158	1.123	1.038	1.146	1.095	1.059	1.143	1.102	±.044
J. L.	N	21.41	19.77	24.33	22.37	22.16	24.03	21.48	22.19	23.99	21.46	22.32	±1.44
	Ca	1.129	1.136	1.061	1.154	1.129	1.032	1.139	1.131	1.029	1.139	1.108	±.048
E. W.	N	19.88	21.41	25.94	25.22	27.32	25.46	24.67	24.64	24.80	24.68	24.40	±2.17
	Ca	1.043	1.151	1.057	1.088	1.212	1.074	1.111	1.022	1.026	1.111	1.090	±.059
M. C.	N	22.32	21.13	26.03	26.22	26.06	28.55	25.38	26.02	28.69	25.41	25.58	±2.36
	Ca	1.149	1.148	1.060	1.168	1.147	1.056	1.178	1.144	1.087	1.180	1.132	±.047

Crewman	Element	Postflight control days[a]				Mean	S.D.
		1	2	3	4		
F. B.	N	20.78	27.83	21.06	21.60	22.82	±3.36
	Ca	1.053	1.182	.968	1.204	1.102	±.111
J. L.	N	18.58	24.13	23.48	21.87	22.02	±2.48
	Ca	1.066	1.136	.939	1 220	1.090	±.119

[a]All data are in grams per 24 hours.

TABLE III. - METABOLIC-BALANCE DATA FOR ASTRONAUT F. B.

Phase	Duration, days	Source	Constituent							
			Calcium, g/day	Magnesium, g/day	Sodium, mEq/day	Potassium, mEq/day	Phosphate, g/day	Sulfate, g/day	Nitrogen, g/day	Chloride mEq/day
Preflight	10	Diet[a]	1.103 ±.044	0.388 ±.011	151.7 ±15.7	128.9 ±22.8	2.548 ±.239	2.737 ±.368	24.78 ±2.36	--
		Urine[a]	215 ±.024	.117 ±.014	172.4 ±15.8	98.9 ±17.0	1.323 ±.091	1.344 ±.292	22.83 ±2.65	145.3 ±10.9
		Feces	.765	.221	3.0	7.9	357	.182	1.78	18.4
		Sweat	.026	.007	24.7	10.4	.000	.004	.19	.1
		Balance	+.097	+.043	-48.4	+11.7	+.668	+1.207	-.02	-
Flight	14	Diet[a]	1.042 ±.251	0.198 ±.040	145.1 ±28.4	96.8 ±8.9	1.362 ±.161	0.874 ±.163	15.81 ±2.85	--
		Urine[a]		.129 ±.033	196.3 ±41.1	93.4 ±41.6	1.741 ±.442	1.254 ±.210	17.90 ±2.27	95.7 ±42.5
		Feces	.796	.115	2.3	1.[illegible]	.311	.127	1.31	1.4
		Sweat	.014	.006	18.6	6.9	.000	.003	.03	.2
		Balance	-.006	-.052	-72.1	-64.6	-.690	-.510	-3.43	--
Postflight	4	Diet[a]	1.102 ±.131	0.371 ±.052	167.2 ±29.3	122.9 -20.9	2.424 ±.292	2.655 ±.276	22.82 ±3.36	--
		Urine[a]	.986 ±.002	.093 ±.011	140.1 ±34.8	90.3 ±3.9	1.563 ±.286	1.689 ±.453	25.34 ±3.97	126.7 ±46.6
		Feces	.769	.148	6.5	9.6	.503	.124	1.21	.3
		Sweat	.043	.015	17.0	11.0	.000	.004	.26	15.1
		Balance	+.004	+.115	+8.6	+12.0	+.358	+.838	-3.99	--

[a]Means of daily values ±S. D.

TABLE IV. - METABOLIC-BALANCE DATA FOR ASTRONAUT J. L.

Phase	Duration, days	Source	Constituent							
			Calcium, g/day	Magnesium, g/day	Sodium, mEq/day	Potassium, mEq/day	Phosphate, g/day	Sulfate, g/day	Nitrogen, g/day	Chloride, mEq/day
Preflight	10	Diet[a]	1.108 ±.048	0.366 ±.018	123.6 ±9.8	116.0 ±15.5	2.373 ±.150	2.562 ±.304	22.32 -1.44	--
		Urine[a]	.159 ±.017	.101 ±.015	143.7 ±26.3	74.6 ±7.6	1.259 ±.133	1.077 ±.433	20.36 ±2.20	129.3 ±23.0
		Feces	.431	.173	4.9	±6.9	.407	.090	1.22	16.1
		Sweat	.023	.006	25.2	14.4	.000	.005	.36	.5
		Balance	+.495	+.086	-50.2	+20.1	-.707	+1.390	+.38	--
Flight	14	Diet[a]	1.042 ±.251	0.198 ±.040	145.1 ±48.4	36.8 ±8.9	1.362 ±.161	0.874 ±.163	15.81 ±2.85	--
		Urine[a]	.162 ±.019	.097 ±.016	181.8 ±22.6	50.9 -6.3	1.577 ±.155	1.019 -.102	16.24 ±1.86	146.4 ±22.1
		Feces	.766	.109	10.3	7.2	.289	.096	.87	.2
		Sweat	.016	.007	2.9	1.6	.000	.002	.04	2.2
		Balance	+.098	-.015	-49.9	-22.9	-.504	-.243	-1.34	--
Postflight	4	Diet[a]	1.090 ±.119	0.359 ±.035	125.3 ±30.4	117.6 -12.5	2.376 ±.168	2.588 ±.191	22.02 ±2.48	--
		Urine[a]	.172 ±.014	.093 ±.006	74.5 ±21.8	63 4 ±14.1	1.296 ±.542	1.529 ±.104	19.92 ±2.91	65.5 ±26.8
		Feces	.766	.109	10.3	7.2	.289	.096	.97	.2
		Sweat	.045	.017	9.8	11.4	.000	.010	.29	15.3
		Balance	+.107	+.140	+30.7	+35 6	+.791	+.953	+.84	--

[a]Mean of daily values ±S. D.

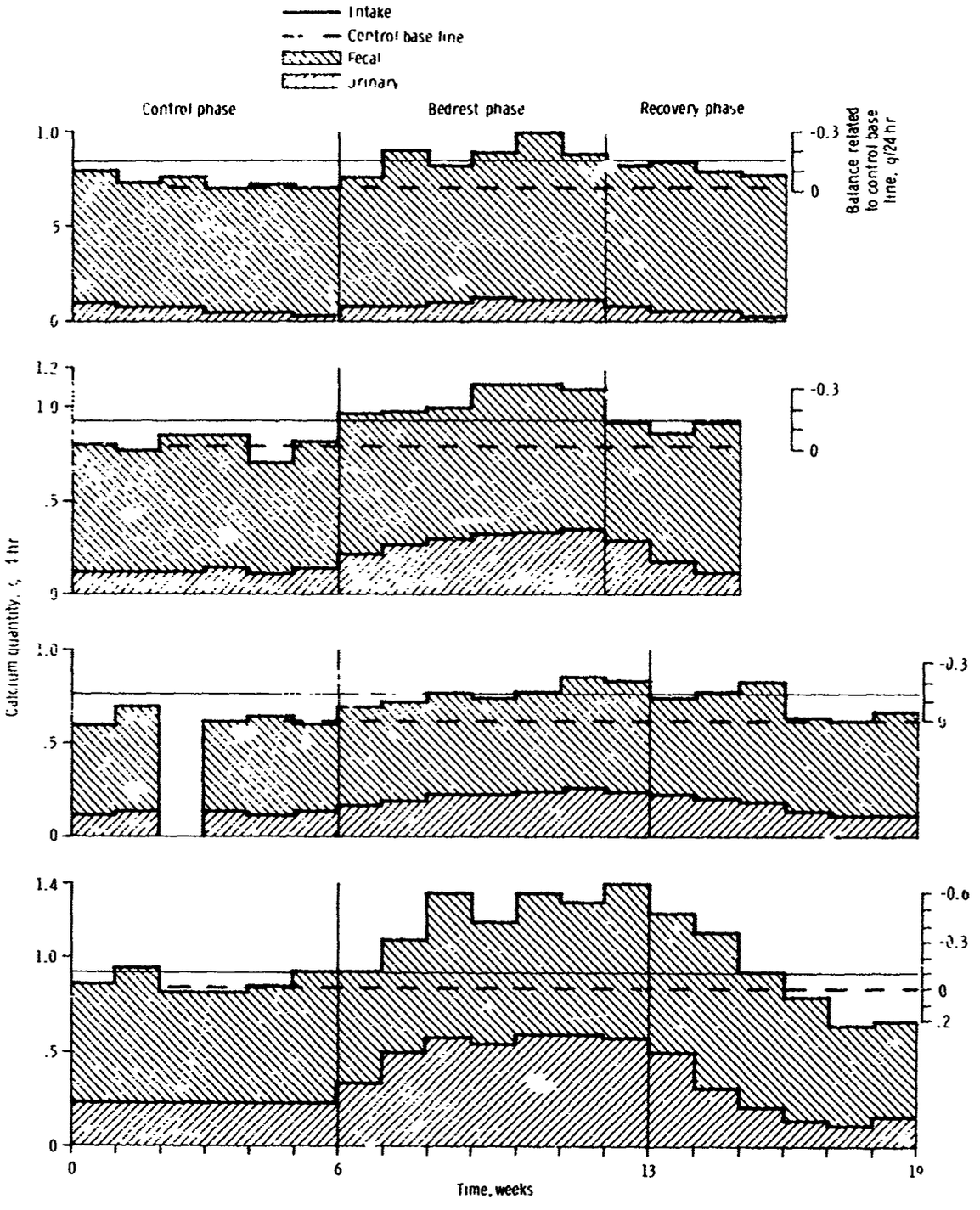

Figure 1. - The effect of immobilization in plaster casts for 6 to 7 weeks on calcium metabolism in four normal male subjects.

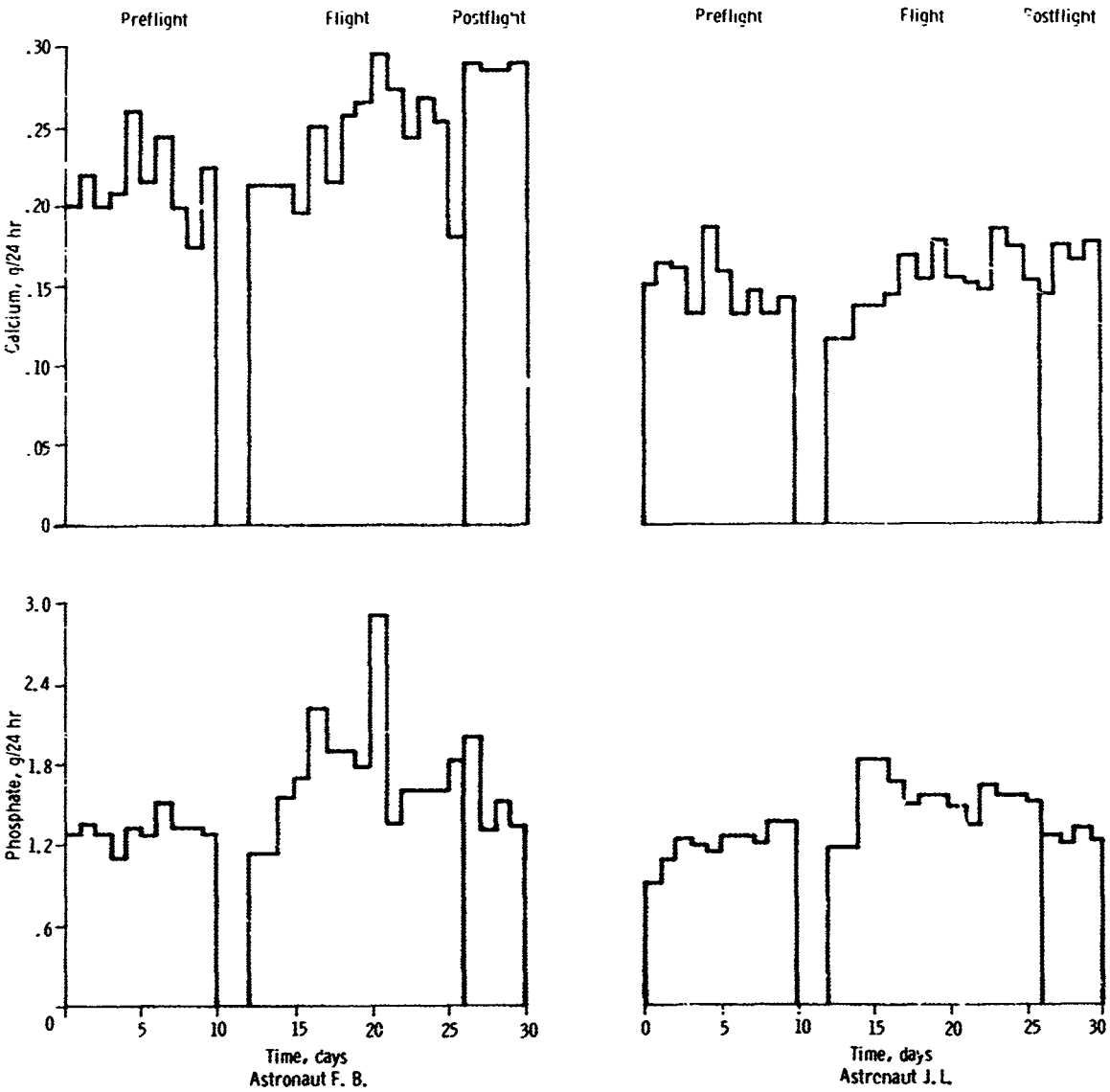

Figure 2. - Data on the urinary excretion of calcium and phosphate by astronauts before, during, and after a 14-day Earth-orbital space flight.

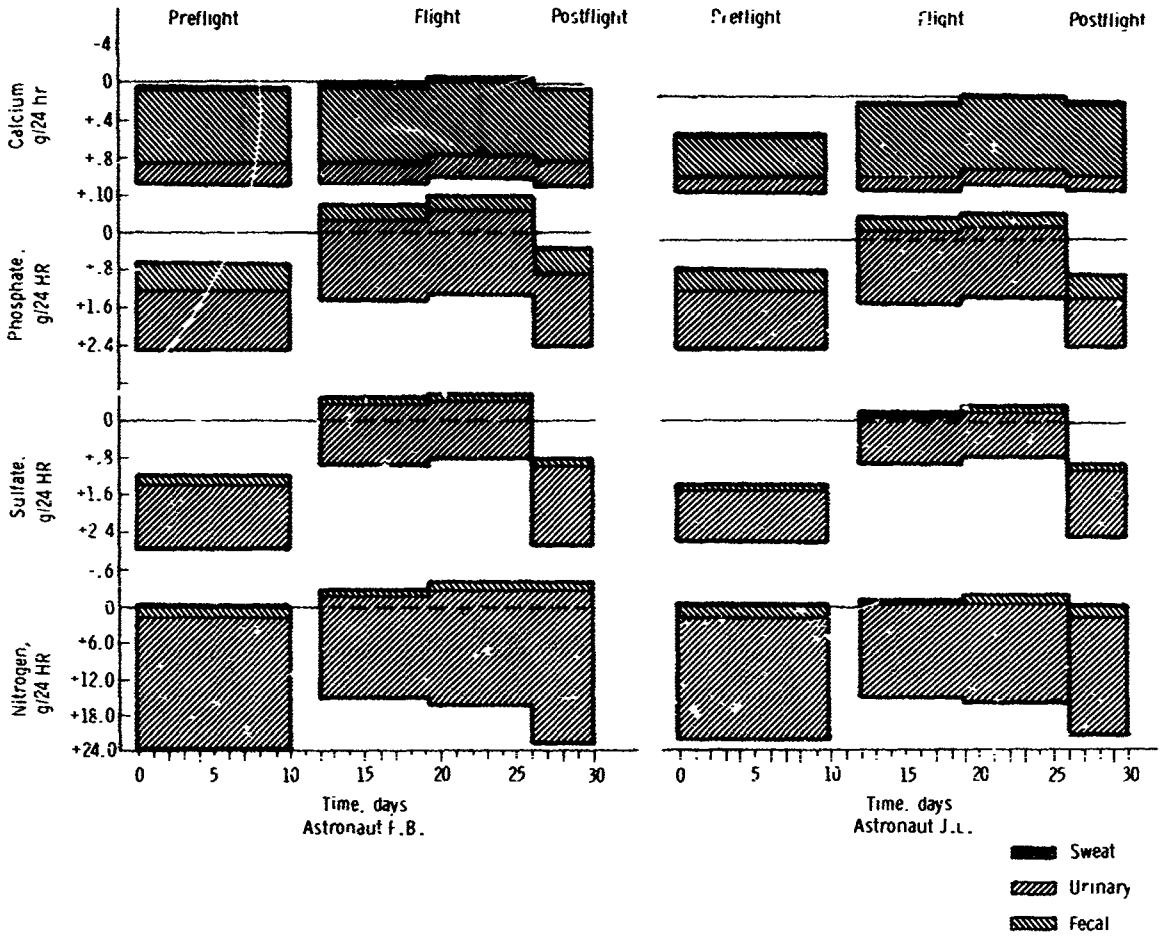

Figure 3. - Metabolic-balance data for astronauts before, during, and after a 14-day Earth-orbital space flight (calcium, phosphate, sulfate, and nitrogen).

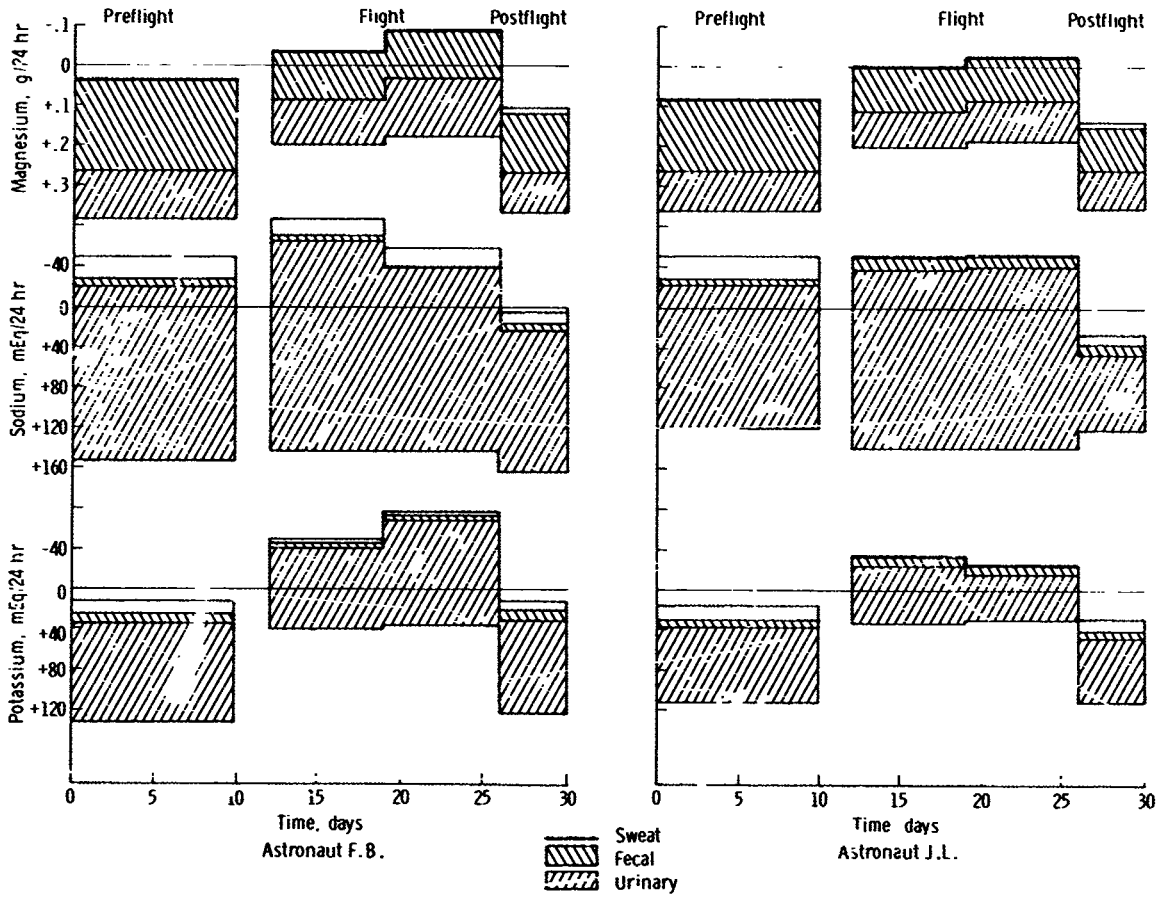

Figure 4. - Metabolic-balance data for astronauts before, during, and after a 14-day Earth-orbital space flight (magnesium, sodium, and potassium).

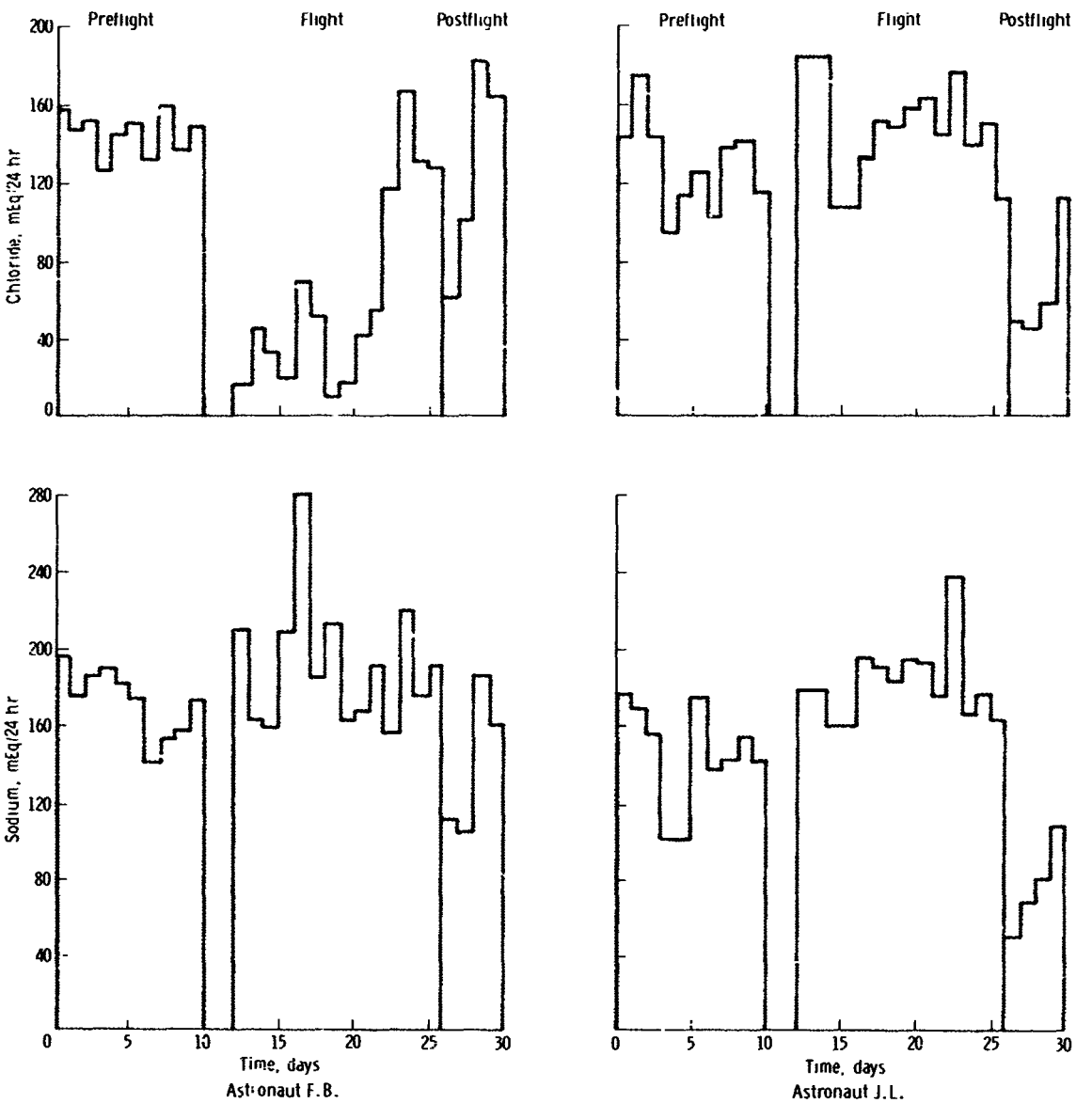

Figure 5. - Data on the urinary excretion of sodium and chloride by astronauts before, during, and after a 14-day Earth-orbital space flight.

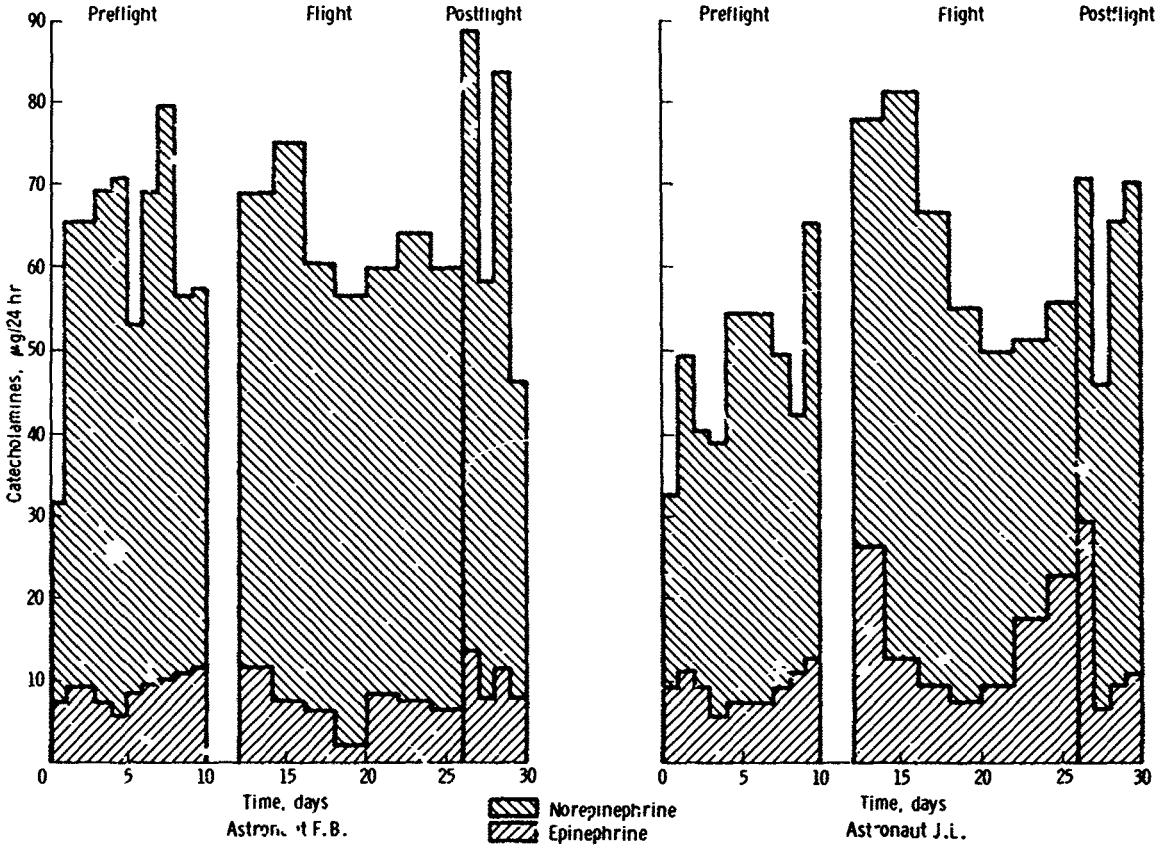

Figure 6. - Data on the urinary excretion of epinephrine and norepinephrine by astronauts before, during, and after a 14-day Earth-orbital space flight.

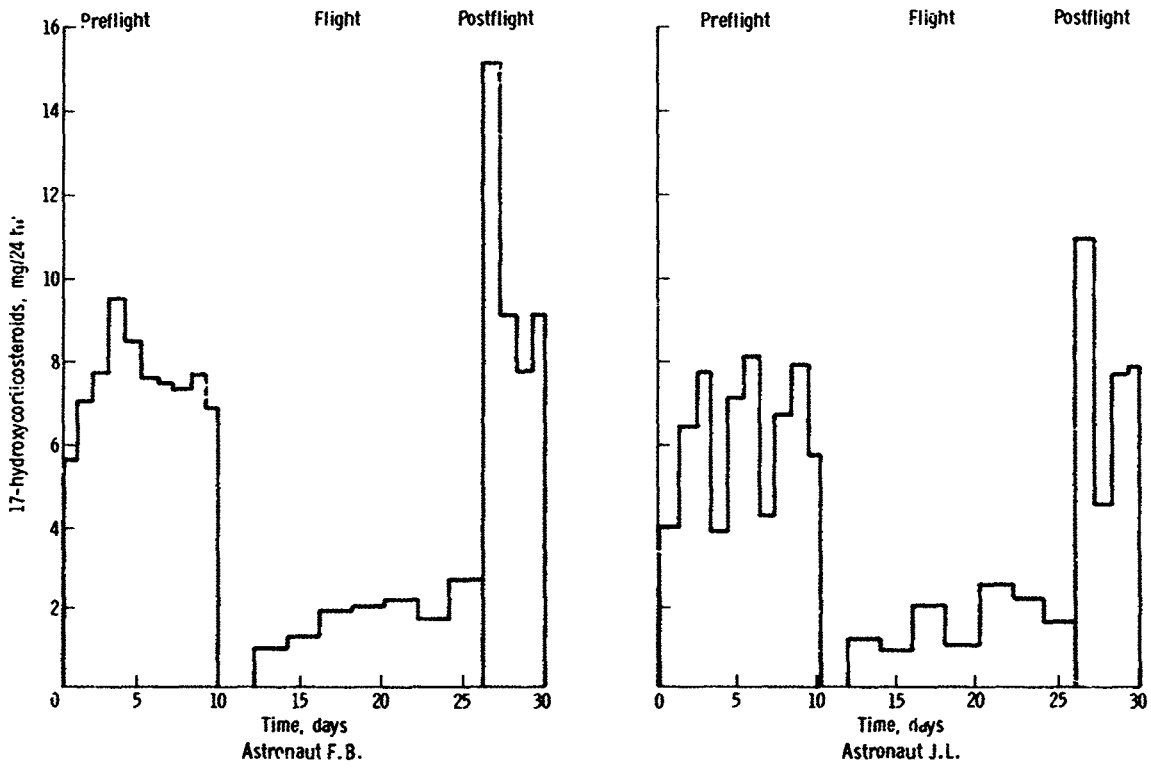

Figure 7. - Data on the urinary excretion of 17-hydroxycorticosteroids by astronauts before, during, and after a 14-day Earth-orbital space flight.

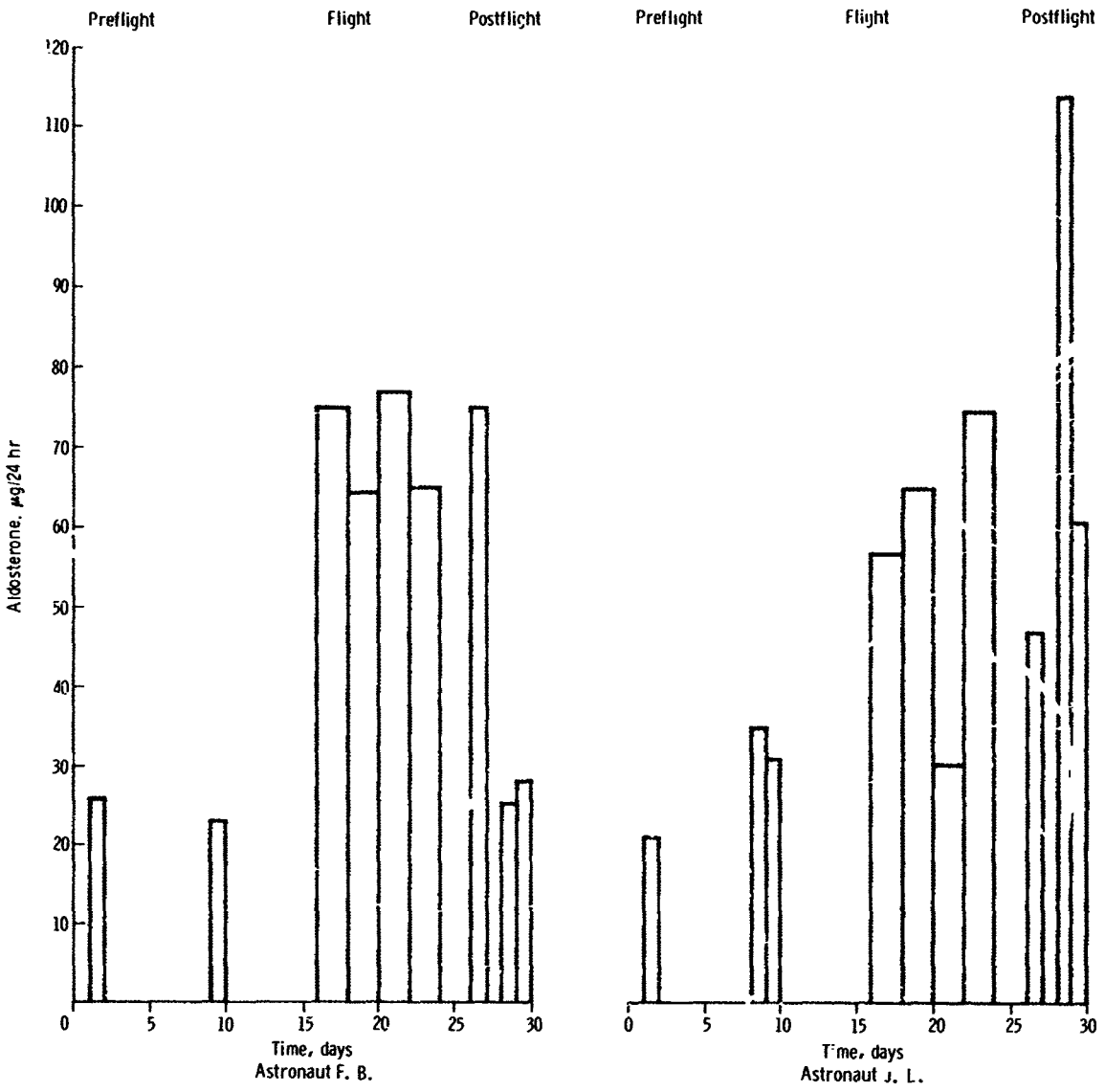

Figure 8. - Data on the urinary excretion of aldosterone by astronauts before, during, and after a 14-day Earth-orbital space flight.

EXPERIMENT M003

INFLIGHT EXERCISE AND WORK TOLERANCE

By Lawrence F. Dietlein* and Rita M. Rapp*

INTRODUCTION AND OBJECTIVE

The response of the cardiovascular system to a known workload is an index of the general physical condition of an individual. The objective of Experiment M003 was the day-to-day evaluation of the general physical condition of the crewmembers during long-duration space flight. The basis of this evaluation was the response of the cardiovascular system, as determined from variation in the pulse rate, to a calibrated workload.

EQUIPMENT

The exercise device (figs. 1 and 2) consisted of a pair of rubber bungee cords; the cords were attached to a nylon handle at one end and to a nylon foot strap at the other. A stainless steel cable limited the stretch length of the rubber bungee cords and limited the isotonic workload of each pull. The device could be used to exercise the arms by holding the feet stationary and pulling on the handle. Inflight bioinstrumentation (fig. 3) was used to collect data on pulse rate, blood pressure, and respiration rate. These data were recorded simultaneously on the onboard biomedical magnetic tape recorder and telemetered (for real-time evaluation) to the ground-based monitoring stations.

PROCEDURE

A force of 70 pounds was required to stretch the rubber bungee cords through a excursion of 12 inches. Exercise periods were of 30 seconds duration, during which time the crewmember stretched the bungee cords through a full excursion one time per second. Seventeen exercise periods were scheduled for the Gemini IV pilot; four exercise periods were scheduled for the command pilot of the Gemini IV mission. Exercise periods were planned three times daily for the Gemini V crewmembers; on the

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Gemini VII mission, the periods were scheduled twice daily. Additional isometric-isotonic exercises were performed by the Gemini VII crewmen approximately three times daily. Blood-pressure measurements were made before and after each exercise period.

RESULTS

Gemini IV Mission

Early in the Gemini IV mission, the command pilot requested and received permission to perform additional exercises; he completed seven exercise periods during the mission. The pilot completed 19 exercise periods. At approximately 32 hours g.e.t., all type 2 medical-data passes (blood pressure-temperature-no exercise) were upgraded to type 1 medical-data passes (blood pressure-exercise-blood pressure), and both crewmembers were given permission to perform unscheduled exercises.

During the 67th hour g.e.t., the pilot reported that the rubber cover on the exerciser was torn. This had no effect on the operation of the equipment or on the experimental results. The crewmembers continued to use the device satisfactorily for the remainder of the mission.

Pulse rates were determined by counting beats during 15-second intervals for 2 minutes before and after exercise, and during the first and last 15-second intervals during exercise. The blood pressure and mean pulse-rate values of the pilot during preflight base-line control studies at 14.7 and 7.5 psia before the mission and during the mission at 5.1 psia are shown in figure 4. Each plot represents the mean value of several trials. The preflight and inflight curves at 0.33 atmosphere are almost superimposable, and the rate of return of the pulse rate to preexercise values is almost identical in the three modes for which data were available (fig. 4). Blood-pressure changes were minimal. Similar data for the command pilot are given in figure 5.

Gemini V Mission

The Gemini V crewmembers exercised as scheduled. Heart rates were determined by counting beats during 15-second intervals for 2 minutes before and after exercise, and during the first and last 15-second intervals during exercise. A comparison of data collected during unit-gravity preflight exercise periods with data obtained during flight revealed little difference in heart-rate response. Comparison of data from the inflight exercise periods from the first to the last day also revealed little difference in heart-rate response. Inflight heart-rate responses are illustrated in figure 6 (command pilot) and in figure 7 (pilot).

Generally, blood-pressure measurements, before and after exercise periods, were not remarkable. Postexercise systolic pressures of the command pilot and the pilot tended to be higher than preexercise values. Generally, postexercise diastolic pressures were slightly higher than, or were identical to, preexercise values; infrequently the values were slightly lower. The pulse pressure of the pilot tended to be significantly wider (160/60 mm Hg compared with 130/70 mm Hg) than that of the

command pilot (130/70 mm Hg compared with 110/80 mm Hg). After the fourth day of flight, both crewmembers used the exerciser frequently between scheduled medical-data passes. Both crewmembers remarked that exercise is essential and beneficial on long-duration space flights.

Gemini VII Mission

The Gemini VII crewmembers performed the exercises as scheduled. Heart rates were determined by counting beats during 15-second intervals for 2 minutes before and after exercise and during the first and last 15-second intervals during each exercise. A comparison of data from unit-gravity preflight exercise periods with data from succeeding periods revealed little difference in heart-rate response.

Inflight responses to exercise are illustrated in figure 8. Heart rates are plotted for the command pilot and pilot before, during, and after exercise. Both crewmembers had a moderate increase in pulse rate during exercise, and had a rapid return to approximately preexercise values within 1 minute after exercise. Similar results were reported for the Gemini IV and Gemini V crewmembers (refs. 1 and 2).

Representative preexercise and postexercise blood pressures for the command pilot are shown in figures 9 and 10. Systolic values tended to be slightly greater following exercise. Diastolic values were more variable, but tended generally to be slighdly greater after exercise. Samples of telemetered physiological data collected during a typical inflight exercise routine are illustrated in figure 11.

DISCUSSION OF GEMINI IV RESULTS

The Gemini IV crewmembers had a more rapid rate of pulse-rate return to preexercise values than did the crewmember on the Mercury-Atlas 9 (MA-9) mission. The pulse rates of the crewmembers on the Gemini IV mission returned to preexercise values within 45 to 60 seconds after cessation of exercise. The MA-9 pilot had a mean postexercise heart rate during flight that was still slightly increased (106 beats per minute compared with a preexercise value of 89 beats per minute) for approximately 2 minutes after exercising (table I). However, it must be remembered that the environmental control system of the Gemini spacecraft was superior to that of the Mercury spacecraft; therefore, the data are not comparable strictly. Evaluation of these pulse-rate data revealed no significant difference between the pulse-rate responses (of both crewmembers) to exercise during the mission and the responses obtained before the mission. Thus, using the rate of return of the pulse rate to preexercise values as an index of physical condition, there was no evidence of cardiovascular deconditioning at any time during the Gemini IV mission.

Although the crewmembers demonstrated their ability to perform physical work during the 4-day mission, it should be noted that the crewmembers commented that they had no strong desire to perform heavy or strenuous exercise. However, they indicated that, in their opinion, periodic exercise during long-duration space flight is extremely desirable.

CONCLUSIONS

Gemini IV Mission

On the basis of the data collected during the Gemini IV mission, the following conclusions are warranted.

1. The response of the cardiovascular system to a calibrated workload was relatively constant for a given individual during space flight, at least for missions lasting for as many as 4 days.

2. The crewmembers were able to perform mild to moderate amounts of work under the conditions of space flight, and this ability continued almost unchanged for missions of as many as 4 days duration.

3. A variation of the Harvard Step Test was used as an index of the physical fitness of the crewmembers; there appeared to be no decrement in the physical condition of the crewmembers during a 4-day mission.

Gemini V Mission

Experiment M003 was performed successfully. On the basis of the data, the following conclusions are warranted.

1. The response of the cardiovascular system to a calibrated workload was relatively constant for a given individual during space flights lasting as many as 8 days.

2. The crewmembers were able to perform mild to moderate amounts of work under the physiologic conditions of space flight and within the confines of the Gemini spacecraft, and this ability continued essentially unchanged for as many as 8 days.

3. A variation of the Harvard Step Test was used as an index of cardiovascular deconditioning, and no decrement in the physical condition of the crewmembers was apparent during an 8-day mission. That is, no decrement was apparent under the stress of the relatively mild workloads that were imposed in this experiment.

Gemini VII Mission

Experiment M003 was performed successfully. On the basis of the data obtained during this mission, the following conclusions are warranted.

1. The response of the cardiovascular system to a calibrated workload was relatively constant for a given individual during space flights of as many as 14 days.

2. The crewmembers were able to perform mild to moderate amounts of work under space-flight conditions and within the confines of the Gemini spacecraft. This ability continued almost unchanged for as many as 14 days in flight.

3. Using a variation of the Harvard Step Test as a cardiovascular-deconditioning index, no decrement in the physical condition of the crewmembers was apparent during the 14-day mission. That is, no decrement was observed under the stress of the relatively mild workloads imposed in this experiment.

REFERENCES

1. Dietlein, L. F.: Experiment M-3, Inflight Exerciser on Gemini IV. Manned Space Flight Experiments Symposium, Gemini Missions III and IV, Washington, D. C., Oct. 1965.

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., Jan. 1966.

TABLE I. - EXERCISE EXPERIMENT RESULTS OBTAINED FOR THE MERCURY-ATLAS 9 PILOT

	Preflight (5) determinations		Inflight (2) determinations	
	Mean heart rate, beats/min	Mean blood pressure, mm Hg	Mean heart rate, beats/min	Mean blood pressure, mm Hg
Prework	74	104 81	89	117/77
During work	115	- - -	131	- - -
Postwork	85	111/79	106	124/95

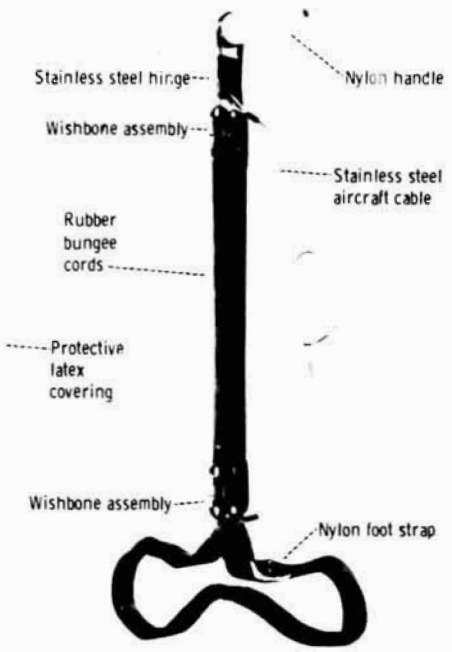

Figure 1. - Main components of the inflight exerciser.

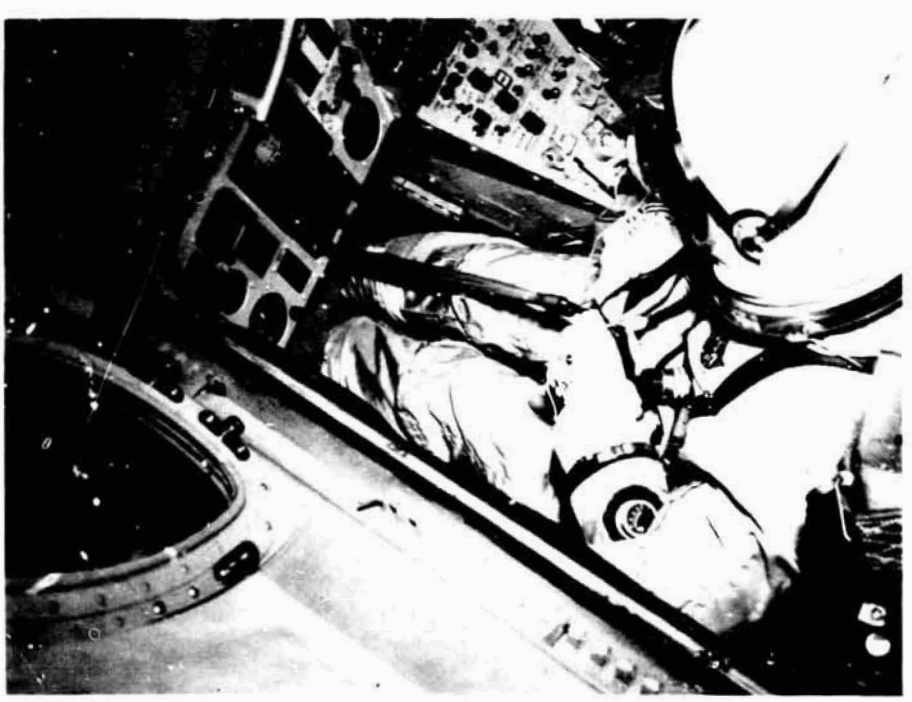

Figure 2. - Inflight exerciser in use.

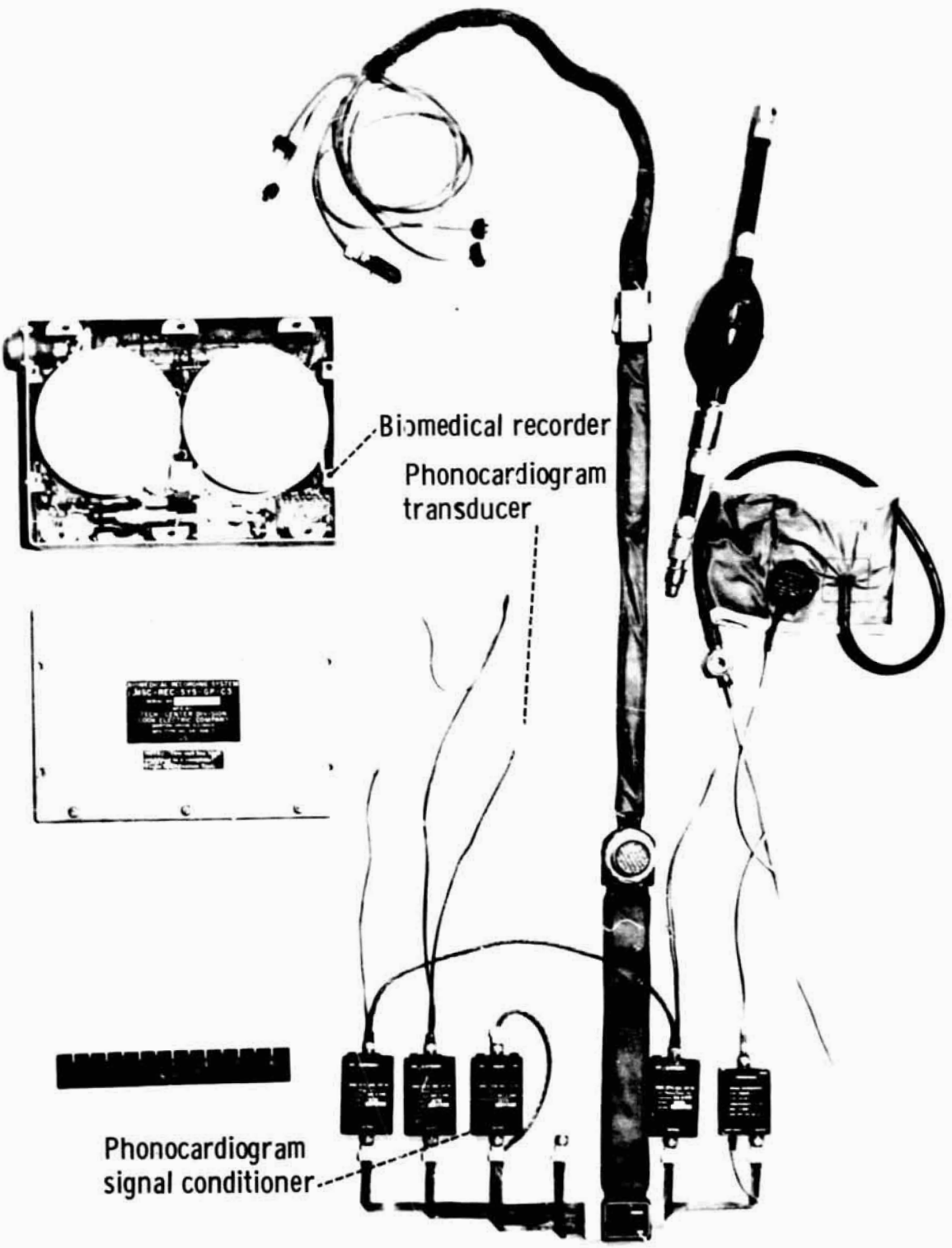

Figure 3. - The biomedical and communications harness that was used during the Gemini IV mission.

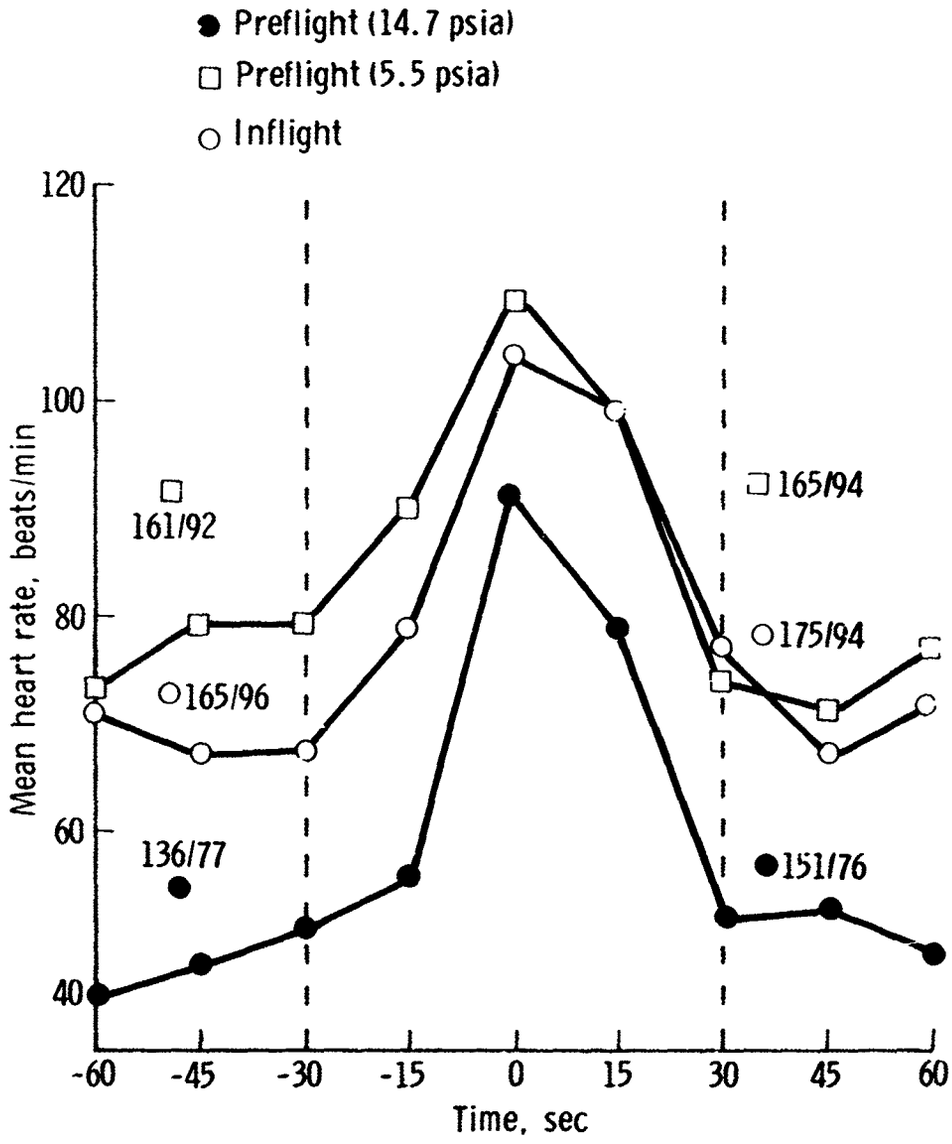

Figure 4. - Drawing of the experimental device showing the geometrical relationships between the blood samples and the ^{32}P β-ray source plates. The blood sample holders are shown in the nonirradiate position.

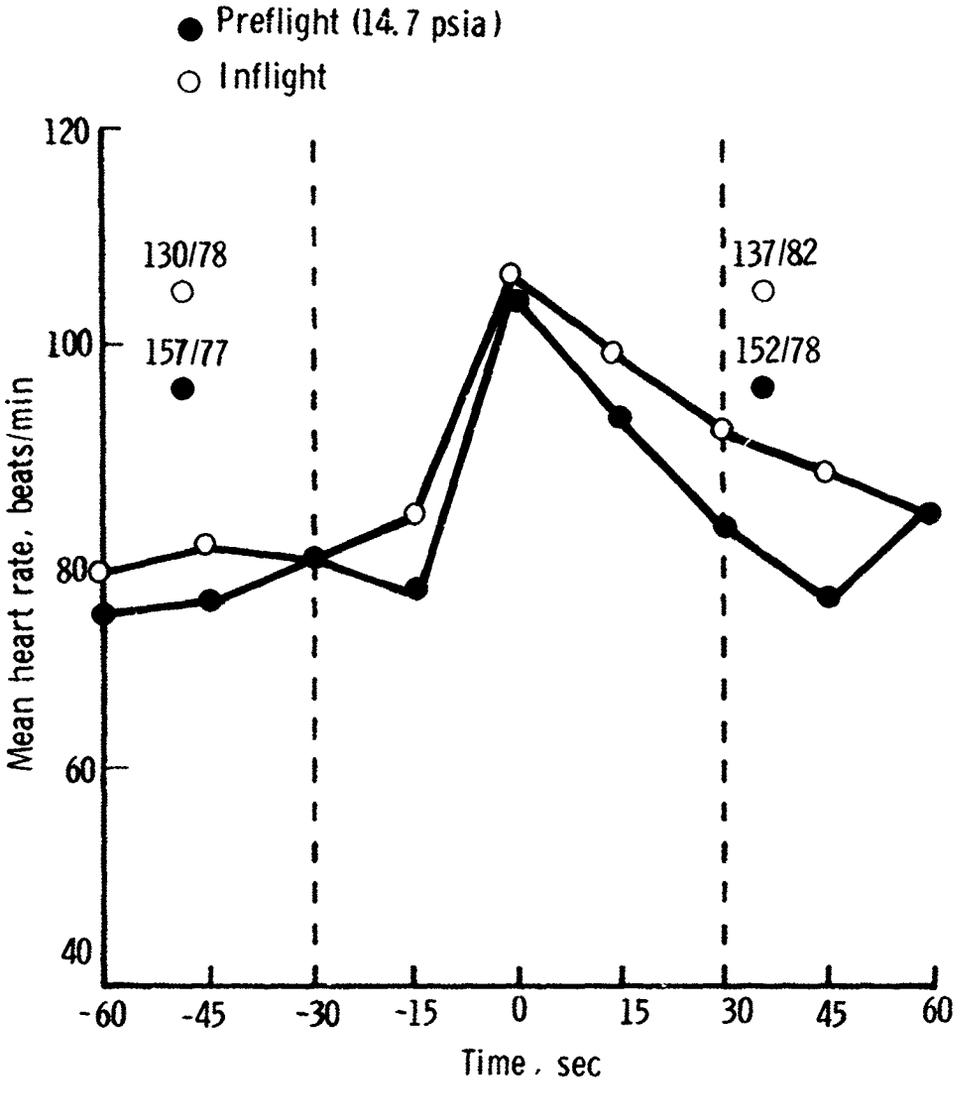

Figure 5. - Cardiographic data for the Gemini VII command pilot.

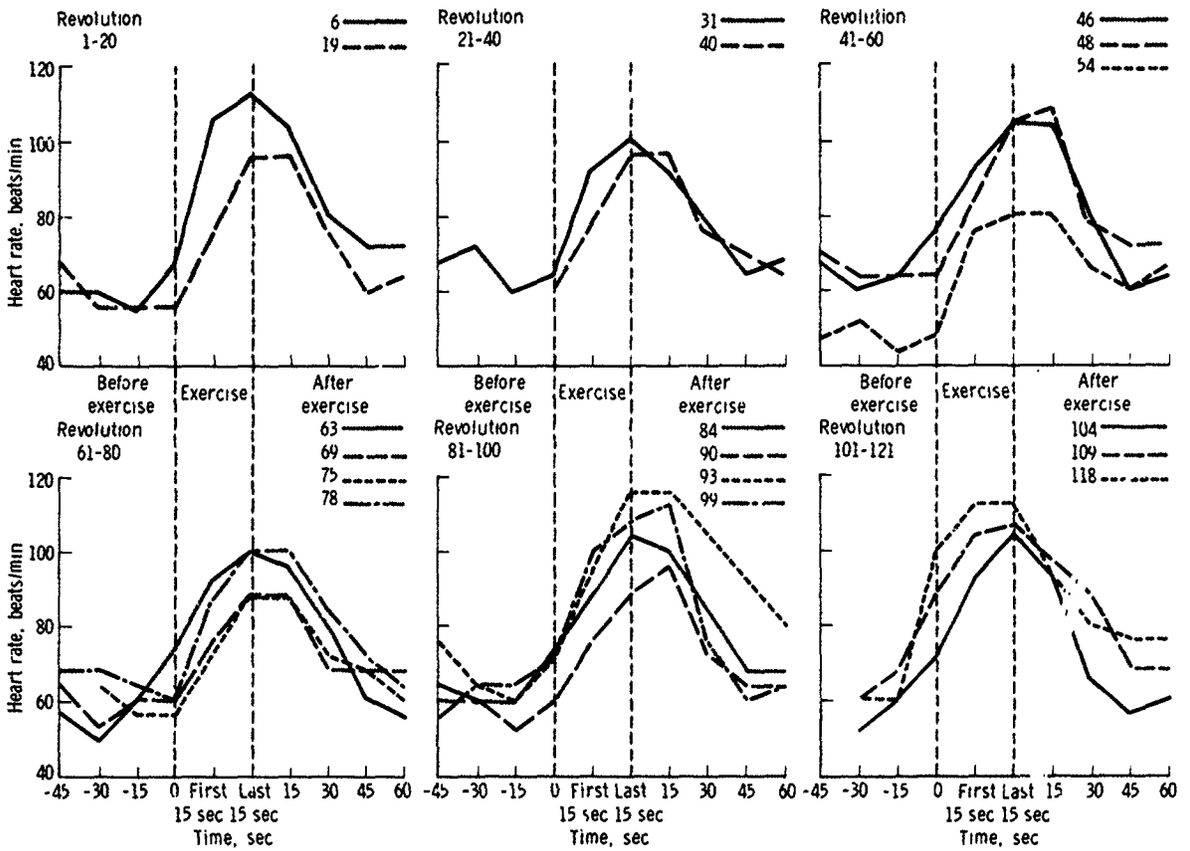

Figure 6. - Inflight heart-rate responses for the Gemini V command pilot.

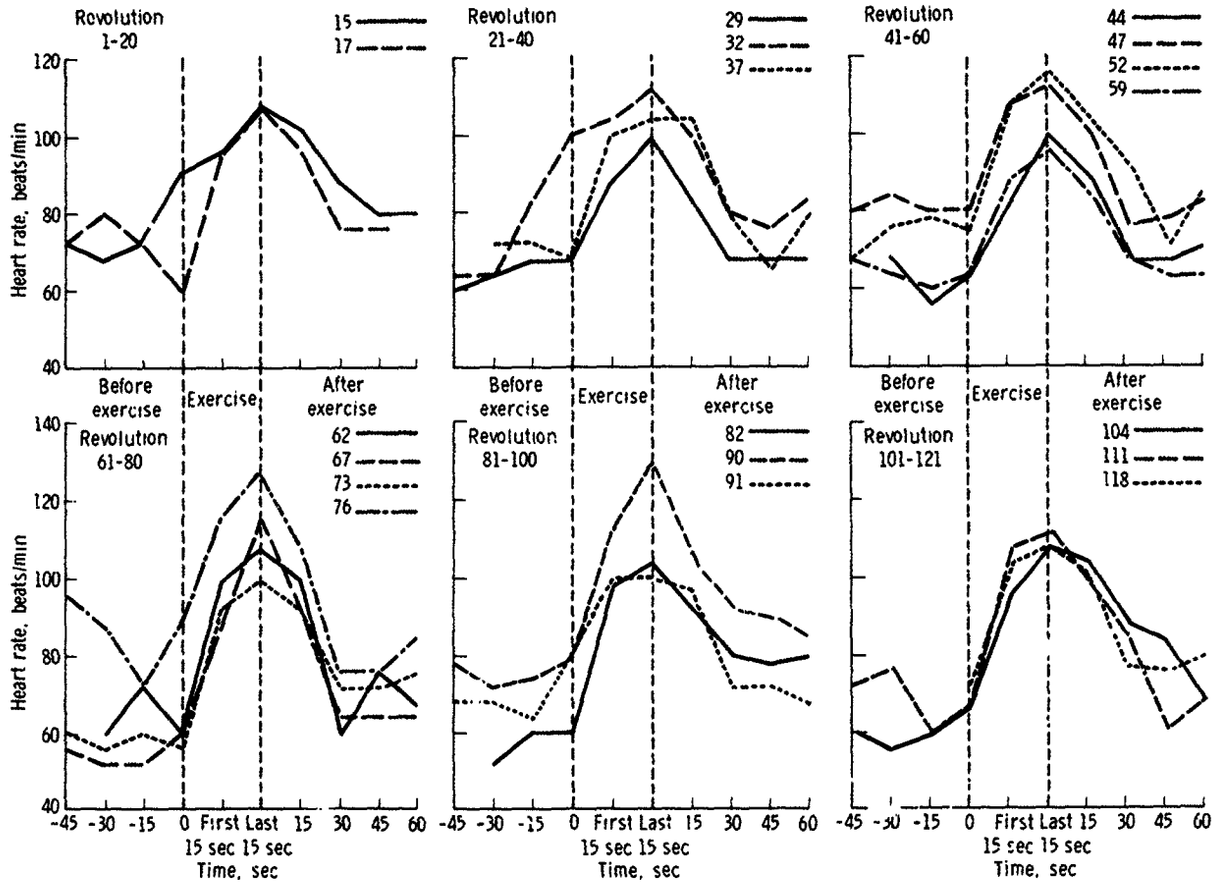

Figure 7. - Inflight heart-rate responses for the Gemini V pilot.

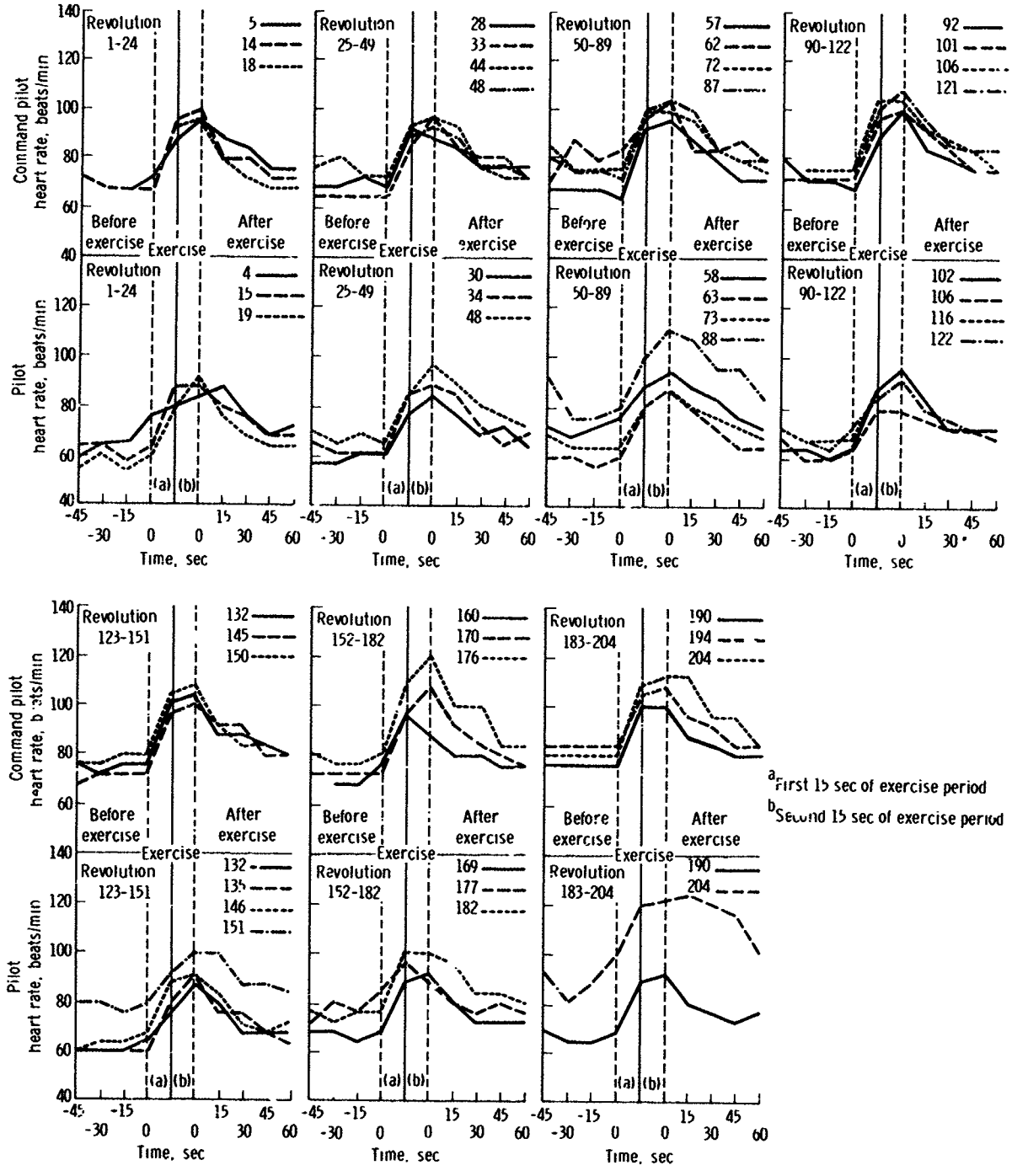

Figure 8. - Inflight responses to exercise for the Gemini VII crewmembers.

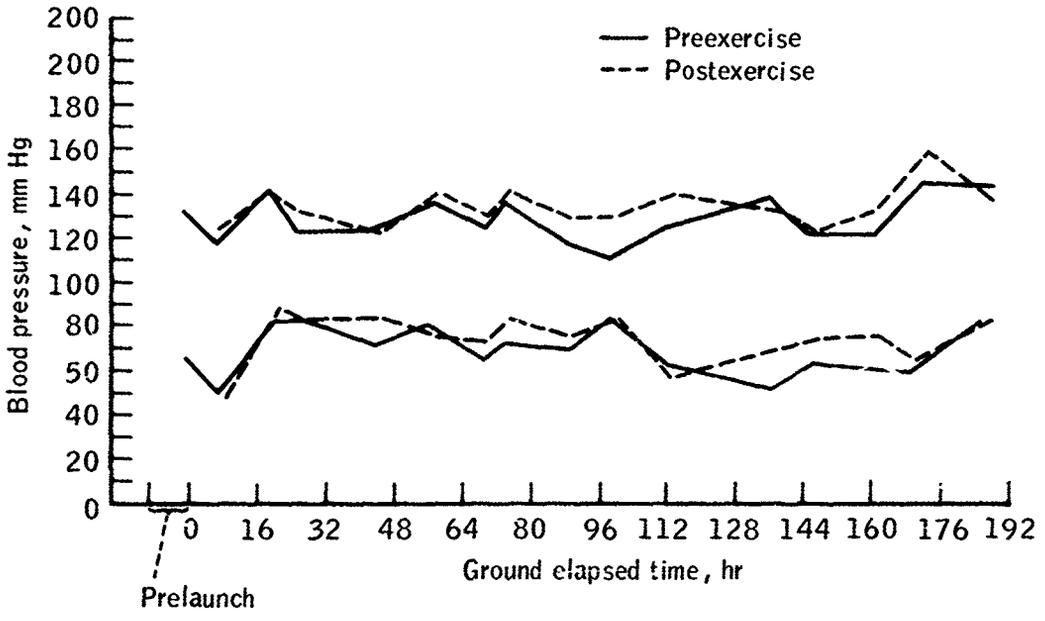

Figure 9. - Blood pressure of Gemini VII command pilot, lift-off to 192 hours g. e. t.

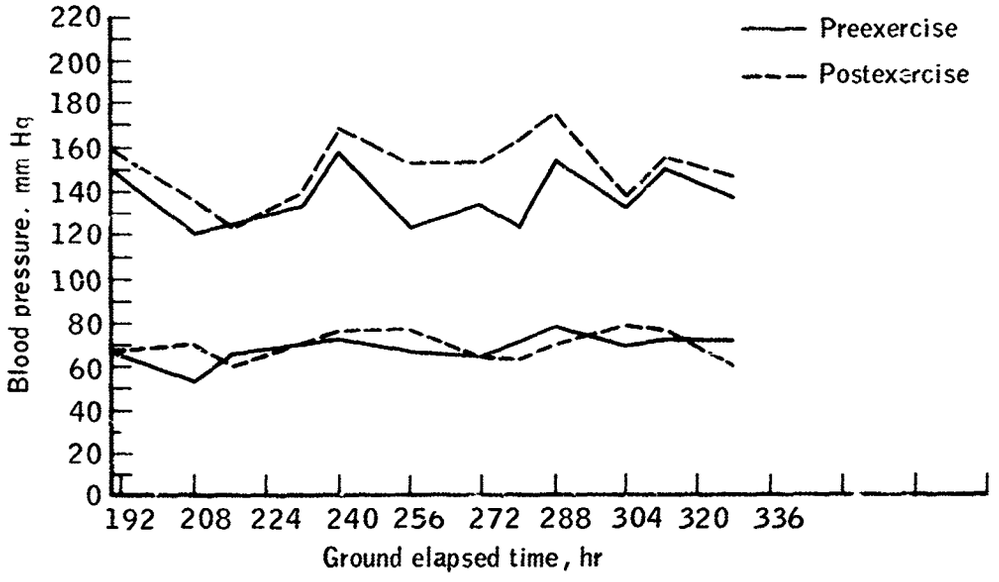

Figure 10. - Blood pressure of Gemini VII command pilot, 192 to 322 hours, g. e. t.

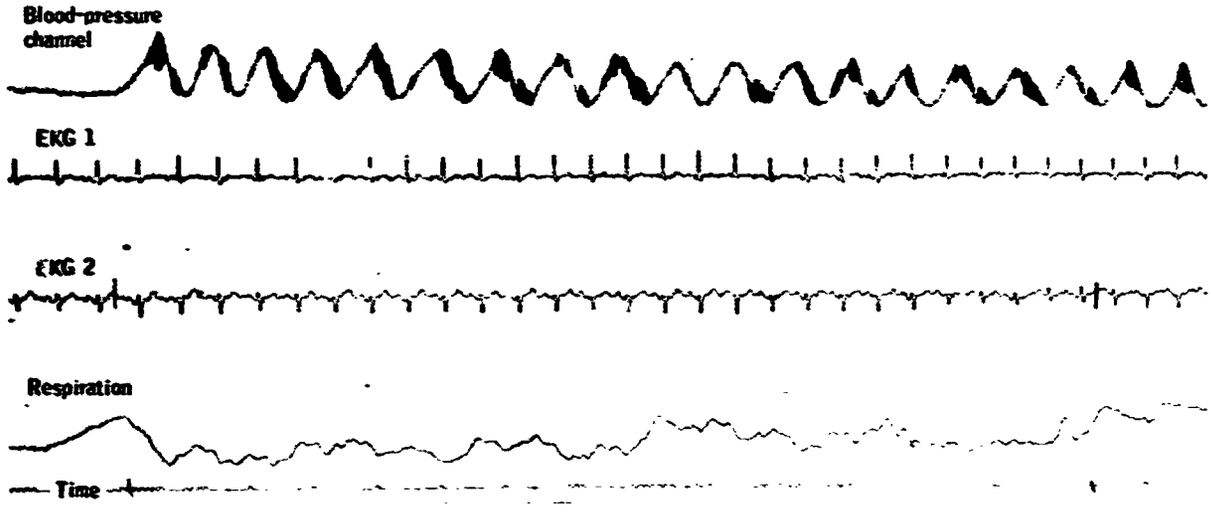

Figure 11. - Samples of telemetered physiological data collected during a typical inflight exercise routine.

EXPERIMENT M005

BIOASSAY OF BODY FLUIDS

By Lawrence F. Dietlein* and Elliott S. Harris*

INTRODUCTION

Body fluids were analyzed to determine the metabolic cost of manned space flight. Results of the analyses were used as an indication of the physiological status of the crewmembers. Inflight and postflight urinary steroid and catecholamine values were useful for assessment of the extent of the stresses to which the crewman was subjected and for measurement of the physiological maintenance cost of a particular performance level during space flight. When physiological changes occurred, efforts were made to determine the responsible mechanisms and to assess their significance relative to space flight. This experiment, as part of an overall evaluation, is applicable to physiologic processes in which effects may be observed by alterations in body fluids. Experiment M005 was performed during the Gemini VII, VIII (mission terminated early), and IX missions.

PROCEDURES

Plasma and urinary electrolyte concentrations, urine volumes, antidiuretic hormone (ADH) concentration, and aldosterone concentration were measured to assess the effects of space flight on electrolyte and water metabolism. The readily recoverable weight loss that occurs during flight may be related to water loss. Water loss may occur through urinary output, perspiration, or insensible routes. The fluid intake, urinary output, and the changes in hormone and electrolyte concentrations were measured in the samples that were collected during flight. Plasma and urine samples were analyzed before flight to obtain base-line data; during flight only urine was sampled. To accomplish this, and to determine the voided volume, a urine-sampling and volume-measuring system was used (fig. 1). The system consisted of a valve through which an exact quantity of tritiated water was introduced into each urine specimen. A sample (approximately 75 ml) of each specimen was taken after addition of the isotope. Upon recovery, the volume was calculated by measurement of the dilution of tritium. Benzoic acid was used as the preservative.

Upon recovery, the first postflight plasma sample was obtained immediately. Samples were taken at 6, 24, and 72 hours after recovery. Urine was collected continuously for 48 hours after recovery. Each sample was frozen and returned to the Manned

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Spacecraft Center (MSC) for analysis. Analyses of the following components were performed.

1. Plasma/serum
    a. 17-hydroxycorticosteroids
    b. Proteins
        (1) Total protein
        (2) Albumin/globulin ratio
        (3) Electrophoretic pattern
    c. ADH
    d. Hydroxyproline
    e. Electrolytes (sodium, potassium, calcium, chloride, 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 (sodium, potassium, calcium, chloride, 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. ADH

j. Aldosterone (preflight and postflight only)

Measurement Routine

The measurement routine was divided into three parts. The first part consisted of the preflight collection of two 48-hour urine samples and two blood samples from each crewman. Thus, base-line values were established for each crewmember. The second part was an analysis of urine samples that were collected during flight. The physiological status of the crewmembers was evaluated from the data that were acquired. The third part was an analysis of a 48-hour urine sample and of the blood samples that were collected immediately postflight. Data from these analyses established the rate of return to preflight base-line values. These biochemical determinations may be grouped into several profiles, each of which contains data that are useful for insight into the effect of space flight on one or more human physiological systems.

Types of Measurements

Water and electrolyte balance. - The first profile (water and electrolyte balance) was associated with an examination of the weight loss that occurred during flight and the mechanisms involved in this loss. The concentration of plasma sodium, potassium, and chloride ions was measured preflight and postflight, and the rates of urinary excretion of these electrolytes were observed in all three phases of the measurements. Total plasma-protein concentrations, measured preflight and postflight, were used to indicate dehydration. Fluid intake and output were measured to determine whether the primary weight loss was caused by sweat and insensible losses or was caused by changes in renal function.

To complement the water measurements and electrolyte-balance measurements and to provide an indication of mechanisms involved, urinary ADH and aldosterone were measured. The production of ADH is responsible to thoracic blood-volume changes, and it was postulated that, as is produced in recumbency, weightlessness would produce an increase in thoracic blood volume. This would, in turn, induce a decrease in ADH secretion and a resultant increase in urinary volume. Also, aldosterone is posture responsive and controls the renal tubular reabsorption of sodium. Aldosterone secretion is decreased in recumbency and is increased in upright posture. An increase in aldosterone secretion results in decreased urinary excretion of sodium, whereas decreased aldosterone production results in increased urinary excretion of sodium.

Assay of 17-hydroxycorticosteroids and catecholamines. - The second measurement profile involved estimation of the physiological maintenance cost of a particular performance level during space flight. This could be considered a measure of the effects of stress during space flight. Two groups of hormones were assayed. The first

group assayed, 17-hydroxycorticosteroids, was indicative of long-term stress responses. The second group assayed, catecholamines, was indicative of short-term or emergency responses. Measurement of these parameters provided an objective long-term evaluation of the physiologic cost of space flight.

Analysis of calcium, magnesium, phosphate, and hydroxyproline.- The third profile of measurements constituted a continuing evaluation of the effects of space flight on bone demineralization. Calcium, magnesium, phosphate, and hydroxyproline were measured in plasma and in urine preflight and postflight and were measured in urine collected in flight. Changes in bone mineralization may be accompanied by alterations in the ratio of bound to unbound calcium in the plasma. This ratio can be approximated from an estimate of plasma protein and calcium. It was anticipated that with demineralization there would be an increase in urinary calcium, phosphate, and magnesium. Also, bone demineralization is known to be accompanied by increased hydroxyproline excretion. This amino acid is unique to collagen; therefore, it is presumed that the increased excretion of hydroxyproline accompanying demineralization results from dissolution of bone matrix.

Protein-metabolism indicator. - Another measurement profile may be related to protein metabolism and tissue status. Urinary urea concentration is proportional to protein intake and to tissue metabolism, whereas alpha-amino nitrogen increases may be related to destructive tissue changes. Creatinine excretion is a function of muscle mass and, for a given individual, is constant over a 24-hour period despite variation of diet, urine volume, or exercise. However, decreases of creatinine excretion are associated with loss of muscle tone and activity.

RESULTS

The experimental results are discussed on the basis of mission. Because the Gemini VIII mission was terminated early, no discussion of it is included. Three studies that are of interest may be found in references 1 to 3.

Gemini VII Mission

Experiment M005 was scheduled first for the Gemini VII mission. However, preflight and postflight plasma samples were obtained from the crewmen of the Gemini IV to VI missions and were analyzed. No values out of the normal range were observed, nor were any trends evident in these samples.

The Gemini VII preflight and postflight plasma samples were analyzed; the results are presented in tables I and II. Electrophoretic patterns were normal. All values were in the normal range, except for an anticipated increase in 17-hydroxycorticosteroids in the first sample taken after recovery. These values decreased to preflight levels within 6 hours. Hydroxyproline, determined because of its presence in collagen and its possible relationship to the decalcification process, did not vary sufficiently to be interpreted in terms of bone-density changes. The decrease in plasma uric acid immediately postflight must be considered further. A likely cause of the decrease could be low purine intake.

Plasma ADH was increased sufficiently for determination only in the first postflight plasma sample from the pilot, although, as may be seen in tables III and IV, significant water retention occurred in both crewmembers immediately postflight. Water retention and the rapid weight gain after flight were consistent with the assumption that the weight lost during flight was the result of water loss. Comparisons of preflight and postflight 24-hour urine samples are shown in tables III and IV.

The retention of electrolytes and water subsequent to entry was consistent with the hypothesis that atrial and thoracic stretch receptors are of physiologic importance in the change back and forth between a condition of unit gravity and a condition of zero gravity. A change from zero gravity to an upright position in a unit-gravity environment would result in a pooling of blood in the lower extremities and an apparent decrease in blood volume, as occurs in the atria and in the thorax. This would result in an increased output of ADH and of aldosterone; consequently, water and electrolyte retention would occur. In zero gravity, the increased thoracic blood volume and atrial blood volume would result in diuresis (as a consequence of reversal of the mechanism just mentioned) and weight loss, equivalent to the water loss, would occur. Other mechanisms, such as alterations in water and electrolyte distributions in the various body compartments, may have contributed to the observed results.

Gemini IX Mission

Two 48-hour urine specimens were collected just prior to the physical examinations 10 days and 3 days before launch. Blood samples were obtained during these examinations and were analyzed prior to flight so that base-line data could be obtained. Only urine was sampled during flight.

Plasma samples were taken upon recovery, and at 6 and 72 hours postflight. Urine was collected continuously for 48 hours. Each specimen was frozen and returned to the MSC for analysis. Calculated inflight urine volumes, based upon tritium dilution, were as great as 12 liters per micturition. This great, and quite obviously unrealistic, variation in urine volumes was indicative of a malfunction; therefore, no further attempt was made to analyze or interpret the urine samples collected in flight.

As is shown in figure 2, there was a significant postflight retention of water. This was accompanied by retention of sodium, potassium, and chloride. A comparison of 24-hour excretions of these electrolytes during the preflight and postflight periods is shown in figures 3 to 5. The significant retention of these electrolytes, expressed on a milliequivalent per minute basis for each urine sample, is shown in figures 6 to 8. As is shown in figure 9, urinary calcium decreased slightly immediately postflight. The excretion of 17-hydroxycorticosteroids was increased immediately postflight (fig. 10).

CONCLUSIONS

The conclusions are arranged according to mission. However, because the Gemini VIII mission was terminated early, no remarks are included for that mission.

Gemini VII Mission

Preflight and postflight urine and plasma samples from the Gemini VII crewmembers were analyzed. Electrolyte and water retention observed immediately postflight was consistent with the assumption that the Gauer-Henry atrial reflex was responsive to a change from the weightless to the unit-gravity environment. Also, alterations in electrolyte and water distribution during flight might have been contributory. Immediately postflight, plasma 17-hydroxycorticosteroid concentrations were increased. Plasma uric acid concentration was decreased; the cause of the reduction is unknown, but is presumed to be dietary.

Gemini IX Mission

The increased excretion of 17-hydroxycorticosteroids immediately postflight probably was caused by the stress of entry. The postflight increase of plasma protein, and the slightly smaller increase of plasma electrolytes postflight, was consistent with an inflight water and electrolyte loss that resulted in postflight retention of water and electrolytes, as shown in figures 1 to 7. It is not known yet whether these losses result from diuresis during flight or from perspiring.

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2. Henry, J. P.; Gauer, O. H.; and Reeves, J. L.: Evidence of Atrial Location of Receptors Influencing Urine Flow. Circulation Res., vol. 4, Jan. 1956, pp. 85-90.

3. Henry, J. P.; Gauer, O. H.; and Siekert, H. O.: Effect of Moderate Changes in Blood Volume on Left and Right Atrial Pressure. Circulation Res., vol. 4, Jan. 1956, pp. 91-94.

TABLE I. - PLASMA ANALYSIS, GEMINI VII COMMAND PILOT

[All dates are in 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
Chloride, 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	(a)	4.5	4.6
17-OH corticosteroids, μg/100 ml	18.8	--	28.3	16.0	--	--
Hydroxyproline, μg/ml						
Free	0.008	0.007	0.010	0.011	--	--
Bound	.131	.146	1.51	.185	--	--
Total	.139	.153	.161	.196	--	--

[a]Quantity not sufficient.

TABLE II. - PLASMA ANALYSIS, GEMINI VII PILOT

[All dates are in 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
Chloride, 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, μg/100 ml	13.3	--	26.2	8.9	--	--
Hydroxyproline, μg/ml						
Free	0.017	0.010	0.010	0.005	--	--
Bound	.161	.167	.182	.187	--	--
Total	.178	.177	.192	.192	--	--

TABLE III. - URINALYSIS, GEMINI VII COMMAND PILOT

[All dates are in 1965]

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

[a]Each component is in concentration units per 24-hour specimen volume for the applicable date.

TABLE IV. - URINALYSIS, GEMINI VII PILOT

[All dates are in 1965]

Components[a]	Preflight		Postflight	
	Nov. 23	Nov. 30	Dec. 18	Dec. 19
Chlorine, meq/vol	177	139	40	45
Calcium, mg/vol	182	126	115	207
Uric acid, g/vol	.91	1.14	.45	.92
Total volume, ml	1912	1737	735	1405
Sodium, meq/vol	162	145	35	58
Potassium, meq/vol	76	93.0	44	58
Phosphate, g/vol	1.12	1.27	.80	1.07
17-hydroxycorticosteroids, μg/vol	8.0	9.07	7.83	8.33
Total nitrogen, g/vol	19.94	21.6	12.81	22.8
Urea nitrogen, g/vol	17.19	17.06	11.75	21.51
Hydroxyproline, mg/vol	39.39	43.1	31.9	37.4
Creatinine, g/vol	2.27	2.25	1.75	2.16

[a]Each component is in concentration units per 24-hour specimen volume for the applicable date.

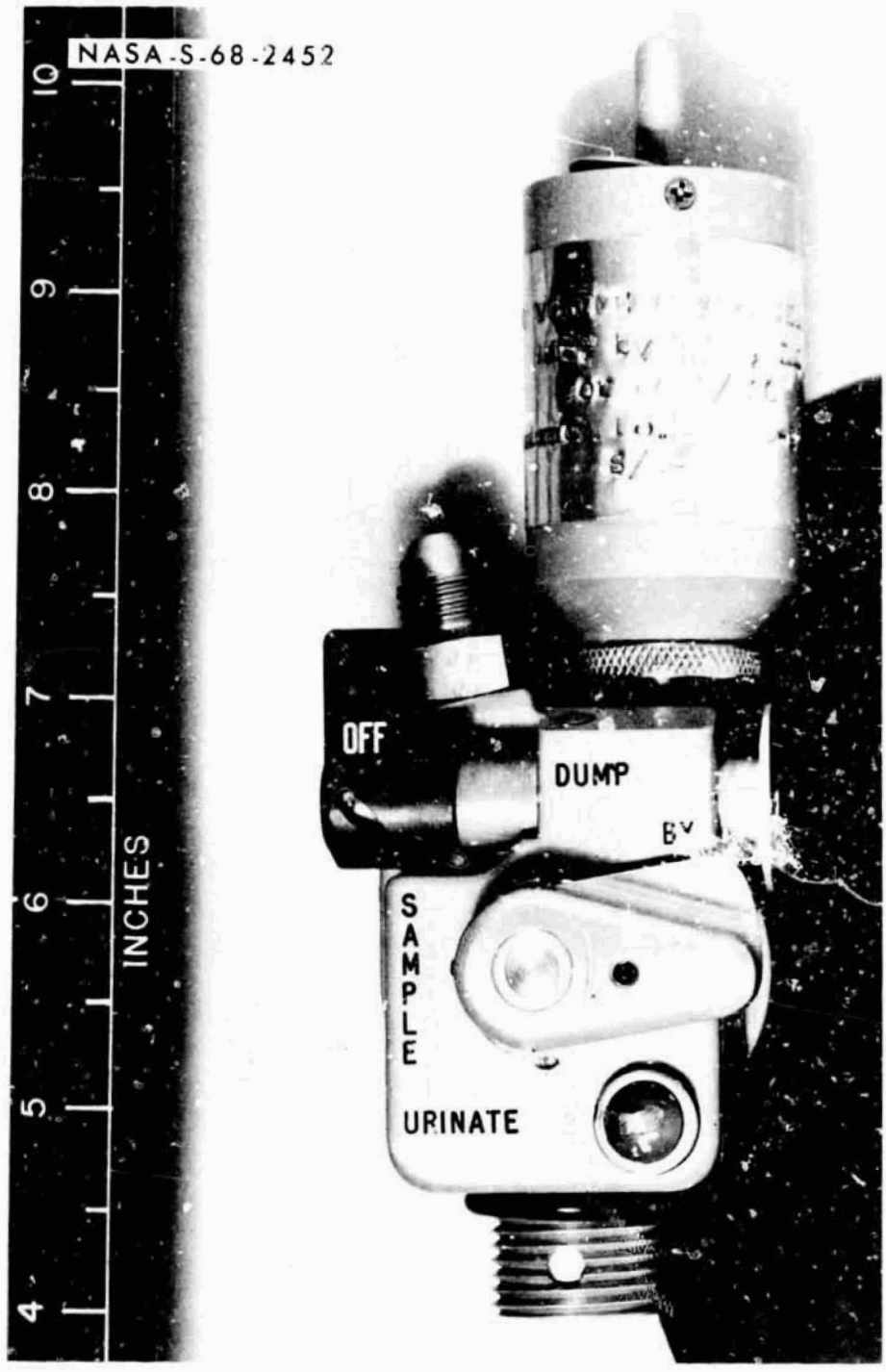
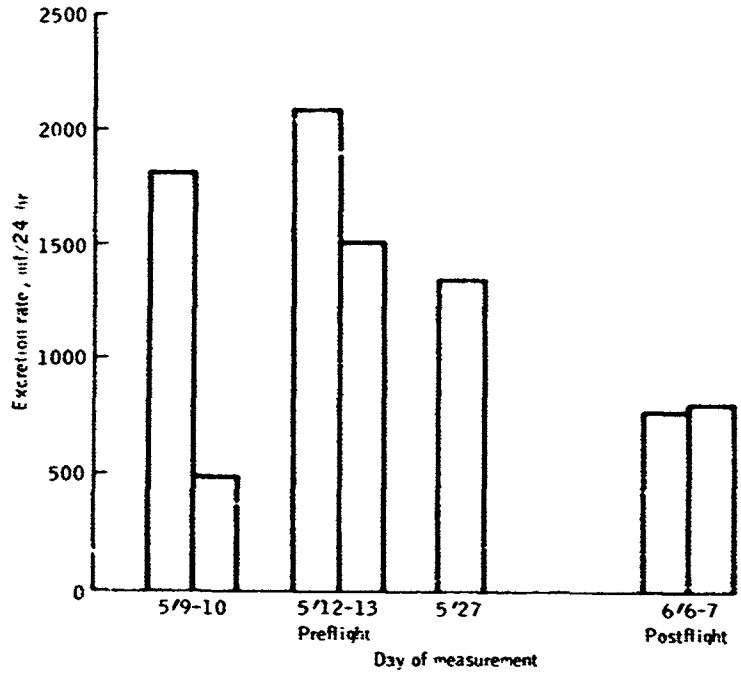
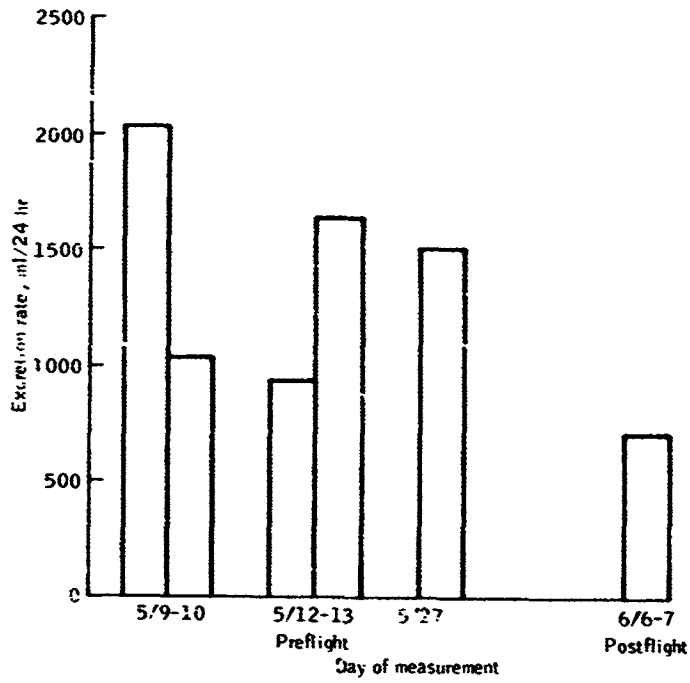


Figure 1. - Urine-sampling and volume-measurement system.

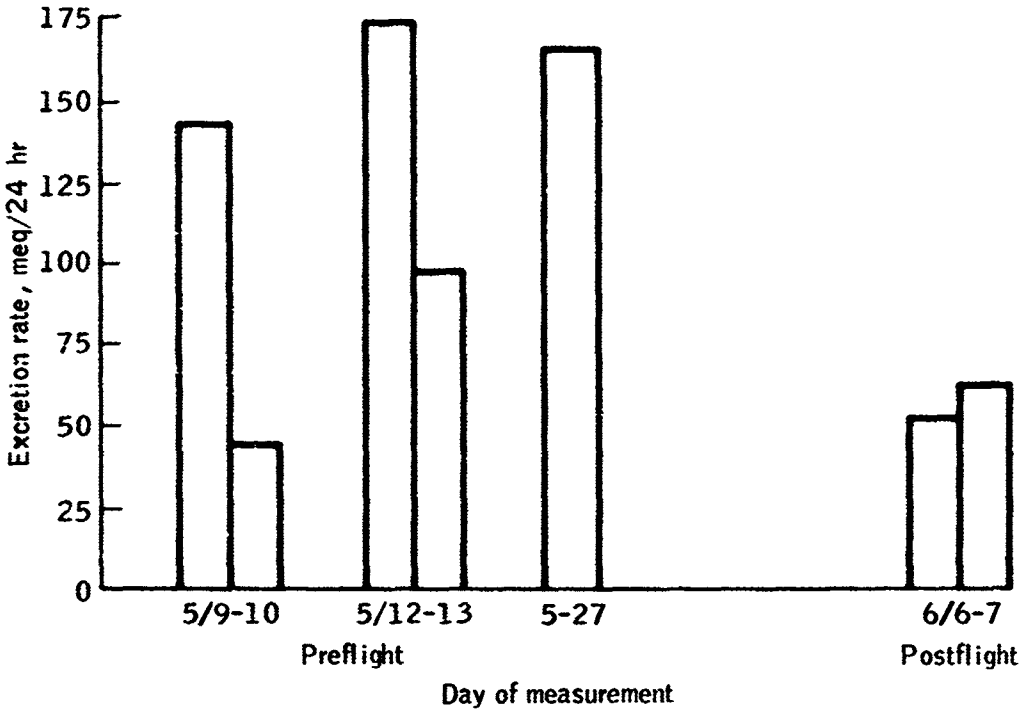


(a) Gemini IX command pilot.



(b) Gemini IX pilot.

Figure 2. - Total urine volumes.



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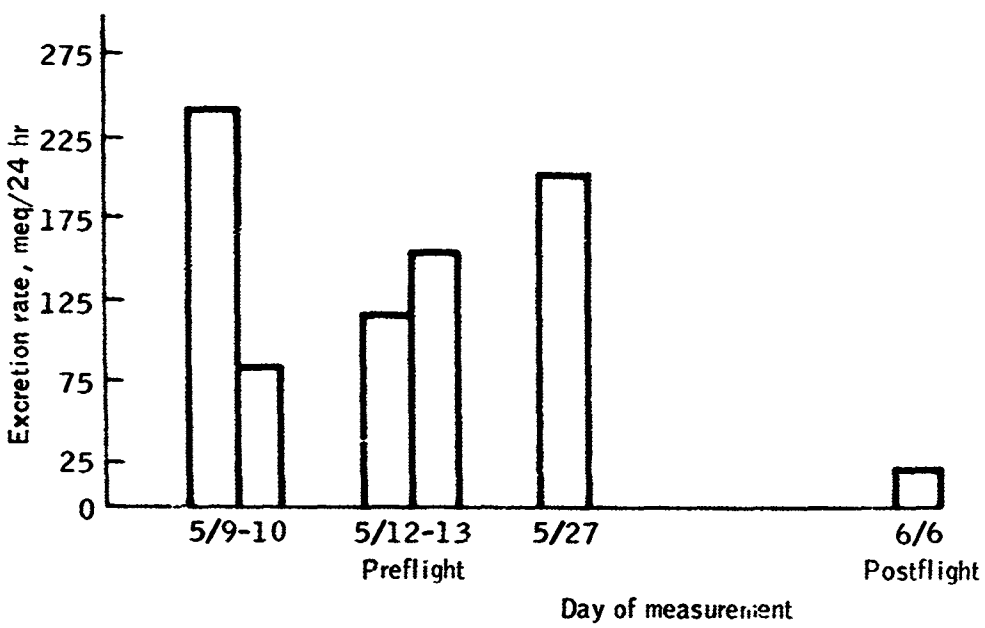
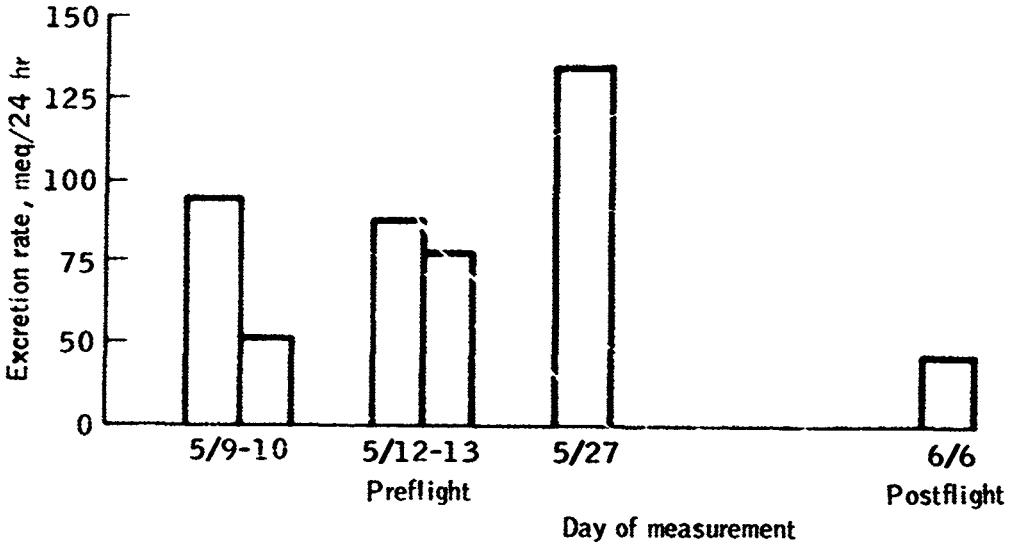


(b) Gemini IX pilot.

Figure 3.- Urinary sodium excretion.



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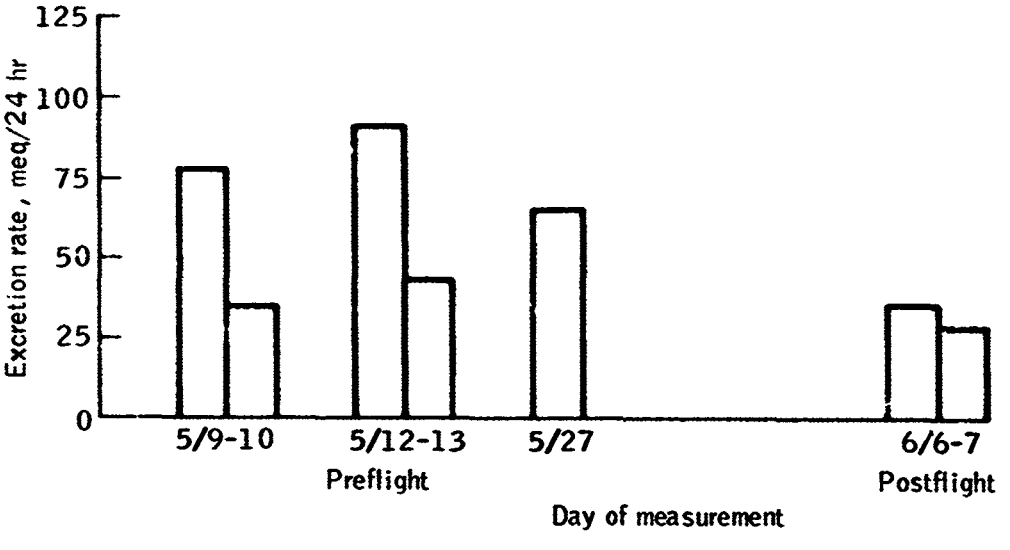
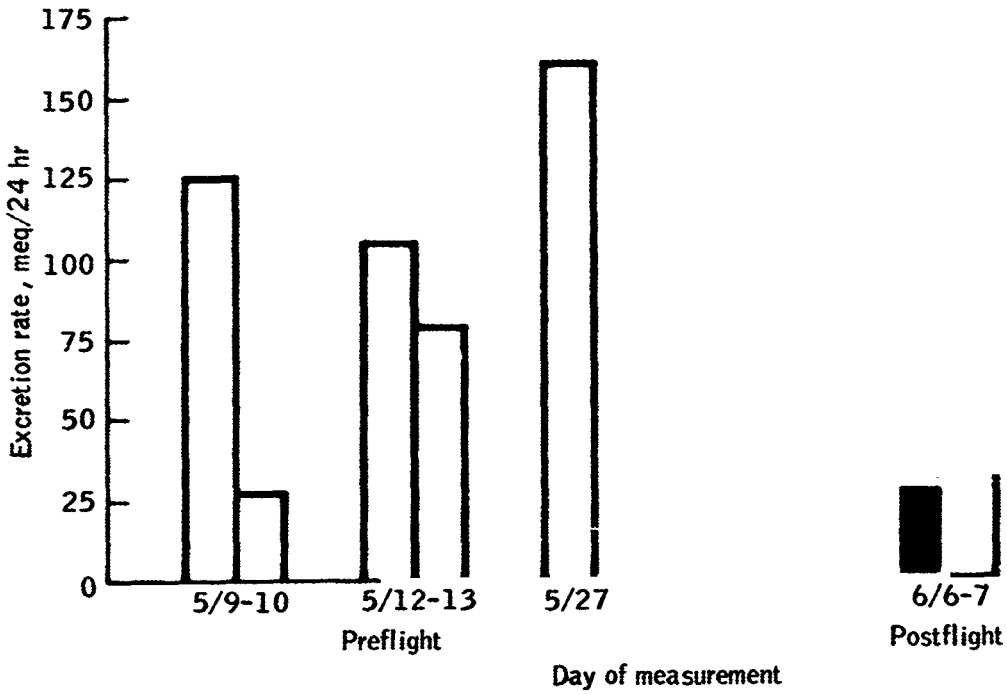


(b) Gemini IX pilot.

Figure 4.- Urinary potassium excretion.



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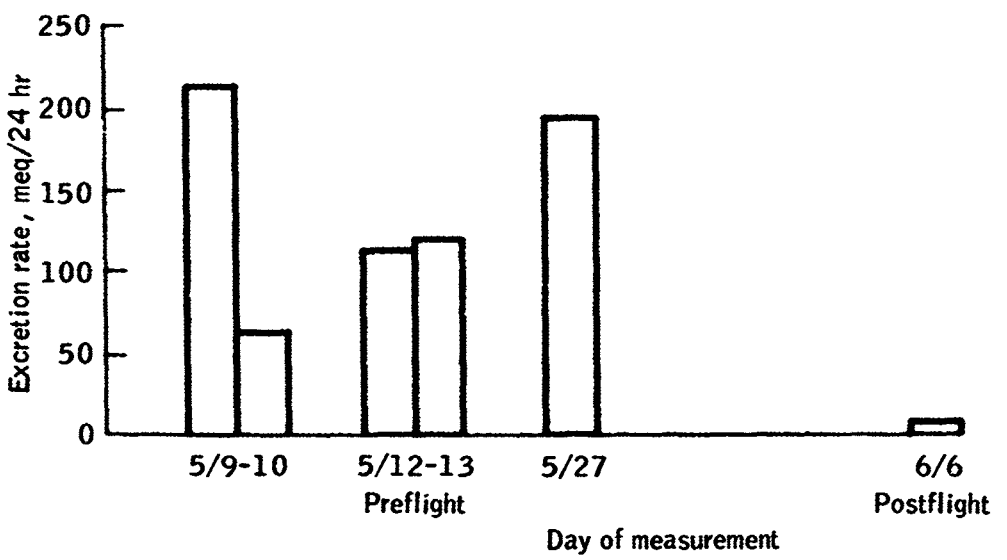
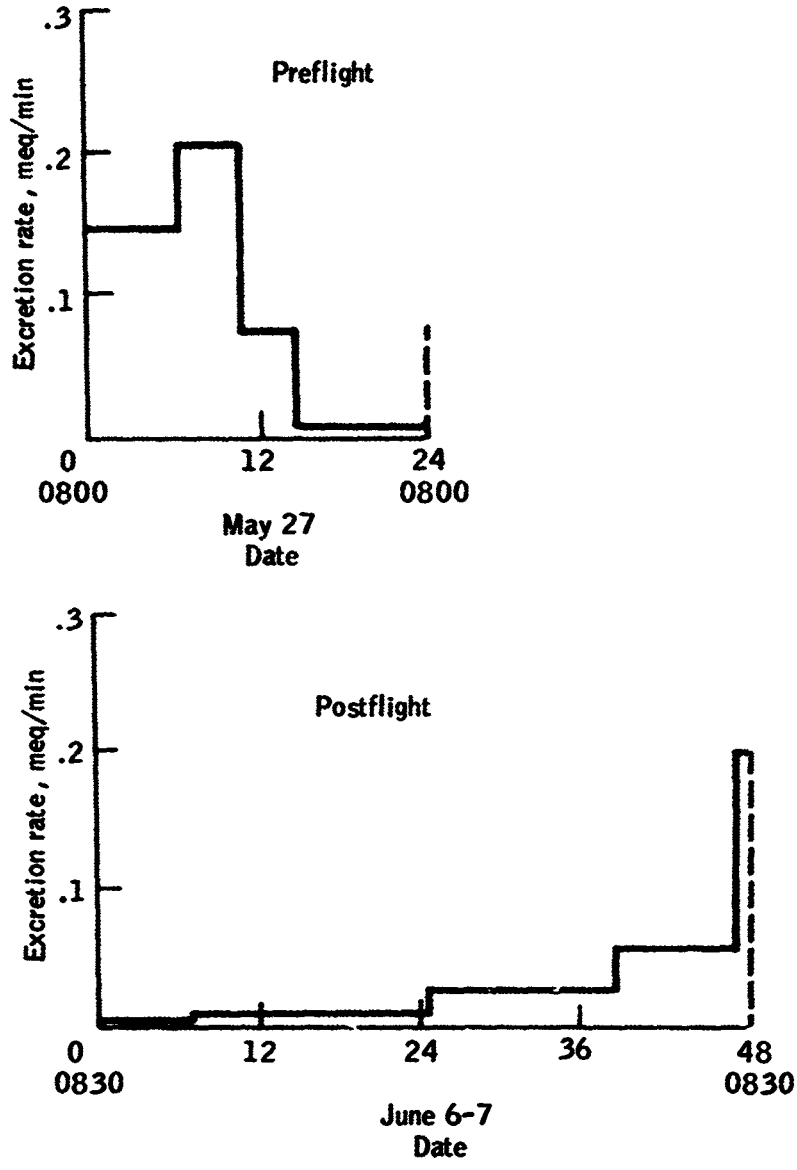


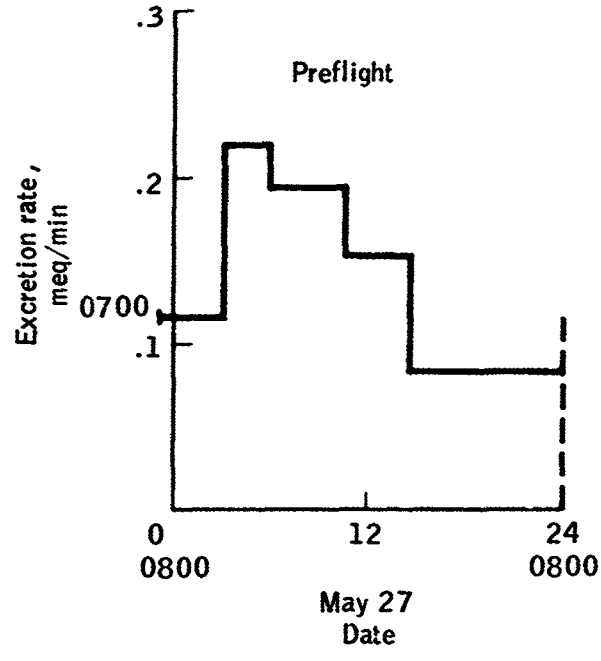
(b) Gemini IX pilot.

Figure 5. - Urinary chloride excretion.



(a) Gemini IX command pilot.

Figure 6. - Urinary sodium excretion.



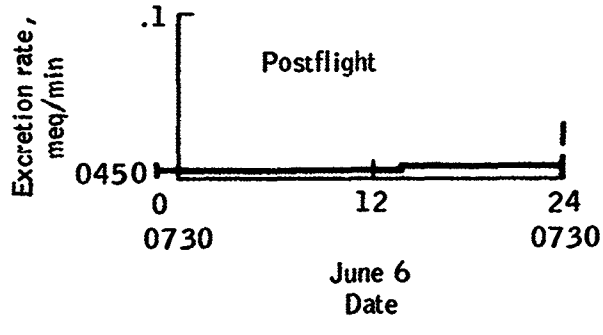


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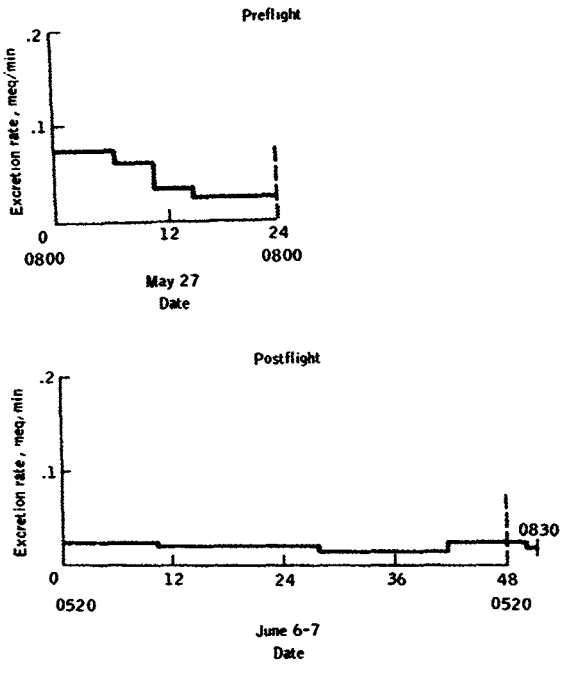
Figure 6.- Concluded.



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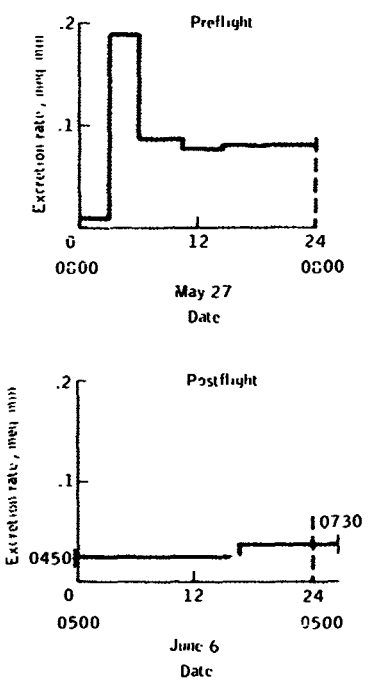
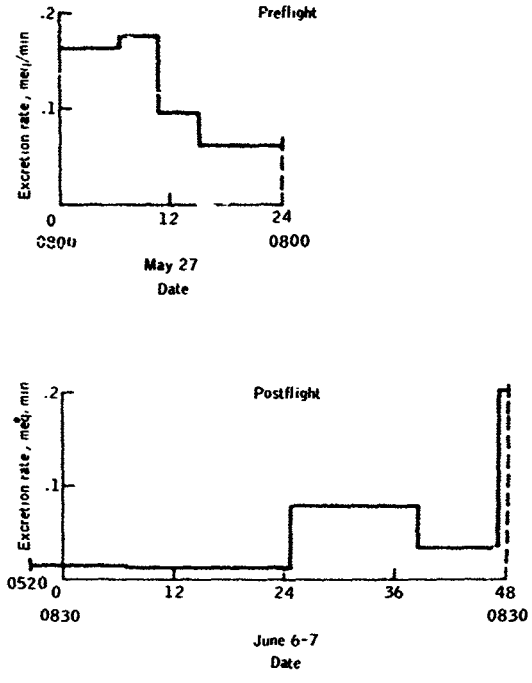


(b) Gemini IX pilot.

Figure 7. - Urinary potassium excretion.



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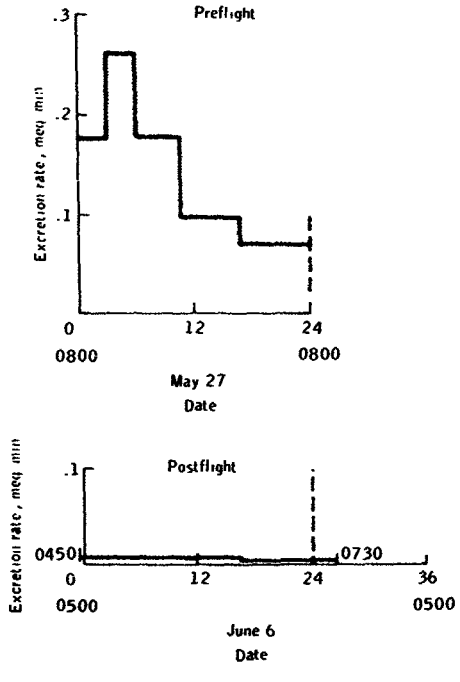

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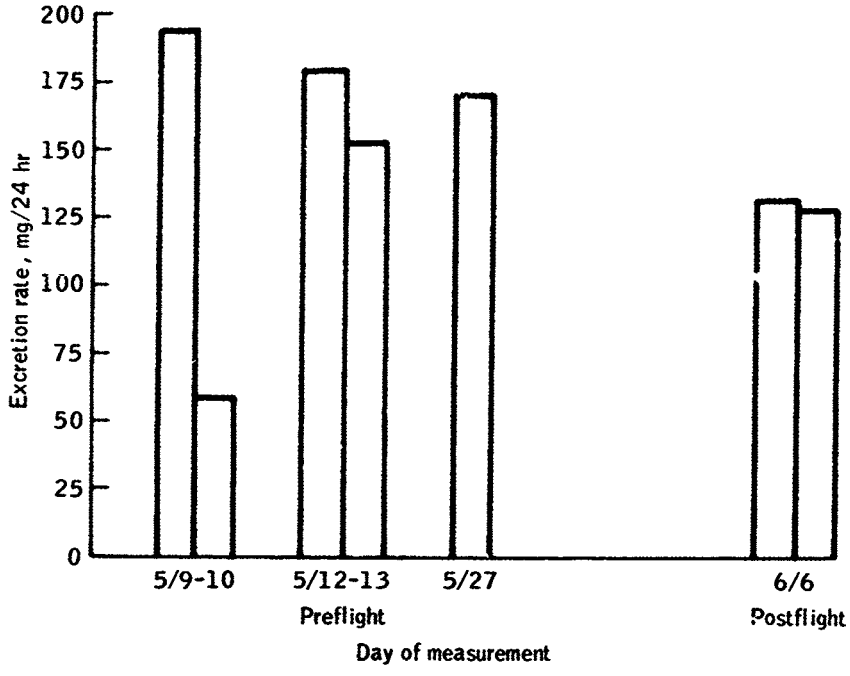
Figure 8. - Urinary chloride excretion.



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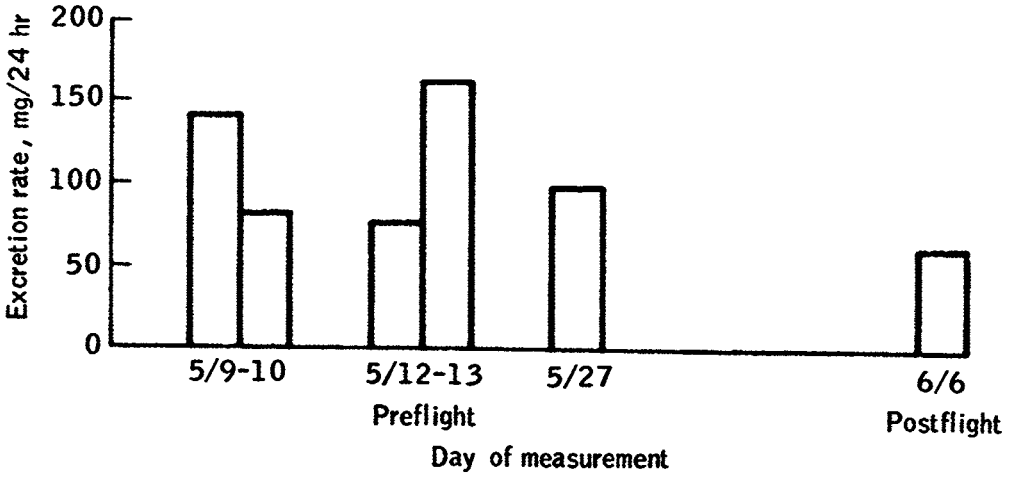

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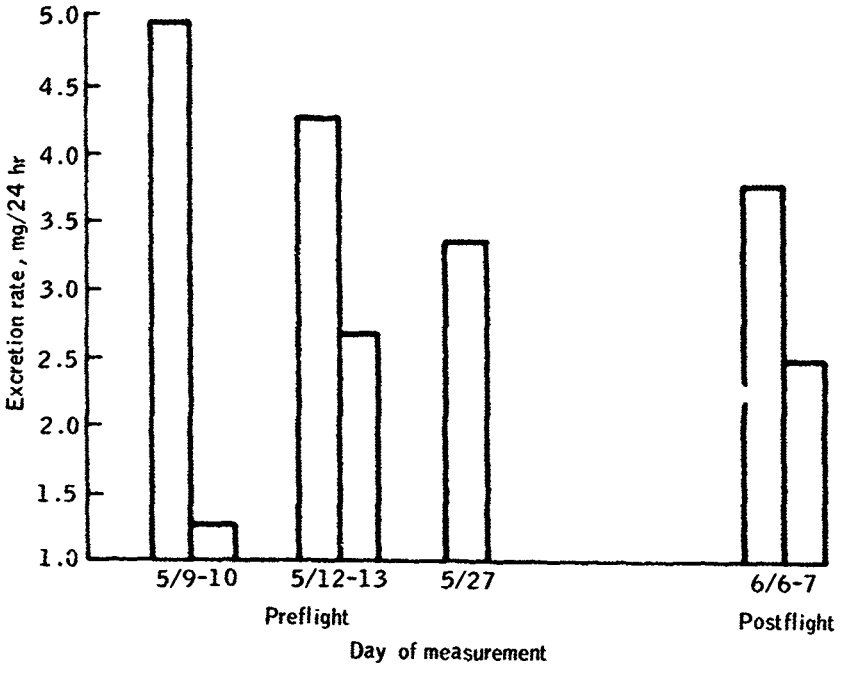
Figure 9.- Urinary calcium excretion.



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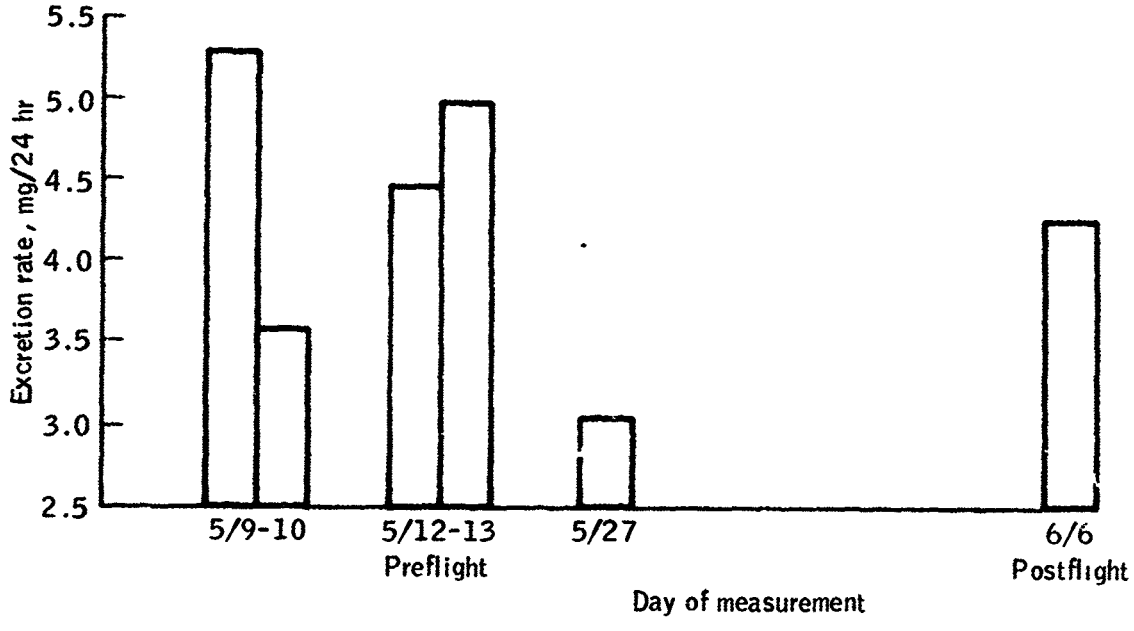

(b) Gemini IX pilot.

Figure 10.- Urinary 17-hydroxycorticosteroid excretion.

EXPERIMENT M008

ANALYSIS OF INFLIGHT SLEEP

By Peter Kellaway*

INTRODUCTION

The necessity for monitoring cardiovascular function during space flight has been recognized since the inception of the manned space-flight program. Recently, attention has been directed to the possibility of monitoring brain function during space flight. A cooperative research program at the Baylor College of Medicine, the University of California at Los Angeles Medical School, and the Manned Spacecraft Center (MSC) represented an attempt to answer the following questions.

1. Will the electrical activity of the brain, as this activity is revealed in the electroencephalogram (EEG) recorded from the scalp, contain important and useful information concerning such factors as the sleep-wakefulness cycle, the extent of alertness, and the readiness to perform mental and physical tasks?

2. Is it feasible and practical to record the EEG (an electrical signal measured in microvolts) during the unique and difficult environmental conditions that prevail during space flight? These conditions consist of the following factors.

a. Possible electrical interference from the various electrical devices located near each other in the spacecraft

b. The necessity for recording during the routine activity of the subjects, with the attendant artifacts produced by muscle action, movements, perspiring, skin-resistance changes, and so on

c. The requirements for miniaturization of necessary instrumentation to a size sufficiently small and light in weight to justify its incorporation as part of the payload of the space vehicle

d. Scalp electrodes and a method of electrode attachment that would facilitate long-duration artifact-free recordings without significant discomfort to, or irritation of, the scalp

*Baylor College of Medicine, Houston, Texas.

3. What is the minimal number of brain regions, that is, the number of channels of electrical data, necessary to collect adequate EEG information to identify and differentiate all levels of sleep and wakefulness?

4. Can a computer or other form of automatic analysis be used effectively to analyze the EEG data to yield the required information, thus avoiding the necessity of having EEG experts constantly present to analyze the records?

5. Can highly complex computerized analytical techniques reveal important correlations between EEG activity and higher brain functions (having to do with such conditions as vigilance and attention) that are not evident upon visual analysis of the EEG record?

These are the practical problems that are being studied. Also, the following problems are under investigation.

1. The possible influences of weightlessness and other effects on brain function, particularly on the sleep-wakefulness cycle, as evidenced by EEG changes

2. The application of computerized analytical techniques to the analysis of the EEG while the subject is undergoing various controlled conditions (sensory simulation, heightened affective states, mental computation, and others)

OBJECTIVES

Already, a major part of this research program has been completed; however, this report contains only the preflight and inflight data that were obtained from the experiment in connection with the Gemini VII mission. The primary purpose of this experiment was to obtain objective and precise information concerning the number, duration, and depth of sleep periods of the command pilot.

The importance of precise information concerning the sleep (that is, rest) of the crew, especially during long-duration flights, is obvious. This information can be obtained with the electroencephalograph because the electrical activity of the brain undergoes clearly established and consistent variations with different levels of sleep. By use of the EEG, it is possible to distinguish four levels of sleep, ranging from drifting or drowsiness to profound sleep, and a special condition which is sometimes called paradoxical sleep (the rapid-eye-movement phase of sleep), believed by many investigators to be important for the psychoaffective well-being of the individual.

EXPERIMENTAL TECHNIQUE

Base-Line Data

Base-line data, multichannel EEG data, and other psychophysiological data were recorded for the command pilot and for the backup command pilot at the Laboratory of Space Neurobiology (Methodist Hospital, Houston, Texas) during all stages of sleep and

during the waking state. These recordings were used as a base line for comparison with the inflight records and with recordings made during altitude-chamber tests.

Electrodes and Recording System

Preliminary studies of the EEG of 200 control subjects, and specifically of the preflight EEG of the command pilot and his alternate, revealed that all sleep stages could be differentiated and identified in records obtained from a single pair of electrodes placed on the scalp. One electrode in the central region and one electrode in the occipital region proved to be adequate. Also, it was learned that if these electrodes were placed on the midline of the head, the minimum possible muscle-activity artifact was observed. Because weight and space limitations permitted only one additional EEG recording channel, a duplicate of the first electrode pair was used, but was displaced a few centimeters to the left of the midline. These electrode placements result in collection of essentially the same information as do the midline pair, but this choice was made to provide for the possibility that one or more of the electrodes of one pair might be dislodged or become defective. Also, this choice was made rather than collect EEG data from another brain region.

The recording system consisted of two miniature transistorized amplifiers, carried by the command pilot in pockets of his underwear, and a small magnetic tape recorder inside the spacecraft. The tape recorder, operating at a very slow speed, had the capability of continuously recording data for 100 hours.

Preflight Tests

Preliminary tests of the electrode system, amplifiers, and tape recorder under flight conditions were made first in an altitude chamber of a contractor, and subsequently were made in an altitude chamber at the MSC. Another dry-run test was conducted at Cape Kennedy, Florida, the day before the flight, and recordings were made at the launch pad prior to lift-off. All of these preflight tests yielded good recordings, clean of all artifacts except those caused 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 mission. During these 4 days, the command pilot was to keep his helmet on unless significant discomfort or other factors necessitated its removal. Therefore, the electrode system was designed for a helmet-on arrangement.

RESULTS

A representation of the events (as determined from the medical recorder data) from 15 minutes before lift-off to the time that one electrode of the second electrode pair was dislodged is given in figure 1. A total of 54 hours 43 minutes of interpretable EEG data were obtained. Most of these data were of excellent quality for visual

interpretation. Electroencephalograph channel 1 became noisy after 25 hours 50 minutes of flight (indicated by point B in the figure), and no interpretable data appeared in this channel after 28 hours 50 minutes (indicated by point C in the figure). Electroencephalograph channel 2 data were good and were artifact-free until 43 hours 55 minutes (point D in figure 1), at which time the channel became intermittently noisy. No interpretable data were recorded after 54 hours 28 minutes of flight (point E in figure 1), at which time the channel 1 electrodes were inadvertently dislodged. The sleep periods will be discussed in detail elsewhere. Meal times are indicated in figure 1 because they represent periods of temporary interruption of the interpretability of the EEG data caused by muscle-action and movement artifacts of rhythmic chewing (fig. 2).

As indicated in figure 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 g.e.t.) without showing signs of drowsiness or sleep. A portion of the record during this period is shown in figure 2.

Sleep is very easy to detect in the EEG records. Distinctive patterns found at each level of sleep are shown in figures 3 and 4. These illustrations were taken from the EEG made during the second sleep period during the mission. The total sleep periods are represented in figure 5. For ease of representation, each sleep period is divided into 1-minute epochs; these are represented by the vertical lines. The length of this line represents the range of sleep-level variation during the minute represented. The uppermost level on the vertical axis of the graph (EO) represents the eyes open, alert type of EEG pattern. The next part of the vertical axis marks the eyes closed, resting pattern (O). The succeeding points on the scale represent the four levels of sleep, from light to deepest. When more than one EEG stage of sleep occurred in a 1-minute epoch, the vertical line indicating the stage of sleep was drawn to show the extent of the alterations of sleep level occurring during this time. This circumstance occurred often. 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 a flight, a similar representation of the control (base-line) sleep period, made in the laboratory in September 1965, is shown to compare the rate and character of the "falling to sleep" pattern. However, this representation cannot be used to compare the cyclic alterations occurring in a full night of sleep because the subject was awakened after 2 hours 45 minutes; but, the first part of the characteristic cyclic changes of level can be seen. The first inflight sleep period contained significant 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. However, in less than 15 minutes abrupt arousal occurred, and sleep was terminated. On the second day (33 hours 10 minutes after lift-off), the command pilot again closed his eyes and immediately showed evidence of drowsiness. Within 34 minutes he was in the deepest level of sleep. During this long period of sleep, there were cyclic alterations in sleep level similar to those which occur during a full night of sleep under normal conditions. Usually, such cyclic changes are irregular and aperiodic, as shown in figure 6 which is taken from a normal control series of subjects. Generally, after the first period of stage 4 sleep has been obtained, each successive swing toward deeper sleep only reaches successively lighter levels of sleep. But in the second night of sleep, the command pilot attained and maintained stage 4 sleep for 20 minutes or more at three different times after the first episode. It is speculative whether this increase in the number of stage 4 periods was a manifestation of deprivation of sleep during the first 24 hours of the flight.

After approximately 7 hours of sleep, a partial arousal from stage 4 sleep occurred. After a brief period (12 minutes) of fluctuation between sleep stages 2 and 3, the command pilot remained in a condition fluctuating between drowsiness and stage 1 sleep, until a condition of full arousal was reached approximately 1.5 hours later. Whether any periods of so-called paradoxical sleep, rapid-eye-movement sleep, or dreaming sleep occurred during this oscitant period cannot be determined with certainty from the data recorded because of the absence of eye-movement records and because paradoxical sleep is generally very similar in character to ordinary stage 1 sleep. However, for relatively long periods on the sleep that occurred on the second day (11:05 G.m.t. and 14:20 G.m.t.), two patterns were recorded which resemble a mixture 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. Typical examples of this activity, which consists of runs of three saw-tooth waves per second, runs of low-voltage theta- and alpha-wave activity, runs of low-voltage beta-wave activity without spindles, and occasional slow transients with a time course of about 1 second, are shown in figure 7.

CONCLUSIONS

This experiment has demonstrated the feasibility of recording the electroencephalogram during space flight. Refinement of technique and the development of more comfortable and efficient electrode systems soon will facilitate recording throughout long-duration space flights. The precise information that can be collected with the electroencephalograph regarding the duration, depth, and number of sleep periods implies that electroencephalogram monitoring should be considered for routine use in the long-duration space flights that are contemplated for the Apollo Program and other programs. The importance of such information in the direction and execution of the flight, both to the medical monitors and to the crewmembers, is obvious.

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

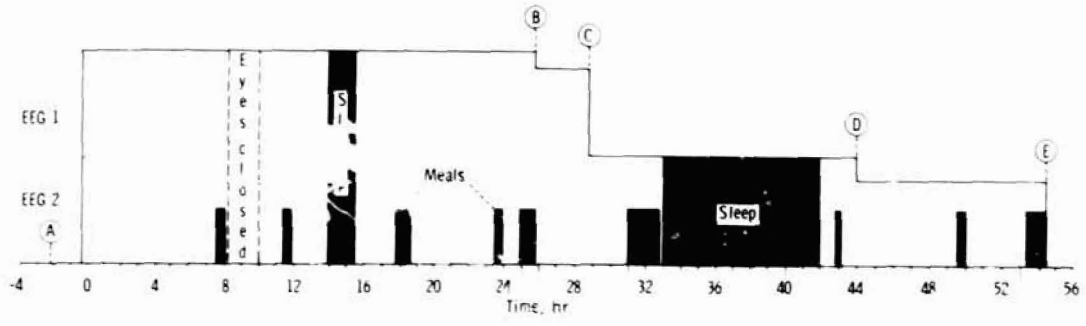

Figure 1. - Electroencephalographic data flow.

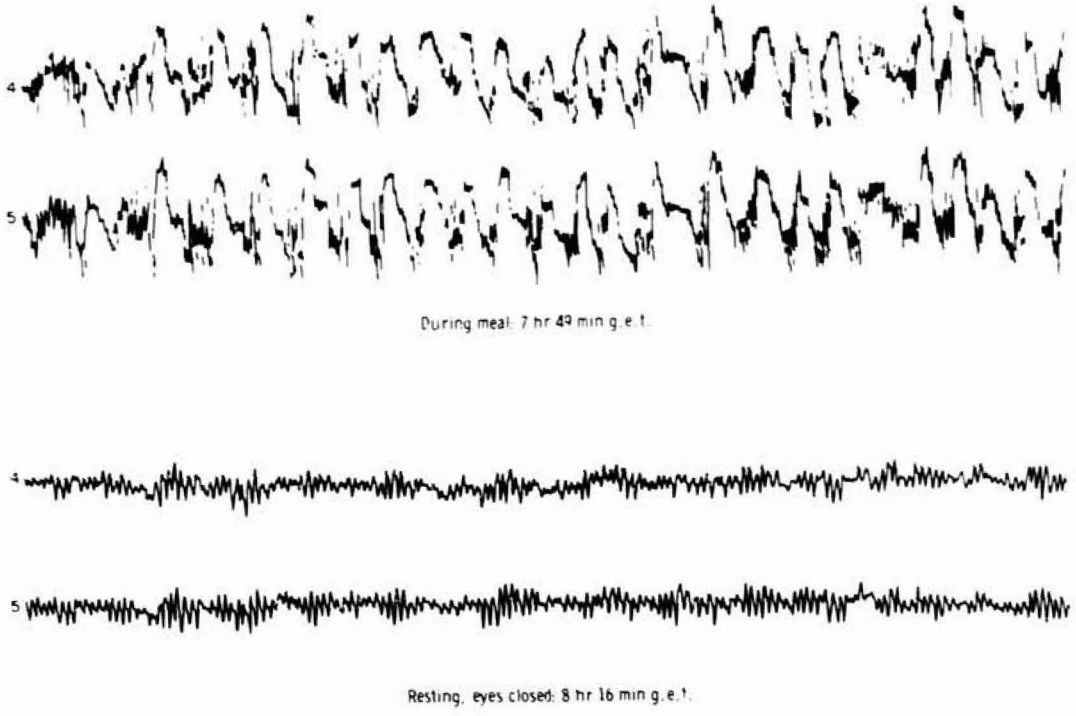

Figure 2. - Electroencephalogram recorded during rhythmic chewing (upper) and during the eyes closed resting condition (lower).

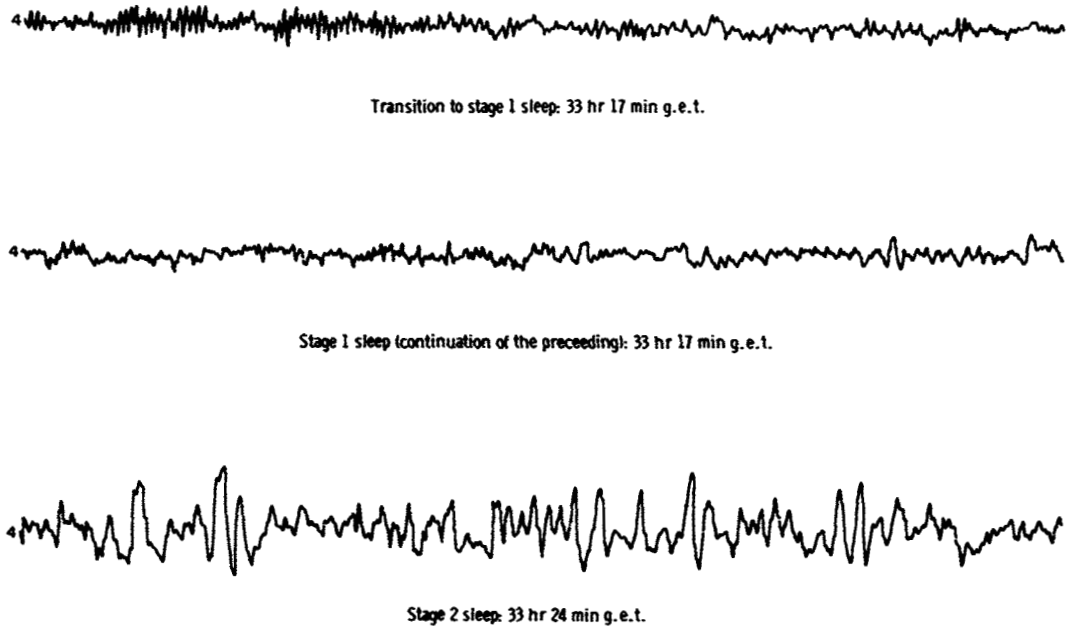

Figure 3. - Electroencephalographs containing progression from awake to light sleep.

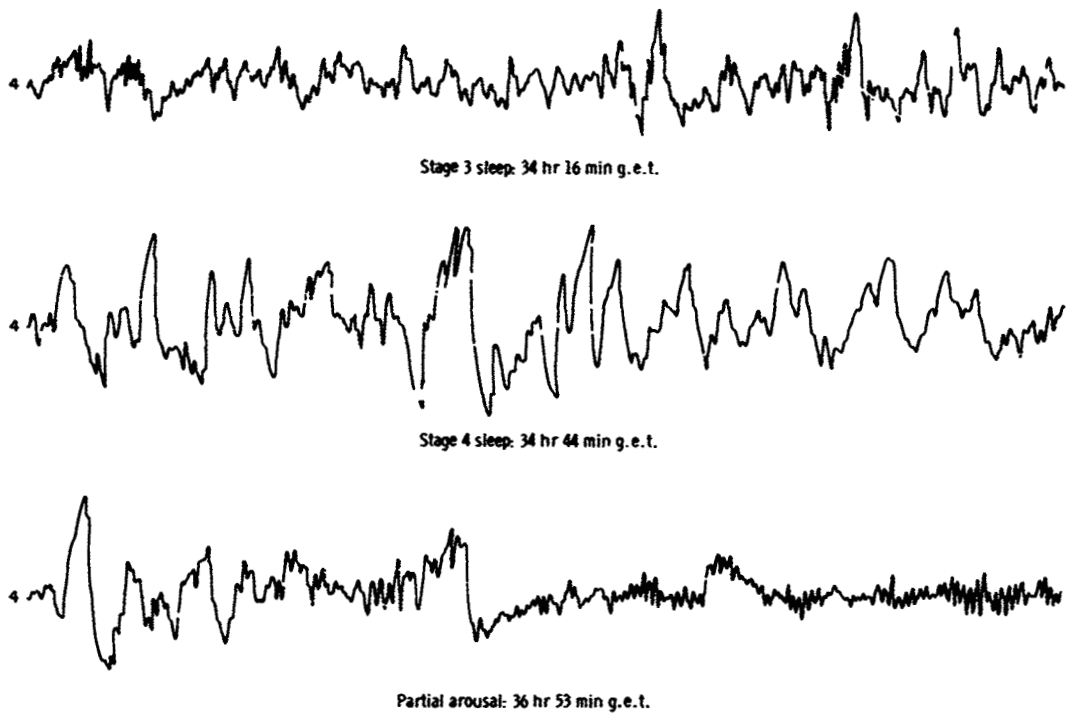

Figure 4. - Example of electroencephalograms recorded during moderate sleep (stage 3), deep sleep (stage 4), and partial arousal.

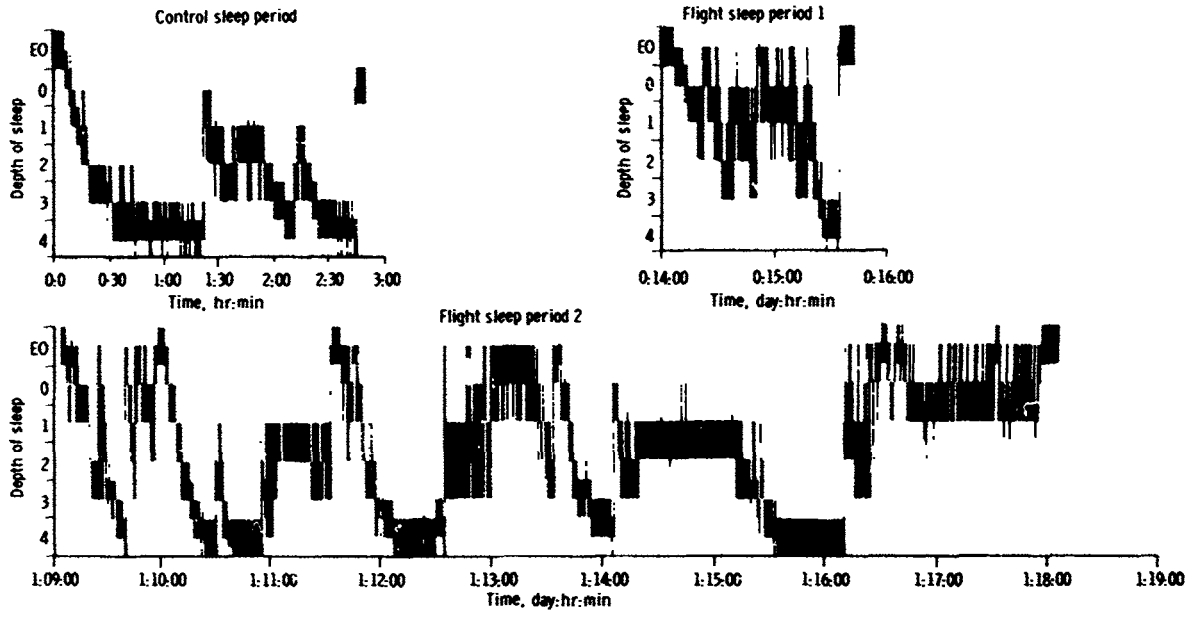

Figure 5. - Analysis of a control sleep period and of two inflight sleep periods.

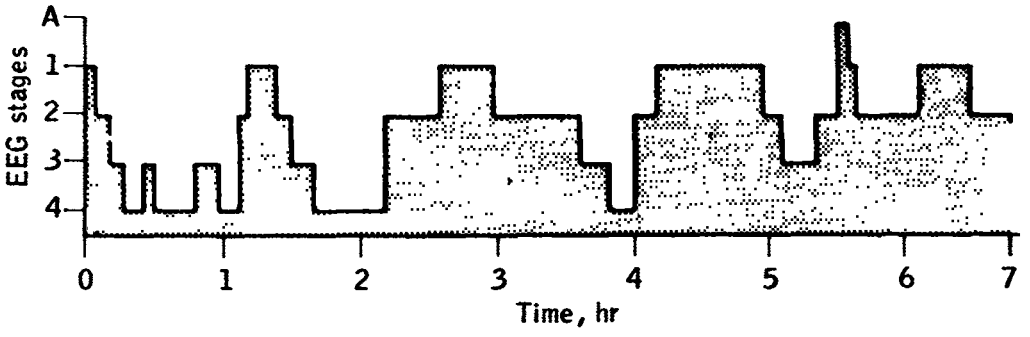

Figure 6. - Cyclic variations during spontaneous sleep.

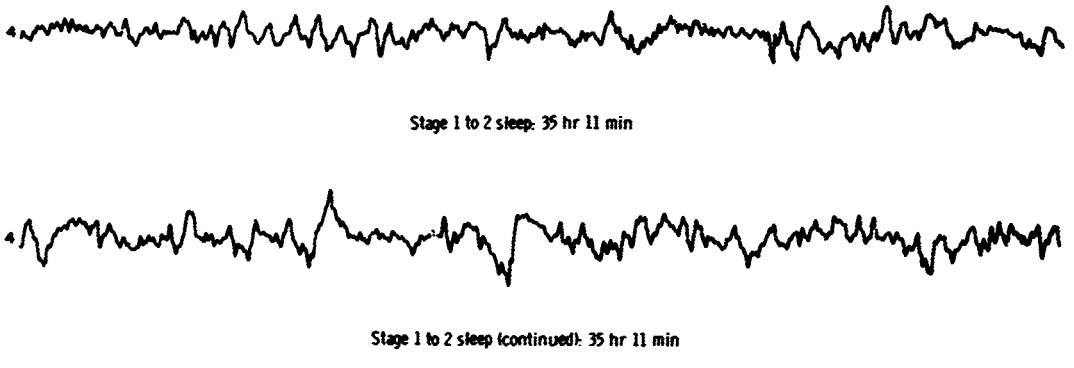

Figure 7. - Sample of an electroencephalogram containing a mixture of stage 1 and stage 2 sleep (possibly representing the paradoxical sleep phase).

EXPERIMENT M009

HUMAN OTOLITH FUNCTION

By Ashton Graybiel* and Earl F. Miller II*

INTRODUCTION

The purpose of Experiment M009 was to obtain information concerning human otolith function in conjunction with exposure t · ·bital space flight. This was done in two ways: (1) by measuring the ability of crew ·.embers to estimate horizontality (with reference to the spacecraft) in the absence of visual and primary gravitational cues and to make similar judgments under normal gravitational c· ·ditions preflight and postflight and (2) by comparing preflight and postflight measurements of ocular counterrolling.

BACKGROUND

Egocentric visual localization of the horizontal (EVLH) was the test that was chosen to measure space perception in the absence of adequate visual cues. If an individual observes a dim line of light in darkness (while seated upright under ordinary conditions), as shown in figure 1, he is able to set a line in the dark to the horizontal with great accuracy (refs. 1 to 3). If an individual is exposed (under proper conditions) to a change in the egocentric gravitoinertial vertical, he is able to set the line approximately perpendicular to the changing direction of the mass acceleration (refs. 4 and 5). This confirms that, in the absence of visual cues, the ability of the observer to estimate the vertical and horizontal is dependent upon the influence of primary and secondary gravitational cues. The line itself is an inadequate cue. Persons with bilateral deprivation of the organs of equilibrium perform this task inaccurately, indicating the important role of the otolith apparatus in detection of the upright (refs. 1, 2, 5, and 6). In weightlessness, primary gravitational cues are lost and the otolith apparatus is physiologically deafferented (refs. 7 and 8); that is, the apparatus has lost its normal stimulus. Thus, a unique opportunity to investigate the role of secondary gravitational cues in orientation to the environment is created. The human in orbital flight, even with eyes closed, relates to the spacecraft by tactile cues. Consequently, as a first step in the exploration of the loss of primary gravitational cues in space flight, it was thought worthwhile to obtain serial EVLH measurements.

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The ocular counterrolling (CR) test is based upon the observation that when a normal person is tilted to the right or to the left, his eyes roll conjugately in the contralateral direction. If proper technique is used (refs. 9 and 10), the amount of the counterroll is a specific and valid measure of otolith function. Persons with bilateral loss of otolith function do not manifest CR, or, if CR occurs, it is minimal and possibly is indicative of residual function (ref. 11). In its present form, this test cannot be performed in a small spacecraft; hence, the test was limited to preflight and postflight conditions. The objective of the test was to determine whether long-duration physiological deafferentation of the otolith apparatus altered its basic sensitivity. For convenience, the crewmen have been designated by letters.

APPARATUS AND PROCEDURE

The apparatus for measurement of the EVLH of the spacecraft was incorporated into the onboard vision tester which was part of Experiments S008 and D013. This was done to save weight and space and constituted only a physical interface; in all other respects, the two experiments were separate. The inflight vision tester was a binocular instrument (figs. 2 and 3) that had an adjustable interpupillary distance (IPD) but did not have a focus adjustment. The device was held at the proper position, with the lines of sight coincident with the optic axes of the instrument, by means of a biteboard that was fitted to the subject. Thus, each time the instrument was used it was similarly located with respect to the axes of the subject, if the proper IPD adjustment had been made. In this position, the eyecups (attached to the eyepieces of the instrument) excluded all extraneous light from the visual field. Direct-current power, regulated by the instrument, was supplied by the spacecraft electrical system.

A headbrace (fig. 3) was provided to connect the biteboard of the instrument to the mapboard 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 the pitch axis was permitted by the folding configuration of the brace (so designed for convenient storage). This method of fixation of the vision tester to the spacecraft was not used on 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 was a modification and miniaturization of a target device that has been described elsewhere (ref. 4). Essentially, it consisted of a collimated line of light in an otherwise dark field. The line could be rotated around its center by manipulation of a knurled knob. A digit read-out of line position was visible easily and was accurate within $\pm 0.25°$. The device was monocular and was fabricated in duplicate so that when the crewmember in the left-hand seat used the right eye, the readout was visible to the crewmember on his right. The converse also was true. The read-out was adjusted so that horizontality to the apparatus (instrument zero) was represented by values other than a zero or 180° (for example, Gemini V, 76.6° and 101.6° for the left and right crewmembers, respectively) to eliminate or reduce the possible influence of knowledge of the setting upon subsequent judgments.

Essentially, the apparatus used for measurement of CR on the Gemini V and VII missions was a tilt device on which a camera system was mounted (ref. 10). The main

supportive part of the CR device acted as a carrier for the stretcherlike section. This section contained Velcro straps and a saddle mount to secure the subject in a standing position within the device. The device could be rotated laterally ±90° around the optic axis of the camera system, and when the subject was properly adjusted, the device also could be rotated around the visual axis of his right or left eye. A custom-fitted biteboard was used to fix the head of the subject with respect to the camera recording system.

The camera system that was used to photograph the iris landmarks included a motor-driven 35-millimeter camera and a bellows extension and an electronic flash unit. A console, located at the base of the tilt device, contained a bank of powerpacks that supplied power for the electronic flash; a timer-control mechanism; and controls for the flashing, round, fixation light which surrounded the camera lens. A triaxial-accelerometer unit that sensed and relayed signals of linear acceleration to a galvanometer recorder was mounted to the head portion of the device for shipboard use. A test cubicle (12 by 16 by 10 feet) that was insulated against outside sounds, light, and temperature was constructed for performance of the postflight tests of EVLH and CR on board the recovery ship.

TEST PROCEDURE

Gemini V Mission

Preflight testing or CR and EVLH for both crewmembers was done at Cape Kennedy, Florida, 16 days prior to the flight. Immediately before preflight and postflight testing of EVLH, 1 drop of a 1-percent ophthalmic solution pilocarpine hydrochloride was instilled into the eye that would not be used for making visual-orientation judgments. Then, the subject was placed in the CR tilt device, was adjusted properly, and was secured. The method of testing EVLH preflight and postflight was as follows.

1. The IPD of the vision tester was adjusted, and the device was positioned by insertion of the biteboard into the mouth of the subject.

2. Initially, the experimenter offset the line target that was presented to only one eye (the other eye observed a completely dark field).

3. By means of the knurled wheel, the subject rotated the target clockwise or counterclockwise until it appeared to be alined parallel to the gravitational horizontal.

This procedure was repeated in each test session until eight settings had been made while the subject was in the upright position.

The method for testing EVLH in flight was as follows. Immediately after completion of Experiments S008 and D013, the instrument was readied for EVLH testing by occlusion of the left eyepiece (command pilot or right eyepiece (pilot) by means of the ring on the eyepiece and by turning on the luminous target before the other eye. Crewman B was tested first. The target appeared against a completely dark background and initially was offset at random by the observer. The experimental task of

the subject was to adjust the target until it appeared horizontal with respect to the spacecraft environment. When satisfied with each setting, the subject closed his eyes and removed his hand from the knurled ring. This was a signal to the observer to record the setting and offset the target. It was planned that this procedure be repeated five times during each of the daily test sessions. Then, the vision tester was handed to crewman A, and the same sequence was performed before his visual-acuity test. Finally, the readings for each subject were tape recorded by voice. In lieu of the use of the bracket for head (and therefore the test instrument) fixation, the subjects were requested to maintain an erect position by alinement with the headrest.

Preflight and postflight measurements of ocular CR were accomplished according to the standard procedure used at the Naval Aerospace Medical Institute. After the EVLH test, the subject remained in the upright position in the tilt device. The vision tester and 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 mouth of the subject, and the position of the appropriate eye was adjusted so that is coincided with the optic axis of the camera system when the subject fixated the center of the flashing red ring of light. Six photographic recordings were made at this position. Then, the subject was tilted slowly in his lateral plane to each of four positions ($\pm 25^\circ$ and $\pm 50^\circ$), and the photographic procedure was repeated. The accelerometer system was used postflight to record continuously the motions of the recovery ship around its roll, pitch, and yaw axes during the EVLH and CR tests.

Blood pressure, pulse rate, and electrocardiographic data were monitored by NASA Manned Spacecraft Center medical personnel during the EVLH and CR tests. Postflight examinations were begun for subject A and subject B approximately 6 and 5 hours, respectively, after recovery at sea.

Gemini VII Mission

Preflight testing of CR and EVLH by both subjects was done at Pensacola and Cape Kennedy, Florida, at 19 and 6 weeks, respectively, before the flight. Essentially, the preflight and postflight procedures for testing EVLH and CR were identical to those used for the Gemini V crewmen.

The method of testing EVLH in flight was identical to the method that was used on the Gemini V mission with the exception that the headbrace was used. The subjects were instructed to apply the same amount of tension on their seatbelts during the EVLH test in an attempt to keep the influence of secondary gravitational cues upon their judgments as constant as possible. Postflight examinations were begun for subject C and subject D approximately 6 and 4.5 hours, respectively, after recovery at sea.

RESULTS

Gemini V Mission

Preflight CR response. - Preflight measurements of ocular CR (fig. 4) were indicative that the basic otolithic function of both crewmembers was at the low normal level, but was within the range of CR response found among a random population of 100 normal subjects (represented by the shaded region in fig. 5). The possibility existed that the lower response manifested by these individuals might be typical for the highly select population of astronaut candidates and might represent some byproduct of their flight experience. However, the test results for six other astronaut candidates (fig. 4) were indicative that this response magnitude was not typical of this select population.

Postflight CR response. - As indicated in figure 4, postflight measurements also revealed a reduced CR response that was not significantly different from the comparable data collected preflight. The slight differences in the CR curves can be explained by consideration of the small rotary oscillations (physiological unrest) of the eye around a mean position of the eyes that is associated with any given body tilt.

Preflight and postflight EVLH measurement. - The deviations of the individual discrete EVLH setting from the instrument zero are summarized in figure 6. The judgments of each crewmember concerning the location of the gravitational horizontal for an upright position were quite accurate and stable prior to flight. On the day of recovery, the pattern of response was similar to that of preflight, but was less accurate and less consistent. Although the seas were relatively calm, the fact that judgments were made on an unstable platform could be responsible for these differences.

Inflight EVLH measurement. - Inflight EVLH measurements were not made in the early part of the flight, probably in the interest of conservation of spacecraft power. During revolution 24 and during two succeeding revolutions (39 and 54), only one EVLH judgment was made by each subject. Beginning on revolution 72 and continuing through several subsequent revolutions, five EVLH judgments were recorded. Evaluation of the inflight data was indicative that subject B produced accurate and consistent visual estimations, whereas subject A, although no less consistent than subject B, made judgments which were significantly ($<30°$) deviant from the absolute horizontal of the spacecraft environment. A summary of the EVLH data is given in figure 6. The EVLH settings are shown for each crewmember preflight, during specific inflight revolutions, and postflight. The lack of data for the initial part of the flight prevents any statement regarding the possible time of onset of the apparent change in visual orientation of subject A.

Gemini VII Mission

Preflight CR response. - Three separate preflight measurements of ocular CR (fig. 7), made on the same day, were indicative that the basic otolithic function of crewman C and crewman D was within the range of CR response found among a random population of 100 normal subjects (represented by the shaded region in fig. 5). The CR response of each of the Gemini VII crewmen was significantly different from that found for the Gemini V crewmen (A and B), but was similar to the response of other crewmen who had been tested (fig. 5).

Postflight CR response. - As shown in figure 7, postflight measurements revealed no significant change in the mean CR response from that manifested before the flight. Again, the slight differences in the CR curves can again be explained by consideration of the small rotary oscillations (physiological unrest) of the eye and the fact that an average of several recordings was used to define the position of the eyes that was associated with any particular body tilt.

Preflight and postflight EVLH measurement. - The deviations from instrument zero of the discrete EVLH settings of the crewmen are summarized in figure 8. The judgments of each crewman (in an upright position) of the location of the horizontal under normal gravitational conditions were somewhat unstable before the flight. In approximately one-half the settings, deviations greater than 5° were recorded, and the deviation of one setting for each crewmember exceeded 10°. On the day of recovery, the response pattern was similar to the preflight response pattern, in spite of the fact that the judgments were made under unstable though relatively calm sea conditions. The accelerometer tracings revealed that no linear and angular accelerations of significant magnitude had occurred during the postflight test.

Inflight EVLH measurement. - 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 first day of testing, crewman C had somewhat more deviation on the average than he had during succeeding test sessions. In general, estimations of horizontality under weightless conditions were substantially more closely oriented to the immediate physical environment and were more consistent than comparable EVLH settings under standard gravitational conditions. Deviation (from instrument absolute zero) of the individual EVLH settings is shown in figure 8.

DISCUSSION

The experiments that were performed during the Gemini V and VII missions resulted in quantitative information concerning otolithic function and orientation of four subjects exposed to an orbiting spacecraft environment for prolonged periods of time. Preflight counterrolling measurements revealed significant differences between the Gemini V and VII crewmembers with regard to the basic magnitude of otolith response. However, after the flight, each crewmember maintained his respective preflight level

of response. This was indicative that no significant change in otolithic sensitivity occurred as a result of 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 a weightless environment if contact cues are adequate. However, it was noted that the apparent location of the horizontal within the spacecraft may not agree necessarily with its physical correlate in the spacecraft (a line parallel to the pitch axis of the vehicle). For example, data taken from crewmember A were indicative of greater than 30° deviation from the absolute horizontal. These data were indicative that, with closed eyes, cues furnished by contact with the spacecraft did not facilitate correct perception of the cabin axes. Furthermore, the uniformity of the settings by this crewman throughout the flight were suggestive that learning did not occur in the absence of any knowledge of the accuracy of these estimates.

The significant change in the EVLH judgments of crewmember A during flight was probably not caused by a systematic technical error for the following reasons.

1. The same device was used (shortly after impact) in acquisition of the postflight measurements, and these measurements were within the expected range.

2. The device was calibrated postflight, as it was preflight, and the digital readout was accurate in both instances.

3. The possibility that the crewmember, lacking a device to fix the head, used head position as a frame of reference was ruled out, because (by test) the crewman could not incline his head 32°.

4. The procedure was reviewed with the crewmembers postflight, and there was no lack of understanding in performance of the task. Therefore, in the absence of gravity and with eyes closed, the cues furnished by contact with the spacecraft apparently did not allow correct perception of the cabin vertical in the case of crewmember A. However, this crewmember demonstrated that cues were adequate to form a highly stable coordinate space sense even in a weightless environment.

The potential influence of sensory cues on orientation is known to the aviator who has experienced the "leans" and other forms of vertigo. In such a circumstance, with restricted cues (but with cues in relative abundance in comparison with those in a spacecraft), the pilot using instruments can compensate for the illusion; but when flying straight and level, for example, he will feel inclined from the upright. Further experimentation involving serial inflight EVLH measurements is planned for later space flights to increase knowledge of the role of secondary cues in orientation and to explore the possible variations in their influence on the crewmen. The feasibility of this experimental approach was confirmed by the results of the experiment on these Gemini missions.

With one possible exception, already noted for crewmember C in the first inflight test session, egocentric visual localization of the horizontal for three crewmembers was in accord with that of the spacecraft and, for all crewmembers, was more stable in near weightlessness than under normal gravitational conditions. These data prove

that relatively accurate and consistent nonvisual orientation is possible throughout a long period of weightlessness, as long as secondary cues are adequate. However, these same cues may, in certain individuals, contribute to rather large errors in the perception of the principal coordinates of the spacecraft. A more complete resume of the results has been published elsewhere (ref. 12).

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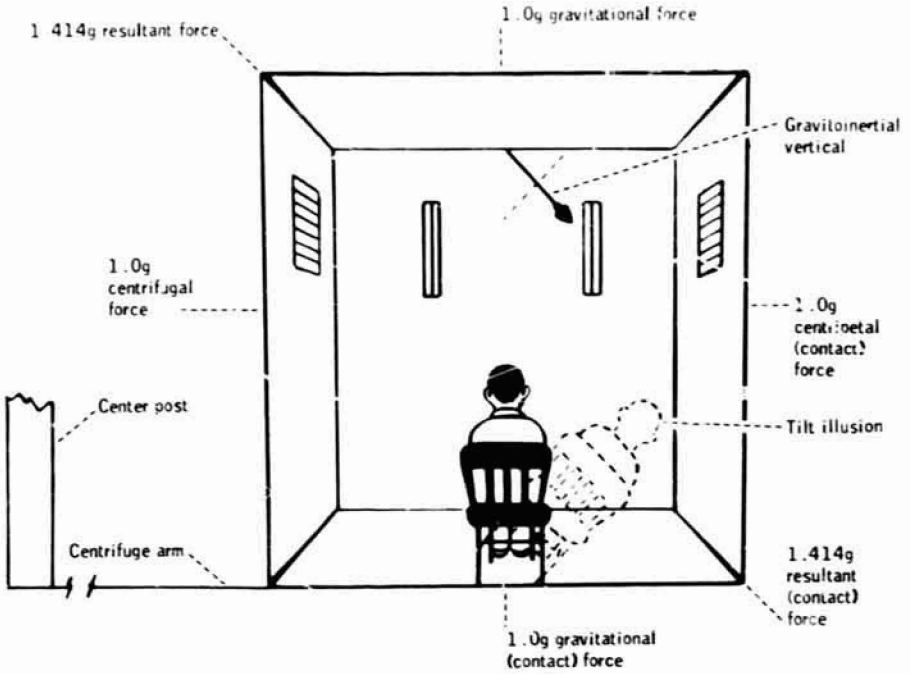

Figure 1. - Egocentric visual localization of the horizontal.

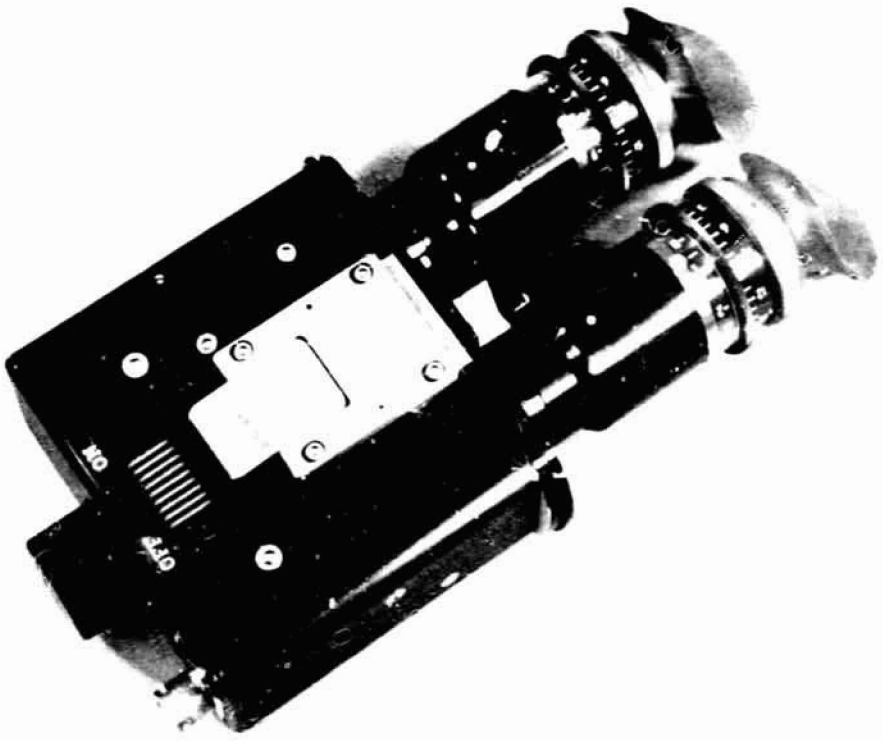

Figure 2. - The inflight vision tester.

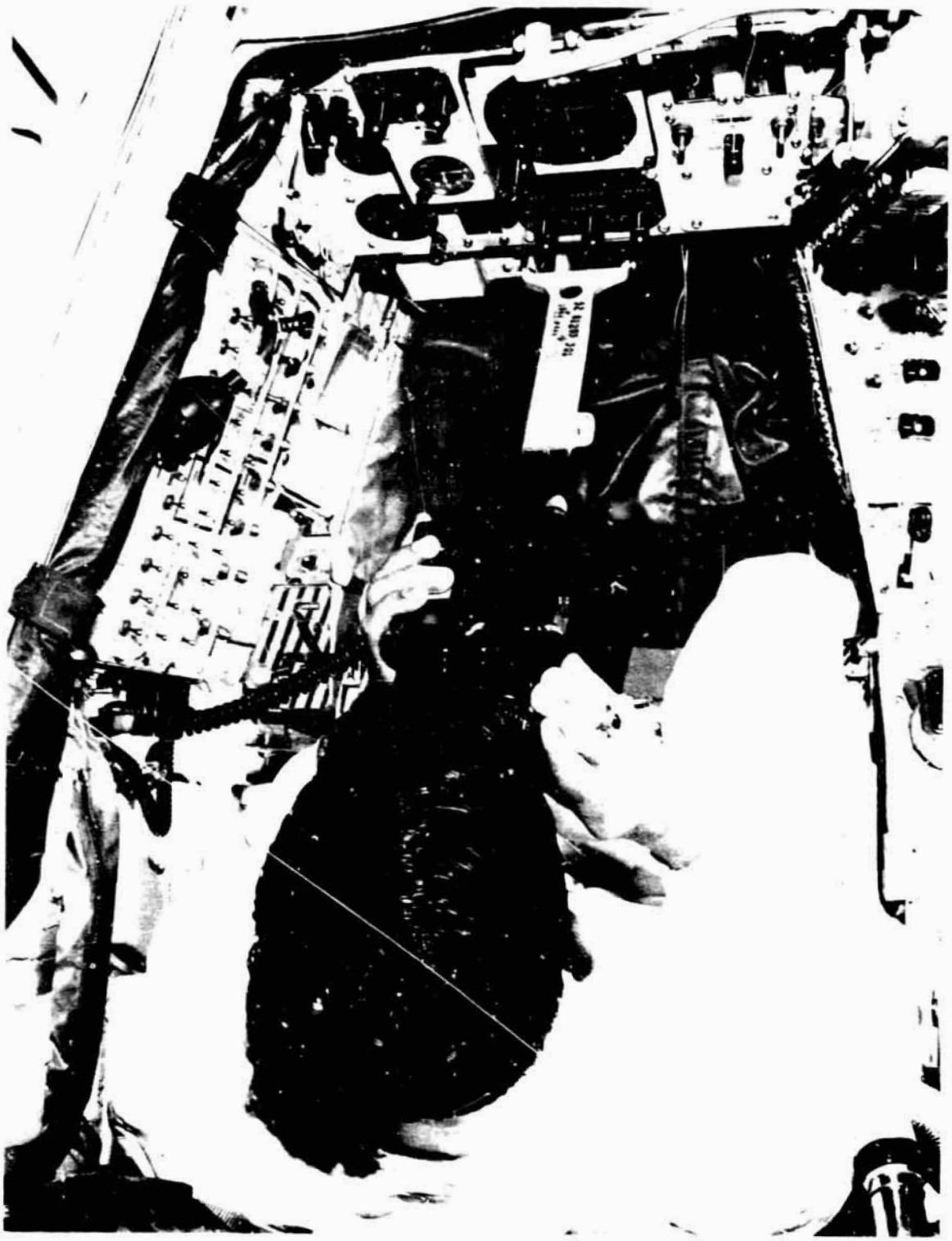

Figure 3. - The vision tester (headbrace attached) as used in flight.

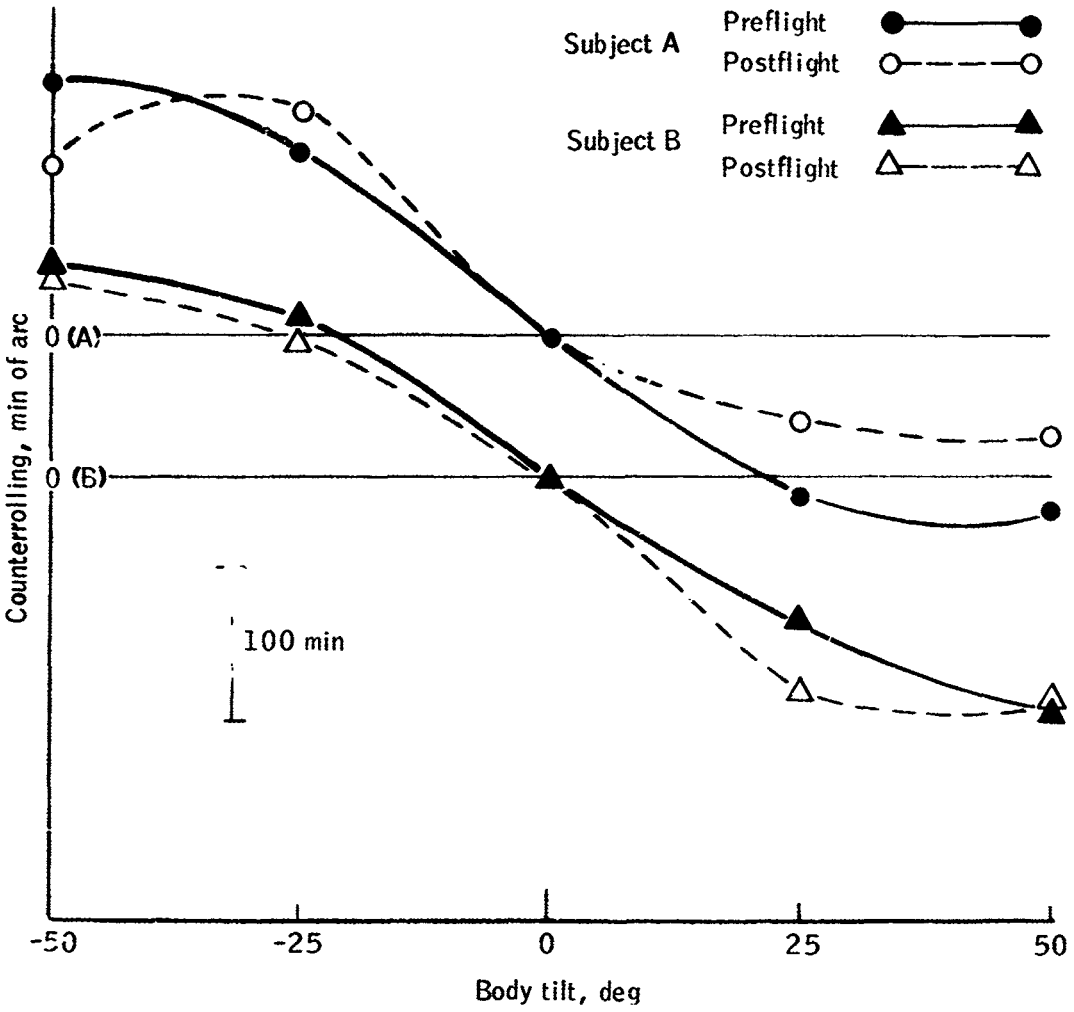

Figure 4. - Preflight and postflight measurements of ocular counterrolling (Gemini V).

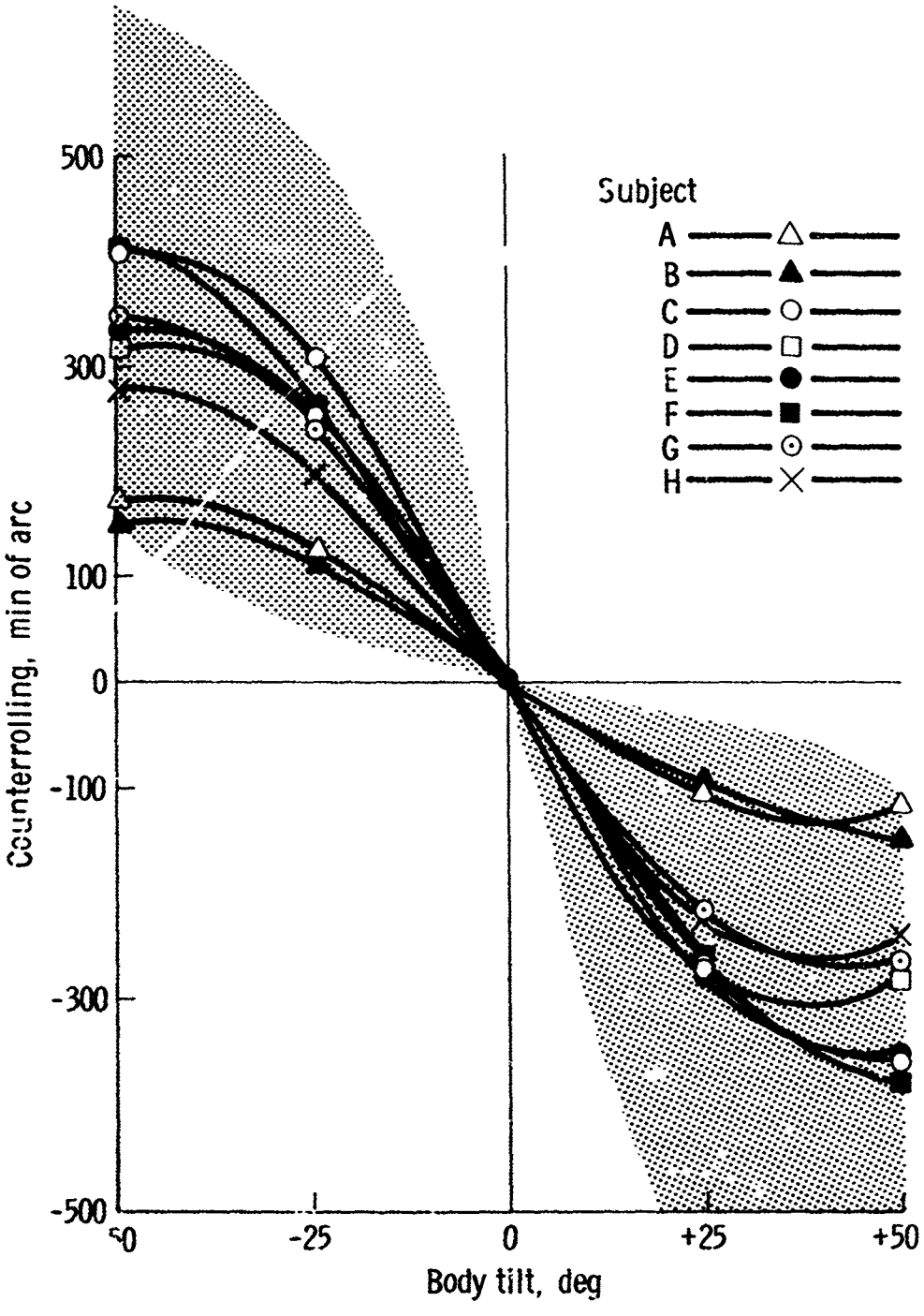

Figure 5.- The counterrolling response curves of the Gemini V and VII pilots compared with the response curves of four other Gemini crewmen, and the range of responses among a randomly selected group of 100 normal subjects (shaded area).

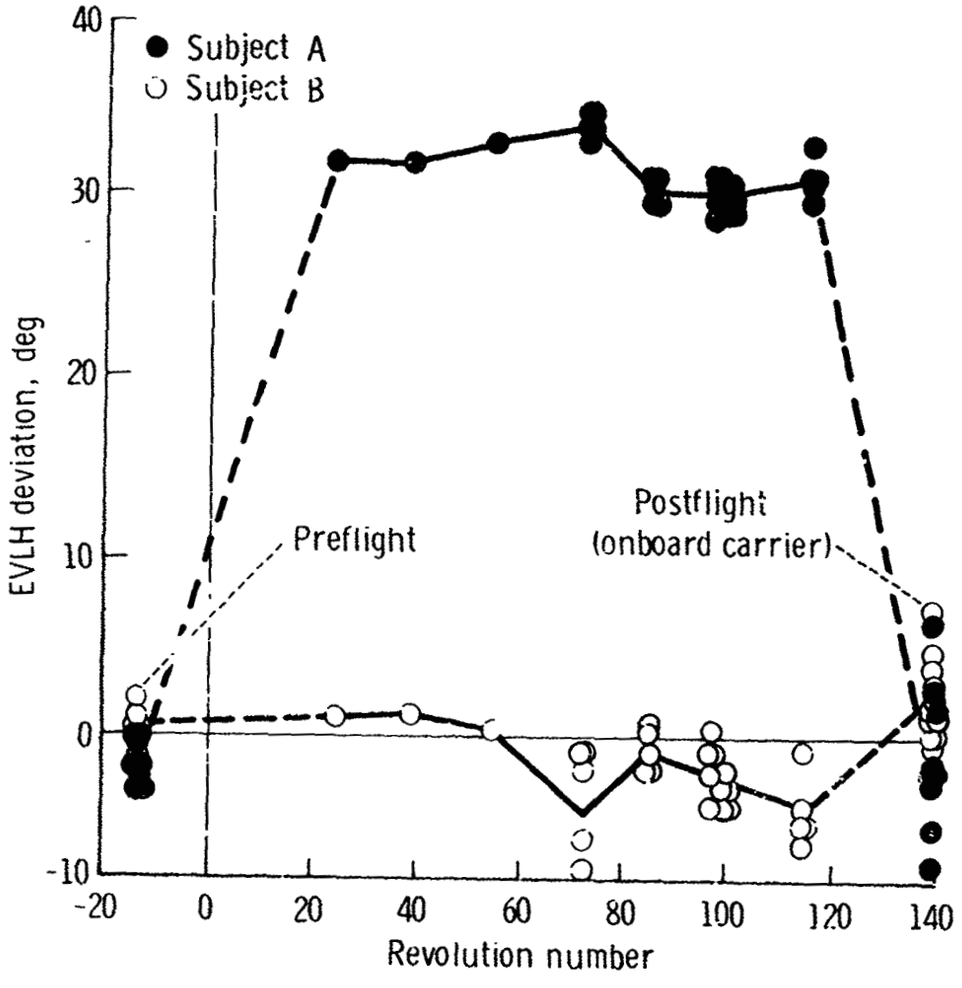

Figure 6. - The deviation of individual settings of EVLH from the instrument absolute zero as recorded before, during, and after the Gemini V mission.

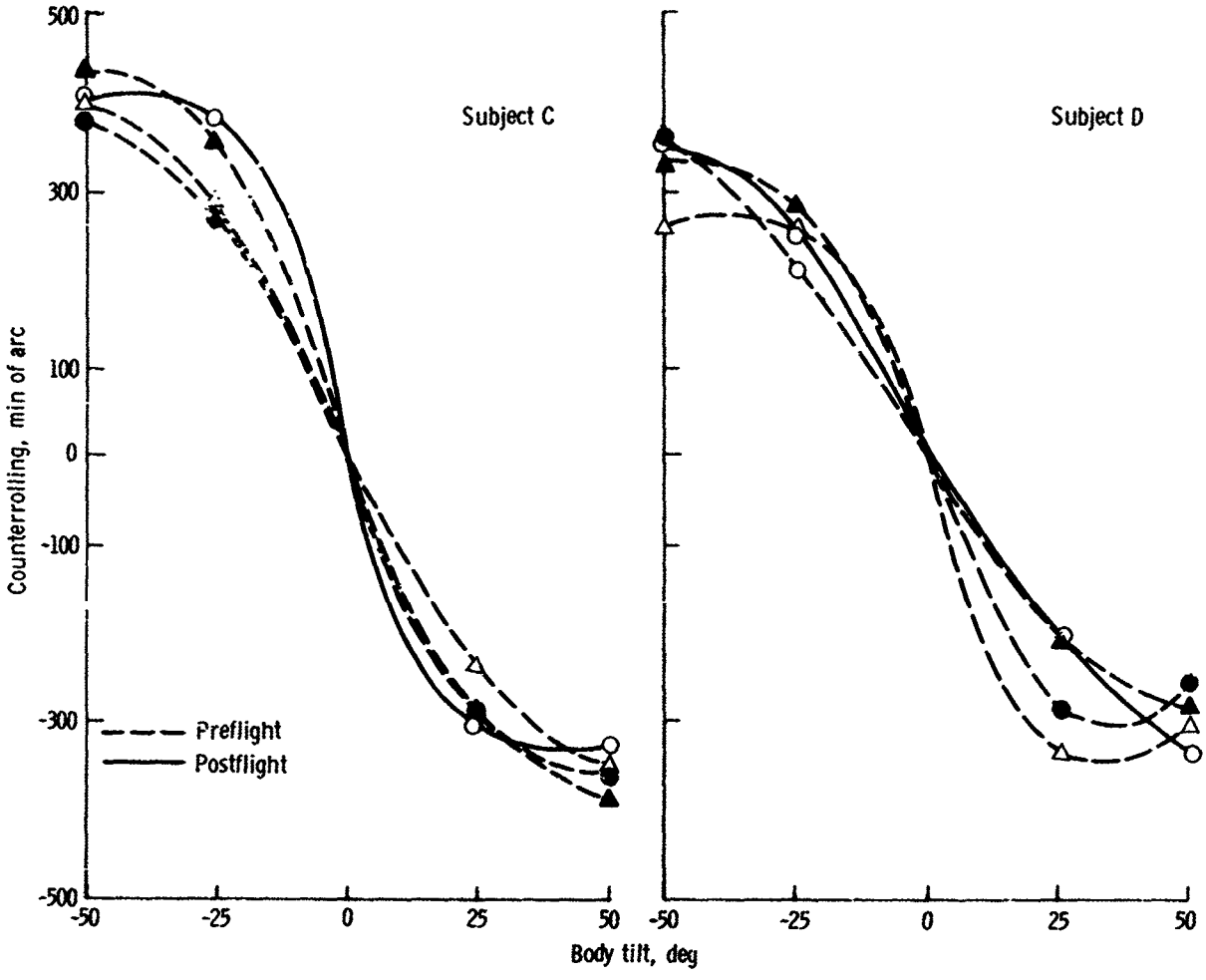

Figure 7. - Separate preflight measurements of ocular counterrolling made on the same day and postflight (Gemini VII).

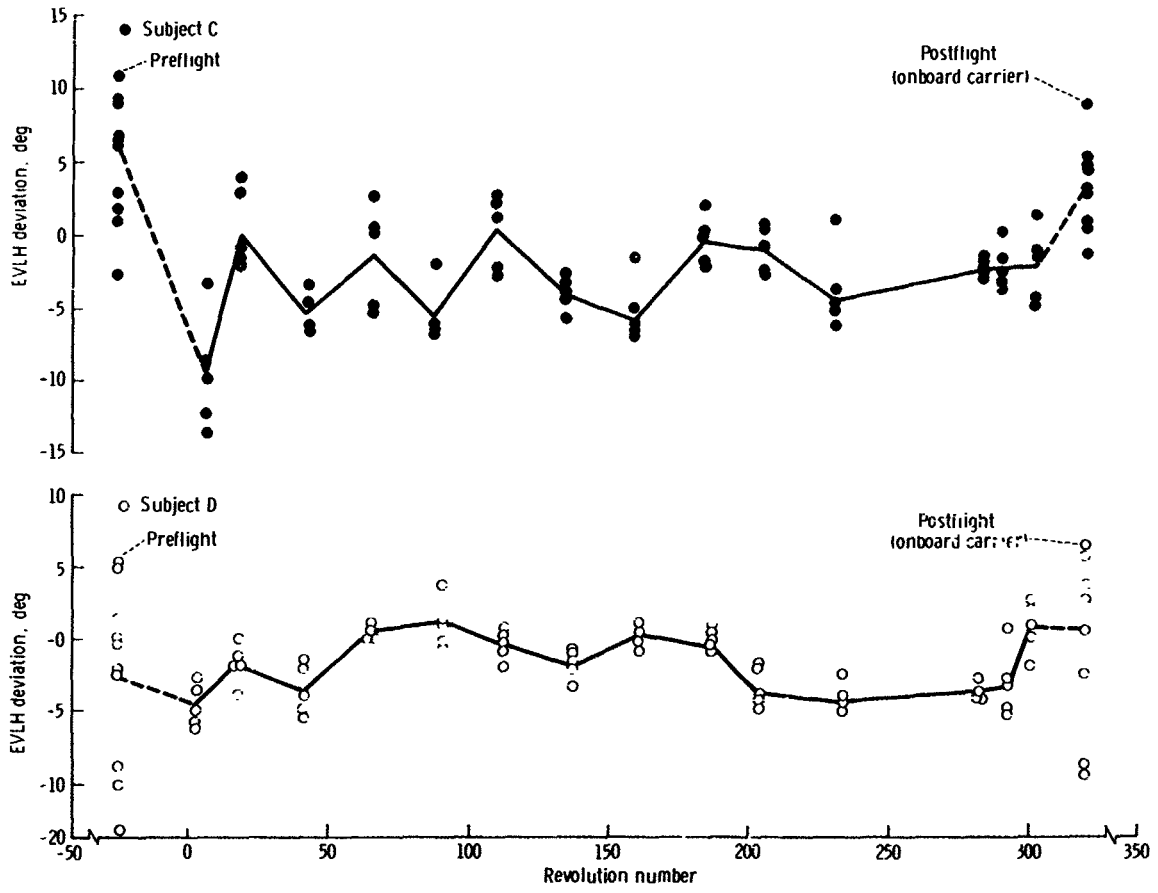

Figure 8. - A summary of deviations from instrument zero of the discrete EVLH settings for the crewmen, as recorded before, during, and after the Gemini VII mission.

EXPERIMENTS S008 AND D013

VISUAL ACUITY AND VISIBILITY

By Seibert Q. Duntley,* Roswell W. Austin,*
John H. Taylor,* and James L. Harris*

INTRODUCTION

Reports by Project Mercury crewmembers of sighting small objects on the ground prompted the initiation of a controlled visual-acuity experiment which was conducted on the Gemini V and VII missions. The primary objective of Experiments S008 and D013 was the measurement of the visual acuity of the crewmembers before, during, and after long-duration space flights to ascertain the effects of a long-duration spacecraft environment. The secondary objective was to test the use of basic visual-acuity data, combined with measured optical properties of ground-based objects and their natural lighting, and the optical properties of the atmosphere and the spacecraft window. Data on these topics could be used for prediction of the limiting naked-eye visual capability of the crewmen to discriminate small objects on the surface of the earth in daylight.

INFLIGHT VISION TESTS

Inflight Vision Tester

Throughout the Gemini V and VII flights, the visual performance of the crewmembers was tested one or more times each day by means of an inflight vision tester. This was a small, self-contained, binocular optical device that contained a transilluminated array of 36 high-contrast and low-contrast rectangles. Half of the rectangles were oriented vertically and half were oriented horizontally in the field of view. Rectangle size, contrast, and orientation were randomized, the presentation was sequential, and the sequences were nonrepetitive. Each rectangle was viewed singly at the center of a 30° adapting field, the apparent luminance of which was 116 foot-lamberts. Both crewmembers made forced-choice judgments on the orientation of each rectangle and indicated their responses by punching holes in a record card. Electrical power for illumination within the instrument was derived from the spacecraft.

The space between the eyes of the crewman and the sloping inner surface of the spacecraft window (8 to 9 inches) were important constraints on the size of the instrument. The superior visual performance of all crewmembers, as evidenced by clinical

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test scores, made it necessary to use great care in alinement of the instrument with the eyes of the observer, since the eyes, not the instrument, set the limit of resolution.

To achieve this, the permissible tolerance of decentering between a corneal pole and the corresponding optical axis of the eyepiece was less than 0.005 inch. This tolerance was met by use of a biteboard, equipped with a dental impression of the crewmember, to utilize the fixed geometrical relation between his upper teeth and his eyes. A photograph of the inflight vision tester is shown in figure 1.

Selection of the Test

The choice of test was made after careful study and many interacting requirements were considered. For example, if the visual capabilities of the crewmen should change during the long-duration flight, it would be of prime importance to measure the change in such a way that the inflight ability of man to recognize, classify, and identify landmarks or unknown objects on the ground or in space could be predicted. These higher order visual discriminations depend upon the quadratic content of the difference images between alternative objects, but almost all of the conventional patterns used in testing vision yield low-precision information on this important parameter. Thus, the prediction requirement eliminated the use of Snellen letters, Landolt rings, checkerboards, and all forms of detection threshold tests.

The readings must not go off the scale if visual changes should occur during flight. This requirement for a broad range of testing was not readily compatible with the desire to have fine steps within the test and yet have sufficient replication to ensure statistically significant results.

It also was desirable that the pattern chosen for the inflight vision tester be compatible with that used on the ground where search contamination of the scores must be carefully avoided; this consideration made any conventional detection-threshold test undesirable. The pattern on the ground was in sight for at least 2 minutes during all usable passes, but variations caused by atmospheric effects, geometrical foreshortening, directional reflectance characteristics, and so forth made it necessary to select a test which could be completed in a 20-second period centered about the time of closest approach.

The optimum choice of test was the orientation discrimination of a bar that was narrow enough to be unresolved in width but long enough to provide for threshold orientation discrimination. The size and apparent contrast of all the bars used in the test were sufficient to make them readily detectable, but only the larger members of the series were above the threshold of orientation discrimination. These two thresholds are more widely separated for the bar than for any other known test object. The inherent quadratic content of the difference image between orthogonal bars is of greater magnitude than the inherent quadratic content of the bar itself. Interpretation of any changes in the visual performance of the crewmembers is, therefore, more generally possible on the basis of orientation-discrimination thresholds for the bar than from any other known datum.

Rectangles in the Vision Tester

The rectangles presented for viewing within the inflight vision tester were reproduced photographically on a transparent disk. Two series of rectangles were included; the major series was set at a contrast of -1, and the minor series was set at about one-fourth of this value. The higher contrast series constituted the primary test and was chosen to simulate the expected range of apparent contrast presented by the ground panels to the eyes of the crewmen in orbit. The series consisted of six sizes of rectangles. The sizes were over a sufficient range to guard against virtually any conceivable change in the visual performance of the crewmembers during the long-duration flight. The size intervals were small enough, however, to provide a sufficiently sensitive test.

The stringent requirements imposed by conditions of space flight made it impossible to use as many replications of each rectangle as were desirable from statistical considerations. After much study, it was decided to display each of the six rectangular sizes four times. This compromise produced a sufficient statistical sample to make the sensitivity of the inflight test comparable to that ordinarily achieved with the most common type of clinical wall chart. This sensitivity corresponds roughly to the ability to separate performance at 20/15 from performance at 20/20. It was judged that this compromise between the sensitivity of test and the range of variables tested was the proper one for this investigation.

A secondary test at lower contrast was included as a safeguard against the possibility that visual performance at low contrast might change in some different way. Because only 12 rectangles were assignable within the inflight vision tester for the low-contrast array, it was decided to use only three widely different rectangle sizes, and to present each of these sizes four times.

Because of the accelerated launch schedule of the Gemini V mission, it was not possible to use the flight instrument for preflight experiments. Preflight data were, therefore, obtained with the first of the inflight vision testers (serial number 1), whereas the last instrument to be constructed (serial number 5) was put on board the spacecraft. The two instruments were optically identical except for their 12 low-contrast rectangles, capable of measurement of a contrast of -0.332 and -0.233, respectively. On the Gemini VII mission, all the reported data (preflight, inflight, and postflight) were obtained with serial number 5 tester.

Analysis of Correct Scores on the Gemini V Mission

A comparison of the correct scores made by the Gemini V crewmembers on the ground (preflight) and in flight can be used to ascertain whether their observed visual performance differed in the two environments or changed during the 7-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown in figure 2 for both crewmembers. The results of standard statistical tests applied to these data are shown in tables I to IV. All Student's t tests contain no significant difference in means. All Snedecor's F tests contain no significant difference in variances at the $p < 0.05$ level, with the exception of the high-contrast comparison by the command pilot which shows no significant difference at the $p < 0.01$ level. Comparisons between the inflight data collected at the beginning of the mission with that collected at the end of the mission are made in tables III and IV. All Student's t tests

and Snedecor's F tests show no significant difference at the $p \leq 0.05$ level, with the exception of the F test on the low-contrast comparison by the pilot which contains no significant contrast at the ≤ 0.01 level.

These statistical findings support the null hypothesis advanced by many scientists before the Gemini V mission. Examination of the sensitivity of the test must next be considered.

Analysis of Correct Scores on the Gemini VII Mission

A comparison of the correct scores made by the Gemini VII crewmembers on the ground (preflight) and in flight can be used to ascertain whether their observed visual performance differed in the environments or changed during the 14-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown for both crewmembers in figure 3. The results of standard statistical tests applied to these data are shown in tables V and VI.

Comparisons between preflight and inflight data are given in tables I and II. All Students's t tests showed no significant difference in means. All Snedecor's F test results contained no significant difference in variances at the $p \leq 0.05$ level, with the exception of the low-contrast comparison by the command pilot which contained a weakly significant difference at the $p \leq 0.01$ level.

Comparisons between the inflight data at the beginning of the mission with those at the end of the mission are made in tables VII and VIII. All Student's t tests and Snedecor's F tests showed no significant difference at the $p \leq 0.05$ level, with the exception of the F test on the low-contrast comparison by the command pilot which showed no significant contrast at the $p \leq 0.01$ level. These statistical findings also provide additional support for the null hypothesis advanced by many scientists before the Gemini missions.

Preflight Physiological Base Line

Design of the inflight vision tester and the ground-sighting experiments (to be described in another section) and the interpretation of the results from both experiments imposed the constraint that a preflight physiological base line be obtained for both crewmembers. For this purpose, a NASA van was equipped as a portable vision-research laboratory, was moved to the Manned Spacecraft Center (MSC), Houston, Texas, and was operated by Visibility Laboratory personnel. A cutaway drawing of this research van is shown in figure 4. The crewmen, seated at the left, viewed rear-screen projections from an automatic projection system located in the opposite end of the van. Each crewman participated in several sessions in the laboratory van, during which they became experienced in the psychophysical techniques of the rectangle orientation-discrimination visual task. A sufficiently large number of presentations were made to secure an adequate statistical sample. The forced-choice visual thresholds for the discrimination task of the crewmembers were measured accurately, and their response distributions were determined so the standard deviations and confidence limits of preflight visual performance could be determined.

Gemini V mission. - A logarithmic plot of the preflight visual thresholds of the pilot for the rectangle orientation-discrimination task is shown in figure 5. The solid-angular subtense of the rectangles is plotted along the horizontal axis because both the inflight vision tester and the ground-observation experiments used angular size as the independent variable. The solid line in this figure represents the forced-choice rectangle-orientation threshold of the pilot at the $p \leq 0.05$ level. The dashed curves indicate the $-\sigma$, $+\sigma$, and $+2\sigma$ levels in terms of contrast. The six circled points in the upper row indicate the angular sizes of the high-contrast ($C = -1$) rectangles presented by the inflight vision tester. The three circled points of the middle and lower rows show the angular sizes of the low-contrast rectangles used in the training unit (number 1) and the flight unit (number 5), respectively.

By the use of figure 5, the separate discriminations recorded on the record cards in the inflight vision tester can be used to determine a threshold of angular size. These thresholds are plotted for the high-contrast and low-contrast tests of the command pilot (figs. 6 and 7), and of the pilot (figs. 8 and 9). In these four figures, the horizontal solid line represents the forced-choice rectangle-orientation threshold and the horizontal broken lines represent statistical confidence limits in terms of angular size.

These four figures also support the null hypothesis, and their quantitative aspect constitutes a specification of the sensitivity of the test. Thus, as planned, changes in visual performance comparable with those on a one-line conventional clinical wall chart would have been detected. Therefore, preflight threshold data can be used to predict the limiting visual-acuity capabilities of humans during space flight, provided adequate physical information exists concerning the object, its background, its atmospheric effects, and the spacecraft window. A test of such predictions was also performed and is described in other sections of this report.

Gemini VII mission. - Thresholds and confidence limits for the vision tester data collected by the Gemini VII command pilot are shown in figures 10 and 11. Similar data collected by the Gemini VII pilot are shown in figures 12 and 13.

These eight figures also support the null hypothesis, and their quantitative aspect constitutes a specification of the sensitivity of the test. Thus, as planned, variations in visual performance comparable with a change of one line on a conventional clinical wall chart would have been detected. Preflight threshold data can, therefore, be used to predict the limiting visual-acuity capabilities of humans during space flight, if adequate physical information exists concerning the object and its background, atmospheric effects, and the spacecraft window. A test of such predictions was also performed and is described in the following section.

GROUND OBSERVATIONS

Equipment

The experimental equipment consisted of an inflight photometer (used to monitor ambient light scattered by the spacecraft window); the test patterns at two ground-based observation sites; instrumentation for atmospheric, lighting, and pattern measurements at both sites; and a laboratory facility for training the crewmembers to perform visual-acuity threshold measurements and for acquisition of a preflight

physiological base line descriptive of their visual performance and its statistical fluctuations. This equipment, except the last-mentioned item, is described as follows.

Spacecraft window photometer. - A photoelectric inflight photometer was mounted near the lower right corner of the pilot-side window of the Gemini V spacecraft (fig. 14) to measure the amount of ambient light scattered by the window into the path of sight at the moment when observations of the ground-based test patterns were made. The photometer (fig. 15) had a narrow (1.2°) circular field of view, which was directed through the pilot-side window and into the opening of a small black cavity a few inches outside the window. The photometric scale was linear and extended from approximately 60 to 3000 foot-lamberts on the Gemini V mission and from approximately 12 to 3000 foot-lamberts on the Gemini VII mission. Because the apparent luminance of the black cavity was always much less than the minimum luminance just noted for each mission, any reading of the inflight photometer was ascribable to ambient light scattered by the window. Typical data acquired during passes of the Gemini V spacecraft over the Laredo site are shown in figure 16. This information, combined with data on the beam transmittance of the window and with data on the apparent luminance of the background squares in the ground pattern array, enabled the contrast transmittance of the window at the moment of observation to be calculated. Uniformity of the window could be tested by removal of the photometer from its positioning bracket and making a hand-held scan of the window, using a black region of space in lieu of the black cavity. A direct-reading meter incorporated in the photometer enabled the command pilot to observe the photometer readings while the pilot scanned his window for uniformity. A corresponding scan of the command pilot window could be made in the same way. Photometric data were sent to the ground by real-time telemetry. Electrical power for the photometer was entirely provided by batteries within the instrument.

Ground observation sites. - Sites for observations by the Gemini V crewmembers were provided 40 miles north of Laredo, Texas (fig. 17), and 90 miles south of Carnarvon, Australia (figs. 18 and 19). At the Texas site, 12 squares of plowed, graded, and raked soil 2000 by 2000 feet were arranged in a matrix of four squares deep and three squares wide. White rectangles of Styrofoam-coated wallboard were laid out in each square. Their length decreased in a uniform logarithmic progression from 610 feet in the northwest corner (square number 1) to 152 feet in the southwest corner (square number 12) of the array. Each of the 12 rectangles was oriented in one of four positions (north-south, east-west, or diagonal), and the orientations were random within the 12-member series. Preflight knowledge of the rectangle orientations was withheld from the crewmembers, because their task was to report these orientations. Provision was made for changing the rectangle orientations between passes and for adjusting their size in accordance with anticipated slant range, solar elevation, and the visual performance of the crewmen on preceding passes. The observation site in Australia was somewhat similar to the Texas site, but details are unnecessary in this report because no observations were made.

The Australian ground-observation site was not manned during the Gemini VII mission because the afternoon time of launch precluded usable daytime overpasses there until the last day of the mission. The 82.5° launch azimuth used for the Gemini VII mission prevented the use of an otherwise highly desirable ground site in the California desert near the Mexican border. Weather statistics for December made the use of the Texas site appear dubious, but no alternative was available. The afternoon launch made midday passes over this site available on each day of the mission. Experience gained on the Gemini V mission indicated the need for a more prominent orientation marking. This was provided by placing east-to-west strips of crushed

white limestone (26 feet wide and 2000 feet long) across the center of each of the four north background squares in the array. Thus, only eight test rectangles were used in a 2 by 4 matrix on the center and south rows of background squares (fig. 20). The largest and smallest rectangles were the same size as those used on the Gemini V mission.

Instrumentation. - Instrumentation at both ground sites consisted of a single tripod-mounted, multipurpose, recording photoelectric photometer (figs. 21 and 22) capable of acquisition of all data needed to specify (at the moment of observation) the apparent contrast of the pattern as seen from the spacecraft. The apparent luminance of the background squares, needed for evaluation of the contrast loss caused by the spacecraft window, was also ascertained by use of this instrument. A 14-foot mobile tower, constructed of metal scaffolding and attached to a truck, supported the tripod-mounted photometer high enough above the ground to enable observation of the plowed surface of the background squares. This arrangement is shown in figures 23 and 24.

Observations Made on the Gemini V Mission

Observation of the Texas site was first attempted on revolution 18, but fuel-cell difficulties, which prohibited use of the platform, were apparently responsible for lack of acquisition of the site.

The second scheduled attempt to see the Laredo pattern was on revolution 33. Acquisition of the site was achieved by the command pilot but not by the pilot, and no read-out of rectangle orientation was made.

At the request of the experimenters, the third attempt to see the Laredo site, originally scheduled for revolution 45, was made on revolution 48 to secure a higher sun and a shorter slant range. Success was achieved on this pass and is described in the following section.

Unfavorable cloud conditions caused the fourth scheduled observation at the Texas site, on revolution 60, to be canceled. Thereafter, lack of thruster control made observation of the patterns impossible, although excellent weather conditions prevailed on three scheduled occasions at Laredo (revolutions 75, 92, and 107) and once at the Australian site (revolution 88). Long-range visual acquisition of the smoke markers used at both sites was reported in each instance, but the drifting spacecraft was not properly oriented near the closest approach to the pattern to enable observations to be made. A fleeting glimpse of the Laredo pattern during drifting flight on revolution 92 made it possible for the crewmen to photograph it with hand-held cameras. Another fleeting glimpse of the pattern was reported on revolution 107. On revolution 107, roll rates were neutralized by use of thrusters prior to the pass over Laredo, and although the command pilot reported a fleeting glimpse of the pattern at closest approach, the viewing time was not sufficient for him to read successfully the orientation of the rectangles.

Results of Observations Made on the Gemini V Mission

Quantitative observation of ground markings was achieved only once during the Gemini V mission. This observation was made during revolution 48 at the site near

Laredo at 18:16:14 G.m.t. on the third day of the flight. Despite acquisition of the smoke marker by the command pilot and acquisition of the target pattern itself long before the point of closest approach, the pilot could not visually acquire the markings until the spacecraft had been turned to eliminate sunlight incident upon his window. Telemetry records from the inflight photometer show that the pilot-side window produced a heavy veil of scattered light until the spacecraft was rotated. Elimination of the morning sun on the pilot-side window enabled the pilot to make visual contact with the pattern in time to make a quick observation of the orientation of some rectangles. It may be noted that, during approach, the reduction of contrast caused by light scattered by the window was more severe than was that caused by light scattered by the atmosphere.

An ambiguity exists between the transcription of the radio report made at the time of the pass and the written record in the flight log. The writing was made "blind" while the pilot was looking at the pattern; it is a diagram drawn in the manner depicted in the Gemini V flight plan, the mission operation plan, the description of experiment, and other documents. The orientation of the rectangles in the sixth and seventh squares appears to have been correctly noted. The verbal report given several seconds later correctly records the orientation of the rectangle in the sixth square, if it is assumed that the spoken words describe the appearance of the pattern as seen from a position east of the array while going away from the site.

Despite the hurried nature of the only apparently successful quantitative observation by the pilot of a ground site during the Gemini V mission, there seems to be a reasonable probability that the sighting was a valid indication of correct discrimination of the rectangles in the sixth and seventh squares. Because the pilot did not respond to squares 8 through 12, it can only be inferred that the threshold of the pilot was at square 6 or greater.

Tentative values of the apparent contrast and angular size of the sixth and seventh rectangles at the Laredo site at the time of the observation were plotted (fig. 25). The solid line represents the preflight visual performance of the pilot as measured in the vision-research van. The dashed lines represent the 1σ and 2σ limits of his visual performance. The positions of the plotted points indicate that his visual performance at the time of revolution 48 was within the statistical range of his preflight visual performance.

Observations Made on the Gemini VII Mission

Observations of the Texas site were made on revolutions 16, 17, and 31 during very favorable weather conditions. Heavy clouds blanketed the site throughout the remainder of the mission, however, and no further observations were possible. Contamination of the outer surface of the pilot-side window made observation of the pattern difficult and made the result uncertain. The contamination, observed to have occurred during launch, was mapped during revolution 19 by means of a window scan with the inflight photometer in the manner previously described. Some numerical results of this scan are given in figure 26, and figure 27 is a photograph of a shaded pencil sketch intended to portray the appearance of the window as deduced from the telemetered scan curves. Comparison of this sketch with a similar one made by the pilot during the flight revealed good correlation.

The command pilot window was not measurably contaminated on its inboard side (figs. 26 and 27). Successful observations of the pattern were made on revolutions 17 and 31 by the command pilot through the clear portion of the window. Direct sunlight was not incident upon the window during these observations.

Results of Observations Made on the Gemini VII Mission

The results of observations made by the command pilot on revolutions 17 and 31 of the Gemini VII mission are shown in figure 28. These observations occurred at 27: 04: 49 and 49: 26: 48 g. e. t. on the second and third days of the flight, respectively.

In figure 28, the circled points represent the apparent contrast and angular size of the largest rectangles in the pattern. Apparent contrast was calculated on the basis of the following.

1. Measured directional luminances of the white panels and their backgrounds of plowed soil

2. Atmospheric optical properties measured in the direction of the path of sight to the point of closest approach

3. A small allowance for contrast loss in the spacecraft window based upon window-scan data and readings of the inflight photometer at the time of the two observations

Angular sizes and apparent contrast values were both of somewhat larger magnitudes for revolution 31 than for revolution 17 because the slant range was shorter and because the spacecraft passed north of the site, thereby causing the background soil to appear darker (compare figure 20 with figure 29). The orientations of these rectangles, indicated by double circles, were reported correctly, but those represented by single circles were either reported incorrectly or were not reported at all. The positions of the data points for the Gemini VII command pilot are indicative that his visual performance was precisely in accordance with his preflight visual thresholds.

CONCLUSIONS

Both objectives of Experiments S008 and D013 were achieved successfully. Data from the inflight vision tester showed that no change was detected in the visual performance of any of the four crewmembers of the Gemini V and VII missions. Results from observations of the site near Laredo, Texas, confirmed that the visual performance of the crewmen during space flight was within the statistical range of their preflight visual performance. The results also demonstrated that visual data collected in the laboratory can be combined with environmental optical data to predict correctly the limiting visual capability of humans to discriminate small objects on the surface of the earth in daylight.

TABLE I. - VISION TESTER SCORES OF THE COMMAND PILOT (GEMINI V MISSION)

Parameter	Contrast is -1		Contrast is -0.23	
	Ground	Space	Ground	Space
Number	7	9	7	9
Mean	17.6	18.4	8.6	8.3
Standard deviation	2.3	0.96	1.3	1.4
t	0.96		0.31	
$t_{0.05}$	2.14		2.14	
F	6.12		1.02	
$F_{0.05}$	3.58		3.58	
$F_{0.01}$	6.37			

TABLE II. - VISION TESTER SCORES OF THE PILOT (GEMINI V MISSION)

Parameter	Contrast is -1		Contrast is -0.23	
	Ground	Space	Ground	Space
Number	7	9	7	9
Mean	20.7	20.7	9.7	8.6
Standard deviation	2.7	1.7	1.2	2.0
t	0		1.13	
$t_{0.05}$	2.14		2.14	
F	2.79		2.43	
$F_{0.05}$	3.69		4.82	

TABLE III. - GEMINI V MISSION VISION TESTER SCORES OF THE COMMAND PILOT (INFLIGHT TREND)

Parameter	Contrast is -1		Contrast is -0.23	
	First 4	Last 4	First 4	Last 4
Number	4	4	4	4
Mean	18.2	18.8	8.5	8.5
Standard deviation	0.83	1.1	0.87	1.8
t	0.68		0	
$t_{0.05}$	2.45		2.45	
F	1.73		4.33	
$F_{0.05}$	9.28		9.28	

TABLE IV. - GEMINI V MISSION VISION TESTER SCORES OF THE PILOT (INFLIGHT TREND)

Parameter	Contrast is -1		Contrast is -0.23	
	First 4	Last 4	First 4	Last 4
Number	4	4	4	4
Mean	21.3	19.5	8.8	8.75
Standard deviation	1.5	1.1	2.8	0.83
t	1.64		0	
$t_{0.05}$	2.45		2.45	
F	1.96		11.19	
$F_{0.05}$	9.28		9.28	
$F_{0.01}$	--		29.5	

TABLE V. - VISION TESTER DATA FOR THE COMMAND PILOT

(GEMINI VII MISSION)

Parameter	Contrast is -1		Contrast is -0.23	
	Ground	Space	Ground	Space
Number	11	14	11	14
Mean	20.0	19.9	8.45	8.4
Standard deviation	1.3	1.6	0.78	1.7
t	0.12		0.017	
$t_{0.05}$	2.07		2.07	
F	1.49		4.74	
$F_{0.05}$	2.89		2.89	
$F_{0.01}$	4.66		4.66	

TABLE VI. - VISION TESTER DATA FOR THE PILOT (GEMINI VII MISSION)

Parameter	Contrast is -1		Contrast is -0.23	
	Ground	Space	Ground	Space
Number	9	14	9	14
Mean	20.9	20.0	9.1	9.1
Standard deviation	1.4	1.6	0.74	1.4
t	1.29		0.073	
$t_{0.05}$	2.08		2.08	
F	1.17		3.64	
$F_{0.05}$	3.26		3.26	
$F_{0.01}$	5.62		5.62	

TABLE VII. - GEMINI VII MISSION VISION TESTER DATA FOR THE COMMAND PILOT (INFLIGHT TREND)

Parameter	Contrast is -1		Contrast is -0.23	
	First 5	Last 5	First 5	First 5
Number	5	5	5	5
Mean	19.0	20.0	8.0	9.0
Standard deviation	1.4	1.4	1.3	1.8
t	1.00		0.91	
$t_{0.05}$	2.31		2.31	
F	1.00		2.00	
$F_{0.05}$	6.39		6.39	

TABLE VIII. - GEMINI VII MISSION VISION TESTER DATA FOR THE PILOT (INFLIGHT TREND)

Parameter	Contrast is -1		Contrast is -0.23	
	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.8	20.4	8.8	9.2
Standard deviation	1.3	1.5	1.2	1.6
t	0.60		0.40	
$t_{0.05}$	2.31		2.31	
F	1.27		1.88	
$F_{0.05}$	6.39		6.39	

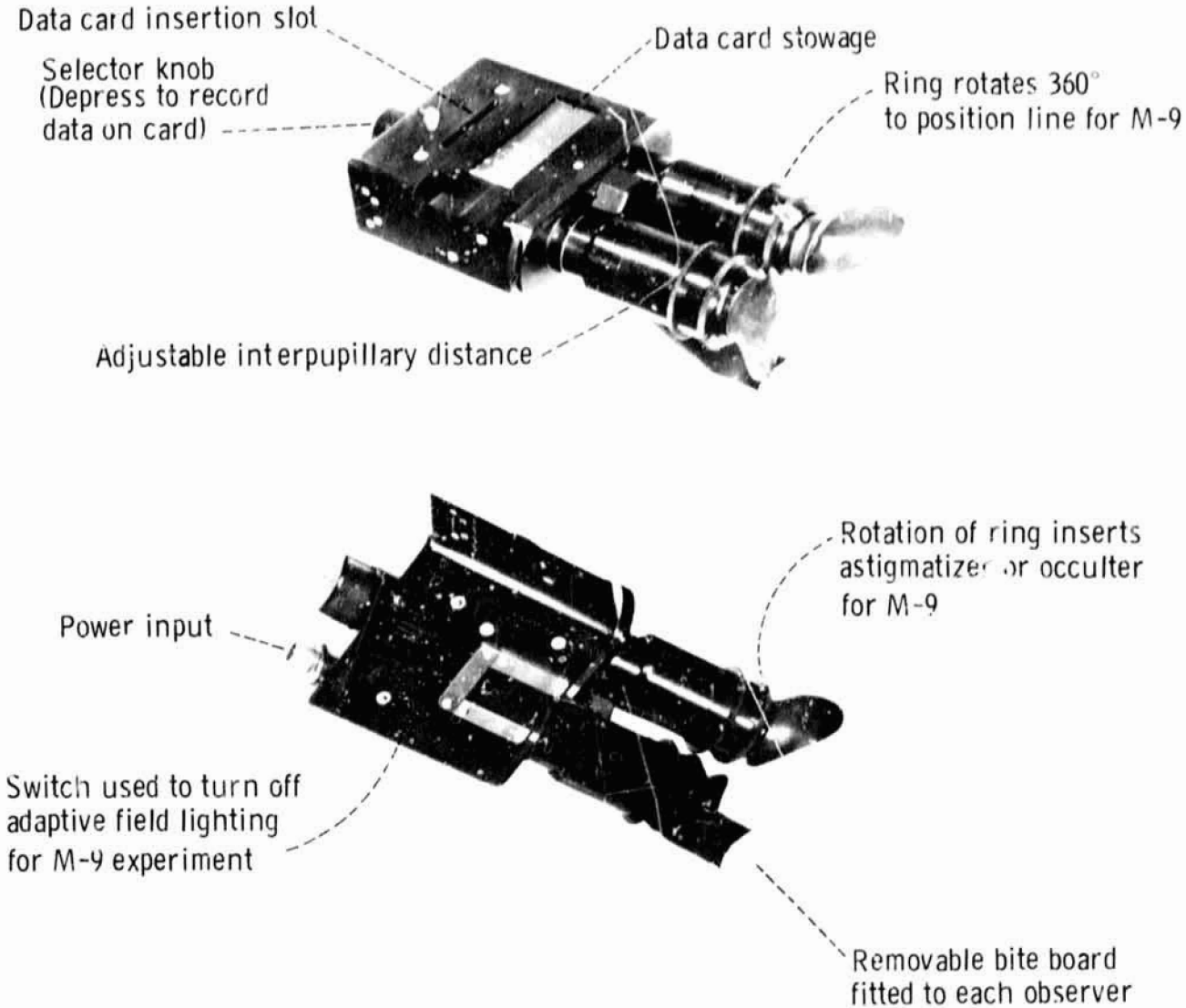

Figure 1. - Inflight vision tester.

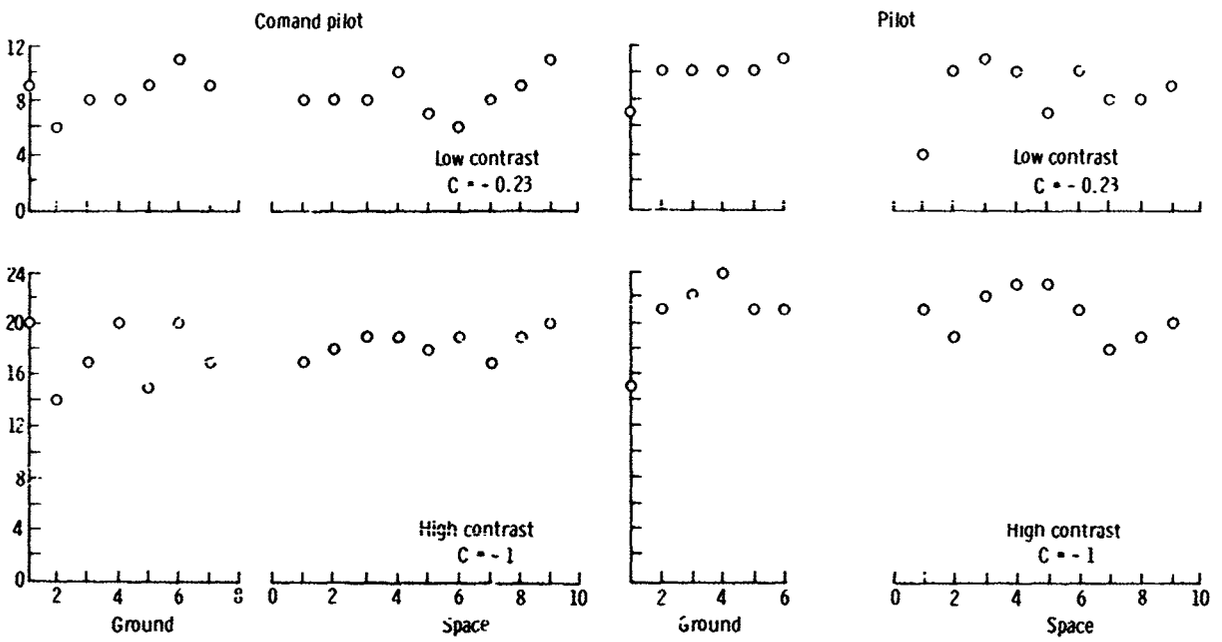

Figure 2. - Vision-tester scores for the Gemini V crewmen.

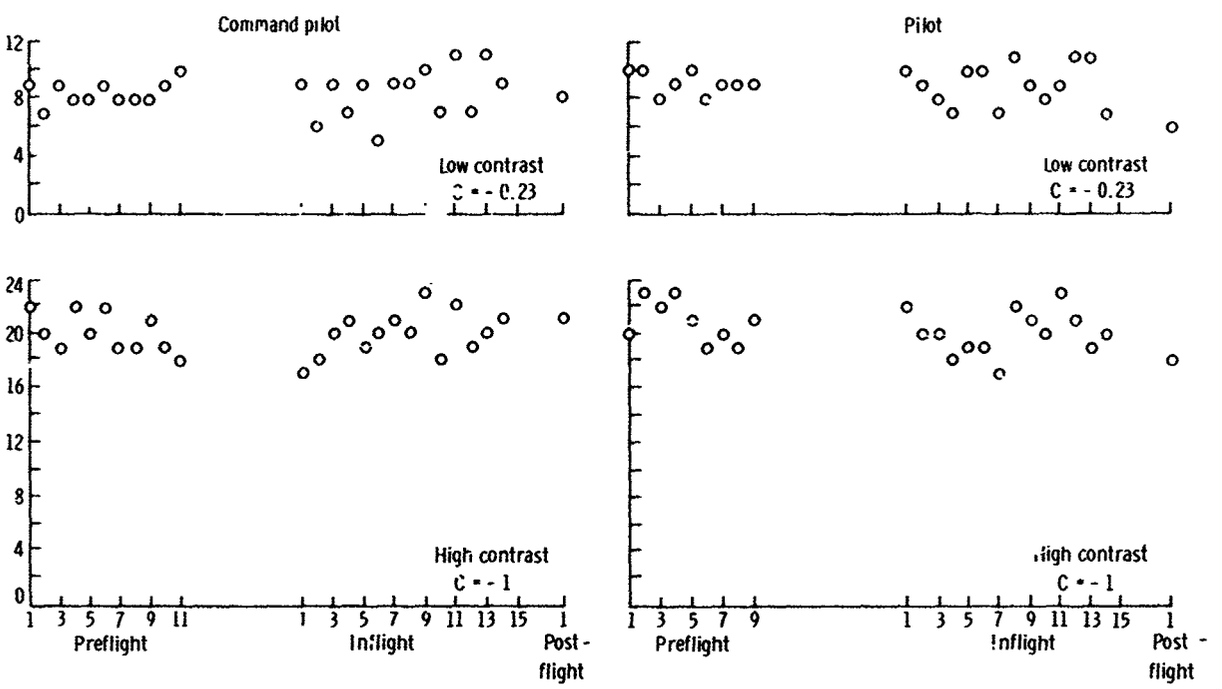

Figure 3. - Vision-tester scores for the Gemini VII crewmen.

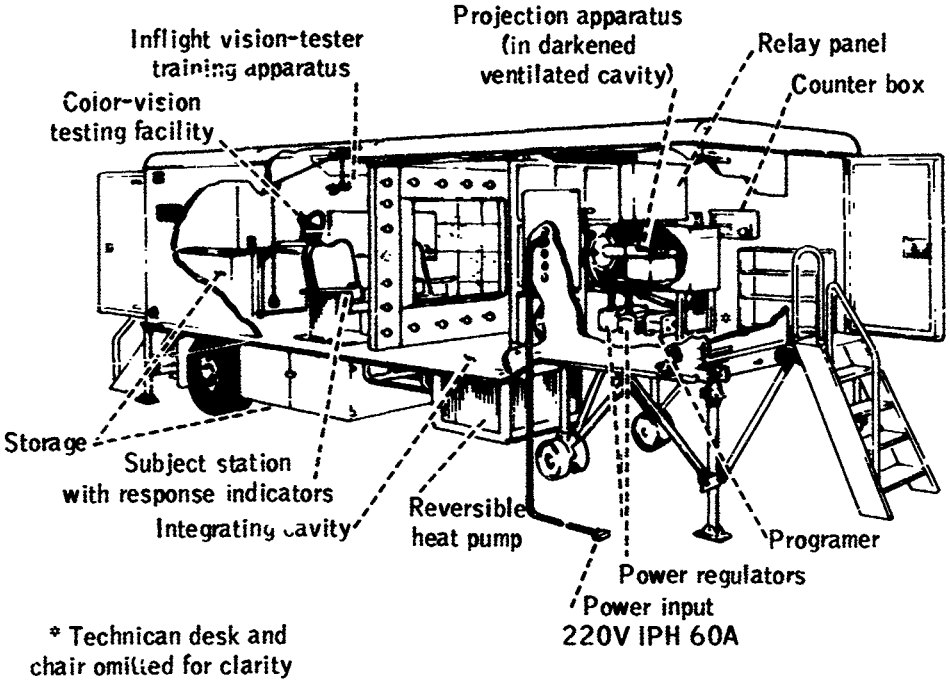

Figure 4. - Vision research and training van.

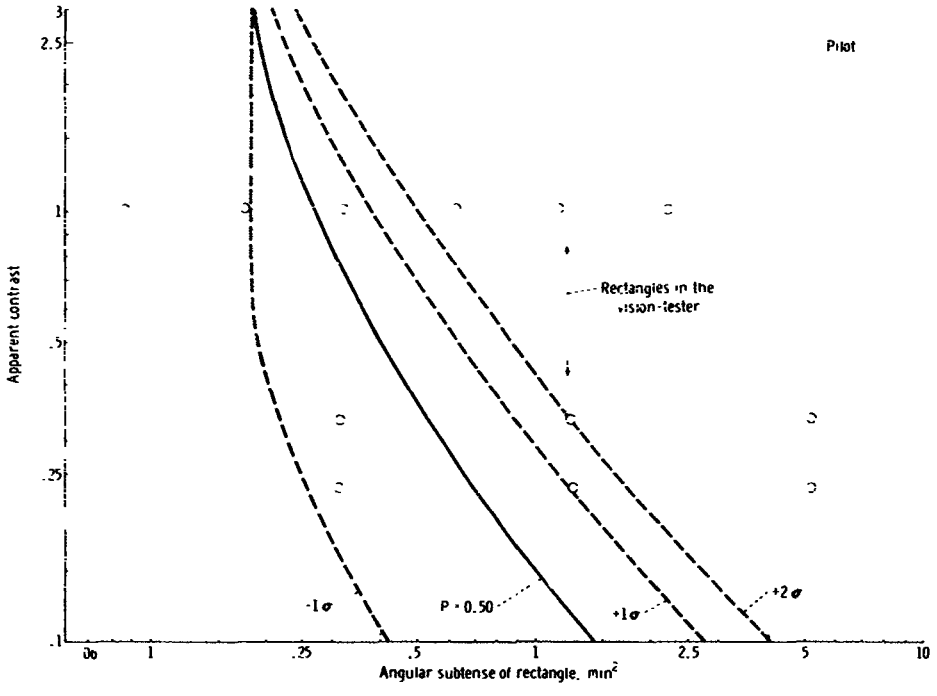

Figure 5. - Plot of preflight visual thresholds for the Gemini V pilot.

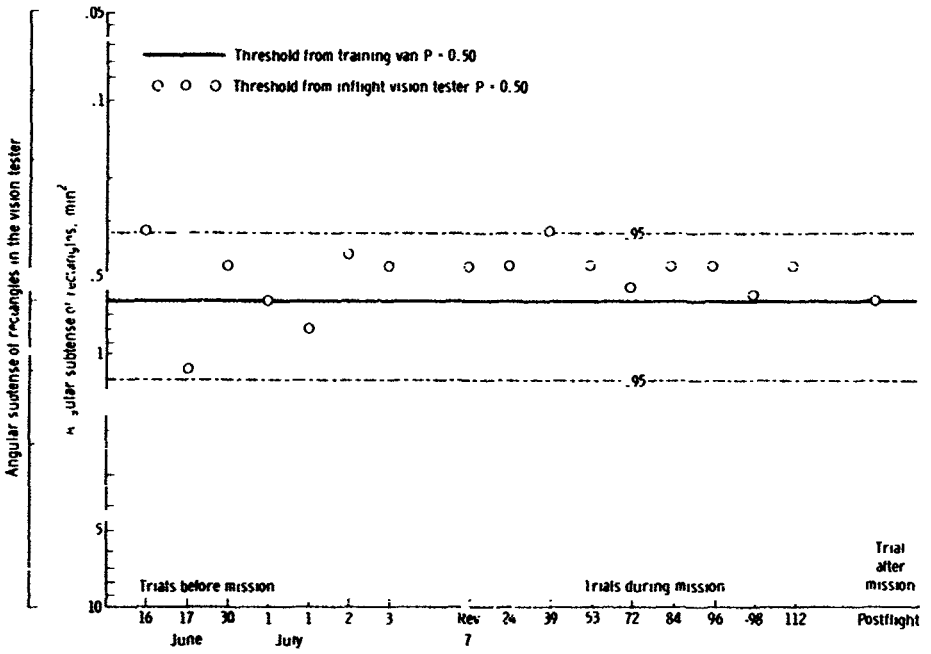

Figure 6. - Rectangle discrimination thresholds (C = -1) for the Gemini V command pilot.

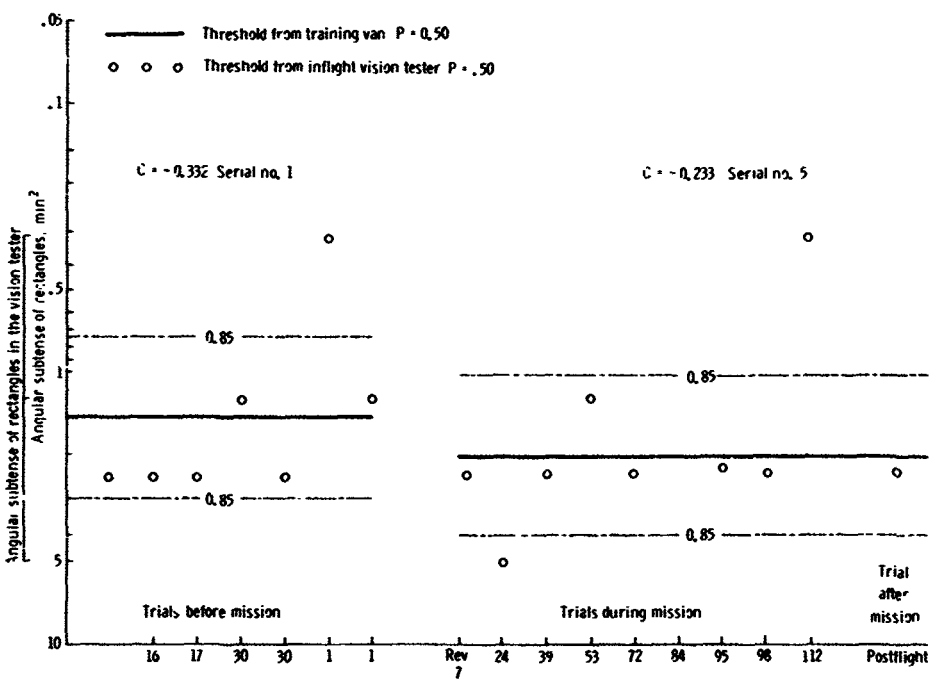

Figure 7. - Rectangle discrimination thresholds for the Gemini V command pilot.

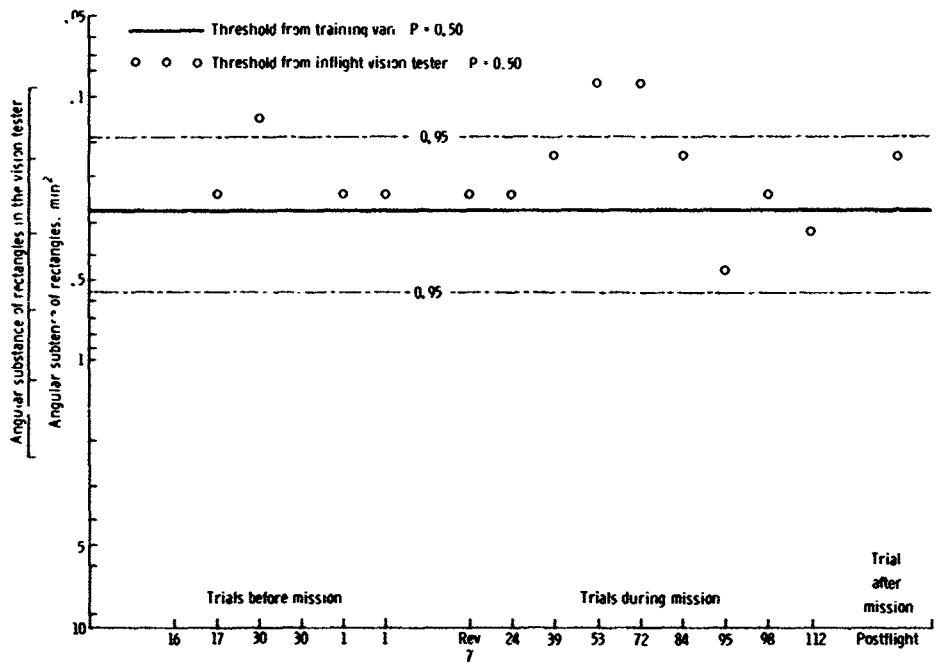

Figure 8. - Rectangle discrimination thresholds (C = -1) for the Gemini V pilot.

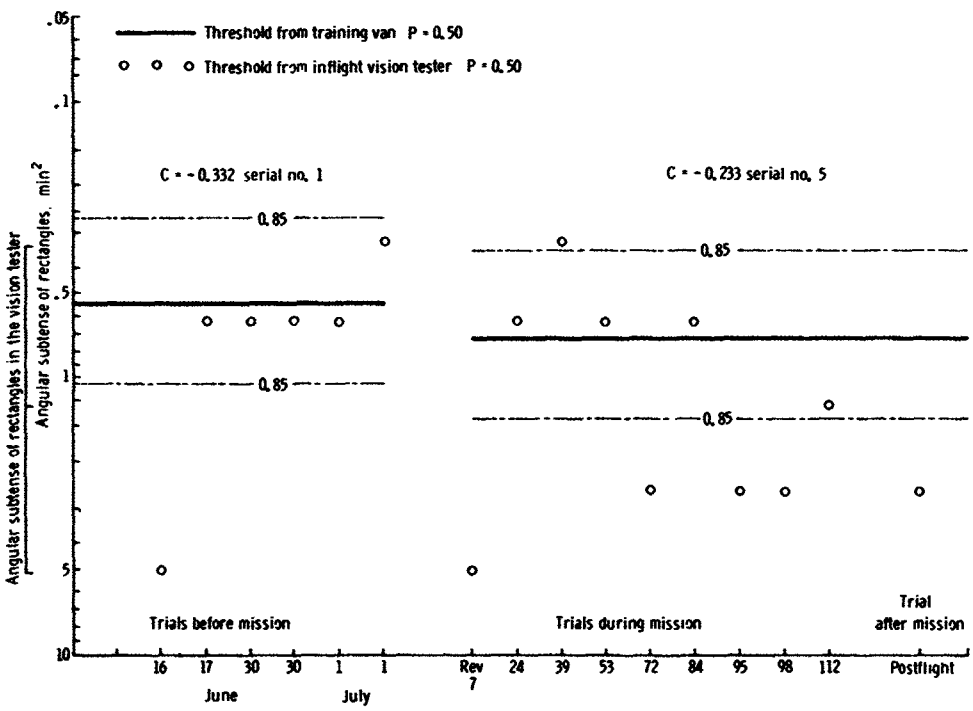

Figure 9. - Rectangle discrimination thresholds for the Gemini V pilot.

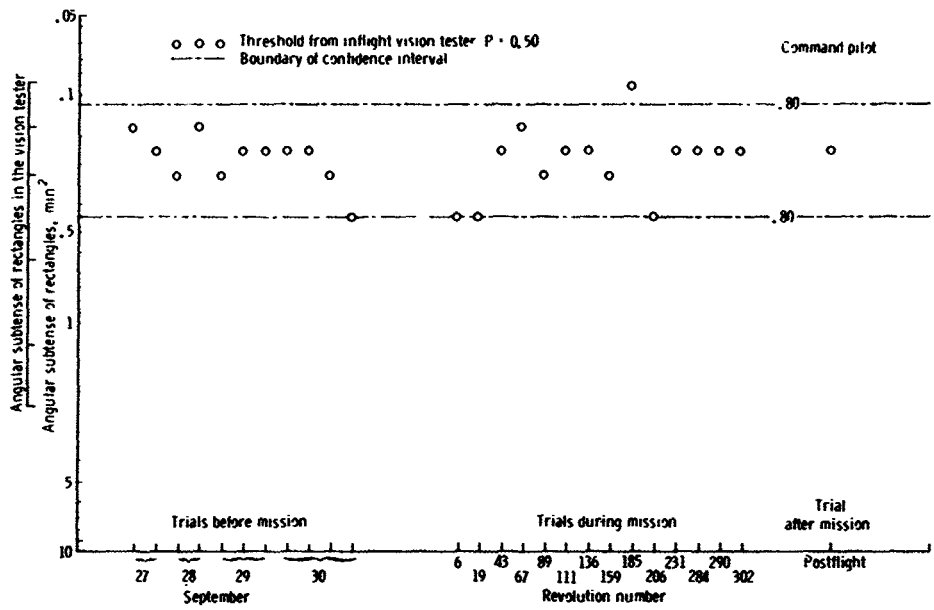

Figure 10. - Rectangle discrimination thresholds (C = -1) for the Gemini V pilot.

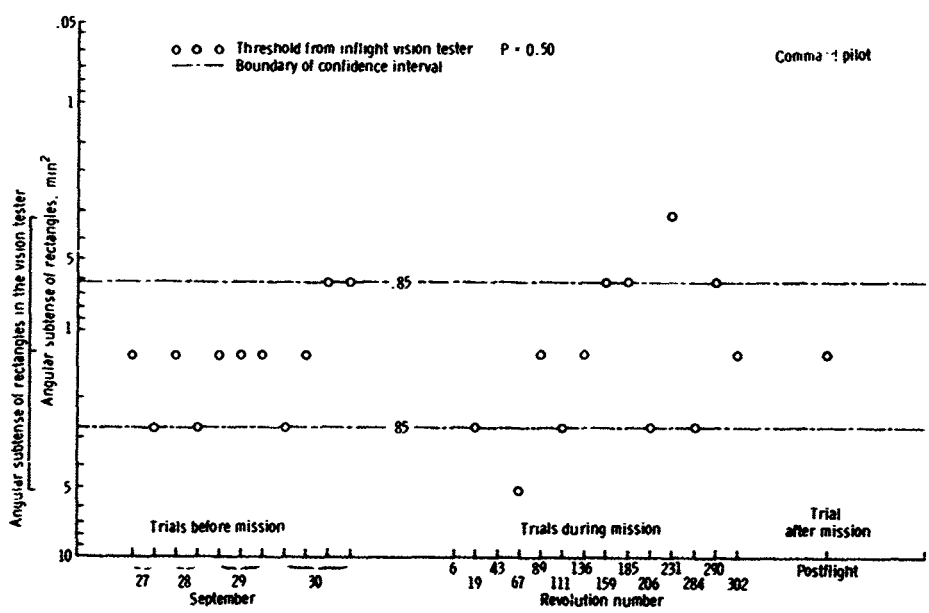

Figure 11. - Rectangle discrimination thresholds (C = -0.233) for the Gemini VII command pilot.

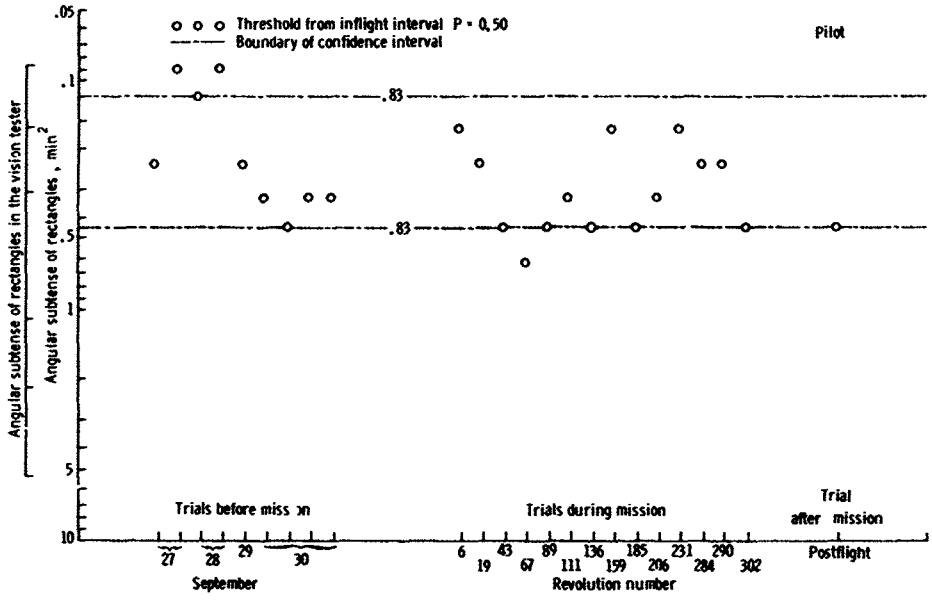

Figure 12. - Rectangle discrimination thresholds (C = -1) for the Gemini VII pilot.

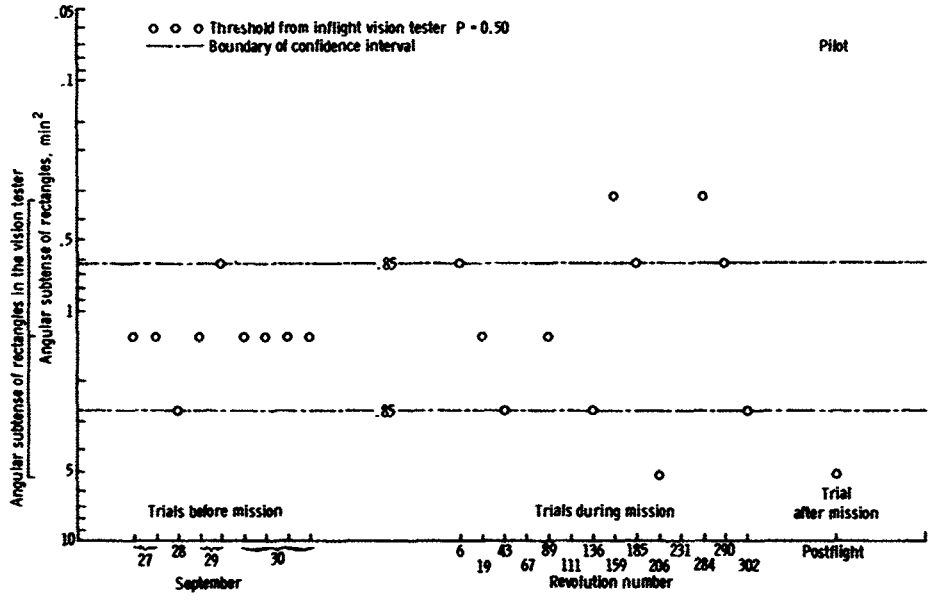

Figure 13. - Rectangle discrimination thresholds (C = -0.233) for the Gemini VII pilot.

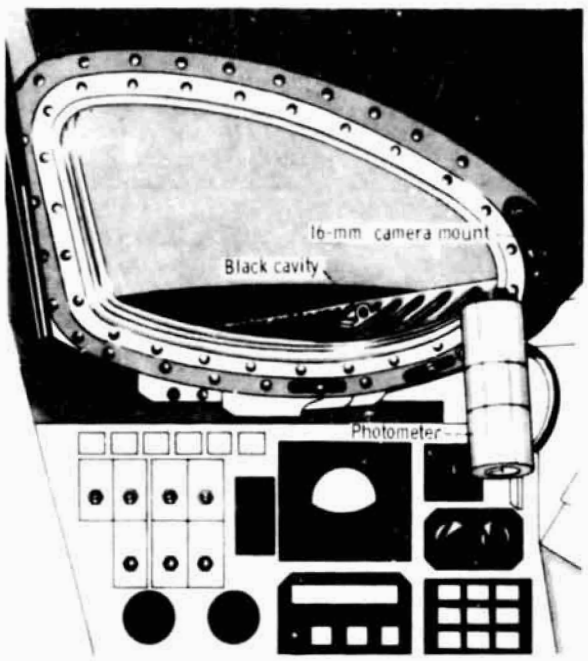

Figure 14. - Location of inflight photometer.

Figure 15. - Components of inflight photometer.

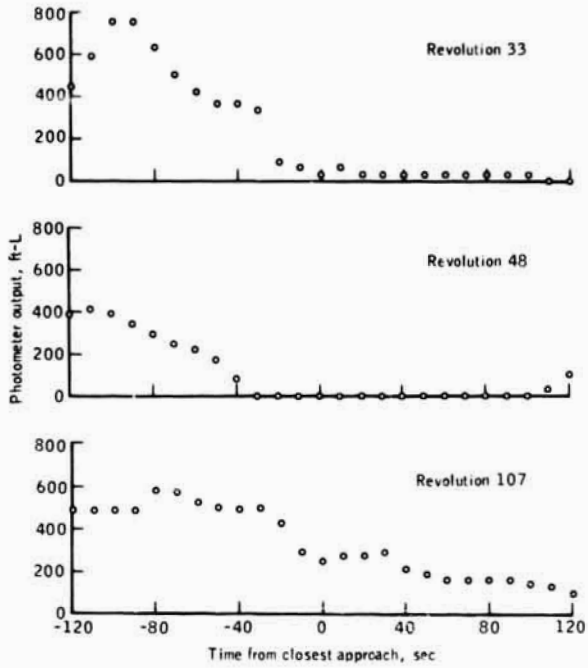

Figure 16. - Photometer data for Laredo, Texas, ground observation site.

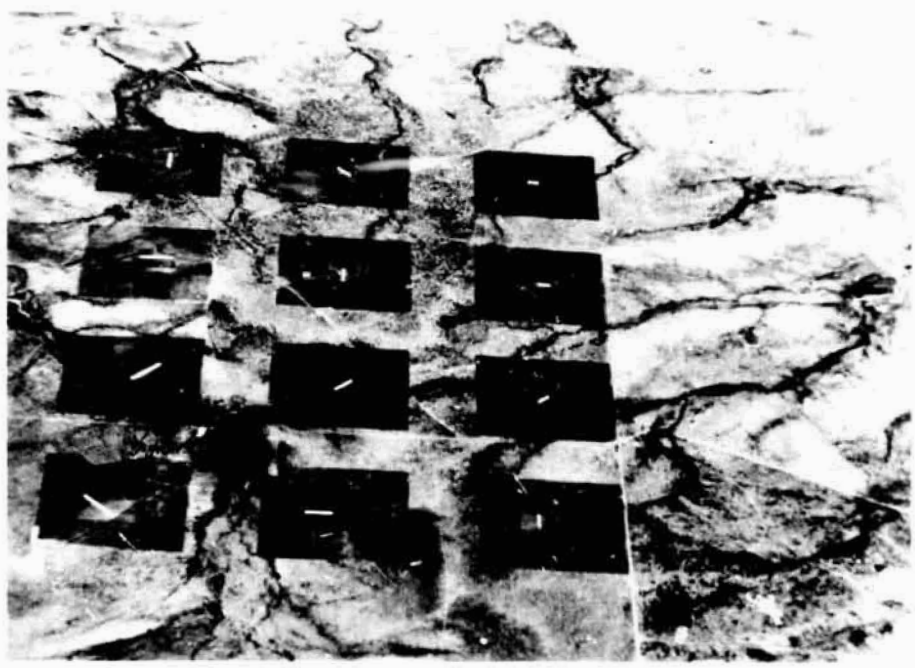

Figure 17. - Aerial photograph of Gemini V visual-acuity experiment ground pattern at Laredo, Texas.

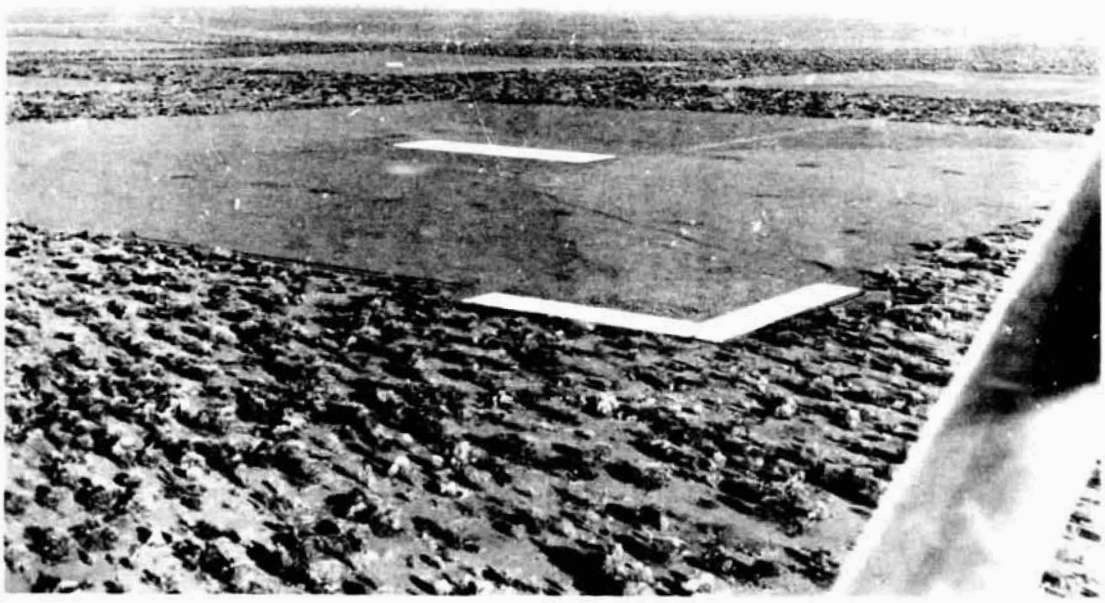

Figure 18. - Aerial photograph of the Gemini V visual-acuity experiment ground observation pattern at Carnarvon, Australia.

Figure 19. - Aerial photograph of the Gemini V visual-acuity experiment ground pattern at Carnarvon, Australia.

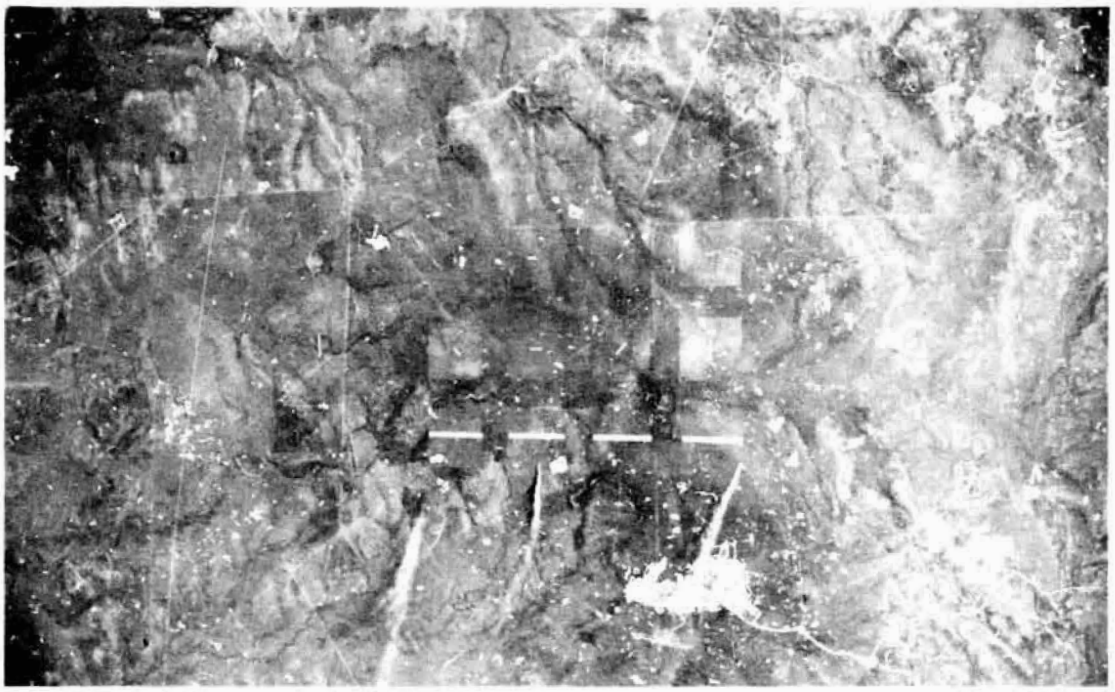

Figure 20. - Aerial photograph of the Gemini VII visual-acuity experiment ground pattern at Laredo, Texas.

Figure 21. - Ground site tripod-mounted photoelectric photometer.

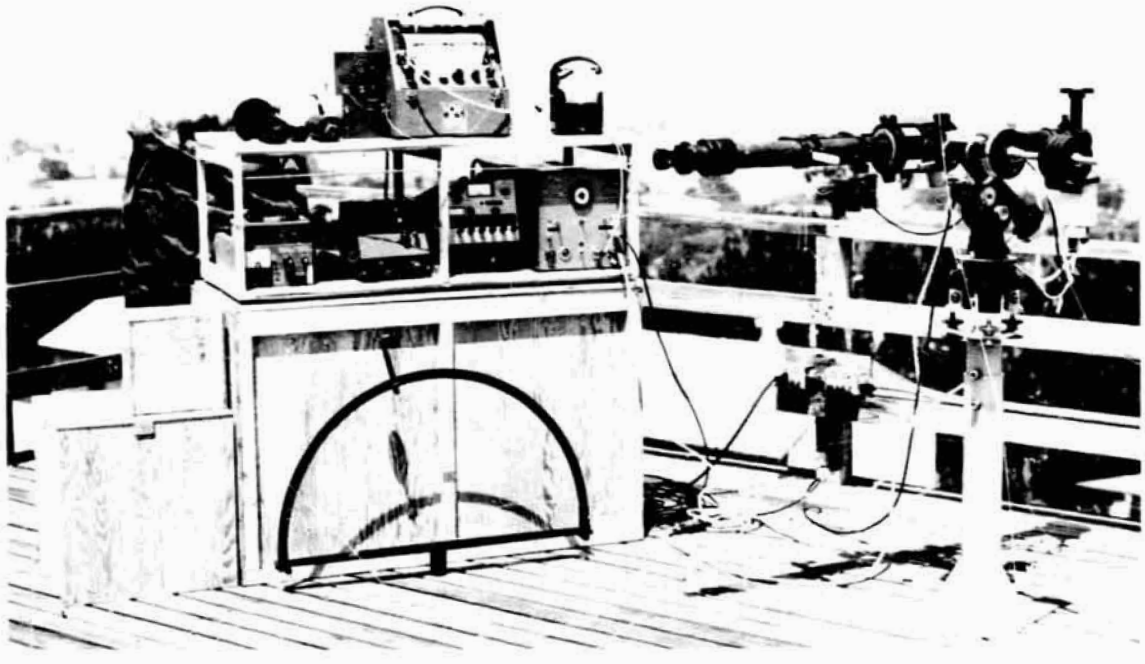

Figure 22. - Ground site photoelectric photometer with recording unit.

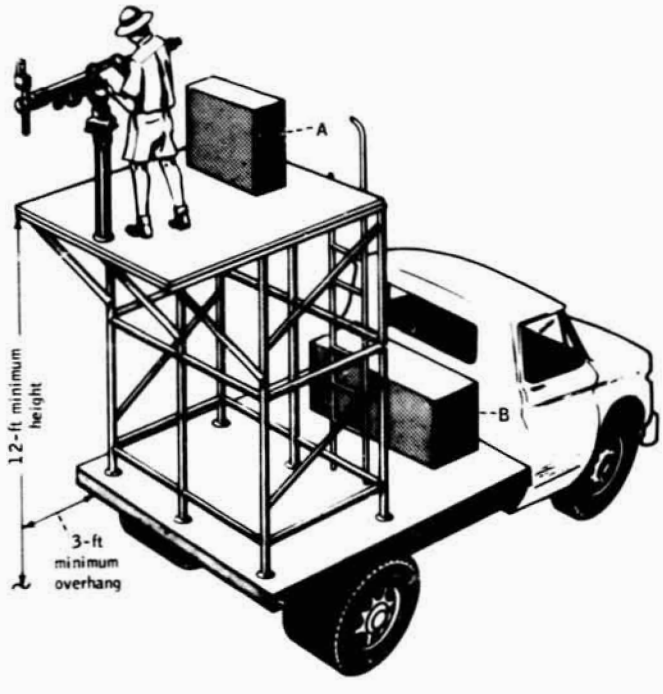

Figure 23. - Drawing of photoelectric photometer mounted on a truck.

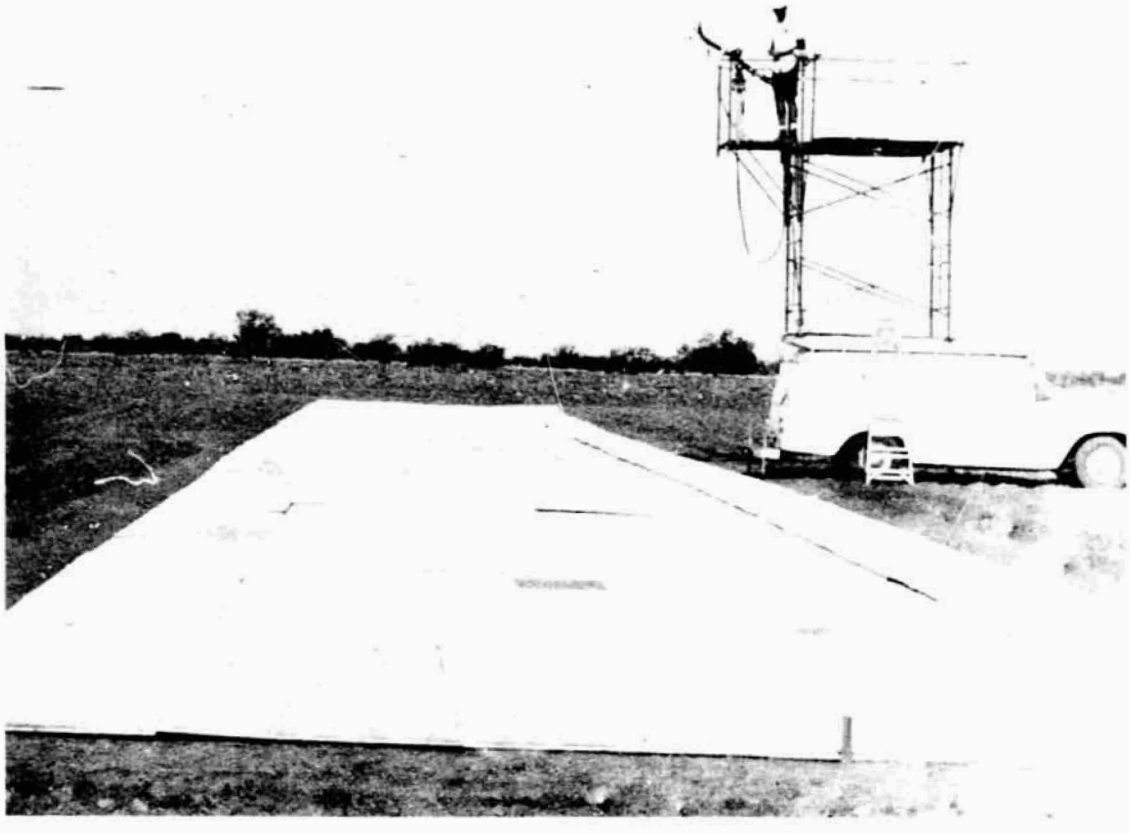

Figure 24. - Photograph of truck-mounted photoelectric photometer.

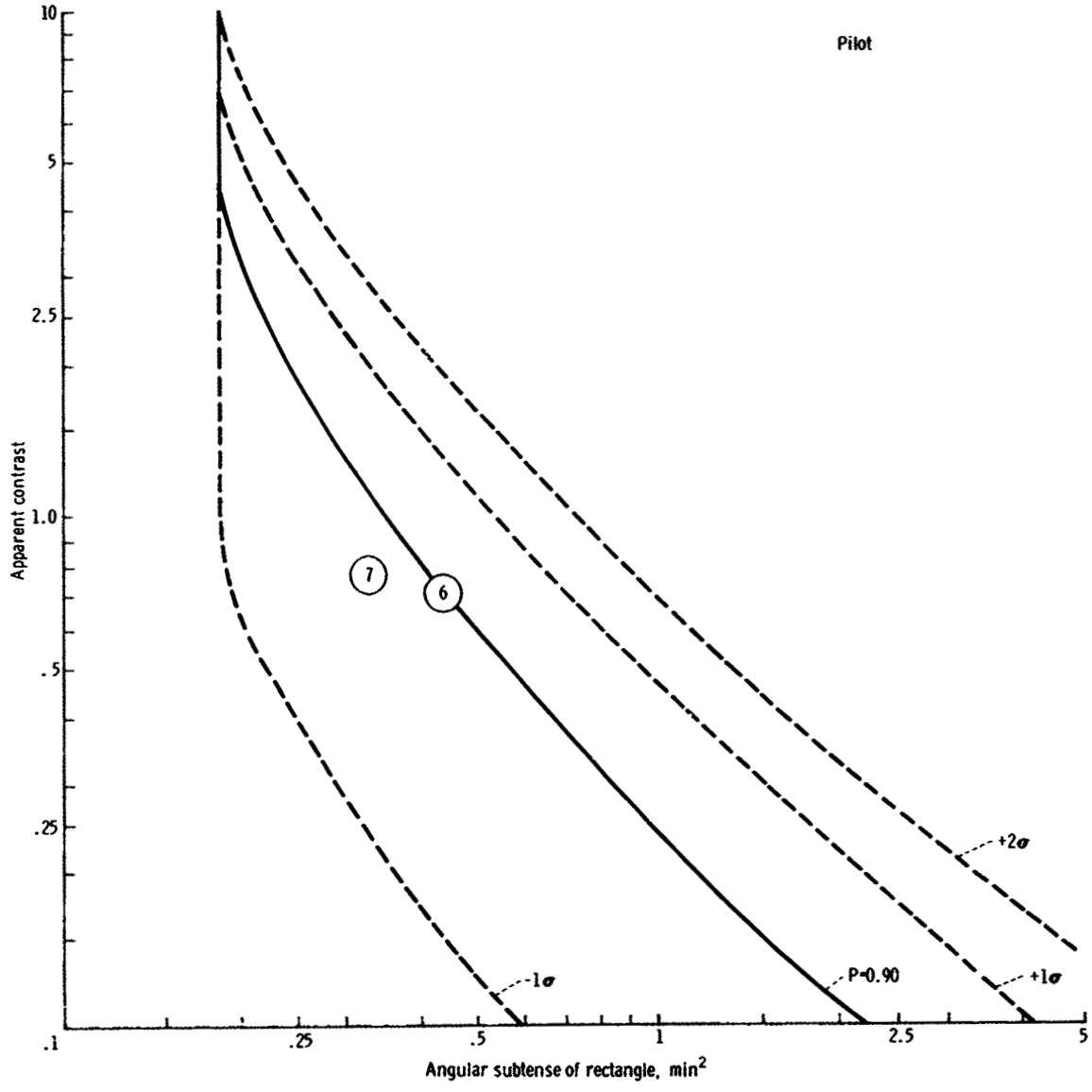

Figure 25. - Apparent contrast compared with angular size of the sixth and seventh rectangles for revolution 48 of the Gemini V mission.

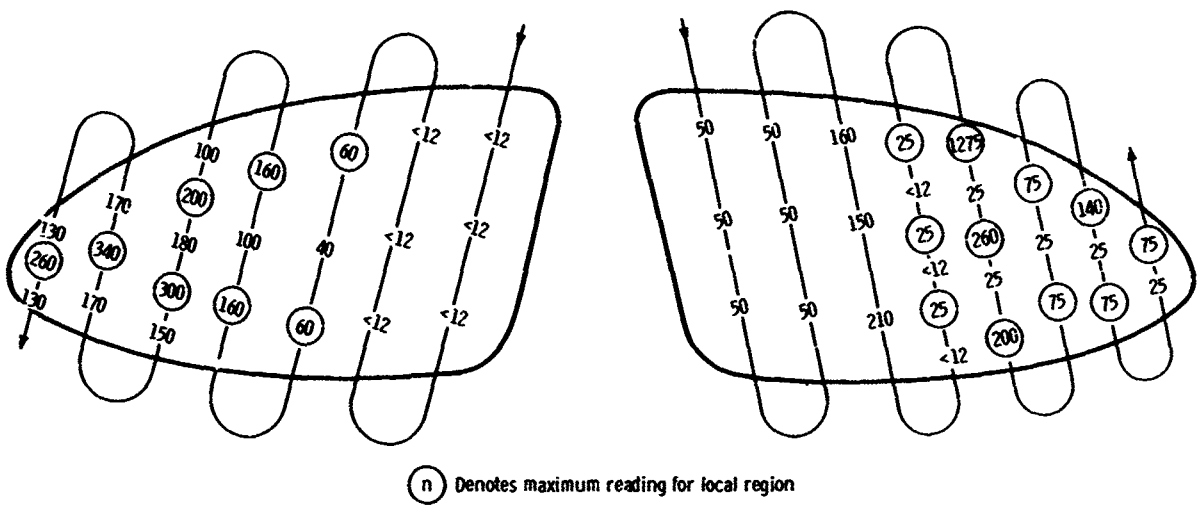

Figure 26. - Numerical results of window scan.

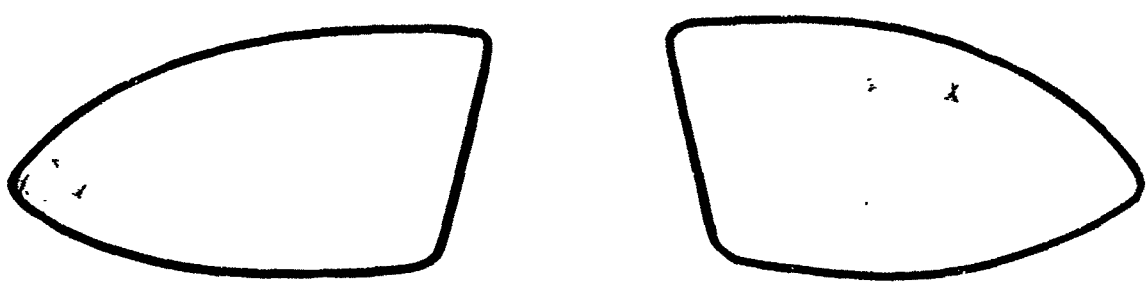

Figure 27. - Shaded pencil sketch of window contamination.

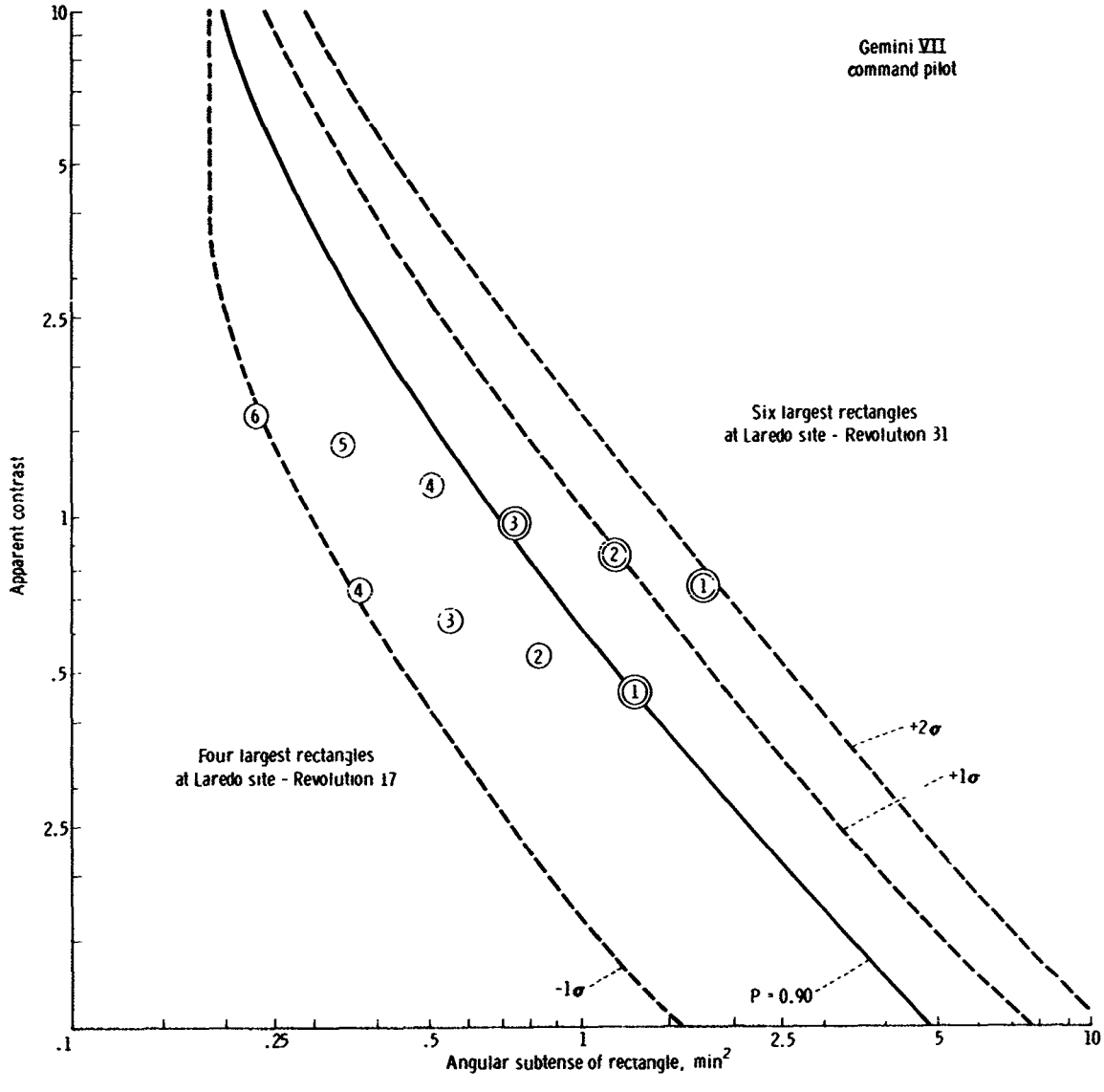

Figure 28. - Apparent contrast compared with angular size of rectangles.

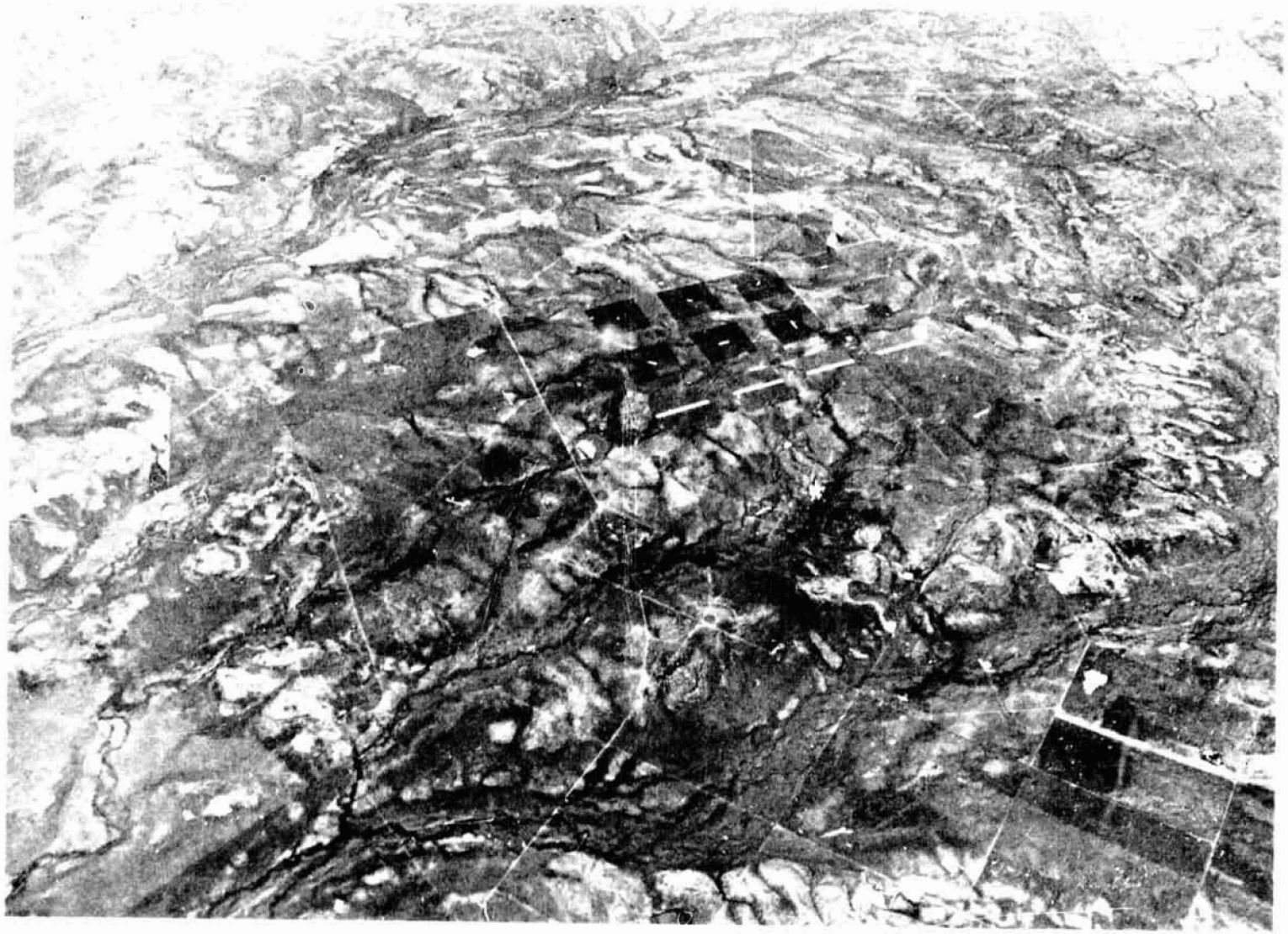

Figure 29. - Visual-acuity experiment ground pattern at Laredo, Texas, photographed by the Gemini VII crewmen during revolution 31.

EXPERIMENT S004

RADIATION AND ZERO-GRAVITY EFFECTS ON HUMAN LEUKOCYTES AND NEUROSPORA CRASSA

By Michael A. Bender,* F. J. de Serres,* P. Carolyn Gooch,* I. R. Miller,* D. B. Smith,* and Sohei Kondo*

INTRODUCTION

Biological effects, of the types usually associated with radiation damage, have been observed after ballistic and orbital space flights (refs. 1 and 2). These effects include mutation, chromosomal aberration, and cellular death. In some instances, these effects were of magnitudes that were many times greater than would have been predicted from the radiation exposure that was received during the flight. Obviously, if real, such phenomena would be of importance in manned space-flight programs and would be of general interest to radiation biologists.

An unpredicted radiobiological effect could be caused by either or both of two things. Because one component of the radiation (heavy primaries) encountered above the atmosphere of the Earth is not available for test use in terrestrial laboratories, the possibility that these particles have unexpected biological effects must be admitted. Also, it is possible that other parameters associated with space flight, such as long-duration weightlessness, interact synergistically with radiation to produce unexpectedly large effects. Experiment S004 was prepared to test such possibilities and to settle the question of the existence of large radiobiological effects after space flight.

This experiment was performed on the Gemini III and XI missions. Because of the peculiar results obtained on Experiment S004 (Gemini III mission), the experiment was extended and repeated during the Gemini XI mission. In addition to repetition of the experiment using human leukocytes, another parallel test was performed on the bread mold Neurospora crassa. Although the experimental design was a duplicate of the first experiment (as closely as was possible), the longer duration of the Gemini XI mission necessitated a much longer preirradiation weightless period.

Experiment S004 was performed during the Gemini III mission under interagency agreement between NASA and the United States Atomic Energy Commission. Design, fabrication, and testing of the experimental hardware were done by personnel of the Oak Ridge Y-12 Plant; isotope preparation and biological work were done at the Oak Ridge National Laboratory (ORNL).

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*Oak Ridge National Laboratory, Oak Ridge, Tennessee.

EXPERIMENTAL DESIGN

Experiment S004 was flown on the Gemini III and XI missions. The experimental design is discussed according to mission.

Gemini III Mission

A practical plan to test for synergism between radiation and space-flight parameters such as weightlessness was to irradiate a thoroughly studied biological material with a known quantity and type of radiation. The experiment consisted of the simultaneous ^{32}P β-irradiation of a series of samples of human whole blood during the mission. Irradiation was accomplished by the use of identical experimental devices, one located on the right-hand hatch of the spacecraft and one that was ground based (at the launch site). Upon mission completion, a cytogenetic analysis was made of each blood sample and the frequencies of chromosome aberrations were determined. The yields of both single-break and multiple-break aberrations were calculated for both the experimental and the control specimens. A greater effect in the experimental material, including the inflight control, would be evidence of an effect of some space-flight parameter. However, any greater effect in the experimental material that did not include the inflight control would be evidence of a synergism between the radiation and some space-flight parameter. The substitution of a series of doses and samples in this simple experimental plan made possible the determination of dose-effect curves, the study of any effect observed in terms of the kinetics of the response studied, and, possibly, the elucidation of the mechanism of the effect.

Human leukocytes were chosen as the experimental material because of several technical advantages which are listed as follows.

1. The cells are all in a uniformly sensitive stage in the cellular reproductive cycle (first generation, G_1) when the whole blood is irradiated either in vivo or in vitro.

2. The investigators had extensive experience with this cellular system (refs. 3 to 8).

The small volume and mass that could be allotted to the experimental device on board the spacecraft precluded the use of X-rays or γ-rays, primarily because of the shielding that would have been necessary to protect the crewmen. Instead, β-radiation, against which shielding is easy, was chosen. Phosphorus-32 was selected as the radiation source because it emits only a single β-particle, because the particle energy (average $e = 0.7$ MeV) is suitable, and because ^{32}P has been used extensively in radiation biology. The use of a liquid-phase biological test material, in conjunction with isotopic radiation sources, facilitated the adoption of plane-parallel irradiation geometry. This geometry resulted in a compact physical arrangement that would result in reasonably homogeneous radiation exposures of the entire sample.

Because chromosomal-aberration induction is a nonlinear function of radiation dose, a graded series of four different radiation exposures and an unirradiated control were used. To ensure against loss of one or more samples, two sets of blood samples

were used. Blood from a different donor was used for each set. Thus, the experimental material consisted of ten 3-milliliter whole-blood samples, a pair of samples irradiated at each of the radiation doses, and a pair of samples unirradiated (the inflight control). The simultaneous ground-based experiment (control) consisted of a duplicate set of samples taken from the same donors at the same time as were the inflight specimens. As an additional inflight control, blood samples were obtained from the crewmembers, both before and after the mission.

Gemini XI Mission

The Neurospora crassa experiment involved spores of a two-component heterokaryon obtained from the fusion of two different (haploid) strains, each of which contained a series of genetic markers. These spore samples were substituted for blood samples in an irradiation device. Survival of the heterokaryon asexual spores and mutability of two different genes were studied to determine the effect of irradiation during space flight on the frequencies of chromosome breakage and of gene mutation. Spore samples were irradiated on the surface of filters and in the form of a suspension (to simulate the conditions of the human-blood portion of the experiment).

Inactivation of the heterokaryotic conidia with ionizing radiation, that results from one-hit events, is believed to be caused by terminal chromosome deletions. Gene mutation results from both one-hit and two-hit events. The type of one-hit event that results in mutation is qualitatively different from the type of one-hit event that results in cellular inactivation. Two-hit mutations result from chromosome breakage and deletion and were expected to respond to changes in environmental conditions in the same way as do the one-hit events that result in cellular inactivation. Thus, the experiment consisted of two parts. One part, as in Experiment S004 on the Gemini III mission, involved human leukocytes and chromosomal-aberration production as the endpoint. The other part involved the mold Neurospora crassa as test material; survival and mutation were measured as endpoints. Both parts of the experiment consisted of the simultaneous irradiation of two series of biological samples with measured doses of ^{32}P β-rays. One series of samples was ground based and the other series was on board the spacecraft. The existence of the postulated synergism was tested by postflight analyses of leukocytes from the inflight and ground-based blood samples for induced chromosomal aberrations and by postflight analyses of the spores from the inflight and ground-based Neurospora crassa samples for survival and for mutation.

The Neurospora crassa portion of the experiment was added to the original human-leukocyte experiment to extend the observations to another organism and to other radiobiological endpoints. The Neurospora crassa assay system was designed to evaluate the genetic effects of any insult to the organism that resulted in chromosome breakage and gene mutation. This system has been used to evaluate the genetic effects of various ionizing radiations and a variety of chemical mutagens (refs. 9 and 10). Neurospora crassa has the same chromosomal structure as do higher plants and animals, and there is every reason to expect that genetic effects that are detectable with this haploid system are comparable with those found in higher diploid forms. Although the Neurospora crassa experiment was flown on the Gemini XI mission primarily because of the results which had been obtained in the blood experiment during the

Gemini III mission, the design of the experiment also made possible a completely independent evaluation of the genetic effects of radiation and space-flight parameters on chromosome breakage and production of gene mutations at specific loci.

EXPERIMENTAL DEVICE

The device that was developed for use in the experiment is shown in figure 1. For convenience, description of the experiment hardware is divided according to the particular Gemini mission involved.

Gemini III Mission

The experimental device included a sealed aluminum box approximately 9 by 9 by 3.2 centimeters; an operating handle protruded from one end of the box. The major components of the device are illustrated in figure 2. The exploded, cutaway drawing (fig. 3) is representative of the arrangement of parts within the assembled device. The blood-sample holders and operating handle are in the nonirradiate position. Each of the five epoxy resin and fiber-glass holders contained two sterile, heparinized, 3-milliliter blood samples in the form of disks 3 millimeters thick. The four blood-sample holders to be irradiated were inserted in the aluminum housing in tracks that ran between the paired aluminum and ^{32}P-source-plate holders. When the operating handle was pushed in, the four blood-sample holders were moved into position between the pairs of ^{32}P-source plates, thus starting irradiation of the blood samples through the thin blood-chamber window. When the operating handle was pulled out, the blood-sample holders were withdrawn, stopping irradiation. The unirradiated control-blood-sample holder was located behind and was shielded from the ^{32}P-source-plate array. The space above the control holder was occupied by an instrument package. The ^{32}P-source-plate pairs were arranged in a graded series of total activities in a ratio of 1:2:3:4 to yield the requisite series of radiation doses during the simultaneous exposure of the blood samples. The geometrical relationships between the ^{32}P sources and the blood samples are shown in figure 4.

A number of measuring devices were included within the experimental device to help confirm correspondences between the inflight and the ground-based portions of the experiment. Two silver metaphosphate fluoroglass dosimeter rods were located within the stems of the blood-sample chamber-sealing screws, where the dose received by each blood sample was recorded. The instrument package was designed to record the temperature within each device during the experiment, particularly to record extremely high or low temperatures, and to record the time of irradiation. These records were written by spots of colored light that moved slowly across strips of color film. The time was read across the resulting strips on the developed film; the color at any given point indicated the temperature at that time. The times at which an irradiation was begun and was ended were recorded by another colored spot. Also, the instrument package contained a pair of large-volume silver metaphosphate fluoroglass dosimeter

blocks. These blocks measured the ambient radiation within the experimental device. A more complete description of the design of this experimental device and of its qualifications for flight use has been reported elsewhere (ref. 11).

Gemini XI Mission

Because of the longer duration planned for the Gemini XI mission, some modification of the Gemini III blood experiment was necessary to make it feasible. To ensure survival of the leukocytes, refrigeration of the samples was required during most of the flight. Also, it was decided to reduce the quantity of ^{32}P, because the blood samples would be subjected to leakage β-particle and bremsstrahlung irradiation within the experimental device for a longer time than on the Gemini III mission. Consequently, a longer exposure to the sources was required to deliver the doses that were desired. The same experimental device was used for the human-blood and the Neurospora crassa portions of the experiment. Except for the reduction in the ^{32}P-source strength and an increase in the thickness of one side of the housing to achieve better heat transfer for the blood experiment, the Gemini XI experiment apparatus was identical to that used on the Gemini III mission. Detailed descriptions of this experimental device have been presented elsewhere (refs. 12 to 14).

To cool the experimental device (to extend the time that the leukocytes would remain viable), a thermoelectric cooler was incorporated into the mounting bracket. This refrigerator bracket used power from the spacecraft to transfer heat from the experimental device to the spacecraft hatch structure; also, the device provided a telemetry signal for monitoring the temperature of the device during the mission. The experimental hardware assembly is shown in figure 5. The experimental hardware was mounted on the left-hand hatch torque box of the Gemini XI spacecraft, as shown in figure 6. A refrigerator on-off switch was provided on the right-hand circuit-breaker panel of the spacecraft.

Because of electrical-power restrictions, no attempt could be made to control the temperature of the Neurospora crassa device. The device was mounted on the inboard side of the right-side foot well of the Gemini XI spacecraft (fig. 7) and was oriented so that the Z-axis of the spacecraft was parallel to a diameter of the sample chambers. An identical ground-based device was kept at the launch site.

EXPERIMENTAL PROCEDURE

The experimental procedure was somewhat complex. The procedure has been divided into two parts for convenience of discussion.

Gemini III Mission

The actual performance of the experiment was somewhat complex because of the short time the blood samples would remain viable, the relatively short half life of

^{32}P, and the tissue-culture procedure that was necessary to produce chromosome preparations for analysis. Blood samples had to be obtained as close as possible to the time of lift-off. The experimental devices then had to be assembled and tested. The flight device had to be installed in the spacecraft just before launch. Then, immediately upon recovery of the spacecraft, the experimental device had to be recovered from the spacecraft and opened. Tissue cultures had to be made both from each blood sample and from postflight blood samples taken from the crewmembers. To execute this program, special facilities had to be provided at the launch site and on board the prime recovery vessel (and also on the vessels in the first- and second-orbit recovery regions).

Preflight. - Two days before launch, peripheral-blood samples were obtained from the flight crewmen and from the backup crewmen. Short-term leukocyte cultures were prepared and incubated at 37° C. Approximately 9 hours before launch, peripheral-blood samples were obtained from two pretested donors. Two experimental devices were then assembled and tested. Approximately 210 minutes before launch, the flight device was mounted in an insulated bracket located inside the right-hand hatch of the spacecraft. The ground-based control device was placed in a controlled-temperature cabinet, in which the temperature was adjusted periodically to correspond constantly to the temperature inside the spacecraft cabin.

Flight. - After launch, the inflight experimental device became and remained essentially weightless until irradiation was begun. Irradiation was initiated by the pilot at 00:50:18 g.e.t. Twenty minutes later (at 01:10:18 g.e.t.) the pilot terminated irradiation. The corresponding activation and deactivation of the ground-based experimental device occurred at 00:52:00 and 01:12:00 g.e.t., respectively. Except for minor accelerations produced by the "Texas burn" at 01:32:59 g.e.t., the "lateral burn" at 02:16:59 g.e.t., and the "preretroburn" at 04:21:23 g.e.t., the inflight experimental device remained essentially weightless for approximately 3.5 hours after irradiation.

Postflight. - Peripheral-blood samples were obtained from the crewmen approximately 6.5 hours after launch. All blood samples had been cultured by 10 hours after launch; these samples were from the ground-based control device at the launch site and from the inflight samples on the prime recovery vessel. The crewmember preflight cultures were fixed the day after launch, approximately 72 hours after they had been made. The experimental cultures and the crewmember postflight cultures were fixed approximately 77 hours after launch.

Gemini XI Mission

As in the Gemini III human-blood experiment, execution of the experiment on the Gemini XI mission was complex. The leukocyte and Neurospora crassa samples had to be obtained and loaded, and the flight and ground-based devices had to be assembled and tested as close as possible to the time of lift-off. The tissue-culture procedures that were necessary to make chromosome preparations from the blood samples after recovery of the spacecraft had to be performed on board the recovery vessel. Real-time coordination during and after the mission was required to achieve the closest possible correspondence between the flight and ground-based portions of the experiment. Each experiment manipulation during the mission was counted down from the Mission Control Center in Houston, Texas.

Preflight. - Nine days before lift-off, leukocyte specimens were obtained from peripheral-blood samples from the crewmen. Short-term leukocyte cultures were prepared and were incubated at 37° C for 63 hours. Then, the cultures were treated with colchicine for 5 hours, fixed, and chromosome preparations were made. Almost 10 hours before lift-off, peripheral-blood samples were taken from the same two donors used on the Gemini III mission. The flight and ground-based devices were assembled and tested, and the flight device was mounted in the refrigerated bracket on the left-hand hatch of the spacecraft approximately 150 minutes before lift-off. The ground-based control device was placed in a refrigerator in the launch-site assembly facility. Both refrigerators were switched on, and the temperatures on the experimental devices rapidly decreased to the normal control range (4° ± 2° C), which was indicative of satisfactory operation.

The Neurospora crassa samples were prepared as a suspension (approximately 5×10^7 cells/milliliter in 0.12-percent agar solution to prevent settling) or were collected on the surface of 25-millimeter filters at the ORNL. These samples were kept refrigerated and were hand-carried to the launch site. The flight and ground-based sample holders were prepared and inserted into the experimental devices approximately 10 hours and 5 hours, respectively, before lift-off; then, they were refrigerated briefly. The flight experimental device was installed in the spacecraft about 300 minutes before lift-off. The ground-based control device was kept at 25° C in the launch-site assembly facility.

Flight. - After the launch phase, the experimental devices on board the spacecraft remained weightless, except during the two Agena primary propulsion system (PPS) burns, until retrofire. Each PPS burn produced an acceleration of approximately 1.2g, but only for approximately 22 seconds. The second PPS burn was completed at 43:54:27 g.e.t.

Starting approximately 14 minutes after lift-off, the temperature of the experimental device on board the spacecraft increased beyond the normal control range and remained between 6° and 10° C during the first 24 hours of the mission. The device temperature rapidly decreased to the normal control range when the spacecraft was depressurized for the first extravehicular activity (EVA). Except for a brief increase to approximately 7° C at approximately 62:00:00 g.e.t., the device operated within this temperature range until it was switched off at 65:38:00 g.e.t. The ground-based unit remained in the normal control range until switched off simultaneously with the flight unit. After the refrigerators were turned off, the temperatures of both devices rapidly increased to approximately 25° C and remained approximately at this temperature until after recovery.

The control Neurospora crassa device was maintained at 25° C, although cabin temperature appeared to have been higher during the first 24 hours of the mission (prior to irradiation of the mold samples). The temperature that was indicated by the cabin-temperature telemetry channel was as high as 33° C, but averaged approximately 28° to 29° C. However, no direct measurements of the temperature of the mold device were obtained. Nevertheless, it seemed extremely likely that the inflight samples were at a higher temperature than were the ground-based control samples during this period.

Irradiation of the Neurospora crassa samples was begun at 30:09:00 g.e.t. Both PPS burns occurred during irradiation, and the burns were completed at 43:54:27 g.e.t. Irradiation of the mold was terminated at 67:53:50 g.e.t. The inflight samples were weightless during all of the irradiation except during the two PPS burns and during the remaining approximately 3.5 hours prior to retrofire. Irradiation of the leukocytes was begun at 66:43:00 g.e.t. and was terminated at 67:53:00 g.e.t. Thus, the inflight blood samples were weightless during irradiation and for approximately 3.5 hours after irradiation.

Postflight. - The flight devices were removed from the spacecraft shortly after recovery. The blood samples had been removed from both the inflight and the ground-based control devices at 75:32:00 g.e.t. and were in culture by 75:14:00 g.e.t. Also, postflight peripheral-leukocyte samples were obtained from the crewmen and were placed in culture at 75:14:00 g.e.t. All cultures were fixed after 66 hours of incubation, after exposure to colchicine for 5 hours. The resulting preparations were scored (at the ORNL) in the same manner as were those from the experiment on the Gemini III mission (refs. 12 and 13).

The samples were taken out of the inflight Neurospora crassa device by 73:13:00 g.e.t. The ground-based control samples were removed by 73:38:00 g.e.t. All mold samples were refrigerated at 4° C and were returned to the ORNL for analysis.

Genetic analysis was initiated by the preparation of suspensions from each of the samples for inoculation into the assay medium. Inoculation volume was varied so that the total number of expected survivors per flask would be approximately 10^6 in a total volume of 10 liters of medium. In this medium, heterokaryotic survivors form a tiny white colony that is approximately 2 millimeters in diameter after incubation in the dark at 30° C for approximately 7 days. Specific-locus mutations of the ad-3A and the ad-3B genes cause accumulation of a reddish-purple pigment, and such mutations can be recognized by their unusual colony color. Five to 10 replicate flasks were made from each spore sample. When the specimens were harvested, the total volume was measured and the total number of colonies per flask was determined by counting aliquots. The number of purple colonies per flask was determined by hand counting; typically, the number varies from 0 to 500 per flask.

The relationship between total colony counts and the number of spores inoculated for each of the samples was used to obtain dose-survival curves. The relationship between the total number of purple colonies and the total colony count was the forward-mutation frequency. The forward-mutation frequencies obtained with each set of samples were expressed as dose-effect curves for forward mutation. Samples of ad-3 mutants from each of the inflight and ground-based samples were reserved for a more detailed genetic analysis.

RESULTS

Gemini III Mission

Postflight analysis of the fluoroglass dosimeters and of other instruments proved that the doses, the times of actuation, and the temperatures of the inflight and ground-based control experiments were consistent. The instrument-package film records were consistent with the actuation information and temperature information acquired through other sources. Indications were that the inflight experimental device attained a temperature of 30° C during assembly (that is, during the heliarc welding of the top). The temperature did not exceed 38° C, nor did it decrease below 14° C, at any time during the preflight, inflight, or recovery periods. The ground-based control device never became this warm; it remained between 29° and 2° C during these same periods. Postflight determinations of circuit-element function, of battery voltages, and of coulometer gap positions indicated that both instrument packages functioned perfectly. No indicator of excessively high or low temperature had been activated. The activation markers appeared in the proper position, and in that position only, on both the inflight and the ground-based control instrument-package film records; this was consistent with the communications records. That the exposures were of the required duration was confirmed by analysis of the fluoroglass dosimeters that were incorporated into the blood-sample-chamber screws. The 44 dosimeters were analyzed on a fluorometer that was calibrated by means of fluoroglass standards that had been given known ^{60}Co γ-ray exposures at the National Bureau of Standards. The readings for each pair of dosimeters were consistent. Also, preflight and postflight doses were estimated by means of fluoroglass and Fricke-solution dosimetry. The results are presented in table I. Values were averaged for the dosimeters from each blood sample. Both the analyzed values and the dose estimates were consistent with the theoretical expectations and with the results of control experiments that had been performed previously. A large part of the approximately 2-radian dose to the control-blood samples was caused by bremsstrahlung that had a peak energy of approximately 65 keV. The large-volume fluoroglass dosimeter blocks located in the ground-based control instrument package also registered this exposure. Dosimeters from the inflight instrument package registered somewhat higher exposures.

All blood-sample cultures were successful and resulted in satisfactory chromosome preparations. Very little haemolysis was noted after the blood samples had been centrifuged, and no other evidence of gross cellular damage was seen. For the entire experiment, 4600 cells were analyzed. The results are shown in table II.

Crewmember chromosome-aberration analyses resulted in data that did not establish an increase in aberration frequency caused by space flight. The two dicentric chromosomes that were seen in the samples from one crewmember appeared to be identical and were without acentric fragments. Therefore, their cause could not be attributed to the space flight. The deletion frequencies were typical of normal individuals.

The aberration frequencies that were observed in the control-blood samples were as expected in cells that had been exposed to such a low radiation dose (from β-ray leakage and from bremsstrahlung within the experimental devices). These frequencies were consistent with what was noted in control experiments that had been performed

previously. The irradiated samples produced the expected types of aberrations. The two major classes of aberration induced are shown in figures 8 and 9. The cell shown in figure 10 was normal, with 46 chromosomes and without breaks, fragments, or rearrangements. The cell shown in figure 8 contained one chromosome deletion and the resulting acentric fragments. Because only one break is required, the yield of this aberration type is a linear function of dose and may be described as

$$Y = a + bD$$

where Y = yield

D = radiation dose

a = spontaneous frequency

b = coefficient of aberration production

The cell illustrated in figure 9 contained a discentric chromosome and the resultant acentric fragments. This class of aberration, including rings and dicentric chromosomes, requires two independent chromosome breaks. Consequently, the yield is a function of the square of the radiation dose and approximates the expression

$$Y = cD^2$$

where c is the coefficient of dicentric production. The data of table II were fitted to these expressions by iterative least-squares regression analyses. The resulting coefficients of aberration production are shown in table III with those for a typical control experiment that was performed before the flight (run 5).

Yields for ring and dicentric chromosomes in the inflight and ground-based control experiments and for deletions in the ground-based control experiment were consistent with the results of the previously performed control experiments. The ring and dicentric yields for the inflight and ground-based control experiments did not differ significantly from each other. However, the yield of deletions in the inflight experiment was approximately twice that which was observed in the ground-based control experiment and in the control experiments that had been performed previously. The difference was significant and, as may be seen in table II, was completely consistent.

Gemini XI Mission

Human leukocytes and Neurospora crassa were the biological materials that were used on the Gemini XI mission.

Leukocytes. - Postflight inspection and testing of the experimental hardware proved that the equipment had functioned properly. Apparently, the inability of the refrigerator on board the spacecraft to maintain the device temperature within the design range was caused by unexpectedly high hatch temperature and was not caused by

equipment malfunction. However, the slightly higher temperature of the inflight blood samples during the first day of the mission did not affect the success of the experiment and did not affect the results.

Analysis of the fluoroglass dosimeters and other instruments from the experimental devices resulted in values for temperature, time, and radiation exposure that were consistent with the information available from other sources. The doses, indicated by the dosimeters, were consistent both with the theoretical calculations and with the actual measurements made with fluoroglass dosimeters, lithium fluoride dosimeters, and Fricke dosimeters after completion of the experiment. Approximately one-third of the total dose to which the control-blood samples were exposed was from bremsstrahlung that had a peak energy of 65 keV. The estimated doses, shown in table IV, are the calculated theoretical doses with which the dosimetric data were consistent.

No evidence of excessive haemolysis or gross cellular damage was observed in the recovered blood samples. All the blood cultures were successful and yielded satisfactory chromosome preparations, although the cultures from the blood samples from the ground-based portion of the experiment yielded somewhat fewer mitoses than was predicted. A total of 4340 cells was analyzed for chromosomal aberrations; the results are shown in table IV.

The crewmember blood samples contained no significant increase in aberration frequencies postflight. This result is consistent with the results from the experiment flown on the Gemini III mission and with the results of similar determinations made for the crewmen of other Gemini missions.

The chromosome-aberration frequencies that were observed in the control-blood samples were typical of what was expected in cells exposed to such low radiation doses. These frequencies were consistent with what was observed in previous ground-based experiments and in the samples from the Gemini III mission. A least-squares regression analysis was performed to obtain the best estimates of the coefficients of chromosome deletion and ring-chromosome and dicentric-chromosome production for ground-based portions and for inflight portions of the experiment. The chromosome-deletion data were fitted to a linear model, whereas the multiple-break aberration data were fitted to the dose-square model. For comparative purposes, the results of these analyses and the results from a typical preflight control experiment (run 1) are shown in table V. There was no significant difference between the values of deletions or of rings and dicentrics for the flight and ground-based samples. Neither did the values for the actual experiment differ from the results of the preflight experiment.

Mold. - A review of data from the analysis of the Neurospora crassa samples that were irradiated on filters resulted in no significant difference in either the survival curves (fig. 11) or the forward-mutation curves (fig. 12). Estimates of the forward-mutation frequencies obtained with ^{32}P β-rays were consistent with chronic 250-kilovolt X-ray and ^{137}Cs or ^{85}Sr γ-ray exposures. None of the estimates of the slopes of these curves were different significantly from 1.0. Results that were obtained with the mold samples on filters were indicative that there was no genetic effect of radiation under conditions of space flight that differed from the same radiation exposures on the surface of the Earth. In this respect, both the mold-experiment results and the

blood-experiment results from the Gemini XI mission are consistent. Neither experiment confirmed the apparent synergism that was observed during the Gemini III mission.

Analysis of data from the Neurospora crassa samples in suspension resulted in the conclusion that a significantly higher ($P = 0.02$) survival was obtained with the inflight samples than with the ground-based samples. Also, the forward-mutation frequencies were lower for the inflight suspensions than for the ground-based suspensions, but the difference in the slopes of these curves was not significant ($P = 0.09$). Taken at face value, data from the mold suspensions would cause one to conceive of an antagonism between radiation exposures and some factor associated with space flight; to this extent, these data are inconsistent with the data that were obtained for the Neurospora crassa filter samples and for the blood experiment.

DISCUSSION

Gemini III Mission

The lack of aberrations in the blood samples obtained postflight from the crewmembers made unlikely the possibility that the radiation encountered during the flight produced any unprecedented effect, at least on genetic material such as that used in this experiment. This conclusion was strengthened by the low aberration levels that were observed in the flight control-blood samples. All physical evidence contradicted the possibility that the flight and the ground-based control samples received significantly different radiation doses. Also, the aberration data were indicative that the doses were substantially the same. If the high-deletion yields from the flight samples were caused by reception of a higher dose than received by the ground-based control samples, the ring and dicentric chromosome yields also would have been increased in the flight samples. Of course, the possibility that something associated with the flight produced chromosome breaks quite independently of the radiation can be dismissed for several reasons.

Comparison of the data resulted in the conclusion that although there was no significant difference between the yields of multiple-break aberrations, the frequency of single-break aberrations was significantly higher in the experimental samples. Several lines of evidence ruled out the possibility that this difference was caused by differences in absorbed dose, temperature, oxygen tension, or other parameters that are known to influence chromosome aberration. That the space flight itself induced aberrations was ruled out by the control samples and by preflight and postflight blood samples obtained from the crewmembers. A synergism between radiation and some parameter of space flight appeared to exist for human-chromosome aberration. It seemed likely that this effect was on the normal restitution of chromosome breaks, not on chromosome breakage itself.

The small positive effect demonstrated in this experiment was of definite scientific interest. However, the experiment failed to confirm the existence of any large effect, such as had been suggested previously, and which might constitute a special obstacle to long-duration manned space flight.

Gemini XI Mission

The results from the Gemini XI leukocyte experiment have failed to result in confirmation of the increase in single-break chromosome aberrations that were observed in the Gemini III experiment. The Gemini XI results were consistent with the Gemini III results, both in containing no significant increase in aberration levels in samples taken from crewmen after an orbital mission and in not containing any increase in multiple-break aberration yields when the cells were irradiated during orbital flight. Although the absolute values of the coefficients of deletion production from the Gemini III and the Gemini XI experiments were different, this difference was to be expected as a consequence of the change in the interval between the time the blood sample was taken and its irradiation. Control experiments performed before the Gemini XI mission consistently resulted in this conclusion. Thus, the Gemini XI blood experiment did not result in confirmation of the apparent synergism that was observed in the experiment on the Gemini III mission.

Neurospora crassa samples were collected on filters so that any data could be compared directly with existing information on the genetic effects of chronic and acute exposures to various ionizing radiations (refs. 9 and 10). Usually, such samples are irradiated under aerobic conditions, even in sealed containers, because the rate of respiration is low for Neurospora crassa spores on filters, and the oxygen content of the air stabilizes at approximately 16 to 17 percent (ref. 15). In suspension, spores of Neurospora crassa respire rapidly and become anaerobic, the rate depending upon the concentration of the suspension and upon the temperature (ref. 16). Aerobic suspensions of conidia, at the concentration that was used on the Gemini XI mission, kept in containers impermeable to oxygen, would become anaerobic within 75 minutes after incubation at 25° C. Anaerobic conditions protect the cell against various genetic effects of ionizing radiations. In Neurospora crassa, anoxia resulting from endogenous metabolism has been shown to result in high survival rates and lower reverse mutation rates (mutant to wild type, ref. 16). Analysis of data from other experiments on aerobic and anaerobic suspensions of the same type as used in the mold experiment has led to the conclusion that anoxia produces a similar effect on forward-mutation frequencies (wild type to mutant), although an extensive information background does not yet exist on Neurospora crassa samples irradiated in anaerobic suspensions.

Analysis of data from the Neurospora crassa feasibility experiments and the data from the inflight and ground-based control samples from the Gemini XI mission clearly resulted in proof that the anaerobic samples had higher survival rates and lower forward-mutation frequencies than did the aerobic samples on filters.

Direct measurements of the permeability of the plastic sample holders that were used in the experimental device have resulted in proof that the containers are somewhat permeable to oxygen. If the spores in suspension were metabolically active during the first 24 hours of the Gemini XI mission, the higher cabin temperatures could have resulted (1) in more rapid diffusion of oxygen through the walls of the sample holder and (2) in more rapid respiration of the mold spores in suspension. Thus, the inflight samples may have been in a different physiological state (possibly more complete anaerobiosis) during irradiation.

It is more likely that the differences that were found between the inflight and ground-based samples of Neurospora crassa in suspension reflect differences in the physiology of the spores, resulting from the higher cabin temperatures during the first day of the mission, rather than from antagonism between radiation and some space-flight parameter. The simplest interpretation of the results of Experiment S004 is that the significant increase in chromosome-deletion yield that was observed in the experiment on the Gemini III mission was the result of a statistical sampling error. If it is argued that the difference in the Gemini III results actually reflects a real synergistic effect, then the conditions under which such an effect can occur must be very special. Certainly, the Gemini III and XI mission profiles contain the same major elements of vibration, weightlessness, and so forth. A third possibility, that the lack of a significant difference in the Gemini XI experiment results is itself caused by a statistical sampling error, seems extremely unlikely, based on the results of the Neurospora crassa experiment.

The recovered ad-3 mutants result from two different types of events, namely from point mutations (resulting from genetic alterations of the deoxyribonucleic acid, ranging from single base-pair substitutions to small intralocal deletions) and from chromosome deletions (resulting from chromosome breakage events outside of the ad-3A or ad-3B genes that interact to cause gene loss (ref. 9)). Point mutations increase linearly with radiation dose and occur more frequently than do chromosome-deletion mutations, which increase with the square of the dose (fig. 12). Because there was no difference in the slopes of the curves for all ad-3 mutations, the data from this portion of the mold experiment also should result in proof that there is no interaction between radiation and the various parameters associated with space flight, and that the genetic effects, with regard to events giving rise to chromosome breakage or gene mutation by either point mutation or chromosome deletion, are identical with those found in ground-based experiments.

Whether or not it is eventually possible to ascribe the differences seen in the inflight and ground-based Neurospora crassa samples to differences in the level of anoxia caused by the difference in the temperature of the experimental devices, it is clear that no synergism between radiation and space flight was demonstrated for either survival or for forward-mutation by the Neurospora crassa experiment.

The two parts of this experiment have resulted in proof, in contrast to the results reported from earlier observations (refs. 1 and 2), that neither orbital space flight nor any of the stresses connected with it produced significant, unpredicted genetic damage, at least insofar as chromosomal-aberration production is a valid measure of this general type of effect. Furthermore, the Gemini XI results lead to the conclusion that no synergistic effect exists between radiation and factors that are associated with space flight. No significant difference was found between dose-effect curves for survival or mutation induction of the inflight and ground-based samples irradiated on filters. Thus, like the blood experiment, this part of the experiment failed to result in data that were appropriate for confirmation of the apparent synergism that was observed in the Gemini III blood experiment. Also, the Neurospora crassa experiment provided conclusive data that there is no difference in the genetic effects of irradiation during space flight and the genetic effects obtained in ground-based experiments.

Significant differences were found between the dose-effect curves for survival ($P = 0.02$) but not for mutation induction ($P = 0.09$) of the inflight and ground-based Neurospora crassa samples irradiated in suspension. At face value, these data might have suggested antagonism between space-flight parameters and radiation. However, they clearly were not consistent with the data from the blood experiments on either the Gemini III or Gemini XI mission, nor were they consistent with the data obtained from Neurospora crassa samples on filters. The difference between the data obtained from inflight and ground-based suspensions was believed to be caused by differences in the relative anoxia resulting from high spacecraft cabin temperature rather than from weightlessness.

Both the Gemini XI blood experiment and the Neurospora crassa experiment thus have failed to result in data confirmatory of the apparent synergism observed on the Gemini III mission. It has been concluded that the difference in the Gemini III single-break chromosome-aberration rates probably was the result of statistical sampling errors. Even if the effect found in the Gemini III experiment was true, it evidently was not the result of a general synergism between weightlessness and radiation.

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TABLE I. - DOSE ESTIMATES FROM FLUOROGLASS DOSIMETERS INCORPORATED IN BLOOD-SAMPLE CHAMBERS

Device	Theoretical dose, rad	Average reading,[a] μA	Net β-ray dose, μA	Estimate of β-ray dose, rad	Estimated total dose, rad
Ground-based control	2	4.5	--	--	2
	45	18.1	13.6	50	52
	91	27.7	23.2	86	88
	136	41.9	37.2	138	140
	181	51.0	46.5	172	174
Flight	2	4.2	--	--	2
	45	18.0	13.8	51	53
	91	29.5	25.3	94	96
	136	38.3	34.1	126	128
	181	46.8	42.5	157	159

[a]As the instrument was arranged, 1 μA = 2 ^{60}Co γ-ray rads.

TABLE II. - RESULTS OF EXPERIMENT S004

CHROMOSOME-ABERRATION ANALYSES

[Gemini III mission, blood]

Subject	Sample	Cells scored	Estimated dose, rad	Chromatid deletions	Chromosome deletions	Rings and dicentric chromosomes
Crew						
A	Preflight	100	--	3	0	0
	Postflight	200	--	2	0	0
B	Preflight	100	--	0	1	[a]1
	Postflight	200	--	0	1	[a]1
Experiment						
	Ground	400	2	3	3	1
	Flight	400	2	1	3	0
	Ground	400	52	1	6	5
	Flight	400	53	3	14	1
	Ground	400	88	5	13	13
	Flight	400	96	6	28	16
	Ground	400	140	6	32	43
	Flight	400	128	6	48	34
	Ground	400	174	6	45	36
	Flight	400	159	2	88	48

[a]These two dicentric chromosomes appeared identical; both lacked acentric fragments.

TABLE III. - COEFFICIENTS OF ABERRATION PRODUCTION

[Gemini III mission]

Source	Deletions, 1×10^4/cell/rad^2	Rings and dicentrics, 1×10^6/cell/rad^2
Ground-based control	4.79 ± 0.72	3.23 ± 0.59
Inflight	9.11 ± 1.02	3.48 ± 0.53
Run 5	5.36 ± 0.86	2.66 ± 0.60

TABLE IV. - RESULTS OF EXPERIMENT S004

CHROMOSOME-ABERRATION ANALYSES

[Gemini XI mission, blood]

Subject	Sample	Cells scored	Estimated dose, rad	Chromatid deletions	Chromosome deletions	Rings and dicentric chromosomes
Crew						
A	Preflight	150	--	1	0	0
	Postflight	200	--	8	7	0
B	Preflight	150	--	1	1	0
	Postflight	200	--	11	5	2
Experiment						
	Ground	364	10	4	11	1
	Flight	400	8	18	10	8
	Ground	380	76	15	33	17
	Flight	400	76	13	24	20
	Ground	310	145	7	49	[a]43
	Flight	400	145	21	69	49
	Ground	321	216	5	71	[a]70
	Flight	400	216	13	84	76
	Ground	265	283	8	94	65
	Flight	400	233	26	106	[b]121

[a]Included a tricentric scored as two dicentrics.

[b]Included one dicentric ring scored as one dicentric and one ring.

TABLE V.- COEFFICIENTS OF ABERRATION PRODUCTION

[Gemini XI mission]

Source	Deletions, 1×10^4/cell/rad^2	Rings and dicentrics, 1×10^6/cell/rad^2
Ground-based control	10.22 ± 0.87	3.84 ± 0.70
Inflight system	9.01 ± 0.98	3.64 ± 0.26
Run 1	8.16 ± 1.12	3.22 ± 0.57

The operating handle is in nonirradiate position. The thermoelectric refrigeration unit and associated electronics are enclosed in the insulated outer casing. Heat transfer to the spacecraft structure is through the bottom surface.

Figure 1. - Experimental device before sealing; the operating handle is in the nonirradiated position.

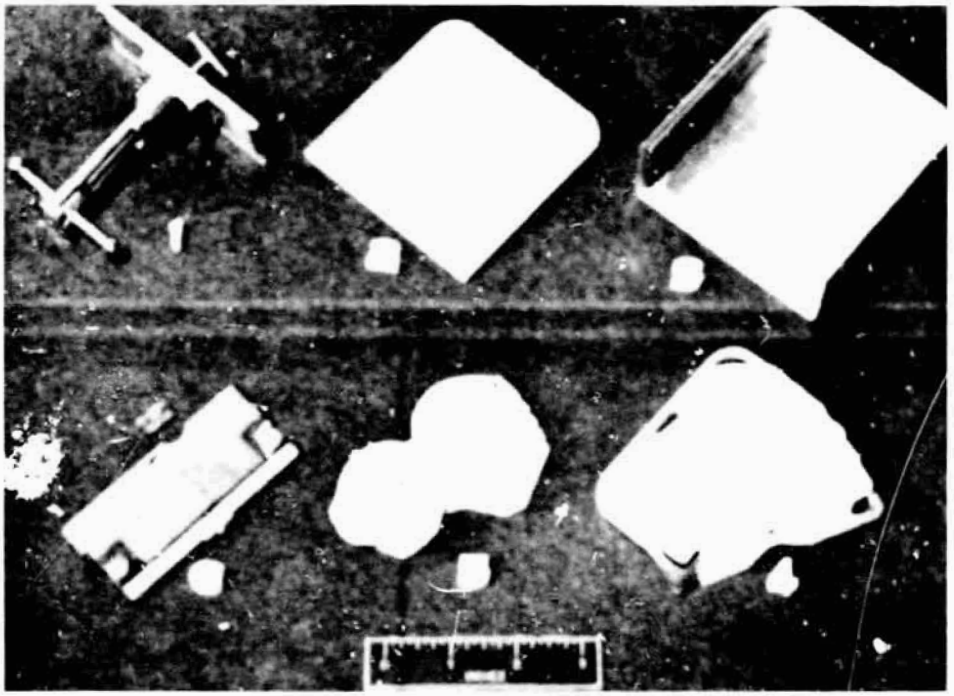

Figure 2. - Major components of the experimental device.

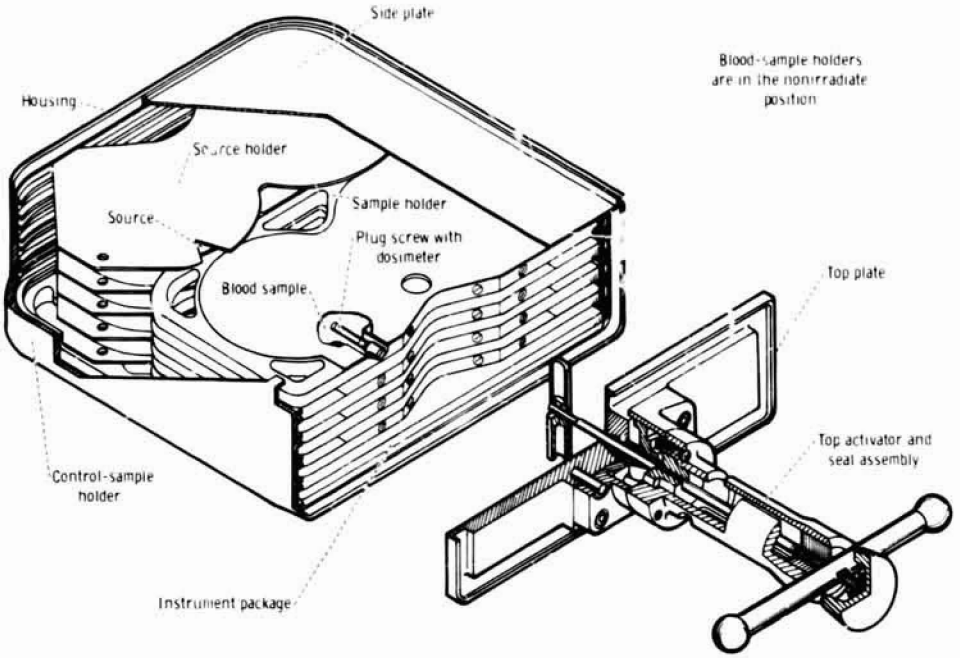

Figure 3. - The geometrical relationships between the blood samples and the ^{32}P β-ray source plates of the experimental device.

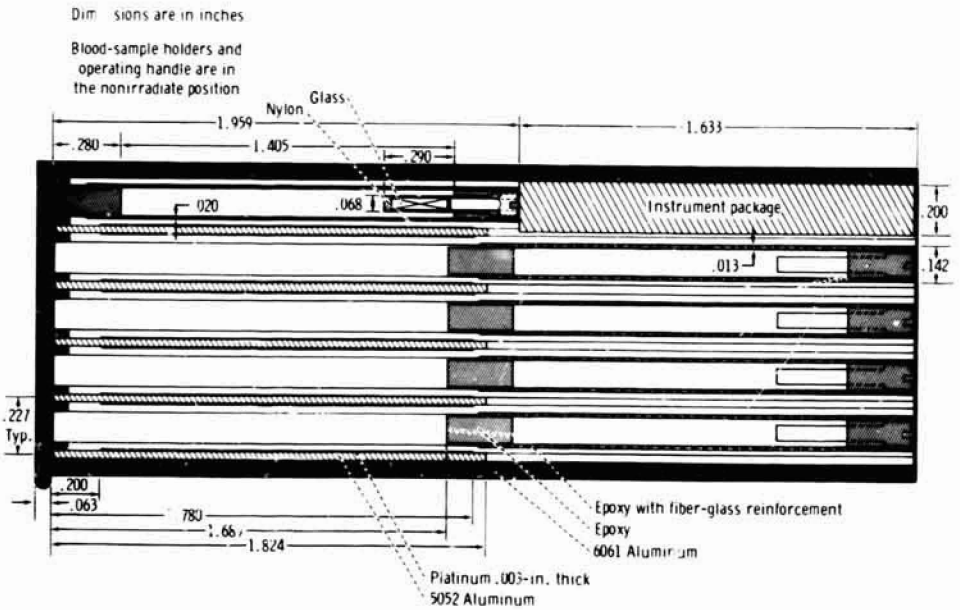

Figure 4. - The relationships between the component parts of the experimental device.

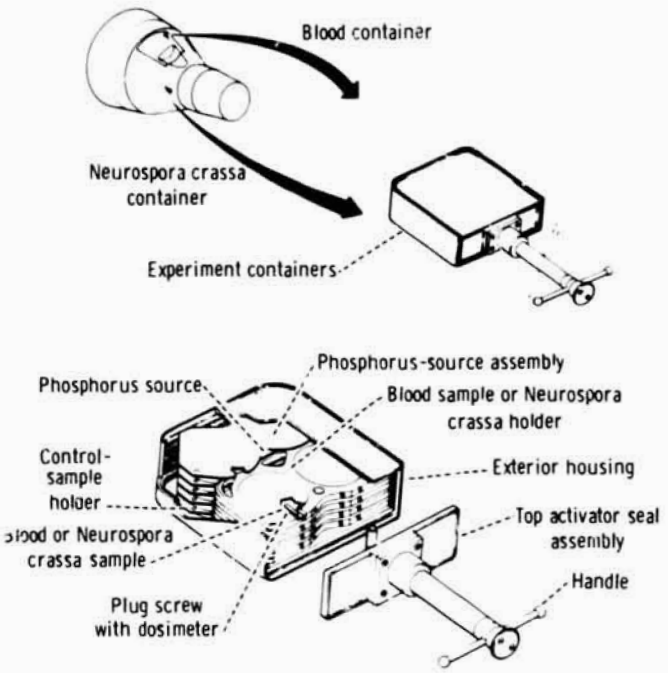

Figure 5. - Blood cell and Neurospora crassa experiment equipment.

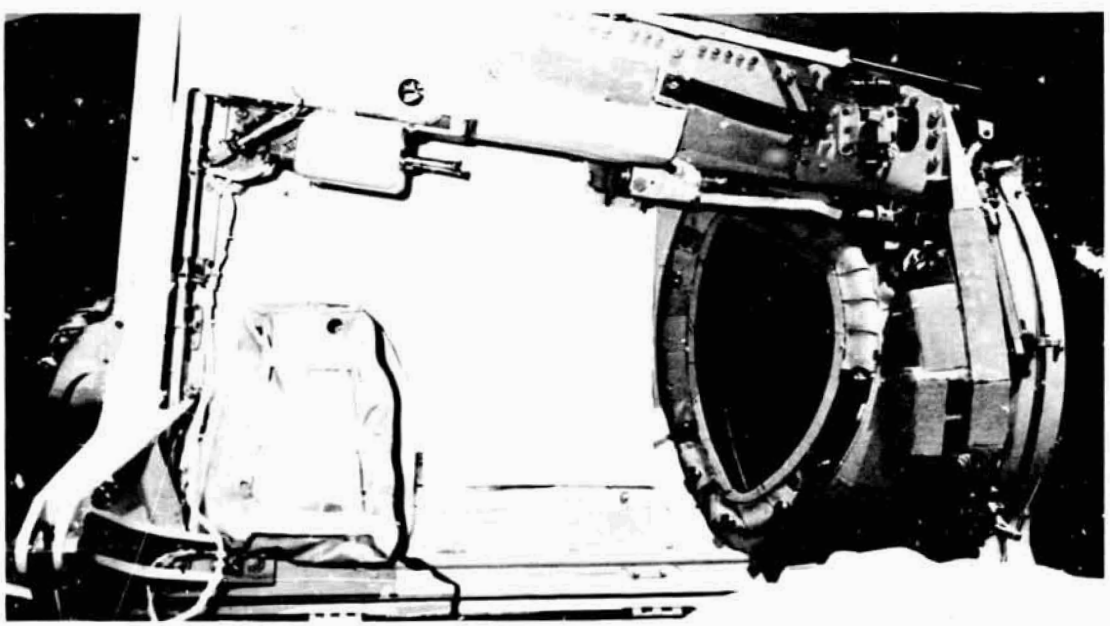

Figure 6. - Blood cell experimental equipment mounted on the Gemini IX left-hand hatch, shown shortly after spacecraft recovery.

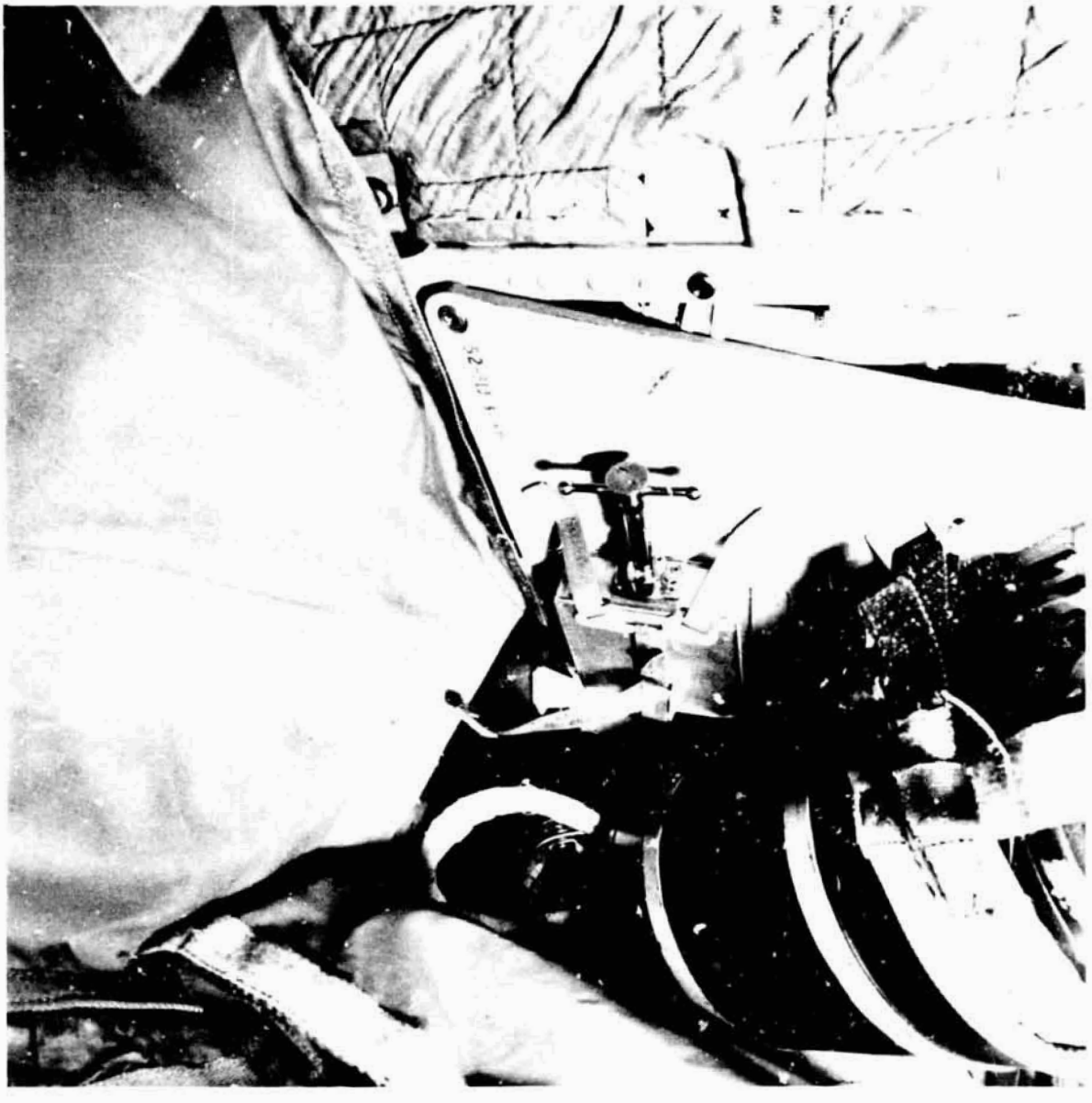

Figure 7. - Location of Neurospora crassa experimental device on the in-board side of the right-side foot well of the Gemini XI spacecraft.

Figure 8. - An irradiated cell involving a single-break chromosome deletion.

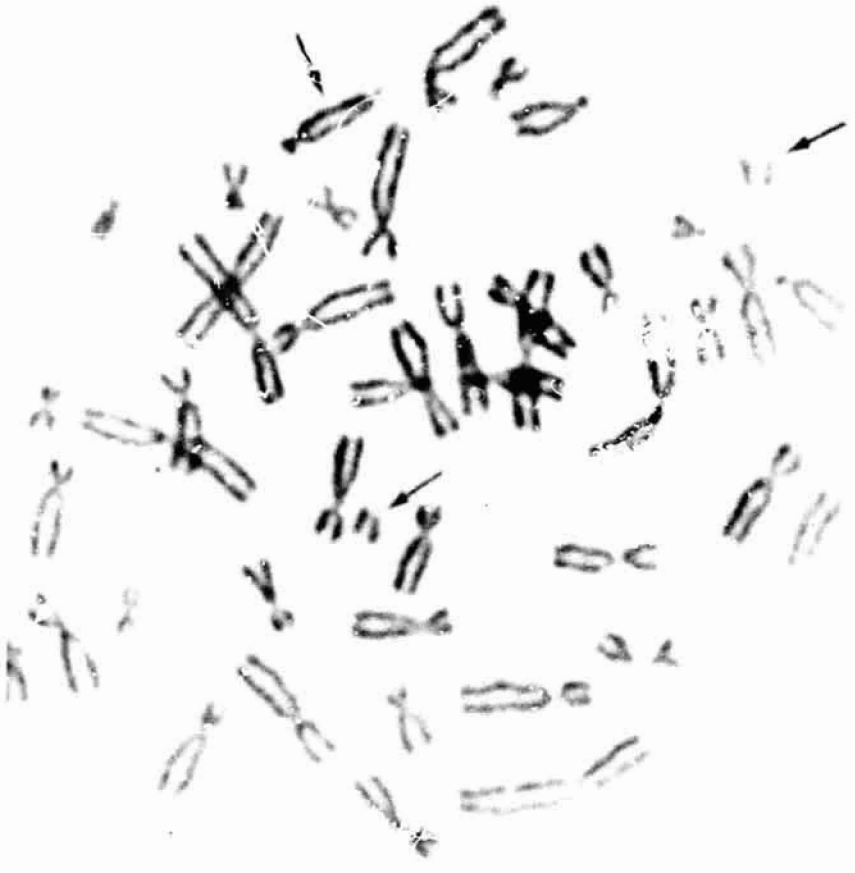

Figure 9 - An irradiated cell showing a typical two-break abberation, a dicentric chromosome with fragment.

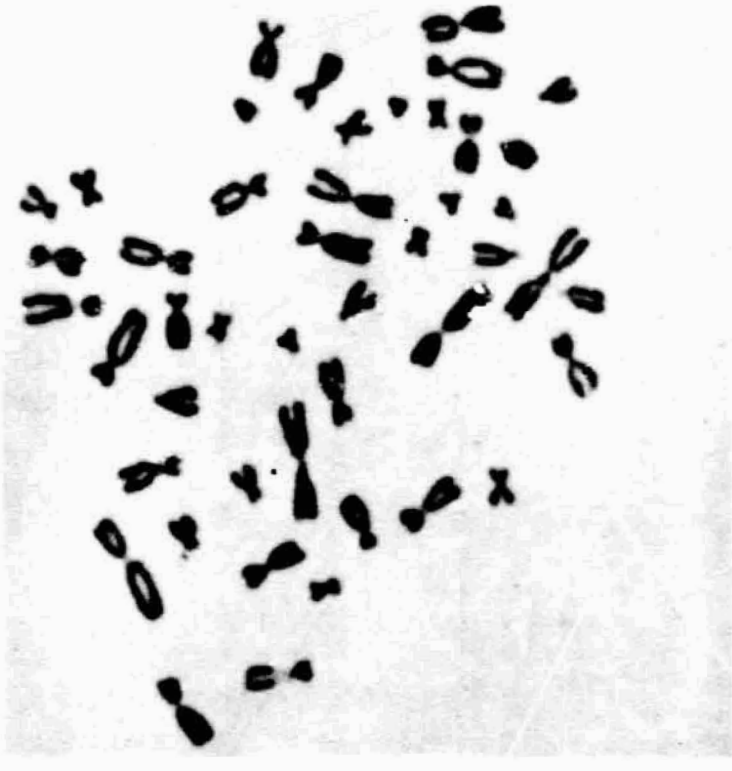

Figure 10. - A chromosome preparation of a normal unirradiated cell without chromosome breaks, fragments, or rearrangements.

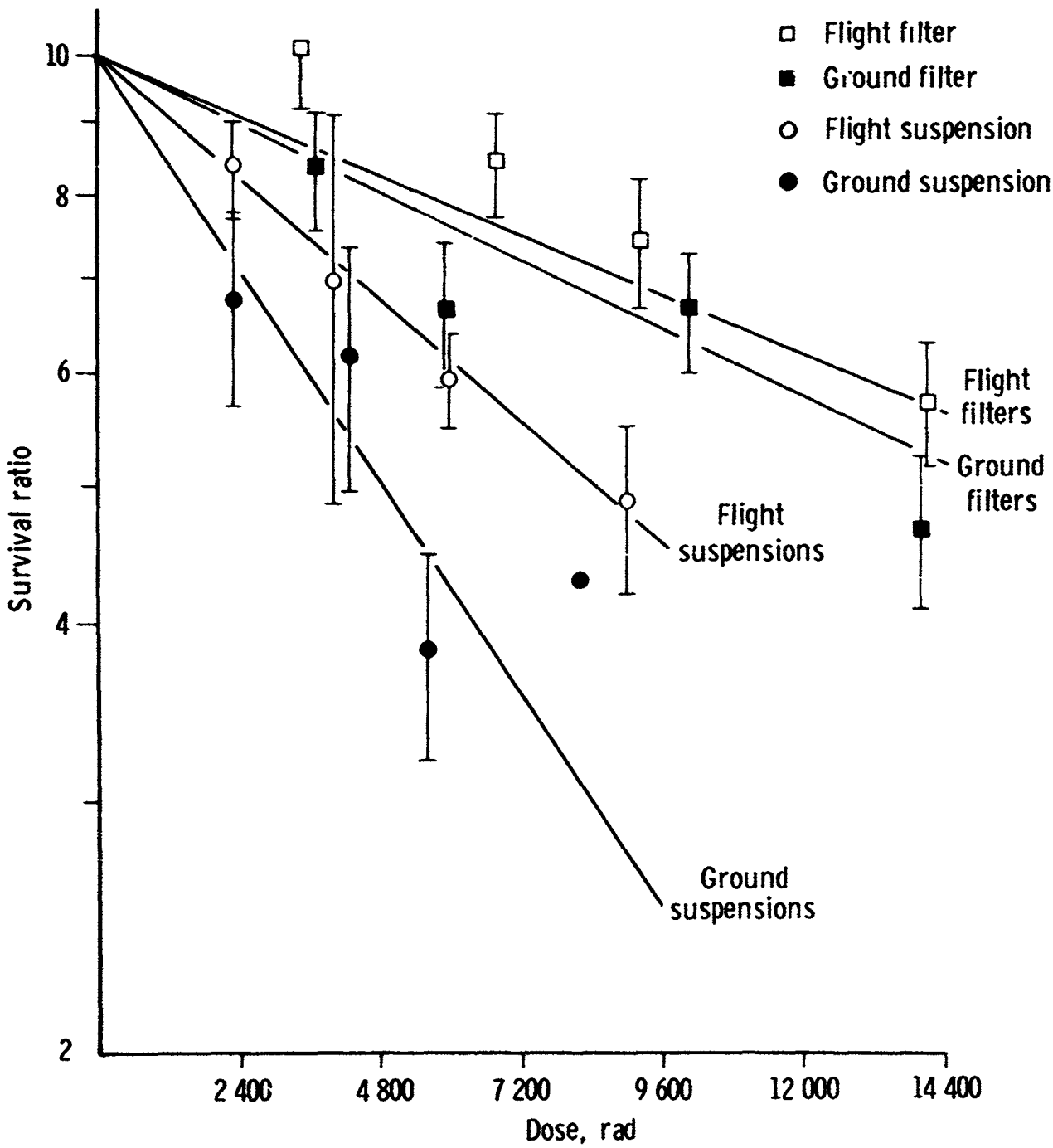

Figure 11. - Dose-effect curves for survival of flight samples and ground-based samples of Neurospora crassa.

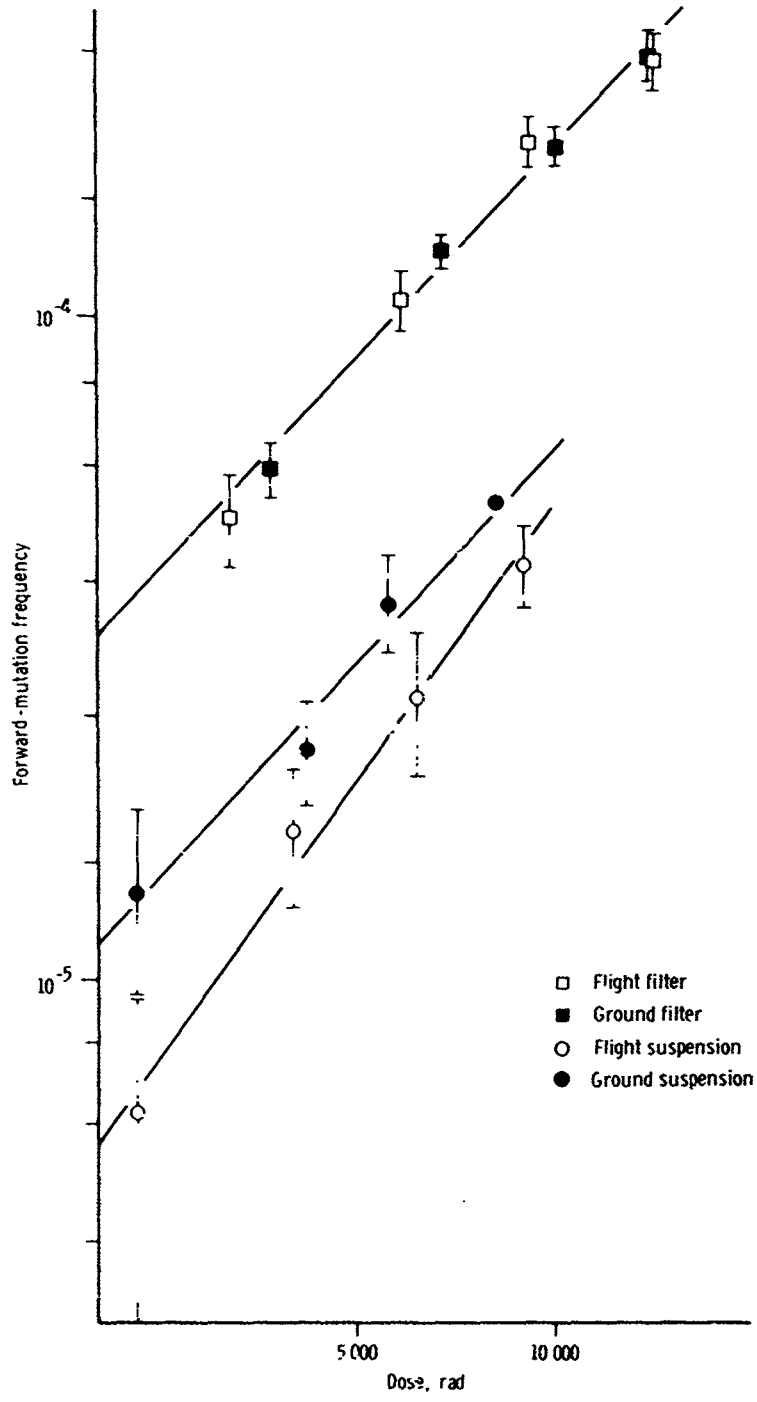

Figure 12. - Dose-effect curves for forward mutation in the ad-3 region for flight samples and ground samples of Neurospora crassa.

EXPERIMENT S003

FROG EGG GROWTH

By Richard S. Young* and J. W. Tremor*

OBJECTIVE

The objective of the experiment was to determine the effect of weightlessness on the ability of a fertilized frog egg to divide normally and to differentiate and form a normal embryo. This experiment was first attempted on the Gemini VIII mission and was completed only partially because of the early termination of that mission.

EQUIPMENT

The experiment was contained in a package mounted on the right-hand hatch of the Gemini vehicle. The package had four experimental chambers containing frog eggs in water and had a partitioned section containing a fixative (5 percent formalin). The entire package was insulated and contained a thermal-control system to maintain a temperature of approximately 70° F at all times during the mission, including during extravehicular activity (EVA). Electrical power was obtained from the spacecraft electrical system. The experiment was actuated by means of two handles on the outside of the package. These handles, and a toggle switch for the heating element, were manipulated by the pilot, either by request of ground-control personnel or according to a schedule. Identical equipment was used and controlled on the ground during these same time sequences. The experimental equipment is shown assembled in figure 1, and the hardware is shown partially disassembled in figure 2.

PROCEDURES

Eggs were obtained from several dozen frogs (Rana pipiens). An injection of a frog pituitary gland extract, approximately 48 hours prior to lift-off, ensured ovulation at the desired time. The best of these eggs (from two frogs) were selected for flight and were fertilized by immersion in a sperm suspension made by maceration of frog testes in spring water. The fertilized eggs were removed to a cold room (43° F) and were placed in approximately 10 cubic centimeters of spring water in each of the four experimental chambers. The fixative was placed behind leakproof partitions in three of the four chambers. The fourth chamber contained water instead of formalin.

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Five eggs were loaded into each chamber; thus, 20 eggs were flown. Two sets of control experiments were prepared in identical equipment on the ground. The first control was to be conducted simultaneously with the inflight experiment. The second control was delayed approximately 2 hours so that changes in temperature experienced by the inflight experiment could be duplicated more precisely than in the simultaneous control. Because telemetered temperatures were not received continuously, a delayed control was necessary to duplicate the actual inflight environment.

The inflight experiment was installed in the spacecraft approximately 2.5 hours prior to lift-off. The fertilized eggs were kept at approximately 43° F to retard the first cell division until installation in the spacecraft. Cooling of the eggs was sufficient to retard first cleavage until the zero-gravity phase of the flight. At 41 hours g.e.t., the pilot was scheduled to turn one handle on experimental package to inject the formalin fixative into two of the four egg chambers. This was to kill the eggs in these two chambers and preserve them for microscopic study after recovery. The other handle was scheduled to be actuated at 85 hours g.e.t. to fix the eggs in one of the remaining two chambers. The last chamber was unfixed and the embryos flown in that chamber were recovered alive. All eggs and embryos were studied after recovery for gross morphological abnormalities in cleavage planes and in differentiation. Also, histological examination and electron microscopic studies were accomplished.

RESULTS

Successful early cleavage stages were attained during the Gemini VIII mission. Because of the short duration of this flight, the later cleavage and developmental stages were not obtained. This was the reason for repetition of the experiment on the Gemini XII mission. Postflight analysis of the results from this mission were indicative that all phases of the experiment were performed as scheduled and with good results. The desired later cleavage and embryonic stages were obtained to complete the experiment successfully.

The experiment package was maintained at temperatures between 66° and 74° F throughout the mission, stabilizing at approximately 72° F. Although this temperature was 4° F above the expected average, it was below the maximum allowable of 80° F. The temperature history is shown in figure 3. The experiment-package toggle switch, to turn on the internal heater, was actuated at 17:41:55 g.e.t. to ensure proper experiment temperatures during extravehicular activities. Actuation of the first handle was accomplished at 41:43:40 g.e.t. to release the formalin and fix the eggs in two of the chambers. The other handle was actuated at 85:10:22 g.e.t. to fix the eggs in the third chamber. This completed participation of the crewmembers in this experiment.

The 10 embryos in the 40-hour fixation chambers appeared to be morphologically normal when compared with the ground-based control experiments. No abnormalities were detected by gross observation in either the flight embryos or in the ground-based control embryos. Ground-based control embryos fixed at 2 hours, 47 hours, and 100 hours, respectively, are shown in figures 4 to 6. An inflight frog embryo, fixed at 41 hours, is shown in figure 7. The five embryos fixed at 85 hours g.e.t. were properly developed and wer morphologically normal tadpoles. The five embryos

which were not fixed were properly developed, live, swimming tadpoles when the experimental package was opened on board the prime recovery ship (fig. 8). Morphologically, three of these embryos were normal and two were abnormal. However, the abnormalities were not inconsistent with the ground-based control embryos, and they cannot be ascribed to development under a zero-gravity environment. The five live tadpoles died several hours after their recovery and were fixed for histological sectioning. Reasons for their deaths have not been determined. Embryo specimens were sectioned for histological study; studies were indicative of normal development (figs. 9 and 10).

CONCLUSIONS

Although the frog egg orients itself with respect to gravity during its early development, a gravitational field apparently is not necessary for the egg to divide normally. This is a preliminary conclusion established after the Gemini VIII mission. It can now be concluded that gravity is not necessary for differentiation and morphological changes in the later stages of embryonic development. Whether or not the frog egg will divide and develop normally if it is also fertilized under zero-gravity conditions (so that it never becomes oriented with respect to gravity) is still an unanswered question.

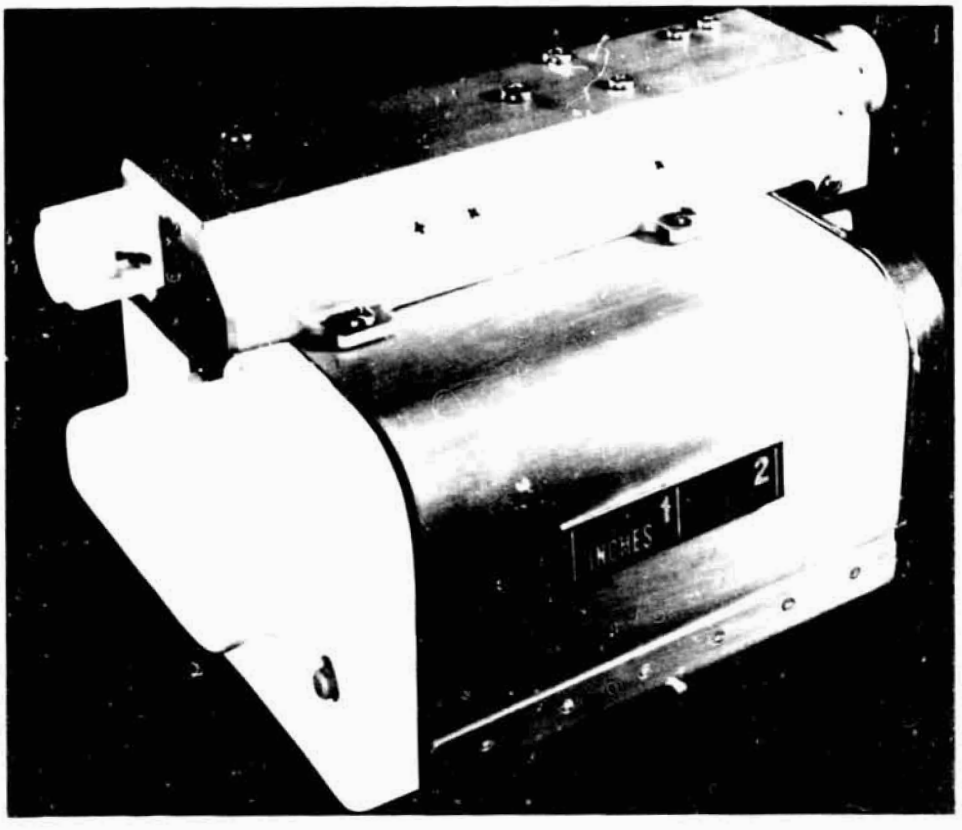

Figure 1. - The experiment package.

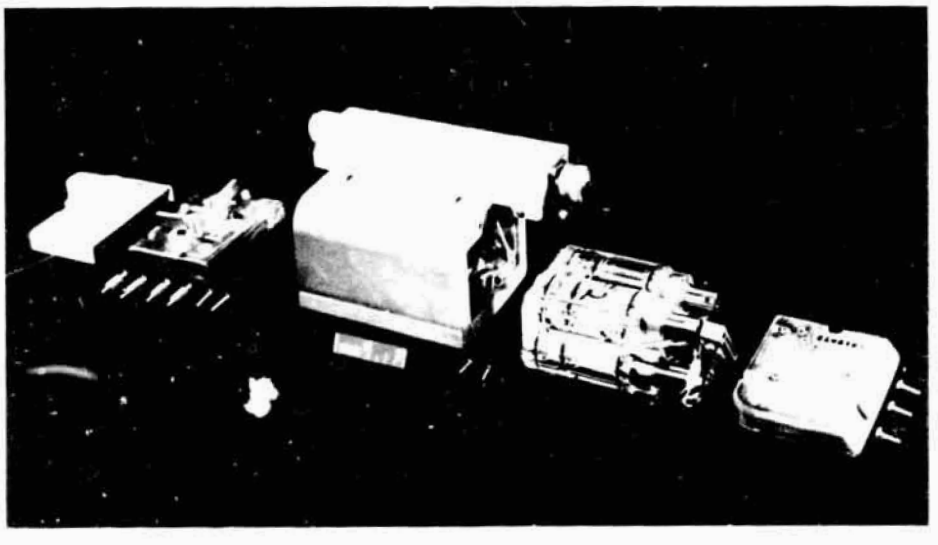

Figure 2. - The experiment package partially disassembled.

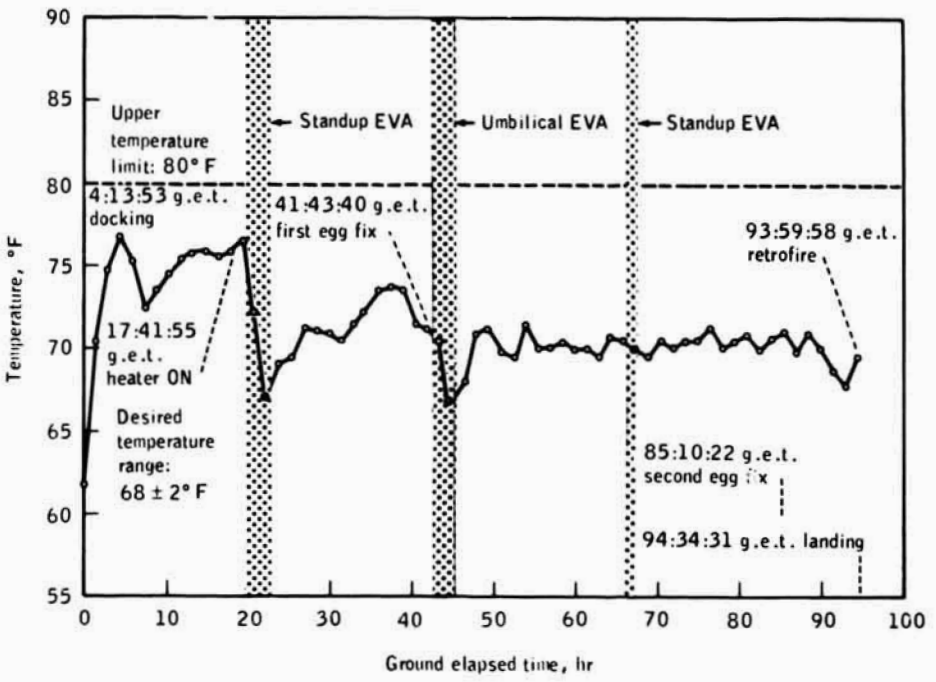

Figure 3. - The internal temperatures of the frog-egg package.

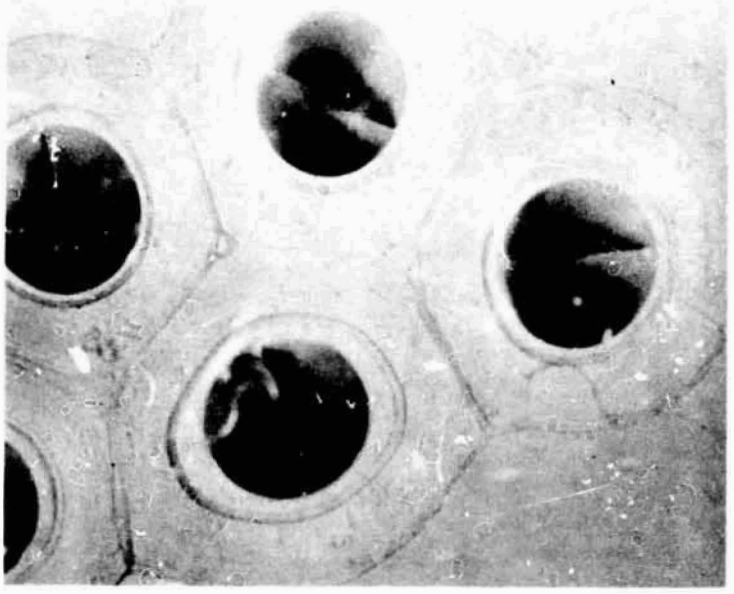

Figure 4. - The control embryo at 2 hours.

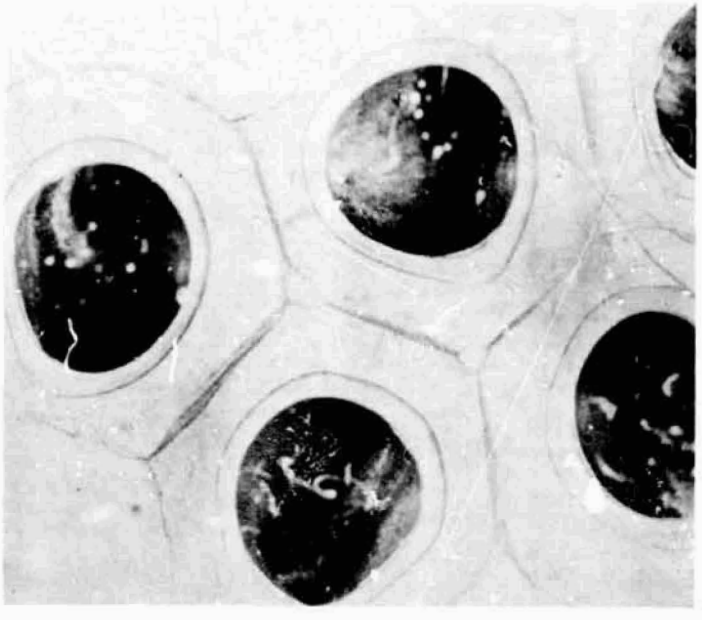

Figure 5. - The control embryo at 47 hours.

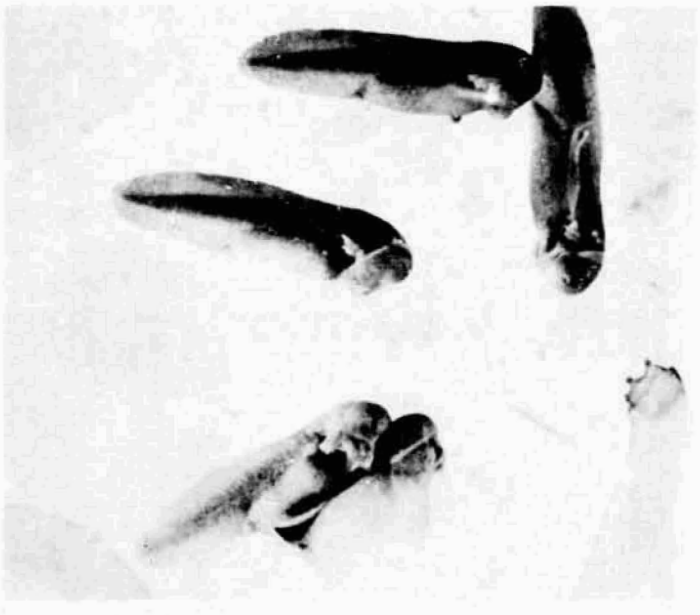

Figure 6. - The control embryo at 100 hours.

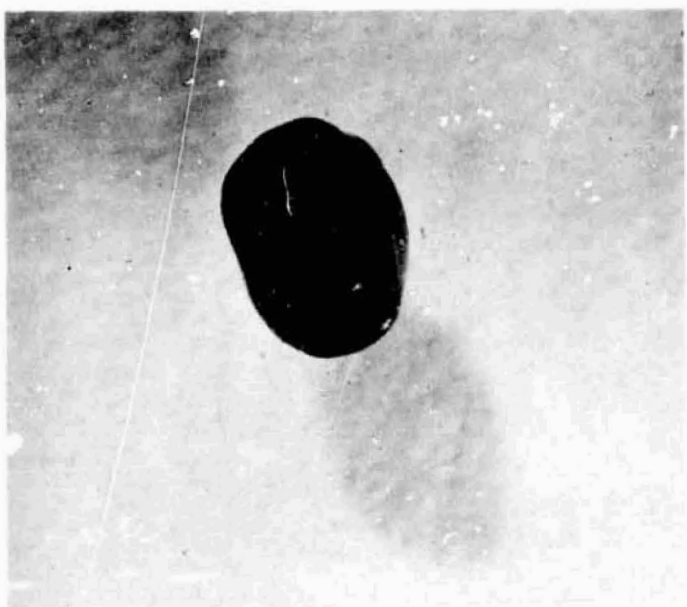

Figure 7. - The experimental embryo at 41 hours.

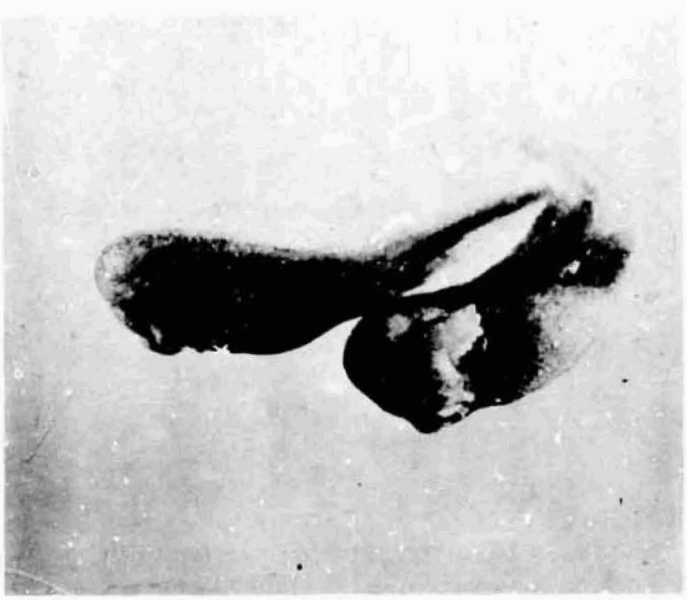

Figure 8. - The fixed experimental embryo returned after 4 days in flight (shown fixed).

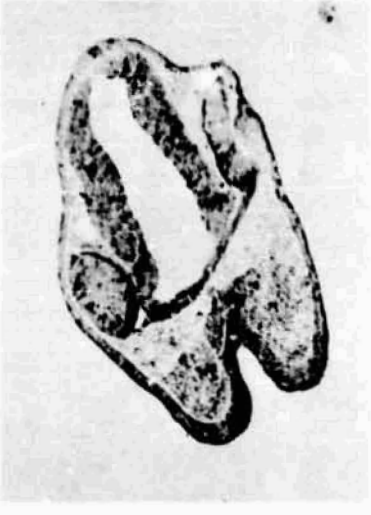

Figure 9. - The anterior section of the control embryo.

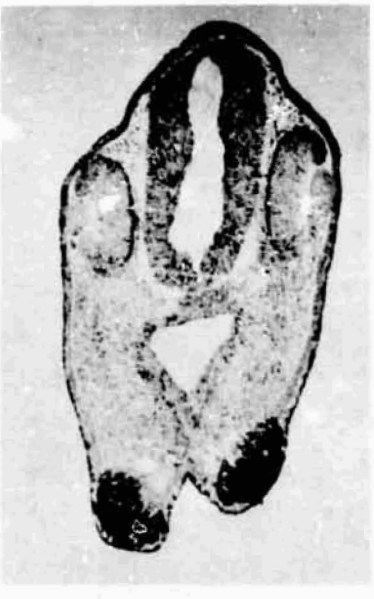

Figure 10. - The anterior section of the experimental embryo.

EXPERIMENT S002

SEA URCHIN EGG FERTILIZATION AND DEVELOPMENT

By Richard S. Young*

INTRODUCTION

The objective of Experiment S002, which was flown on the Gemini III mission, was the investigation of the effects of subgravity (much less than unit gravity) on fertilization, cell division, differentiation, and growth of a relatively simple biological system (eggs of the sea urchin Arbacia punctulata).

EQUIPMENT

The experimental apparatus was cylindrical and consisted of eight specimen chambers (fig. 1). Each chamber was divided into three compartments so that the sperm, ova, and fixative solutions were separated. Rotation of a handle actuated either fertilization or the fixation process within the chambers.

PROCEDURE

The specimens in four chambers were fertilized just before launch; specimens in the other four chambers were fertilized shortly after orbital insertion. Growth of specimens in each group of fertilized eggs was inhibited at different stages of development by the addition of the fixative solution. Simultaneously with the inflight experiment, an identical experiment was performed on earth.

Performance of the experiment necessitated five scheduled manipulations. That is, the handle was rotated 12° to the right and released, after which it returned to the start position. A summary of the manipulations is shown in table I.

Each manipulation was verified so that the manipulation of the ground-based control experiment could be synchronized with the inflight experiment. Cabin temperature and time were recorded for each inflight experiment manipulation.

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RESULTS

Immediately after spacecraft recovery, the experimental apparatus was removed and returned to Cape Kennedy, Florida, for analysis. This analysis was a comparison of the inflight and ground-based experimental specimens.

The experiment was flown and recovered as scheduled. However, the experiment objectives were not achieved, primarily for mechanical reasons. There may have been sufficient leakage from the formalin chambers to result in egg damage. Also, the operation mechanism failed. After mechanical failure, manipulation of the handle did not operate the device properly. These problems resulted in an incomplete experiment and in conditions that were prohibitive to accurate interpretation of that portion of the experiment that was completed.

TABLE I. - SCHEDULED OPERATIONS

Time	Operation	Description
30 minutes prelaunch	1	Fertilization of specimens in chambers 1 to 4
00:20:00 g.e.t.	2 and 3	Fertilization of specimens in chambers 5 to 8
		Fixation of specimens in chambers 2 and 4
01:10:00 g.e.t.	4	Fixation of specimens in chambers 1, 3, 5, and 6
03:50:00 g.e.t.	5	Fixation of specimens in chambers 7 and 8

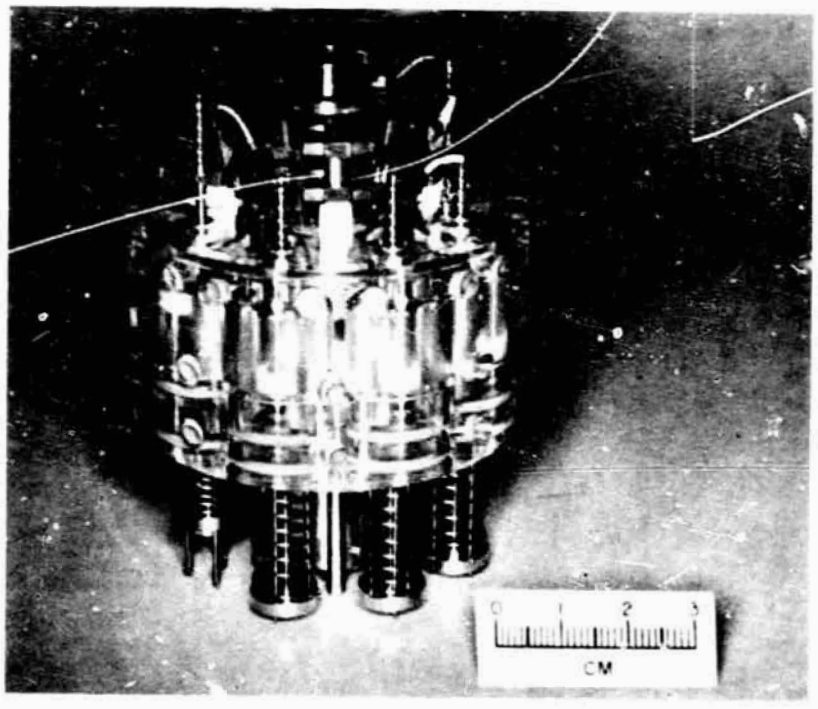

Figure 1. - The specimen chambers used in Experiment S002.