SPACE MEDICINE DIRECTORATE

OFFICE OF MANNED SPACE FLIGHT

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

A REVIEW OF MEDICAL RESULTS OF GEMINI 7 AND RELATED FLIGHTS

HELD AT:

MANAGEMENT CENTER

JOHN F. KENNEDY SPACE CENTER

KENNEDY SPACE CENTER, FLORIDA

AUGUST 23, 1966

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INTRODUCTION

On August 23, 1966, a review of the medical findings of the fourteen day Gemini 7 mission and related flights was conducted.

This review was organized at the request of Dr. George E. Mueller, Associate Administrator for Manned Space Flight, and consisted of presentations by the Principal Investigators of the Gemini Medical Flight Experiments and by the Director, Medical Research and Operations, Manned Spacecraft Center.

This document is a compilation of the material presented at the review. The Principals cooperated most significantly by reviewing a transcription of a tape recording of their presentation, editing and providing a final version for publication. Without this most generous assistance, this document could not have been published.

Table I, which follows immediately after this Introduction, is presented to acquaint the reader with the scope and sequence of medical measurements and experiments which were conducted during Project Gemini. This review was held prior to the conduct of the Gemini 11 and 12 missions, therefore, material derived from those flights is not included in this document.

Grateful acknowledgement is given to Miss Joyce M. Patterson, Space Medicine, for her efforts in compiling the final papers and preparing the material for publication.

E. J. McLaughlin

E. J. McLaughlin, Ph.D.
Biomedical Program Specialist
Space Medicine

TABLE I

MEDICAL EXPERIMENTS/MEASUREMENTS CONDUCTED ON FLIGHT CREWS
DURING PROJECT GEMINI

EXPERIMENT/MEASUREMENT IN-FLIGHT	GEMINI-3 5 Hours#	GEMINI-4 98 Hours#	GEMINI-5 191 Hours#	GEMINI-6 26 Hours#	GEMINI-7 331 Hours#	GEMINI-8 11 Hours#	GEMINI-9 72 Hours#	GEMINI-10 71 Hours#	GEMINI-11 71 Hours#	GEMINI-12 95 Hours#	TOTAL
M001 - Cardiovascular Conditioning			X		X						2
M003 - In-Flight Exerciser		X	X		X						3
M004 - In-Flight Phonocardiogram		X	X		X						3
M005 - Bioassays Body Fluids					X	X					2
M006 - Bone Deminera-lization		X	X		X						3
M007 - Calcium Balance Study					X						1
M008 - In-Flight Sleep Analysis					X						1
M009 - Human Otolith Function			X		X						1
Heart Rate	X	X	X	X	X	X	X	X	X	X	10
Respiration Rate	X	X	X	X	X	X	X	X	X	X	10
Blood Pressure	X	X	X	X	X						5
Oral Temperature	X	X	X	X	X	X	X	A	A	A	7
PRE AND POST FLIGHT*											
Tilt Table	X	X	X	X	X	✓	X	X	X	X	10
Hematology*	X	X	X	X	X	X	X	X	X	X	10
A. Blood Volume		X	X		X			X	X	X	6
B. RBC Indices			X		X			X	X	X	5
C. Reticulocyte Count			X		X			X	X	X	5
Urine*	X	X	X	X	X	X	X	X			9
Exercise Tolerance					X		X	X	X	X	5
Body Weight	X	X	X	X	X		X	X		X	8

A = Available; # = To Nearest Hour; ✓ = Pre-Flight Only
*Standard blood and urine examinations, physical examinations and verbal debriefings followed each flight.

Medical Experiment M001

CARDIOVASCULAR CONDITIONING

Principal Investigators:

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William V. Judy
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N68-10182

EXPERIMENT M-1, CARDIOVASCULAR CONDITIONING

By

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and

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INTRODUCTION

Ground baseline studies in support of Experiment M-1 indicated that leg cuffs alone, when inflated to 70 to 75 millimeters of mercury for 2 out of every 6 minutes, provided protection against cardiovascular "deconditioning" which was occasioned by 6 hours of water immersion (ref. 1). Four healthy, male subjects were immersed in water to neck level for a 6-hour period on two separate occasions, 2 days apart. Figures 39-1, 39-2, 39-3, and 39-4 indicate that 6 hours of water immersion resulted in cardiovascular "deconditioning", as evidenced by cardioacceleration in excess of that observed during the control tilt and by the occurrence of syncope in two of the four subjects. The tilt responses following the second period of immersion, during which leg cuffs were utilized, revealed that a definite protective effect was achieved. Cardioacceleration was less pronounced, and no syncope occurred.

The physiological mechanisms responsible for the observed efficacy of the cuff technique remain obscure. One might postulate that the cuffs prevent thoracic blood volume overload, thus inhibiting the so-called Gauer-Henry reflex with its resultant diuresis and diminished effective circulating blood volume. Alternatively, or perhaps additionally, one might postulate that the cuffs induce an intermittent artificial hydrostatic gradient (by increasing 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 1-g 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 increase the effective circulating blood volume upon return to a 1-g environment following weightlessness or its simulation. The precise mechanism, or mechanisms, of action must await further study.

EQUIPMENT AND METHODS

The equipment used in Experiment M-1 consisted of a pneumatic timing or cycling system and a pair of venous pressure cuffs (figs. 39-5 and 39-6). The cycling system was entirely pneumatic and alternately inflated and deflated the leg cuffs attached to the pilot's thighs. The system flown on Gemini V (fig. 39-7) consisted of three basic components:

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

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

(3) A pneumatic oscillator system for periodically inflating and deflating the leg cuffs.

The equipment flown on Gemini VII was almost identical with that used on Gemini V and was supplied with oxygen pressure from the spacecraft environmental control system. The pneumatic venous pressure cuffs were formfitted to the proximal thigh area of the pilot. The cuffs consisted essentially 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 to insure proper fit.

RESULTS

The Cardiovascular Conditioning Experiment (M-1) was flown on the Gemini V and VII missions. The pilots for these missions served as 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 13.5 days of the Gemini VII mission.

Prior to these missions, each crewmember was given a series of tilt-table tests. These control tilts are summarized in table 39-I, the numerical values indicated being mean values for the three control tilts. The results of six consecutive postflight tilts for the Gemini V command pilot and pilot are summarized in figures 39-8 and 39-9. Figure 39-10 summarizes the heart-rate change during the initial postflight tilt expressed as a percent of the preflight value for all the Gemini flights to date. The results of four consecutive postflight tilts for the Gemini VII command pilot are indicated in figures 39-11 through 39-14, and for the Gemini VII pilot in figures 39-15 through 39-18. Figure 39-19 summarizes the Gemini VII tilt-table data.

The crewmembers for both the Gemini V and VII missions exhibited increased resting pulse rates during the first 12 to 24 hours after recovery. Resting pulse rate changes for both crews are indicated as deviations from the preflight mean values in table 39-II.

The Gemini V crew exhibited a higher postflight mean resting pulse rate than did the Gemini VII crew, with a maximal difference of 2-fold (pilot's) occurring 2 to 4 hours after recovery. This elevated resting pulse rate gradually returned to the preflight levels. The Gemini VII crew exhibited a slight increase in postflight mean resting pulse rate over preflight levels; these values returned to preflight levels approximately 24 hours after recovery. The crewmembers for both Gemini V and VII exhibited changes in their resting systolic and diastolic blood pressures after the missions. These values are indicated as deviations from the preflight mean values in table 39-III.

All crewmembers had a decreased resting systolic blood pressure 2 to 4 hours after recovery. The Gemini V command pilot and the Gemini VII pilot maintained a lower-than-preflight systolic pressure throughout the postflight test period. All crewmembers exhibited a decreased resting diastolic blood pressure during each postflight tilt test except during the first and last tilts for the Gemini V command pilot, and during the second tilt for the Gemini VII pilot.

Daily changes in resting blood pressures are indicated in figures 39-9 and 39-19 as deviations from the preflight mean values.

During the postflight tilts, all the Gemini V and VII crewmembers exhibited increased pulse rates. Highest rates were observed during the tilts performed 2 to 4 hours after recovery. Pulse rate increases over preflight mean values for each postflight tilt are indicated in table 39-IV.

The Gemini V crew exhibited a twofold greater increase in pulse rate than did the Gemini VII crew during the first two postflight tilts. Although the Gemini VII crew sustained 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 is illustrated in figure 39-15. This untoward experience during 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 near preflight levels (figs. 39-8 and 39-19).

All crewmembers exhibited narrowed pulse pressures during the first postflight tilt (compared with the preflight tilt and the post-flight resting values). The Gemini V crew also exhibited a marked 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 Gemini V pilot returned to normal preflight levels after the second postflight tilt. The Gemini VII crew revealed no marked pulse pressure narrowing during their second, third, or fourth postflight tilts. The changes in systolic and diastolic pressures for both crews are indicated as deviations from the preflight mean values in table 39-V.

During the postflight recovery phase, the blood pressure values for the Gemini V and VII crewmembers returned to near pretilt resting levels (figs. 39-8 and 39-19). Leg volume changes during the postflight tilts indicate that the pilots who wore the pneumatic cuffs did indeed pool significantly less blood in their legs during the tilts than did the command pilots. These values are indicated at percent increase above the preflight control values in table 39-VI.

Although the Gemini VII pilot exhibited a vasodepressor type syncope during his first postflight tilt, he did not pool an excessive amount of blood in his legs (2 percent above the preflight control value). In addition, despite the fact that the V and VII command pilots pooled similar quantities of blood in their legs during the first postflight tilt, they differed considerably in the volume pooled during the remaining tilts. These differences, as well as those of the Gemini V pilot, may be a reflection primarily of differences in the state of hydration.

Changes in total blood volume, plasma volume, and red cell mass were determined before and after flight. Radioactive isotope (I^{125}, Cr^{51}) techniques were utilized in these measurements. The results are indicated as percent changes in table 39-VII.

The Gemini VII crew sustained a 4- to 15-percent increase in plasma volume during the 14-day mission, whereas the Gemini V crew lost 4 to 8 percent of their plasma volume during the 8-day mission. Both crews lost 7 to 20 percent of their red cell mass. The Gemini VII pilot, however, sustained only a 7-percent decrease as compared with the 19- to 20-percent decrease of the other crewmembers. The decrease in red cell mass and the increase in plasma volume of the Gemini VII crew offset each other to give a net zero-percent change in total blood volume, whereas the reduction in plasma volume and the red cell mass of the Gemini V crew contributed to the measured 13-percent decrease in total blood volume. These changes in total blood volume may reflect, in part, the state of hydration of the Gemini V crew, but this is not true in the case of the Gemini VII crew. The postflight changes in body weight are indicated in table 39-VIII.

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 previous missions of shorter duration.

DISCUSSION

The flight conditions operative during the Gemini VII mission were notably different from those of the Gemini V flight. These variables or differences were of sufficient magnitude that a comparison of the M-1 results on the two missions is difficult, if not impossible. Gemini VII was decidedly different from previous Gemini flights in that the Gemini VII crew did not wear their suits during an extensive portion of the 14-day flight. Their food and water intake was more nearly optimal than in previous flights; this assured better hydration and electrolyte balance, and the Gemini VII exercise regimen was more rigorous than that utilized on previous flights. These variables, in addition to the usual individual variability always present, preclude any direct comparison of M-1 results on the two missions. This is particularly true since the pulsatile cuffs were operative during only the first half of the 8-day Gemini V mission. The Gemini VII pilot's physiological measurements should be compared only with those of the command pilot who served as the "control" subject.

It is indeed true that the postflight physiological responses of the Gemini VII crew were vastly different from, and generally improved over, those observed in the Gemini V crew. It is difficult, however, to determine which of the previously mentioned variables were responsible for the observed improvement. This improvement is perhaps best shown in figure 39-8, which depicts the change in heart rate during the initial postflight tilts expressed as a percentage change with respect to the preflight value. The responses of the Gemini VII crew were far superior to the responses observed in the Gemini IV and V crews, and they were very nearly comparable to the response following 14 days of recumbency.

Additional comparisons between the Gemini VII and V crews may be summarized as follows:

(1) The Gemini VII crew exhibited less increase in postflight mean resting pulse rate (4 and 10 beats per minute versus 21 and 59 beats per minute).

(2) The Gemini VII crew exhibited signs of orthostatic intolerance for only 24 hours postflight; the Gemini V crew exhibited these signs for 24 to 48 hours.

(3) The Gemini VII crew pooled less blood in their lower extremities during all postflight tilts.

(4) The Gemini VII crew exhibited less pronounced changes in intravascular fluid volumes in the postflight period as shown in the following:

(a) Total blood volume: 0 percent versus 13 percent.

(b) Plasma volume: +15 percent and +4 percent versus -8 percent and -4 percent.

(c) Red cell mass: -19 percent and -7 percent versus -20 percent and -20 percent.

(5) The Gemini VII crew lost 10.0 pounds (command pilot) and 6.5 pounds (pilot) during their flight, while the Gemini V crew lost 7.5 and 8.5 pounds, respectively.

(6) The Gemini VII crew regained less body weight during the first 24 hours postflight (40 percent and 25 percent versus 50 percent).

The physiological findings in the Gemini V crew have been previously reported (ref. 2) and will only be summarized here.

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

(2) The pilot's pulse pressure narrowing during tilt and at rest was less pronounced than that of the command pilot.

(3) The pilot's plasma volume decreased 4 percent, and the command pilot's decreased 8 percent.

(4) The pilot's body weight loss was 7.5 pounds; the command pilot's was 8.5 pounds.

(5) The pooling of blood in the legs of the pilot was generally 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 demonstrating any protective effect of the pulsatile thigh cuffs. The Gemini V tilt data are summarized in figures 39-9 and 39-10.

Tilt-table data are graphically presented in figures 39-11 through 39-14 for the command pilot and in figures 39-15 through 39-18 for the pilot. All the Gemini VII tilt data are summarized in figure 39-19. During the first postflight tilt, the pilot exhibited signs of vasodepressor syncope; the procedure was interrupted, and the pilot was returned to the supine position. This episode occurred despite the fact that there was no evidence of increased pooling of blood in the lower extremities. In subsequent tilts, the pilot exhibited no further signs of syncope or 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 levels.

It would seem possible that this syncopal episode was the result of sudden vasodilitation with pooling of blood in the splanchnic area, diminished venous return, diminished cardiac output, and decline in cerebral bloodflow.

As previously mentioned, there was no diminution in the total blood volume of either crewmember after the mission. The pilot's plasma volume increased 4 percent; the command pilot's increased 15 percent. The pilot's red cell mass decreased 7 percent; the command pilot's, 19 percent. The pilot lost 6.5 pounds (nude body weight) 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 value within the first 24 hours following recovery.

The pilot's subsequent tilts revealed a moderate cardioacceleration during tilts 2 and 3, with normal pulse pressure and insignificant pooling of blood in the lower extremities (figs. 39-16, 39-17, and 39-18). The command pilot exhibited moderate cardioacceleration, marked narrowing of the pulse pressure, and increased pooling of blood in the lower extremities during the initial postflight tilt. Subsequent tilts revealed a rather rapid return to normal of heart rate and pulse pressure, but a greater tendency to pool blood in the legs than was observed in the pilot.

CONCLUSIONS

On the basis of the preflight and postflight data, it must be concluded that the pulsatile cuffs were not effective in lessening postflight orthostatic intolerance. This conclusion is based not on the occurrence of syncope during the pilot's first tilt, but rather on the higher heart rates observed during subsequent tilts, as compared with the control subject. It is well established that syncope in itself is a poor indicator of the extent or degree of cardiovascular deconditioning.

The pulsatile cuffs appeared to be effective in lessening the degree of postflight pooling of blood in the lower extremities as judged by the strain gage technique.

REFERENCES

1. VOGT, F. B.: Effect of Extremity Cuff-Tourniquets on Tilt-Table Tolerance After Water Immersion. Aerospace Medicine, vol. 36, May 1965, pp. 442-446.

2. DIETLEIN, L. F.; AND JUDY, W. V.: Experiment M-1, Cardiovascular Conditioning. Manned Space-Flight Experiments Interim Report, Gemini V Mission, Washington, D. C., January 1966.

FIGURE LEGEND

Fig. 39-1 Six-hour water immersion studies, first subject.

Fig. 39-2 Six-hour water immersion studies, second subject.

Fig. 39-3 Six-hour water immersion studies, third subject.

Fig. 39-4 Six-hour water immersion studies, fourth subject.

Fig. 39-5 Cardiovascular reflex conditioning system.

Fig. 39-6 Cardiovascular conditioning pneumatic cuffs.

Fig. 39-7 Schematic diagram of cardiovascular reflex conditioner..

Fig. 39-8 Summary of pulse rate during tilt-table studies of Gemini V flight crew.

Fig. 39-9 Summary of blood pressure during tilt-table studies for Gemini V flight crew.

Fig. 39-10 Pulse-rate change after Gemini missions compared with bed-rest data.

Fig. 39-11 Data from first tilt-table study of Gemini VII command pilot.

Fig. 39-12 Data from second tilt-table study of Gemini VII command pilot.

Fig. 39-13 Data from third tilt-table study of Gemini VII command pilot.

Fig. 39-14 Data from fourth tilt-table study of Gemini VII command pilot.

Fig. 39-15 Data from first tilt-table study of Gemini VII pilot.

Fig. 39-16 Data from second tilt-table study of Gemini VII pilot.

Fig. 39-17 Data from third tilt-table study of Gemini VII pilot.

Fig. 39-18 Data from fourth tilt-table study of Gemini VII pilot.

NASA-S-65-7382

SIX HOUR WATER IMMERSION STUDIES M-1

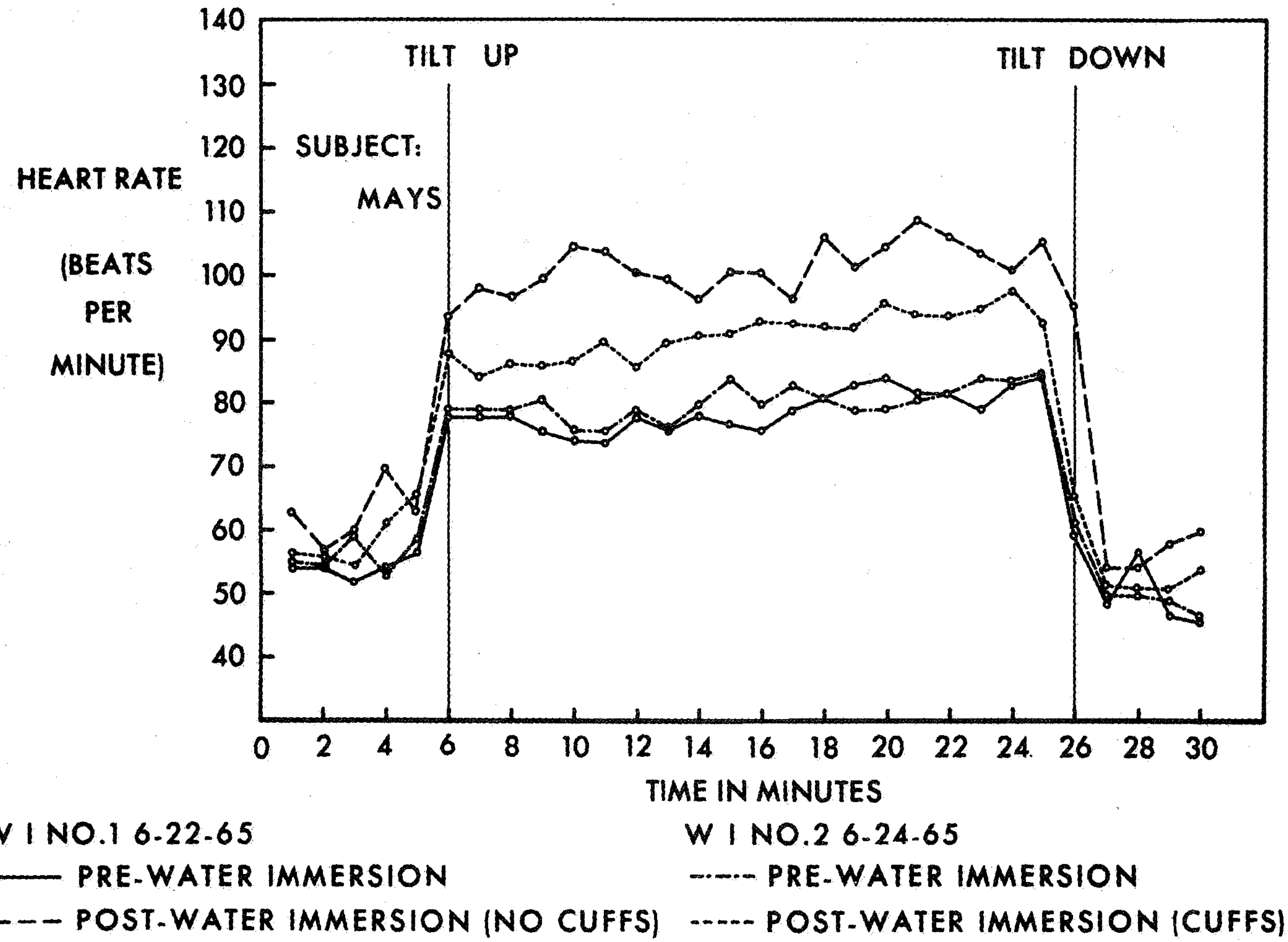


Fig. 39-1

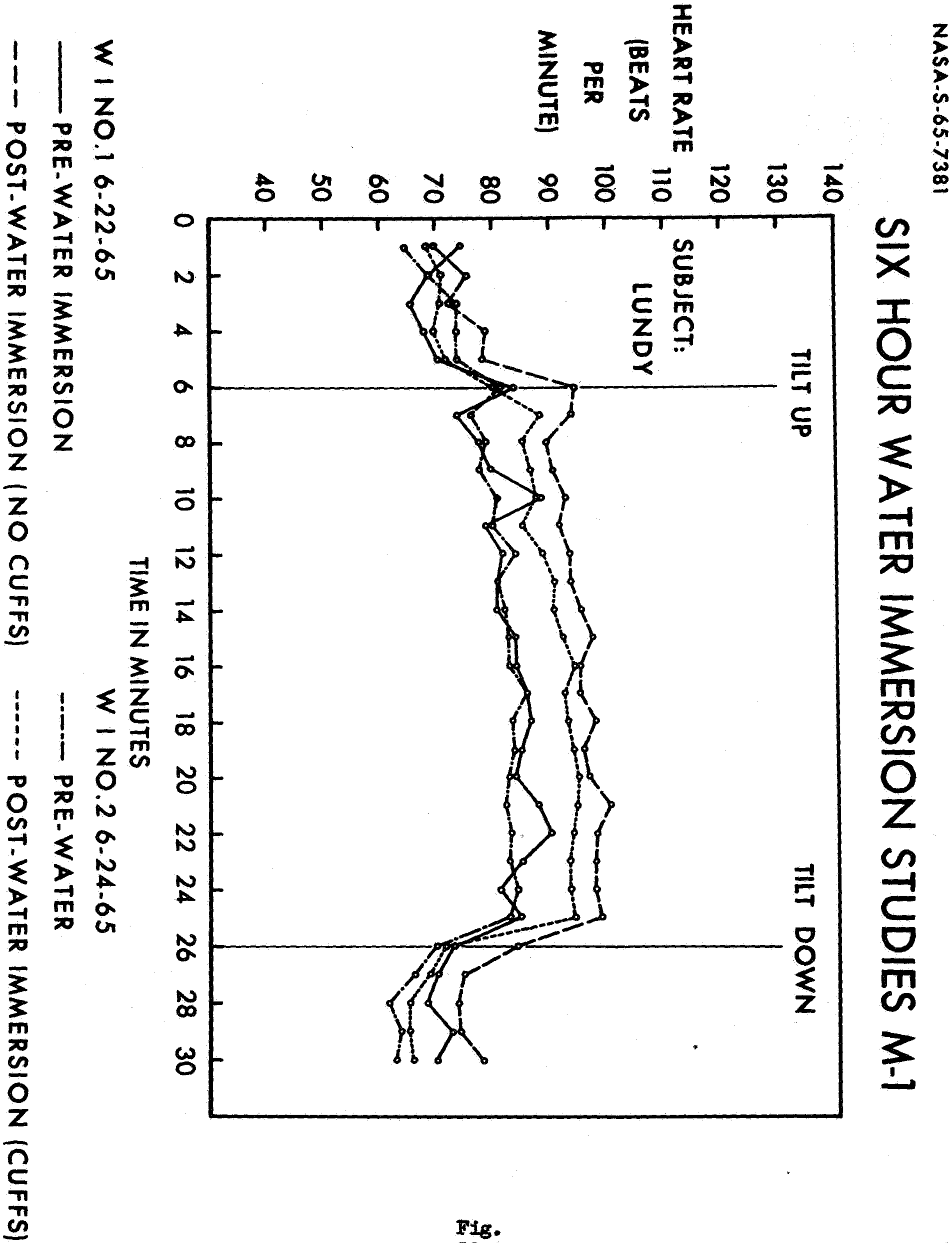

NASA-S-65-7381
SIX HOUR WATER IMMERSION STUDIES M-1
SUBJECT: LUNDY
TILT UP
TILT DOWN
HEART RATE (BEATS PER MINUTE)
140
130
120
110
100
90
80
70
60
50
40
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
TIME IN MINUTES
W I NO.1 6-22-65
PRE-WATER IMMERSION
POST-WATER IMMERSION (NO CUFFS)
W I NO.2 6-24-65
PRE-WATER
POST-WATER IMMERSION (CUFFS)

Fig.
39-2

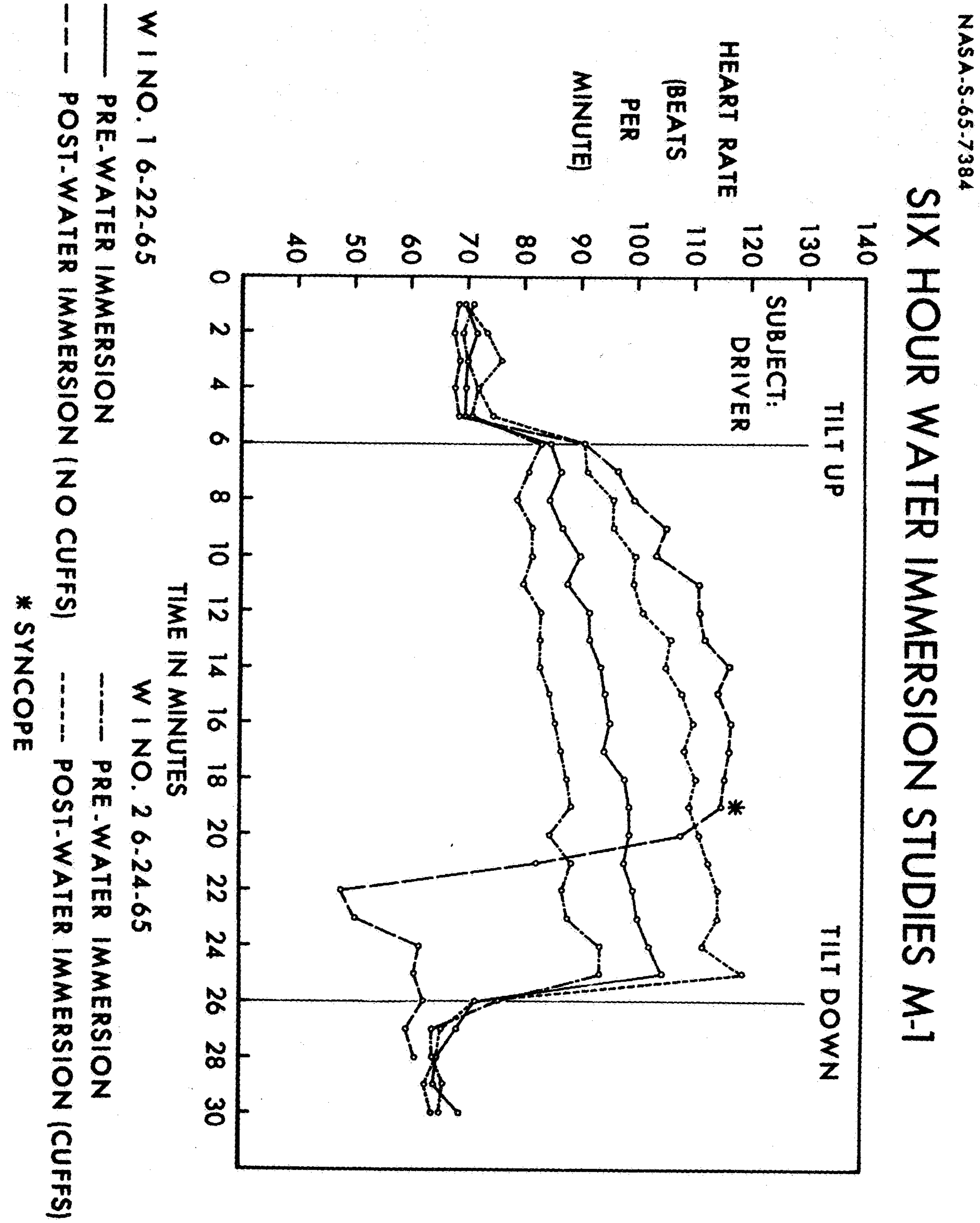

NASA-S-65-7384
SIX HOUR WATER IMMERSION STUDIES M-1
HEART RATE (BEATS PER MINUTE)
140
130
120
110
100
90
80
70
60
50
40
SUBJECT: DRIVER
TILT UP
TILT DOWN
*
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
TIME IN MINUTES
W I NO. 1 6-22-65
PRE-WATER IMMERSION
POST-WATER IMMERSION (NO CUFFS)
W I NO. 2 6-24-65
PRE-WATER IMMERSION
POST-WATER IMMERSION (CUFFS)
* SYNCOPE

Fig.
39-3

NASA-S-65-7383

SIX HOUR WATER IMMERSION STUDIES M-1

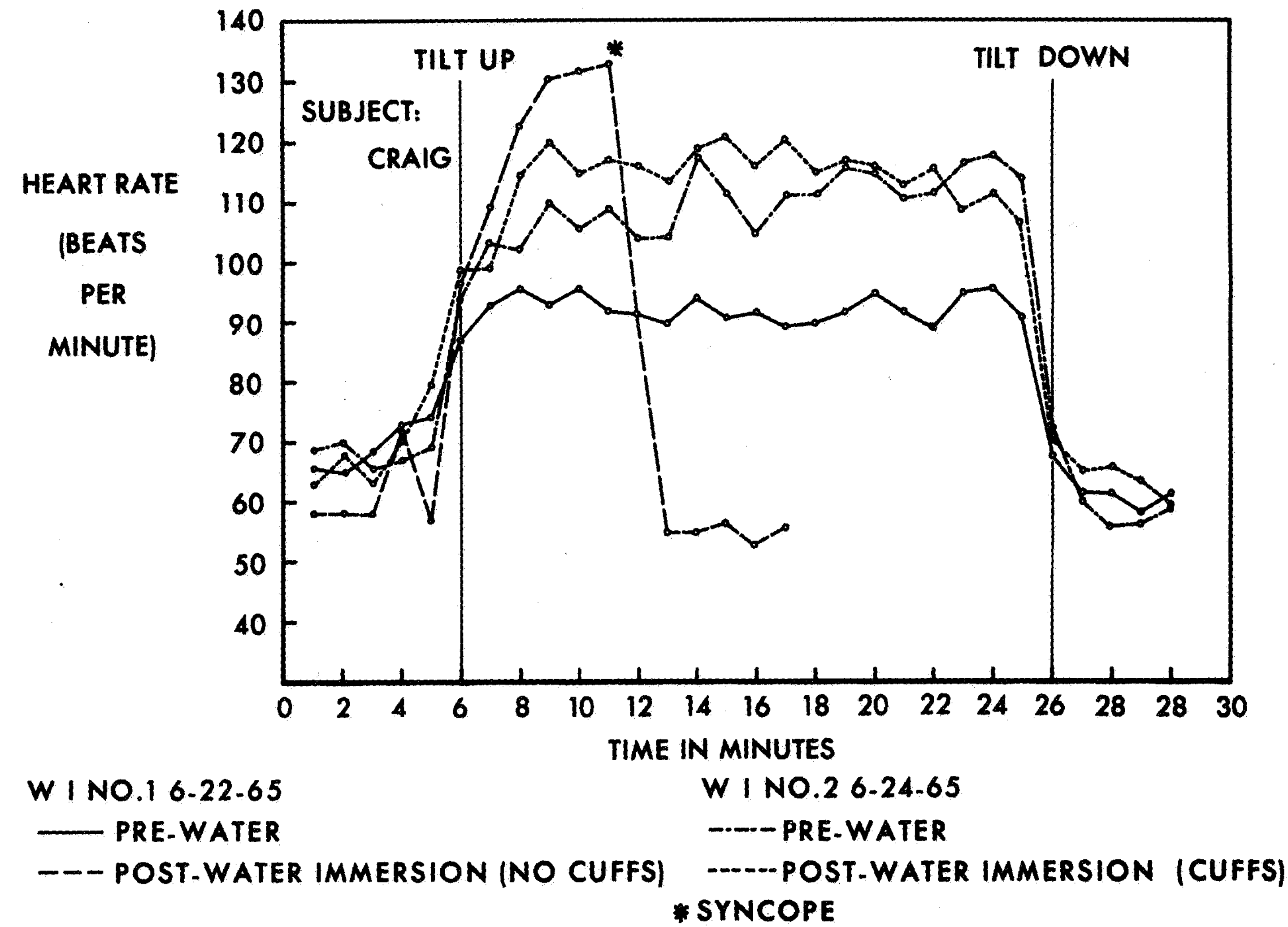


Fig. 39-4

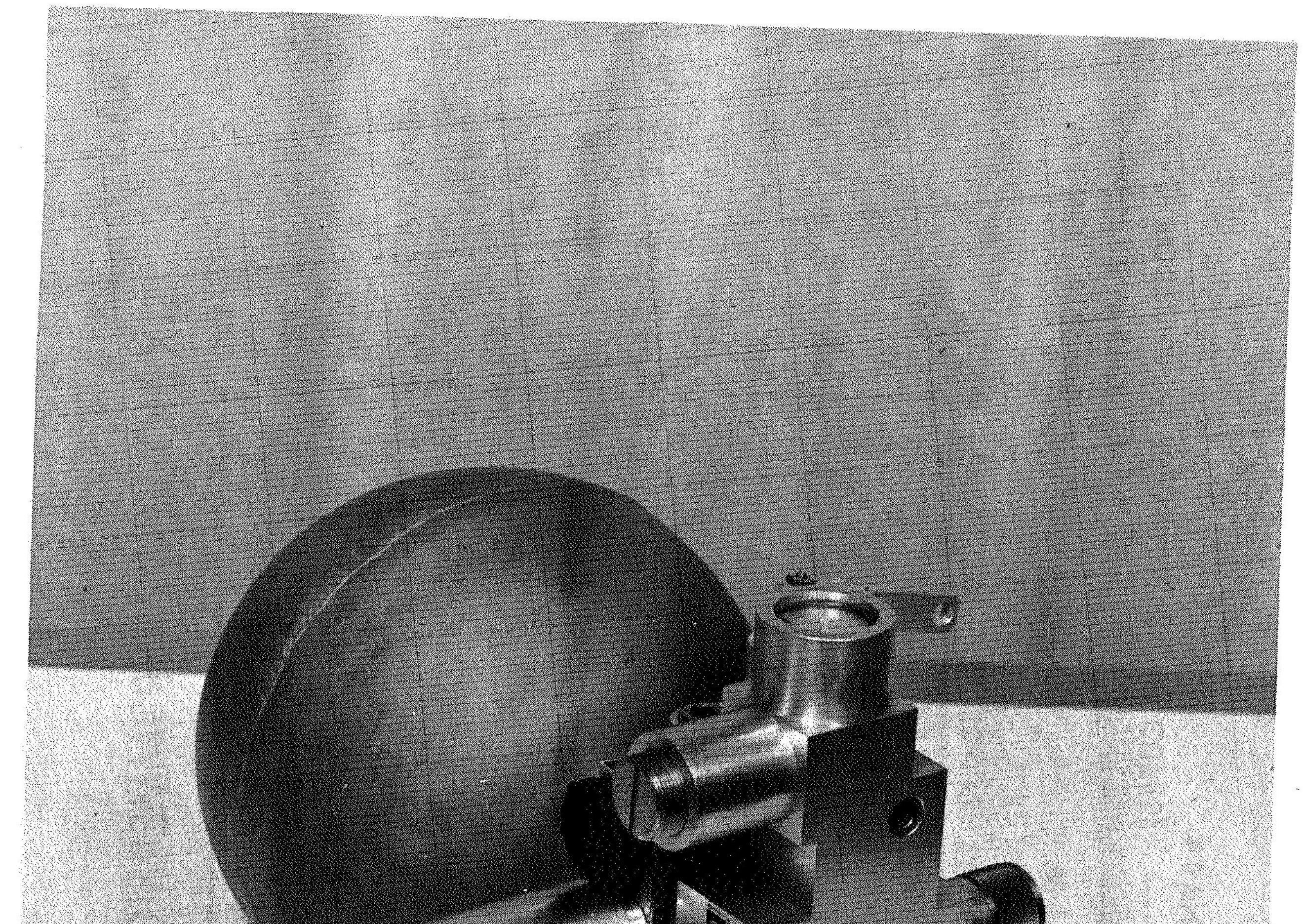


Fig.
39-5

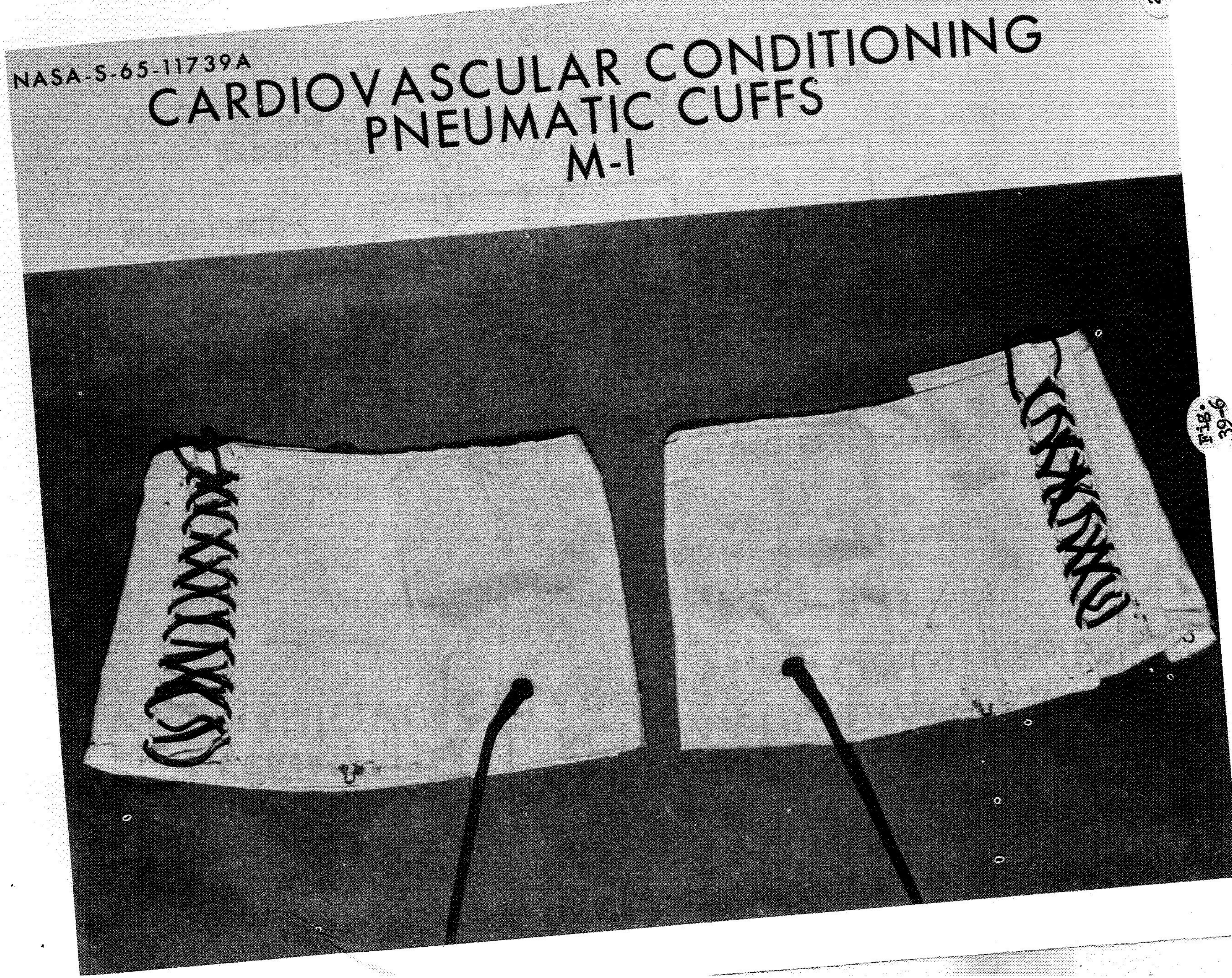

NASA-S-65-11739A
CARDIOVASCULAR CONDITIONING
PNEUMATIC CUFFS
M-I

Fig. 39-6

NASA-S-66-1170 FEB 7

EXPERIMENT M-1, SCHEMATIC DIAGRAM OF CARDIOVASCULAR REFLEX CONDITIONER

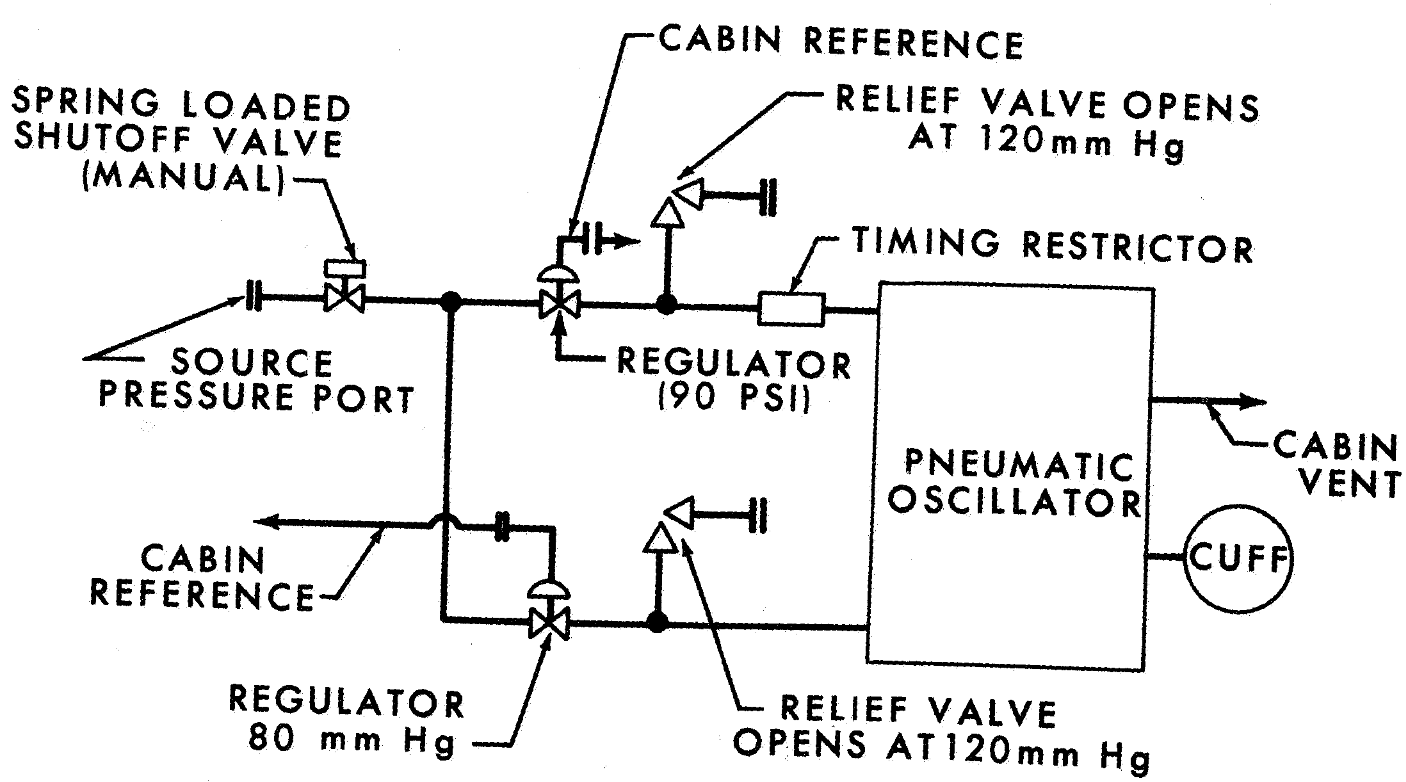


Fig. 39-7

NASA-S-66-1158 FEB 7

GEMINI V

EXPERIMENT M-1, TILT TABLE SUMMARY

PULSE RATE

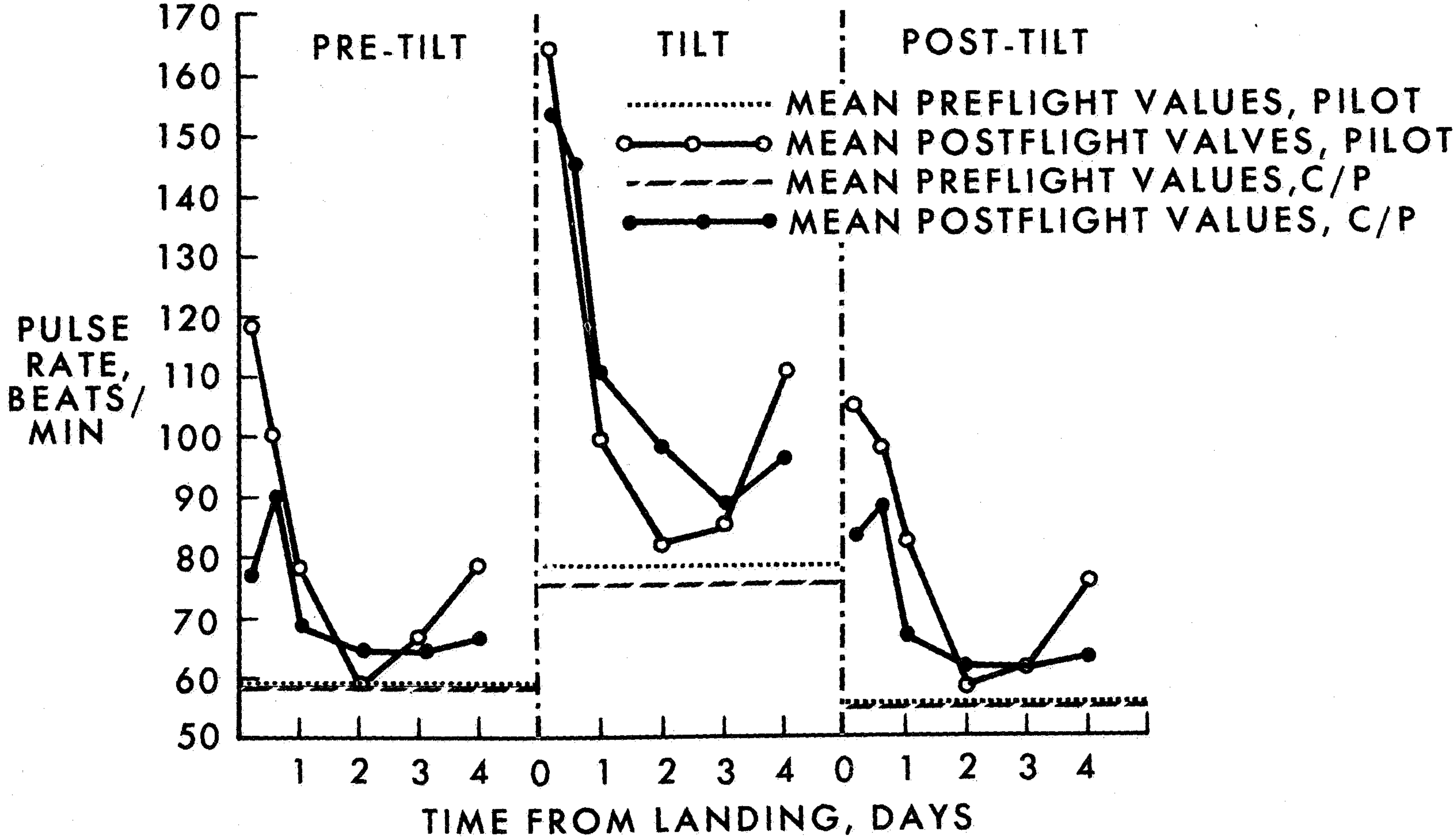


Fig. 39-8

NASA-S-66-1157 FEB 7

GEMINI V

EXPERIMENT M-1, TILT TABLE SUMMARY

BLOOD PRESSURE

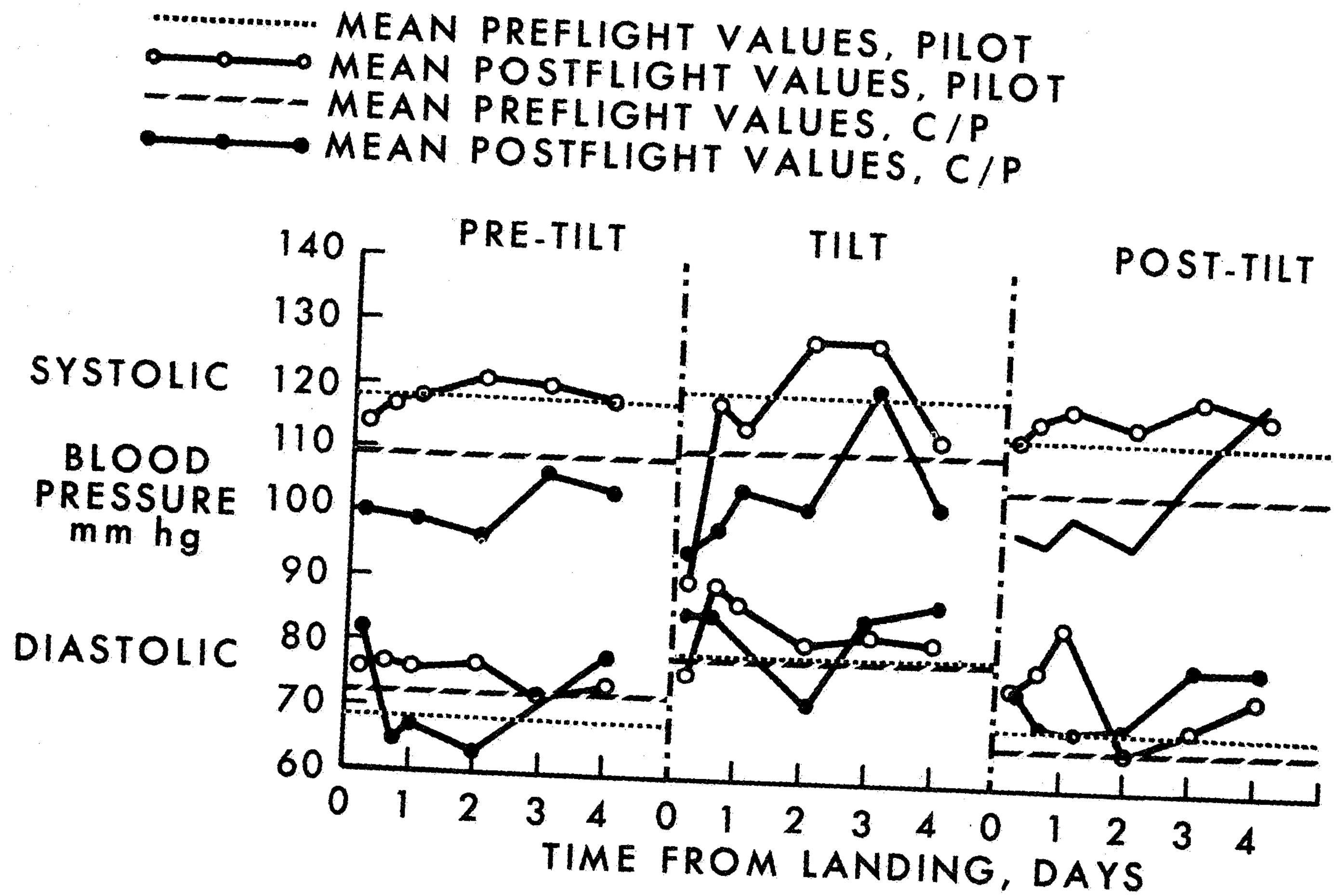
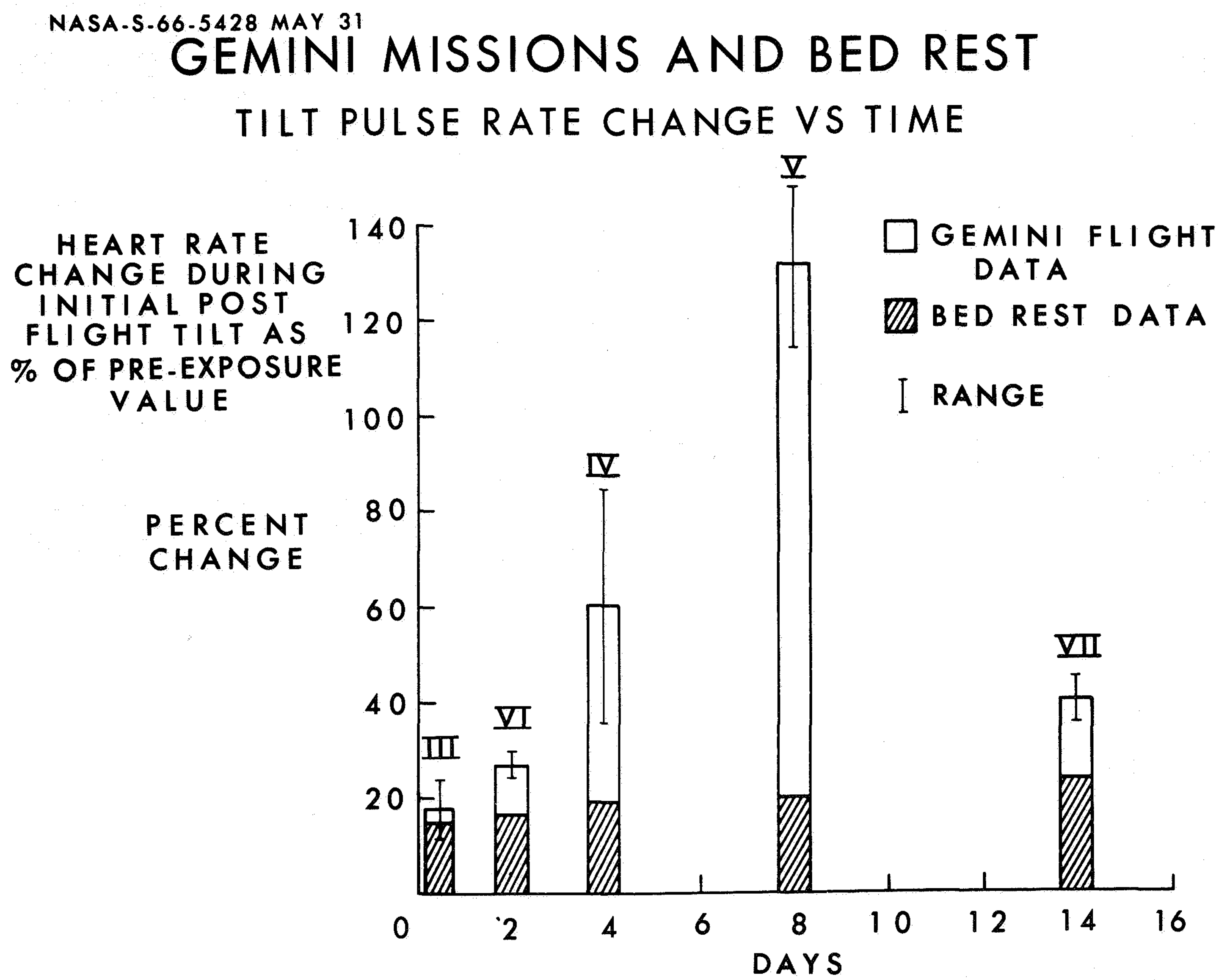


Fig. 39-9



NASA-S-66-5428 MAY 31
GEMINI MISSIONS AND BED REST
TILT PULSE RATE CHANGE VS TIME
HEART RATE CHANGE DURING INITIAL POST FLIGHT TILT AS % OF PRE-EXPOSURE VALUE
PERCENT CHANGE
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
DAYS
III
VI
IV
V
VII
GEMINI FLIGHT DATA
BED REST DATA
RANGE

Fig. 39-10

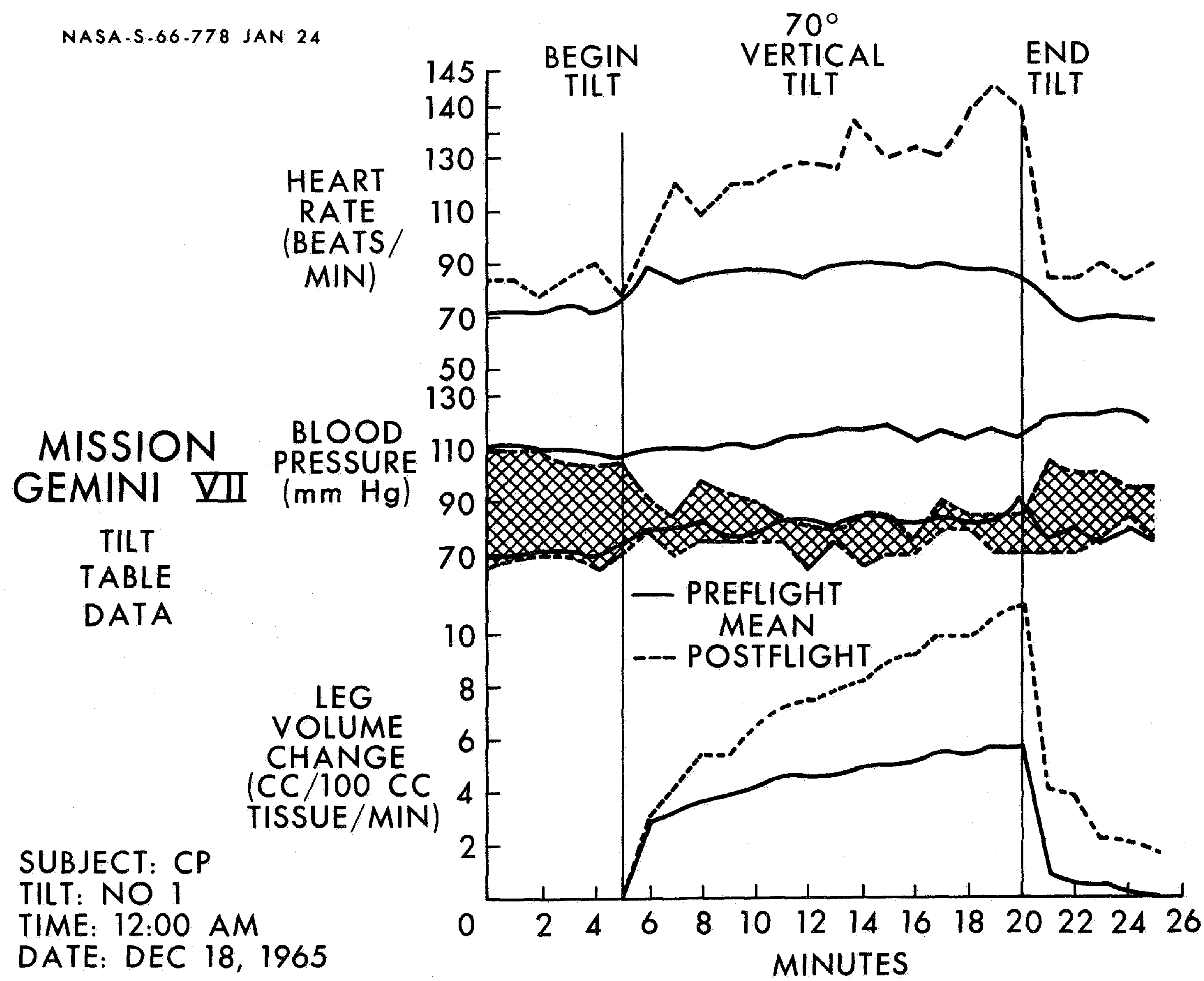

NASA-S-66-778 JAN 24
MISSION GEMINI VII
TILT TABLE DATA
SUBJECT: CP
TILT: NO 1
TIME: 12:00 AM
DATE: DEC 18, 1965
BEGIN TILT
70° VERTICAL TILT
END TILT
HEART RATE (BEATS/MIN)
BLOOD PRESSURE (mm Hg)
LEG VOLUME CHANGE (CC/100 CC TISSUE/MIN)
145
140
130
110
90
70
50
130
110
90
70
10
8
6
4
2
0
2 4 6 8 10 12 14 16 18 20 22 24 26
MINUTES
— PREFLIGHT MEAN
--- POSTFLIGHT

Fig. 39-11

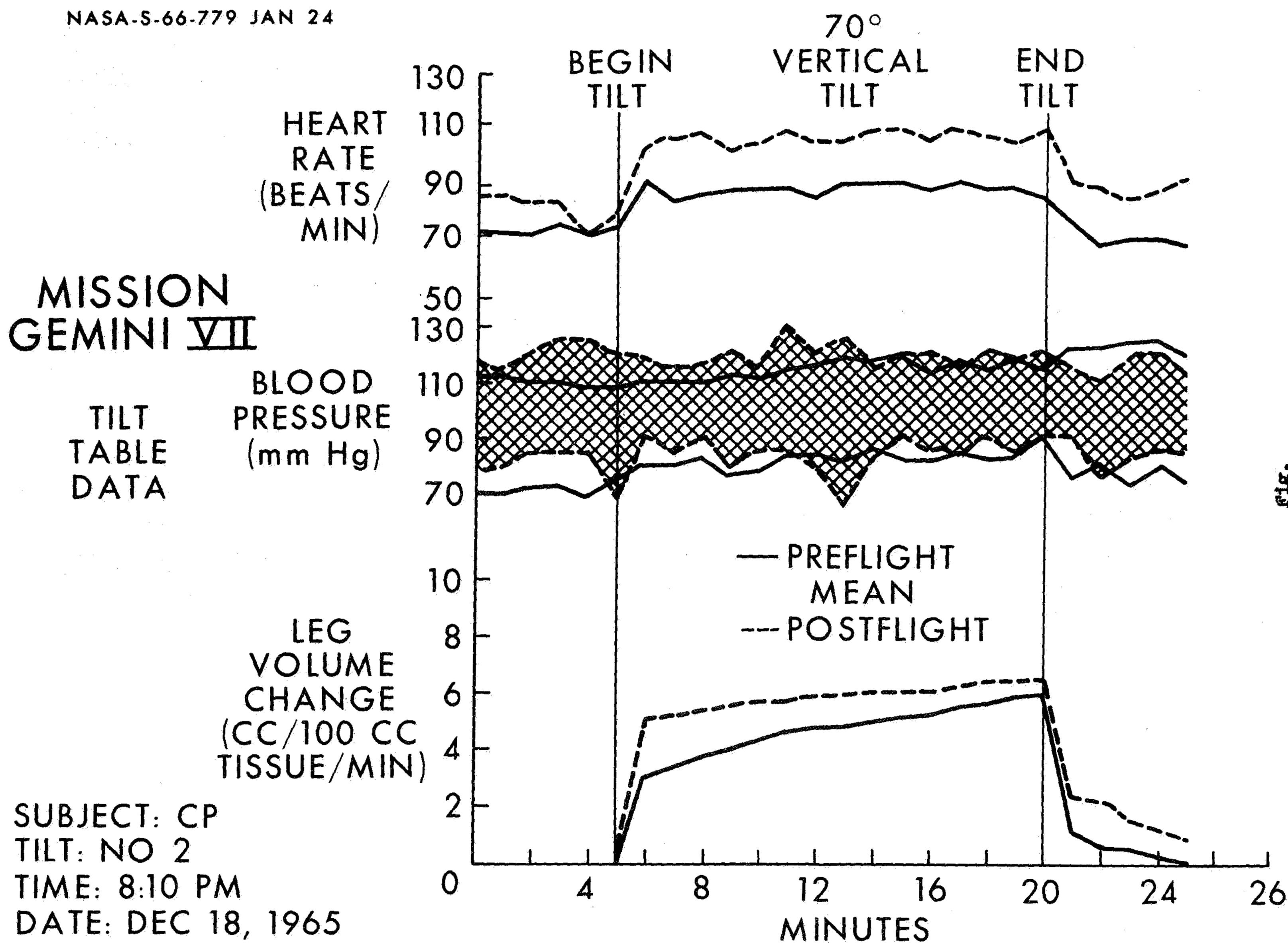

NASA-S-66-779 JAN 24
MISSION
GEMINI VII
TILT
TABLE
DATA
HEART
RATE
(BEATS/
MIN)
BLOOD
PRESSURE
(mm Hg)
LEG
VOLUME
CHANGE
(CC/100 CC
TISSUE/MIN)
SUBJECT: CP
TILT: NO 2
TIME: 8:10 PM
DATE: DEC 18, 1965
BEGIN
TILT
70°
VERTICAL
TILT
END
TILT
— PREFLIGHT
MEAN
--- POSTFLIGHT
130
110
90
70
50
130
110
90
70
10
8
6
4
2
0
4
8
12
16
20
24
26
MINUTES

Fig.
39-12

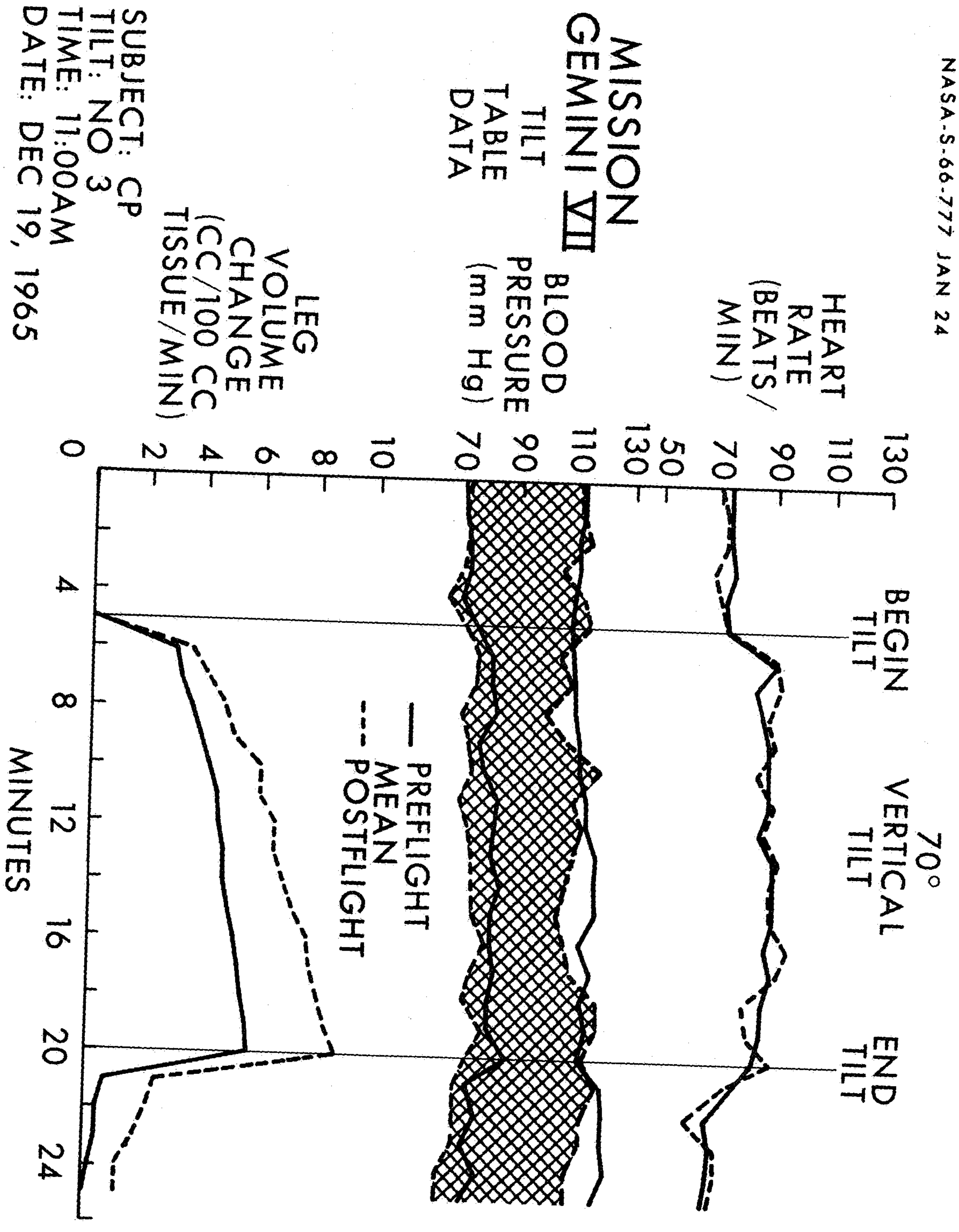

NASA-S-66-777 JAN 24
MISSION GEMINI VII
TILT TABLE DATA
SUBJECT: CP
TILT: NO 3
TIME: 11:00AM
DATE: DEC 19, 1965
HEART RATE (BEATS/MIN)
BLOOD PRESSURE (mm Hg)
LEG VOLUME CHANGE (CC/100 CC TISSUE/MIN)
BEGIN TILT
70° VERTICAL TILT
END TILT
— PREFLIGHT MEAN
--- POSTFLIGHT
MINUTES
130
110
90
70
50
130
110
90
70
10
8
6
4
2
0
4
8
12
16
20
24

Fig.
39-13

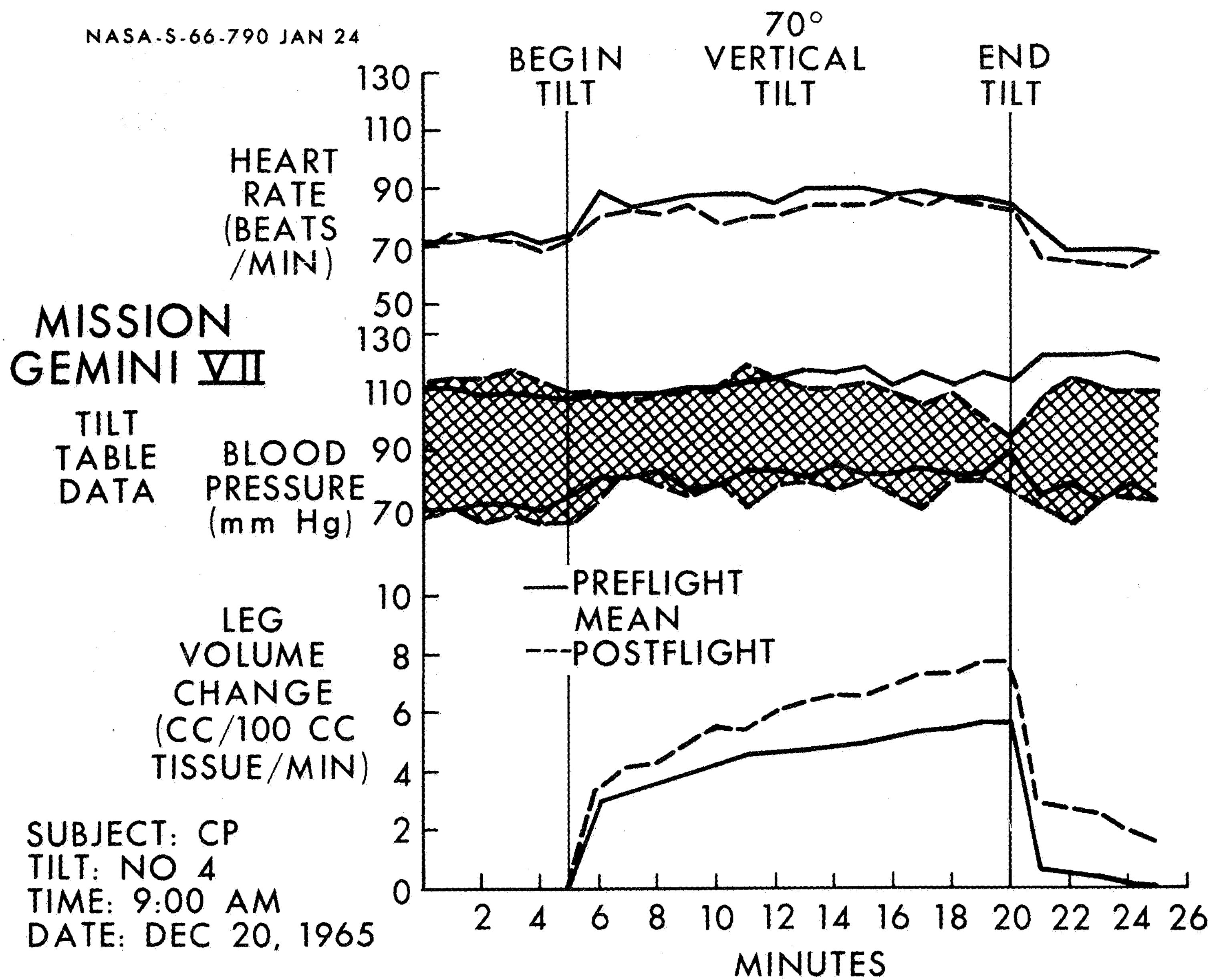

NASA-S-66-790 JAN 24
MISSION
GEMINI VII
TILT
TABLE
DATA
HEART
RATE
(BEATS
/MIN)
BLOOD
PRESSURE
(mm Hg)
LEG
VOLUME
CHANGE
(CC/100 CC
TISSUE/MIN)
SUBJECT: CP
TILT: NO 4
TIME: 9:00 AM
DATE: DEC 20, 1965
BEGIN
TILT
70°
VERTICAL
TILT
END
TILT
—PREFLIGHT
MEAN
---POSTFLIGHT
130
110
90
70
50
130
110
90
70
10
8
6
4
2
0
2 4 6 8 10 12 14 16 18 20 22 24 26
MINUTES

Fig.
39-14

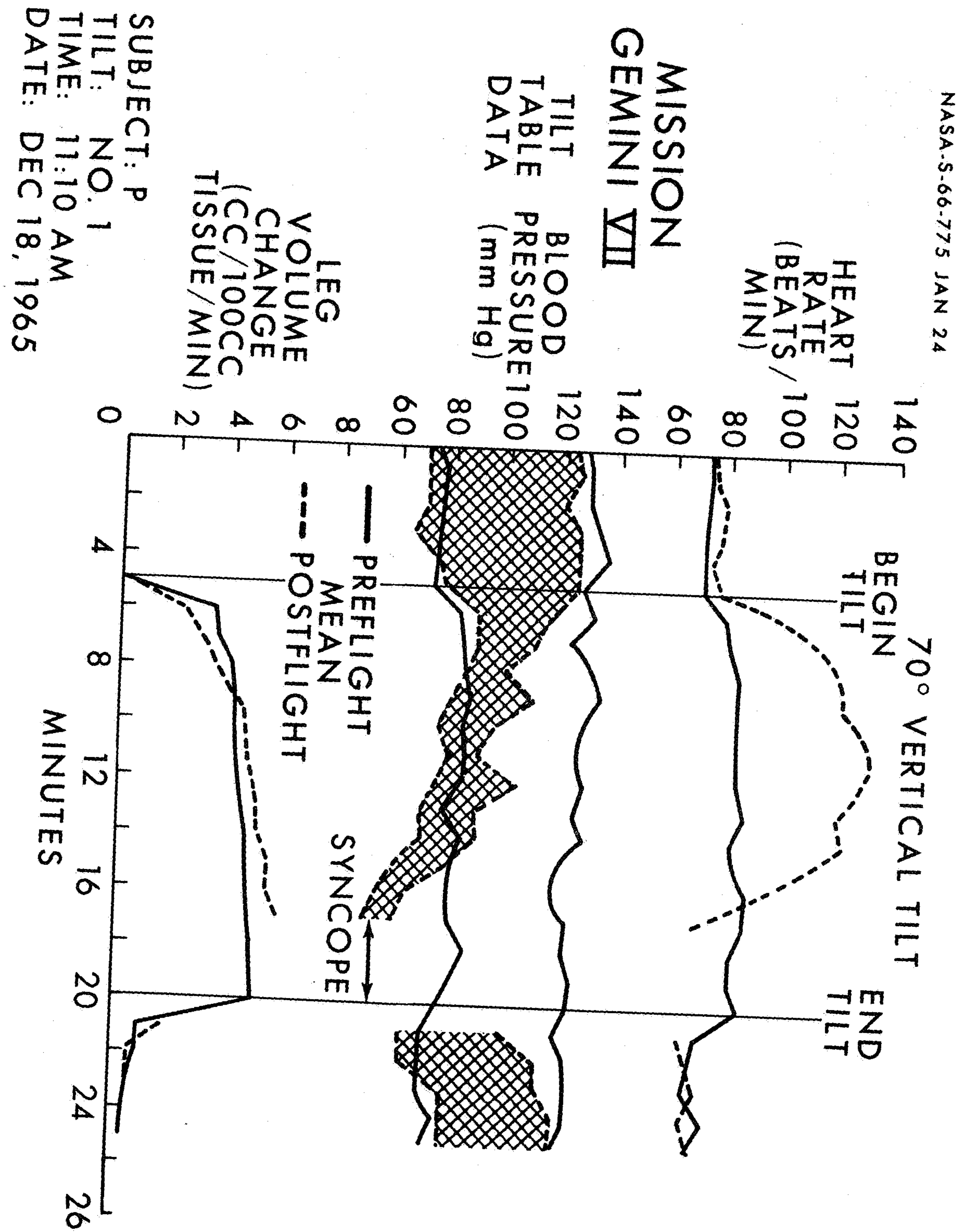

NASA-S-66-775 JAN 24
MISSION
GEMINI VII
TILT TABLE DATA
HEART RATE (BEATS/MIN)
BLOOD PRESSURE (mm Hg)
LEG VOLUME CHANGE (CC/100CC TISSUE/MIN)
SUBJECT: P
TILT: NO. 1
TIME: 11:10 AM
DATE: DEC 18, 1965
70° VERTICAL TILT
BEGIN TILT
END TILT
PREFLIGHT MEAN
POSTFLIGHT
SYNCOPE
MINUTES
140
120
100
80
60
140
120
100
80
60
8
6
4
2
0
4
8
12
16
20
24
26

Fig.
39-15

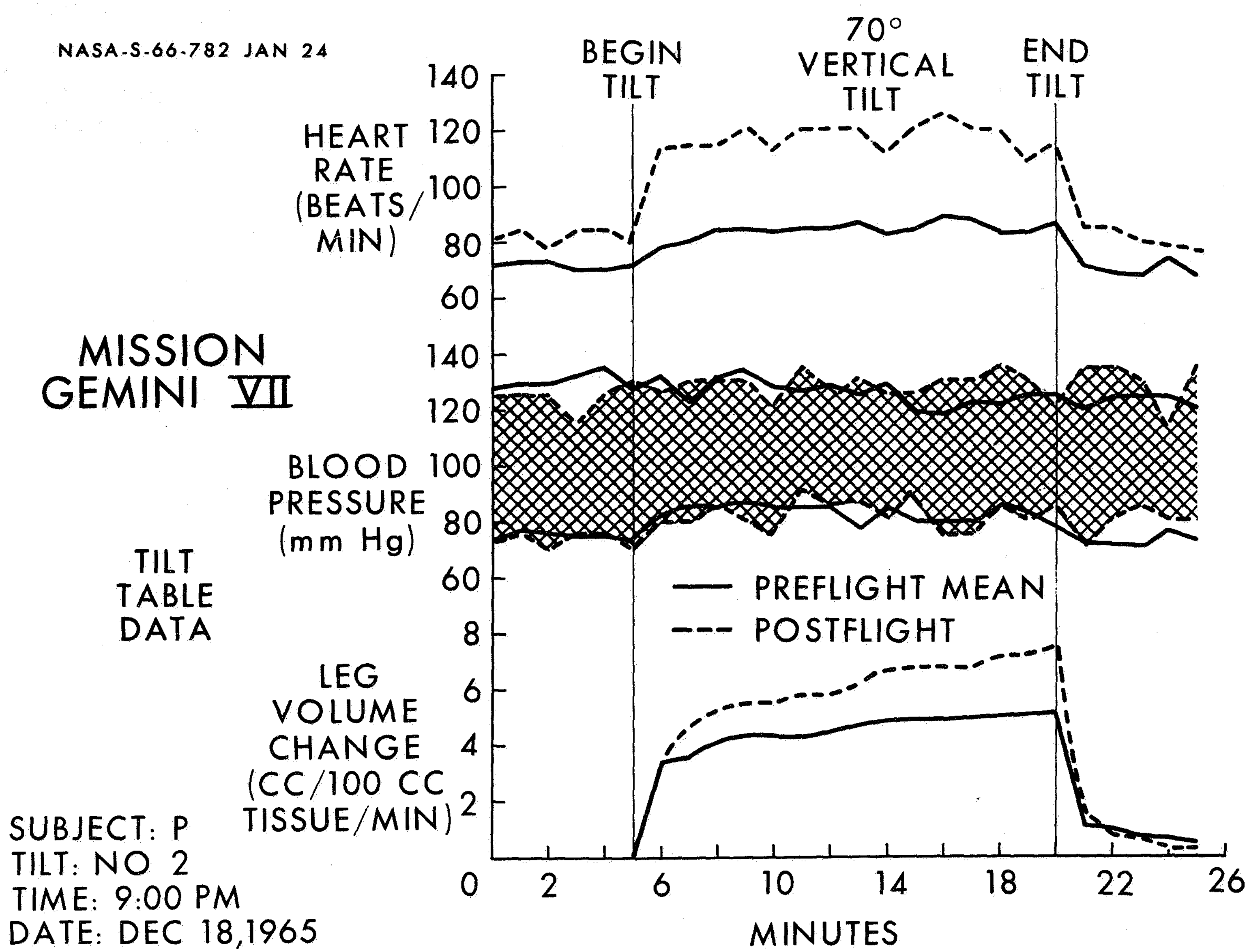
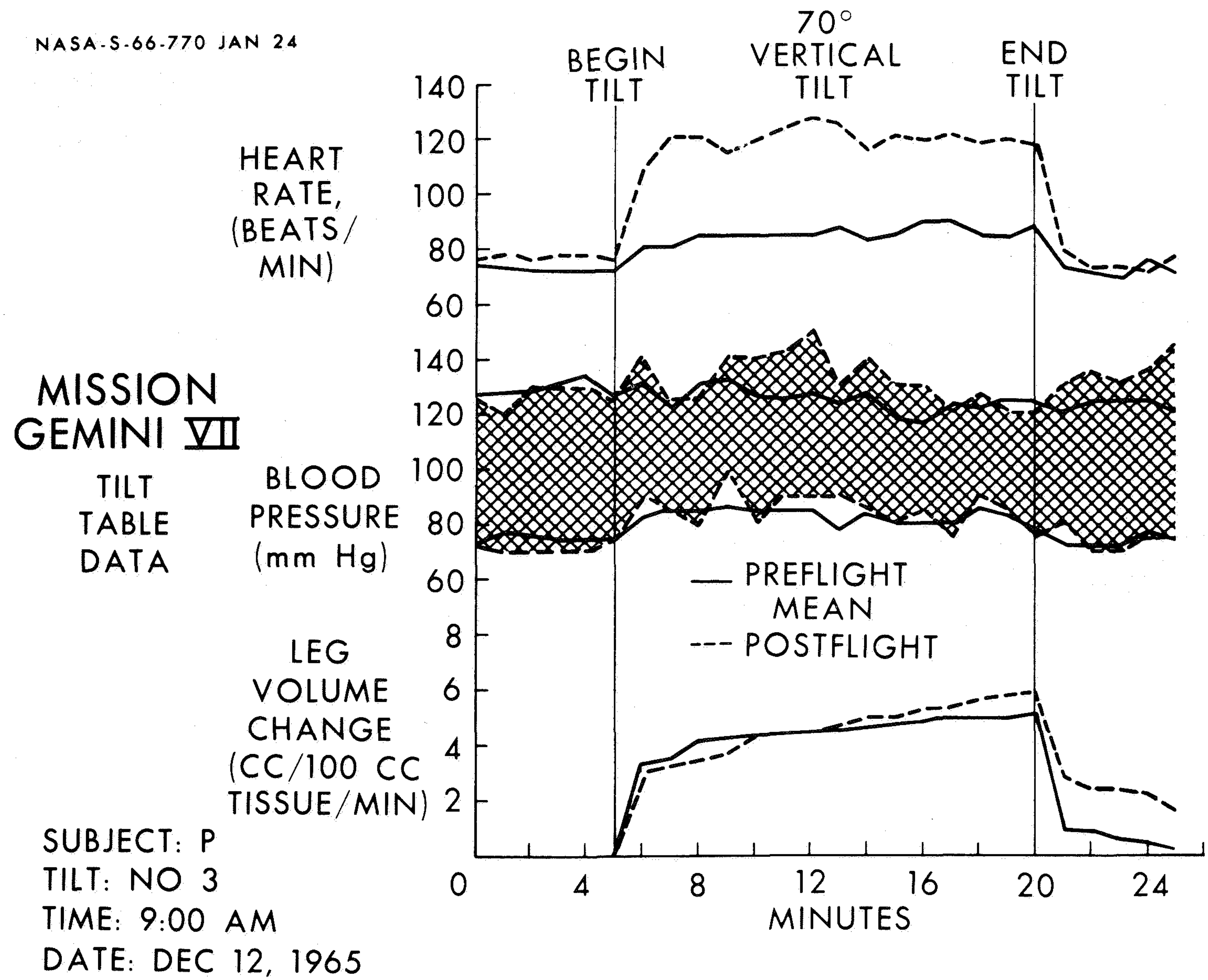

NASA-S-66-782 JAN 24
MISSION
GEMINI VII
TILT
TABLE
DATA
SUBJECT: P
TILT: NO 2
TIME: 9:00 PM
DATE: DEC 18,1965
BEGIN
TILT
70°
VERTICAL
TILT
END
TILT
HEART
RATE
(BEATS/
MIN)
BLOOD
PRESSURE
(mm Hg)
LEG
VOLUME
CHANGE
(CC/100 CC
TISSUE/MIN)
PREFLIGHT MEAN
POSTFLIGHT
MINUTES
140
120
100
80
60
140
120
100
80
60
8
6
4
2
0
2
6
10
14
18
22
26

Fig. 39-16



NASA-S-66-770 JAN 24
MISSION
GEMINI VII
TILT
TABLE
DATA
HEART
RATE,
(BEATS/
MIN)
BLOOD
PRESSURE
(mm Hg)
LEG
VOLUME
CHANGE
(CC/100 CC
TISSUE/MIN)
BEGIN
TILT
70°
VERTICAL
TILT
END
TILT
140
120
100
80
60
140
120
100
80
60
8
6
4
2
0
4
8
12
16
20
24
MINUTES
— PREFLIGHT
MEAN
--- POSTFLIGHT
SUBJECT: P
TILT: NO 3
TIME: 9:00 AM
DATE: DEC 12, 1965

Fig. 39-17

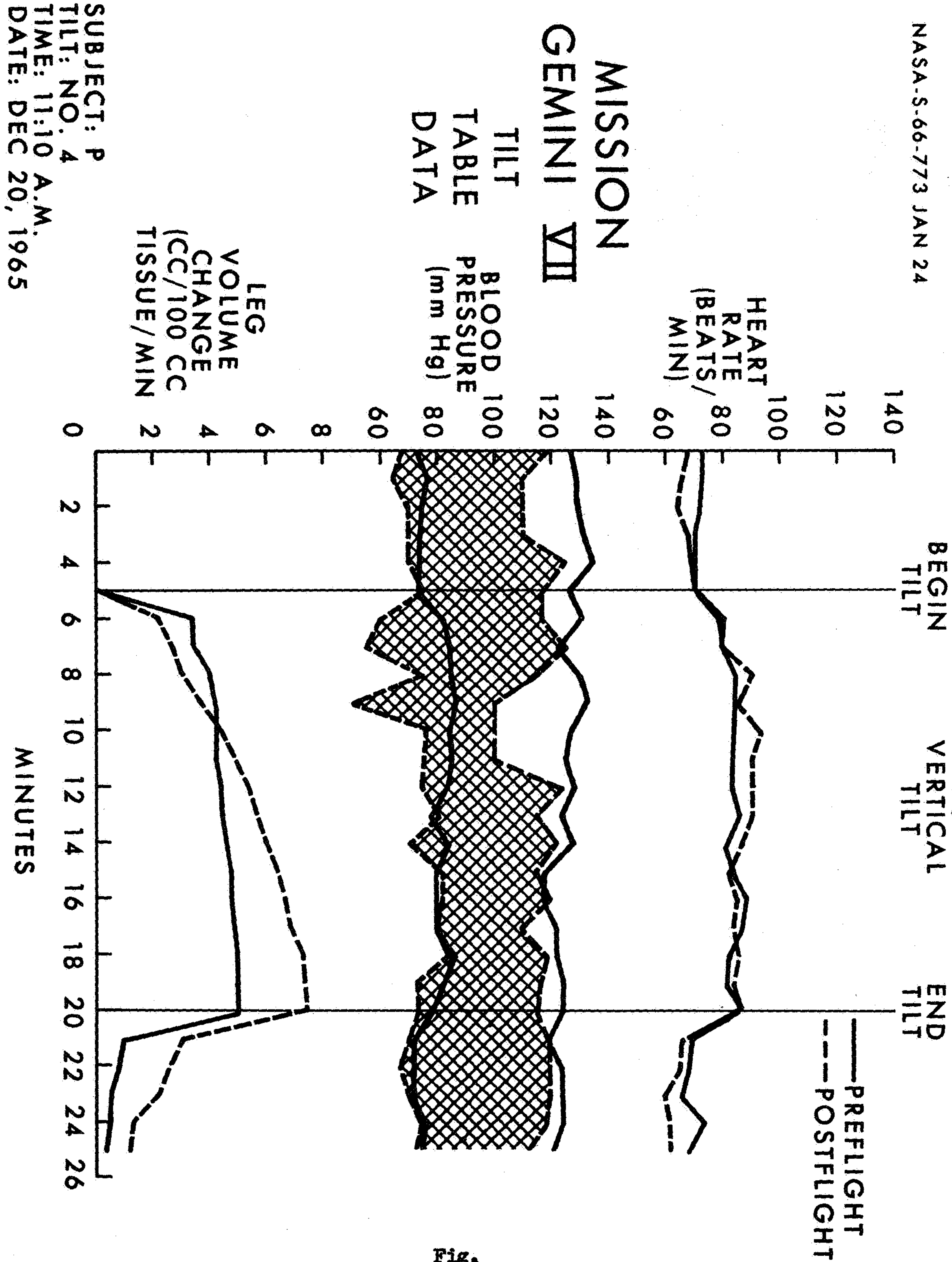
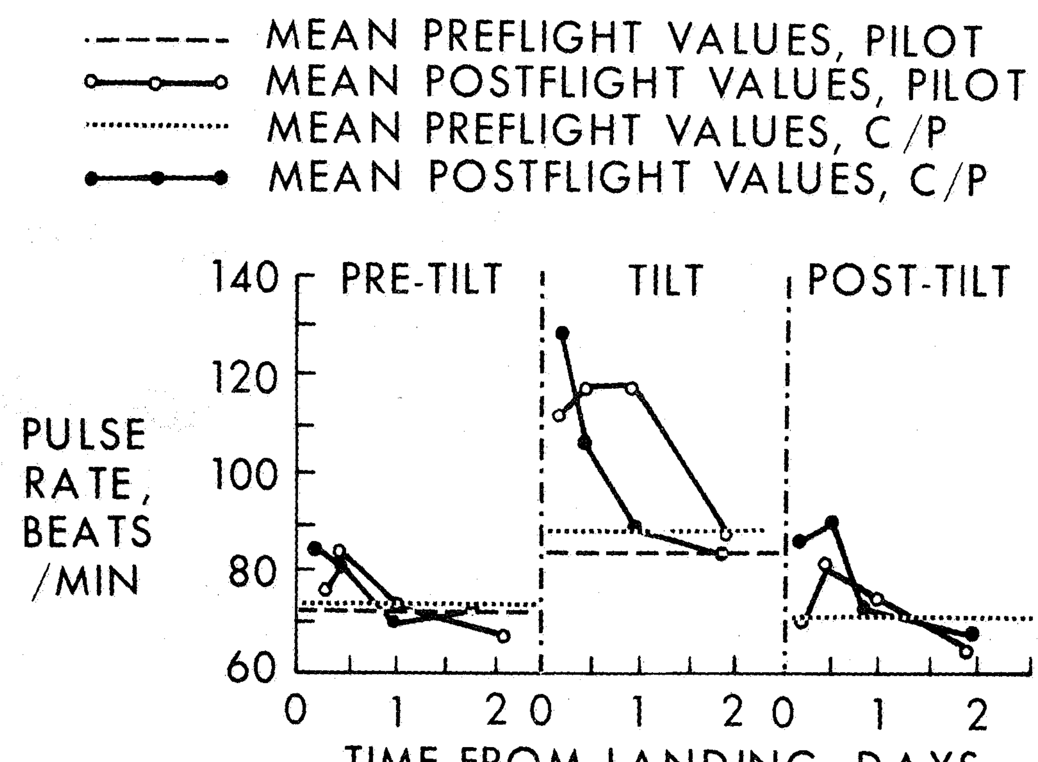

NASA-S-66-773 JAN 24
MISSION
GEMINI VII
TILT
TABLE
DATA
HEART
RATE
(BEATS/
MIN)
140
120
100
80
60
BLOOD
PRESSURE
(mm Hg)
140
120
100
80
60
LEG
VOLUME
CHANGE
(CC/100 CC
TISSUE/MIN
8
6
4
2
0
BEGIN
TILT
70°
VERTICAL
TILT
END
TILT
PREFLIGHT
POSTFLIGHT
0 2 4 6 8 10 12 14 16 18 20 22 24 26
MINUTES
SUBJECT: P
TILT: NO. 4
TIME: 11:10 A.M.
DATE: DEC 20, 1965

Fig.
39-18

NASA-S-66-4365 APR 29

GEMINI VII

EXPERIMENT M-1, TILT TABLE SUMMARY



NOTE: PILOT : POSTFLIGHT TILT NO. 1 IS THE MEAN OF 12 MINUTES TILT SUBJECT TILTED TO SUPINE AFTER EXHIBITING TENDENCY TOWARD FAINTING

Fig. 39-19a

NASA-S-66-1167 FEB 7

GEMINI VII
EXPERIMENT M-1, TILT TABLE SUMMARY

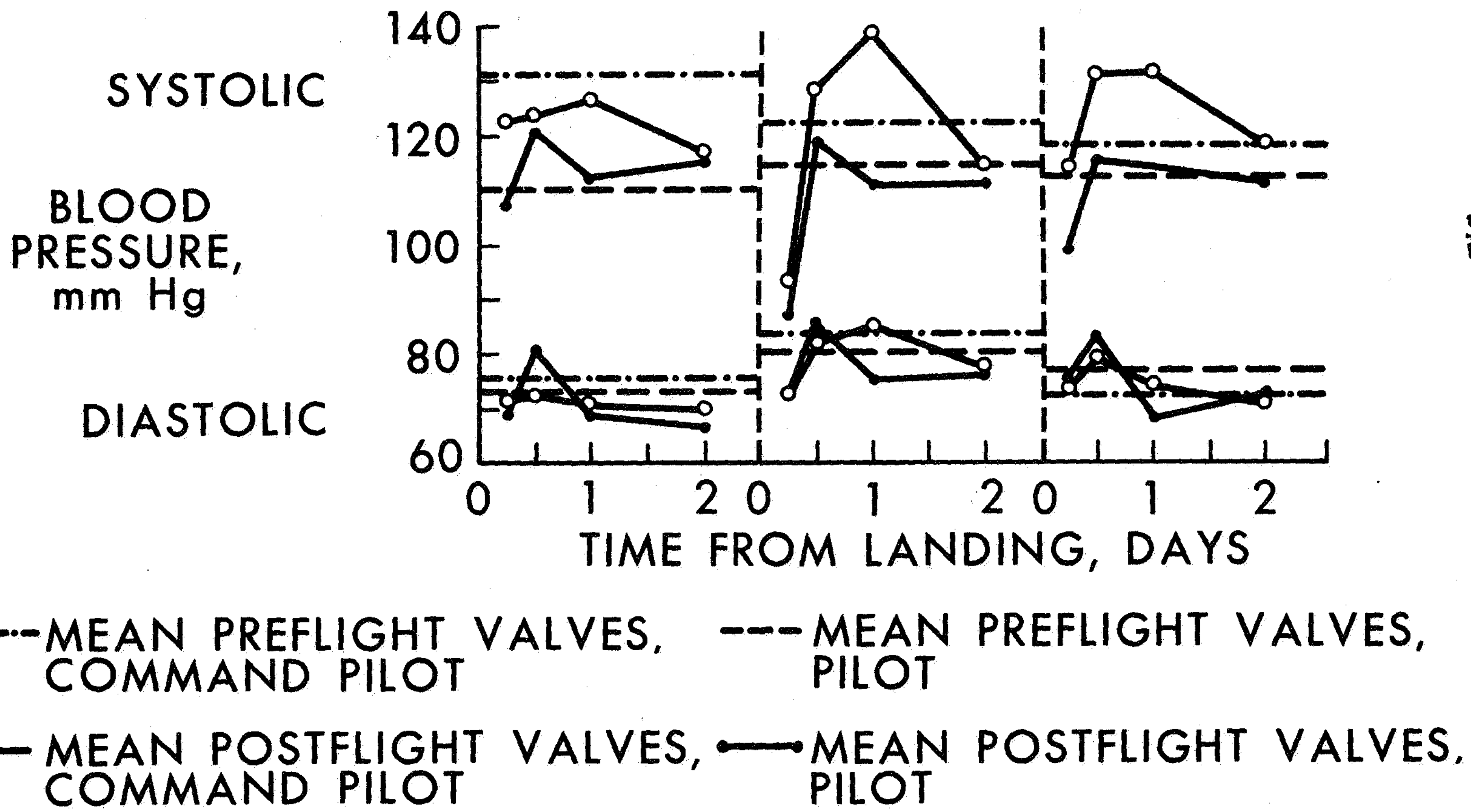


Fig. 39b 19

Medical Experiment M003

INFLIGHT EXERCISER

PRINCIPAL INVESTIGATORS:

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Rita M. Rapp
Biomedical Research Office
NASA Manned Spacecraft Center
Houston, Texas

EXPERIMENT M-3, INFLIGHT EXERCISE - WORK TOLERANCE

by

Lawrence F. Dietlein, M.D.
Chief, Biomedical Research Office
NASA Manned Spacecraft Center

and

Rita M. Rapp
Biomedical Research Office
NASA Manned Spacecraft Center

SUMMARY

The response of the cardiovascular system to a quantified workload is an index of the general physical condition of an individual. Utilizing mild exercise as a provocative stimulus, no significant decrement in the physical condition of either of the Gemini VII crewmembers was apparent. The rate of return of the pulse rate to preexercise levels, following inflight exercise periods, was essentially the same as that observed during preflight baseline studies.

OBJECTIVE

The objective of Experiment M-3 was the day-to-day evaluation of the general physical condition of the flight crew with increasing time under space flight conditions. The basis of this evaluation was the response of the cardiovascular system (pulse rate) to a calibrated workload.

EQUIPMENT

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

PROCEDURE

The device used in Gemini VII required 70 pounds of force to stretch the rubber bungee cords maximally through an excursion of 12 inches. Exercise periods(crew status reports) were scheduled twice daily for each crewmember. Additional isometric-isotonic exercises were performed by each astronaut approximately three times daily. Blood pressure measurements were obtained before and after each exercise period (crew status report).

RESULTS

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

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

CONCLUSIONS

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

(1) The response of the cardiovascular system to a calibrated

workload is relatively constant for a given individual during space flights lasting 14 days.

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

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

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., October 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., January 1966.

FIGURE LEGEND

Fig. 1	Inflight exerciser major components.
Fig. 2	Inflight exerciser in use.
Fig. 3	Biomedical and communications harness used during Gemini IV mission.
Fig. 4	Inflight responses to exercise.
Fig. 5	Blood pressure of Gemini VII command pilot from lift-off through 192 hours ground elapsed time.
Fig. 6	Blood pressure of Gemini VII command pilot from 192 through 322 hours ground elapsed time.
Fig. 7	Sample of telemetered physiological data during inflight exercise. (Recorder speed, 25 mm/sec.)

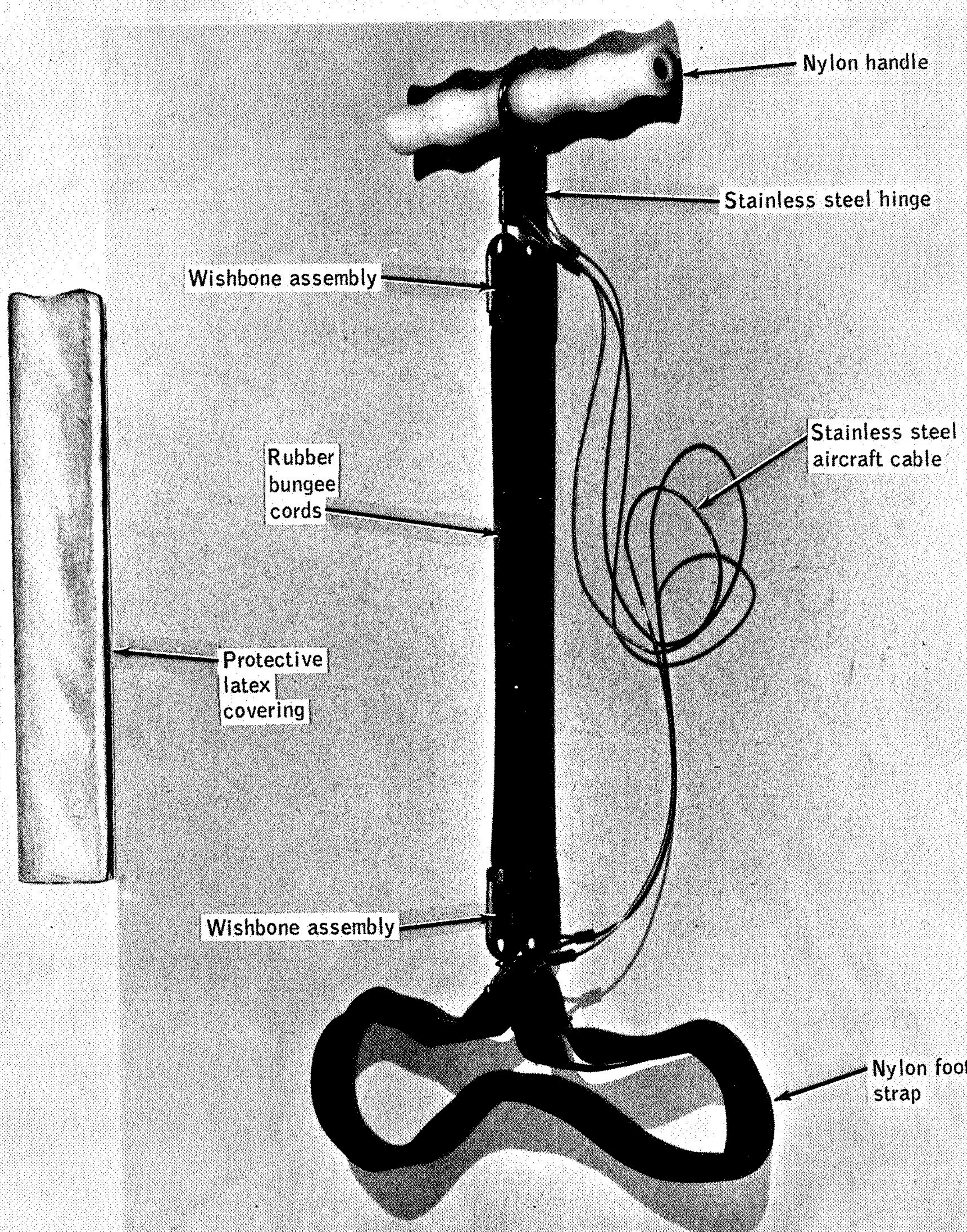
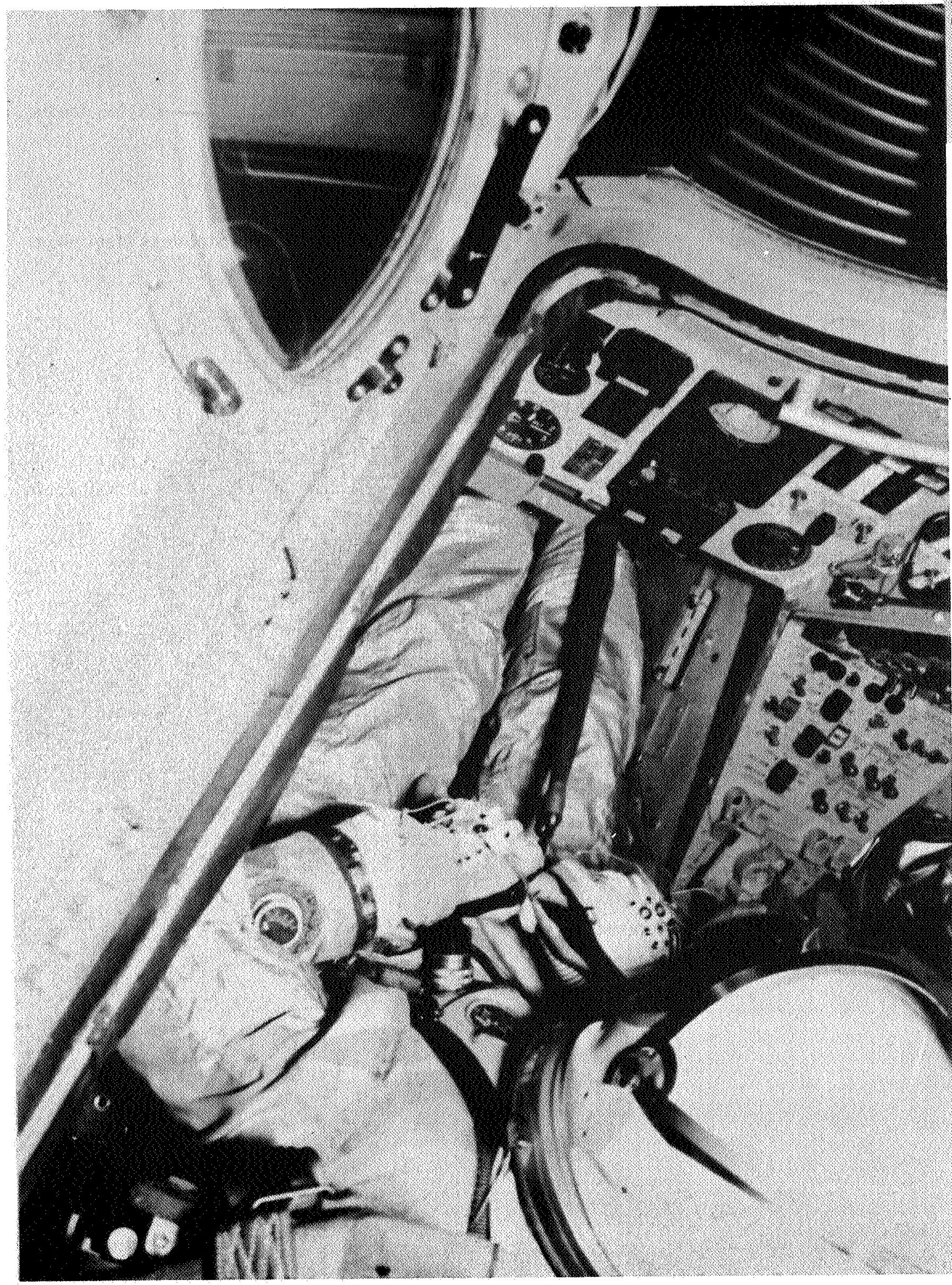

Nylon handle
Stainless steel hinge
Wishbone assembly
Stainless steel aircraft cable
Rubber bungee cords
Protective latex covering
Wishbone assembly
Nylon foot strap

Fig. 1

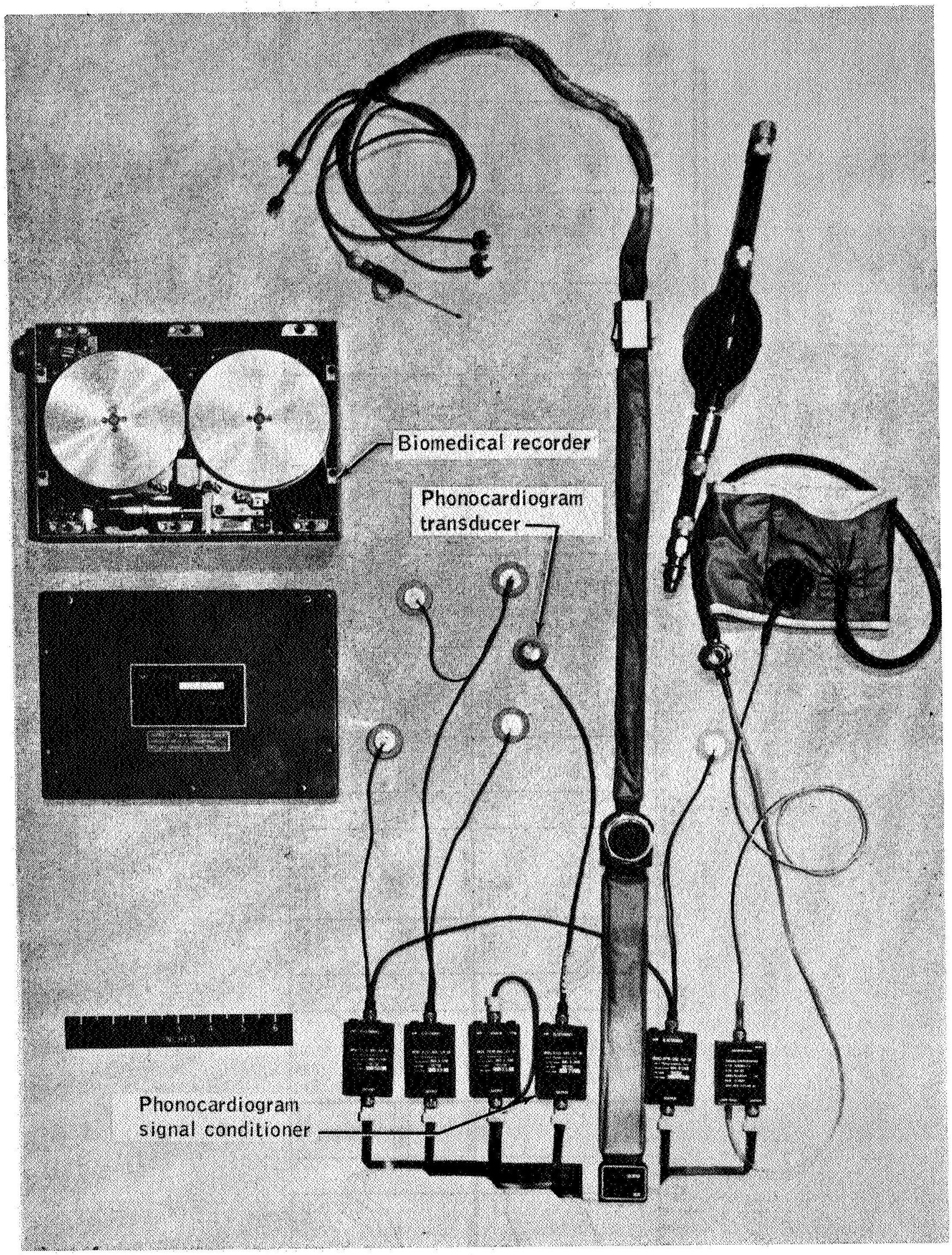
NASA-S-65-2854



Inflight exerciser in use by astronaut

Fig. 2

NASA-S-65-3507



GT-4 biomedical and communications harness

Fig. 3

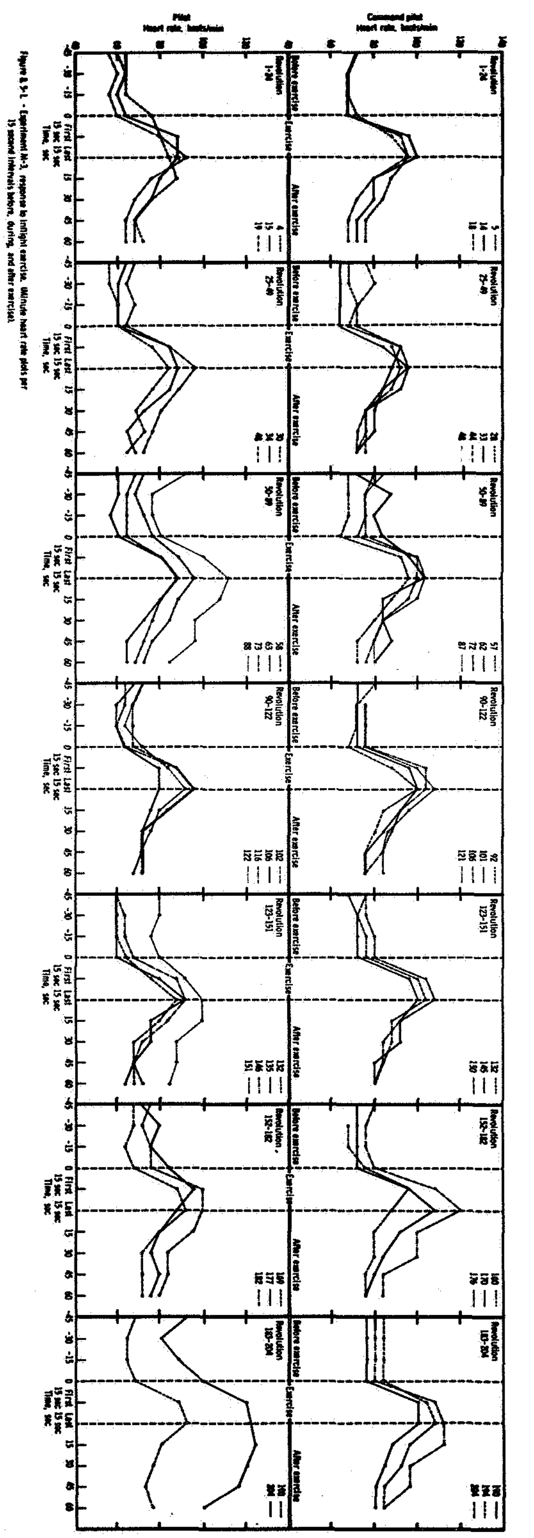
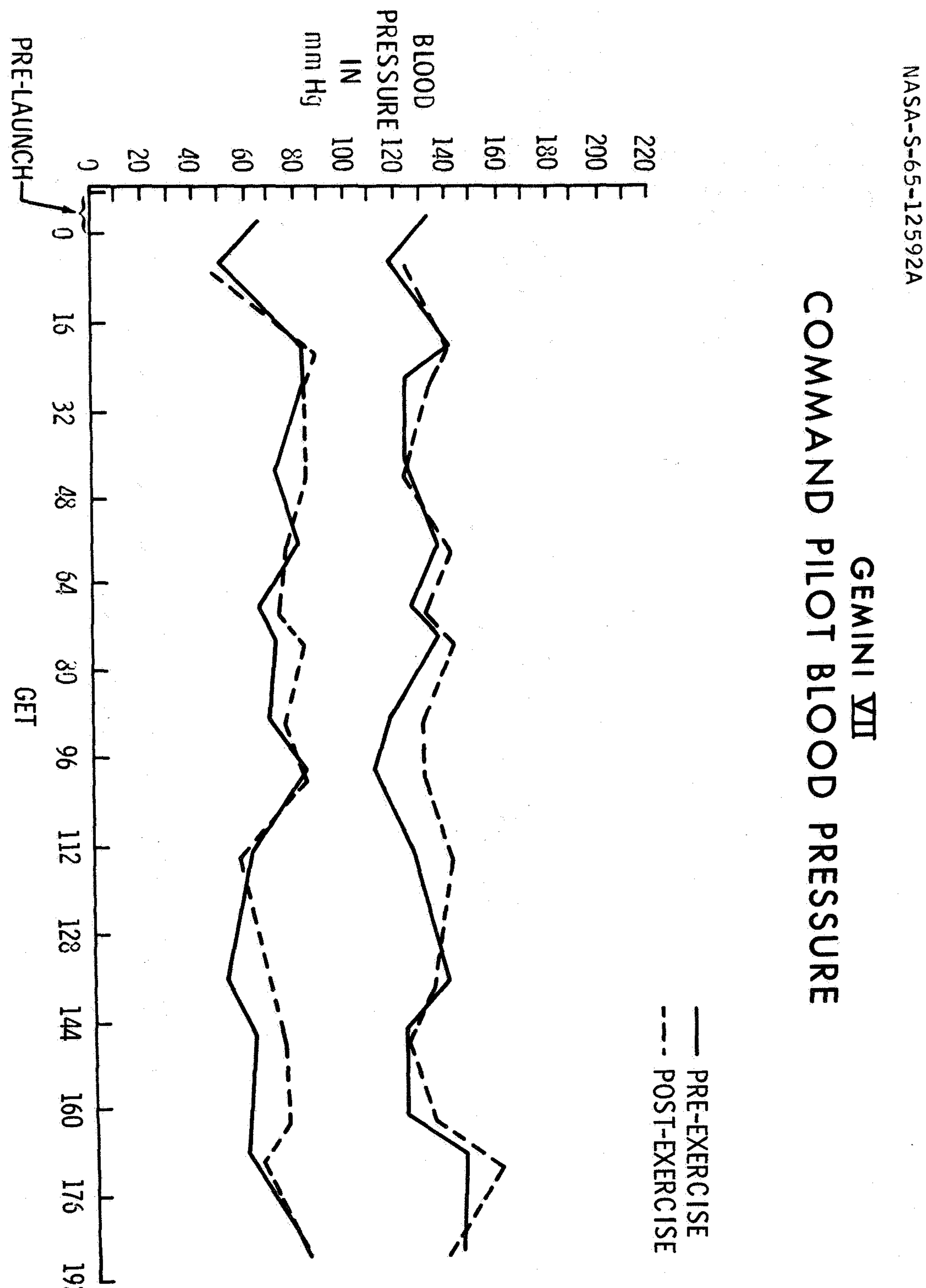


Fig. 4



NASA-S-65-12592A
GEMINI VII
COMMAND PILOT BLOOD PRESSURE
PRE-EXERCISE
POST-EXERCISE
BLOOD PRESSURE IN mm Hg
220
200
180
160
140
120
100
80
60
40
20
0
PRE-LAUNCH
0
16
32
48
64
80
96
112
128
144
160
176
192
GET

Fig. 5

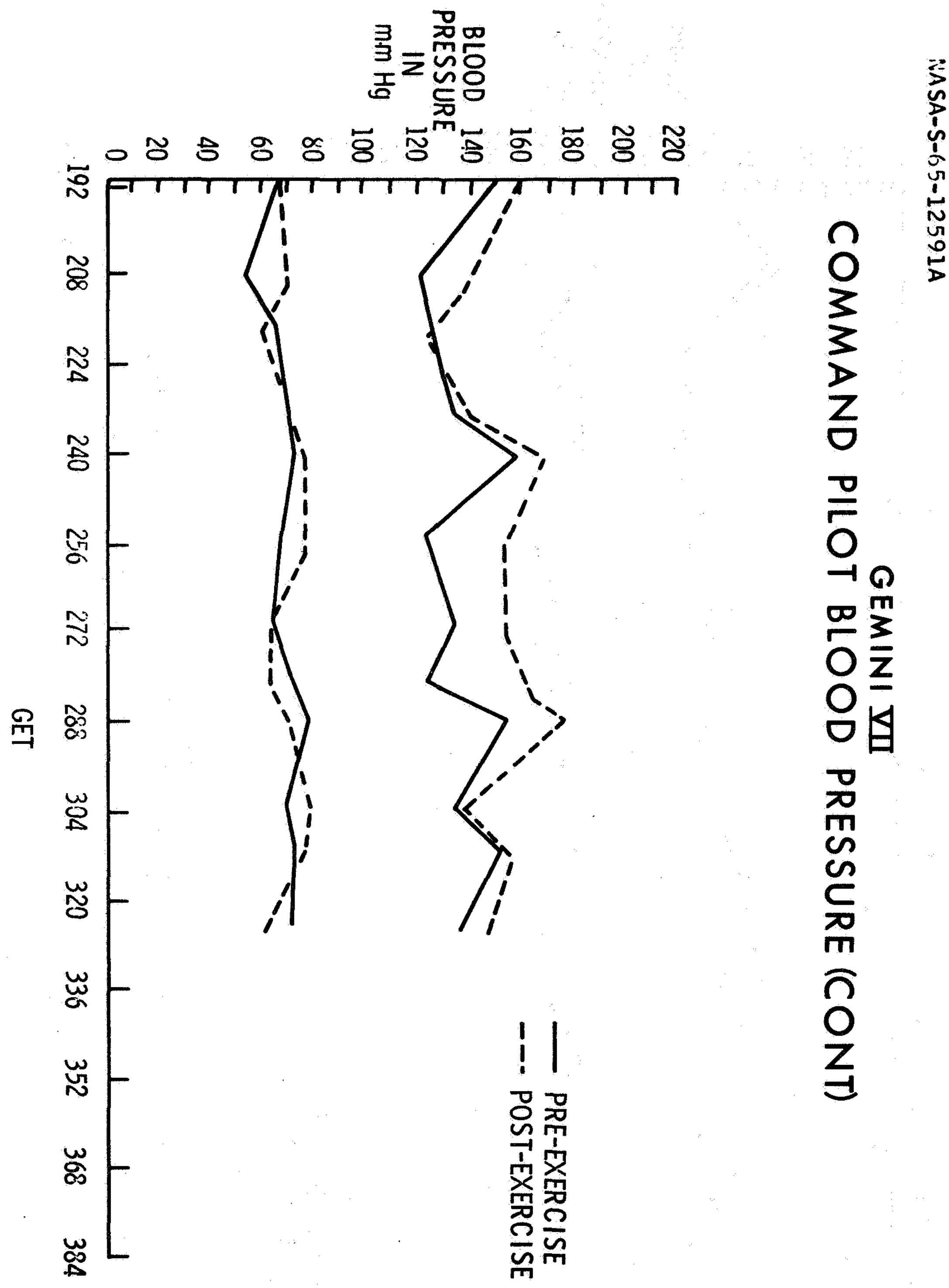
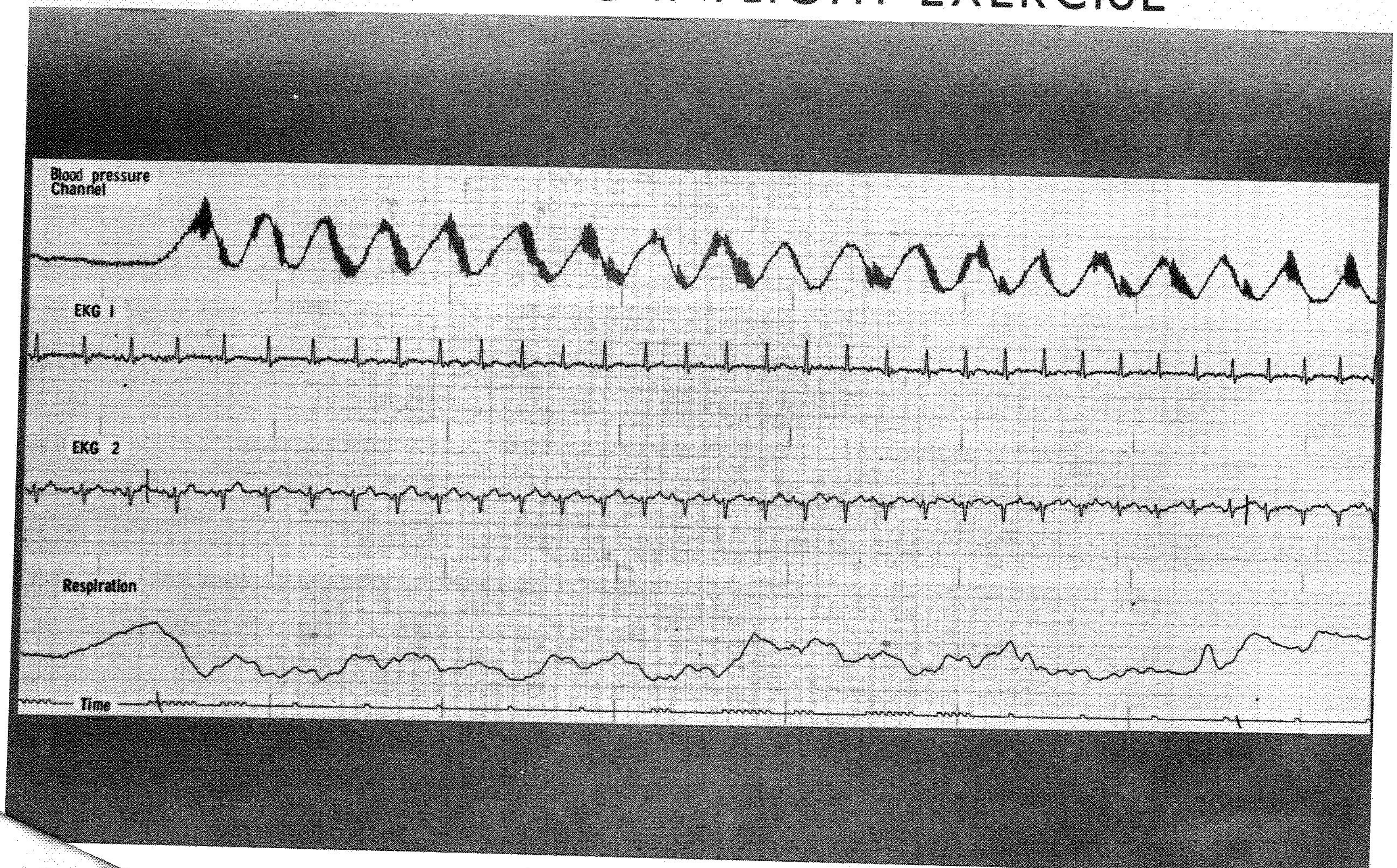

NASA-S-65-12591A
GEMINI VII
COMMAND PILOT BLOOD PRESSURE (CONT)
BLOOD PRESSURE IN mm Hg
0
20
40
60
80
100
120
140
160
180
200
220
192
208
224
240
256
272
288
304
320
336
352
368
384
GET
PRE-EXERCISE
POST-EXERCISE

Fig. 6

NASA-S-66-1336 FEB 10

SAMPLE OF TELEMETERED PHYSIOLOGICAL DATA DURING INFLIGHT EXERCISE



Medical Experiment M004

INFLIGHT PHONOCARDIOGRAM

Principal Investigators:

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Baylor University College of Medicine
Texas Institute for Rehabilitation and Research
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L. F. Dietlein, M.D.
Chief, Biomedical Research Office
NASA Manned Spacecraft Center
Houston, Texas

MEASUREMENTS OF THE DURATION OF THE CARDIAC CYCLE AND ITS PHASES IN THE GEMINI ORBITAL FLIGHTS

By C. Vallbona, M.D. and

L.F. Dietlein, M.D.

Baylor University College of Medicine

Texas Institute for Rehabilitation and Research

and

NASA Manned Spacecraft Center

SUMMARY

Simultaneous electrocardiographic and phonocardiographic records were obtained on both crew members during the flight of Gemini IV and Gemini V and on the Pilot of Gemini VII. Analysis of the data recorded during flight revealed: 1) wide fluctuations of the duration of the cardiac cycle within physiological limits throughout the mission; 2) fluctuations in the duration of the electromechanical systole that correlated with the changes in heart rate; 3) stable values for the electromechanical delay; 4) higher values for duration of systole and electromechanical delay in the Command Pilot of Gemini V suggesting cholinergic influences; and 5) evidence of adrenergic response at lift-off, at reentry, and for the few hours preceding reentry. This adrenergic response was observed in all astronauts participating in this experiment.

OBJECTIVE

The objective of Experiment M-4 was to measure the duration of the various electrical and mechanical phases of the cardiac cycle of astronauts during orbital flight in order to gain information relative to the functional cardiac status of flight crew members during prolonged space missions.

EQUIPMENT

The experimental equipment system consisted of: a) a phonocardiographic transducer, b) an electrocardiographic signal conditioner (preamplifier and amplifier), and c) an on-board biomedical magnetic tape recorder.

The transducer and signal conditioners were housed within the Gemini pressure suit, as reported previously (1). The sensor for the heart sounds was applied parasternally in the left fourth intercostal space of each subject, and remained attached to the chest throughout the mission. Electrodes for the detection of the ECG signals were applied in the usual location for the MX (manubrium-xiphoid) lead. The phonocardiographic transducer used to detect the chest vibrations produced by each heart beat, consisted of a 7 mm. piezoelectric microphone, 1 inch in diameter and 0.2 inches in thickness. It was developed by the Bioinstrumentation Section of the Crew Systems Division. A 10-inch shielded cable connected the heart sounds transducer to the signal conditioner housed in a pocket of the astronaut's undergarment. The phonocardiographic signal was then conducted from the signal conditioner output to the suit bioplug and thence to the biomedical recorder.

The electrocardiogram and phonocardiogram were recorded simultaneously throughout the flights of Gemini IV and Gemini V. They were recorded intermittently in the Pilot of the flight of Gemini VII. The recording procedure was entirely passive and did not require active participation on the part of the flight crew members.

ANALYSIS OF DATA

The analog data registered on the magnetic tapes were played back in real time after completion of the mission. The records were semiautomatically digitized with a Telecordex analog-to-digital converter. Digital readings were taken at each one of the following points: a) at the onset of the QRS complex or the beginning of the electrical systole, b) at the onset of the first heart sound, c) at the onset of the second heart sound which indicates the end of the mechanical systole and the beginning of diastole, and d) at the onset of the next QRS complex which indicates the end of the cardiac cycle (Fig. 1). A computer program permitted the calculation of the duration of systole and diastole, the interval between the onset of QRS and the first heart sound (electro-mechanical delay), and the interval between the first and second heart sounds. The same program computed the means and standard deviations of these variables after each 15 consecutive beats (Fig. 2). The regression equation proposed by Hegglin and Holzmann was used to predict the duration of systole for a given heart rate (2).

Data were obtained during the following periods: a) continuously starting a few minutes before lift-off until the spacecraft had stabilized in orbit, b) continuously from 5 minutes before reentry until splashdown, and c) continuously for 1 minute at hourly intervals for the first 24 hours of the mission and at 4-hour intervals for the remainder of the flight until 5 minutes before reentry.

Data on the Pilot of Gemini VII were obtained: a) continuously from 15 minutes before lift-off to 11 minutes into the mission, b) continuously for 1 minute at 1, 3, and 4 hours, and c) continuously for 1 minute at hourly intervals during the periods assigned for rest (night, Cape Kennedy time) from the 5th day through the 14th day of the mission. Limitations in the number of measurements in the Pilot of Gemini VII were imposed by the 100-hour recording capability of the biomedical tape recorder. No recordings were made during reentry.

RESULTS AND DISCUSSION

Similar patterns of change were observed throughout the missions, although there were quantitative differences among the individual astronauts.

Figure 3 indicates the serial changes in the duration of the total cardiac cycle (line R), electromechanical systole (line S), the electromechanical delay (line T), and the time interval between the first and the second heart sounds (line X) of the Pilot during the flight of Gemini V. The pattern of changes presented here is similar to the patterns observed in all the astronauts who participated in this experiment.

There is usually a marked acceleration of the heart at the time of lift-off. This is reflected in a very short cardiac cycle accompanied by a proportional shortening of systole and the period of electromechanical delay.

There is a gradual deceleration following insertion into orbit, but a steady state is not reached until approximately 16 hours from the onset of the mission. Throughout the mission the duration of the cardiac cycle varies considerably with concomitant changes in the duration of electromechanical systole and of the time interval between the first and second heart sounds. The electromechanical delay remains relatively constant, but usually there is a significant "anticipatory" shortening that begins several hours before reentry. In the instance of the Pilot of Gemini V, this phenomenon began 20 hours before reentry. Low values for the duration of the cardiac cycle and for its various components are always observed at reentry when peak heart rates of about 160 beats per minute are not uncommon. Electromechanical systole and the electromechanical delay reach their lowest values at this time.

An interpretation of the significance of these findings requires the establishment of a functional relationship among the measured variables: the duration of electromechanical systole, of the electromechanical delay, and the total duration of the cardiac cycle. Figure 4 illustrates this relationship. The average values for the duration of the cardiac cycle corresponding to 15 heart beats at different periods of recording are plotted on the ordinate. The corresponding average values for electromechanical systole (S), for the electromechanical delay (T), and for the time interval between the first and the second heart sounds (X) are plotted along the abscissa. It is clear that the values of S, X, and T are longer when the total duration of the cardiac cycle is also longer (that is, when the heart rate is slower). The normal relationship is shown in the regression lines.

In the case of the Pilot of Gemini V, these relationships were normal in practically all instances, although lower-than-predicted values for systole were recorded at the time of reentry. In the case of the Command Pilot of Gemini IV and to a lesser extent in the Pilots of Gemini IV and VII, observed values were slightly lower than normal (Figs. 5, 6, and 7). The Pilot of Gemini VII exhibited a very prolonged cardiac cycle (i.e. low heart rate) during periods of rest, the highest values having been recorded during mid-mission night sleep periods (instantaneous heart rates of 37 to 45 beats per minute) (Fig. 8).

It may be stated that, in general, shorter-than-predicted measurements of cycle components for a cardiac cycle of given duration are observed under the influence of adrenergic or stress factors, whereas longer-than-predicted measurements are indicative of the influence of cholinergic or vagal factors. A preponderance of adrenergic influences was thus uniformly noticed in all the astronauts at the time of lift-off and especially at the time of reentry.

A remarkable quantitative difference was observed in the Command Pilot of Gemini V (Fig. 9). In this individual the durations of electromechanical systole and of electromechanical delay were significantly longer than predicted for normal healthy subjects There was a relative shortening of these periods only at the time of lift-off and reentry. It may be assumed that the longer duration of systole and of electromechanical delay of the Command Pilot of Gemini V was an expression of increased vagal tone except at lift-off and reentry. Increased vagal tone was further suggested by the marked sinus arrhythmia recorded during sleep and quiet periods.

A prolongation of the electromechanical delay was reported by Baevskii and Gazenko in the flight of Cosmonaut Titov (3). An absolute and relative prolongation of the mechanical systole was reported also in the flights of Tereshkova and Bykovskii (4). It is likely that an increased vagal tone accounted for these observations; however, since in the case of the Command Pilot of Gemini V, manifestations of nausea or other untoward symptoms of vagal preponderance did not occur, we may conclude that the isolated finding of a prolonged electromechanical delay period does not in an of itself have pathological significance.

ACKNOWLEDGEMENT

The authors acknowledge the assistance of Mr. W. Young, of the Bioinstrumentation Section of the Crew Systems Division, MSC-NASA and of Mr. T. O. Townsend of the Texas Institute for Rehabilitation and Research for their participation in the playback and digitization of records, and of Mrs. S. Gotcher and Mrs. E. Stallworth for their assistance in the preparation of the reports.

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2. Hegglin, R. and Holzmann, M.: Ztschr. f. klin. Med. 132: 1, 1937.
3. Baevskii, R. M., and Gazenko, O. G.: Kosmicheskie Issledovaniya: 2 (2): 307, 1964.
4. Baevskii, R. M. and Volkov, Yu. N.: Klinicheskaya Meditsina. 43: 6, 1965.

FIGURE LEGENDS

Fig. 1 Analog record of electrocardiogram and phonocardiogram simultaneously registered. The duration of the cardiac cycle and its various intervals can be derived from digitization of these records at the indicated points.

Fig. 2 Sample of the computer output of beat-by-beat measurements of the duration of the cardiac cycle and its phases and of averages and standard deviations for 15 consecutive beats.

Fig. 3 Serial changes in the duration of the cardiac cycle (R), in the duration of electromechanical systole (S), in the interval between first and second heart sounds (X), and in the duration of the electromechanical delay (T) in the Pilot of Gemini V. Midnight, Cape Kennedy time, is indicated by arrows.

Fig. 4 Relationship between electromechanical systole (S), the time interval between first and second heart sounds (X), the electromechanical delay (T), and the duration of the cardiac cycle (R), throughout the mission for the Pilot of Gemini V. Each plot represents average values for each period of recording.

Fig. 5 Relationship between electromechanical systole (S), the time interval between first and second heart sounds (X), the electromechanical delay (T), and the duration of the cardiac cycle (R), throughout the mission for the Command Pilot of Gemini IV. Each plot represents average values for each period of recording.

Fig. 6 Relationship between electromechanical systole (S), the time interval between first and second heart sounds (X), the electromechanical delay (T), and the duration of the cardiac cycle (R), throughout the mission for the Pilot of Gemini IV. Each plot represents average values for each period of recording.

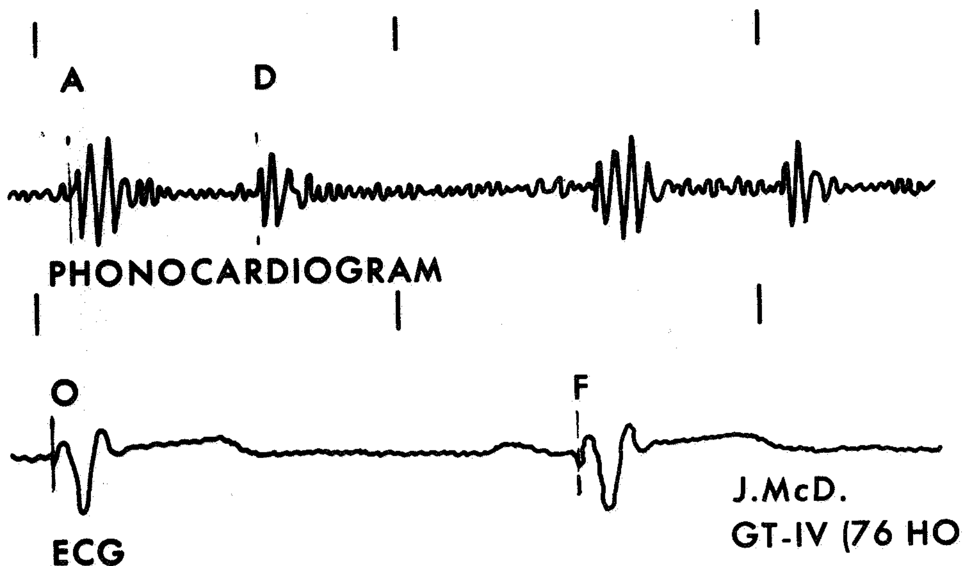
Fig. 7 Relationship between the electromechanical systole (S), the time interval between first and second heart sounds (X), the electromechanical delay (T), and the duration of the cardiac cycle (R), throughout the mission for the Pilot of Gemini VII. Each plot represents average values for each period of recording. The values shown in this graph include those obtained at lift-off but not at reentry. Most of the values were obtained during periods of rest.

Fig. 8 Serial changes in the duration of the cardiac cycle (R), the duration of electromechanical systole (S), the interval between first and second heart sounds (X), and the duration of the electromechanical delay (T) in the Pilot of Gemini VII. Midnight (Cape Kennedy time) is indicated by arrows.

Fig. 9 Relationship between electromechanical systole (S), the time interval between first and second heart sounds (X), the electromechanical delay (T), and the duration of the cardiac cycle (R), throughout the mission for the Pilot of Gemini V. Each plot represents average values for each period of recording.

NASA-S-66-8694 SEP

INFLIGHT PHONOCARDIOGRAM



J.McD.
GT-IV (76 HOURS)
6-6-65

O TO F = RR INTERVAL (R)

O TO D = MECHANICAL SYSTOLE PLUS EXCITATION PERIOD (S)

F - D = DIASTOLE (D)

O TO A = Q TO 1ST SOUND (T)

D - A = 1ST TO 2ND SOUND (X)

Fig. 1

******************** J. A. MCDIVITT GT-4 ******************** PAGE 1361

192. -0. -0. J. A. MCDIVITT 70050 /POSIT 1 /TIME 81001 /DATE 60665 CALIB. 3138(.31949

OBSERVATION		11				
	A		D	F		
	92.		1015.	2609.		
	T	S	X		R	S'
	29.39	324.28	294.89		833.55	356.07
OBSERVATION		12				
	A		D	F		
	84.		983.	2685.		
	T	S	X		R	S'
	26.84	314.06	287.22		857.83	361.21
OBSERVATION		13				
	A		D	F		
	92.		1025.	2786.		
	T	S	X		R	S'
	29.39	327.48	298.08		890.10	367.95
OBSERVATION		14				
	A		D	F		
	98.		1015.	2687.		
	T	S	X		R	S'
	31.31	324.28	292.97		858.47	361.35
OBSERVATION		15				
	A		D	F		
	137.		1004.	2396.		
	T	S	X		R	S'
	43.77	320.77	277.00		765.50	341.22

******************** J. A. MCDIVITT GT-4 ******************** PAGE 1362

192. -0. -0. J. A. MCDIVITT 70050 /POSIT 1 /TIME 81001 /DATE 60665 CALIB. 31381 .31949

AVERAGE FOR BEAT 1 TO 15

AVERAGE T	AVERAGE S	AVERAGE X	AVERAGE R	AVERAGE S'
30.33	320.45	290.12	843.49	359.14
STD.DEV. T	STD.DEV. S	STD.DEV. X	STD.DEV. R	STD.DEV.S'
4.74	7.32	9.13	41.53	8.21

RATIO S/S'
.892263

	RANGE OF S		RANGE OF R	
	MIN	MAX	MIN	MAX
CALCULATED	272.38	368.51	506.10	1180.89
ACTUAL	301.92	332.27	765.50	897.76

Fig.
2

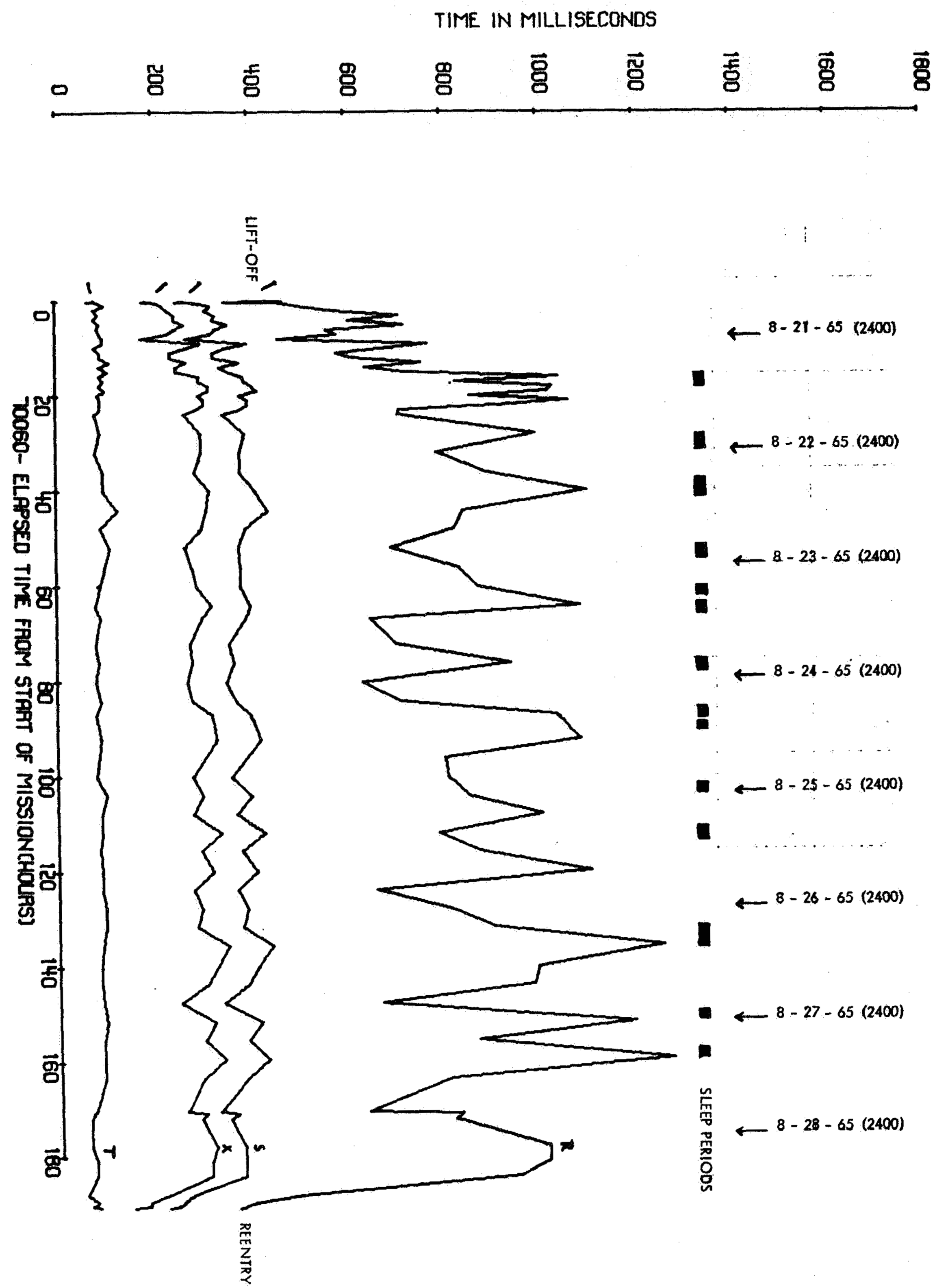

TIME IN MILLISECONDS
0
200
400
600
800
1000
1200
1400
1600
1800
LIFT-OFF
REENTRY
SLEEP PERIODS
8 - 21 - 65 (2400)
8 - 22 - 65 (2400)
8 - 23 - 65 (2400)
8 - 24 - 65 (2400)
8 - 25 - 65 (2400)
8 - 26 - 65 (2400)
8 - 27 - 65 (2400)
8 - 28 - 65 (2400)
R
S
X
T
0
20
40
60
80
100
120
140
160
180
TD060- ELAPSED TIME FROM START OF MISSION(HOURS)

Fig. 3

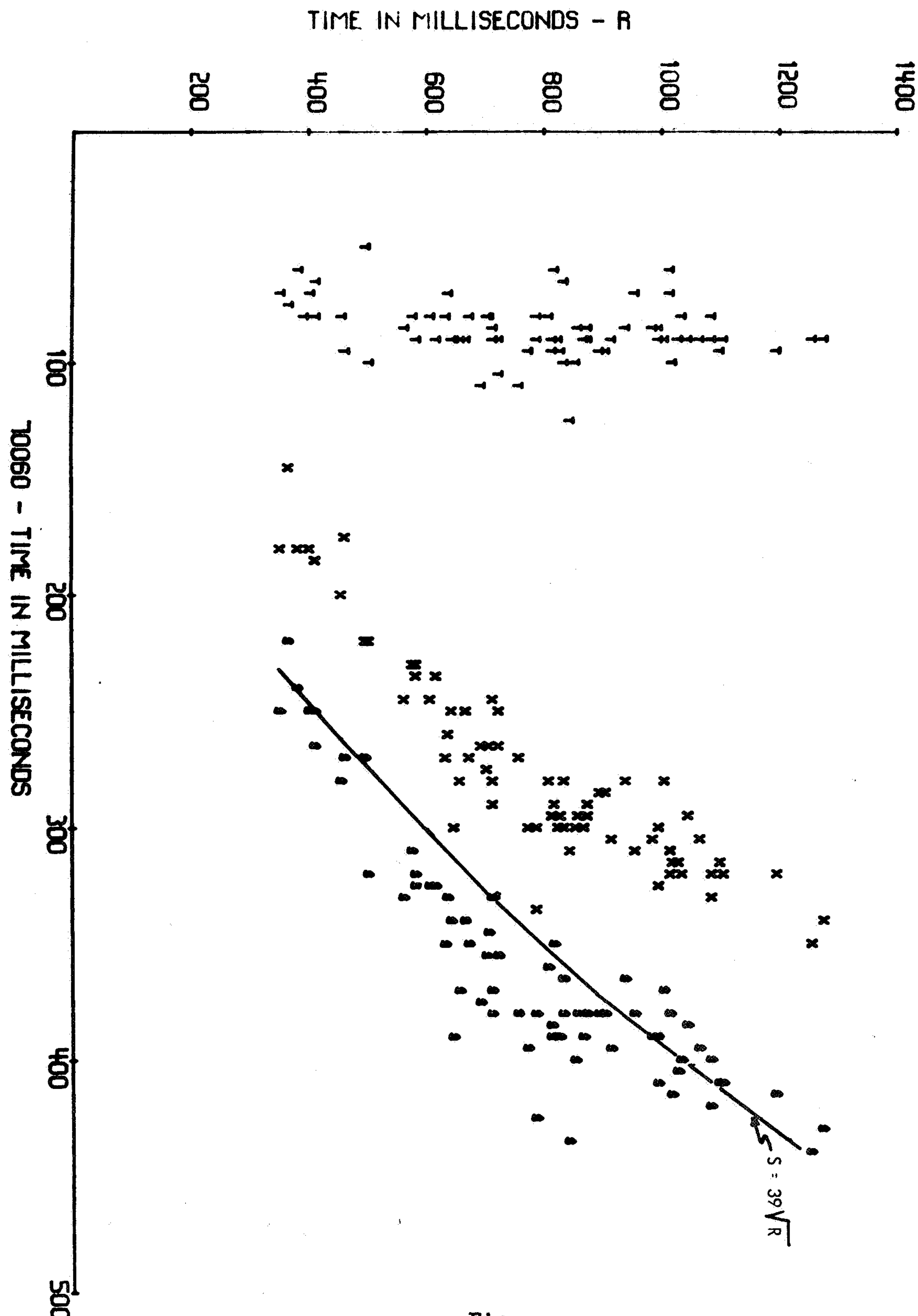

TIME IN MILLISECONDS - R
200
400
600
800
1000
1200
1400
T0060 - TIME IN MILLISECONDS
100
200
300
400
500
S = 39√R

Fig. 4

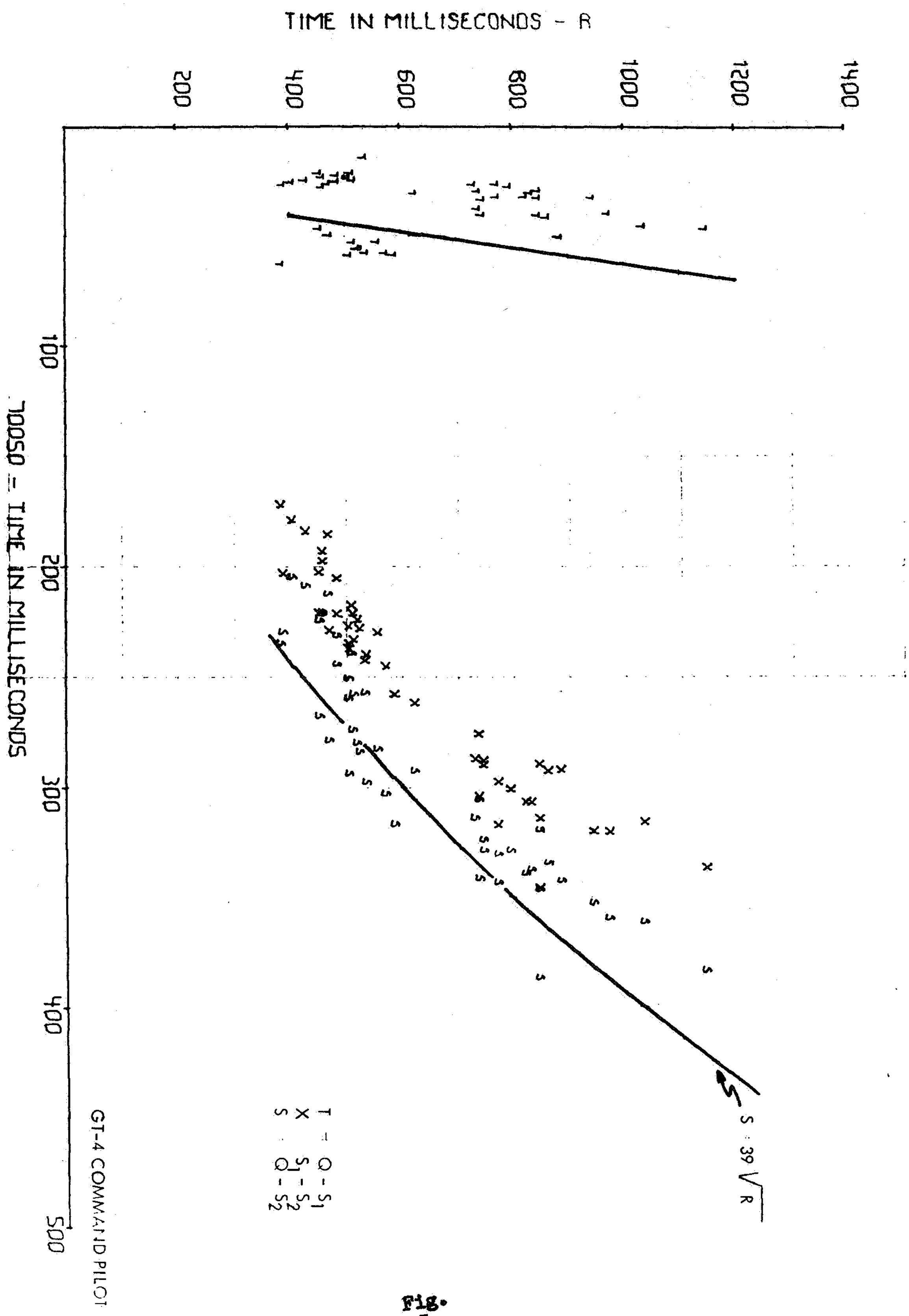

TIME IN MILLISECONDS - R
200
400
600
800
1000
1200
1400
100
200
300
400
500
S = 39 √R
T = Q - S1
X = S1 - S2
S = Q - S2
GT-4 COMMAND PILOT

Fig. 5

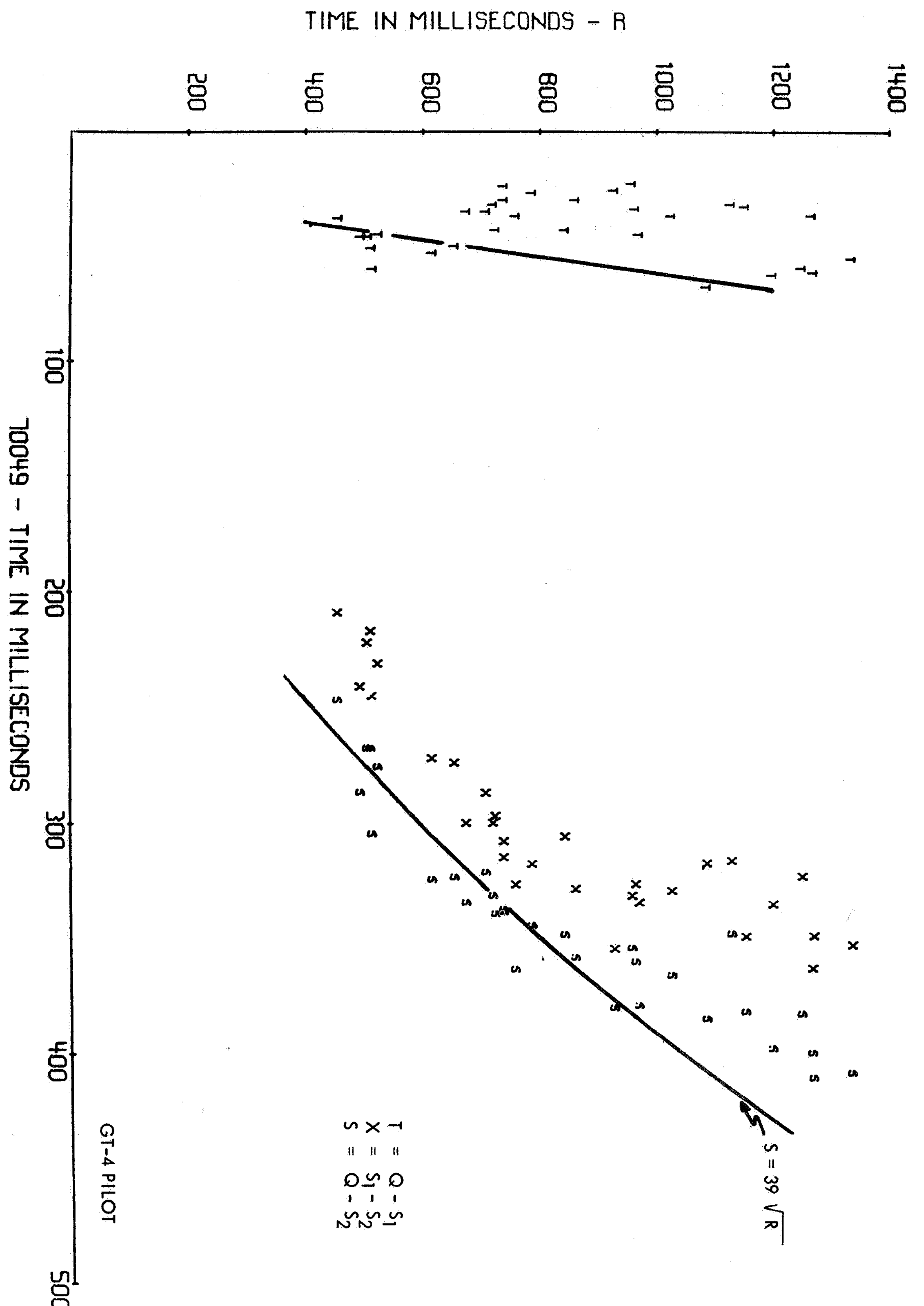
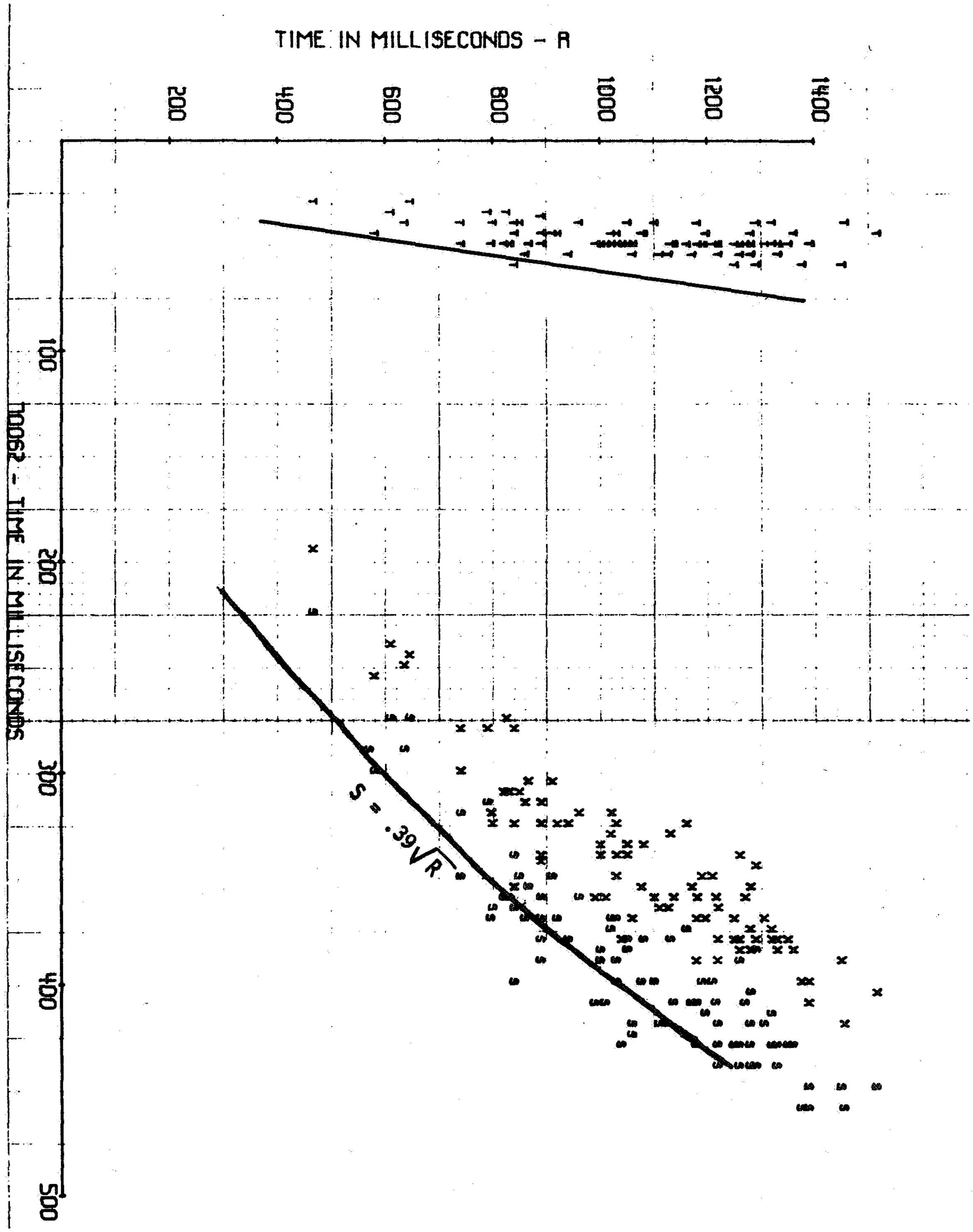

TIME IN MILLISECONDS - R
200
400
600
800
1000
1200
1400
100
200
300
400
500
10049 - TIME IN MILLISECONDS
S = 39 √R
T = Q - S1
X = S1 - S2
S = Q - S2
GT-4 PILOT

Fig. 6



TIME IN MILLISECONDS - R
200
400
600
800
1000
1200
1400
TIME IN MILLISECONDS
100
200
300
400
500
S = .39√R

Fig.
7

NASA-S-66-8693 SEP

INFLIGHT PHONOCARDIOGRAM

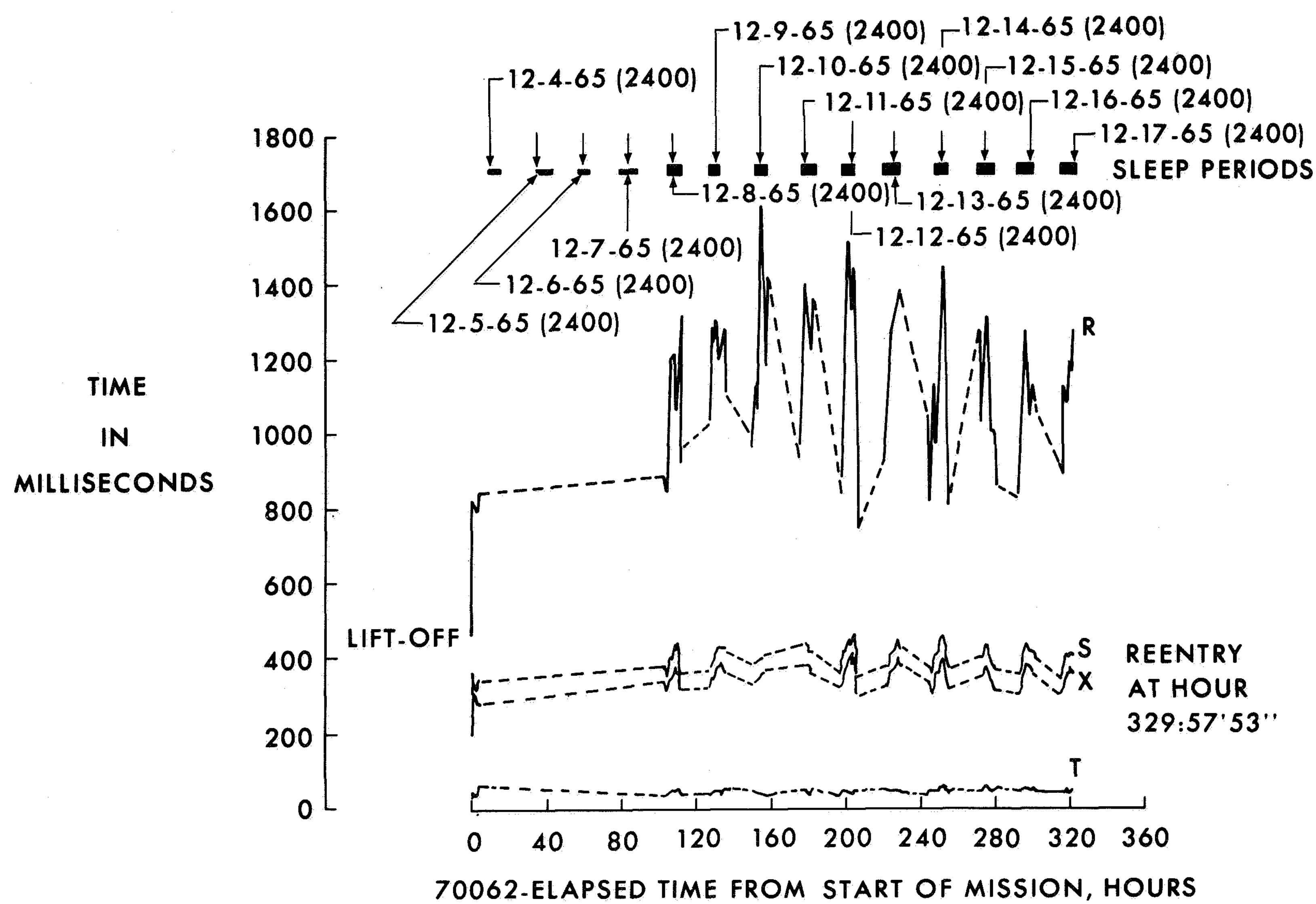
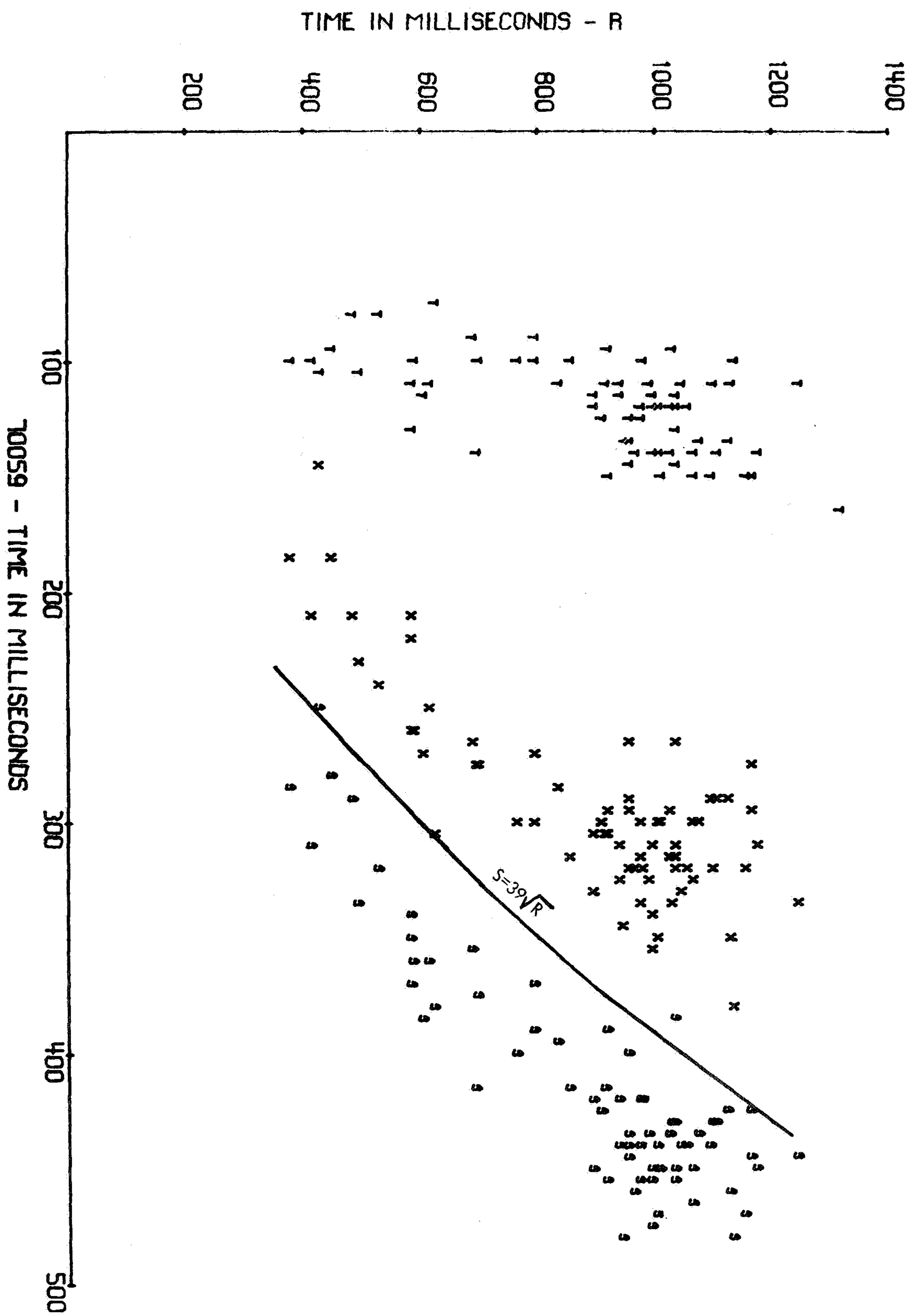


Fig. 8



TIME IN MILLISECONDS - R
1400
1200
1000
800
600
400
200
100
200
300
400
500
70059 - TIME IN MILLISECONDS
S=39√R

Fig. 9

Medical Experiment M-5

BIOCHEMICAL ANALYSIS OF BODY FLUIDS IN MANNED SPACEFLIGHT

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MEDICAL EXPERIMENT M-5

BIOCHEMICAL ANALYSIS OF BODY FLUIDS

IN MANNED SPACEFLIGHT

It is the purpose of the M-5 experiment to determine the metabolic cost of manned spaceflight by the analysis of biological fluids. Results of these biochemical analyses are used as an indication of the physiological status of the astronaut. Where changes are found to occur, efforts are made to understand the mechanisms producing these changes and to assess their significance relative to the spaceflight. The measurements are thus divided into three parts. The first part consists of pre-flight collection of urine samples and whole blood from each crewman to establish baseline values for the individual astronaut. The second portion of the measurements assesses the physiological status of the crewmen as reflected through analysis of urine samples collected in-flight. The final portion of these measurements utilizes urine and blood samples collected immediately post-flight, and on two subsequent occasions at 24 and 48 hours post-flight to establish the rate of return to baseline pre-flight values. Within this context a series of biochemical determinations are performed consisting essentially of fluid and electrolyte balance, hormonal studies, and correlation of the two.

In the first profile, water and electrolyte balance is related to an examination of the loss in body weight which occurs during flight and an attempt at correlation of these losses to changes in fluid distribution and the compartments of the electrolyte space. This involves measurement of sodium, potassium, and chlorides, cations and anions which serve a critical role in regulation of membrane transport. Total plasma protein concentrations measured both pre- and post-flight are used as an indicator, along with blood volume and hematocrit studies, as an indicator of possible dehydration. Water intake and urine output are measured to determine whether the primary loss of weight is the result of insensible loss or of changes in renal function. To aid in an understanding of water and electrolyte balance and renal function, the hormone vasopressin (the antidiuretic hormone from the posterior lobe of the pituitary) and the adrenal mineralocorticoid, aldosterone, are measured in the urine. The release of the posterior lobe hormone vasopressin is regulated by changes both in the osmolar concentration of the blood perfusing the hypothalamus as well as by changes in pressure sensed by centers within the large vessels of the neck. It has been postulated that, as in recumbency, zero gravity should produce an increase in the thoracic blood volume. This increase in thoracic blood volume reflected by increased pressure in the carotid artery baroreceptors in the neck would lead to a reflex decrease in the secretion of antidiuretic hormones, resulting in an increased urine output during flight. Release of the hormone aldosterone from the adrenal cortex is also posture- and perhaps pressure-sensitive. Aldosterone stimulates the renal tubular reabsorption of sodium and, pari passu, water. Its release is decreased in recumbency and increased by an erect position. It is postulated that, as in recumbency, zero gravity would produce a decreased secretion of aldosterone with diminished sodium reabsorption and an increased urinary output. It can thus be seen that the secretion of vasopressin and aldosterone is postulated to be decreased during both the recumbent and the zero gravity conditions. The net effect of these should be a striking increase in urinary output. These relationships are depicted in Figure 1. Implicit in this study, therefore, is the necessity for absolutely correct measurement of total urine output, both pre- and post-flight, as well as during the spaceflight proper. Since the volume of urine varies widely throughout the 24-hour periods, and because the osmolar concentration of dissolved solutes in this urine also varies widely, it is clear that single urine samples collected during flight are insufficient for an assessment of physiological function. It is for this reason, in fact, that the urine collection device has been employed in flights to the most effective advantage of allowing us to secure total urine outputs, as well as aliquot the various urine collection periods and obtain some idea of fluctuation in the output of both fluid and solute.

The second profile involves the estimation of the physiological cost of maintaining a given level of performance during spaceflight. This could be considered a measure of the effects of stress during flight. To this end, two groups of hormones are assayed. The first, 17-hydroxycorticosteroids (17-OH-CS), the stress hormones from the adrenal cortex, provide a measure of long-term stress responses. The second group of hormones, generically called catecholamines, is represented by the substances epinephrine or norepinephrine (adrenalin or nor-adrenalin), which are secreted in response to immediate short-term emergency situations. Assessment of 17-hydroxycorticosteroids and catecholamines provides us with an objective evaluation of both the short- and long-term stresses of manned spaceflight. In 1912, Cannon first described the "fight or flight" reaction to stress. This response, characterized by increased heart rate, increased cardiac output, increased coagulability of the blood, elevation of blood sugar, and dilatation of the pupils, prepares one for an immediate protection from danger. The development of more accurate methods for determining plasma and urinary levels of catecholamines has furnished one of the most important biochemical indicators of the degree of this very rapid response to stress.

In the 1920's, Selye suggested that the glucocorticosteroids, hormones of the adrenal cortex, and especially the 17-hydroxycorticosteroids, were important in the stress response. More recent work has suggested that an increase in 17-hydroxycorticosteroids is seldom as sensitive an indicator of stress as the increase in catecholamines. These relationships are depicted in Figure 2. This figure presents a diagramatic representation of the factors involved in the maintenance of plasma volume and fluid and electrolyte balance which may help in the assessment of the stress involved in spaceflight. Both aldosterone and antidiuretic hormone are important in the regulation of plasma volume, and 17-hydroxycorticosteroids are also thought to play a significant role.

Figure 3 reflects the measurement of urinary 17-hydroxycorticosteroids by the crew personnel of GT-7 in the pre- and post-flight periods. The anticipated finding, which is the striking rise in 17-hydroxycorticosteroids immediately following re-entry, reflects essentially the stress of the re-entry procedure proper. We know that this is a normal response which the body manifests to severe stress, and a response, incidentally, which one needs for survival. An interesting and unexplained finding in regard to the 17-hydroxycorticosteroids is the strikingly low levels sustained during flight.

As indicators of the state of hydration and the electrolyte changes occurring in the flight, urinary excretion of sodium, potassium, and chloride was measured for the pre-flight, the in-flight, and the post-flight period.

Urinary sodium excretion decreased slightly during flight in both members of the crew. Immediately post-flight there was a retention of sodium so that its excretion was sharply diminished. Then a short time later there was a marked rise in urinary sodium levels as the retained sodium was being excreted.

The urinary excretion of chloride was found to parallel that of sodium, as expected, with a slight decrease during flight, a marked decrease during the first 24 hours after being out of the craft, and then a return to pre-flight levels.

The amount of potassium excreted in the urine during the 14-day in-flight period was significantly less than the amount excreted either before or after the flight. These findings were seen to be similar in the two crew members.

Urinary aldosterone levels (Figure 3, black dots) are determined by a double isotope dilution technique using both paper and gas-liquid chromatography. The procedure is technically difficult and involved. Recovery rates are about 40 to 60 per cent, and the error of the method under the best of circumstances approaches 20 per cent. This having been said, the pre-flight aldosterone levels are essentially normal in both crew personnel. The trend in both crew members is toward increased aldosterone excretion during flight with a rapid return to normal in the post-flight period. The period of elevated aldosterone excretion correlates with the period of sodium retention.

Urinary excretion of the adrenal medullary hormones (Figure 4) reflecting short-term stress (catecholamines) shows several interesting aspects. In one crew member, adrenalin (epinephrine) is rather stable throughout pre-, in-, and post-flight periods. The other crew member showed significant elevations both on launch and during re-entry. Nor-adrenalin (norepinephrine) for this latter crew member showed parallel launch and re-entry elevations, while the first crew member demonstrated a significant rise of nor-epinephrine only upon re-entry. One is reluctant to speculate upon the significance of these values, since they constitute a very limited series of observations. A much needed study on correlations of degrees of stress with performance in the Gemini program remains to be made.

We now believe that norepinephrine reflects physical stress, while epinephrine more accurately reflects the degree of emotional stress. Ground-based studies are underway at this time to assess the importance of these two hormones as predictors of human performance under conditions of a variety of stresses. In-flight studies of these hormones remain, however, as the most sensitive indicators of both physical and emotional stress.

From the data shown here, the following conclusions can be drawn:

1. There are significant decreases in fluid intake and urinary output during flight.

2. There are marked decreases in the urinary excretion of sodium, of chloride, and of potassium during flight.

3. There is an apparently significant trend toward elevation of aldosterone during flight.

4. As could be expected, there are considerable increases in catecholamine excretion immediately upon re-entry.

5. There is a significant increase in 17-hydroxycorticosteroids at the time of re-entry.

At this time, no explanation can be offered for the low levels of 17-hydroxycorticosteroids during the flight.

Q. What effect would the accuracy of the volume determinations have on your confidence in the reliability of the data?

A. If the urine collecting devices were not working properly and the total volume collections were not correct, the data certainly would not be reliable. In such a case, one would expect erratic results. However, in this case, the values for sodium, potassium, and chloride are so remarkably similar for the two men that we believe the variations seen are valid observations.

Q. Is there anything from ground-based studies that would enable us to predict how best to protect personnel from metabolic problems?

A. One might predict that adequate hydration and assurance of the intake of at least 15-20 grams of sodium chloride a day might prevent some of the in-flight sodium retention observed. On the other hand, the data on aldosterone may reflect an "in-flight" primary hyperaldosteronism, a possible result of the weightless state. More studies are needed, however, to confirm this observation.

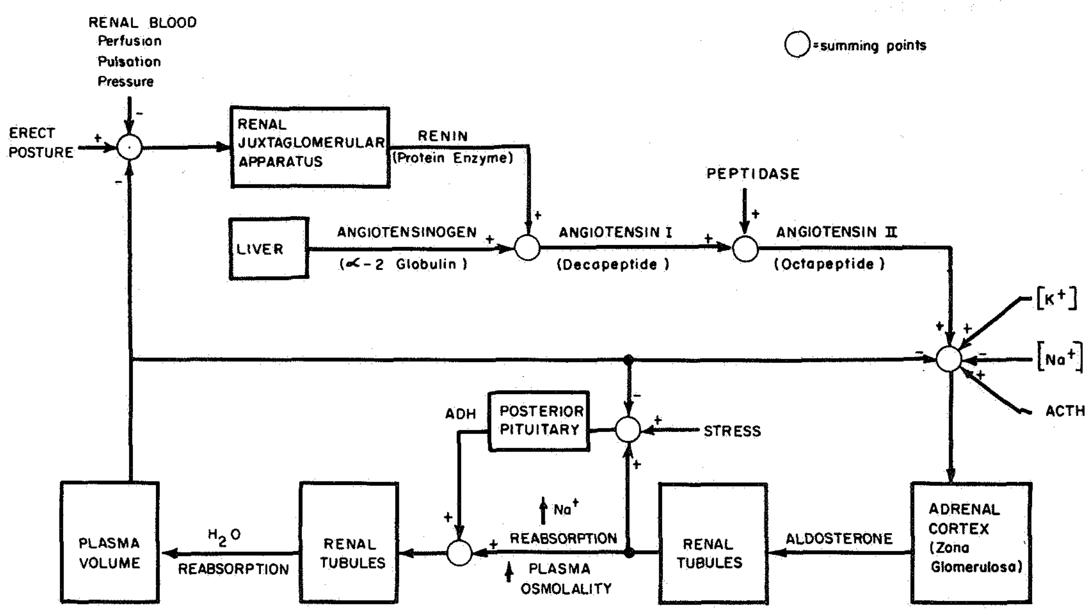

RENAL BLOOD
Perfusion
Pulsation
Pressure
○=summing points
ERECT POSTURE
RENAL JUXTAGLOMERULAR APPARATUS
RENIN
(Protein Enzyme)
PEPTIDASE
LIVER
ANGIOTENSINOGEN
(α-2 Globulin)
ANGIOTENSIN I
(Decapeptide)
ANGIOTENSIN II
(Octapeptide)
[K+]
[Na+]
ACTH
ADH
POSTERIOR PITUITARY
STRESS
PLASMA VOLUME
H_2O
REABSORPTION
RENAL TUBULES
↑ Na+
REABSORPTION
↑ PLASMA OSMOLALITY
RENAL TUBULES
ALDOSTERONE
ADRENAL CORTEX (Zona Glomerulosa)

Fig. 1

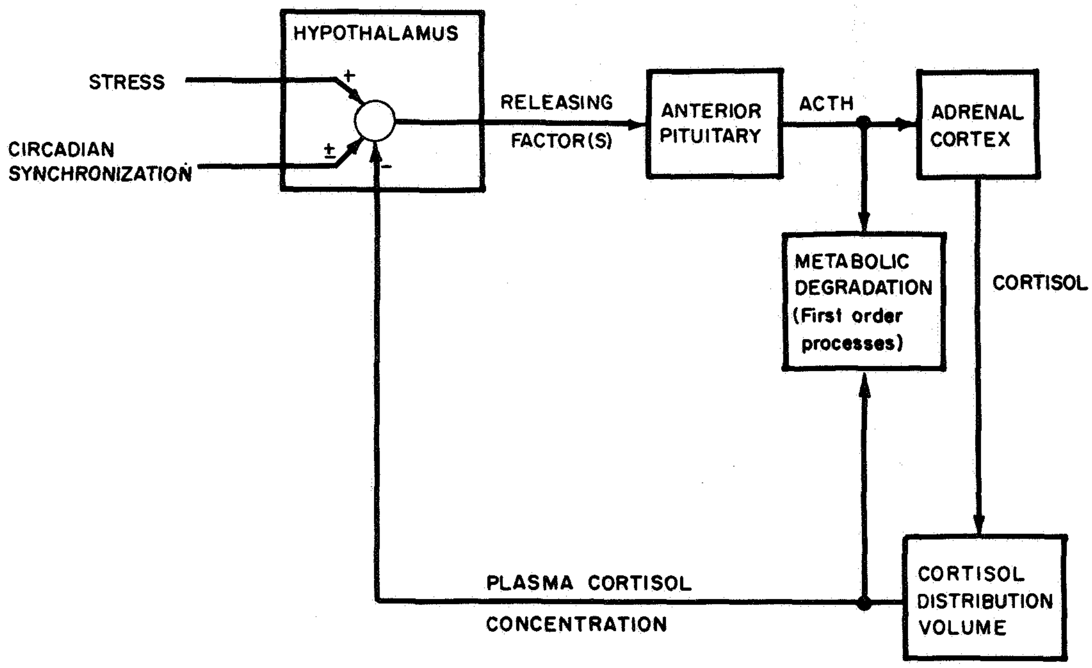
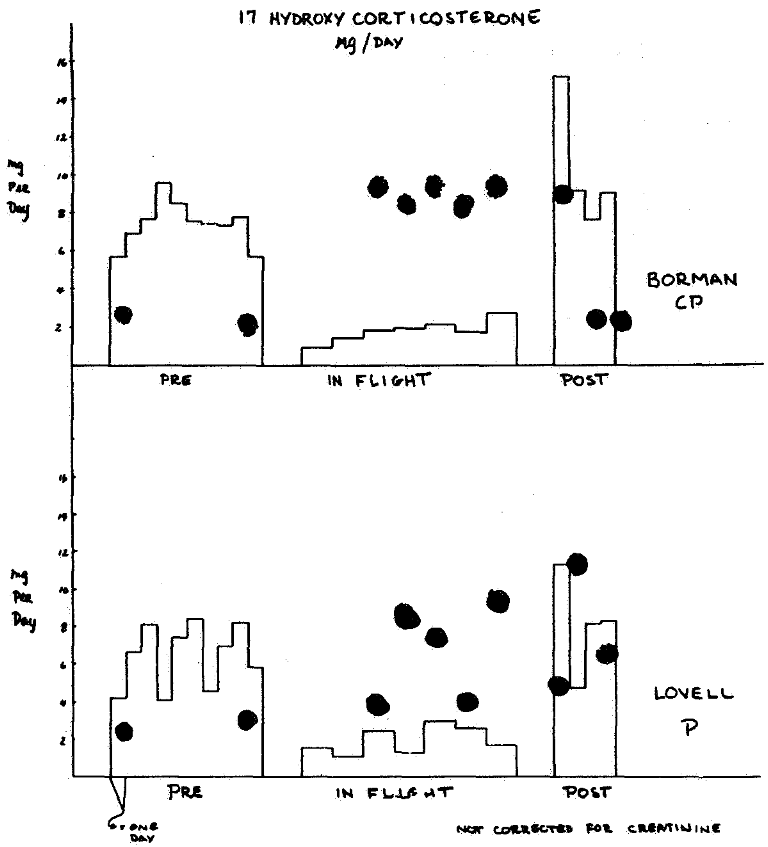

HYPOTHALAMUS
STRESS
+
CIRCADIAN
SYNCHRONIZATION
±
-
RELEASING
FACTOR(S)
ANTERIOR
PITUITARY
ACTH
ADRENAL
CORTEX
METABOLIC
DEGRADATION
(First order
processes)
CORTISOL
PLASMA CORTISOL
CONCENTRATION
CORTISOL
DISTRIBUTION
VOLUME

Fig. 2



17 HYDROXY CORTICOSTERONE
mg / DAY
mg Per Day
BORMAN
CP
PRE
IN FLIGHT
POST
mg Per Day
LOVELL
P
PRE
IN FLIGHT
POST
STONE DAY
NOT CORRECTED FOR CREATININE

Fig. 3

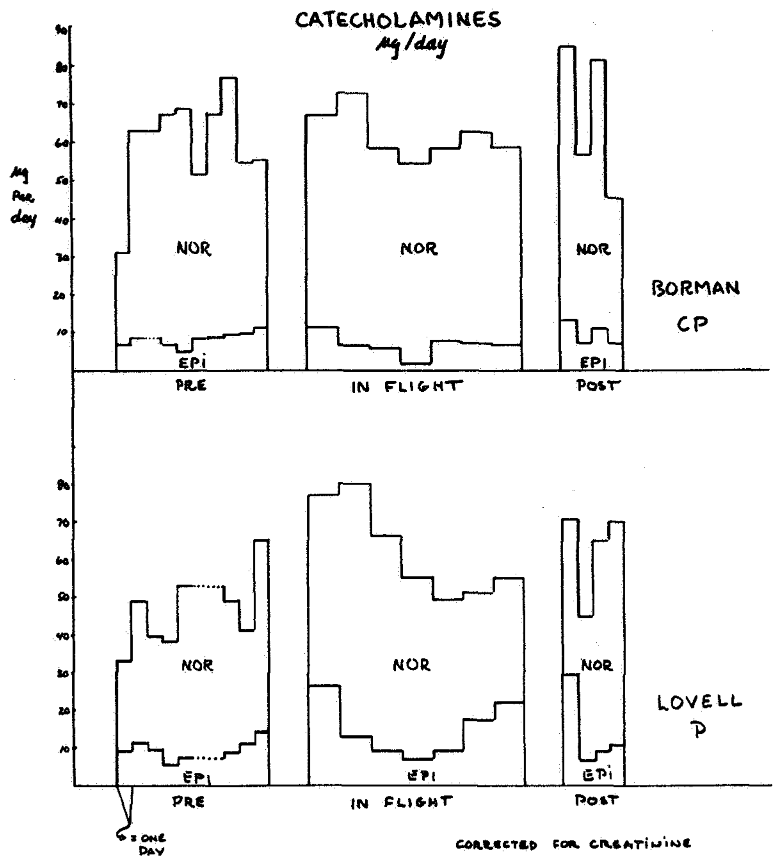

CATECHOLAMINES
μg/day
μg per day
90
80
70
60
50
40
30
20
10
NOR
NOR
NOR
EPI
EPI
PRE
IN FLIGHT
POST
BORMAN
CP
NOR
NOR
NOR
EPI
EPI
EPI
PRE
IN FLIGHT
POST
LOVELL
P
= ONE DAY
CORRECTED FOR CREATININE

Fig. 4

MEDICAL EXPERIMENT M-6

REVIEW OF MEDICAL FINDINGS OF GEMINI VII AND RELATED MISSIONS— BONE DEMINERALIZATION

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Principal Investigator

Paul A. LaChance, Ph.D.

George P. Vose, M.S.

Fred B. Vogt, M.D.
Associate Investigators

REVIEW OF MEDICAL FINDINGS OF GEMINI VII AND RELATED MISSIONS— BONE DEMINERALIZATION

Experiment M-6 of the series of investigations on bone demineralization was designed to find the effect upon the human skeletal system of prolonged weightlessness and immobilization associated with confinement for a period of days in the Gemini spacecraft. This investigation was conducted both on the primary and backup crews of the 14-day Gemini VII mission, using the same method of radiographic bone densitometry as that employed in the Gemini IV and Gemini V studies. Radiographs were made preflight and postflight of the left foot in lateral projection and of the left hand in posterior-anterior projection of each astronaut (a) 10 days and three days preflight and on the day of launch at Cape Kennedy; (b) on the aircraft carrier U.S.S. Wasp immediately after recovery and again 24 hours later; and (c) at the Manned Spacecraft Center at 11 days and 47 days following recovery.

In the laboratories of the Texas Woman's University Research Institute, sections of the bones of the foot and hand were evaluated for changes in skeletal mineralization by the method of radiographic bone densitometry as developed by Mack and associates. Although the left foot, with the distal ends of the leg bones, and the left hand, with the distal parts of the arm bones, are the only parts of the anatomy of the astronauts which are radiographed, a thorough histologic study of multiple sections of cadaver bones of these parts of the body shows that they contain all major types of trabecular and compact skeletal tissue.

As a complement to the space flight skeletal investigations, ground-based bed rest studies have been conducted at the Texas Woman's University for the past three- and one-half years, in which the calcium provision in the diet was varied from one bed rest to the next, so that this nutrient was fed at levels of 300, 500, 700, 800, 1,000, 1,500, and 2,000 milligrams per day, respectively, during seven 14-day bed rest periods and 1,500 and 2,000 milligrams during two 30-day periods of recumbency.

The subjects in these bed rest studies have been kept consistently horizontal, with all of their needs cared for by trained male orderlies, and with their food spoon fed by the dietitians on the project. With the broad range of calcium levels in the bed rest diets, and with x-rays of these subjects taken daily, it has been possible to compare bone density findings of the astronauts with those of certain of the bed rest subjects who were on the same dietary calcium level for the same period of time. Moreover, more extensive radiographs are taken of the bed rest subjects than of the astronauts, with routine balance studies also made on them, which involve calcium, phosphorus, nitrogen, creatine, creatinine, 17-ketosteroids and 17-hydroxycorticosteroids. This gives a basis for making many judgments which aid in the prediction of astronaut findings.

METHODS

Densitometer Assembly

The instrumentation employed for the photometric evaluation of bone density from radiographs in these reported studies was a special analog computer consisting of a series of subassemblies, all designed to operate together as a completely integrated system. The basic units of the overall assembly, the theoretical aspects of the technique, and the history of the development of the method have been reported in references 1, 2, 3, and 4. Certain applications of the use of the bone densitometric method employed in this study have been described in references 5, 6, 7, 8, 9, and 10.

Standard Radiographic Exposure Technique

Because different x-ray units were used at the three locales, the radiographs employed for densitometric measurements at different sites are standardized by three methods: (a) by the use of an aluminum alloy wedge exposed on the film adjacent to the bone; (b) by the use of a roentgen meter to determine the calibrated kilovoltage which would produce identical beam qualities in each of the three x-ray units; and (c) by exposing at each testing site a specially prepared phantom containing a standard quantity of ash enclosed in a tissue-simulating absorber, shaped like an os calcis, to detect possible technique variations.

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

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

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

Anatomical sites for bone evaluation have been chosen and conditions of exposure have been developed which would maximize the x-ray image of the mineral components of bone.

Evaluation of Wedge Mass Equivalency in the Bones Evaluated

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

<u>Central os calcis section</u>. - The tracing path across the left os calcis runs diagonally between conspicuous posterior and anterior landmarks which, by superimposing successive radiographs, can be reproduced accurately in serial films of the same individual. This single path (1.3 mm in width) is known as the "conventional scan." See Figure 1. This is a revealing site for measuring bone mineral changes, since this penetrates a highly trabecular area of this bone, surrounded by a periphery of cortical bone. A cross-section radiograph of a cadaver bone made at the same place at which the "conventional" scan is traced is shown in Figure 2.

<u>Multiple parallel os calcis evaluations</u>. - Approximately 60 per cent of the total os calcis mass was evaluated in the parallel path system. After making the conventional scan, a series of parallel paths 1.0 millimeter apart from center of scan to center of scan were scanned beginning 1 millimeter above the conventional path and continuing to the lowest portion of the bone. The total number of paths scanned thereafter is proportional to the size of the bone which, of course,

has individual variations. For the command pilot of Gemini VII 38 paths and for the pilot 42 paths were required to cover the os calcis portion examined. Figure 3 illustrates the alignment of parallel paths through the os calcis portion examined, although the paths do not go entirely across the bone in the illustration.

The talus. - A single scanning 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 1.

Sections of the 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 aligned tangentially with the longitudinal axis and covering the entire bone area.

The capitate. - A section the width of the scanning beam was traced across the wrist carpal capitate on a diagonal line from a point above the capitate-hamate joint on the left to a point at the lower right, which avoids overlapping of the scaphoid. See Figure 4 for an illustration of the tracing paths of hand phalanges 4-2 and 5-2, and of the capitate.

RESULTS

Bone Mass Changes in Central Os Calcis Section ("Conventional" Path) of Gemini VII Astronauts

The x-ray absorption values (in terms of calibration wedge equivalency) which were obtained from the central os calcis section throughout the Gemini mission are reported in Table I and are shown graphically in Figure 5. Based on a comparison of the data obtained from the radiographs made immediately before and immediately after launch, this central or "conventional" segment of the os calcis exhibited very minor changes during the flight, both for the command pilot and the pilot.

The central os calcis data for the command pilot show that the second and third radiographs made before the orbital flight were closely similar, and were somewhat higher than the initial preflight value. The x-ray made immediately post-flight was only slightly lower than that made immediately pre-flight. The film made the day following recovery was essentially the same in bone mass as the last preflight film, with the last two radiographs showing higher bone mass values than the preflight films.

The values for the pilot ran approximately in the same order as those of the command pilot. For both astronauts, the x-ray made 11 days after the orbital flight was highest in calibration mass equivalency of any radiograph of the series. It should be noted that the astronauts were encouraged to consume foods high in calcium and phosphorus during this period. Moreover, this fell in the Christmas holidays when extensive food consumption was the order of the day.

Os Calcis Values of Back-up Crew

The back-up crew for Gemini VII consisted of Astronaut Edward White and Astronaut Michael Collins. The spread from the highest to the lowest x-ray absorbency value in the central os calcis section of Astronaut White was 2.5 per cent covering a period of three months and 10 days. That of Astronaut Collins was 3.2 per cent over the same period.

The back-up crew was ground based with limited dietary records during the preflight but not during the postflight period.

Bone Mass Changes in Multiple Sections of the Os Calcis

Table II shows that the changes in the overall sum of the sectional values obtained from the parallel scans made in the radiograph taken of the command pilot on the carrier immediately after his recovery was only -2.49 per cent less than that made immediately before launch. The comparable change in values for the pilot was -2.63 per cent (Table III). The tables show also that the greatest change during flight in bone mass in any of the multiple sections of the os calcis of the command pilot was -5.17 per cent, while that of the pilot was -7.66 per cent. A graph of the sums of the calibration wedge equivalency values for the multiple os calcis sections for each of the preflight and postflight radiographs is shown for both astronauts in Figure 6.

Although there are inconsistencies in the magnitude of changes from section to section in the multiple scans of the os calcis, it is seen in Figure 2 that the trabecular tissue in the interior of the os calcis is irregular in design throughout.

X-Ray Absorption Changes in Section of the Talus

Figure 7 shows that, during the preflight the mass of the section evaluated in the talus first increased and then decreased for the command pilot, with a value at the time of launch which was slightly higher than the initial preflight level. The pilot showed a slight decrease in this site preflight. Postflight, both astronauts exhibited a marked increase for 11 days, with final values not markedly different from the initial levels. In general this represents the same pattern of change as that shown by the "conventional" section of the os calcis, although the bone mass losses were slightly greater in the section of the talus which was evaluated than in the os calcis. The calibration wedge mass equivalency at the talus scanning site obtained from the radiograph made immediately postflight was 7.06 per cent lower than the final preflight value for the command pilot and 4.00 per cent lower for the pilot. The talus showed the same directional changes postflight in bone mass as did the os calcis in the central, or "conventional" section.

Bone Mass Changes in the Hand

Hand Phalanx 4-2. The method of positioning the hand for exposure of a radiograph is shown in Figure 8. As in the case of the os calcis, multiple parallel scans were made across hand phalanges 4-2 and 5-2 with distances of 1 millimeter from the center of one scan to that of the next scan. In this manner, the entire area of each phalanx was evaluated in posterior-anterior projection.

From the time of taking the radiograph made immediately before launch until that which was made 14 days later, immediately after recovery on the carrier, the command pilot sustained an overall change in the 25 scans required to cover phalanx 4-2 of -6.53 per cent. The change in this anatomical site for the pilot during the same period was -3.82 per cent, with 25 scans required to cover this bone.

Figure 9 consists of graphs of the calibration wedge equivalency values for hand phalanges 4-2 for the serial radiographs of the two Gemini VII astronauts. The graph of the command pilot shows that the value for phalanx 4-2 was higher at the beginning of the orbital flight than was the first preflight value, with a decline by the close of the flight. This was followed by a gradual increase after the flight. The graph for phalanx 4-2 of the pilot shows a marked increase in bone mass during the first seven days of preflight, followed by a decrease during the last four preflight days. Following the decrease during the flight, there was a sharp and then a gradual postflight increase.

Hand Phalanx 5-2. Figure 10 includes a graph of the calibration wedge mass equivalency data on hand phalanx 5-2 of both Gemini VII astronauts. The values for the command pilot did not experience as marked preflight and postflight changes as did those of the pilot.

From the beginning to the close of the orbital flight, the command pilot sustained an overall change in the 18 parallel sections required to cover phalanx 5-2 amounting to -6.76 per cent. In the 17 scans which covered hand phalanx 5-2 of the pilot, an overall change in bone mass of -7.03 per cent was found.

Capitate. Between the x-ray made immediately before the orbital flight and that made immediately after recovery on the carrier, the change in mass of the section of the capitate which was evaluated was -4.31 per cent for the command pilot and -9.30 per cent for the pilot. (See Figure 11). As in the x-rays made in other anatomic sites, the astronauts both went up slightly between the first two films of the capitate series, and then decreased in calibration wedge mass equivalency between the second and final preflight radiographs. Characteristic of all sites evaluated, the capitate made a marked recovery of mass (in terms of x-ray absorbency) during the first 24 hours following the mission in both astronauts. Then there was a marked increase in mass of this bone during the next 10 days, reaching the highest level at this time. Then the bone mass decreased somewhat until the last radiograph was taken 37 days after the orbital flight was over. The final level of mass in this bone for both men, however, was higher in the last radiograph than in the x-ray immediately before the flight.

Work on Fine Structure Changes in Bone Tissue from Radiographs

In all anatomical sites upon which measurements were made on the astronauts of the Gemini VII mission, rapid gains in bone mass were found during the first 12 hours in which the command pilot and the pilot were ambulatory on the carrier. (See Figures 5, 6, 7, 9, 10, and 11). This same bone mass phenomenon has been found in astronauts during other missions, and in bed rest subjects who have changed from bed rest to an ambulatory phase, or from one extreme dietary level of calcium to another.

A means of verifying these rapid changes is being explored by studying fine structure patterns in bone by methods previously used exclusively for photographic interpretations, with applications primarily made in reconnaissance studies. The first step is being made in this direction by the Principal Investigator in cooperation with Mr. Lyle D. Cahill, using facilities and techniques available at Data Corporation (Dayton, Ohio), a company of which he is president. Some of the x-ray films of Gemini V, a mission during which bone mass changes were greater than in the Gemini VII mission, have been used in this initial x-ray fine structure study (11). This constitutes the beginning of routine three-dimensional tests on our x-rays to locate fine structure pattern changes in the bone sections evaluated.

Comparison of Bone Changes in Astronauts of the Gemini IV, V, and VII Missions

Bone mass losses in the crew of Gemini VII tended to be markedly lower in all anatomical sections which were evaluated than in the astronauts of Gemini IV, and particularly than those of Gemini V. This is shown clearly in Table III, in which the overall values for the various sites are outlined, and in Table IV in which changes are given for all cross-sections of hand phalanx 5-2 for all six of the astronauts of these three missions.

The summary on the following page gives the mean daily calcium intakes and the os calcis bone changes on the part of the astronauts of the three missions under discussion, and of TWU bed rest subjects consuming a comparable quantity of calcium for the same period of time. The general relationships between dietary intake and bone mass changes in the os calcis are obvious from an examination of the summary, both for the astronauts and for the corresponding TWU bed rest subjects. The most distinct differences are seen in a comparison of the results of the astronauts of Gemini V and Gemini VII, the former having consumed about one-third as much calcium during flight as the latter.

GEMINI IV

	Calcium Intake (milligrams)	Bone Density Change (calibration wedge equivalency) (grams)
Command Pilot	679	-7.80
Pilot	739	-10.30
TWU Bed Rest		
Subject 1	675	-2.67
Subject 2	659	-4.25
Subject 3	636	-3.39
Subject 4	636	-3.59
Mean of Bed Rest Subjects	651	-3.47

GEMINI V

	Calcium Intake (milligrams)	Bone Density Change (calibration wedge equivalency) (grams)
Command Pilot	373	-15.10
Pilot	333	-8.90
TWU Bed Rest		
Subject 1	307	-8.65
Subject 2	292	-5.06
Subject 3	303	-7.89
Subject 4	308	-8.06
Mean of Bed Rest Subjects	302	-7.41

GEMINI VII

	Calcium Intake (milligrams)	Bone Density Change (calibration wedge equivalency) (grams)
Command Pilot	945	-2.91
Pilot	921	-2.84
TWU Bed Rest		
Subject 1	931	-3.46
Subject 2	1,021	-3.56
Subject 3	1,034	-5.79
Subject 4	1,020	-5.11
Subject 5	930	-5.86
Mean of Bed Rest Subjects	987	-4.76

Figure 11 brings together the findings concerning the "conventional" segment of the largest bone in the foot, the os calcis, of the astronauts in Gemini IV, Gemini V, and Gemini VII during flight, in comparison with the Texas Woman's University bed rest subjects on the same level of dietary calcium for an equivalent period of time. The astronauts of Gemini VII, who participated in the longest period of flight, experienced far lower losses in the os calcis, as has been shown above, than were found in the crews of Gemini IV or V. The losses were even lower than those in the TWU comparable bed rest subjects. For the crews of Gemini IV and Gemini V, the losses in os calcis values were greater than occurred in the bed rest subjects.

The same comparisons are shown in Figure 12 for hand phalanx 5-2. In this case, however, notably greater decreases in bone mass during flight were found for all astronauts than for the TWU bed rest subjects who consumed equivalent quantities of calcium for a time period equal to the time of the respective flights. This would indicate that there is the need to find whether or not exercise routines are possible which would affect the bone mass in the hands and fingers to a greater degree.

Texas Woman's University 14-Day Bed Rest Study including Isometric and Isotonic Exercises as in the Gemini VII Mission

In order to test the possibility that, aside from the importance of dietary calcium, the isometric and isotonic exercise program practiced on a daily routine basis by Astronauts Borman and Lovell during the Gemini-Titan VII mission could have been one parameter which contributed to the lowered bone mass loss by these astronauts, a 14-day bed rest program was planned and carried out as one of the bed rest units conducted at the Texas Woman's University.

Four men were equilibrated with respect to os calcis bone mass and calcium balance, after which they took part in a 14-day supine, horizontal bed rest unit without exercise. After this initial 14-day bed rest unit, during which 800 milligrams of calcium were provided daily, two of the same men took part in a second bed rest, following an ambulatory period of equilibration. Throughout all phases of this study 800 milligrams of calcium per day was provided, as in the first bed rest. The second bed rest was conducted in exactly the same manner as the first, except for the fact that the exercise program used in Gemini VII was followed.

Dietlein and Rapp (12) reported on the use of an inflight exercise instrument used in Gemini VII. The basis of the evaluation of the exercise on Gemini VII was the response of the cardiovascular system (pulse rate, blood pressure, and respiration rate) to a calibrated workload. The exercise device, used both on the Gemini VII astronauts and on the two TWU bed rest subjects, consisted of a pair of rubber bungee cords attached to a nylon handle at one end and to a nylon foot strap at the other.

The exercise program utilized in the Gemini VII and in the TWU bed rest programs were the same, and were more extensive than that described in the report cited in the above paragraph. The program followed in the bed rest study is described in more detail by Mack and associates (6). A previous bed rest study described in Reference (8) shows the same trend in bone mass of the os calcis in a ground based study conducted cooperatively by the Texas Institute of

Rehabilitation and Research (Houston) and the Texas Woman's University.

When the classical "t" test was applied to a comparison of the bone mass findings during the first bed rest without exercise and the second bed rest with programmed exercise, with the data for both men pooled, the bed rest unit with exercise surpassed that without exercise in bone mass (in terms of wedge mass equivalency) by a difference which was statistically significant ($P < 0.05$).

A comparison of the pooled data of both men on urinary calcium excretion using the "t" test, showed that the amount of calcium lost in the urine was greater when the bed rest without exercise was in progress, than in the bed rest period. The former surpassed the latter by a highly significant difference ($P < 0.01$).

Figure 13 consists of regression lines for the bone mass pooled data of both men for the bed rest periods with and without exercise, drawn by an IBM 1620 computer. The only difference between the regression lines for the two bed rest periods were the slopes, which were steeper for the bed rest without exercise. Figure 14 gives a graphic representation of the regression lines for the urinary calcium excretion levels pooled for both men during the respective bed rest periods, the first with no exercise and the second with a program of isometric and isotonic exercise.

SUMMARY

The level of food intake undoubtedly has been one of the major parameters accountable for the difference in levels of mineral loss by the astronauts. This has been supported by the ground based bed rest studies of the Texas Woman's University series. Another factor probably responsible at least in part for the comparatively low losses in bone mass of the largest bone of the foot by the astronauts of Gemini VII was the fact that they engaged in isotonic and isometric exercise following a pre-designed program and using an exerciser developed by Dietlein and Rapp (12). This exercise routine has been repeated in a TWU bed rest unit with highly positive results (6). In addition, the Gemini-Titan VII astronauts slept for longer periods of time than did those of Gemini IV and Gemini V.

The findings of the bone losses in the various anatomical sites discussed in the three Gemini missions of this report show that time is not the chief factor responsible for skeletal loss during space flight, but that some other factor or factors play a part in these changes.

In closing, it should be noted that the skeletal losses experienced by the astronauts during these studies were replaced within short periods of time following the close of the respective flights. As examples, see Figures 6, 7, and 8.

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TABLE I

BONE DENSITOMETRIC VALUES OBTAINED FROM SCANNING THE CENTRAL SECTION OF THE OS CALCIS OF GEMINI-TITAN VII ASTRONAUTS AT INTERVALS THROUGHOUT THE PRE-FLIGHT, ORBITAL FLIGHT, AND POST-FLIGHT PERIODS

Film	Date	Calibration Wedge Mass Equivalency	
		Command Pilot	Pilot
1	11/24/65	2.1551	2.4061
2	12/1/65	2.2673	2.3846
3	12/4/65	2.2336	2.4693
4	12/18/65	2.1689	2.3991
5	12/19/65	2.2302	2.4145
6	12/29/65	2.3526	2.6428
7	2/3/66	2.3081	2.5171

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

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

TABLE III

PER CENT CHANGE IN BONE MASS AT MAJOR ANATOMICAL SITES OF ASTRONAUTS OF GEMINI IV, GEMINI V, AND GEMINI VII MISSIONS

Anatomical Position of Section Evaluated	Per Cent Change in Bone Mass (In terms of calibration wedge mass equivalency)					
	Gemini IV (from 6/3/65 to 6/7/65)		Gemini V (from 8/21/65 to 8/29/65)		Gemini VII (from 12/4/65 to 12/18/65)	
	Command Pilot	Pilot	Command Pilot	Pilot	Command Pilot	Pilot
Conventional Os Calcis Section	-7.80	-10.30	-15.10	-8.90	-2.91	-2.84
Multiple Os Calcis Sections	-6.82	-9.25	-10.27	-8.88	-2.46	-2.54
Range of Changes in Multiple Os Calcis Sections	From -1.50 to -9.73	From -2.08 to -13.42	From +3.55 to -29.52	From +0.55 to -13.76	From -0.49 to -5.17	From +1.39 to -7.66
Section of Talus	-10.69	-12.61	-13.24	-9.87	-7.06	-4.00
Multiple Sections of Hand Phalanx 5-2	-11.85	-6.24	-23.20	-16.98	-6.78	-7.83
Range of Changes in Hand Phalanx 5-2	From -4.4 to -12.2	From -0.5 to -14.3	From -19.6 to -26.1	From -0.4 to -22.1	From -1.84 to -12.07	From -2.19 to -14.86
Multiple Sections of Hand Phalanx 4-2	-4.19	-8.65	-9.86	-11.80	-6.55	-3.82
Range of Changes in Hand Phalanx 4-2	From -1.28 to -11.27	From +0.49 to -15.28	From -6.00 to -13.10	From -5.30 to -16.90	From -2.88 to -9.11	From -1.66 to -8.54
Section of Capitate	-4.48	-17.64	-17.10	-16.80	-4.31	-9.30

TABLE IV

COMPARISON OF PER CENT CHANGES IN THE MULTIPLE PARALLEL SECTIONS OF HAND PHALANX 5-2 OF THE COMMAND PILOT AND PILOT DURING GEMINI IV, GEMINI V, AND GEMINI VII MISSIONS

Anatomical Position of Section	Per Cent Change in Bone Mass (in Terms of grams of Calibration Wedge Mass Equivalency)					
	Gemini IV (from 6/3/65 to 6/7/65)		Gemini V (from 8/21/65 to 8/29/65)		Gemini VII (from 12/4/65 to 12/18/65)	
	Command Pilot	Pilot	Command Pilot	Pilot	Command Pilot	Pilot
Distal End of Phalanx	-9.7	-4.9	-22.2	-18.3	-4.6	-10.0
1 mm above	-9.6	-14.3	-22.3	-19.0	-9.3	-3.3
2 mm above	-9.5	-8.3	-21.5	-17.7	-8.3	-10.5
3 mm above	-10.3	-2.4	-22.9	-22.1	-10.4	-10.5
4 mm above	-10.1	-0.5	-20.6	-20.2	-12.1	-12.2
5 mm above	-10.2	-1.9	-19.6	-20.9	-6.8	-6.5
6 mm above	-9.8	-3.8	-21.3	-18.3	-3.5	-14.9
7 mm above	-6.2	-3.5	-21.9	-19.6	-1.8	-7.8
8 mm above	-4.4	-3.4	-23.3	-17.9	-3.3	-6.3
9 mm above	-3.5	-5.1	-23.1	-22.0	-4.7	-5.0
10 mm above	-7.6	-3.3	-23.5	-17.3	-4.3	-4.2
11 mm above	-7.8	-4.6	-23.5	-15.8	-3.8	-3.5
12 mm above	-10.7	-7.1	-24.2	-14.2	-4.9	-2.2
13 mm above	-12.2	-5.5	-26.1	-15.5	-6.2	-2.3
14 mm above	-10.6	-5.4	-24.3	-0.4	-10.7	-4.2
15 mm above	-11.7	-5.1	-24.3	-14.7	-8.9	-2.5
16 mm above	X	-7.5	-23.8	-16.5	-8.4	-7.9
17 mm above	X	-8.4	-25.9	X	-7.1	X

FIGURE LEGENDS

Fig. 1 Positive of lateral foot radiograph showing location of the central section of the os calcis ("conventional" section) which is evaluated for bone density changes, as well as the location of the section of the talus which is scanned.

Fig. 2 Cross-section of os calcis at the position at which the "conventional" segment is scanned.

Fig. 3 Radiograph of positive of os calcis showing location of the multiple sections which are evaluated. These scans are made entirely across the bone, parallel with the conventional section. They are 1 mm wide from the center of one scan to the center of the next scan, and hence they cover all of the 60 per cent of this bone which is involved in this evaluation.

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

Fig. 5 Graph of the calibration wedge mass equivalency data on the "conventional" os calcis section which were evaluated for the two Gemini-VII astronauts.

Fig. 6 Graph of the calibration wedge mass equivalency data on the multiple os calcis sections which were evaluated for the two Gemini VII astronauts.

Fig. 7 Graph of the calibration wedge mass equivalency data on the section of the talus which was evaluated for the two Gemini VII astronauts.

Fig. 8 Positioning a subject for a hand x-ray. The subject is shielded by means of vinyl plastic sheeting which is impregnated with a lead compound.

Fig. 9 Graph of the calibration wedge mass equivalency data on hand phalanx 4-2 for the two Gemini-VII astronauts.

Fig. 10 Graph of the calibration wedge mass equivalency data on hand phalanx 5-2 for the two Gemini-VII astronauts.

Fig. 11 Graph of the calibration wedge equivalency data on the capitate for the two Gemini-VII astronauts.

Fig. 12 Comparison of Per Cent Changes in X-Ray Absorbency (Calibration Wedge Mass Equivalency) in the "Conventional" Os Calcis Site by the Command Pilot, the Pilot, and the Mean of TWU Bed Rest Subjects who Consumed Comparable Amounts of Calcium Per Day for the Crews of Gemini IV, V, and VII.

Fig. 13 Comparison of Per cent change in X-ray absorbency (calibration wedge mass equivalency) in the hand phalanx 5-2 site by the Command Pilot, the Pilot, and the mean of TWU bed rest subjects who consumed comparable amounts of calcium per day for the Crews of Gemini IV, V, and VII.

Fig. 14 First order regression lines for bone mass (data for two subjects pooled) during the first 14-day supine, horizontal bed rest when no exercise was taken (lower curve), and during the second bed rest when isometric and isotonic programmed Gemini VII exercises were followed (upper curve). Note: regression lines were drawn by an IBM 1620 computer.

Fig. 15 First order regression lines for urinary calcium excretion (data for two subjects pooled) during the first 14-day bed rest when no exercise was taken (upper curve), and during the second bed rest when programmed Gemini VII exercises were followed. Note: regression lines were drawn by an IBM 1620 computer.

Fig. 1

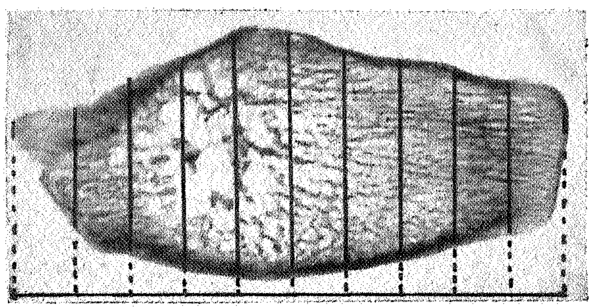


Fig. 2

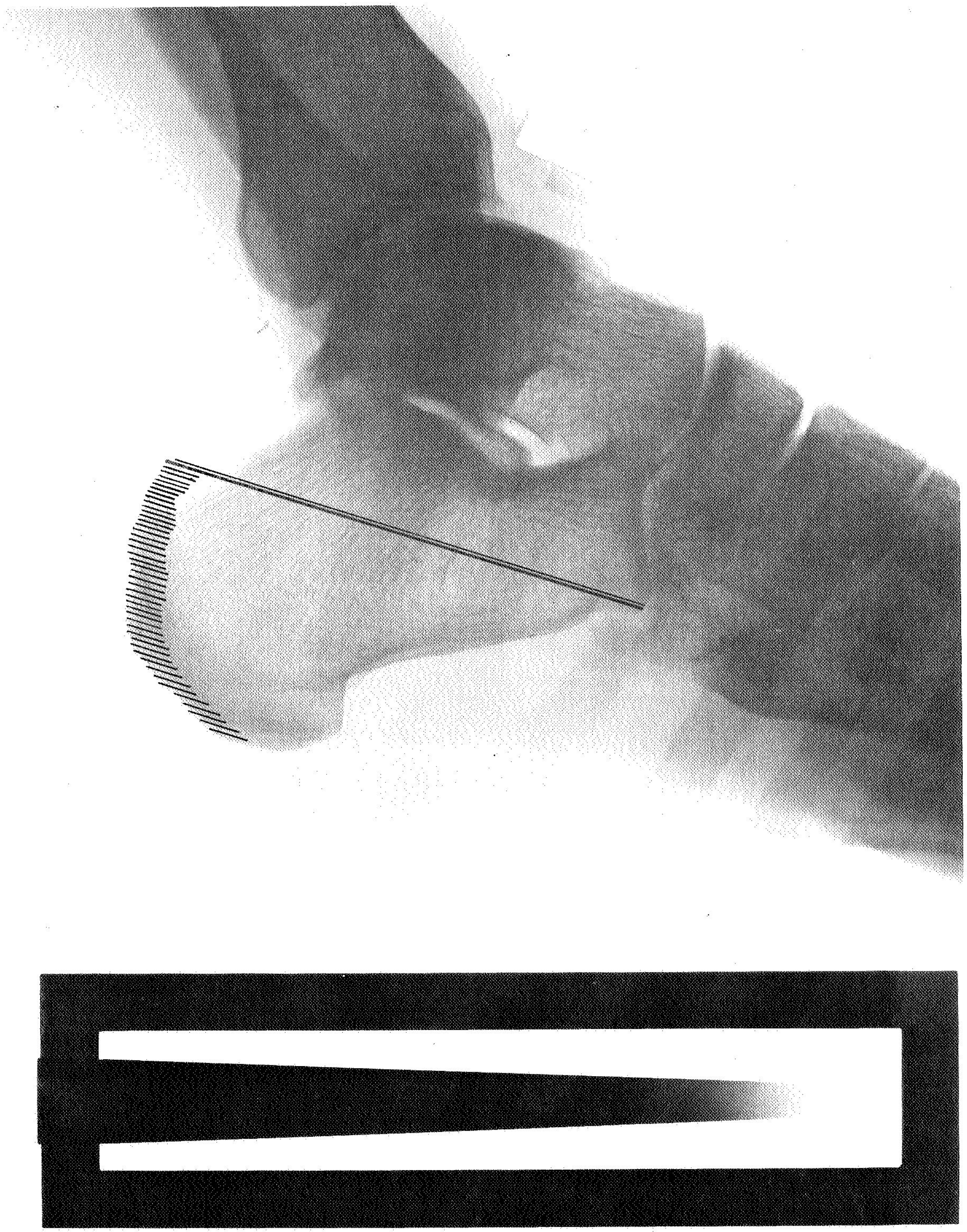


Fig. 3

Fig. 4

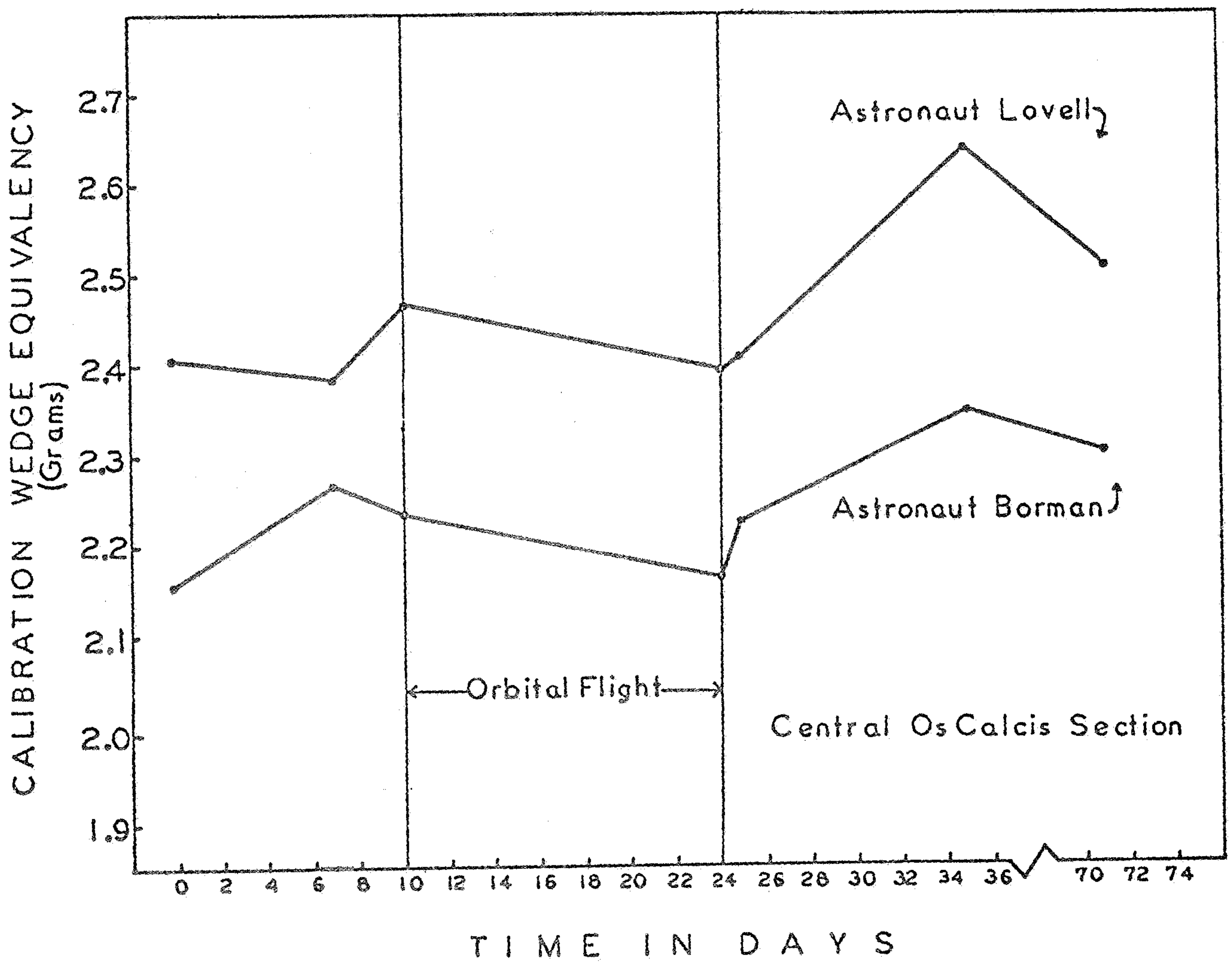


Figure 5. Graph of the calibration wedge mass equivalency data on the "conventional" os calcis section which were evaluated for the two Gemini-VII astronauts

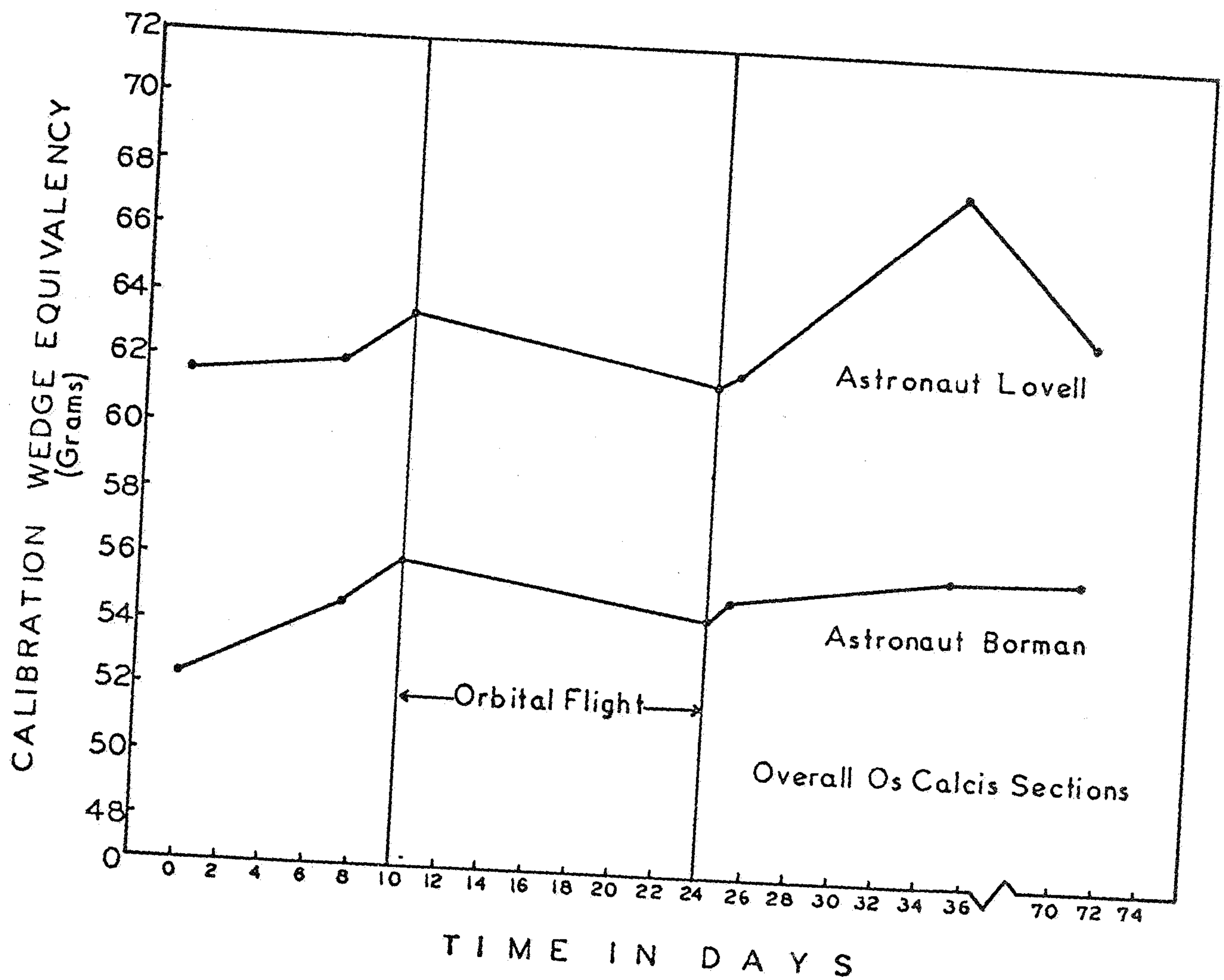


Figure 6. Graph of the calibration wedge mass equivalency data on the multiple os calcis sections which were evaluated for the two Gemini-VII astronauts

Fig. 6

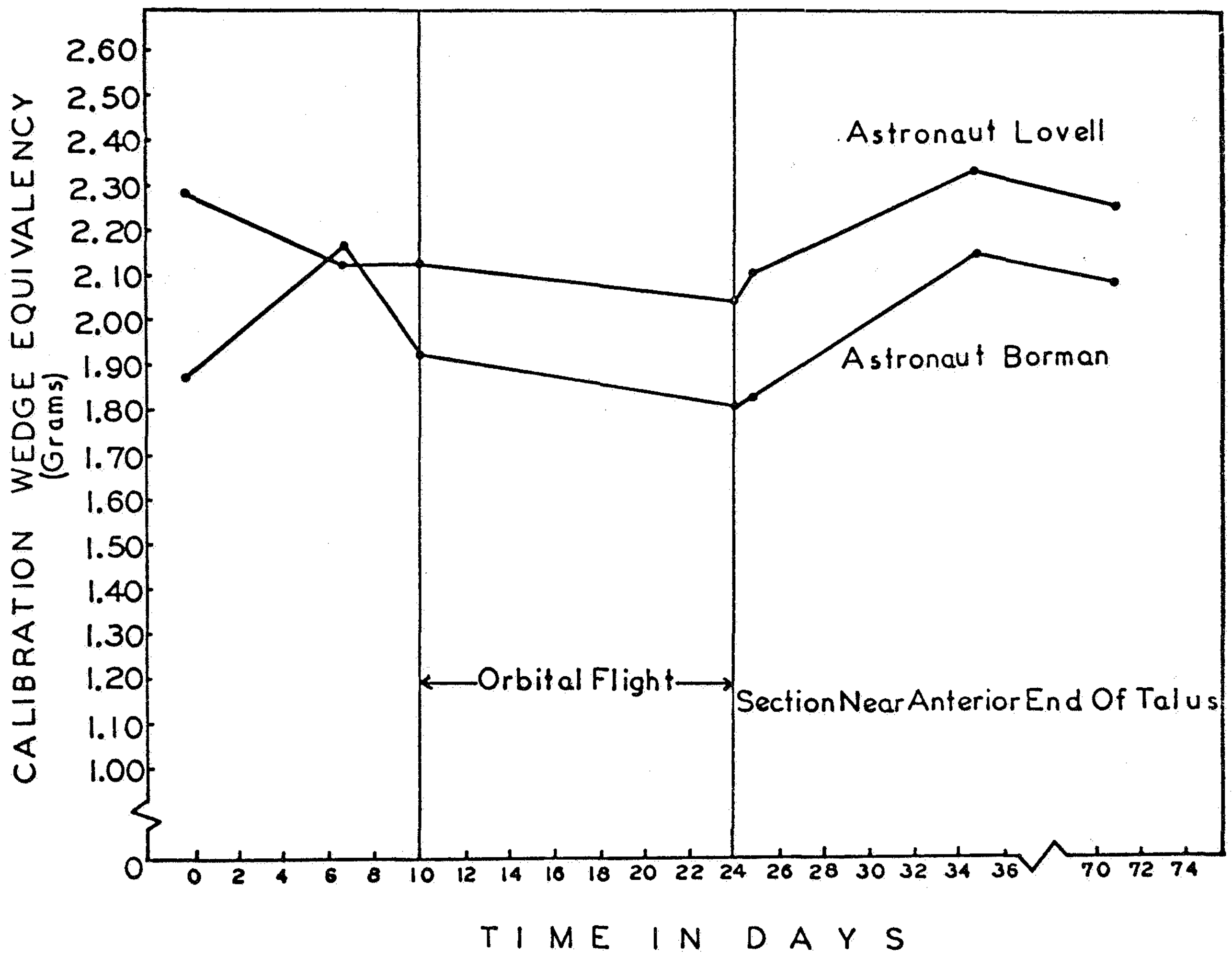


Figure 7. Graph of the calibration wedge mass equivalency data on the section of the talus which was evaluated for the two Gemini-VII astronauts

Fig. 7

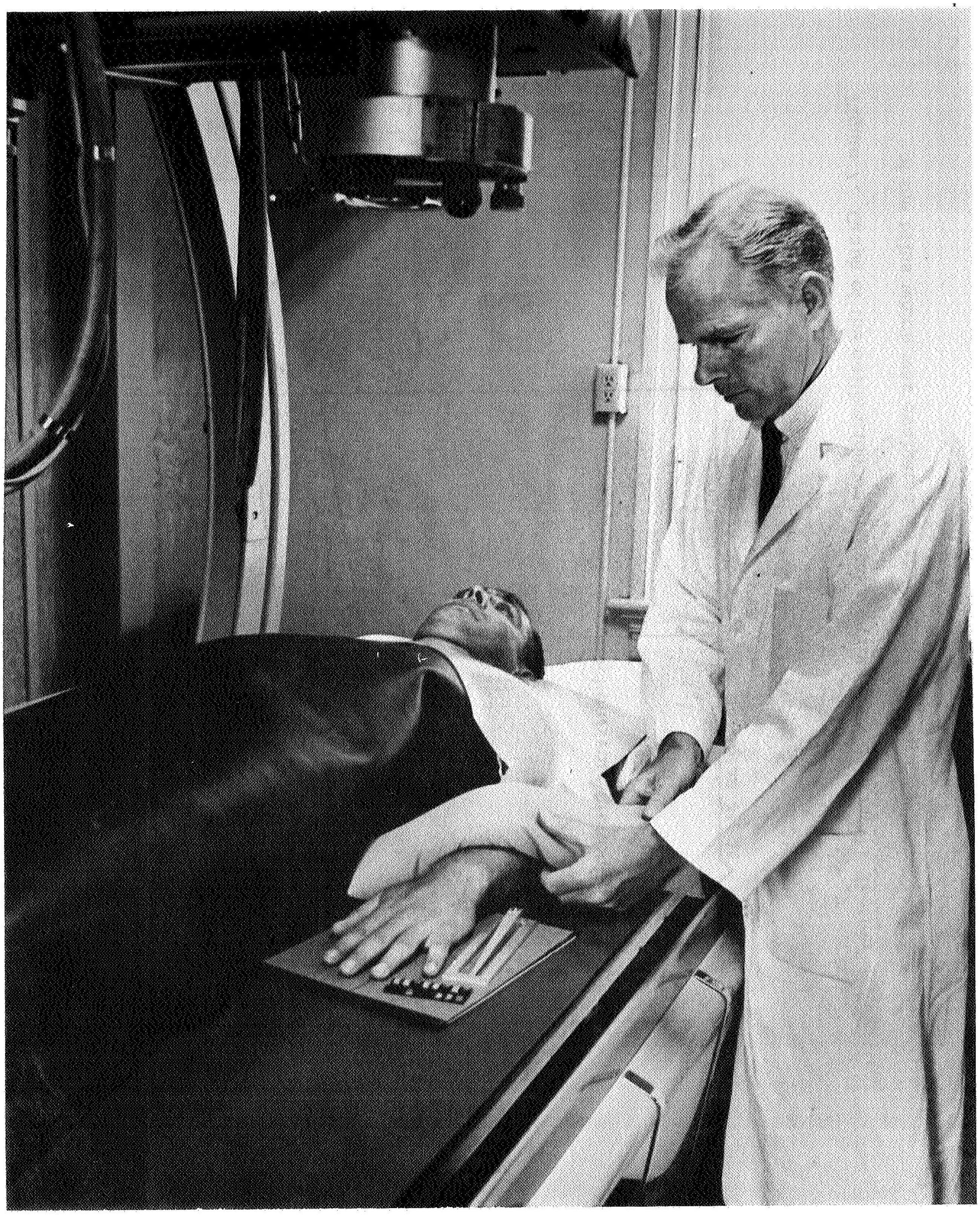


Fig. 8

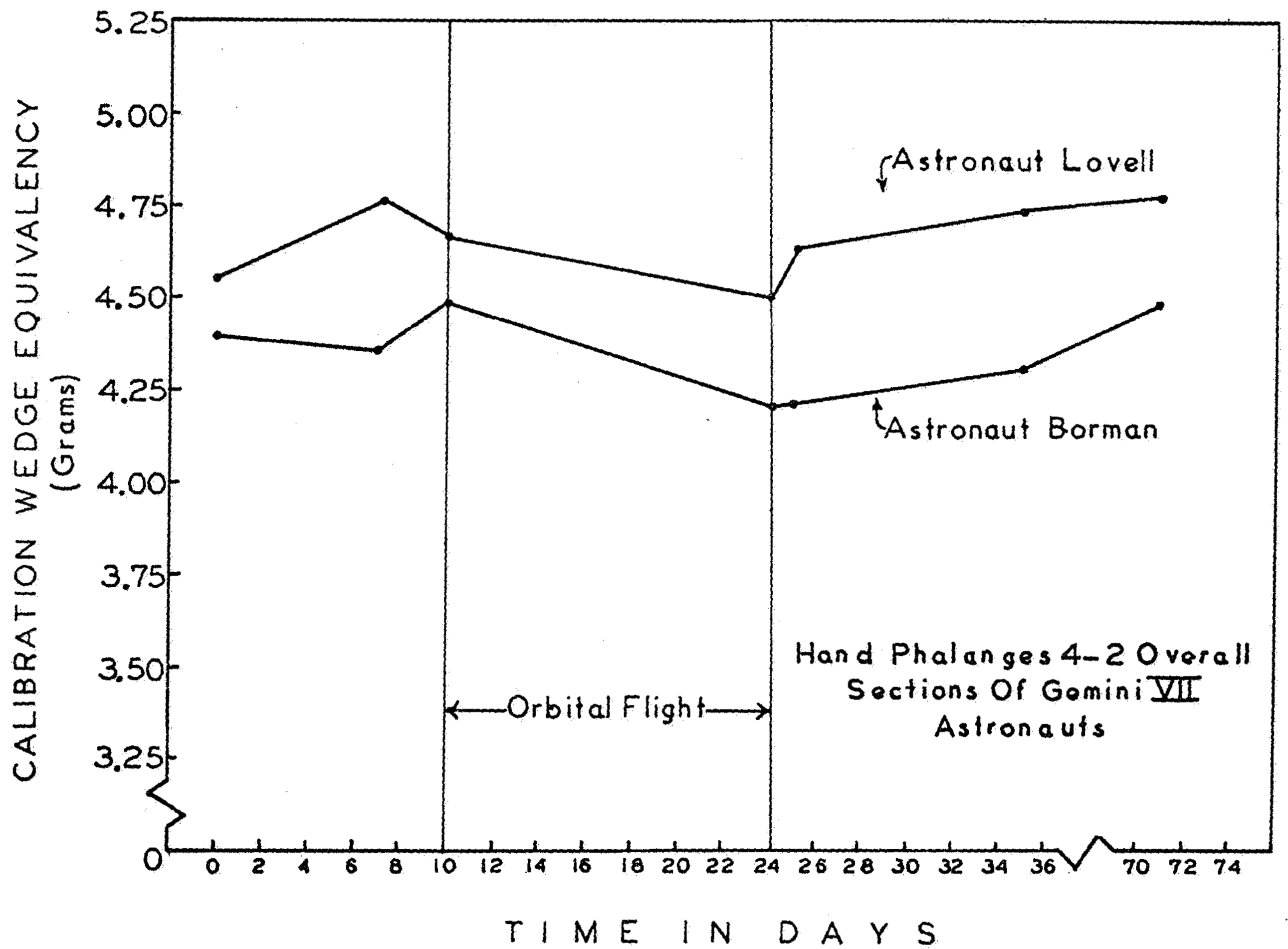


Figure 9. Graph of the calibration wedge mass equivalency data on hand phalanx 4-2 for the two Gemini-VII astronauts

Fig. 9

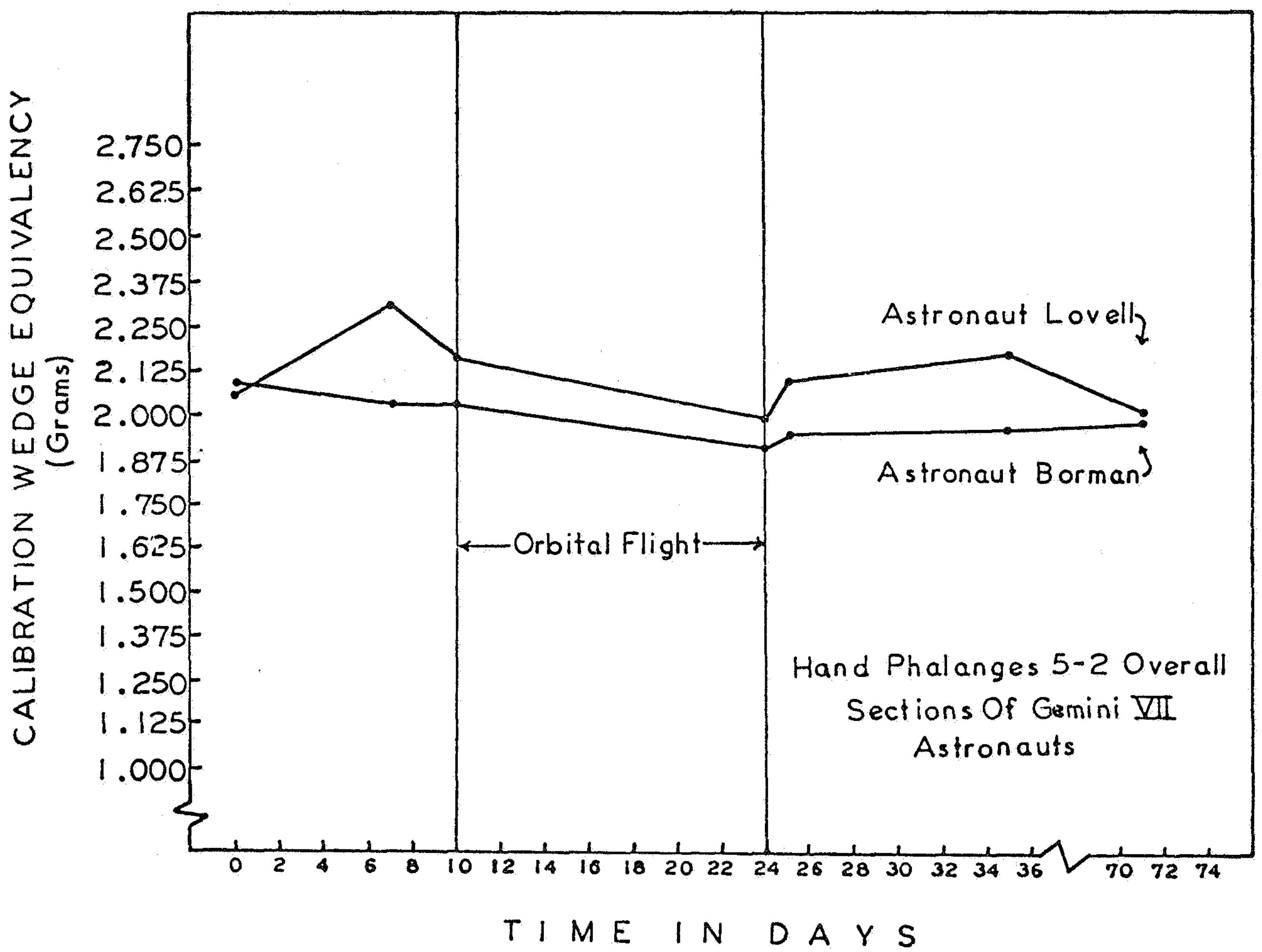


Figure 10. Graph of the calibration wedge mass equivalency data on hand phalanx 5-2 for the two Gemini-VII astronauts

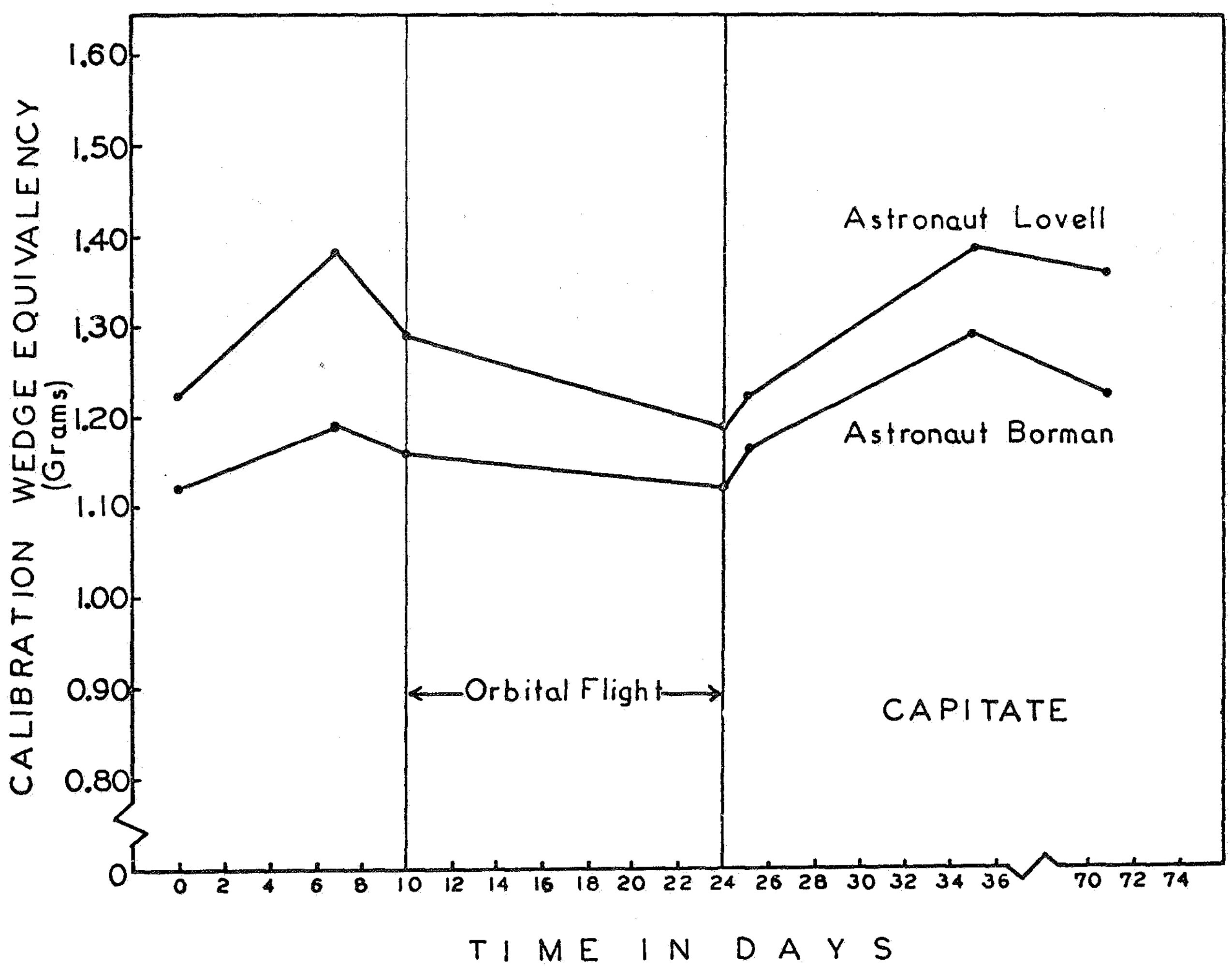
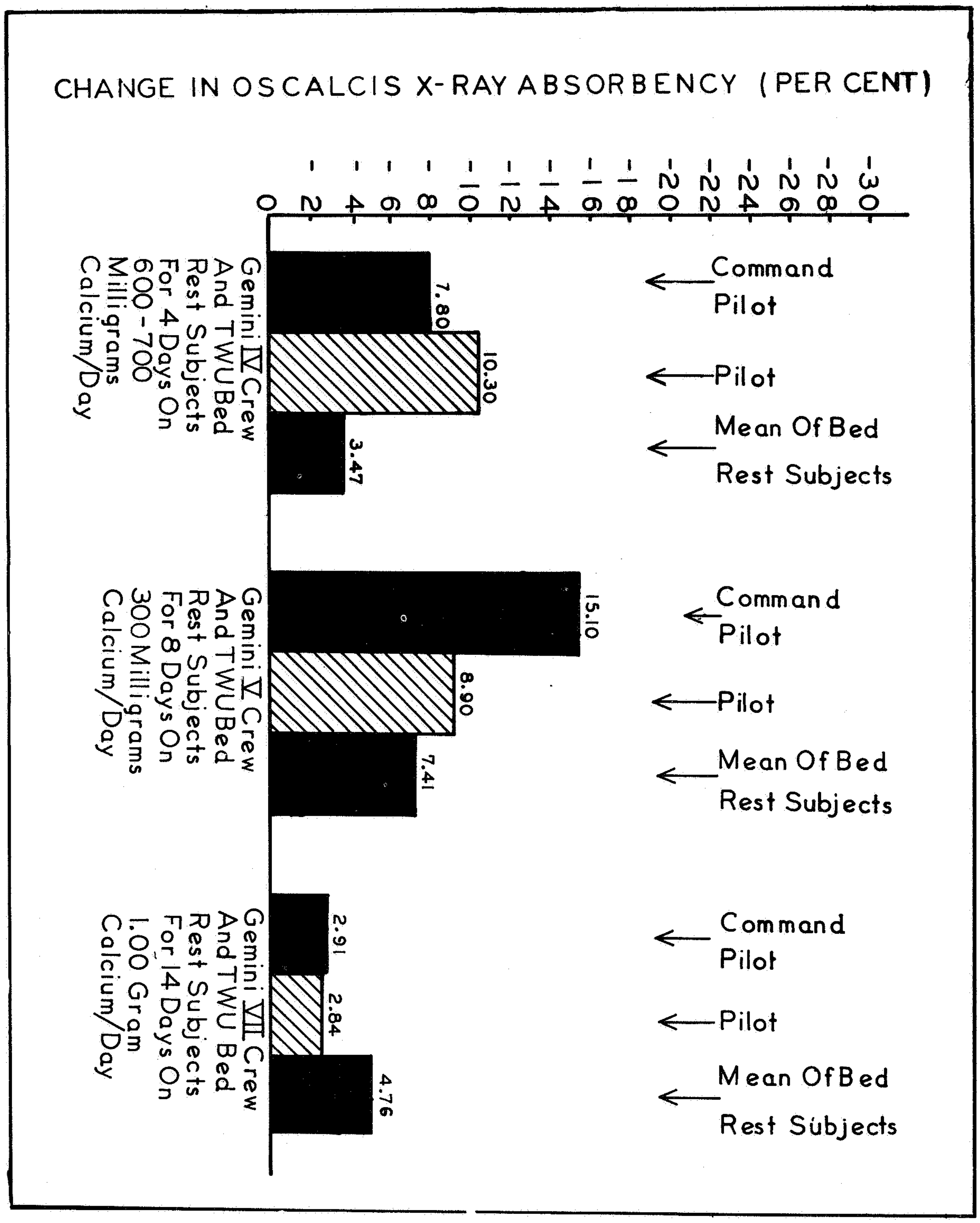


Figure 11. Graph of the calibration wedge equivalency data on the capitate for the two Gemini-VII astronauts



CHANGE IN OSCALCIS X-RAY ABSORBENCY (PER CENT)
0
- 2
- 4
- 6
- 8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
Gemini IV Crew And TWU Bed Rest Subjects For 4 Days On 600-700 Milligrams Calcium/Day
7.80
10.30
3.47
Gemini V Crew And TWU Bed Rest Subjects For 8 Days On 300 Milligrams Calcium/Day
15.10
8.90
7.41
Gemini VII Crew And TWU Bed Rest Subjects For 14 Days On 1.00 Gram Calcium/Day
2.91
2.84
4.76
Command Pilot
Pilot
Mean Of Bed Rest Subjects

Fig. 12

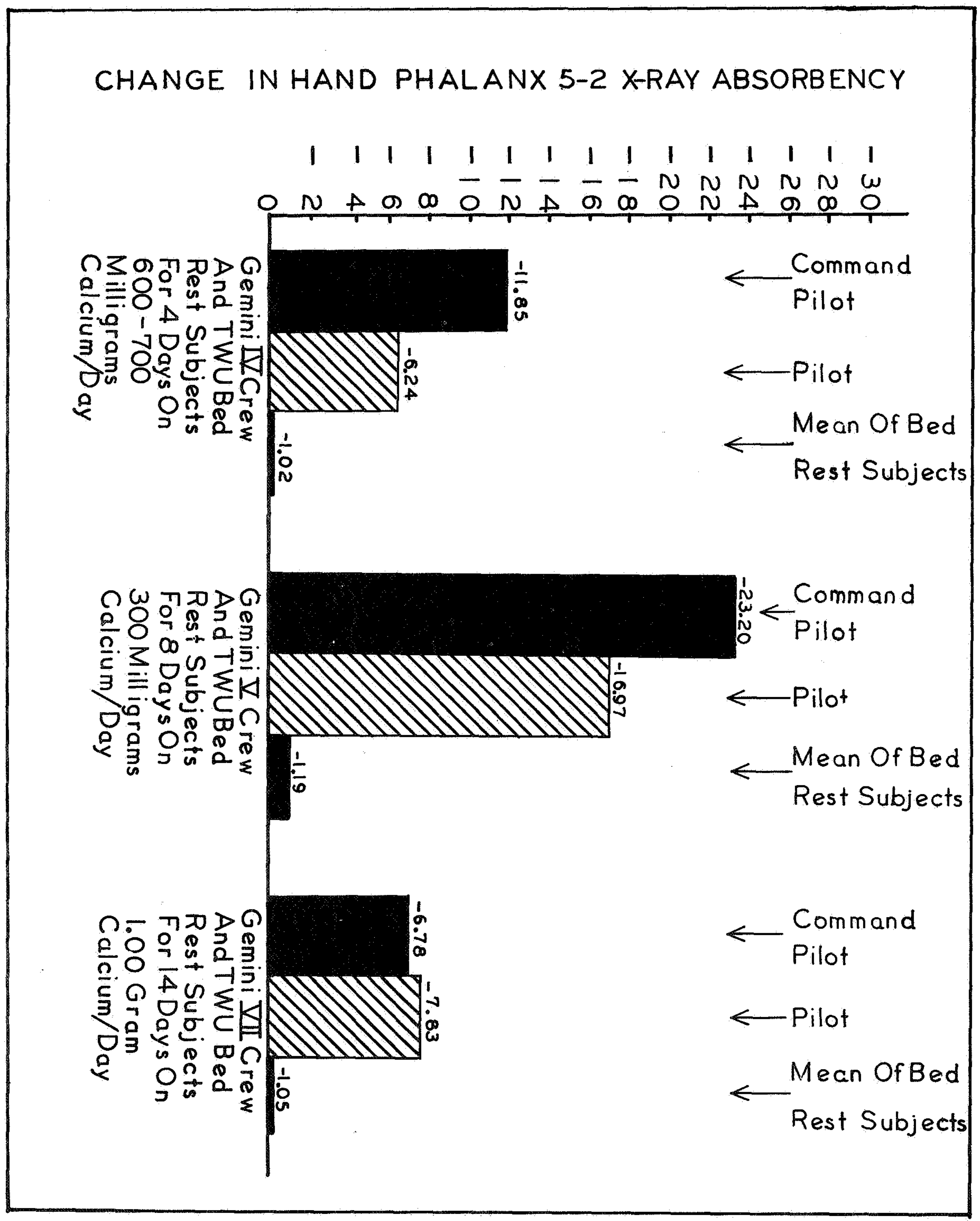

CHANGE IN HAND PHALANX 5-2 X-RAY ABSORBENCY
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
Gemini IV Crew And TWU Bed Rest Subjects For 4 Days On 600-700 Milligrams Calcium/Day
-11.85
-6.24
-1.02
Command Pilot
Pilot
Mean Of Bed Rest Subjects
Gemini V Crew And TWU Bed Rest Subjects For 8 Days On 300 Milligrams Calcium/Day
-23.20
-16.97
-1.19
Command Pilot
Pilot
Mean Of Bed Rest Subjects
Gemini VII Crew And TWU Bed Rest Subjects For 14 Days On 1.00 Gram Calcium/Day
-6.78
-7.83
-1.05
Command Pilot
Pilot
Mean Of Bed Rest Subjects

Fig. 13

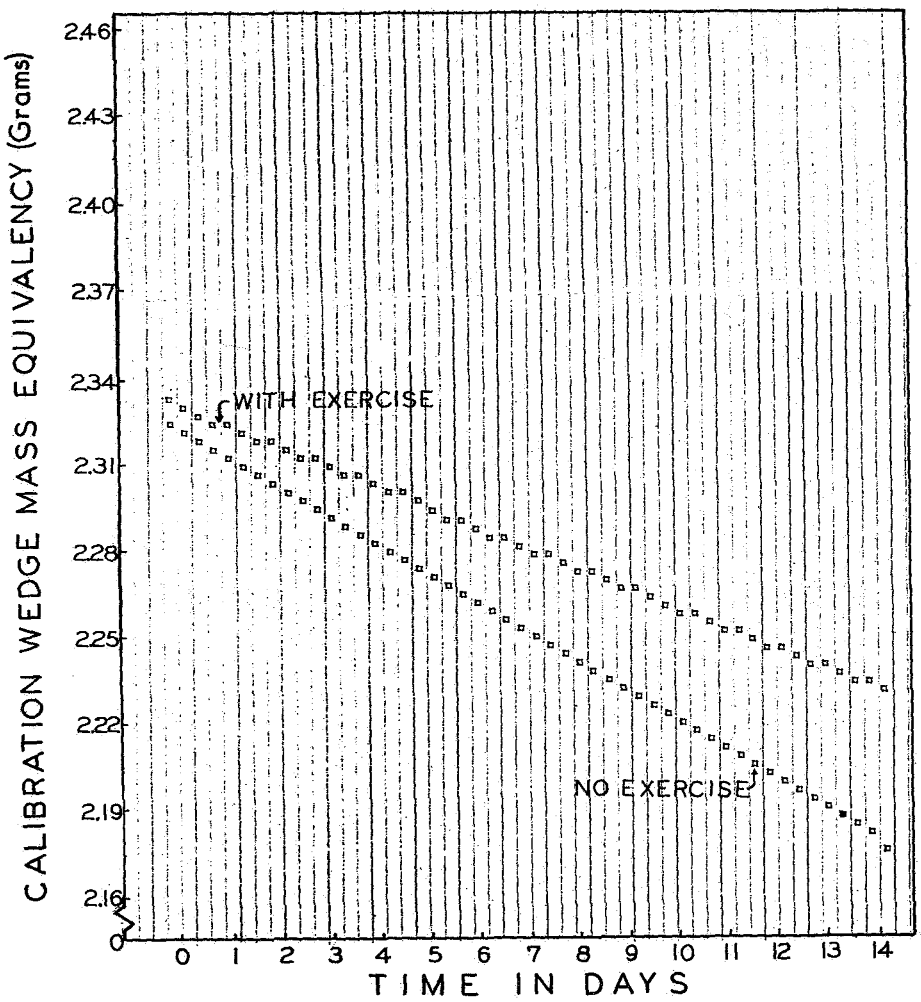

CALIBRATION WEDGE MASS EQUIVALENCY (Grams)
2.46
2.43
2.40
2.37
2.34
2.31
2.28
2.25
2.22
2.19
2.16
0
WITH EXERCISE
NO EXERCISE
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
TIME IN DAYS

Fig. 14

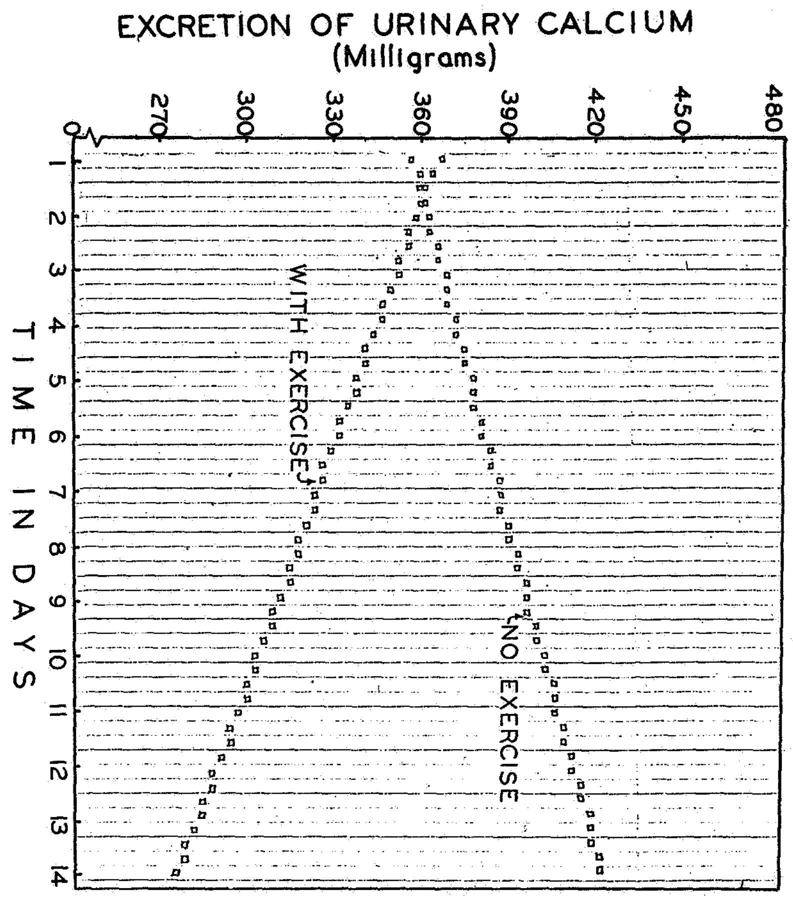

EXCRETION OF URINARY CALCIUM
(Milligrams)
0
270
300
330
360
390
420
450
480
TIME IN DAYS
1
2
3
4
5
6
7
8
9
10
11
12
13
14
WITH EXERCISE
NO EXERCISE

Fig. 15

Medical Experiment M7

CALCIUM AND NITROGEN BALANCE

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N68-10187

MEDICAL EXPERIMENT M7

CALCIUM AND NITROGEN BALANCE

DR. LUTWAK: The M-7 experiment, flown only on the Gemini 7 flight, was a 14-day attempt to learn about metabolic balances in space. Although the formal title describes this as a calcium balance study, the experiment involved more than measurements of calcium alone. About 99 percent of the body calcium is present in the skeleton, but the movement of calcium into and out of the body is dependent upon the movement of other substances as well. Calcium is present in the bone primarily as calcium phosphate; thus if we are interested in calcium balance we must measure phosphate balance as well. Phosphate is also related to protein metabolism and therefore nitrogen balance must also be evaluated.

Balance may be defined as the difference between what comes in and what goes out. If you lose more than you put in, you are in negative balance. If you are retaining, then you are in positive balance. There are various factors that may influence balance of an element. The sources of loss may be through the urine, through the feces, and through the sweat. Other factors can influence the loss of calcium, of phosphorous, and of nitrogen in the urine, feces, and sweat and therefore these were measured as well. The goal was to evaluate the effect of the Gemini 7 flight on the metabolic balances of several substances. Originally the interest was in the effect of weightlessness, but the Gemini 7 flight included variables other than weightlessness. The first slide

(Figure 1) has been borrowed from the Mid-Program Review discussion by Dr. Berry.

In the space flight we were concerned with influences of the full-pressure suit, confinement and restraint, an abnormal atmosphere for breathing, abnormal cabin pressures at various times, abnormal temperatures, varying g forces at different times, weightlessness, vibration, a variable degree of dehydration, and so forth, and one other factor which is not listed in the figure, a variable degree of activity. The subjects were not in a completely inactive state; they performed programmed activity, including Bungee cord exercises at regular intervals in addition to scheduled isometric exercises. Thus we were trying to measure the effects of a variable number of variables on certain parameters that were related to the overall body economy, in an attempt to see what the effect of this space flight could be - to use the word that has been used before - on the cost of performing space flight. Now may I have the next slide please?

(Figure 2)

To this end, we measured many substances in the samples. There were collections of urine and of feces, as well as of sweat. The volume of the urine was measured; we measured the specific gravity, which gave us some indication of the concentration of the urine. Although I am not going to go into great detail in the time we have, I do want to mention in passing that the specific gravity of the urine was definitely increased during the in-flight phase, indicating some degree of concentration; this correlates well with the observation that the urine volumes in-flight were low. We measured the pH of the urine. Creatinine in the urine was determined because this is a breakdown product of endogenous muscle metabolism whose excretion is considered to be relatively constant in any given individual. Variations in creatinine excretion of a small order of magnitude could be attributable to changes in kidney function, but large changes in creatinine excretion would indicate some errors in collection. This is the first time so ambitious a project was undertaken, the determination of complete metabolic balances in the field, where the "field" was several hundred miles away, completely out of the control of the investigators; as we will see, the measurement of constancy of creatinine excretion, therefore, was a rather critical measurement for us.

We measured calcium in the urine, feces, diet, and sweat, as well as magnesium, sodium, potassium, phosphate, sulphate, chloride, and nitrogen.

The overall plan consisted of three phases: a pre-flight control phase; the in-flight study, and a post-flight control. It was obvious that the interpretations would be very limited; there were two subjects involved, and any two individuals in this room could vary from each other by a considerable order of magnitude. Therefore, by using the same individuals as their own controls, we hoped to at least diminish this degree of variability. Each individual was to be studied during a control phase, pre-flight. This involved four subjects, the crew and the back-up crew. Thereafter the crew would be studied during flight, and hopefully we would have a post-flight control phase, to see what the degree of recovery was from whatever changes we might see in-flight.

May I have the next slide?

(Figure 3)

The validity of a balance study depends upon constancy of dietary intake, with at least as good a knowledge of the dietary intake as possible. The discussion today is really going to be a critique of our investigation rather than a series of firm conclusions, because of many things we have learned about how not to do such a study. One of the problems encountered was that the dietary intakes varied considerably during each phase. The standard deviations for the intakes of nutrients during each of the phases are not listed, but the means vary considerably. We tried to provide a constant diet, but since the men were restricted in the amount of time they could spare for pre-flight indoctrination, since they were quite busy with many other tasks, the study was started before having achieved constant intake. Every bit of collection and analyzed material has been used because calcium changes are very slow - a ten day balance study is a bare minimum for validity - as the ten days of pre-flight study were based on essentially ten different diets for each man. Because of this, there was a significant variability in each of the intakes of each of the elements we were studying, for each man as well as from man to man. The pre-flight diet was calculated to be as close as possible to the calculations of the in-flight diet as prepared by Dr. LaChance of the Crew Systems Division.

However, appetites vary, and the men took second helpings of various foods; thus there was a significant difference in the intake of every single food element when the pre-flight phase was compared with the in-flight phase. Post-flight dietary intakes were very similar to the pre-flight, but comparisons between the pre- and in- or in- and post- showed significant differences for both men. These differences were in addition to the day to day variability for each man. This immediately casts doubt on the validity of any of the conclusions that could be drawn based on balance data because of extreme variability, first of all within each phase, and secondly because of the changes between phases by a whole order of magnitude, for instance, in potassium (the pre-flight intake was 100 milliequivalents per day and in-flight was less than 40 milliequivalents per day). This is a serious error for this particular study. May I have the next slide, please.

(Figure 4)

This figure shows some of the degree of variability. The graph expresses balances (without any orders of magnitude) for the four men who were studied during the pre-flight phase of ten-days duration. It can be seen that, generally, there is a similarity of pattern. (Mean values are plotted to show the variability from man to man). Generally, there was constancy in terms of intake. (Intake is plotted from the zero line down; excretions are then plotted from the intake line up. This is the standard technique for plotting balances). The sweat losses were measurable for calcium, magnesium, sodium, potassium, and nitrogen; no phosphate loss could be measured in the sweat. These sweat losses, incidentally, are relatively insignificant in terms of the overall amount ingested and the overall balance. But there was considerable variability from man to man. The purpose of this figure is a plea for more studies before drawing conclusions about balances because of the tremendous interindividual variability.

For the in-flight intake, identical menus were packed for both men. The foods were in sealed meal-packs, labeled in terms of day and Meal A, B, or C for days one through fourteen. However, for reasons which we haven't learned as yet, the meals were not eaten in sequence or were not available to be eaten in sequence. Both men ate the same menu from day to day. We received an in-flight log which we tried to use as our basis for calculation of in-flight intake. The log indicated that Meal 5A may have been the first meal eaten, Meal 7A the second meal, and Meal 10C the third meal. In addition, some of the meals that were ingested in-flight probably were not eaten completely at the time they were logged. Portions that were left over were eaten at a later time.

Therefore, the only data I am going to show are mean figures for the total period.

VOICE: Were you able to get a good enough record so that you knew in general what they ate so that you could go back and reconstruct the diet?

DR. LUTWAK: Well, we have a record. I don't know how good the record is. We are assuming the record is accurate. We know that it probably is not wholely accurate. For instance, the record states that Meal 9A was eaten on Day 7 and then was eaten again on Day 11. Obviously, one of the 9A's must have been a different meal. Presumably there were logging errors which would occur under such strenuous conditions. We were able to arrive at approximate values for the means for 14 days. We have mean values, which are really the only basis we have for arriving at any conclusions. Next slide, please.

(Figure 5)

Our primary interest was in calcium balance, and particularly, urinary calcium excretion. The reason for this derives from ground-based studies of normal subjects. Such studies of immobilization, originally carried out some 20 years ago by Dietrich, Whedon, and Shorr at the Cornell Medical School, and similar studies that have been carried out in many other places subsequently, have indicated that under conditions of complete bedrest, urinary calcium increased in some individuals. Therefore, the urinary calcium excretion might be an indicator of changes in bone metabolism and bone physiology.

If immobilization in ground-based studies may be equated to conditions of zero gravity, the primary change one might expect to see would be an increase in urinary calcium. This has two implications: (1) urinary calcium can be derived from either dietary calcium or from skeletal calcium; if urinary calcium increases excessively, it must come from the skeleton and demineralization of the skeleton would be expected. (2) an increased urinary calcium in some individuals predisposes to kidney stones (which can produce the most excruciating pain known to man). So there are two significant reasons for looking at this question of calcium metabolism.

When the values for urinary excretion of calcium in-flight were examined, these were extremely low, much lower than the urinary calcium measured during the pre-flight and the post-flight phases for both individuals. We then looked at the creatinine excretion. As you recall, creatinine is measured as an index of complete collections; the creatinine values similarly were quite low in comparison with pre- and post-flight phases. This suggested to us that there were errors in the collection system. Whether the error was in the tritium dilution or in the urine transport system itself, we are not in a position to say. However, the in-flight urinary creatinine values were approximately two-thirds those of the pre- and post-flight phases. Since there was no other evidence for severe kidney damage (and it would require extremely severe kidney damage to produce this much of a diminution in urinary creatinine), we felt justified in correcting the data to the pre- and post-flight mean excretions of creatinine. Now this immediately introduces another error of about 15 - 20% in our values for urinary calcium excretion. However, we have corrected all in-flight urinary excretions to this base of creatinine. All subsequent presentations that show in-flight data are based on corrected urinary excretions.

VOICE: Pre-flight or post-flight data?

DR. LUTWAK: We used the mean of the pre- plus post-flight creatinine excretions. There were 10 days of pre-flight and 4 days post-flight collections. We used the sum divided by 14 because we didn't feel justified in dropping any of the values. There was one very high value post-flight in one man; there was one very high value pre-flight in another man. There was no real reason for dropping either of these. May I have the next slide, please.

(Figure 6)

What could we have expected to find? This figure is taken from a paper of Dietrich, Whedon and Shorr, showing the changes that were found with complete bedrest for periods of several weeks duration. Four individuals are shown in this slide and there are several points to be made. Let's just concentrate on the urinary calcium excretions. There is extreme interindividual variability. If our two astronauts were the lower two subjects shown, one would not expect to find any significant changes in urinary excretion of calcium. If, however, our two astronauts resembled the subject in the upper portion of the figure, we would expect to find significant increases. Therefore, we began our analyses with no prejudice. Whether or not we found any change in urinary calcium, it still wouldn't prove an effect of Gemini 7 Flight on calcium excretion. Another point is that calcium excretion usually rose, beginning during the first week and approaching a maximum by the second week. Plateau values weren't reached until after the third week. We were concerned with a two-week flight in the present study and therefore we might or might not expect to find a plateau. Still another significant observation is that urinary calcium changes recover quite rapidly after activity is reinstituted, but it takes at least two to four weeks before baseline values are again achieved. We had planned only a four day post-flight control. May I have the next slide?

(Figure 7)

Now, these are the data for urinary excretion of calcium. The first portion represents the command pilot and the other the pilot. Two points here again. One, the command pilot had a baseline urinary excretion of calcium that was much in excess and significantly different from the baseline excretion of the pilot. If we extrapolate from the findings of the Cornell Medical School study of 20 years ago, one might predict that one man would show a change in-flight and the other would not, because individuals with lower excretions under control conditions did not show significant changes as a result of immobilization. This is essentially what was found in the Gemini VII study. The dotted lines represent one standard deviation from the mean; the points are individual daily values of urinary calcium excretion. There was a significant difference in excretion, using the moving average type of calculation, during the second week, in comparison with the first week; these results are parallel to those of ground-based studies. In both men in-flight calcium excretion was elevated; in the pilot it was slightly elevated while in the command pilot it was significantly elevated. Post-flight, both men showed elevated urinary excretions of calcium in comparison with the pre-flight values. The in-flight data have some elements of doubt about them because of correction factors for creatinine excretion, but the post-flight/pre-flight comparisons are quite significant. Next slide, please.

(Figure 8)

These are the actual figures for urinary excretion of the various elements. There is a tremendous number of numbers on this slide; the standard deviation for each of these values is not listed here. The standard deviations were of the order of 20% of the mean and were quite similar for most of the figures. There was a significant increase in urinary excretion of calcium; there was no significant change in magnesium (I'm talking only about the command pilot). There was a significant increase in urinary excretion of phosphate, a decrease in nitrogen, but if you recall (Figure 3), the nitrogen intake in-flight was much lower. The sodium excretion in-flight was increased, however, not by a significant amount. Urinary potassium was not significantly changed in the command pilot.

The pilot, on the other hand, did show a significant change. The point here again is the factor of interindividual variability. In addition, there is a relationship between the dietary intake and the urinary excretion in some instances. Urinary magnesium is related to dietary intake of magnesium. Urinary phosphate, generally, is related to the intake, and the fact that the phosphate intake was considerably lower in flight while the phosphate excretion was considerably higher means that the increased loss of phosphate is significant. May I have the next slide, please.

(Figure 9)

I'll try to summarize the data very rapidly with a series of balance slides. These are plotted by the traditional technique of Albright and Reifenstein; intake is plotted down from the zero line, excretions are then plotted up from the intake. Sweat losses were insignificant throughout. These comprised less than one milliequivalent of calcium, less than 20 milligrams at any phase of the study. Urinary losses of calcium increased in-flight, and increased by a greater amount during the second week of flight. The intake was less in-flight by about 300 milligrams and the net result was slightly negative calcium balance. The difference between the balance pre-flight and in-flight is significant, but in terms of actual amount lost from the body, this is not a great loss. Post-flight, there appeared to be a slight retention. The actual balance post-flight was very similar to that pre-flight, indicating there probably had not been significant losses. Next slide, please.

(Figure 10)

For the pilot, the losses were even less significant insofar as calcium is concerned and one cannot really detect any serious loss of this element. Next slide, please.

(Figure 11)

Nitrogen balance in the command pilot, which is related to protein metabolism and muscle metabolism, on the other hand, did show significant losses of nitrogen during the flight phase which persisted post-flight despite an increase in dietary intake. Next slide, please.

(Figure 12)

This pilot showed a similar loss in-flight, but then showed a retention post-flight when the dietary intake increased. Next slide, please.

(Figure 13)

The phosphate balances show the most significant losses observed; we have no explanation for this as yet; we will be trying to calculate these losses in terms of nitrogen and bone equivalents. There was a definite loss of phosphate despite a decreased dietary intake. Urinary phosphate increased in-flight indicating significant loss from the body. Next slide.

(Figure 14)

The same was seen for the pilot, a significant loss of phosphate. Next slide.

(Figure 15)

I'm not going to go into detail concerning sodium and potassium, but will simply indicate that the negative balance of sodium that was seen was probably due to a change in the intake. The sodium intake was quite high pre-flight, was significantly lower in-flight, and was back up to the higher values post-flight. However, post-flight there was a definite retention of sodium.

VOICE: Have all of these been corrected for the creatinine?

DR. LUTWAK: All of the in-flight data have been corrected for the creatinine. It was impossible to plot any balance data without corrections. The significant finding with sodium balance was a definite retention of sodium post-flight.

VOICE: Is the height of that sodium output block in the in-flight area less than that in the pre-flight area?

DR. LUTWAK: The urinary output was just about the same, but post-flight there was a definite retention. Next slide, please.

(Figure 16)

The same was seen for the other man, a very definite retention of sodium post-flight which correlates with the aldosterone values that Dr. Lipscomb reported earlier.

VOICE: Do you have any measurements that would show whether or not your creatinine correction is valid?

DR. LUTWAK: Well, we've done this with a great many other samples. We've taken individuals in whom we've collected the urine in separate portions throughout a 24 hour period, analyzed the separate portions, and analyzed the total, and then attempted to apply correction factors. If we have more than 2/3 of 24 hour collection, then the correction factor appears to be valid. If we have less than that, the values are not valid. There is a diurnal variation in creatinine excretion and there are diurnal variations in the excretion of other metabolites which do not always coincide. With a 2/3 of total sample, there is a fair degree of approximation. We had, I believe, about a 2/3 sample in each case, and therefore we have a fair approximation for the 24 hours. This appears to be valid within about 20%. Next slide.

(Figure 17)

Potassium balances are going to give us a lot more trouble because potassium intake in-flight was so different from the pre- and post-flight phases that this in itself may have introduced factors which would have changed the production of aldosterone and other hormones which are dependent upon potassium economy of the body. Here it is hard to say whether we are seeing a cause or an effect because of the very different intakes. The reason for this difference in intake was that pre-flight and post-flight the men ate a good deal of fresh fruits and vegetables. In-flight, of course, the menu was all prepared dehydrated food much lower in fruit and vegetable content and therefore in potassium content. Next slide, please.

(Figure 18)

The same is seen for the other man in regard to potassium balance. Next slide, please.

(Figure 19)

This is a summary of all of the balances that have been calculated thusfar. The chart summarizes the balance figures in terms of actual numbers. There are significant differences in balance for calcium between the pre-flight and in-flight phases. This is possibly due to dietary intake. Significant differences in magnesium were definitely due to dietary changes. Significant differences occurred in phosphate balance which we have not explained. Significant differences in nitrogen balance were definitely due to dietary intake variability. Sodium and potassium balance changes were probably also due partly at least to dietary variability.

In summary, we have tried to do a balance study. We knew initially that what we were attempting was an estimation of the feasibility of carrying out a long-term balance study under extremely arduous conditions, arduous for the investigator, but even more arduous for the subjects. We feel fortunate that we were able to obtain any type of data. We have not obtained sufficient data to be able to come to any conclusions. To forestall the up-coming question, I don't think we can say that providing high calcium diets or low calcium, feeding high protein intakes or low protein, may be of any benefit or of any harm until we have more data of this type, until we have more opportunity to evaluate this type of study. This meeting can be used as an occasion to plead. We'd like to plead for longer pre-flight control phases and longer post-flight control phases so that we can interpret some of this data more significantly.

VOICE: Does that profound difference in the potassium intake during flight automatically cast a considerable amount of doubt on the significance of the aldosterone observations in flight?

DR. LUTWAK: Yes, because low potassium diets can change aldosterone secretion as has frequently been shown also for low sodium diets.

VOICE: I guess I can't argue that it would be nice to have longer pre- and post-flight controls, but more particularly, it appears that you need a better control of the actual diet.

DR. LUTWAK: There were mechanical problems and technical problems that have been discovered and I hope we won't run into the same ones next time around. This was a learning process for us; it was a learning process for everyone involved in the study. We had to learn where the errors could come in, and I think we have now.

VOICE: Have you really sat down now and set up a set of specifications, I call it, as to how you're going to carry out this experiment, if you have to carry it out again, so that we don't have unanswered questions about how much they've eaten in the way of potassium and how much in calcium? It should be specified that the crew is to eat meals in a certain order. The crew should understand why it is important to the whole experiment.

DR. LUTWAK: These are the original specifications that were written into the first description of the M-7 project. All we can do is to reiterate them and hope that next time other problems won't come along that will confuse and confound the issue.

VOICE: Do you want us to accept that experiment with the same ground rules except for a few minor changes?

DR. LUTWAK: That would be a very good approximation. Yes.

VOICE: It would be a valid experiment, then.

DR. LUTWAK: It would be a better approximation than this one; it would be a more valid one than this one.

VOICE: It seems that you are saying that due to the fact that the diet was switched in the in-flight area - it was very different from the pre- and post-flight area - that much of this is really masked by the change of diet. Now, this would indicate that if you really want to get meaningful data, you have to put the crew for the entire pre-, in-, and post-flight periods on the same diet formula.

DR. LUTWAK: The ideal situation which we've talked about but which apparently is not feasible at present is the use of a formula diet. A formula diet would be identical pre-flight, in-flight, and post-flight.

VOICE: It seems to me that it is important to try to be sure that we understand all of these variables and also understand how this works on the ground as well as in-flight, I would think, and I haven't heard it discussed, that one could duplicate everything here, including keeping people in bed for the duration of a 14-day flight or 28 days, and run the same type of blood tests and urine tests.

DR. LUTWAK: That's been done many times. The ultimate question still remains...

VOICE: How does this compare with all of these balance studies?

DR. LUTWAK: Well, this comparison is what we have attempted, but we can't do it successfully because of the variability of the conditions encountered in-flight. We can say that there seems to be a <u>tendency</u> so far as calcium, nitrogen, and phosphate metabolism are concerned, for parallel results to have been observed as a result of weightlessness as compared with the bedrest studies.

VOICE: Do we have a bedrest study now that has the same dietary variations that this flight had?

DR. LUTWAK: No, because we prefer to study one variable at a time. Here we have about 15 variables simultaneously. This is a difficult experiment to interpret. What we would like to do is to isolate variables.

TABLE 24-IV

SPACE FLIGHT STRESSES

FULL PRESSURE SUIT
CONFINEMENT AND RESTRAINT
100% OXYGEN 5 psi ATMOSPHERE
CHANGING CABIN PRESSURE (LAUNCH AND ENTRY)
VARYING CABIN AND SUIT TEMPERATURE
ACCELERATION-G FORCE
WEIGHTLESSNESS
VIBRATION
DEHYDRATION
FLIGHT PLAN PERFORMANCE
SLEEP NEED
ALERTNESS NEED
CHANGING ILLUMINATION
DIMINISHED FOOD INTAKE

FIGURE 1

ANALYSES PERFORMED

ANALYSES	MATERIAL*	METHOD
Volume	U	a)Routine, pre-and post- flight b) T_2O dilution, in-flight
Specific Gravity	U	a)Routine, pre- and post-flight b) Refractometry, in-flight
pH	U	Routine, pre- and post=flight
Creatinine	U	Autoanalyser colorimetry
Calcium	U,F,D,S	Autoanalyzer Atomic Absorption
Magnesium	U,F,D,S	Autoanalyzer Atomic Absorption
Sodium	U,F,D,S	Flame Photometry
Potassium	U,F,D,S	Flame Photometry
Phosphate	U,F,D	Autoanalyzer colorimetry
Sulfate	U,F,D	Atomic Absorption
Chloride	U,F,D,S	Coulometry
Nitrogen	U,F,D,S	Autoanalyzer
Fat	F,D	Wistreich Extraction

*U = Urine; F = Feces; D = Diet; S = Sweat

FIGURE 2

DIETARY INTAKE

		F.B.	P<	J.L.	P<
Calcium	pre-	1.3121		1.3085	
	pre-/in-		.001		.001
	in-	1.0033		1.0033	
	in-/post-		.05		.05
	post-	1.3035		1.2835	
	pre-/post-		n.s.		n.s.
Magnesium	pre-	.4466		.4172	
	pre-/in-		.001		.001
	in-	.1941		.1941	
	in-/post-		.001		.001
	post-	.4298		.3947	
	pre-/post-		n.s.		n.s.
Phosphate	pre-	2.8088		2.8024	
	pre-/in-		.001		.001
	in-	1.3359		1.3359	
	in-/post-		.001		.001
	post-	2.7231		2.6403	
	pre-/post-		n.s.		n.s.
Nitrogen	pre-	25.807		23.240	
	pre-/in-		.001		.001
	in-	15.475		15.475	
	in-/post-		.001		.001
	post-	23.769		22.954	
	pre-/post-		n.s.		n.s.
Sodium	pre-	226.43		199.93	
	pre-/in-		.001		.01
	in-	143.73		143.73	
	in-/post-		.01		.05
	post-	238.61		199.44	
	pre-/post-		n.s.		n.s.
Potassium	pre-	140.04		129.85	
	pre-/in-		.001		.001
	in-	35.96		35.96	
	in-/post-		.001		.001
	post-	132.69		128.52	
	pre-/post-		n.s.		n.s.

FIGURE 3

Pre-Flight Balances

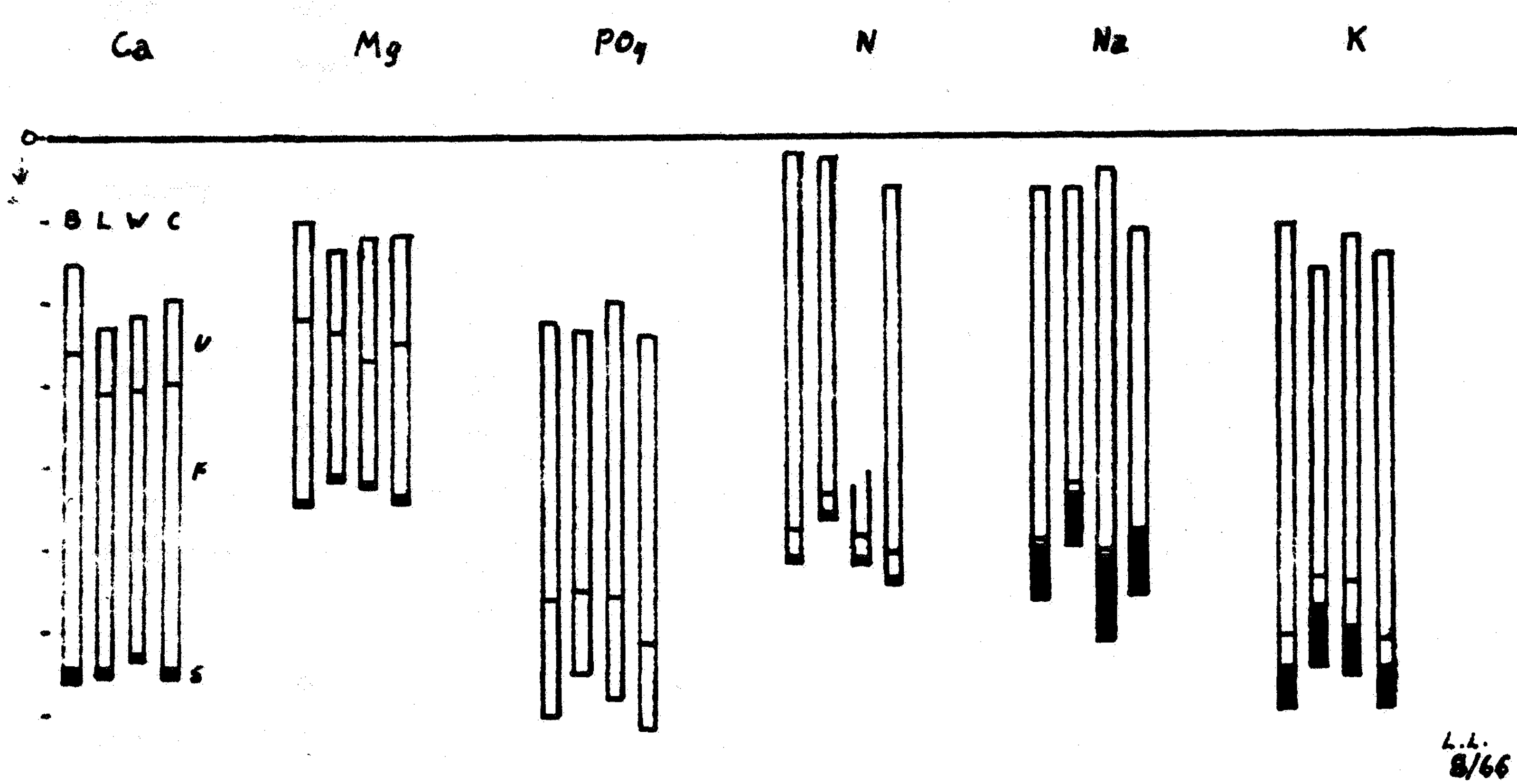


FIGURE 4

UNCORRECTED URINARY EXCRETIONS

In-Flight Day	Borman Calcium	Borman Creatinine	Lovell Calcium	Lovell Creatinine
1	0.150	1.676	0.092	1.198
2	0.132	1.472	0.082	1.474
3	0.118	1.322	n.s.	n.s.
4	0.129	1.583	0.108	1.667
5	0.148	1.423	0.143	2.107
6	0.134	1.495	0.138	1.737
7	0.230	2.115	0.128	1.763
8	0.156	1.420	0.176	2.085
9	0.178	1.442	0.135	1.849
10	0.200	1.753	0.146	2.032
11	0.200	1.985	0.111	1.581
12	0.230	2.056	0.142	1.624
13	0.175	1.665	0.101	1.240
14	0.089	1.202	0.138	1.894
Mean-pre	0.215	2.285	0.159	2.150
Mean-post	0.286	2.676	0.179	2.352

FIGURE 5

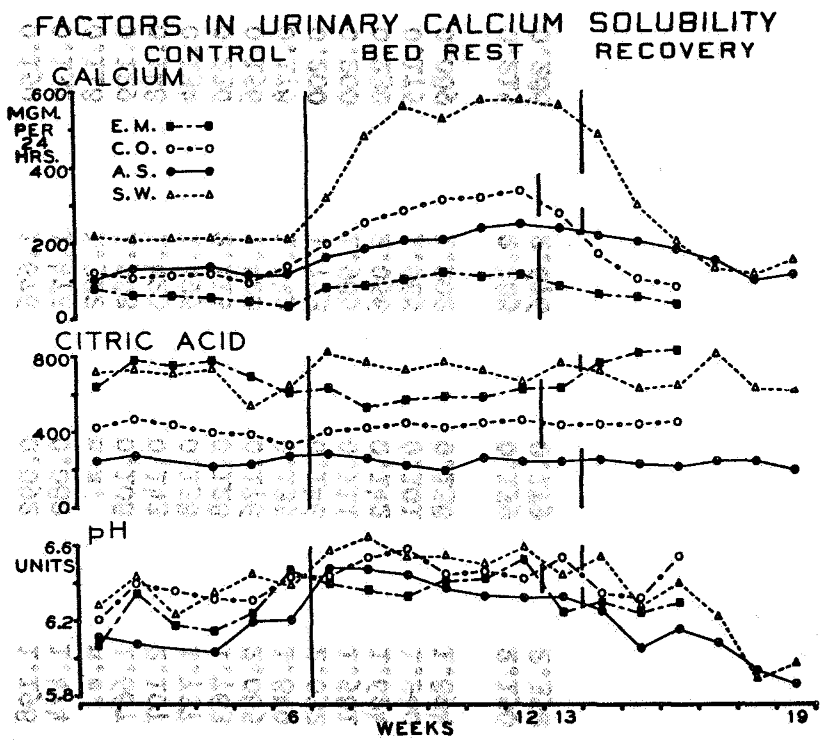


Fig. 118. Effect of immobilization on the urinary excretion of calcium and citric acid and on urinary pH in four normal male subjects. Daily calcium intake was 0.852 gm. for subject E.M., 0.920 gm. for subjects C.O., A.S. and S.W.

FIGURE 6

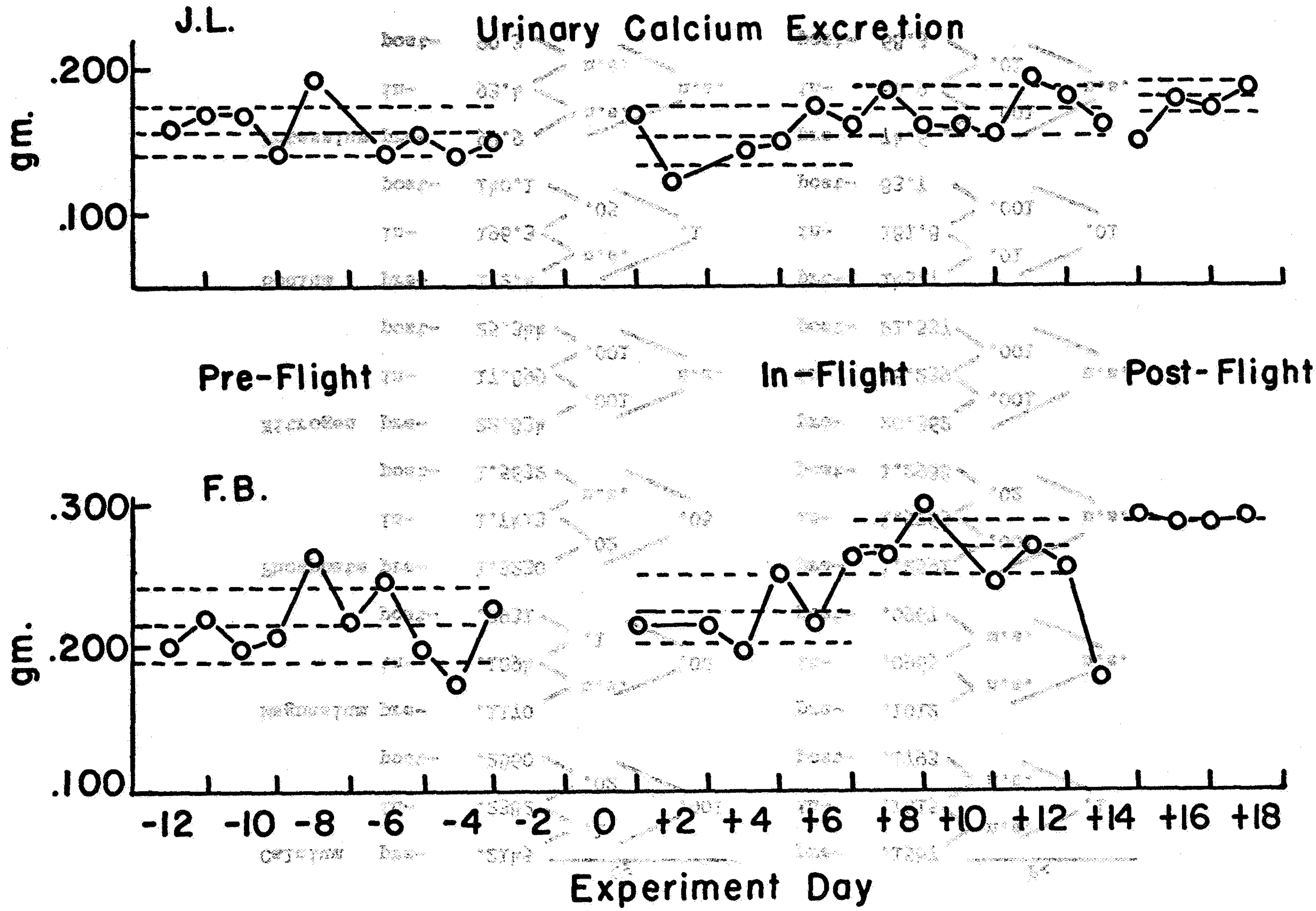
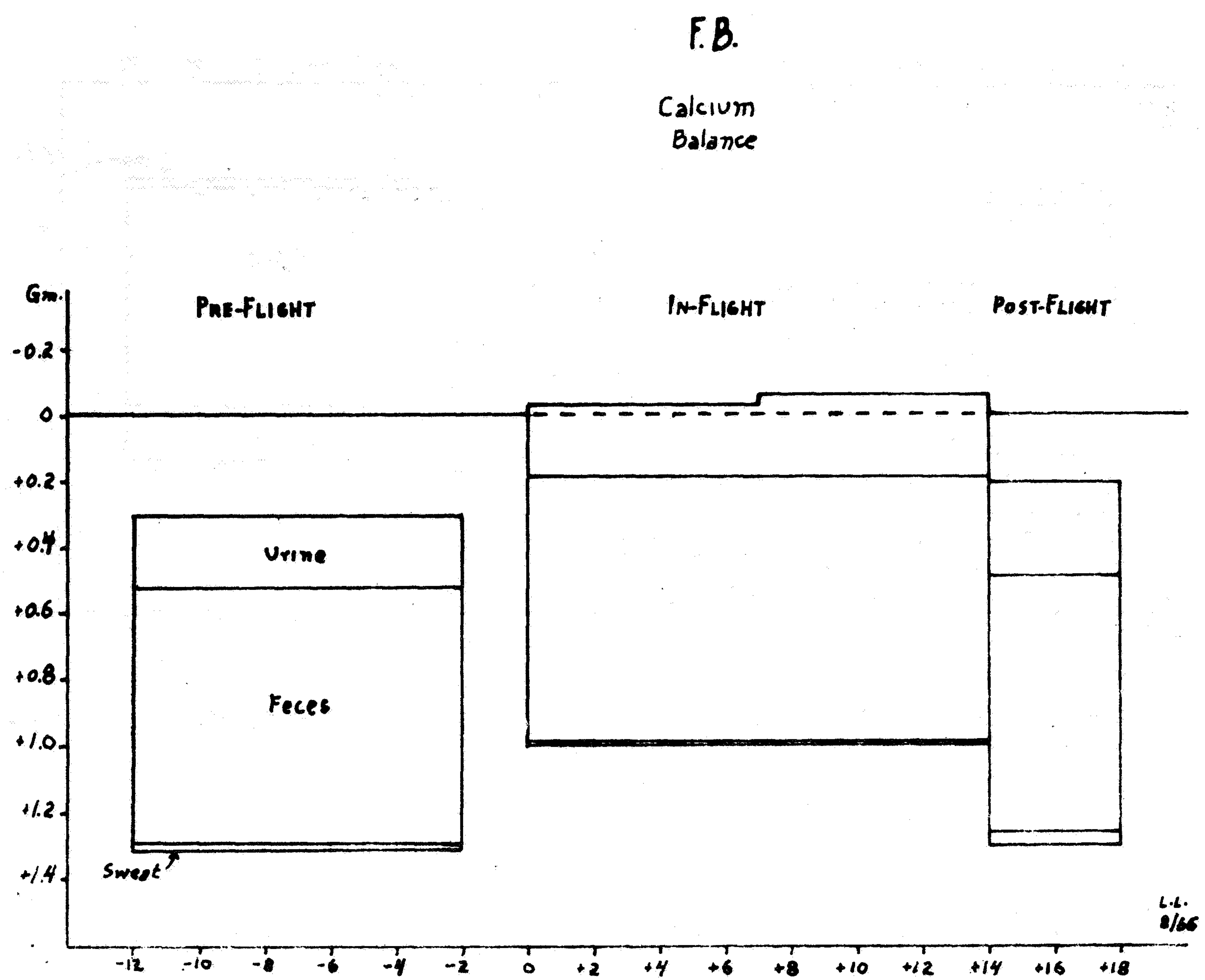

J.L.
Urinary Calcium Excretion
.200
.100
gm.
Pre-Flight
In-Flight
Post-Flight
F.B.
.300
.200
.100
gm.
-12 -10 -8 -6 -4 -2 0 +2 +4 +6 +8 +10 +12 +14 +16 +18
Experiment Day

FIGURE 7

URINARY EXCRETION

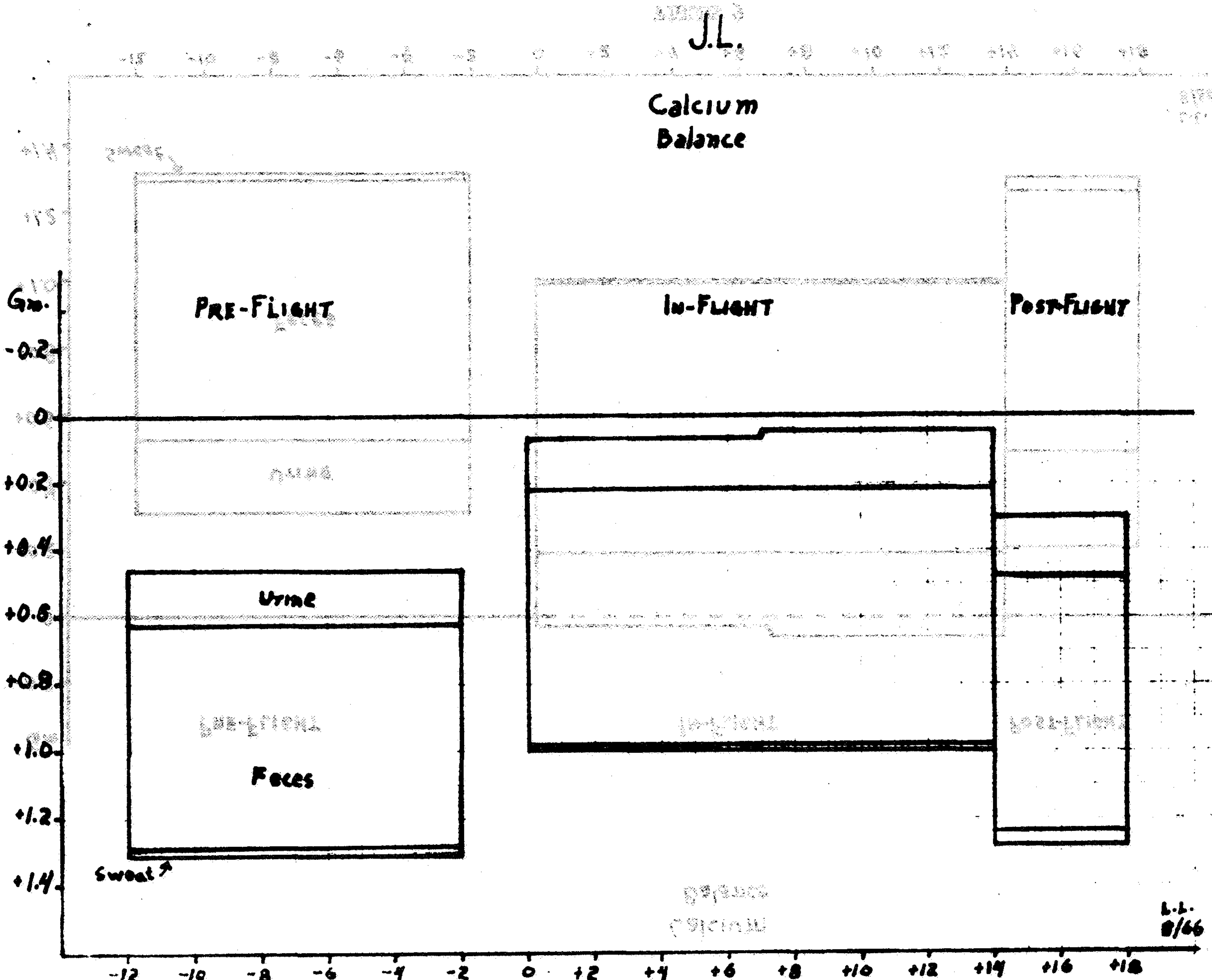
		F.B.	P<	P<		J.L.	P<	P<
Calcium	pre-	.2145			pre-	.1587		
			.1				n.s.	
	in-	.2382		.001	in-	.1615		.1
			.02				n.s.	
	post-	.2860			post-	.1793		
Magnesium	pre-	.1170			pre-	.1012		
			n.s.				n.s.	
	in-	.1294		.02	in-	.0965		n.s.
			.1				n.s.	
	post-	.0931			post-	.0967		
Phosphate	pre-	1.3230			pre-	1.2591		
			.02				.001	
	in-	1.7413		.05	in-	1.5765		n.s.
			n.s.				.02	
	post-	1.5632			post-	1.2988		
Nitrogen	pre-	22.834			pre-	20.362		
			.001				.001	
	in-	17.899		n.s.	in-	16.239		n.s.
			.001				.001	
	post-	25.344			post-	21.537		
Sodium	pre-	172.4			pre-	143.7		
			n.s.				.01	
	in-	196.3		.1	in-	181.8		.01
			.05				.001	
	post-	140.1			post-	83.7		
Potassium	pre-	98.9			pre-	74.6		
			n.s.				.001	
	in-	93.4		n.s.	in-	50.9		n.s.
			n.s.				.01	
	post-	90.3			post-	68.3		

FIGURE 8



F.B.
Calcium
Balance
Gm.
-0.2
0
+0.2
+0.4
+0.6
+0.8
+1.0
+1.2
+1.4
Pre-Flight
In-Flight
Post-Flight
Urine
Feces
Sweat
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
+12
+14
+16
+18
L.L.
8/66

FIGURE 9



J.L.
Calcium
Balance
PRE-FLIGHT
IN-FLIGHT
POST-FLIGHT
Gm.
-0.2
0
+0.2
+0.4
+0.6
+0.8
+1.0
+1.2
+1.4
Urine
Feces
Sweat
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
+12
+14
+16
+18
L.L.
8/66

FIGURE 10

F.B.

Nitrogen
Balance

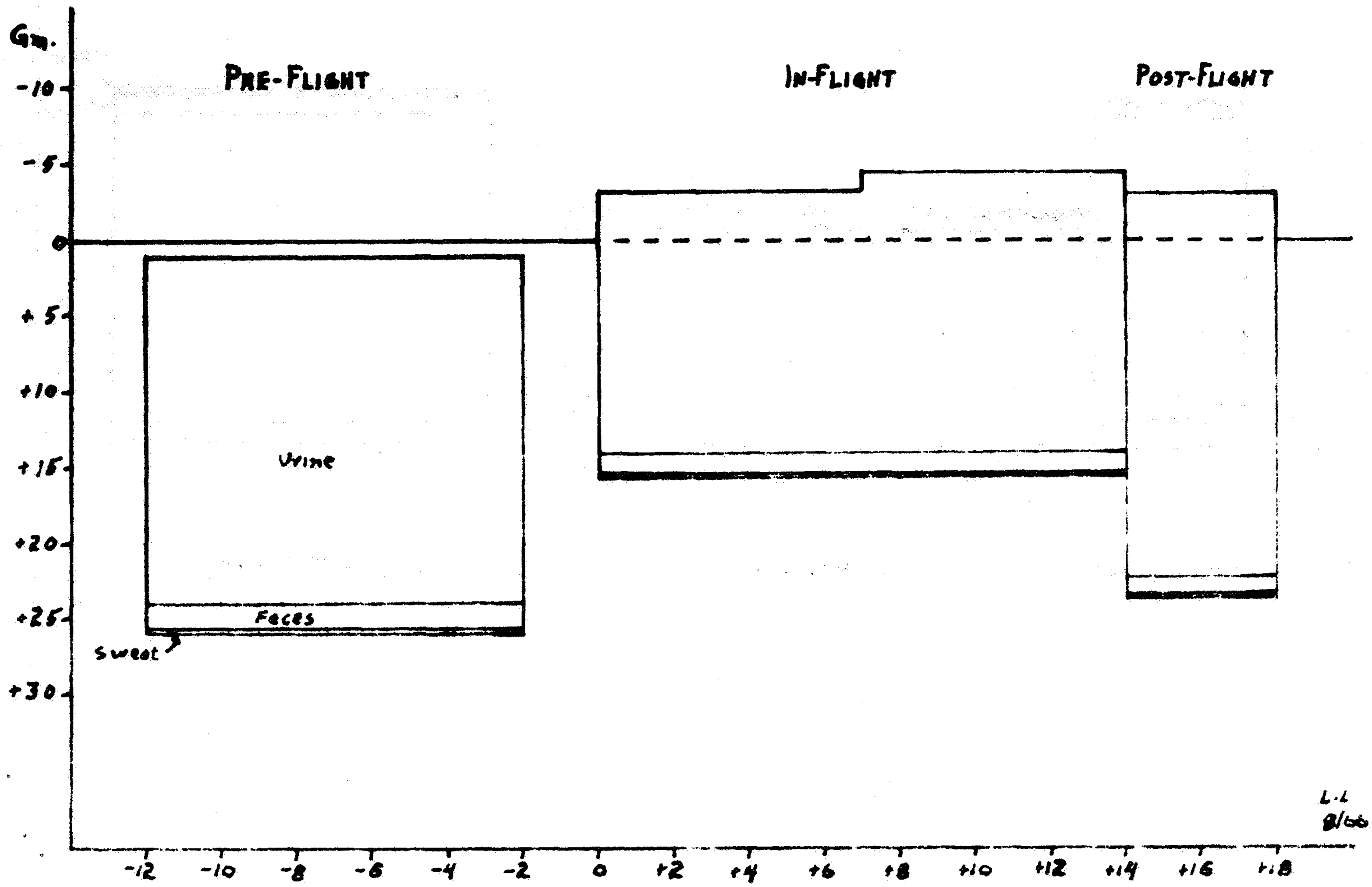


FIGURE 11

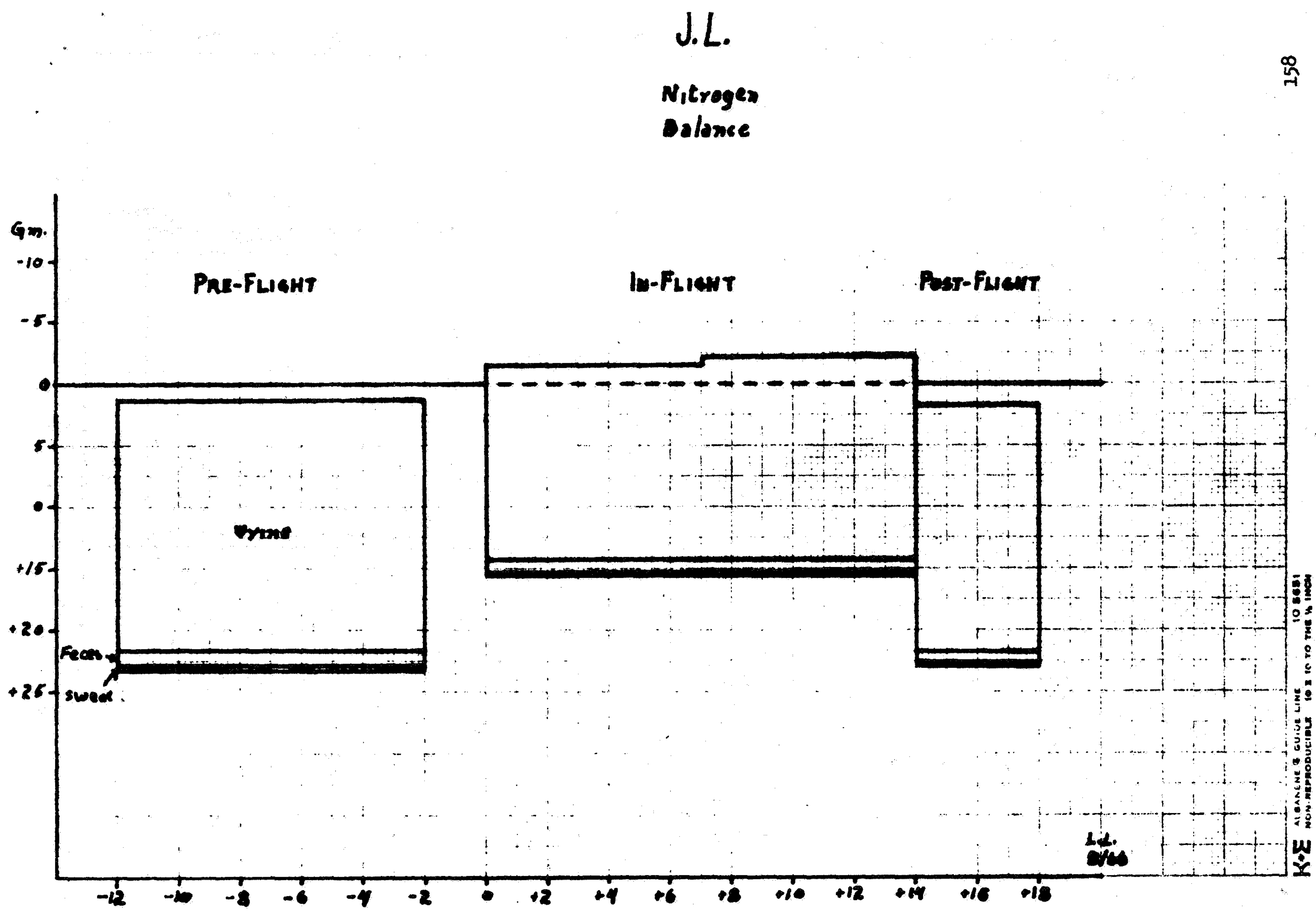

J.L.
Nitrogen
Balance
Gm.
-10
-5
0
5
0
+15
+20
+25
Pre-Flight
In-Flight
Post-Flight
Urine
Feces
Sweat
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
+12
+14
+16
+18

FIGURE 12

F.B.

Phosphate Balance

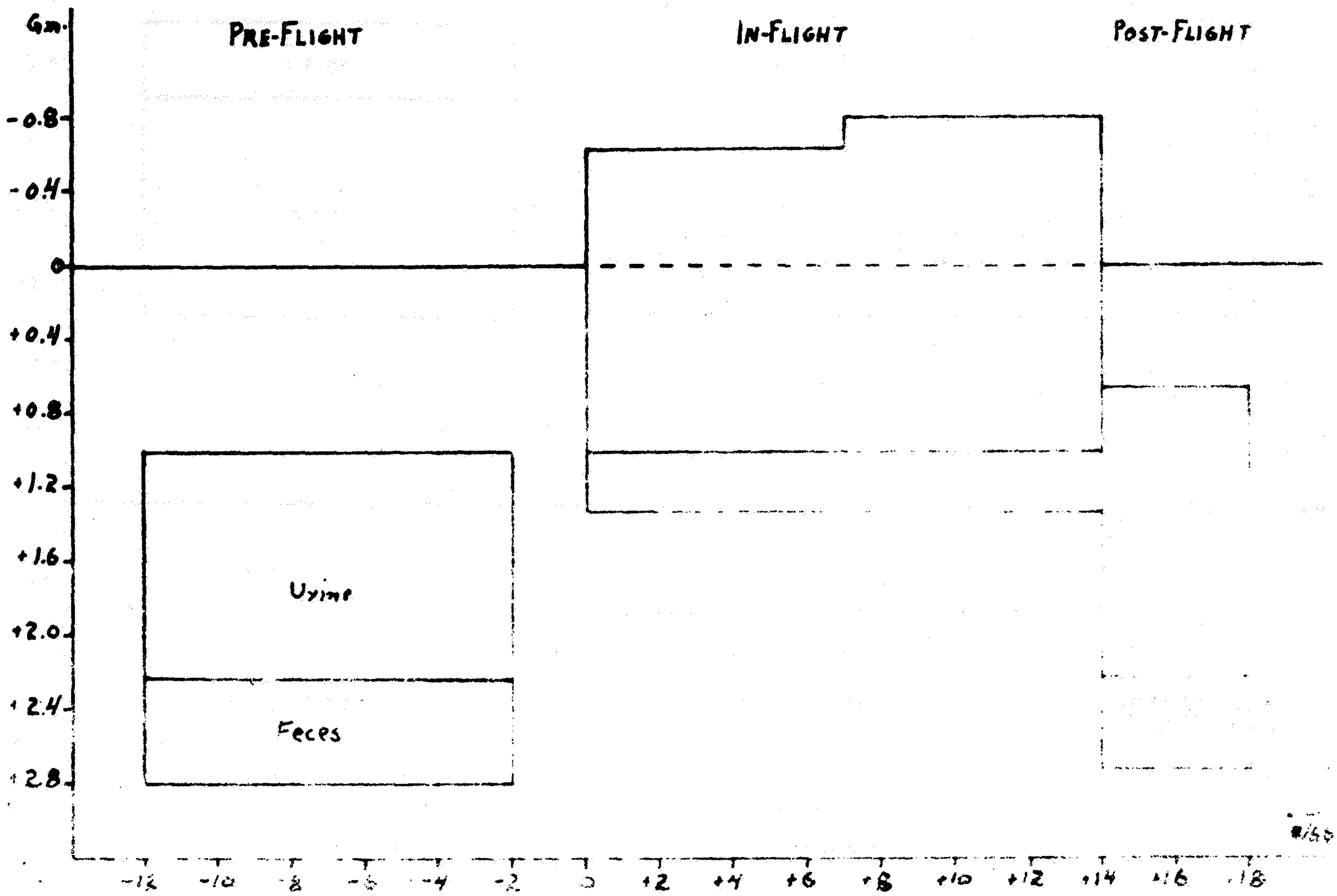


FIGURE 13

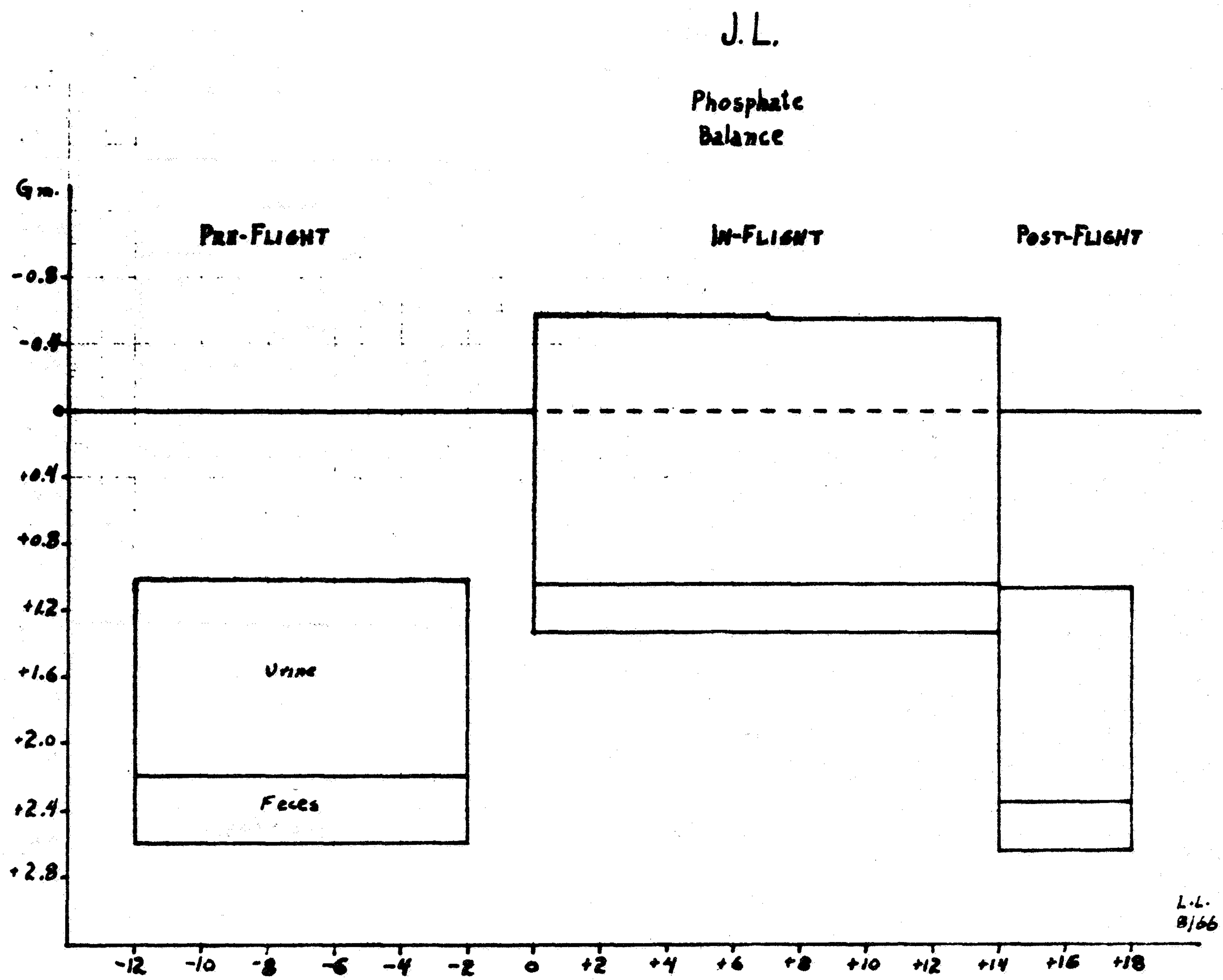

J.L.
Phosphate
Balance
Gm.
PRE-FLIGHT
IN-FLIGHT
POST-FLIGHT
-0.8
-0.4
0
+0.4
+0.8
+1.2
+1.6
+2.0
+2.4
+2.8
Urine
Feces
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
+12
+14
+16
+18
L.L.
8/66

FIGURE 14

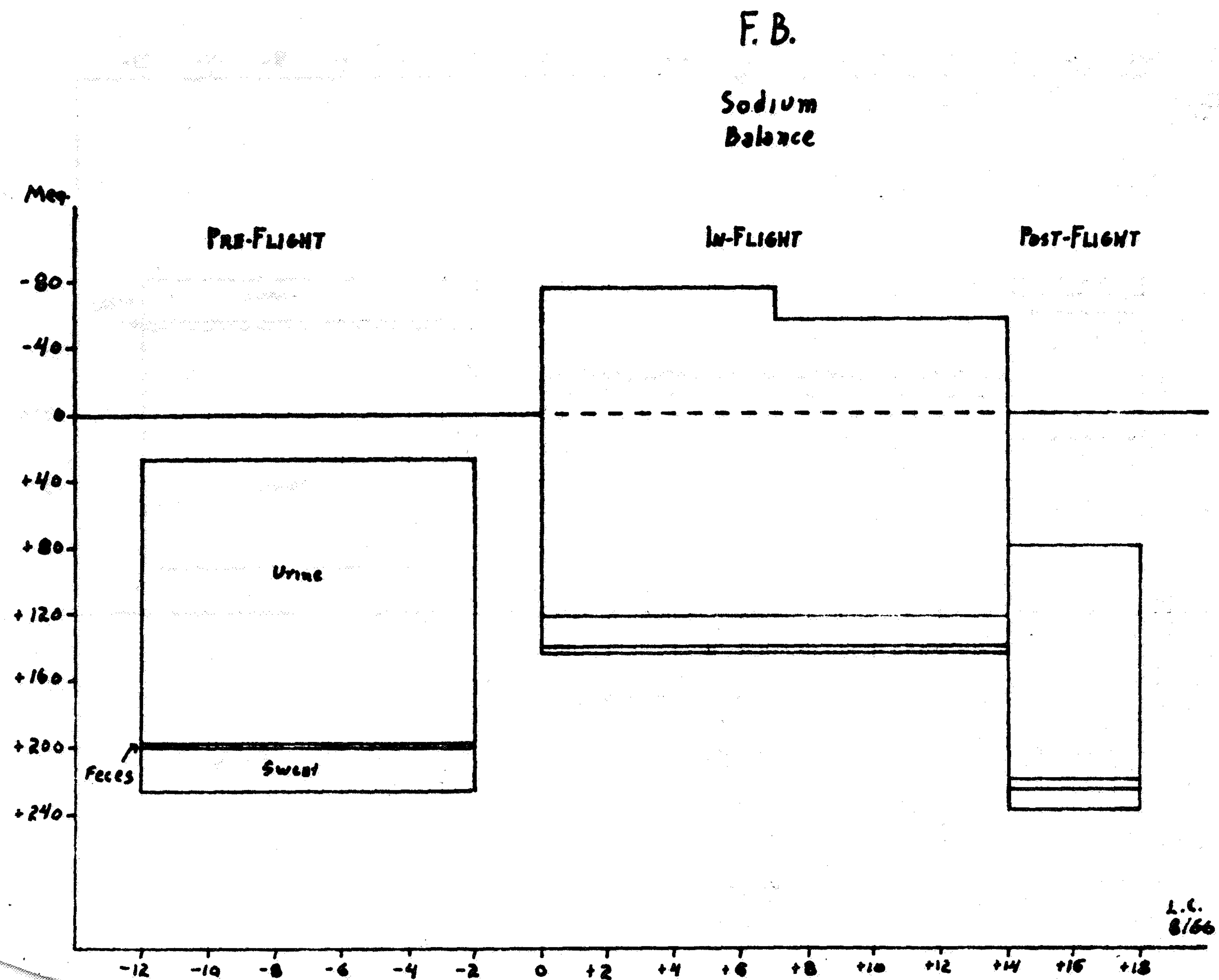

F. B.
Sodium
Balance
Meq.
PRE-FLIGHT
IN-FLIGHT
POST-FLIGHT
-80
-40
0
+40
+80
+120
+160
+200
+240
Urine
Feces
Sweat
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
+12
+14
+16
+18
L.C.
8/66

FIGURE 15

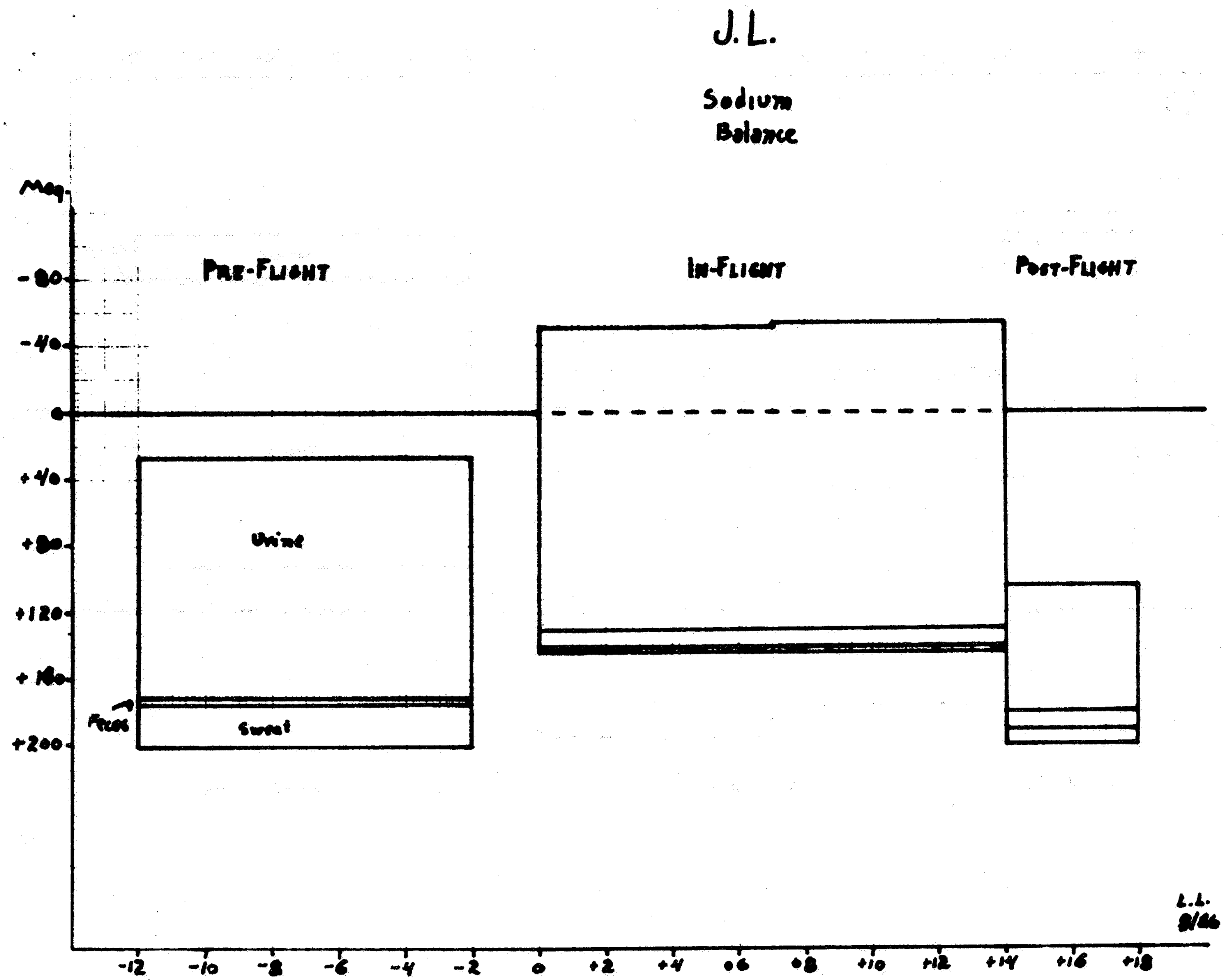
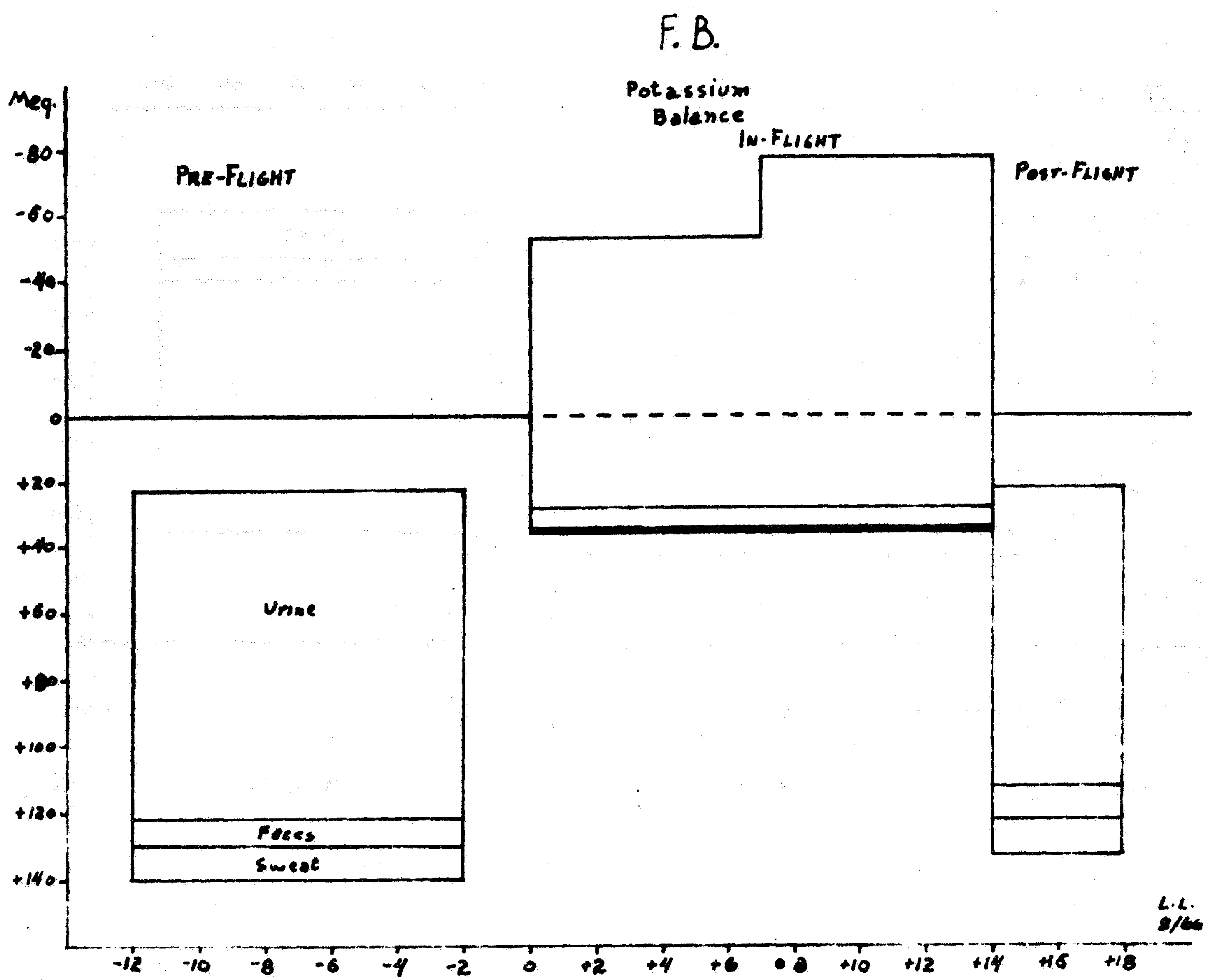

J.L.
Sodium
Balance
Meq.
-80
-40
0
+40
+80
+120
+160
+200
PRE-FLIGHT
IN-FLIGHT
POST-FLIGHT
Urine
Feces
Sweat
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
+12
+14
+16
+18
L.L.
8/66

FIGURE 16



F. B.
Potassium
Balance
Meq.
-80
-60
-40
-20
0
+20
+40
+60
+100
+120
+140
PRE-FLIGHT
IN-FLIGHT
POST-FLIGHT
Urine
Feces
Sweat
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+10
+12
+14
+16
+18
L.L.

FIGURE 17

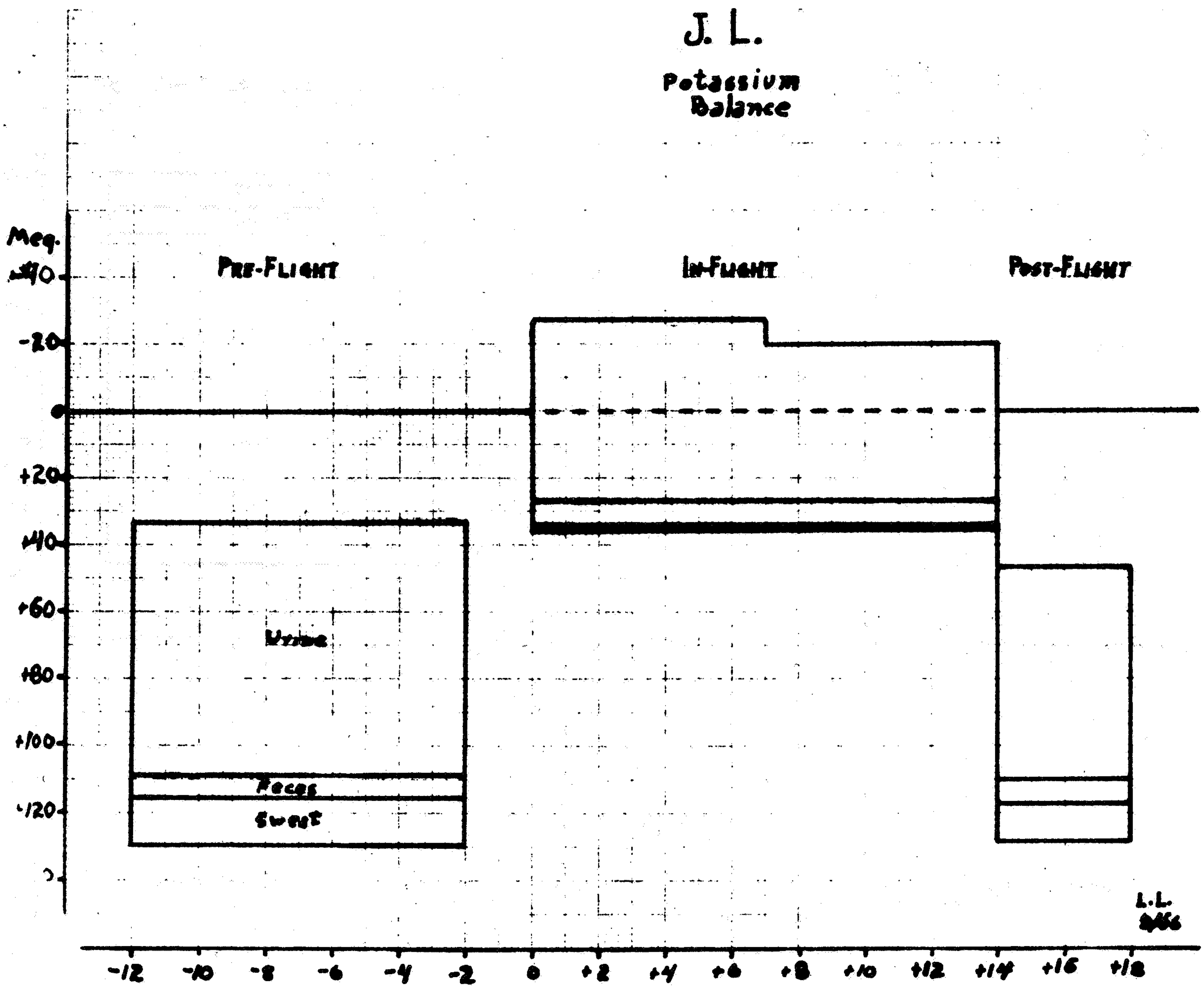

J. L.
Potassium
Balance
Meq.
-40
-20
0
+20
+40
+60
+80
+100
+120
PRE-FLIGHT
IN-FLIGHT
POST-FLIGHT
Urine
Feces
Sweat
L.L.
-12
-10
-8
-6
-4
-2
0
+2
+4
+6
+8
+10
+12
+14
+16
+18

FIGURE 18

BALANCES

		F.B.	P<	P<		J.L.	P<	P<
Calcium	pre-	+.3071			pre-	+.4615		
			.001				.001	
	in-	-.0452		n.s.	in-	+.0740		.01
			.1				.1	
	post-	+.2065			post-	+.3017		
Magnesium	pre-	+.1023			pre-	+.1365		
			.001				.001	
	in-	-.0560		.02	in-	-.0165		.02
			.001				.001	
	post-	+.1739			post-	+.1765		
Phosphate	pre-	+.9091			pre-	+.9367		
			.001				.001	
	in-	-.7161		n.s.	in-	-.5493		n.s.
			.001				.001	
	post-	+.6574			post-	+1.0555		
Nitrogen	pre-	+1.001			pre-	+1.305		
			.001				.01	
	in-	-3.768		.05	in-	-1.629		n.s.
			n.s.				.02	
	post-	-3.044			post-	+1.770		
Sodium	pre-	+26.40			pre-	+26.22		
			.001				.01	
	in-	-71.31		n.s.	in-	-50.77		.05
			.01				.001	
	post-	+80.03			post-	+104.79		
Potassium	pre-	+22.84			pre-	+33.08		
			.001				.001	
	in-	-65.46		n.s.	in-	-23.91		n.s.
			.01				.001	
	post-	+21.86			post-	+46.54		

FIGURE 19

Medical Experiment M008

INFLIGHT SLEEP ANALYSIS

Principal Investigators

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MEDICAL EXPERIMENT M008

INFLIGHT SLEEP ANALYSIS

SUMMARY

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

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

OBJECTIVES

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

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

METHODS

Two channels of EEG data from Command Pilot Frank Borman were recorded on an onboard tape recorder. The electrodes were chlorided silver discs imbedded in a lucite cup. These were filled with NASA electrolyte jelly and attached to the scalp with Eastman 910^{R} adhesive over sites which had been denuded with depilatory cream and drilled with a high-speed dental burr. EEG channel No. 1 was derived from the left central and left occipital electrodes; EEG channel No. 2, from the midline central and midline occipital electrodes. The lining material of the astronaut's helmet was designed with indentations over each electrode position in order to avoid pressure on the electrodes. Transistorized signal conditioners were worn in pockets of the astronaut's underwear.

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

RESULTS

Quality and Quantity of Data--Most of the EEG data recorded was of excellent quality from the standpoint of visual interpretation. During rest and sleep, the tracings were as good as any obtained on earth, even in carefully-controlled laboratory situations. When the astronaut was alert and active, the record contained electrode movement and muscle potential artifacts which tended to obscure the normal low voltage wakeful pattern. Except during meals, however, the artifacts in active periods were not of such magnitude as to have prevented detection of pathological changes, since the latter are almost always characterized by an increase in voltage and a decrease in frequency.

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

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

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

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

DISCUSSION

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

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

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

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

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

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

The sleep periods were located by visually scanning the write-out of the tape. Each minute of sleep was classified as to stage of sleep according to the above criteria, and plotted graphically versus time, as shown in Figure 8 which illustrates the sleep pattern of both flight sleep periods, as well as a control sleep period recorded prior to flight. The uppermost level on the vertical axis represents the eye-open, alert pattern. The next level is the eyes-closed, resting pattern, or stage 0. The heavy horizontal line in the center of stage 0 represents the division between waking and sleeping EEG patterns. The next four levels represent the four stages of sleep from light sleep down to deep sleep. When, as is the usual case, more than one EEG sleep stage was seen during a one-minute epoch, the vertical line for that epoch was drawn to overlap the two or more stages seen during that minute. The horizontal axis of these graphs is marked in elapsed flight time. The control sleep period (upper left graph in Figure 8) was similarly analyzed for comparison of rate of falling to sleep and depth, but the overall pattern cannot be compared to the flight periods since the subject was not allowed to complete a spontaneous sleep period.

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

An attempt was made to correlate the transient arousals from sleep with various environmental factors, such as suit and cabin temperature variations, cabin pressure variations, and the shadow history of the spacecraft. In spite of the runs of low voltage alpha rhythm superimposed upon a somewhat unsteady baseline and mixed with eye-blink potentials (transient downward deflections). Occasional runs of low voltage 5-7 cycle per second activity also appeared in the record; these resemble theta activity but are difficult to distinguish with certainty from rapid ocular or eyelid movement potentials. During ascent (Figure 3A) continuous high frequency muscle potentials were superimposed upon the trace. After 24 hours in orbit (Figure 3B) the record showed a more "relaxed" pattern, with more rhythmic alpha activity and less muscle potential artifact.

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

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

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

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

From a medical point of view, the results of the current study were essentially negative in that no pathological EEG changes were observed, and visual inspection of the tracing revealed no changes which could be attributed to the "weightless" state. Furthermore, it is difficult to draw conclusions from the two recorded sleep cycles. The first sleep period was definitely inadequate in terms of length and depth of sleep, but the pattern was typical of ordinary insomnia or disturbed sleep, which can easily be explained on the basis of the understandable anxiety of the situation and the unique conditions of orbital flight. The second sleep period was adequate in terms of depth and length, but this cannot be used as definite evidence against orbital sleep disturbance since the pilot was probably quite fatigued due to loss of sleep in the first sleep period. Sleep patterns in subsequent sleep periods later in the flight will have to be obtained in order to arrive at any definite conclusions as to whether orbital flight *per se* tends to disturb sleep.

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

CONCLUSIONS

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

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

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

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

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

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FIGURE LEGEND

Fig. 1 Bar graph representing quantity of EEG data obtained. See text for explanation.

Fig. 2 A. (Upper two tracings): Write-out of calibration signals which were applied to the data tape prior to liftoff. All EEG illustrations in this paper used this gain and chart speed.

B. (Lower two tracings): EEG pattern prior to liftoff.

Fig. 3 A. (Upper two tracings): EEG pattern during ascent, near peak acceleration.

B. (Lower two tracings): EEG pattern during orbital flight.½

Fig. 4 A. (Upper two tracings): Artifacts produced in EEG pattern by rhythmic chewing motions.

B. (Lower two tracings): Fully expressed alpha rhythm present when eyes are closed while pilt is alert.

Fig. 5 A and B. (Upper two tracings): Illustration of the transition from the alert, resting pattern to drowsiness, or stage 1 sleep.

C. (Lower trace): Light sleep pattern, or stage 2 sleep.

Fig. 6 A. (Upper trace): Stage 3 sleep, or moderate sleep.

B. (Middle trace): Deep sleep, or stage 4.

C. (Illustration of a transient arousal from Stage 4 sleep to stage 0.

Fig. 7 Continuous tracings showing a mixture of sleep stages 1 and 2. This pattern occurred for long intervals and resembles the EEG seen during the rapid eye movement phase of sleep, or "paradoxial sleep."

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

NASA-S-66-2919 APR 1

GEMINI MEDICAL EXPERIMENTS M-8

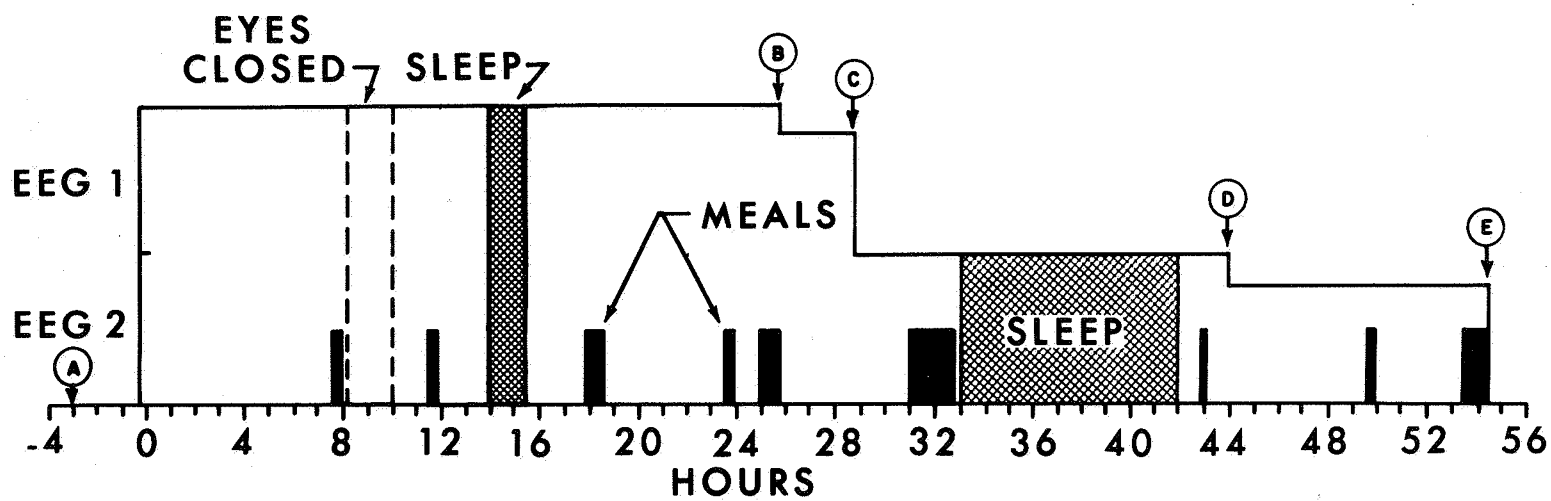
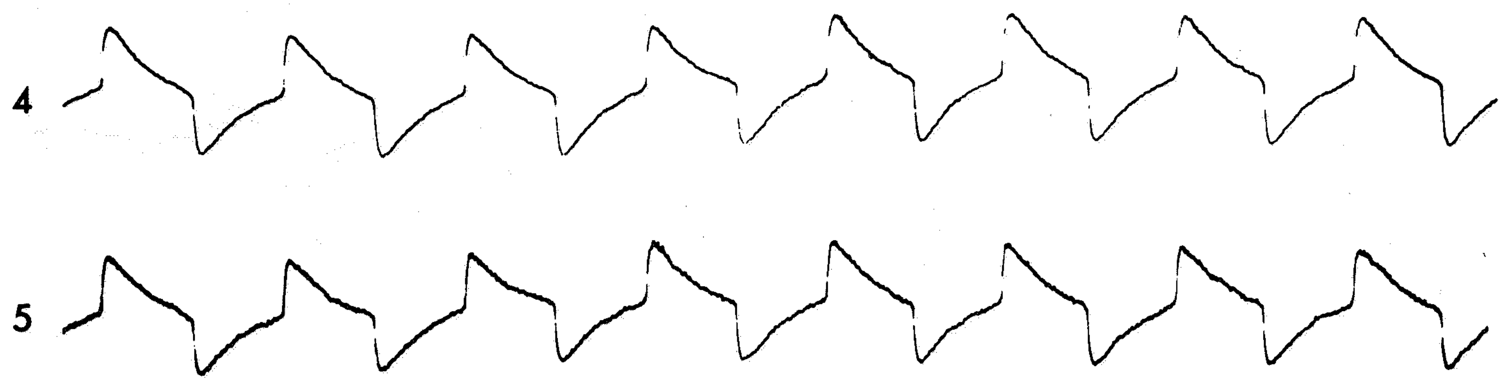


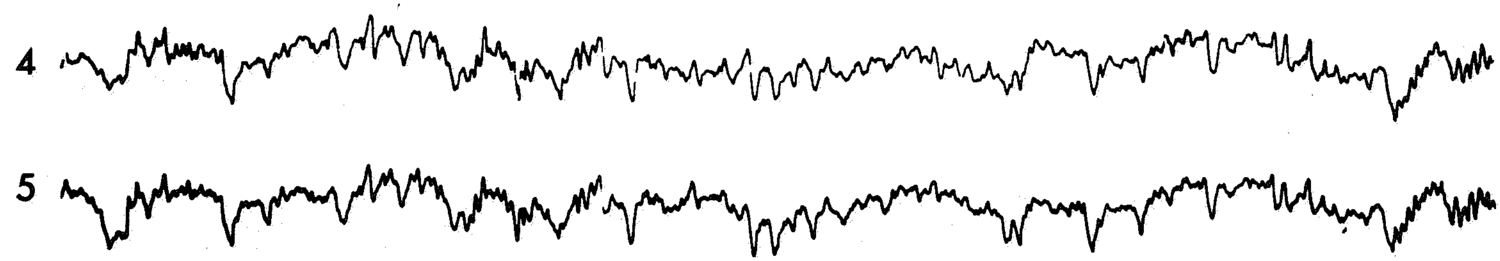
Fig. 1

NASA-S-66-2923 APR 1

GEMINI MEDICAL EXPERIMENTS M-8



CALIBRATION: 50 MICROVOLT SQUARE WAVES, 0.5 CPS

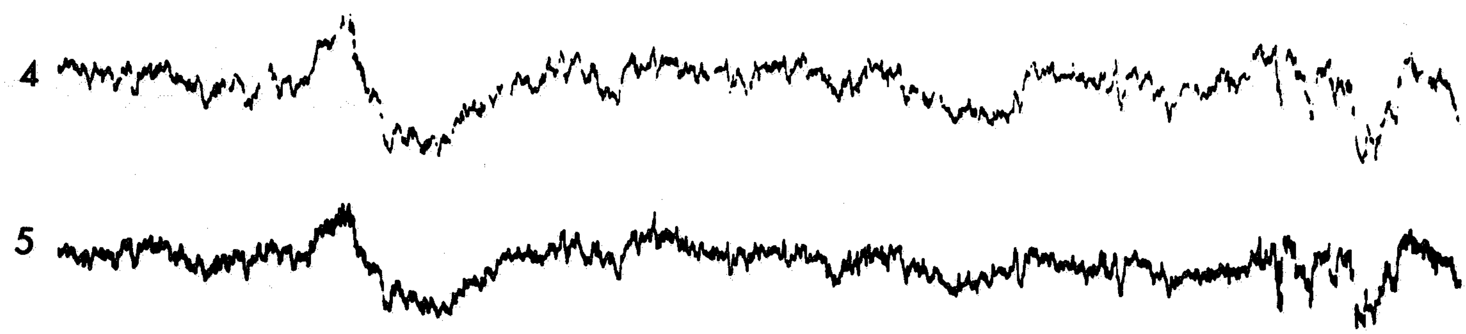


BEFORE LIFT OFF: MINUS 10 MIN

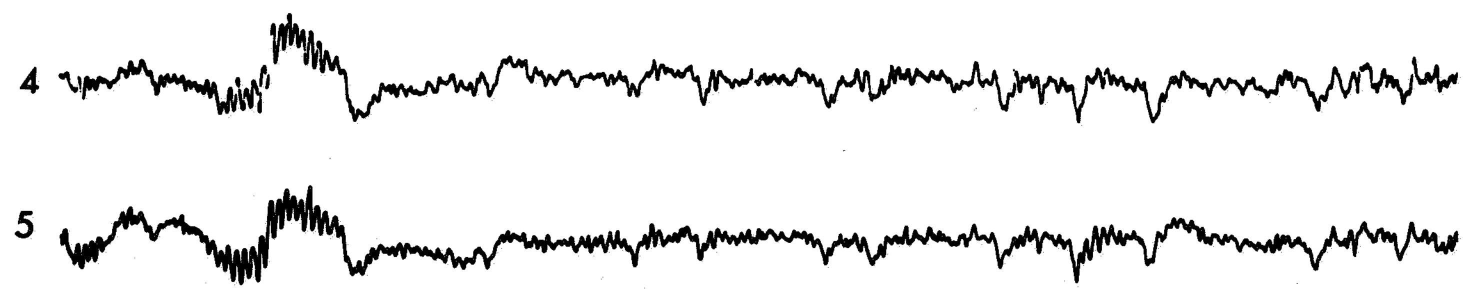
Fig. 2

NASA-S-66-2920 APR 1

GEMINI MEDICAL EXPERIMENTS M-8



DURING ASCENT: PLUS 5 MIN



IN ORBIT: 24 HR, 27 MIN

Fig. 3

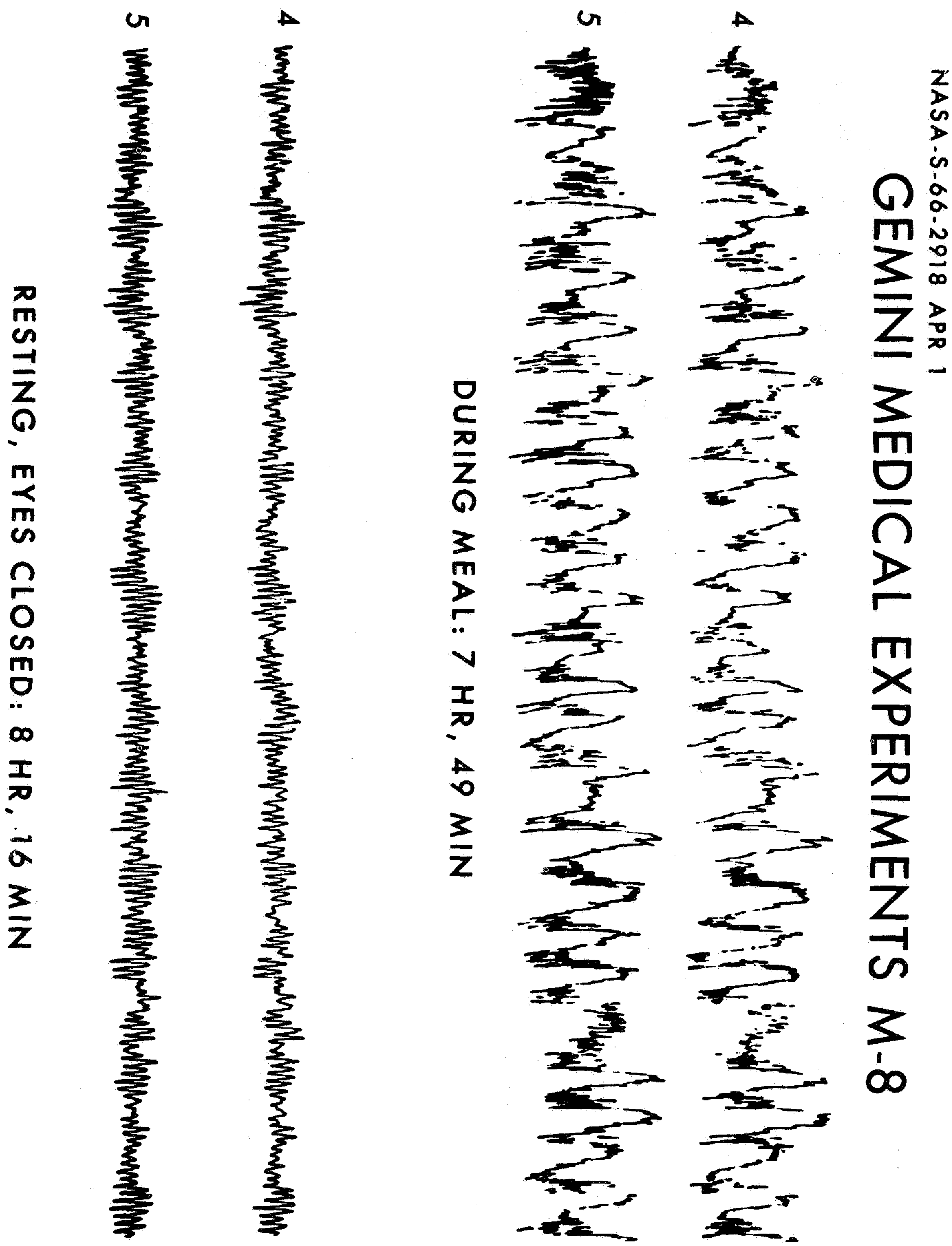

NASA-S-66-2918 APR 1
GEMINI MEDICAL EXPERIMENTS M-8
4
5
DURING MEAL: 7 HR, 49 MIN
4
5
RESTING, EYES CLOSED: 8 HR, 16 MIN

Fig. 4

NASA-S-66-2922 APR 1

GEMINI MEDICAL EXPERIMENTS M-8

4 

TRANSITION TO STAGE 1 SLEEP: 33HR, 17 MIN

4 

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

4 

STAGE 2 SLEEP: 33HR, 24 MIN

Fig. 5

NASA-S-66-2926 APR 1

GEMINI MEDICAL EXPERIMENTS M-8

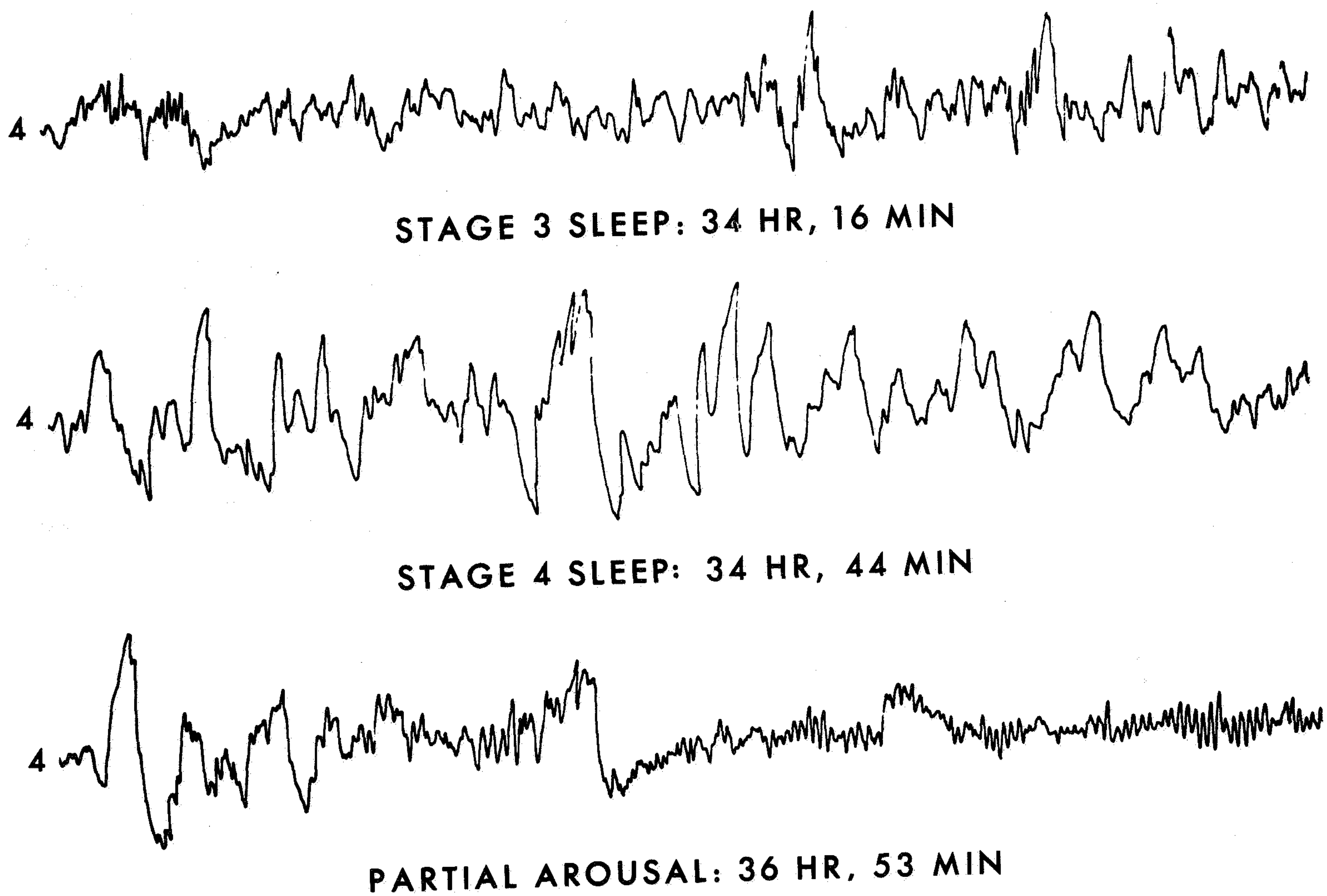
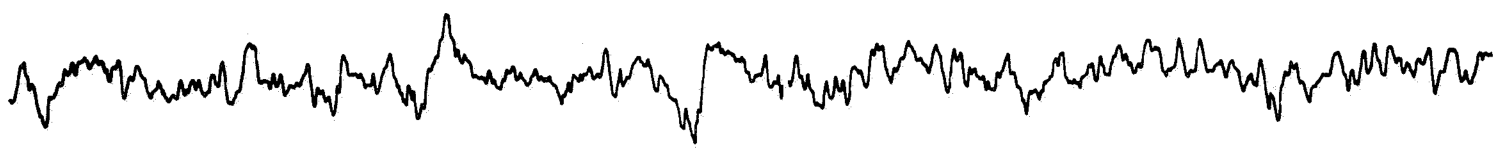


Fig. 6

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



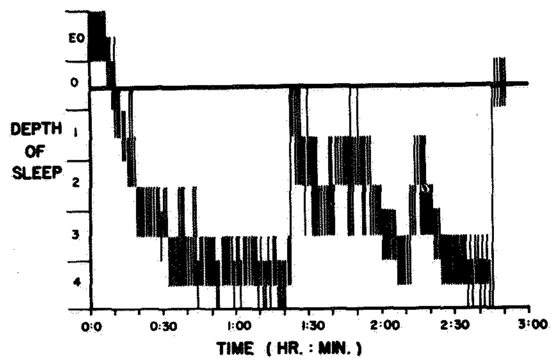
STAGE 1-2 SLEEP (continued): 35 hr., 11 min.

Fig. 7

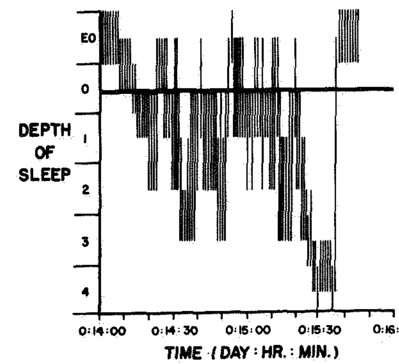
NASA-S-66-2925 APR 1

GEMINI MEDICAL EXPERIMENTS M-8

CONTROL SLEEP PERIOD



FLIGHT SLEEP PERIOD NO. 1



FLIGHT SLEEP NO. 2

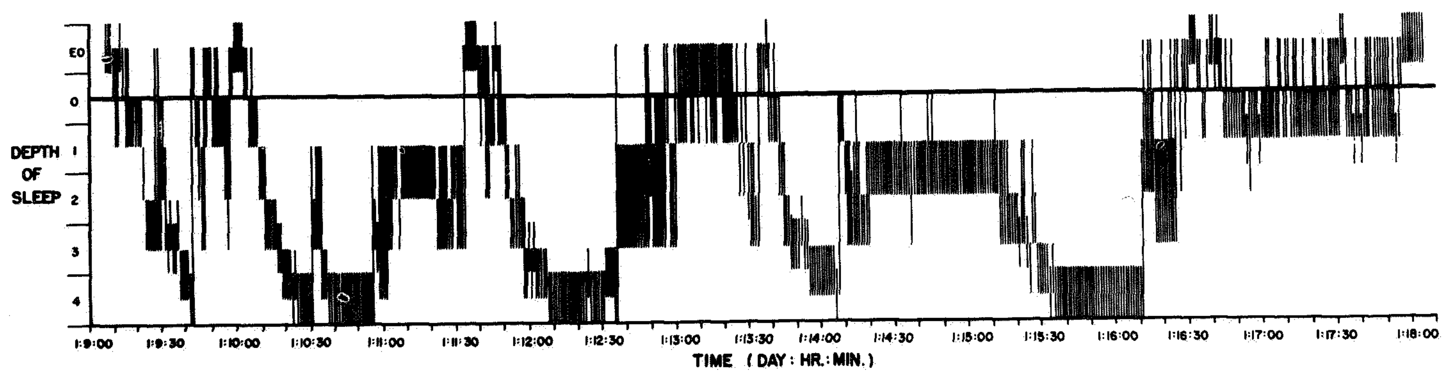


Fig. 8

EXPERIMENT M-9, HUMAN OTOLITH FUNCTION:

MEASUREMENTS IN GEMINI FLIGHTS V AND VII

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N68-10189

EXPERIMENT M-9, HUMAN OTOLITH FUNCTION: MEASUREMENTS IN GEMINI FLIGHTS V AND VII*

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

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

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

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

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

SPATIAL LOCALIZATION

The purpose of this experimental probe was to compare the influence of nonvisual sensory information under terrestrial and weightless conditions on the visually perceived direction of space. Data obtained from earlier experiments not only are relevant for comparative purposes but also serve as a necessary introduction.

SENSORY SYSTEMS

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

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

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

Examples of Interactions Between Cues From Visual and Force Environments

In Figure 2 (top) is shown a naive normal subject on an open centrifuge and facing the center of rotation. When he is exposed to a centripetal force of 1.0 g unit, the centrifuge appears to slope upward away from him and the room appears similarly sloped (2). This is at once a demonstration of preternatural control over the force environment and a partial conformity of the visually perceived upright to the gravitoinertial upright. This has been termed the oculogravic illusion (3) based on the Earth reference.

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

In Figure 3a the subject is seated in a closed lighted room on a human centrifuge and facing in the direction of rotation. When exposed to a centripetal force of 1.0 g unit, he perceives the room as sloped with down on his right side. When visual cues are greatly reduced (Figure 3b), the slope increases, and there may be good concordance between the visual and force upright. This orientation of the subject creates a more favorable opportunity for him to indicate horizontality by clockwise or counterclockwise rotation of a visual target or rod than when he faces the center where estimates would be made as deviations above or below an imaginary horizon.

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

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

THE OCULOGRAVIC ILLUSION

In Figure 4 a subject is shown seated facing the direction of rotation while exposed to a centripetal force of 1.0 g unit (13). The sketch depicts the arrangement of physical objects as viewed by closed circuit television. Note the free swinging plumb bob which is the only indication of the gravitoinertial vertical. Figure 5 shows how a naive subject perceives the situation with eyes closed; he feels as if he is tilted to the right in an upright room. A sophisticated subject is also aware of the tilt but will realize his position has not changed with reference to the room. Both subjects, if viewing a luminous line in the dark while suddenly subjected to a centripetal force of 1.0 g unit, would perceive the line as rotating slowly clockwise from the horizontal position through an arc usually greater than 45°. This is an illusory or apparent motion representing influences of cues from the force environment on visual spatial localization. If the subject is requested to set the line to the Earth horizontal, he rotates it counterclockwise from its original setting toward the gravitoinertial horizontal, usually overcompensating at this level of force; grasping a swivel rod with eyes closed, he also sets this near the gravitoinertial horizontal. The results are scored in terms of correspondence of the settings to the gravitoinertial horizontal. With the visual target the threshold* of perception for perceiving the

*75 per cent (or greater) correct responses.

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

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

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

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

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

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

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

Certain Effects of Lateral Tilt in the Gravitational and Gravitoinertial Fields

Seated upright in a tilt chair normal subjects set a luminous line approximately to the gravitational horizontal but manifest a characteristic bias as they are tilted leftward or rightward through 90°. Initially, the bias appears as an over- and later as an under-compensation termed, respectively, the E- and A-phenomenon, as shown in Figure 10 (18). The bias is greater and the consistency less in L-D subjects.

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

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

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

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

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

THE IN-FLIGHT EXPERIMENT

Methodology

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

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

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

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

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

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

The method in-flight was as follows: Immediately after completion of the Visual Acuity Experiment, and without removing the instrument from his face, the subject prepared for making his judgments of horizontality by occluding the left eyepiece and turning on the luminous target before the opposite eye. The target appeared against a completely dark background. The observer astronaut offset the line, and the subject's task was to set it parallel to an element of the spacecraft panel horizontal with respect to himself. When satisfied with the setting, he closed his eyes and removed his hand from the knurled knob. This served as a signal to the observer to record the setting and offset the target. This procedure was scheduled to be repeated five times during each of the daily test sessions. In the interest of conserving vital spacecraft power during the early part of the Gemini V flight, no settings were made; for the same reason during revolution 24, 39, and 54 only one judgment of horizontality was made by each subject. Upon completion of a test session by the first subject the Vision Tester was handed to the other pilot, and the same sequence was carried out after completion of the visual acuity test. Finally, the readings for each pilot were tape-recorded by voice.

RESULTS

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

The findings obtained on the two astronauts in GT VII are shown in Figure 17. For Pilot C there is no systematic variance differences among the pre-, post- and in-flight measurement. For Pilot D variance of pre-flight measurements was significantly greater than variances for all other sets of measurements including post-flight. Post-flight variance was significantly greater than the variances of in-flight measurement and for 9 of the 14 sets of measurements obtained during orbital flight.

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

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

As pointed out above, in attempting to anticipate the influence of agravic cues on spatial localization the loss of G loading might be expected, by extrapolation, to reduce the tendency toward a bias while the unusual patterning of sensory cues, especially in the absence of otolith function, might tend to increase this tendency. The small intra- and inter-test variance in setting the line during exposure to weightlessness strongly suggests that agravic cues exert a weak influence on central intergravitational processes underlying visual spatial localization. Stated in another way, the loss of sensory information from the otolith organs and other receptor organs stimulated by gravity following transition into weightlessness did not appear to influence visual mechanisms concerned with the perceived direction of space. Under these circumstances the sensory information is so meager and the pattern so unusual that it would hardly serve as adequate primitive sense experience out of which to construct a concept of physical space. Once this concept has been established, however, meager postural cues may suffice for spatial orientation even in darkness.

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

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

With regard to the in-flight settings of astronaut A, they differed from those of the other three in that they were approximately 30° clockwise with respect to the external horizontal reference but were similar in that the intra- and inter-trial variance were small. The question arises whether the settings near 30° represent a systematic procedural error, a bias, or settings with reference to independent symbolic cues. The same goggle device was used post-flight; hence, a mechanical error is ruled out. Inasmuch as the task involved setting the line to a horizontal cabin reference coinciding with the astronaut's body horizontal, it did not matter if the body reference was chosen, thereby eliminating any confusion between the two. Our experience is so limited that we cannot even answer the question whether a bias of this magnitude based on nonvisual sensory inputs under agravic conditions is possible. The phenomenon does not seem typical of the characteristics of biases manifested under terrestrial conditions, but this does not rule out the possibility. This can of course be put to the test whenever it becomes feasible in weightlessness to manipulate sensory cues and investigate the effects on spatial localization. There is too the possibility that the settings were made using a cue other than the internal coordinates of the body. This of course can be controlled in the future.

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

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

APPARATUS AND PROCEDURE

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

The camera system used to photograph the natural iris landmarks includes a motor driven 35 mm camera with bellows extension and an electronic flash unit (25). A console located at the base of the tilt device contains a bank of power packs which supply the electronic flash, a timer control mechanism, and controls for the flashing, round-fixation light which surrounds the camera lens. A triaxial accelerometer unit which senses and relays signals of linear acceleration to a Consolidated Electrodynamics Corporation galvonometer recorder was mounted to the head portion of the device for shipboard use.

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

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

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

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

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

OTOLITH FUNCTION AS DETERMINED BY OCULAR COUNTERROLLING

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

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

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

RESULTS

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

DISCUSSION

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

SUMMARY AND CONCLUSIONS

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

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

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

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

ACKNOWLEDGMENTS

We are extremely pleased to acknowledge the support of the Cffice of Advanced Research and Technology (Biotechnology and Human Research) in obtaining ground-based data which provided important background information for the in-flight experiments. We are grateful to the Manned Spacecraft Center for extending us the remarkable opportunity together with the necessary support for conducting vestibular experiments in conjunction with the Gemini V and VII manned space flights. The success of these experiments was in large part dependent upon the subjects involved, astronauts Frank Borman, Charles Conrad, Gordon Cooper, and James Lovell. These men deserve special commendation for their extraordinary effort in gathering these research data under the considerable constraints necessarily imposed in these historical events.

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TABLE LEGEND

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

PERCEPTION Extrapersonal Space (EPS)

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

★Astronaut secured in couch; fixates line in dark ★★Visual memory a factor

† Joint Capsule Compression & Displacement

Table 1

FIGURE LEGENDS

Figure 1 - Extrapersonal Space

Figure 2 - Interaction Between Cues From Visual and Gravitoinertial Force Environments.

Figure 3 - Depicting the Illusory Tilt of a Physically Upright Room Perceived by a Subject on a Human Centrifuge.

Figure 4 - Physical conditions as perceived by closed circuit television with subject fixed during exposure on human centrifuge. Plumb bob only indication of change.

Figure 5 - Naive subject facing away from direction of rotation fixating a luminous line in the dark regards himself as tilted in an upright room.

Figure 6 - Change in setting of star as function of time compared with change in direction of resultant force of 20°. Curves depict mean values.

Figure 7 - Mean values for the oculogravic illusion in five normal subjects with progressively longer delay time in presenting the target.

Figure 8 - Estimates of the oculogravic illusion by normal and L-D subjects. Single settings of star.

Figure 9 - Change in direction of gravitoinertial vertical with respect to subject (Angle Phi).

Figure 10 - Mean curves represent E & A phenomena of individual test sessions of one subject.

Figure 11 - Change in E-phenomenon as a function of increasing G level in normal subjects.

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

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

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

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

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

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

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

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

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

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

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

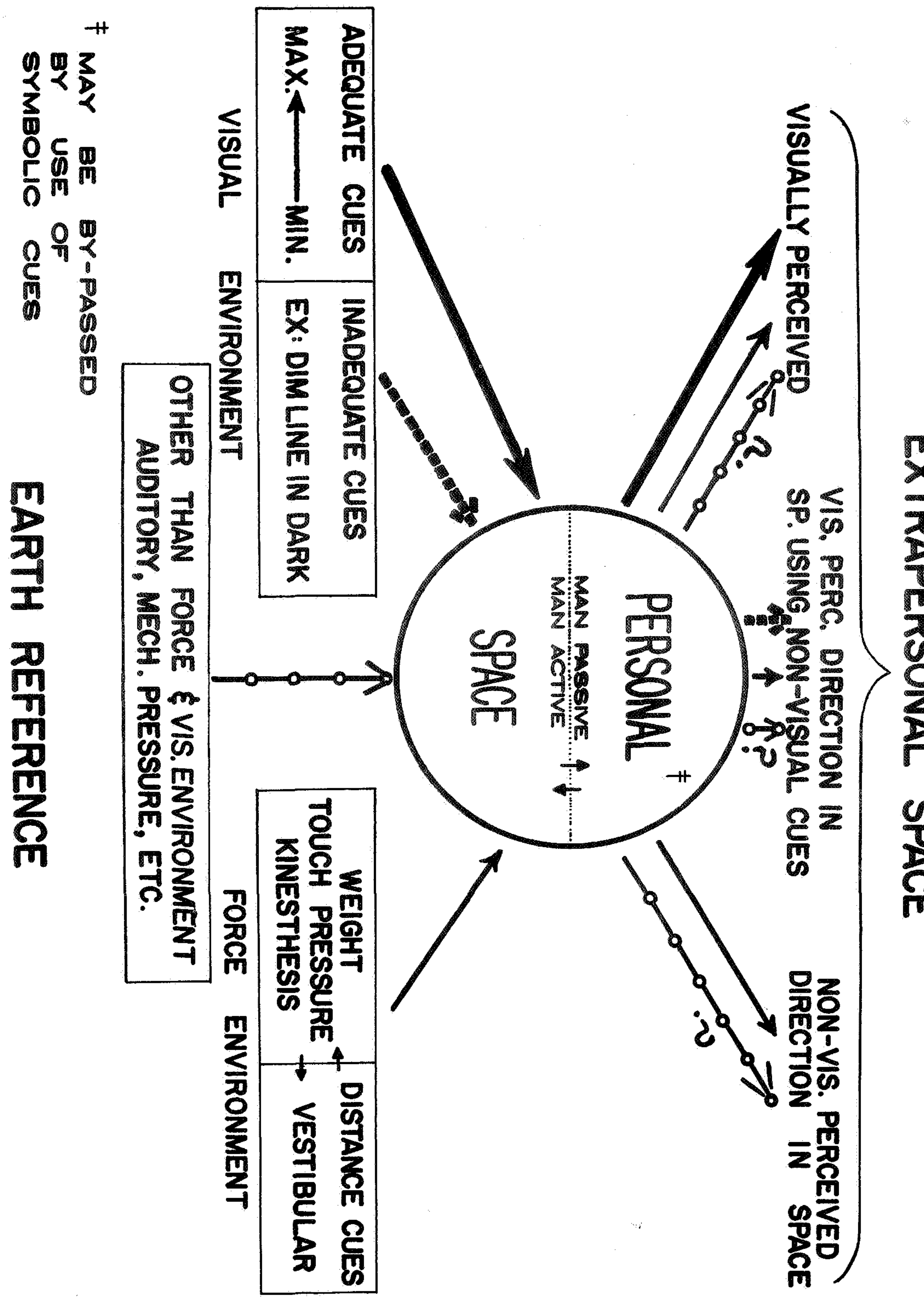

EXTRAPERSONAL SPACE
VISUALLY PERCEIVED
VIS. PERC. DIRECTION IN SP. USING NON-VISUAL CUES
NON-VIS. PERCEIVED DIRECTION IN SPACE
PERSONAL SPACE
MAN PASSIVE
MAN ACTIVE
ADEQUATE CUES
MAX.
MIN.
INADEQUATE CUES
EX: DIM LINE IN DARK
VISUAL ENVIRONMENT
OTHER THAN FORCE & VIS. ENVIRONMENT
AUDITORY, MECH. PRESSURE, ETC.
WEIGHT
TOUCH PRESSURE
KINESTHESIS
DISTANCE CUES
VESTIBULAR
FORCE ENVIRONMENT
‡ MAY BE BY-PASSED BY USE OF SYMBOLIC CUES
EARTH REFERENCE

Fig. 1

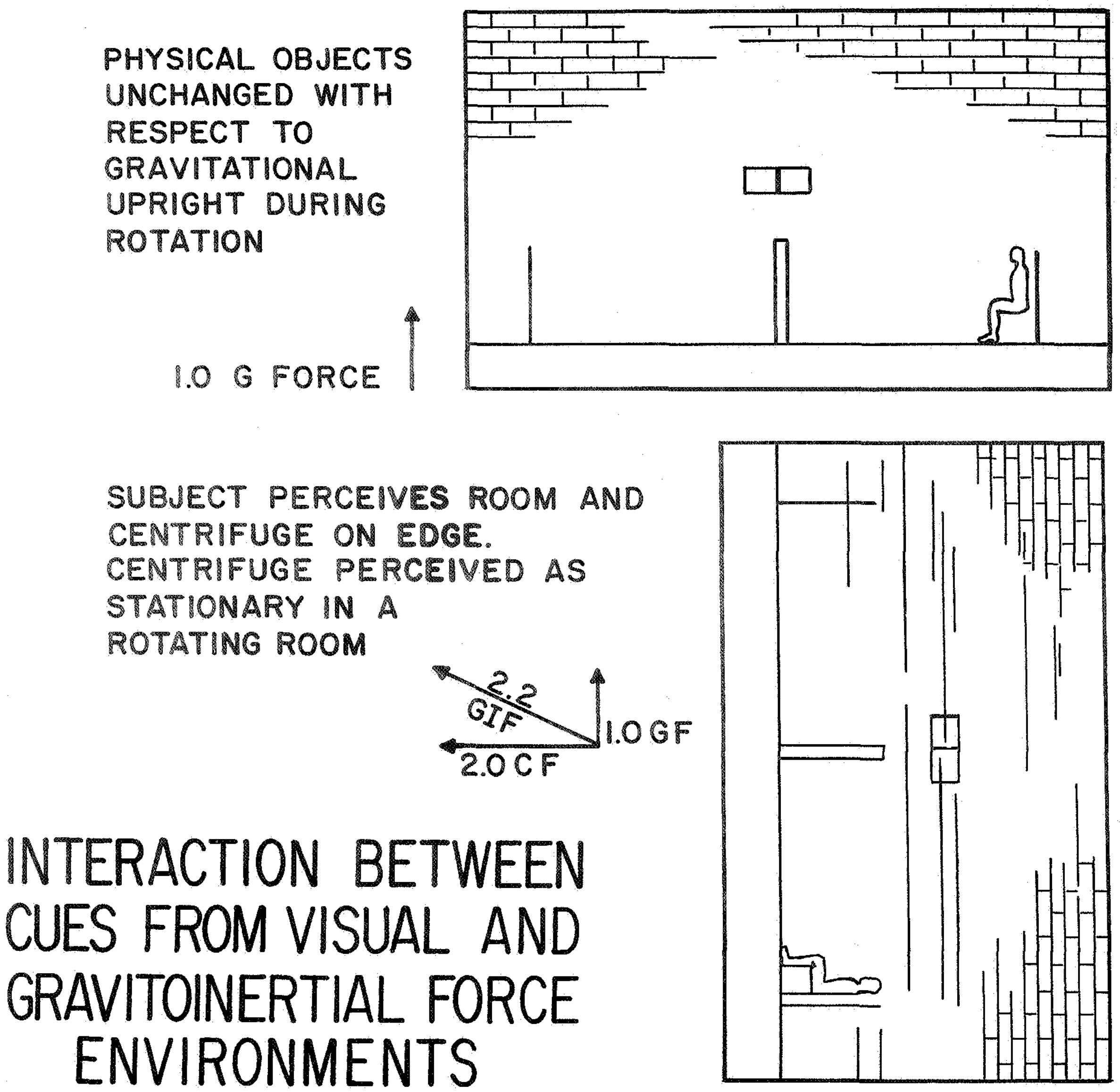
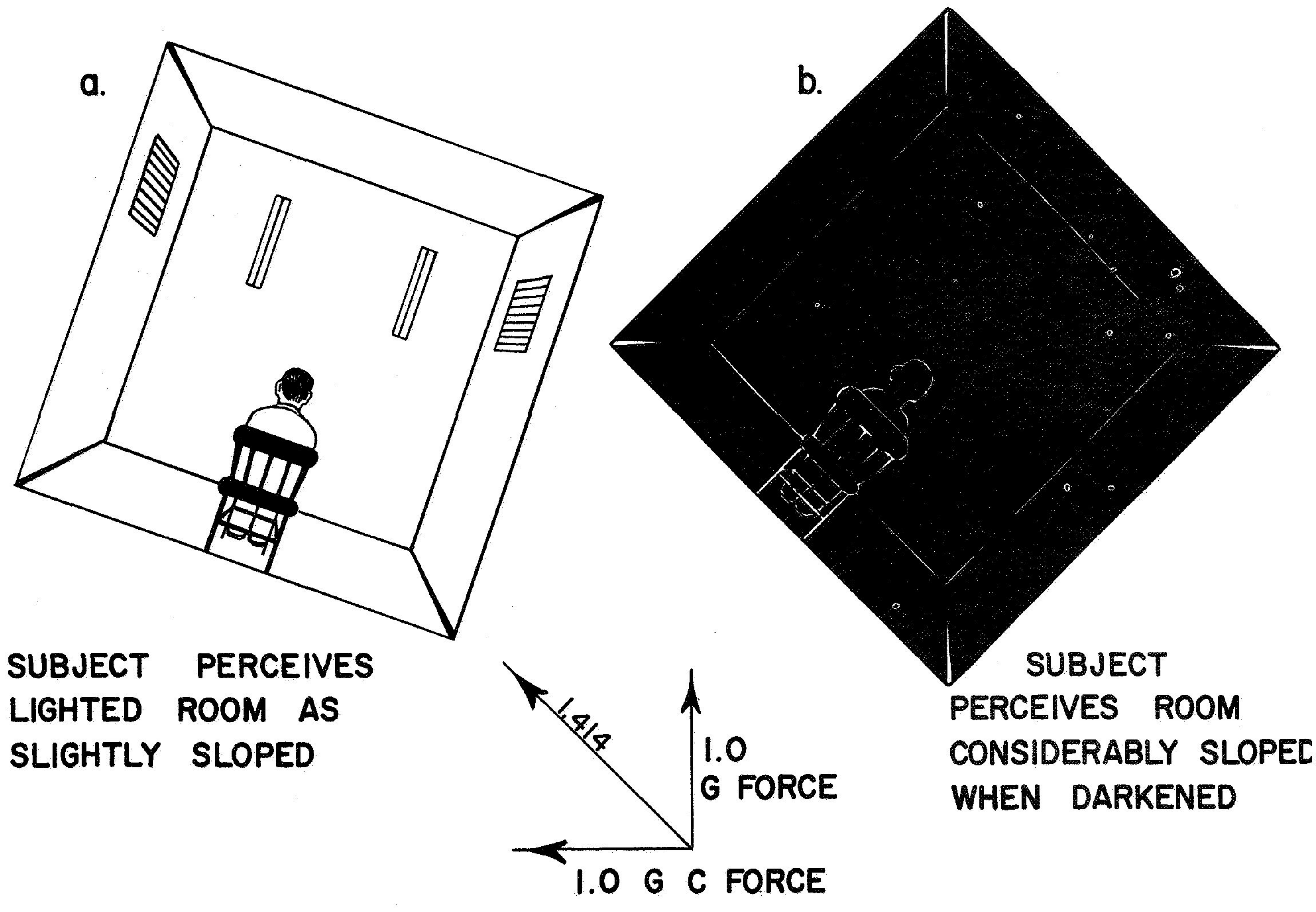

PHYSICAL OBJECTS UNCHANGED WITH RESPECT TO GRAVITATIONAL UPRIGHT DURING ROTATION
1.0 G FORCE
SUBJECT PERCEIVES ROOM AND CENTRIFUGE ON EDGE. CENTRIFUGE PERCEIVED AS STATIONARY IN A ROTATING ROOM
2.2 GIF
1.0 GF
2.0 C F
INTERACTION BETWEEN CUES FROM VISUAL AND GRAVITOINERTIAL FORCE ENVIRONMENTS

Fig. 2



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

Fig. 3

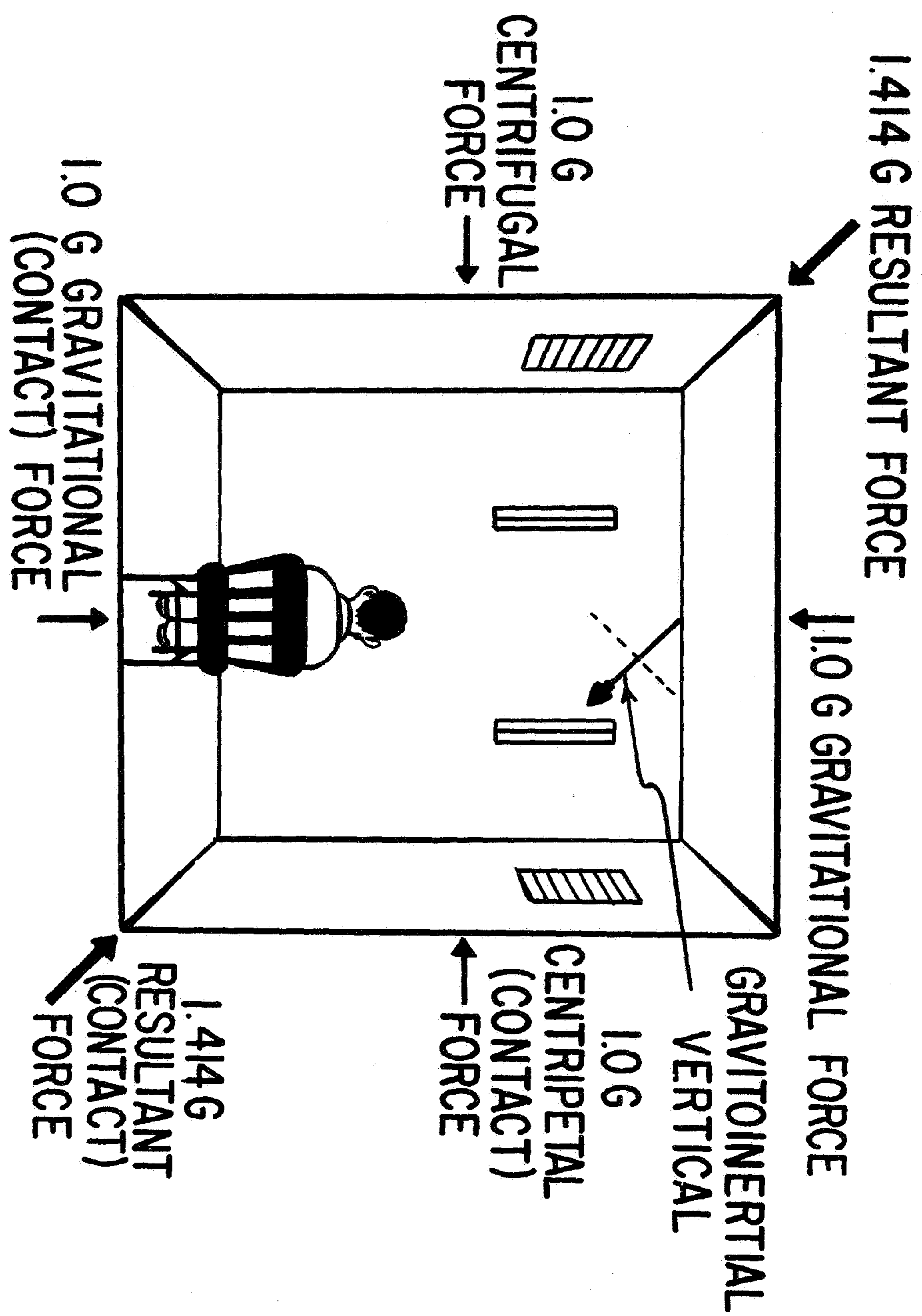
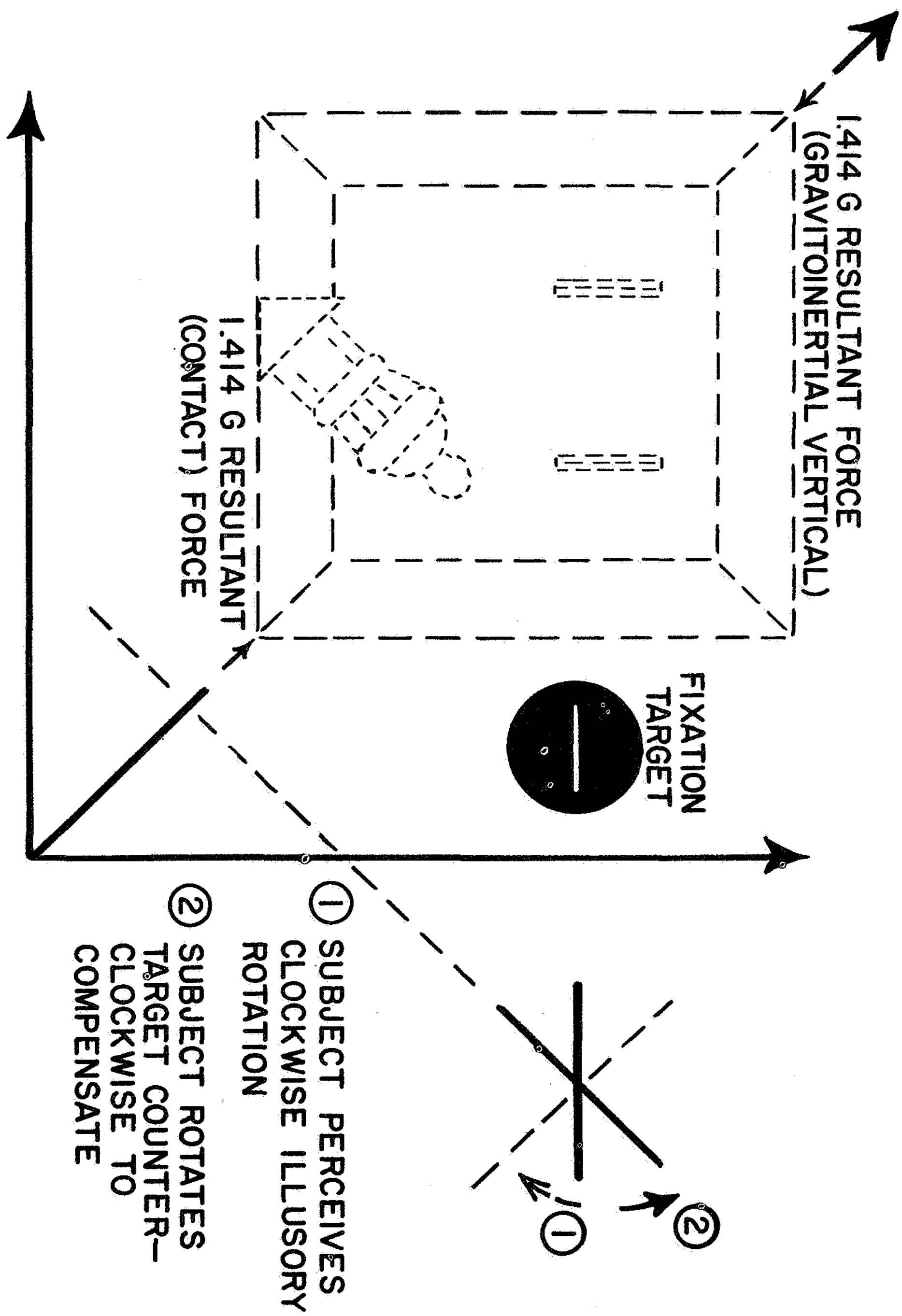
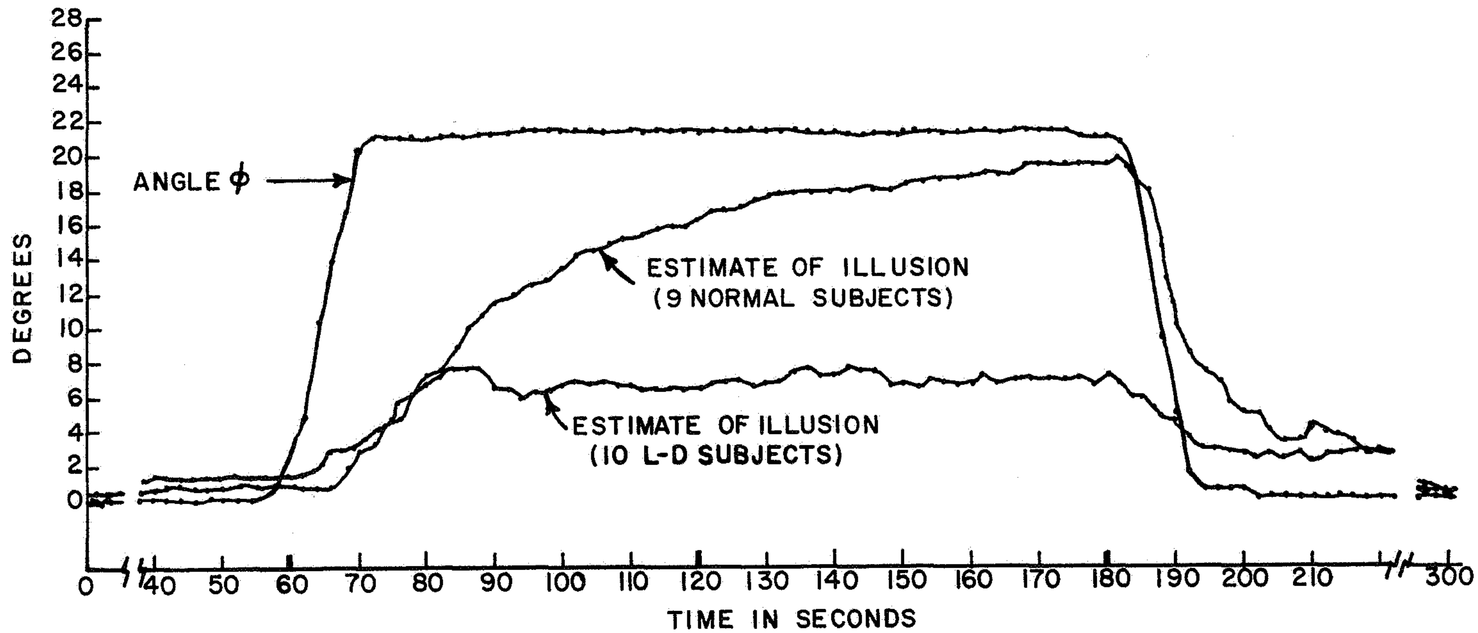

1.414 G RESULTANT FORCE
1.0 G GRAVITATIONAL FORCE
GRAVITOINERTIAL VERTICAL
1.0 G CENTRIPETAL (CONTACT) FORCE
1.414 G RESULTANT (CONTACT) FORCE
1.0 G GRAVITATIONAL (CONTACT) FORCE
1.0 G CENTRIFUGAL FORCE

Fig. 4



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

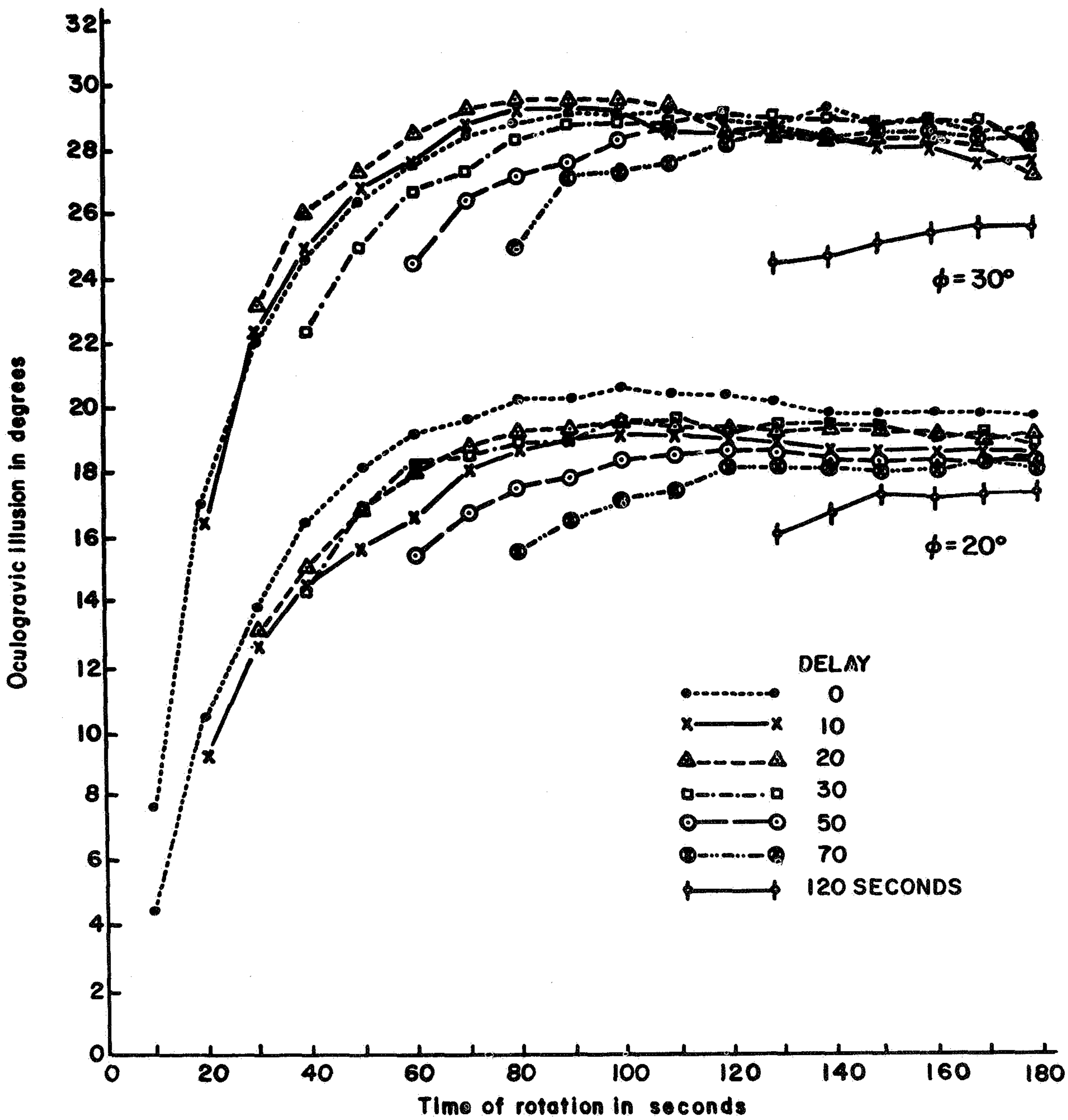
Fig. 5



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

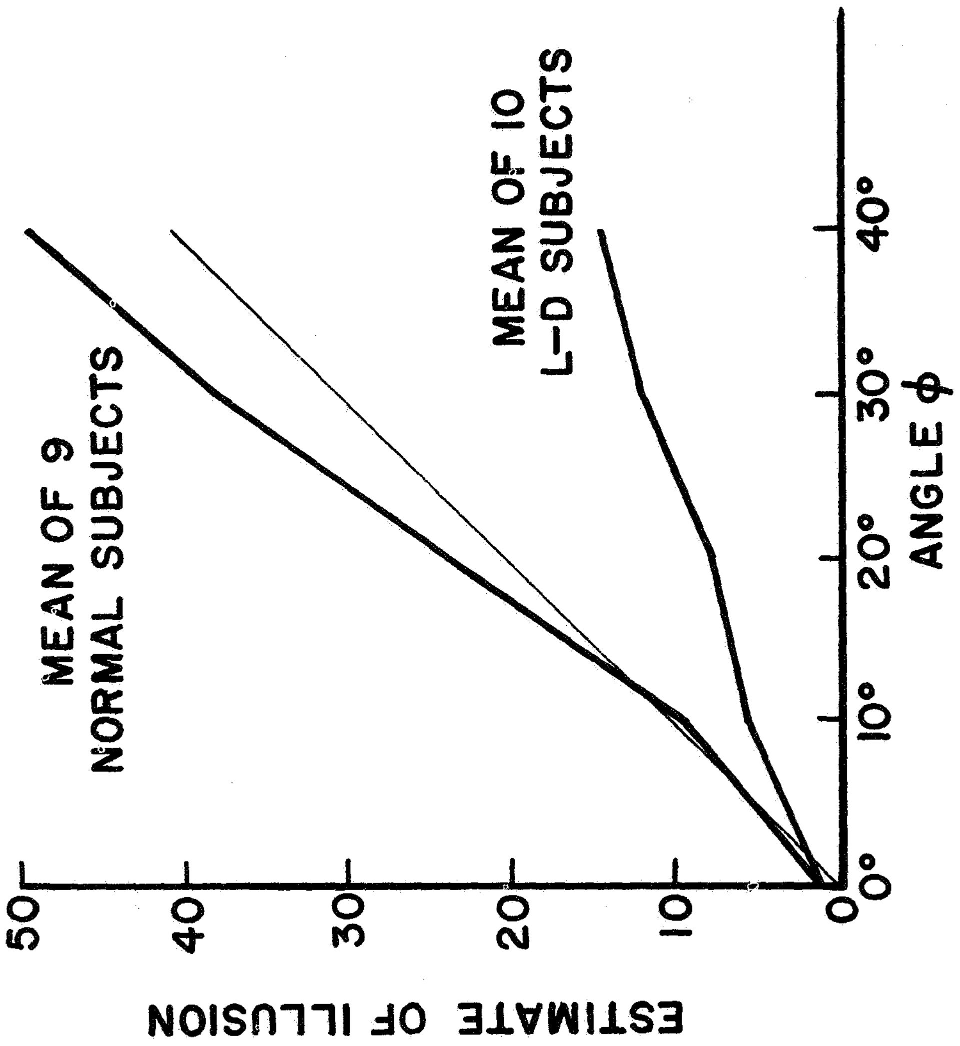
Fig. 6

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



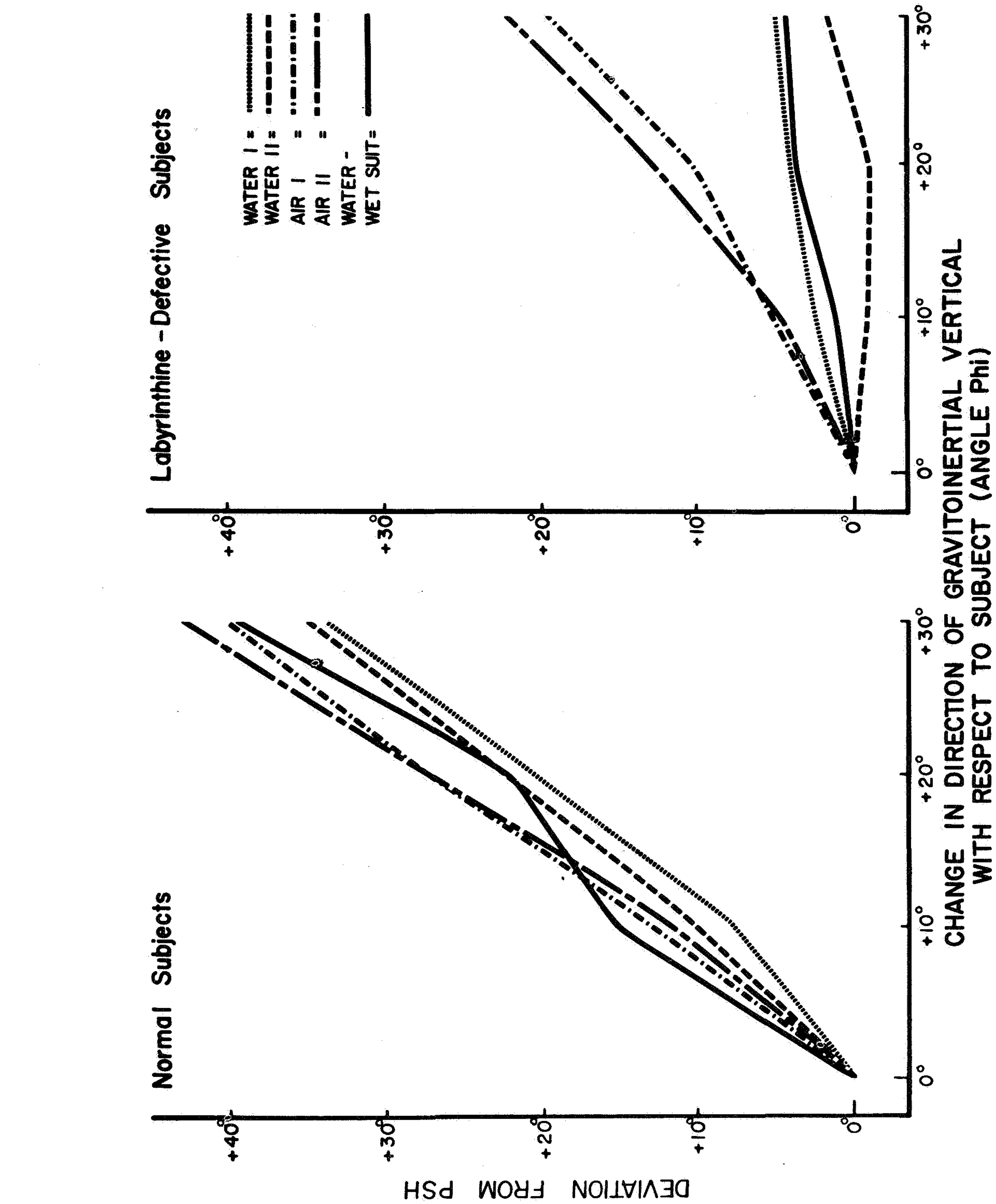
CONTINUOUS SETTINGS, NORMAL SUBJECTS

Fig. 7



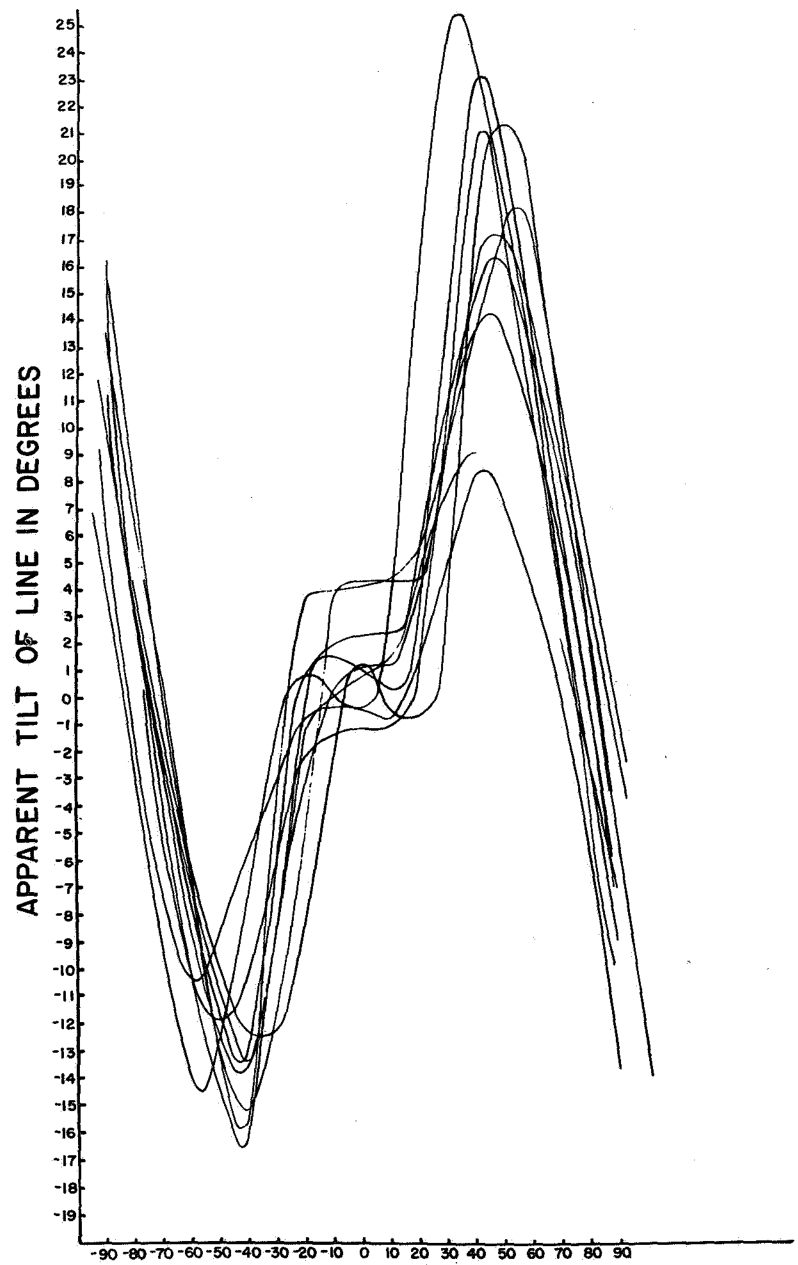
ESTIMATES OF THE OCULOGRAVIC ILLUSION BY NORMAL AND L-D SUBJECTS. SINGLE SETTINGS OF STAR.

Fig. 8



Normal Subjects
Labyrinthine -Defective Subjects
WATER I =
WATER II =
AIR I =
AIR II =
WATER - WET SUIT =
DEVIATION FROM PSH
+40°
+30°
+20°
+10°
0°
CHANGE IN DIRECTION OF GRAVITOINERTIAL VERTICAL
WITH RESPECT TO SUBJECT (ANGLE Phi)

Fig. 9



MEAN CURVES REPRESENT E & A PHENOMENA OF INDIVIDUAL TEST SESSIONS OF ONE SUBJECT

Fig. 10

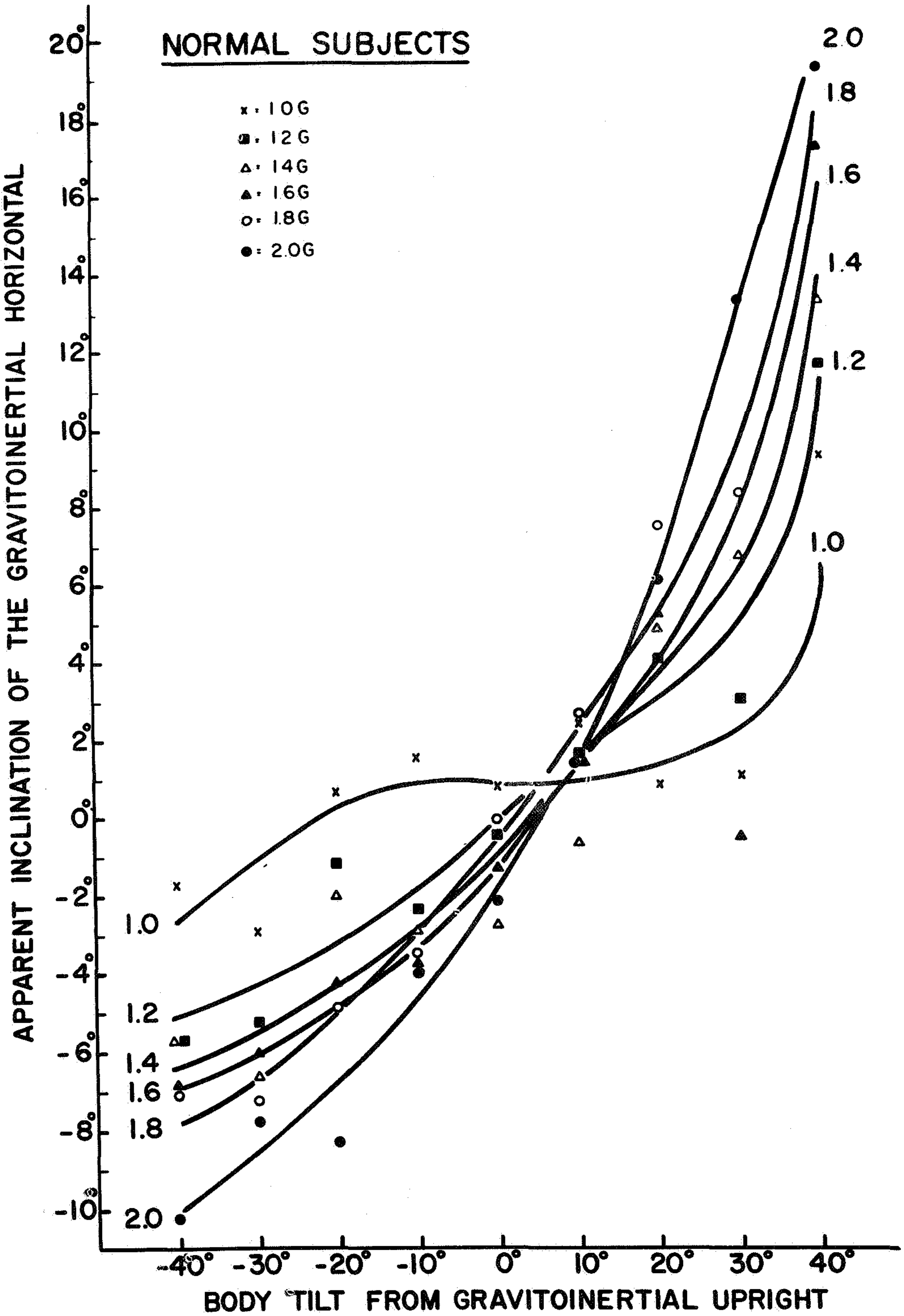
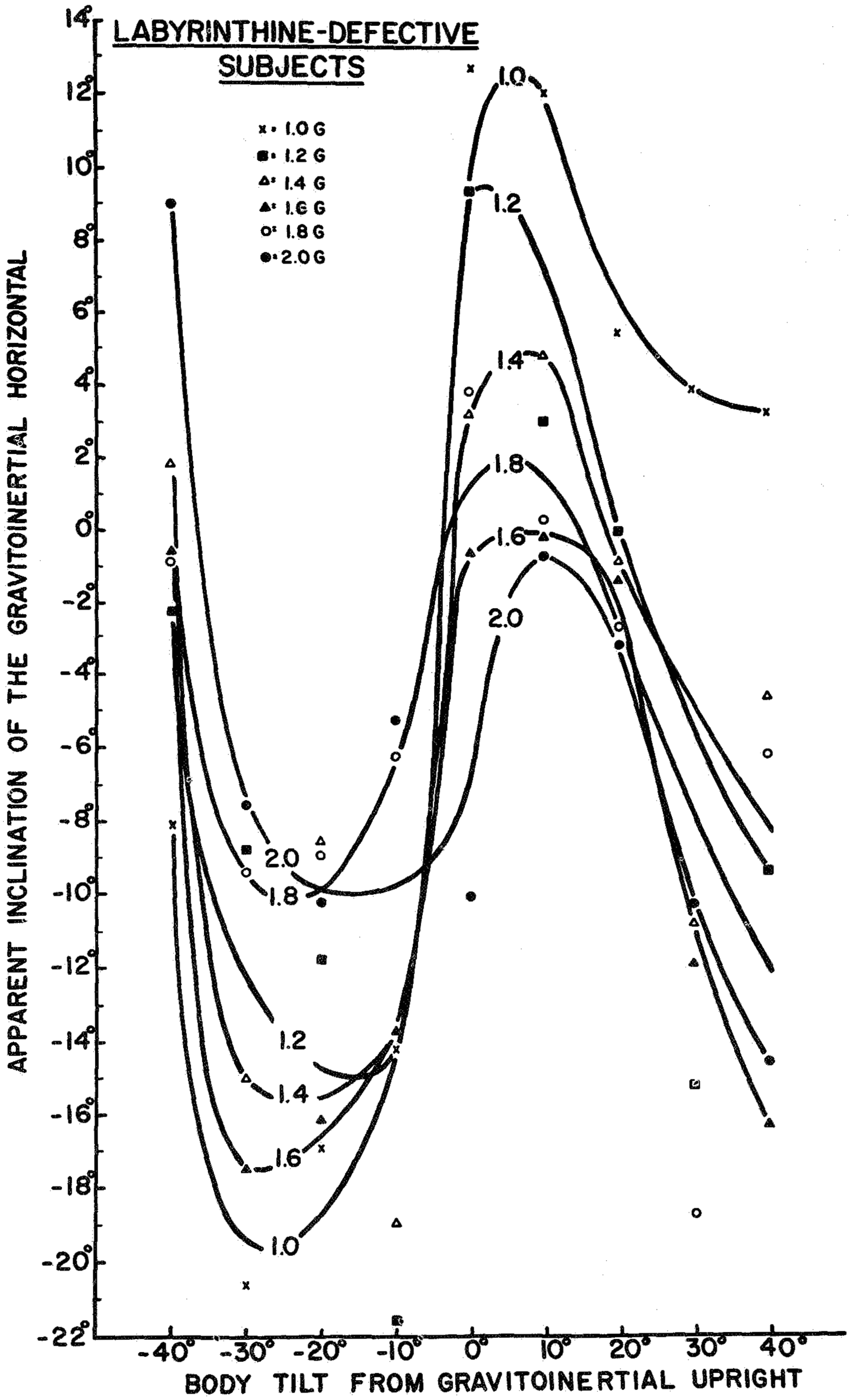

NORMAL SUBJECTS
x = 1.0G
■ = 1.2G
△ = 1.4G
▲ = 1.6G
○ = 1.8G
● = 2.0G
APPARENT INCLINATION OF THE GRAVITOINERTIAL HORIZONTAL
BODY TILT FROM GRAVITOINERTIAL UPRIGHT
20° 18° 16° 14° 12° 10° 8° 6° 4° 2° 0° -2° -4° -6° -8° -10°
-40° -30° -20° -10° 0° 10° 20° 30° 40°
2.0
1.8
1.6
1.4
1.2
1.0

Fig. 11



LABYRINTHINE-DEFECTIVE SUBJECTS
x = 1.0 G
■ = 1.2 G
△ = 1.4 G
▲ = 1.6 G
○ = 1.8 G
● = 2.0 G
APPARENT INCLINATION OF THE GRAVITOINERTIAL HORIZONTAL
BODY TILT FROM GRAVITOINERTIAL UPRIGHT
14°
12°
10°
8°
6°
4°
2°
0°
-2°
-4°
-6°
-8°
-10°
-12°
-14°
-16°
-18°
-20°
-22°
-40°
-30°
-20°
-10°
0°
10°
20°
30°
40°
1.0
1.2
1.4
1.6
1.8
2.0

Fig. 12

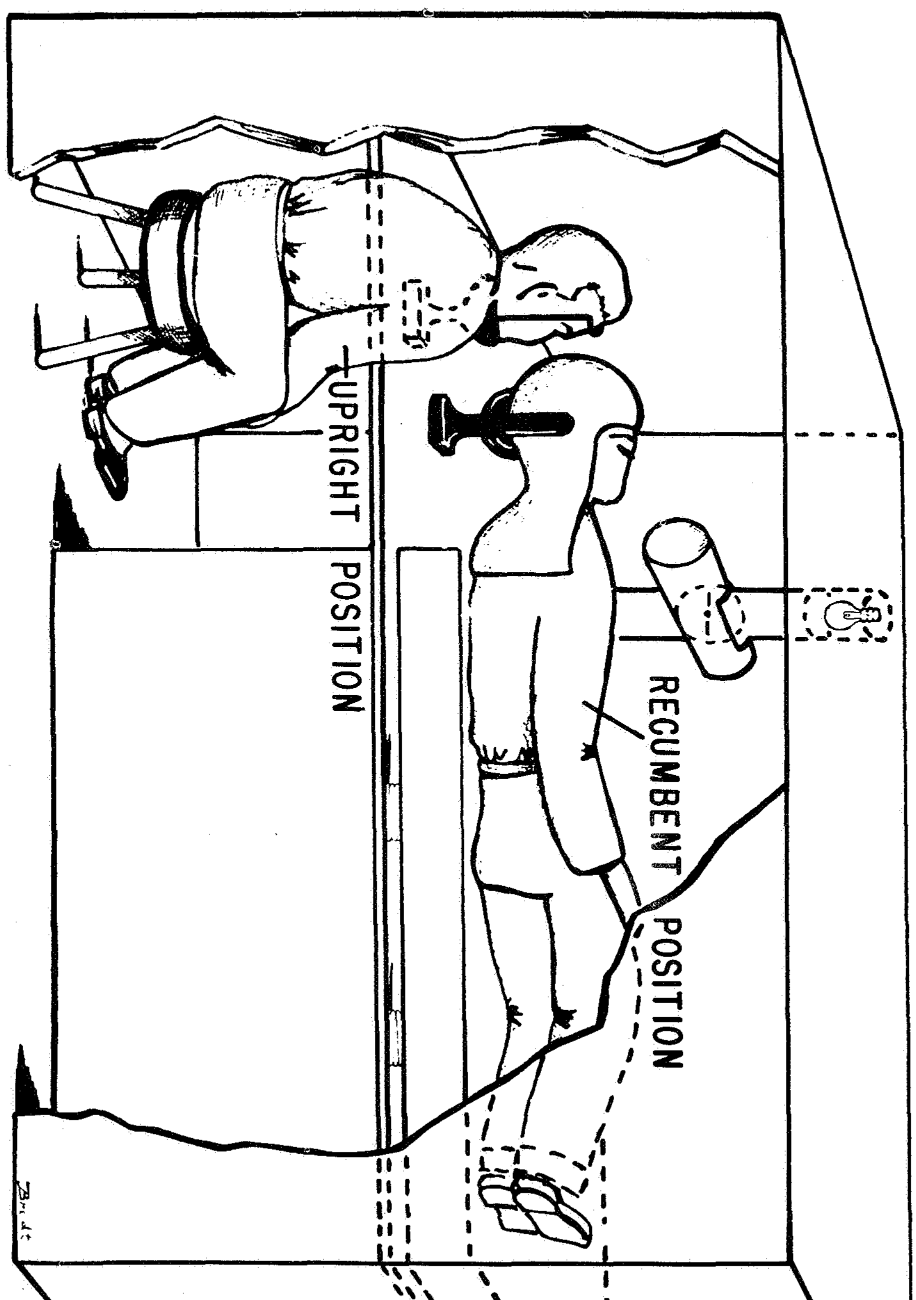


Fig. 13

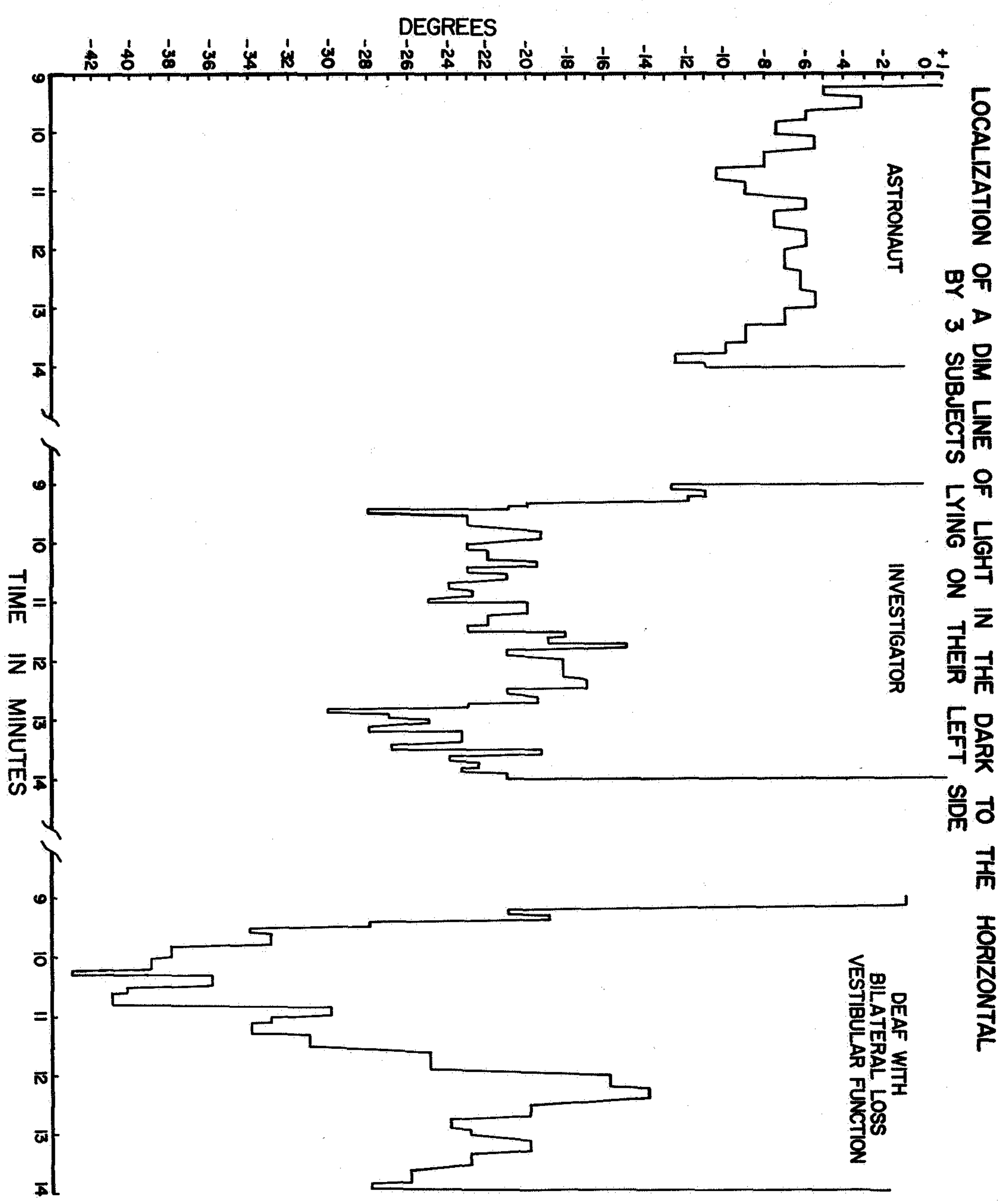
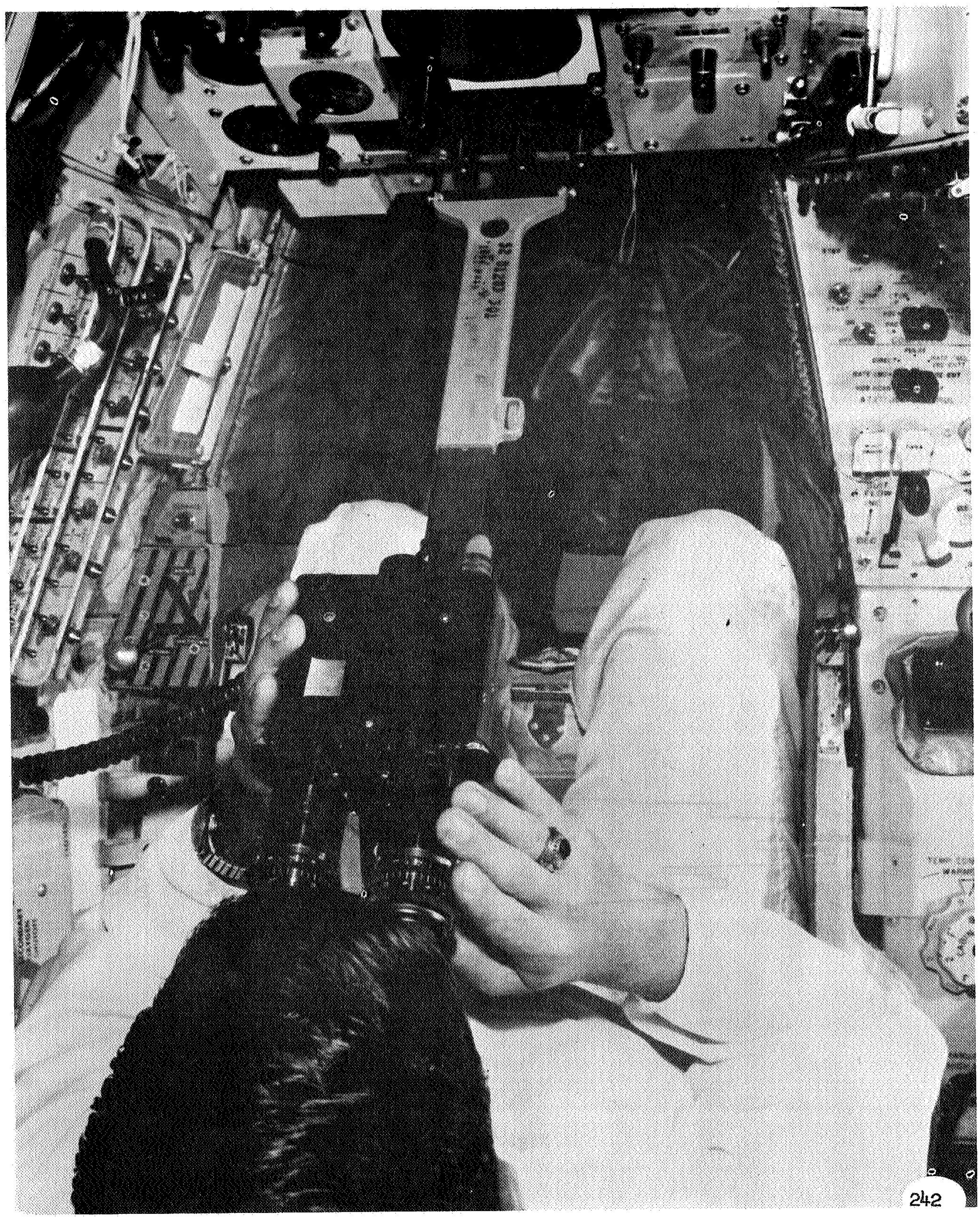

LOCALIZATION OF A DIM LINE OF LIGHT IN THE DARK TO THE HORIZONTAL
BY 3 SUBJECTS LYING ON THEIR LEFT SIDE
DEGREES
+1
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
-30
-32
-34
-36
-38
-40
-42
ASTRONAUT
INVESTIGATOR
DEAF WITH
BILATERAL LOSS
VESTIBULAR FUNCTION
9
10
11
12
13
14
TIME IN MINUTES

Fig. 14



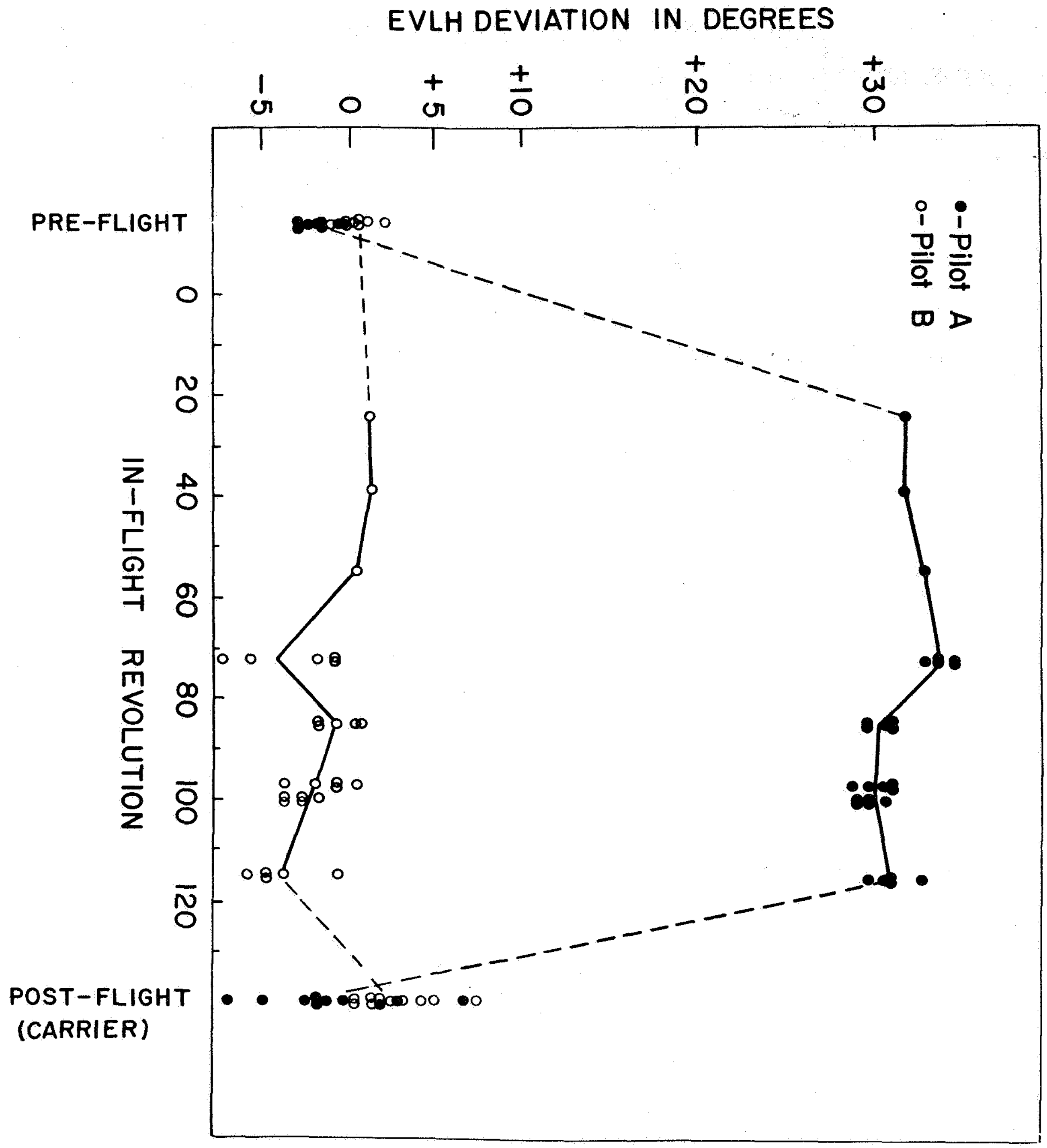

EVLH DEVIATION IN DEGREES
+30
+20
+10
+5
0
-5
•-Pilot A
o-Pilot B
PRE-FLIGHT
0
20
40
60
80
100
120
IN-FLIGHT REVOLUTION
POST-FLIGHT
(CARRIER)

Fig. 16

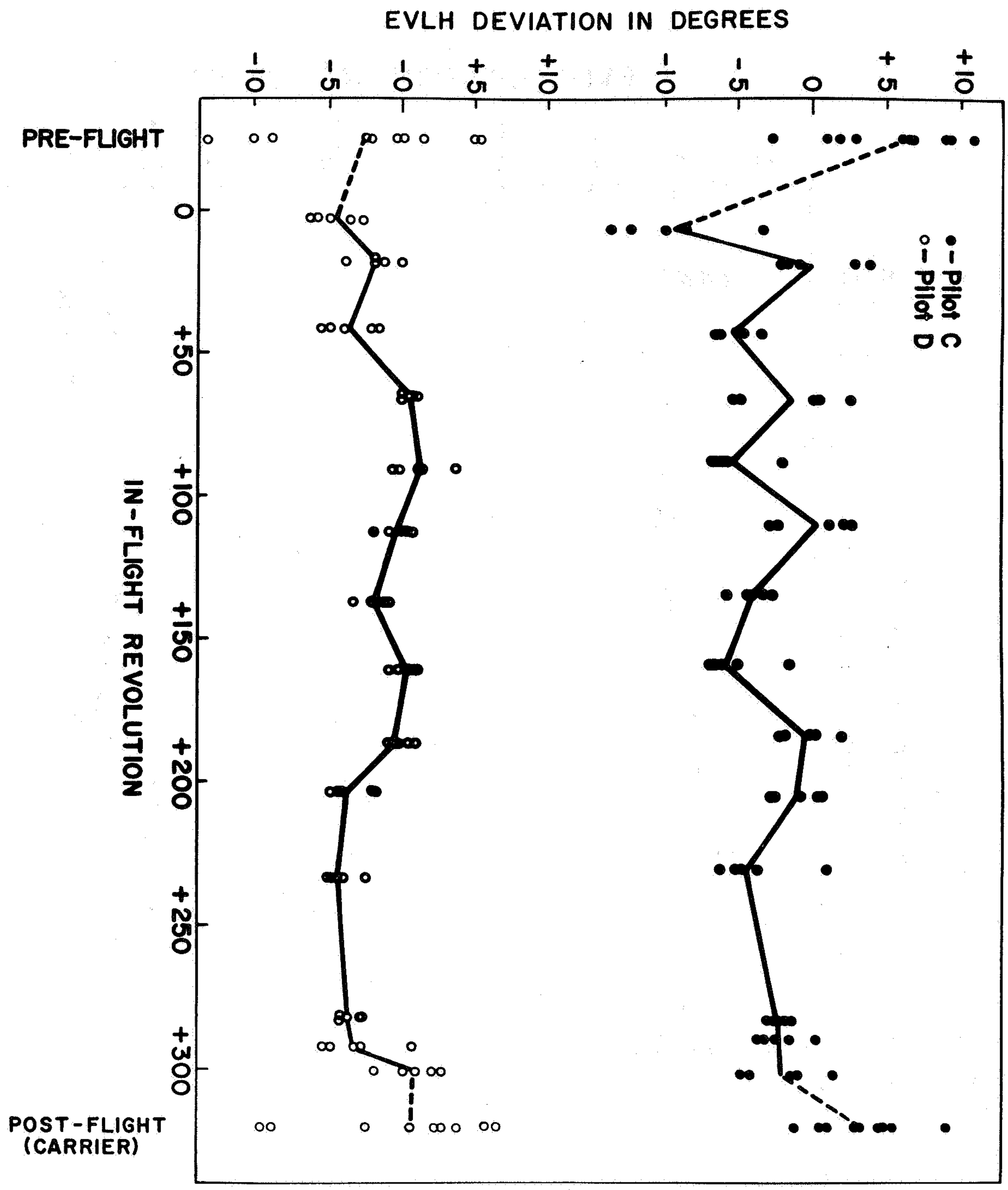

EVLH DEVIATION IN DEGREES
● – Pilot C
○ – Pilot D
PRE-FLIGHT
IN-FLIGHT REVOLUTION
POST-FLIGHT
(CARRIER)

Fig. 17

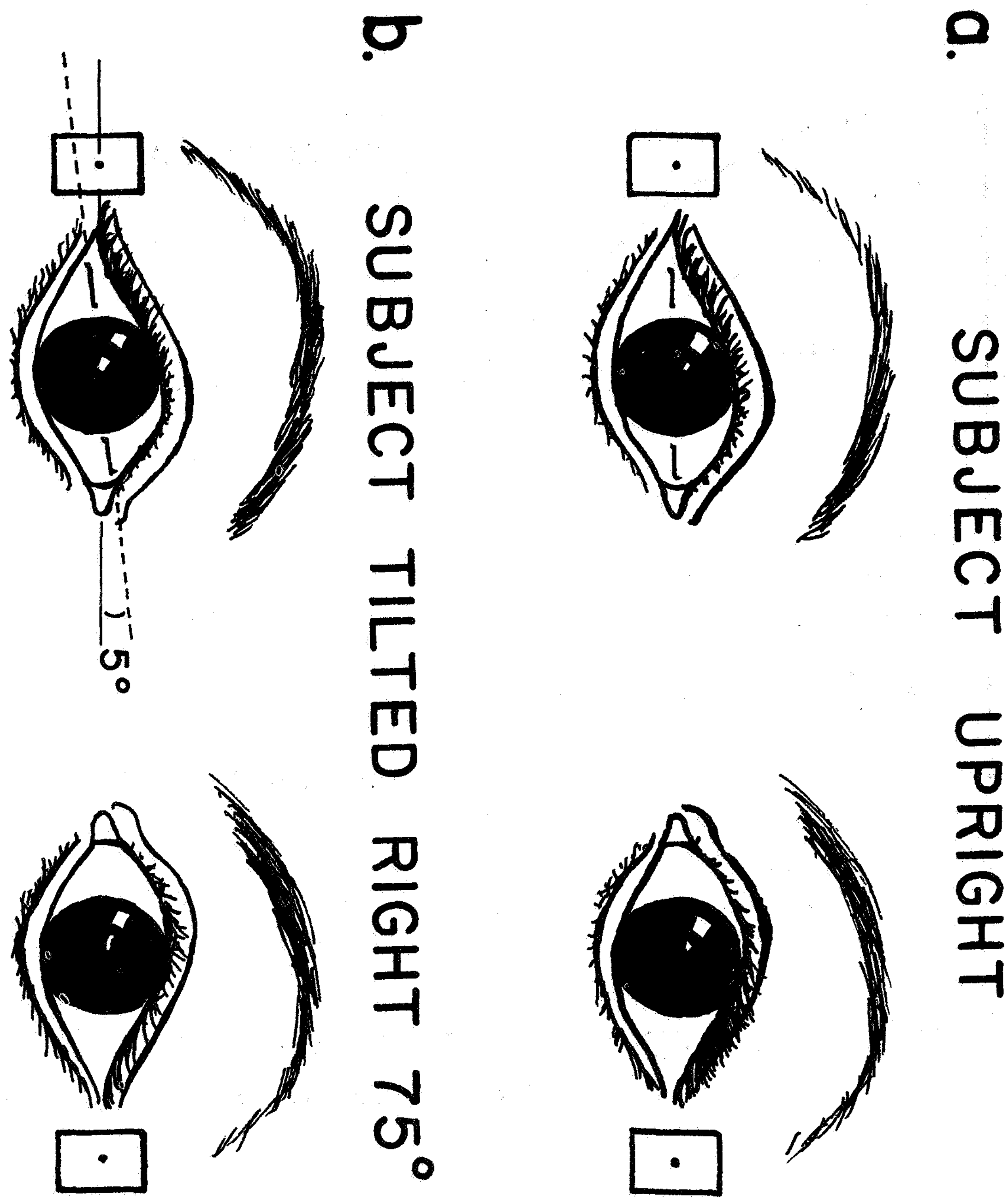


Fig. 18

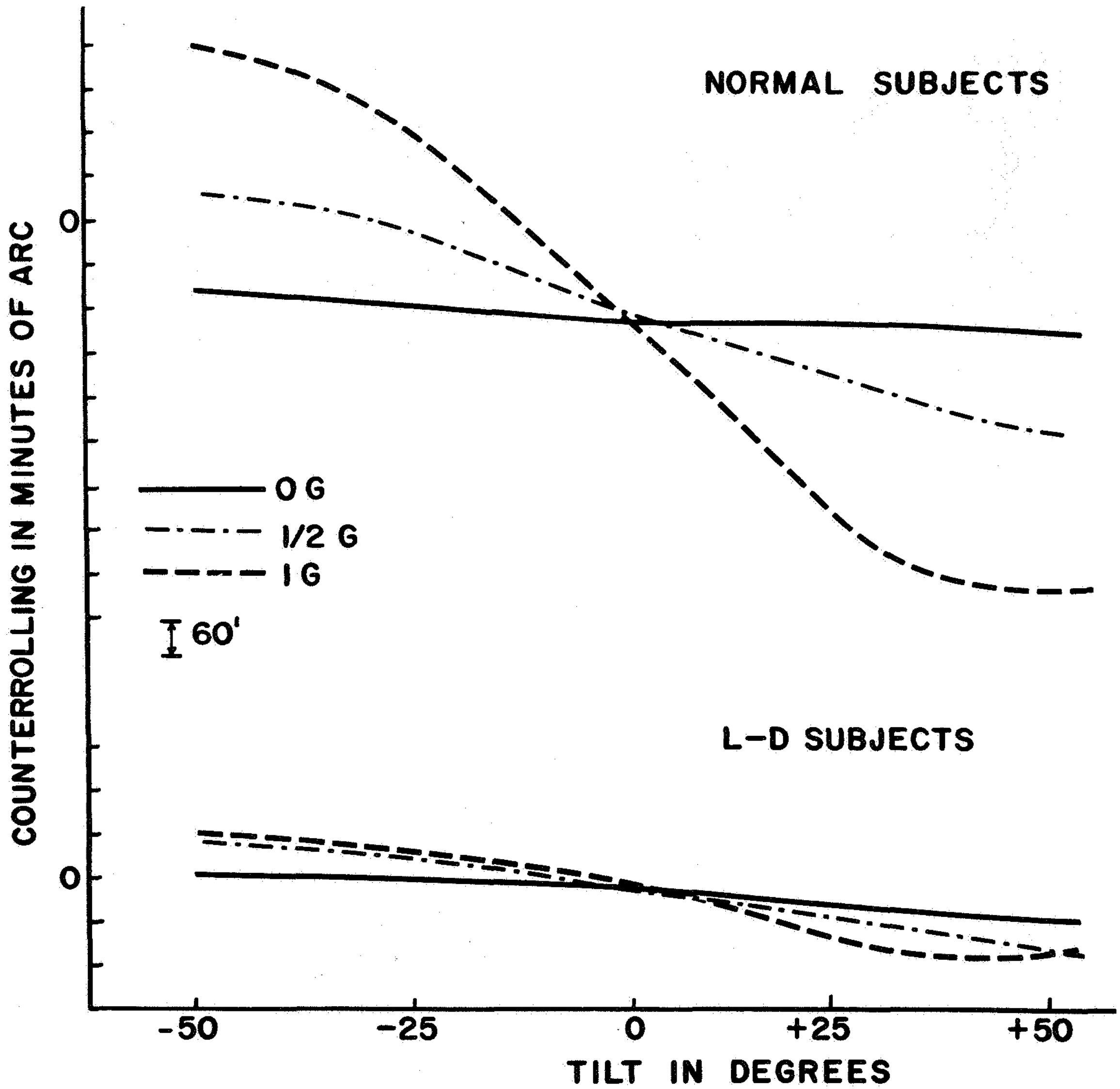

NORMAL SUBJECTS
L-D SUBJECTS
COUNTERROLLING IN MINUTES OF ARC
0
0
0 G
1/2 G
1 G
60'
-50
-25
0
+25
+50
TILT IN DEGREES

Fig. 19

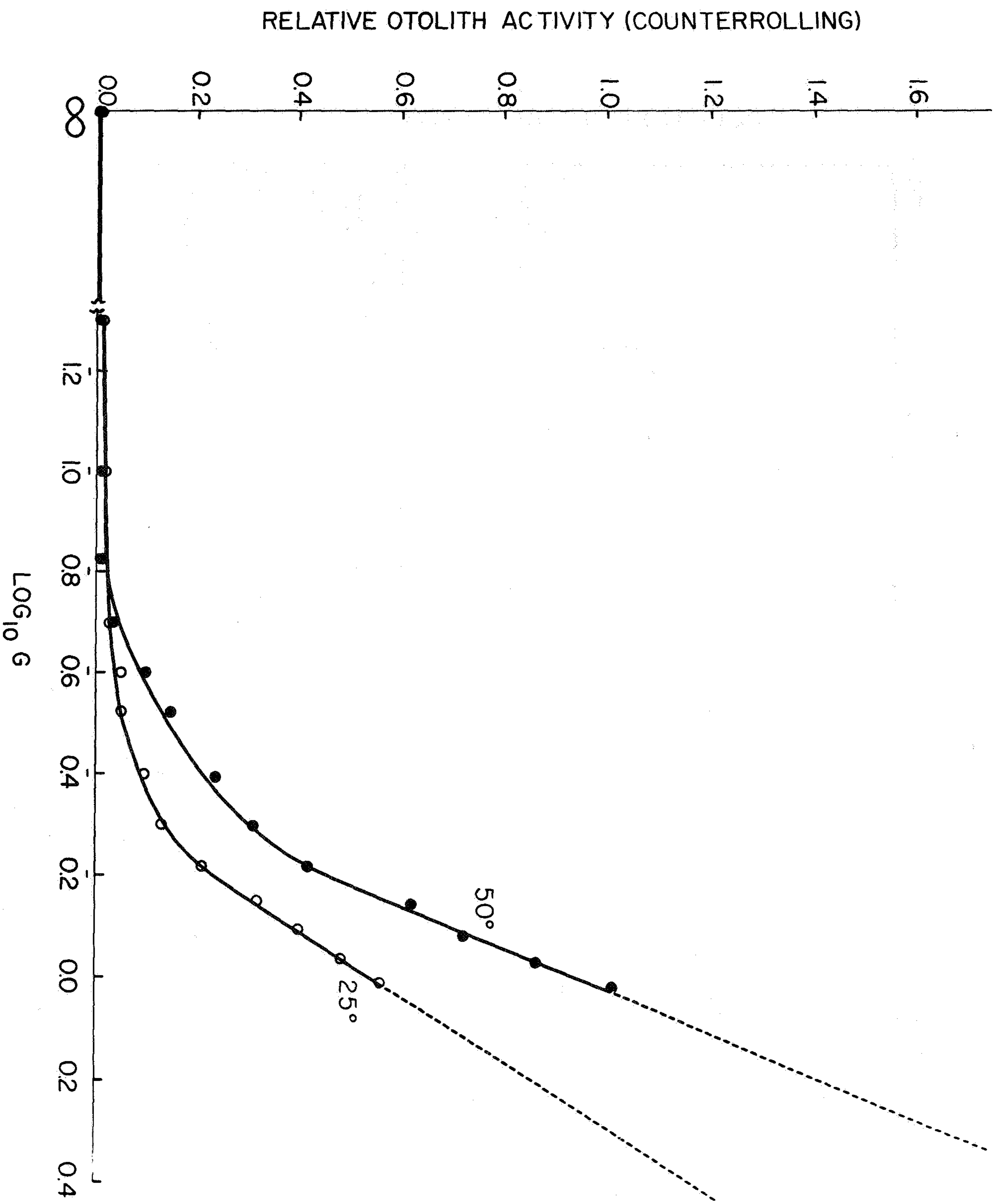
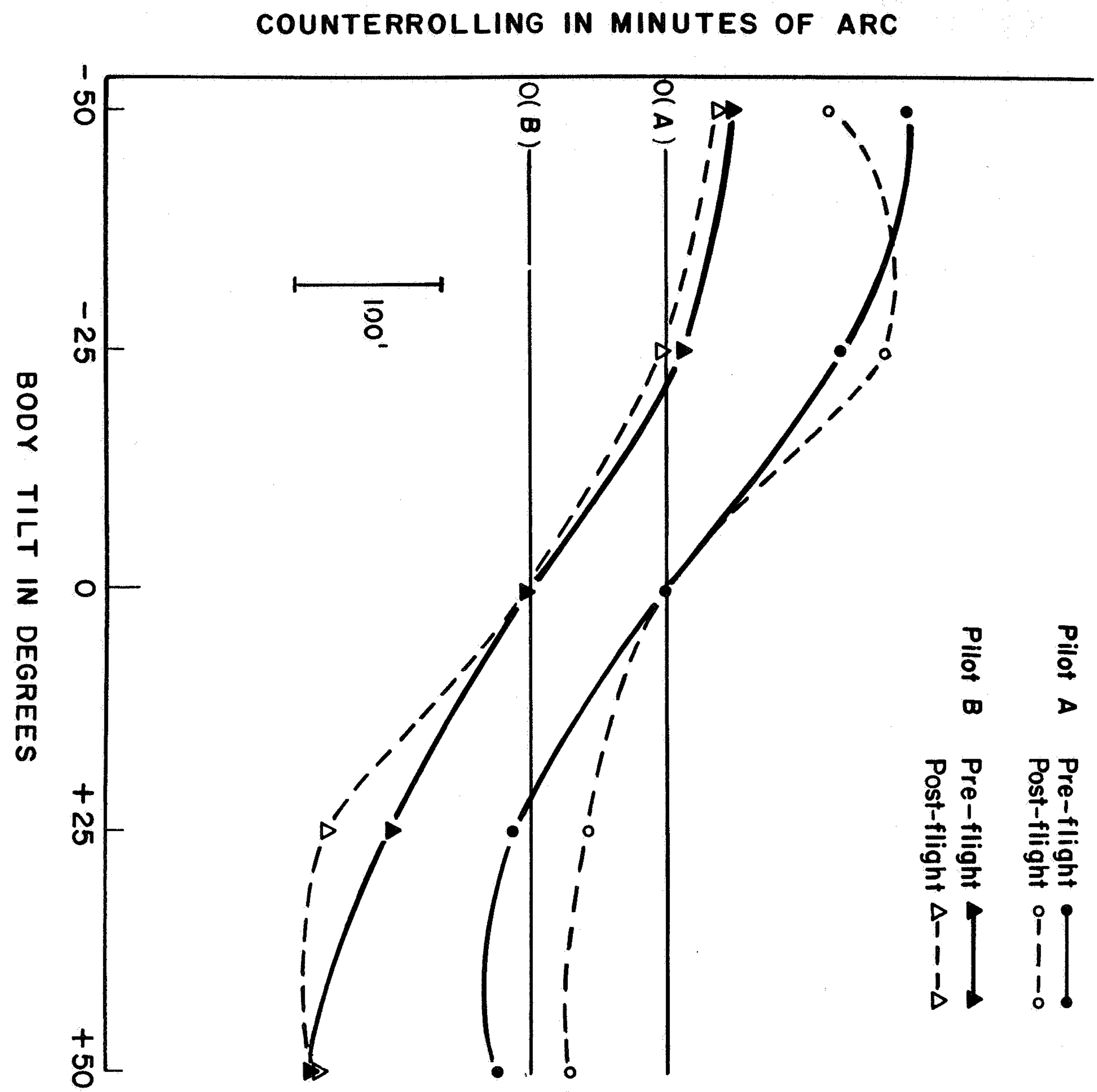
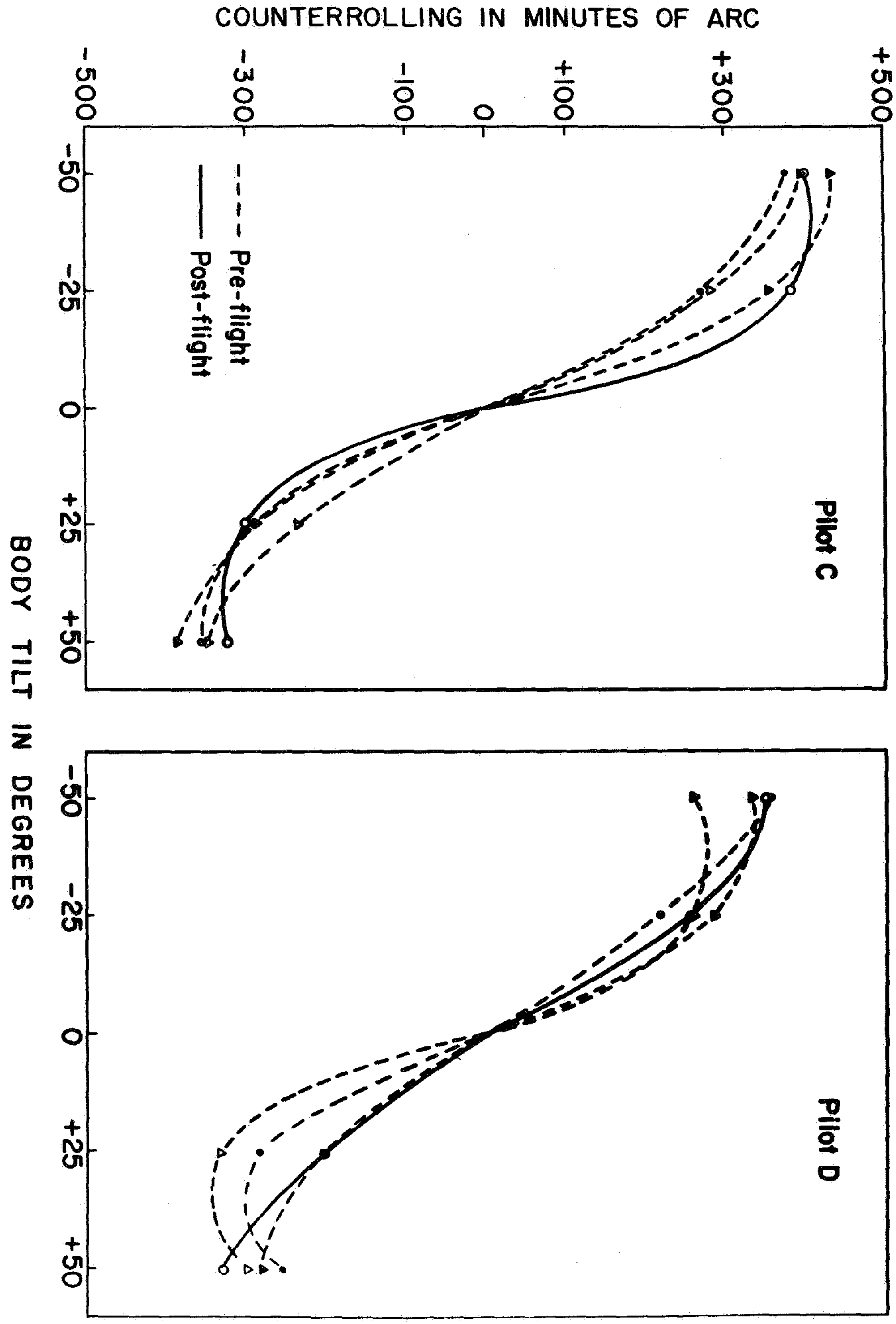

RELATIVE OTOLITH ACTIVITY (COUNTERROLLING)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
∞
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0.2
0.4
LOG_{10} G
50°
25°

Fig. 20



COUNTERROLLING IN MINUTES OF ARC
BODY TILT IN DEGREES
-50
-25
0
+25
+50
0(A)
0(B)
100'
Pilot A
Pre-flight
Post-flight
Pilot B
Pre-flight
Post-flight

Fig. 21



COUNTERROLLING IN MINUTES OF ARC
+500
+300
+100
0
-100
-300
-500
Pilot C
Pilot D
Pre-flight
Post-flight
-50
-25
0
+25
+50
BODY TILT IN DEGREES

Fig. 22

10190

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

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

I think you are all well aware of our medical position prior to Gemini. There were many predictions about what man could and could not do and indeed many people felt that man was the limiting factor as far as our space activities were concerned. Our primary job then became one of obtaining information enabling us to commit man to longer periods of time in the space environment. Our immediate goal was to qualify him if possible for the lunar mission.

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

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

The next major group of observations conducted as operational procedures involved the blood studies. In addition to the normal routine of blood counts pre- and postflight, blood volume studies were conducted on the four- eight- and 14-day flights. Figure 2 graphically represents the absolute neutrophilia observed. It has returned to normal in 24 hours. Figure 3 summarizes the blood volume results obtained, the most noteworthy being a decrease in red blood cell mass which like the tilt data appeared to be increasing through the eight-day flight. We had expected to see most of the change in plasma volume studied by the RISA technique. The data reveal a normal vascular or blood volume maintained by an increase in plasma volume of the 14-day flight. A decrease in red cell mass is still noted, but it does not appear to increase with increasing duration of flight. The RISA and chromium-51 studies have not been done since the 14-day flight and we look to the Apollo flights to provide additional data in this area. An example of the Cr-51 data is seen in Figure 4. Continued study of the red cells has shown that there is an increased hemolysis noted postflight. This may be seen graphically in the case of the command pilot on the 14-day flight in Figure 5. This increased tendency to hemolysis had disappeared by 48 hours postflight. The increased hemolysis has also been demonstrated on flights as short as the one day Gemini VI mission. It appears that we have cells that are increased in size, more fragile and thus easily destroyed by some mechanism requiring further investigation. The routine count and fragility determinations can be made on every mission.

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

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

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

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

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

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

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

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

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

SKIN

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

THE CENTRAL NERVOUS SYSTEM

With the exception of the EEG used in only one instance to evaluate the depth of sleep, our best assessment of central nervous system function comes from the overall crew response during these missions. As we relate the ability of the crew to to respond to the demands placed upon them, it is obvious that the central nervous system must have functioned in a very normal manner. They have responded to many normal and emergency demands through the various flight phases some of which are summarized in Figure 12.

THE SPECIAL SENSES

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

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

EAR NOSE AND THROAT

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

THE CARDIOVASCULAR SYSTEM

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

THE RESPIRATORY SYSTEM

We have seen no respiratory problems to date.

THE GASTROINTESTINAL SYSTEM

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

THE GENITO-URINARY SYSTEM

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

THE MUSCULOSKELETAL SYSTEM

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

In evaluating the response of man as a system thus far, it would appear that he has functioned in a very acceptable manner and has shown himself to be capable of conducting prolonged missions in space. We certainly expect to see some physiologic change but expect that the changes noted will be within the ranges which we have seen to date. In retrospect, our doubling of man's exposure has been demonstrated to be an acceptable approach in obtaining data allowing us to commit man for longer duration flight. Therefore, I feel that we may confidently commit man to a 30-day flight if he is given the proper environmental support.

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

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

The second point relates to the need to have some operational flexibility in conducting an assessment of man's responses through operational measures rather than necessarily by the laborious experiment route. Many of the things that have been called medical experiments are not experiments at all; but are merely measures of a particular function of a body system. You could put a number of these together and say that you have one large experiment. For instance, the large number of studies which have been conducted on the cardiovascular system are indeed a series of measures which, when put together, could be called an experiment or at least an evaluation of the cardiovascular system.

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

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

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

NASA-S-66-11665 DEC 20

HEART RATE TILT RESPONSE COMPARED WITH MISSION DURATION

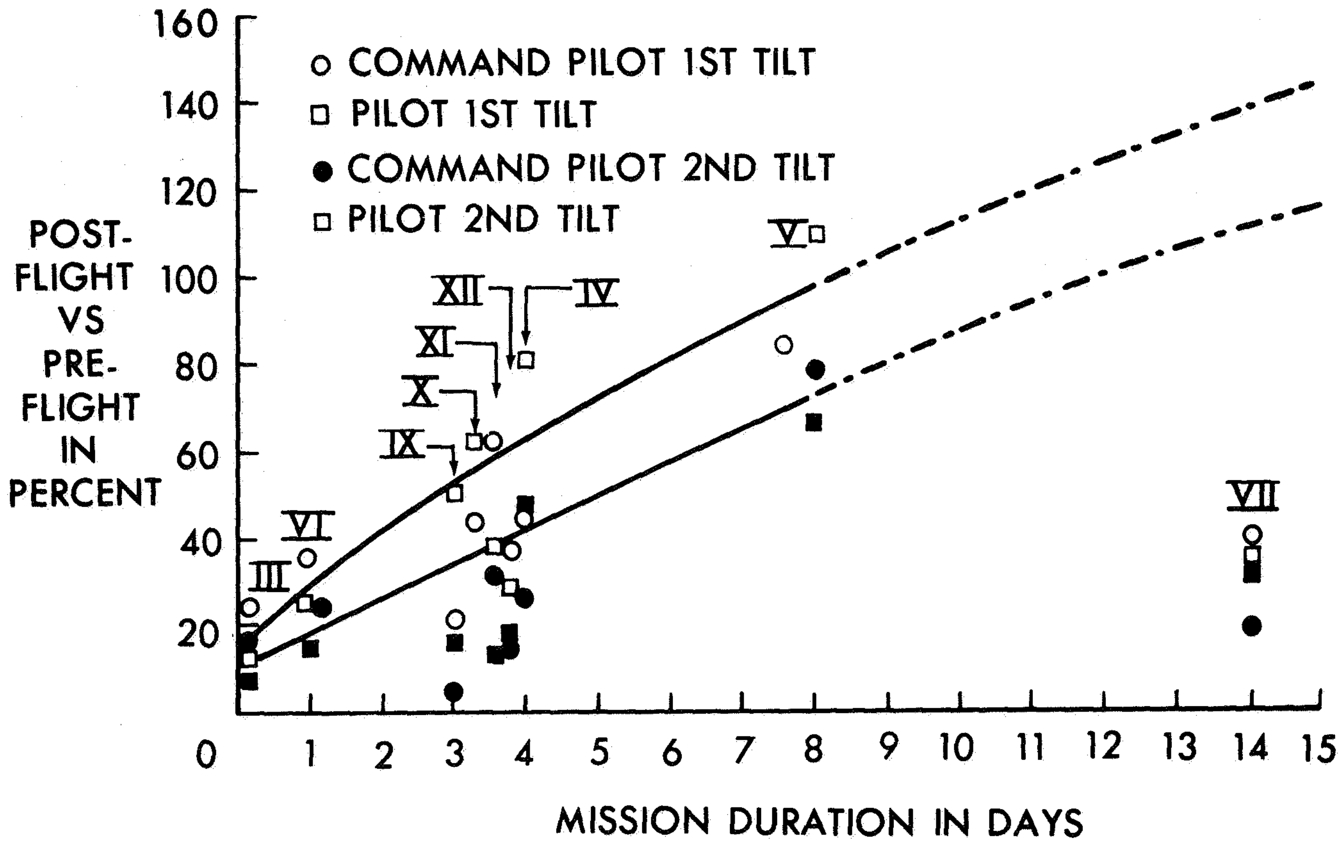


Fig 1

NASA S 66 11534 NOV 26

GEMINI PILOTS' WHITE BLOOD CELL RESPONSE

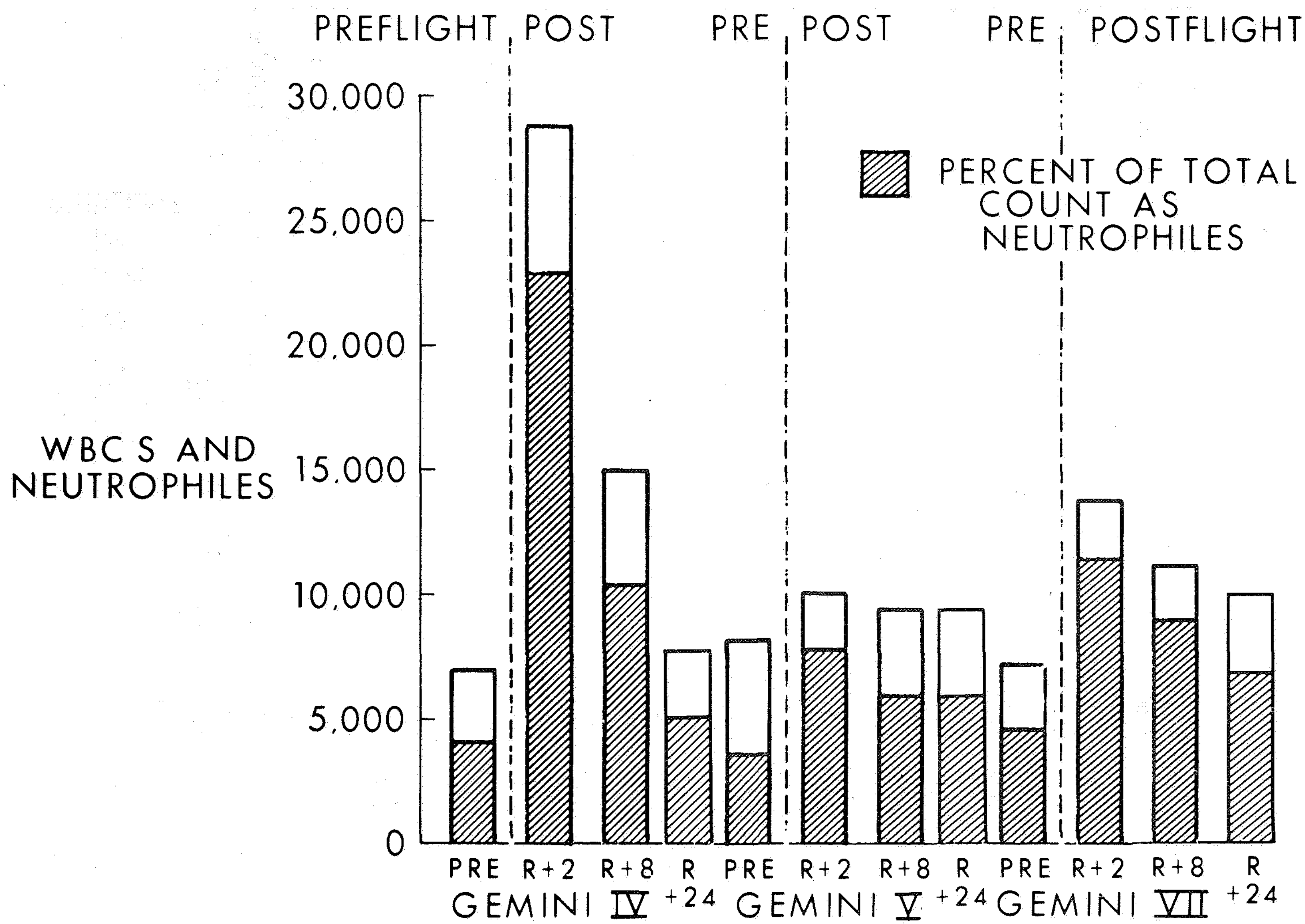


Fig 2

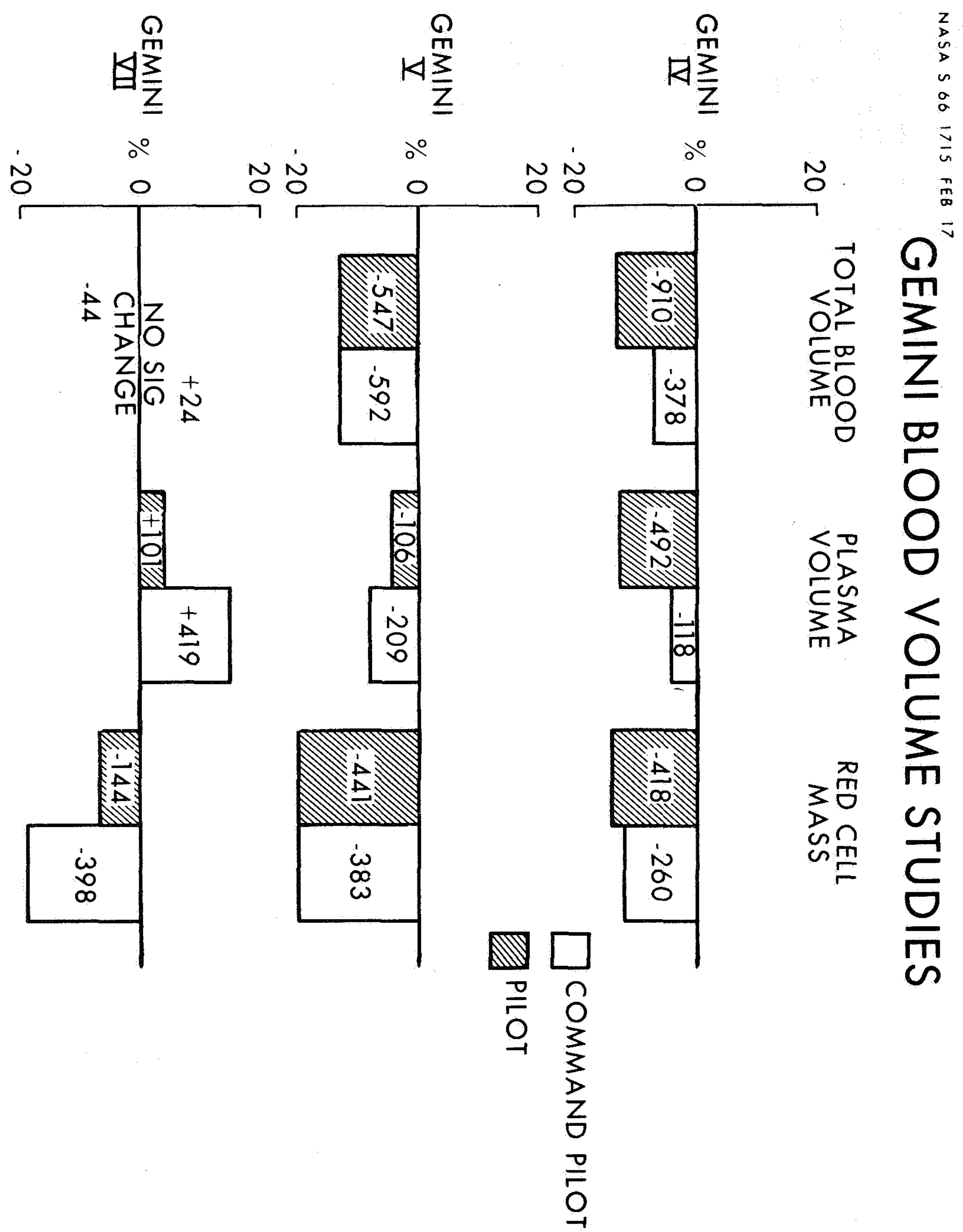

NASA S 66 1715 FEB 17
GEMINI BLOOD VOLUME STUDIES
TOTAL BLOOD VOLUME
PLASMA VOLUME
RED CELL MASS
COMMAND PILOT
PILOT
GEMINI IV
GEMINI V
GEMINI VII
% 0
20
-20
-910
-378
-492
-118
-418
-260
-547
-592
-106
-209
-441
-383
-44
NO SIG CHANGE
+24
+101
+419
-144
-398

Fig. 3

NASA-S-65-8969

GEMINI V

BLOOD VOLUME DETERMINATIONS (I^{125})

COMMAND PILOT

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

Cr-51 RED CELL SURVIVAL STUDY

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

Fig. 4

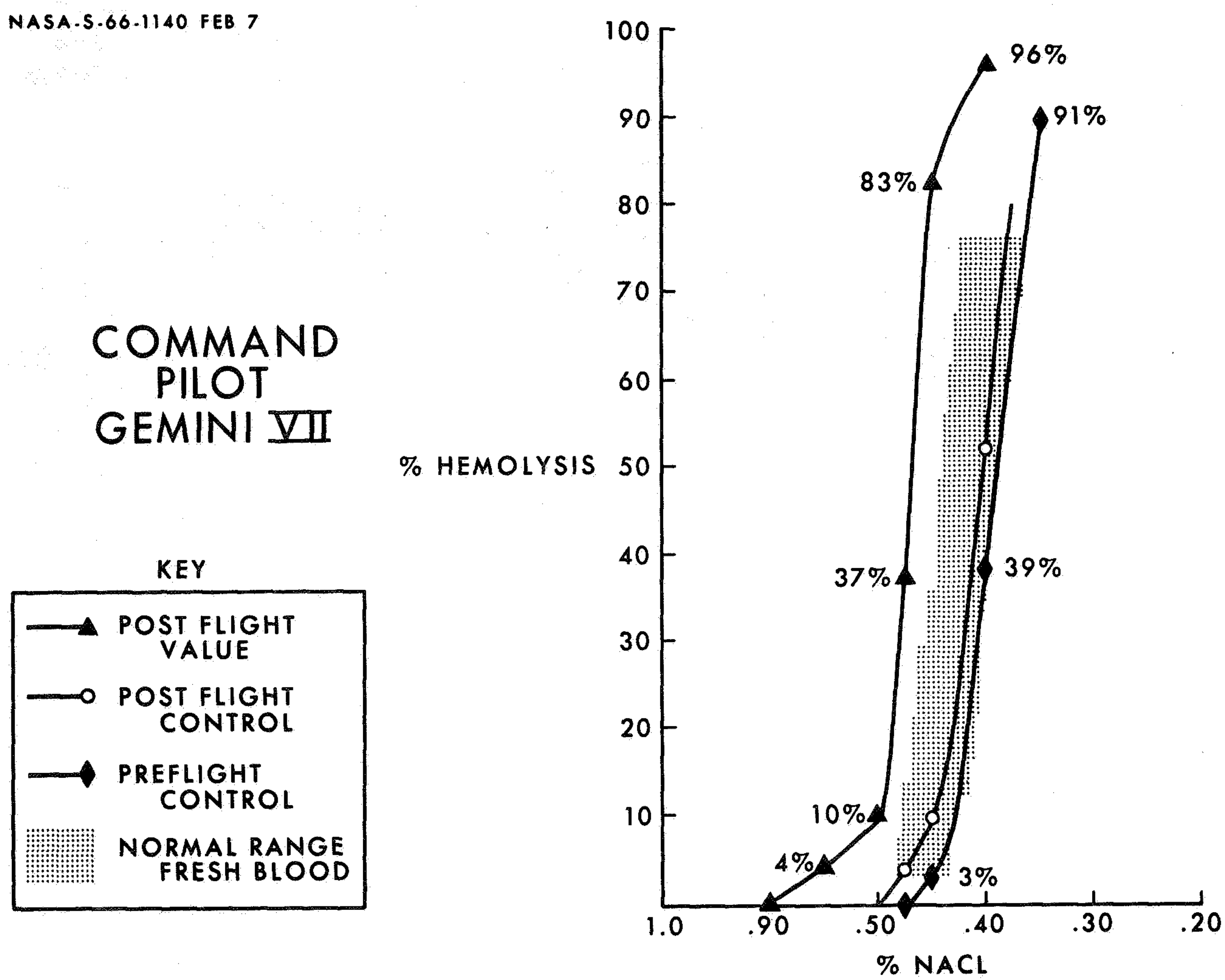
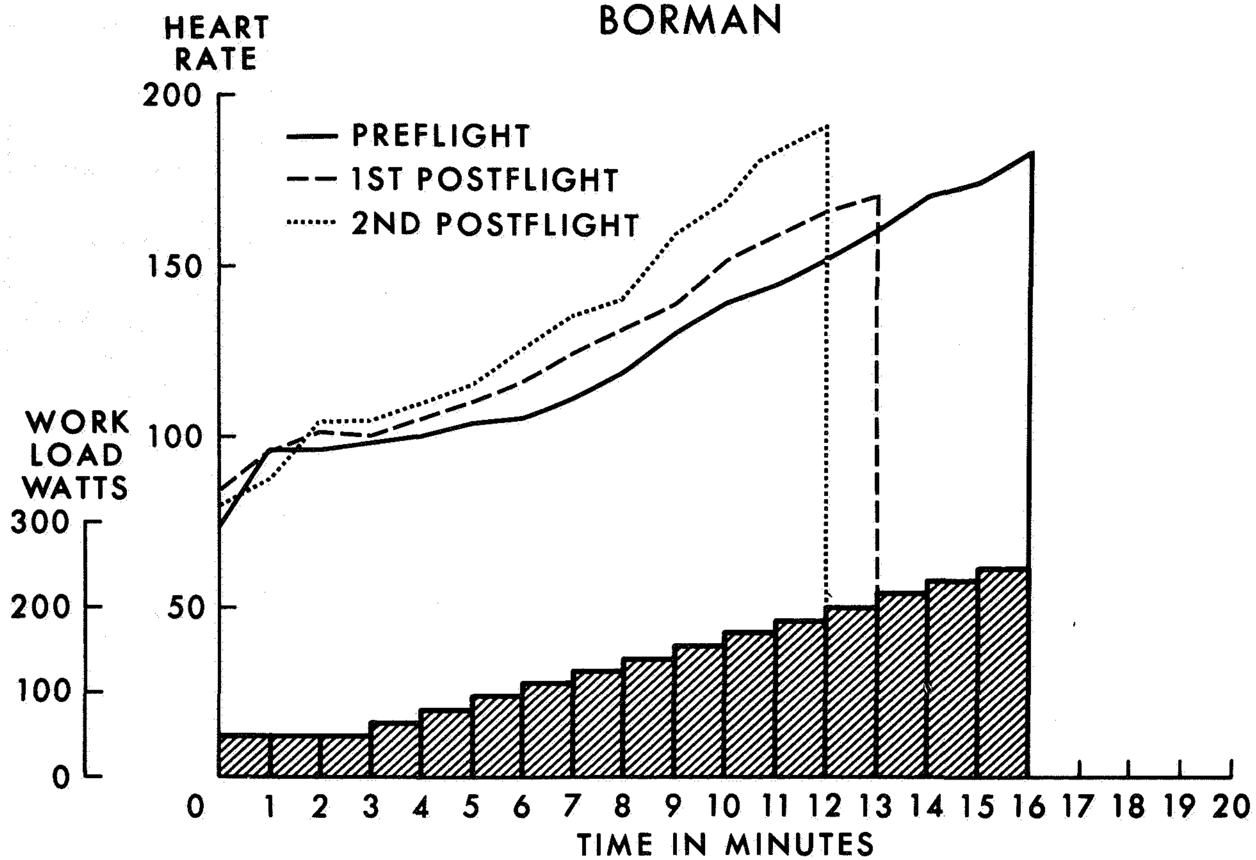

NASA-S-66-1140 FEB 7
COMMAND
PILOT
GEMINI VII
KEY
POST FLIGHT VALUE
POST FLIGHT CONTROL
PREFLIGHT CONTROL
NORMAL RANGE FRESH BLOOD
% HEMOLYSIS
100
90
80
70
60
50
40
30
20
10
1.0
.90
.50
.40
.30
.20
% NACL
96%
91%
83%
37%
39%
10%
4%
3%

Fig. 5

NASA-S-66-5463 JUN 1

GEMINI VII ERGOMETRY STUDIES

BORMAN



WEIGHT
PRE 73.7 kg
POST 71.2 kg
Δ2.5 kg

PERFORMANCE
PRE 245 WATT
POST I 200 WATT 18%
Δ45 WATT

PRE 245 WATT
POST II 185 WATT 24.5%
Δ60 WATT

Fig. 6

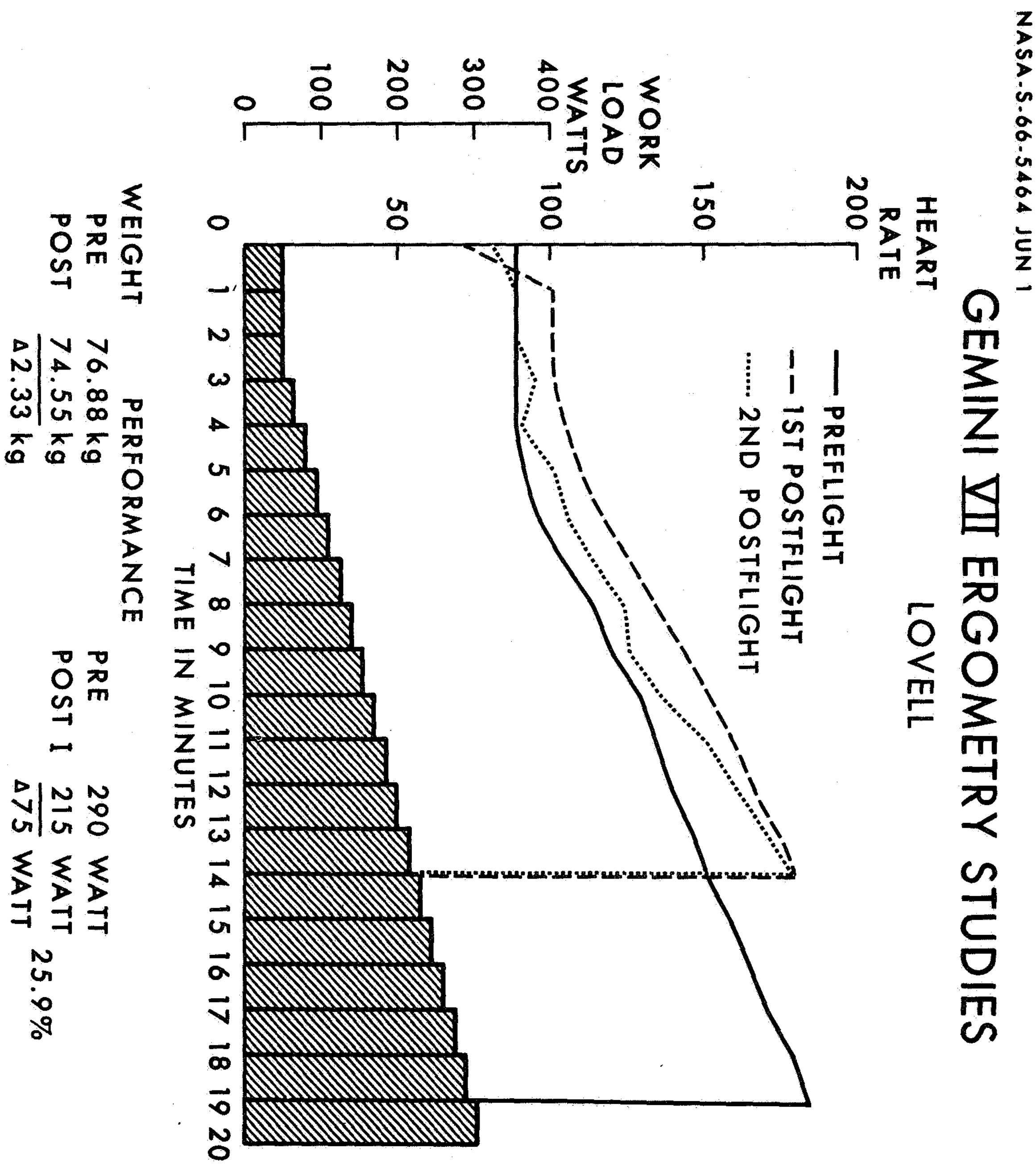

NASA-S-66-5464 JUN 1
GEMINI VII ERGOMETRY STUDIES
LOVELL
HEART RATE
200
150
100
50
0
WORK LOAD WATTS
400
300
200
100
0
— PREFLIGHT
— — 1ST POSTFLIGHT
...... 2ND POSTFLIGHT
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
TIME IN MINUTES
WEIGHT
PRE 76.88 kg
POST 74.55 kg
Δ2.33 kg
PERFORMANCE
PRE 290 WATT
POST I 215 WATT
Δ75 WATT 25.9%

Fig. 7

NASA-S-66-11663 DEC 20

GEMINI

PEAK HEART RATES, BEATS/MIN

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

Fig. 8

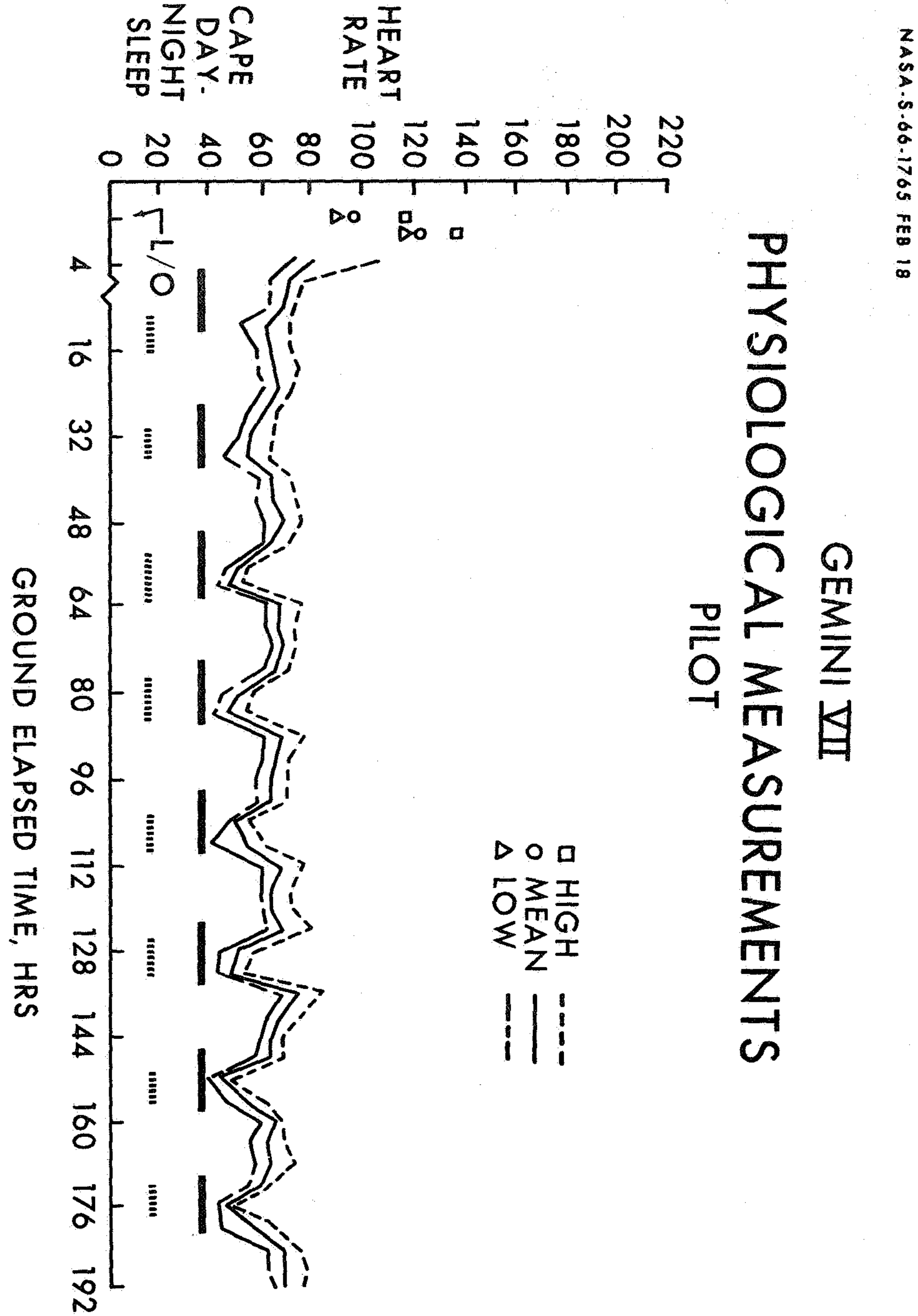

NASA-S-66-1765 FEB 18
GEMINI VII
PHYSIOLOGICAL MEASUREMENTS
PILOT
HIGH
MEAN
LOW
HEART RATE
220
200
180
160
140
120
100
80
60
40
20
0
CAPE DAY-NIGHT SLEEP
L/O
4
16
32
48
64
80
96
112
128
144
160
176
192
GROUND ELAPSED TIME, HRS

Fig. 9

NASA-S-65-12599A

GEMINI VII
PILOT HEART RATE (CONT)
4 HOUR INTERVALS

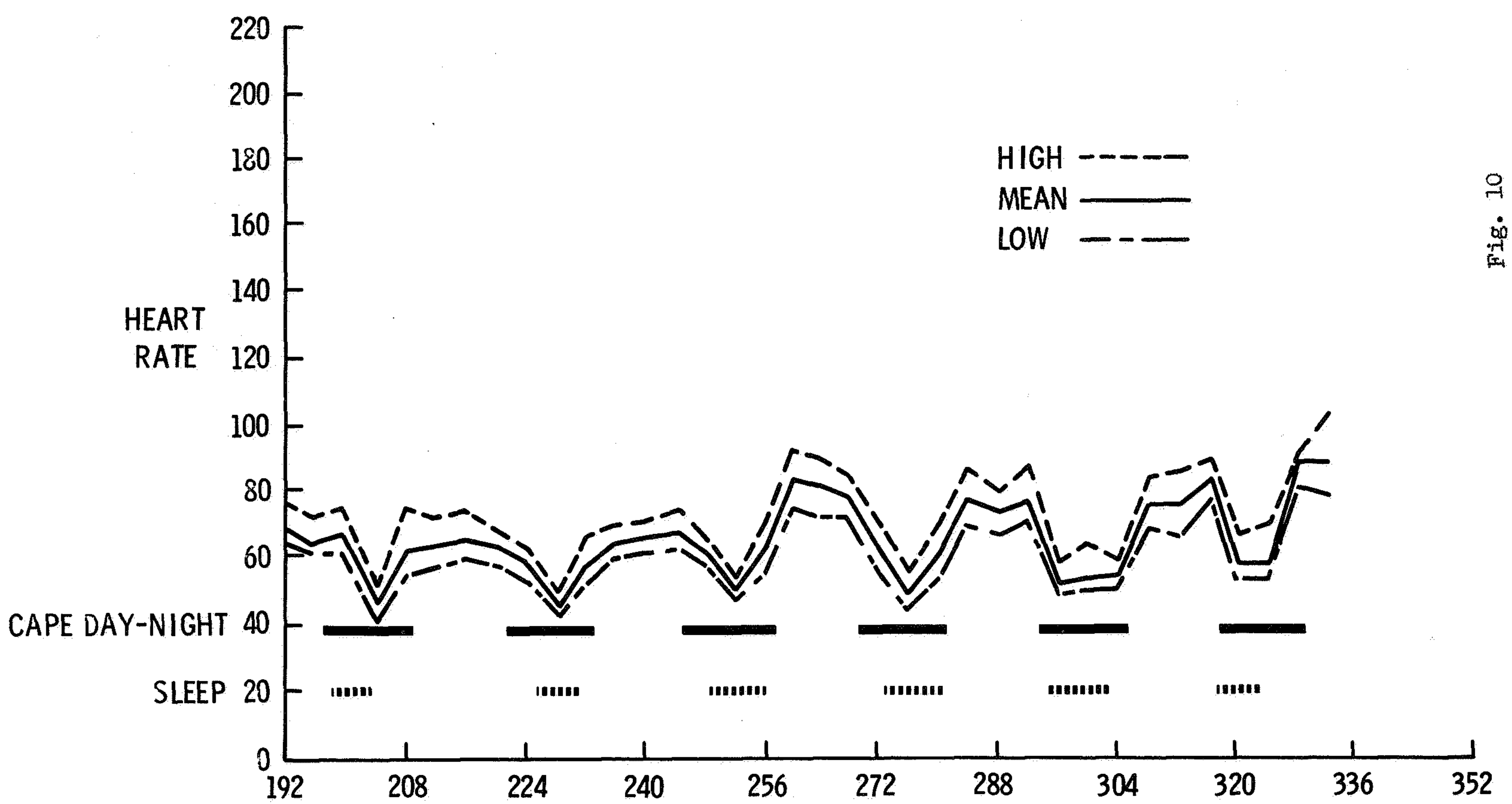


Fig. 10

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GEMINI VII
COMMAND PILOT BLOOD PRESSURE

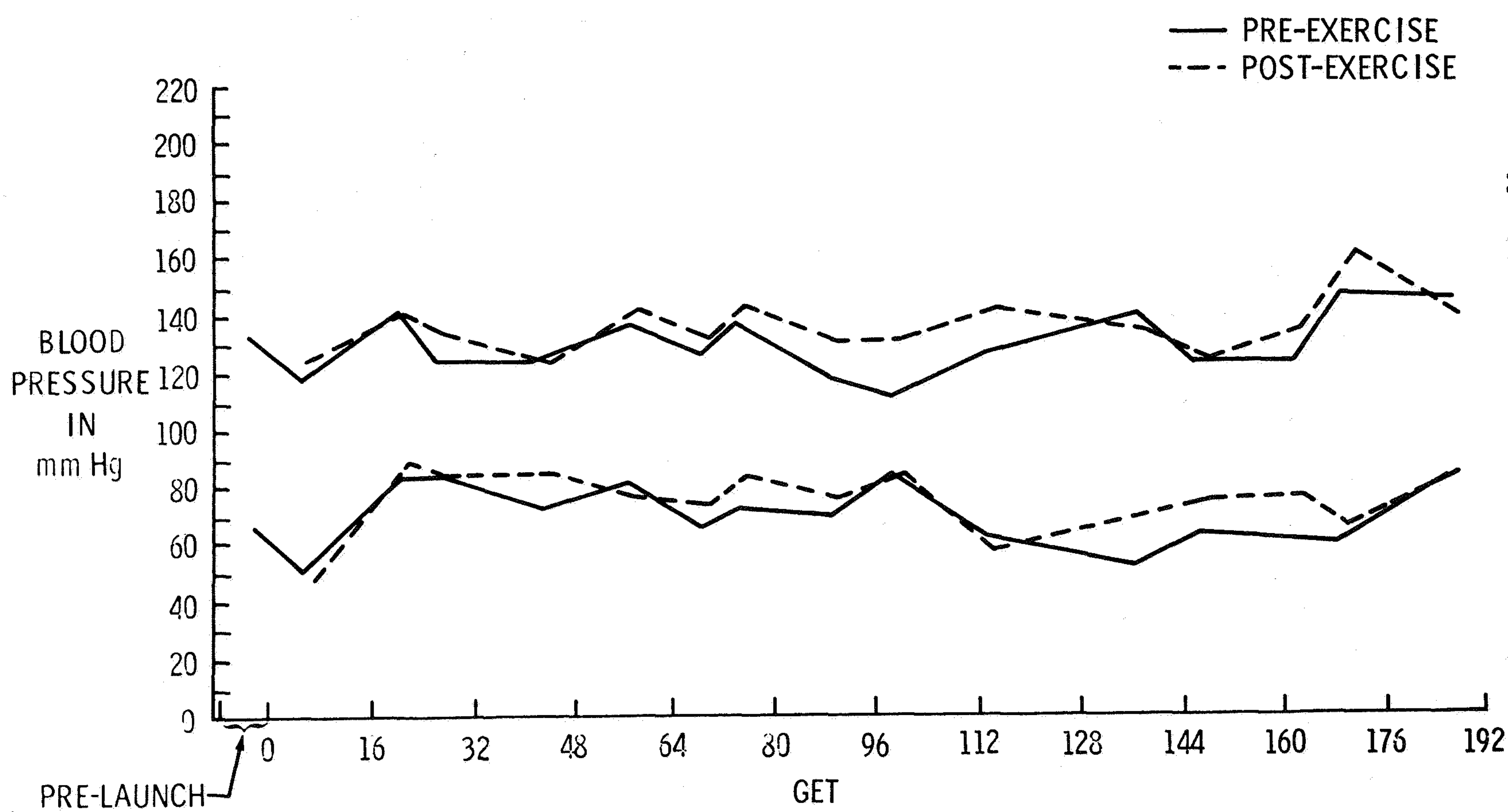

Fig. 11

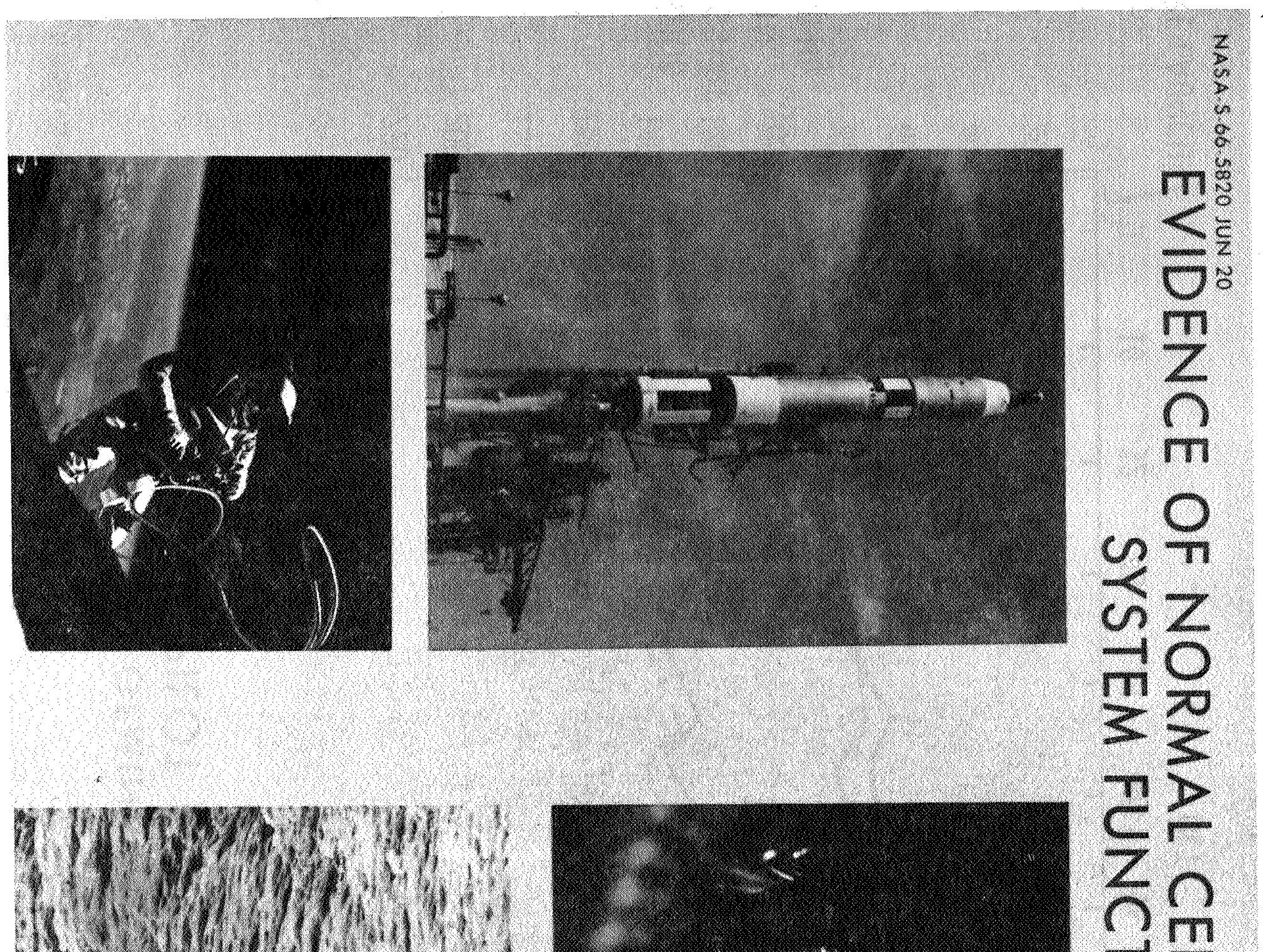
EVIDENCE OF NORMAL CENTRAL NERVOUS
SYSTEM FUNCTION
NASA S-66-5820 JUN 20

Fig. 12

10191

SUMMARY OF MEDICAL EXPERIMENTS PROGRAM

REVIEW OF FINDINGS THROUGH GEMINI 7

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N68-10191

SUMMARY OF MEDICAL EXPERIMENTS PROGRAM

REVIEW OF FINDINGS THROUGH GEMINI 7

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

From M001, the Cardiovascular Reflex Experiment, we have learned that a preventive measure against circulatory de-adaptation which has proven valid on the ground has not been successful in flight. This has led to the scheduling of a new and more promising therapeutic measure for trial aboard Apollo. The tilt table studies have confirmed the tendency toward cardiovascular deconditioning and show some evidence that a semblance of a trend pattern may be emerging. The need for determining specific causal relationships will require the repetition of these studies during space flight missions and the extension of associated ground-based studies. The clear-cut evidence of individual variation in these as well as other findings further emphasizes this need.

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

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

The Exercise Tolerance Experiment, M003, has shown us that a heavier exercise regimen will be required for its successful accomplishment in the future. By virtue of its relatively low sensitivity, a provocative exercise regimen of this sort may lend itself to calibration as a specific predictive index of significant cardiovascular change on future flights.

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

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

The Bone Densitometry Experiment, M006, has demonstrated what has long been anticipated; that there is, indeed, a reduction of bone density during space flight. Although these changes have not been severe, this experiment has further shown that bone density reduction in the non-weightbearing bones (upper extremities) was clearly more pronounced than that seen in the same areas during equivalent periods of bed rest on earth. Paradoxically, bone density was seemingly less affected by the 14-day flight than by either the 4- or 8-day flights. The reasons for this are not clear, but here again, individual variation must be separated from the favorable influences of diminished thermal stress, increased food and water intake, and increased exercise program which characterized the environment and events of the 14-day flight.

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

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

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

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

Experiments M004 (the Phonoelectrocardiogram), M005 (Bioassay of Body Fluids), M007 (Mineral Balance), M009 (Human Otolith Function), and the red cell mass and blood volume studies are all contributing data on mechanisms by which these effects are manifested. M003 (In-Flight Exerciser) may prove to be of value as an in-flight predictive index of circulatory changes as they might unfavorably affect post-flight activities. Finally, Experiment M001 (Cardiovascular Reflex) is the evaluation of a technique to prevent circulatory de-adaptation during space flight. The Medical Experiments Program is designed to enable us to effectively plan and carry out long duration manned missions of the future. Our data appear to have confirmed, from a medical viewpoint, the feasibility of the Apollo lunar landing mission, and they support the practicality of currently planning a 28-30-day mission. Although the program is very young, it has also yielded data which promises to contribute to our knowledge of basic physiology, particularly in the areas of red cell enzymology, and dehydration and fluid balance.

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

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