

**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

TAB

EXPER

MOO1

Cor

MOO3

Exe

MOO4

Pho

MOO5

Flu

MOO6

liz

MOO7

Stu

MOO8

Ana

MOO9

Fur

Hea

Res

Blo

Oral

PRE

Tilt

Hema

A. P

B. P

C. P

Urin

Exer

Body

A =

*Stan

fol

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
MO01 - Cardiovascular Conditioning			X		X						2
MO03 - In-Flight Exerciser		X	X		X						3
MO04 - In-Flight Phonocardiogram		X	X		X						3
MO05 - Bioassays Body Fluids					X	X					2
MO06 - Bone Demineralization		X	X		X						3
MO07 - Calcium Balance Study					X						1
MO08 - In-Flight Sleep Analysis					X						1
MO09 - 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 MO01

CARDIOVASCULAR CONDITIONING

Principal Investigators:

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Houston, Texas

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EXPERIMENT M-1, CARDIOVASCULAR CONDITIONING

By

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Chief, Biomedical Research Office

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and

William V. Judy

Biomedical Research Office

NASA Manned Spacecraft Center

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 postflight 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

(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 vasodilatation 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.

----- POST-WATER IMMERSION (NO CUFFS) ----- POST-WATER IMMERSION (CUFFS)

NASA-S-65-7382

SIX HOUR WATER IMMERSION STUDIES M-1

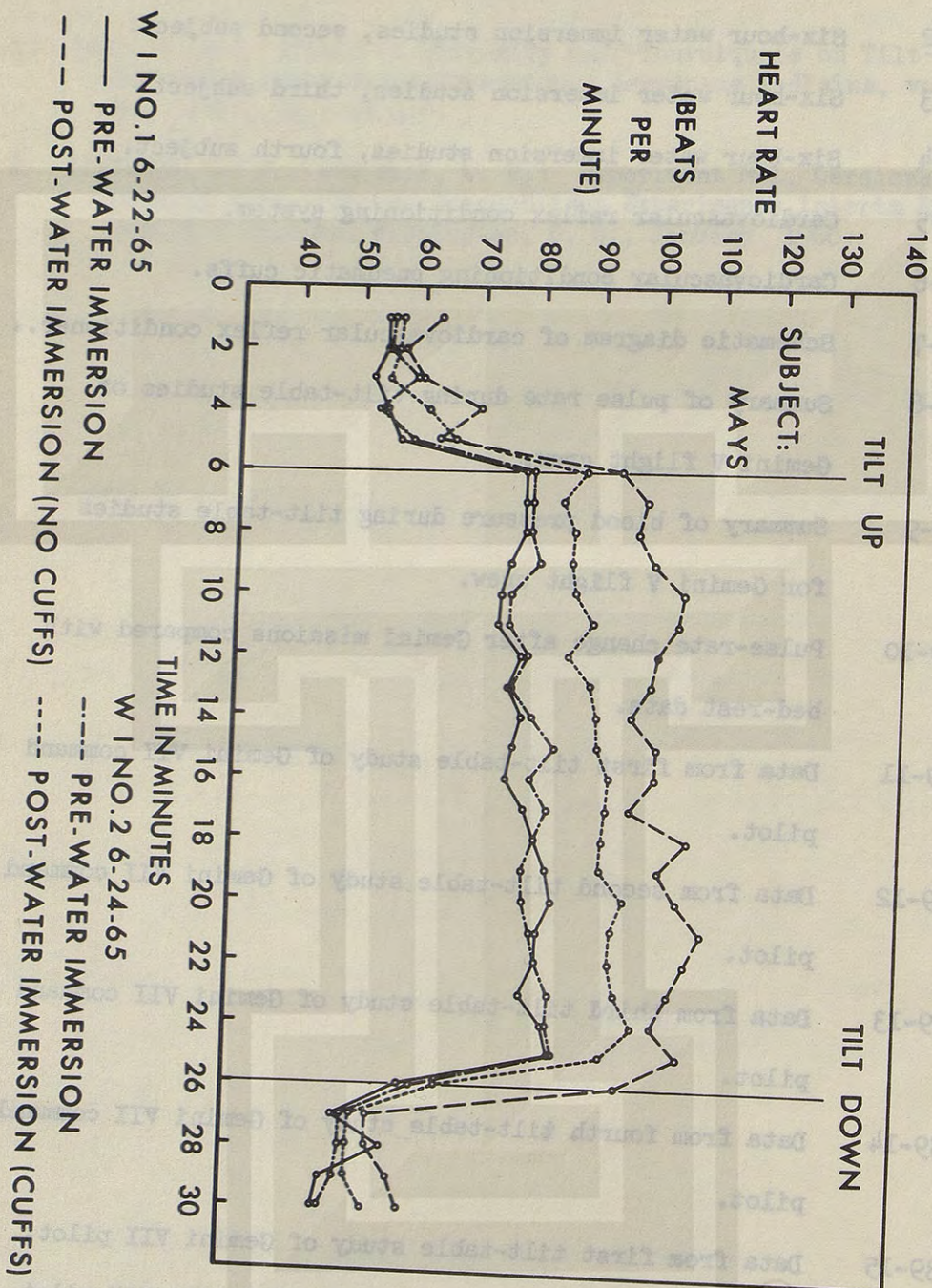


Fig.
39-1

SIX HOUR WATER IMMERSION STUDIES M-1

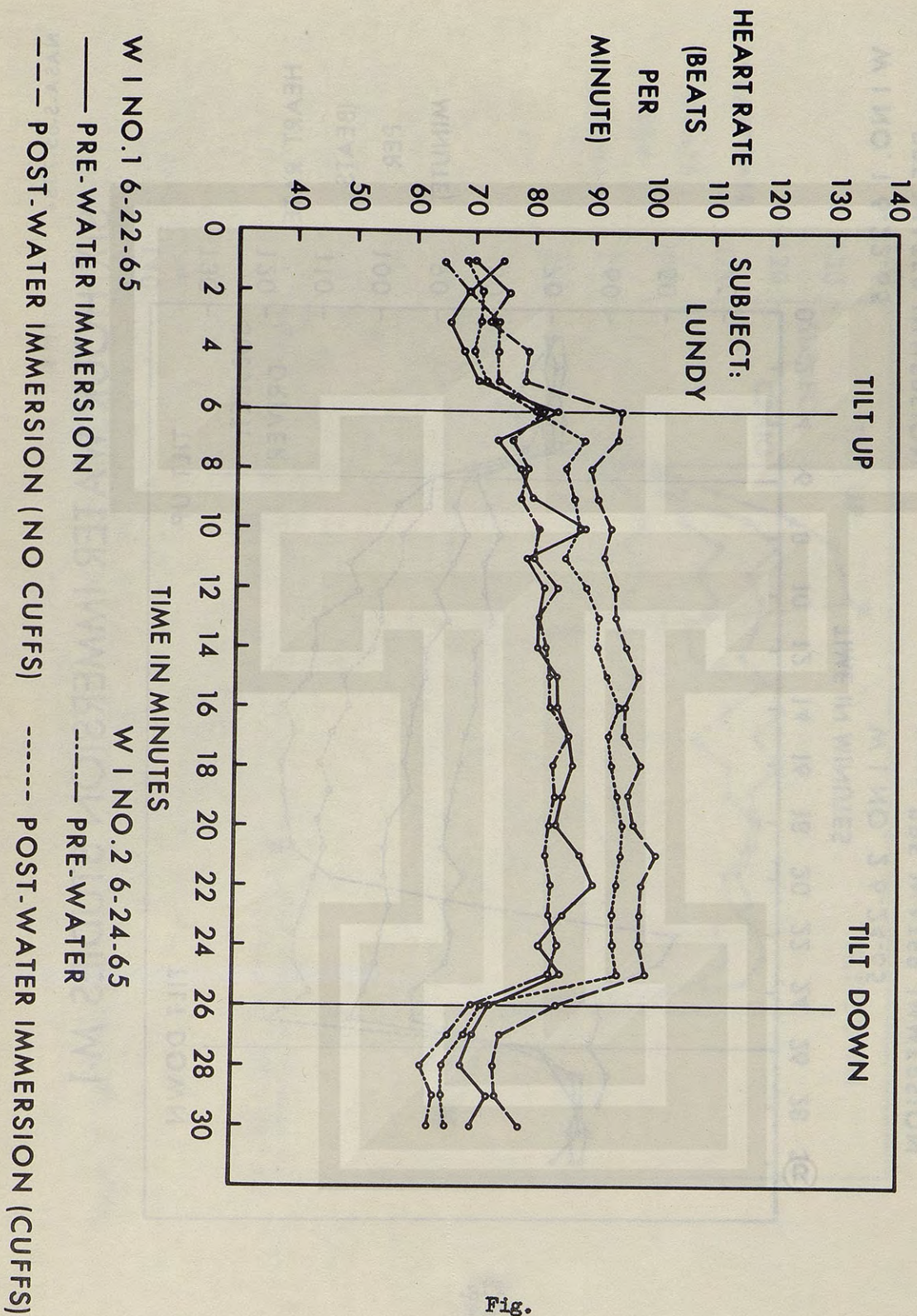


Fig. 39-2

SIX HOUR WATER IMMERSION STUDIES M-1

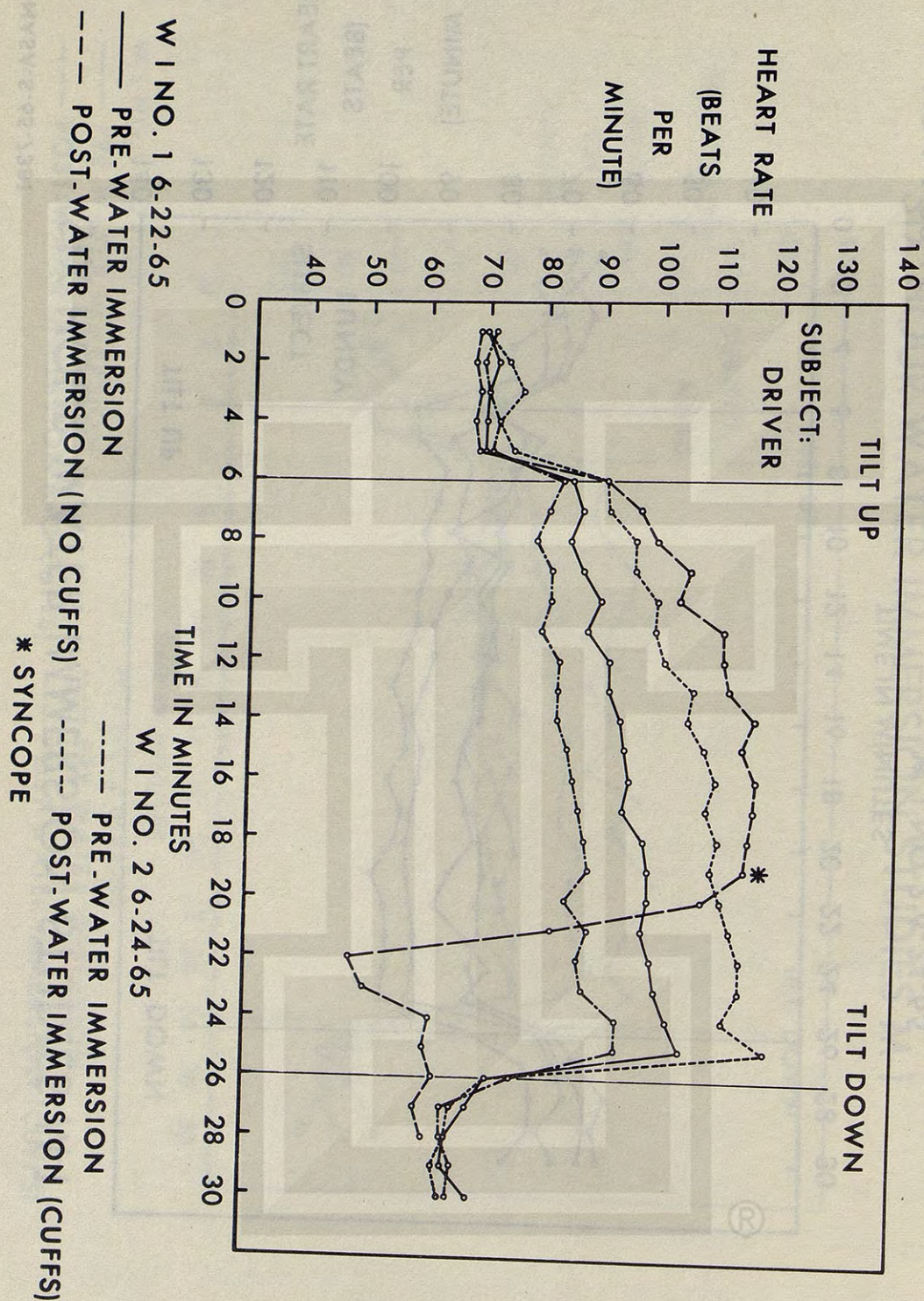


Fig.
39-3

SIX HOUR WATER IMMERSION STUDIES M-1

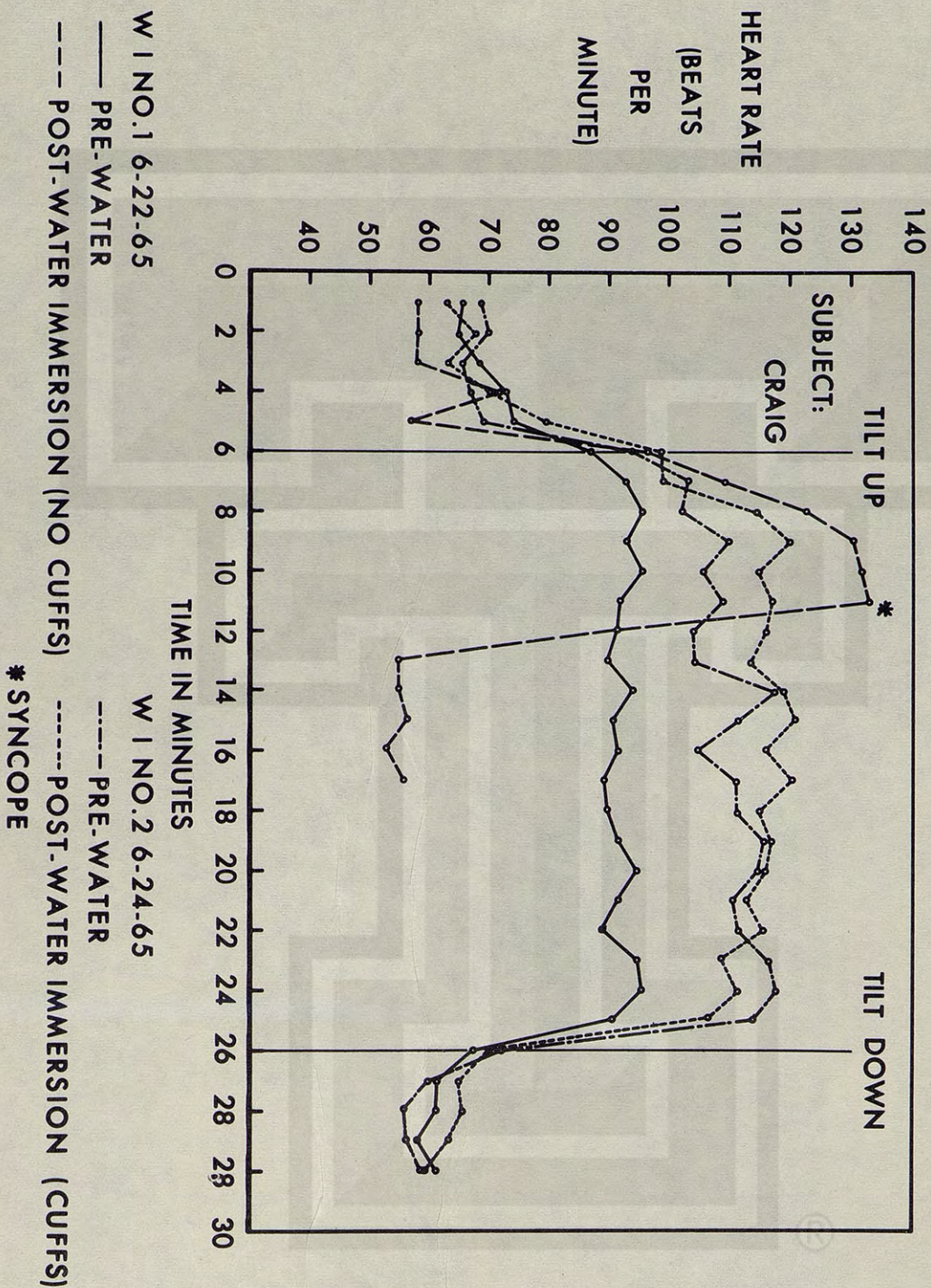


Fig.
39-4

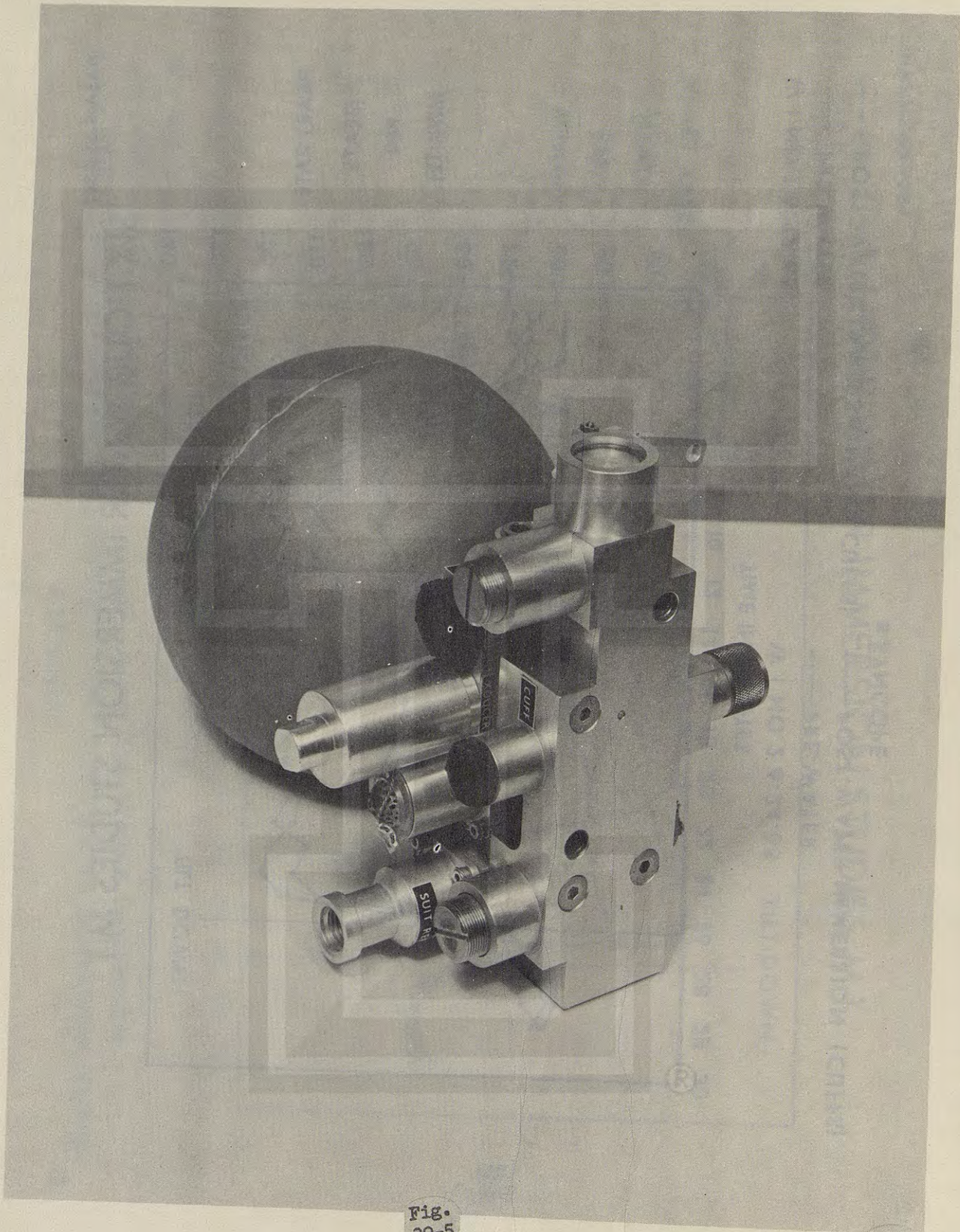


Fig.
39-5

NASA-S-65-11739A

CARDIOVASCULAR CONDITIONING PNEUMATIC CUFFS M-I

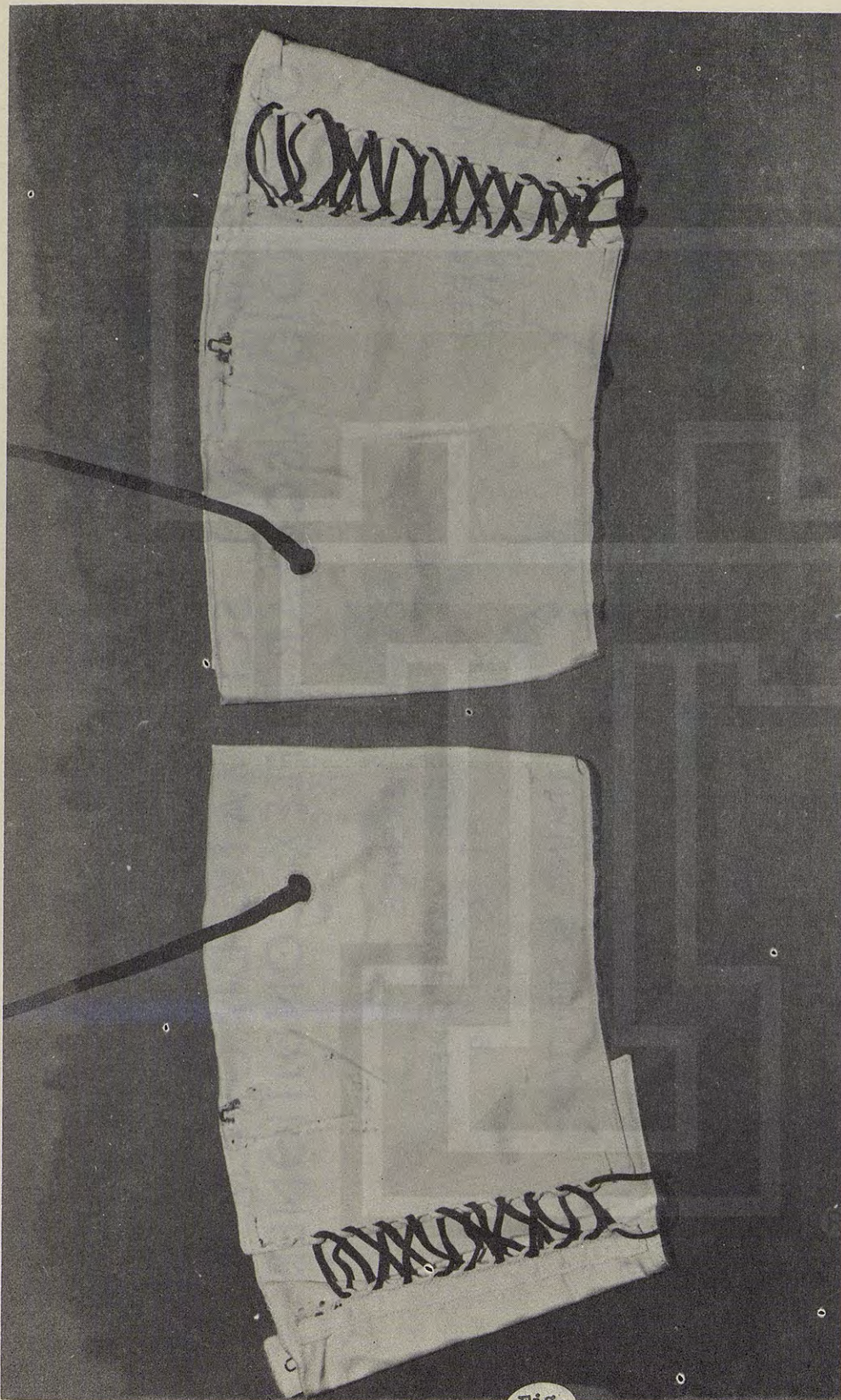


Fig.
39-6

NASA-S-66-1170 FEB 7

EXPERIMENT M-1, SCHEMATIC DIAGRAM OF CARDIOVASCULAR REFLEX CONDITIONER

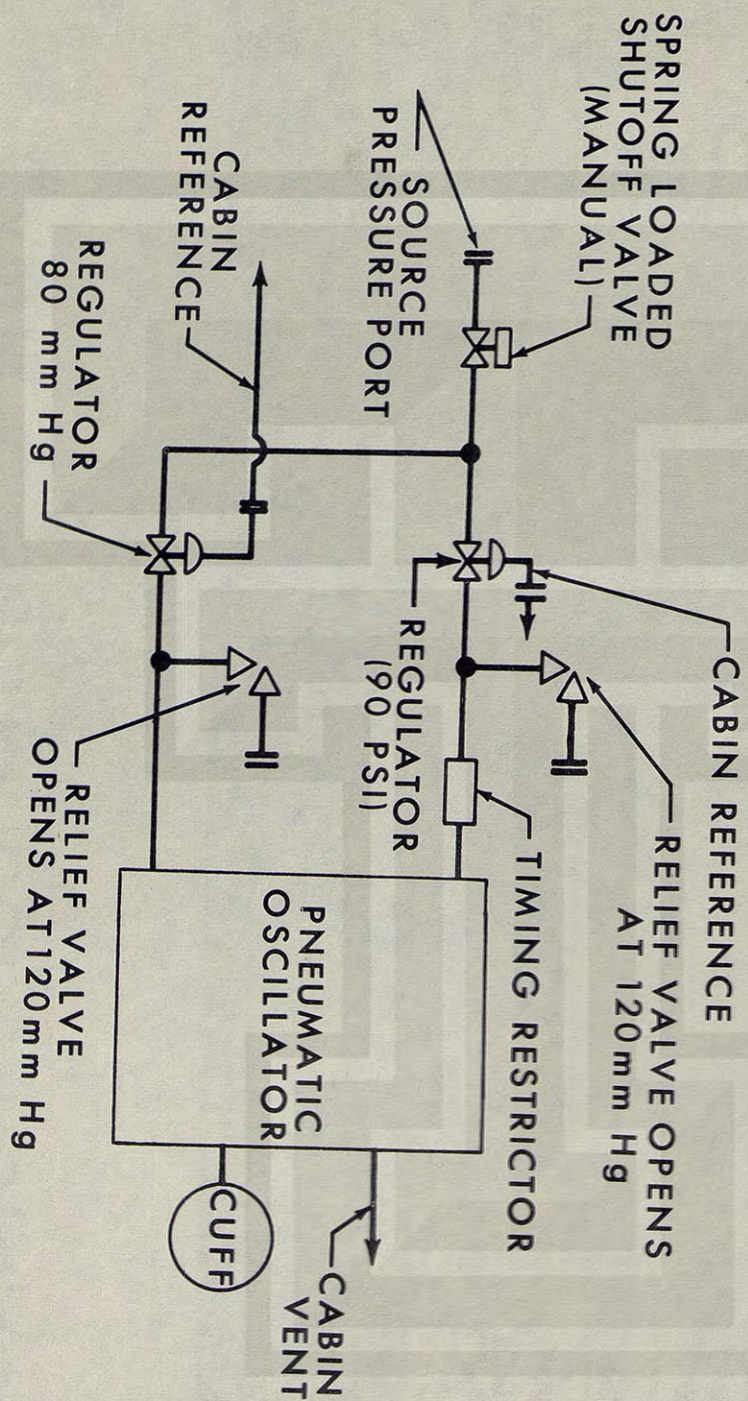


Fig. 39-7

EXPERIMENT M-1, TILT TABLE SUMMARY

PULSE RATE

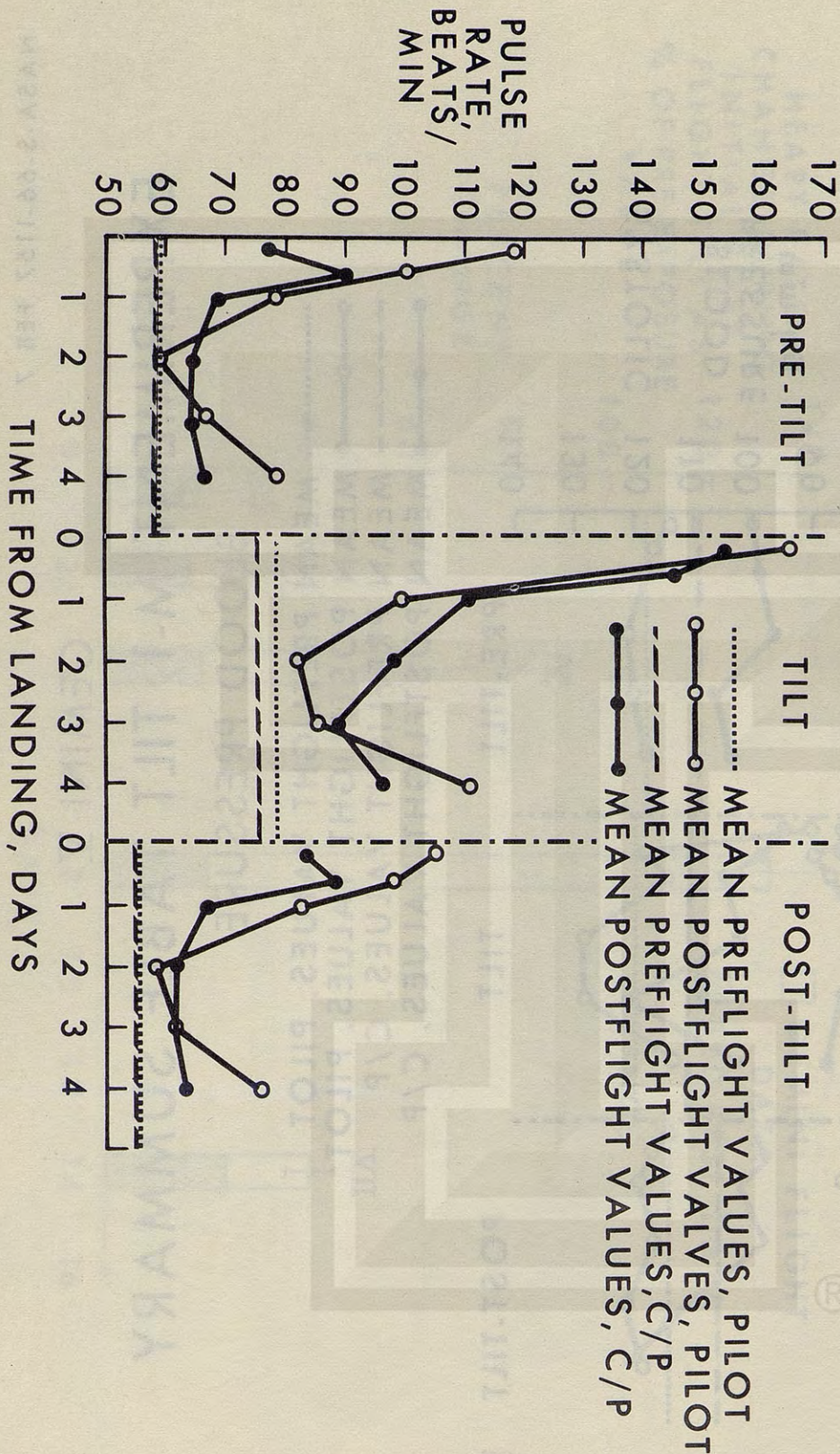


Fig.
39-8

GEMINI V

EXPERIMENT M-1, TILT TABLE SUMMARY

BLOOD PRESSURE

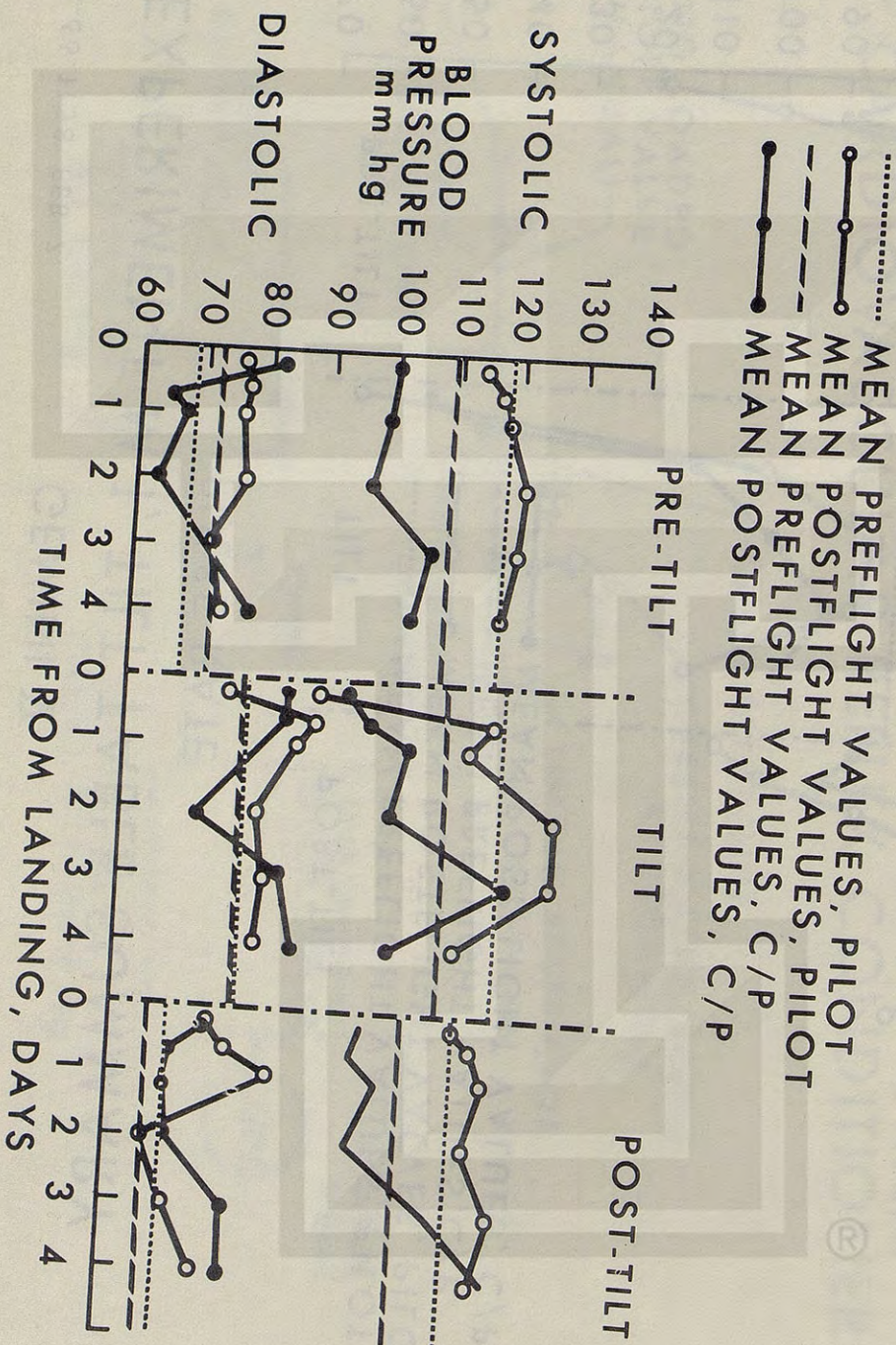


Fig.
39-9

GEMINI MISSIONS AND BED REST

TILT PULSE RATE CHANGE VS TIME

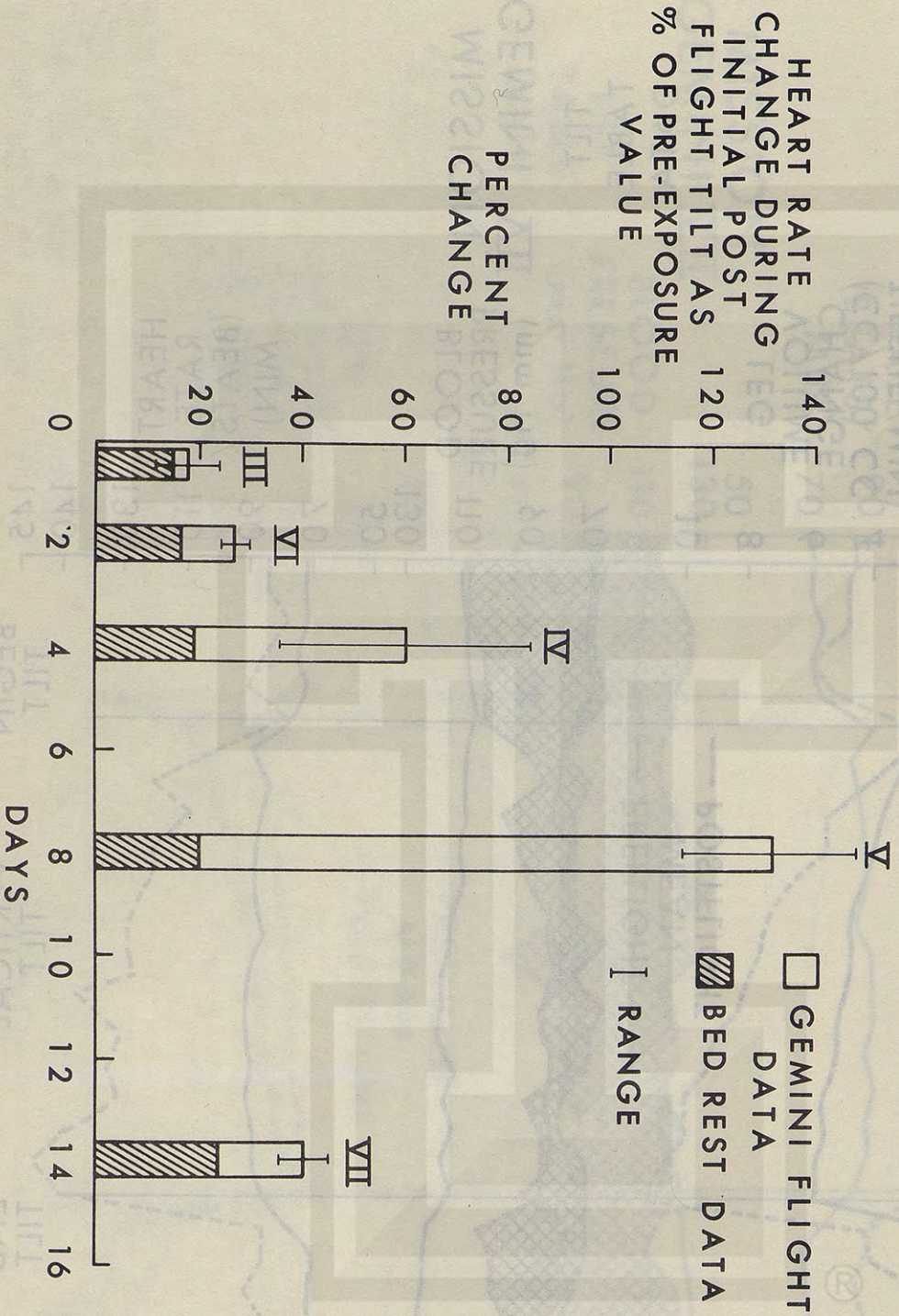


Fig. 39-10

TIME: 0:10 PM
DATE: DEC 18, 1965

MINUTES

NASA-S-66-778 JAN 24

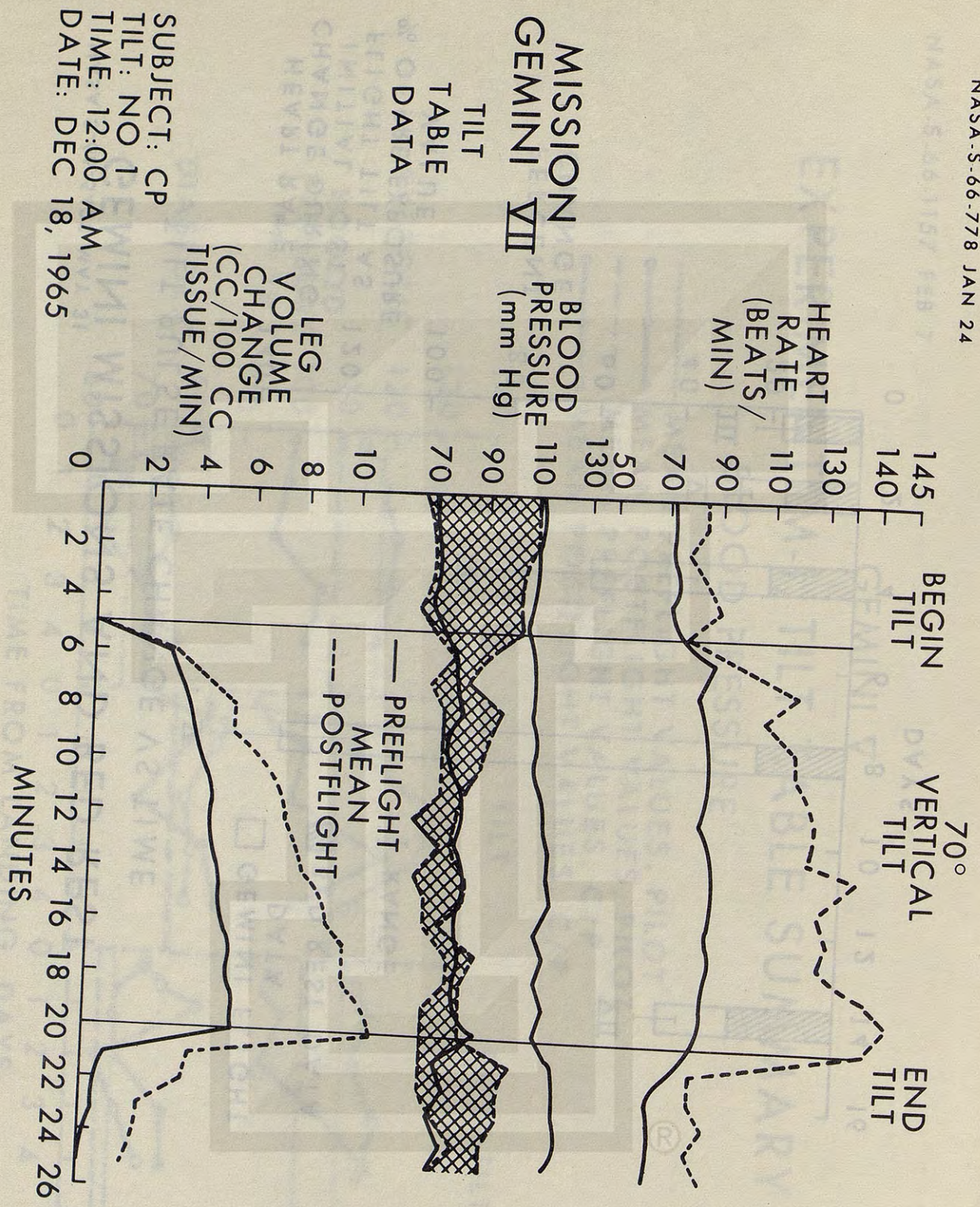


Fig. 39-11

SUBJECT: CP
TILT: NO 1
TIME: 12:00 AM
DATE: DEC 18, 1965

MISSION GEMINI VII

TILT
TABLE
DATA

BLOOD
PRESSURE
(mm Hg)

HEART
RATE
(BEATS/
MIN)

LEG
VOLUME
CHANGE
(CC/100 CC
TISSUE/MIN)

SUBJECT: CP
TILT: NO 2
TIME: 8:10 PM
DATE: DEC 18, 1965

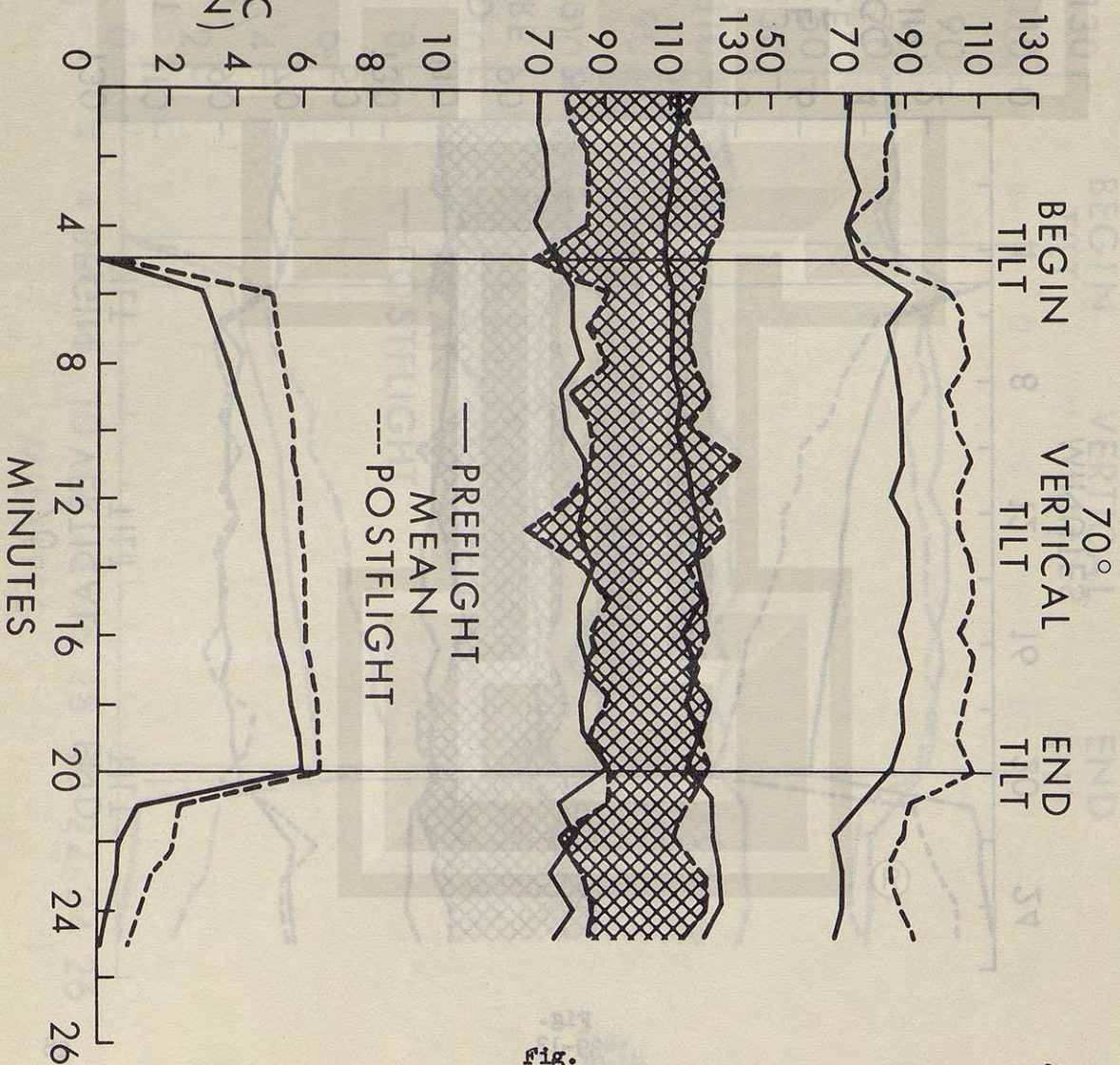


Fig.
39-12

NASA-S-66-777 JAN 24

DATE: DEC 19, 1965
TIME: 8:10 PM
TILT: NO 5
SUBJECT: CP

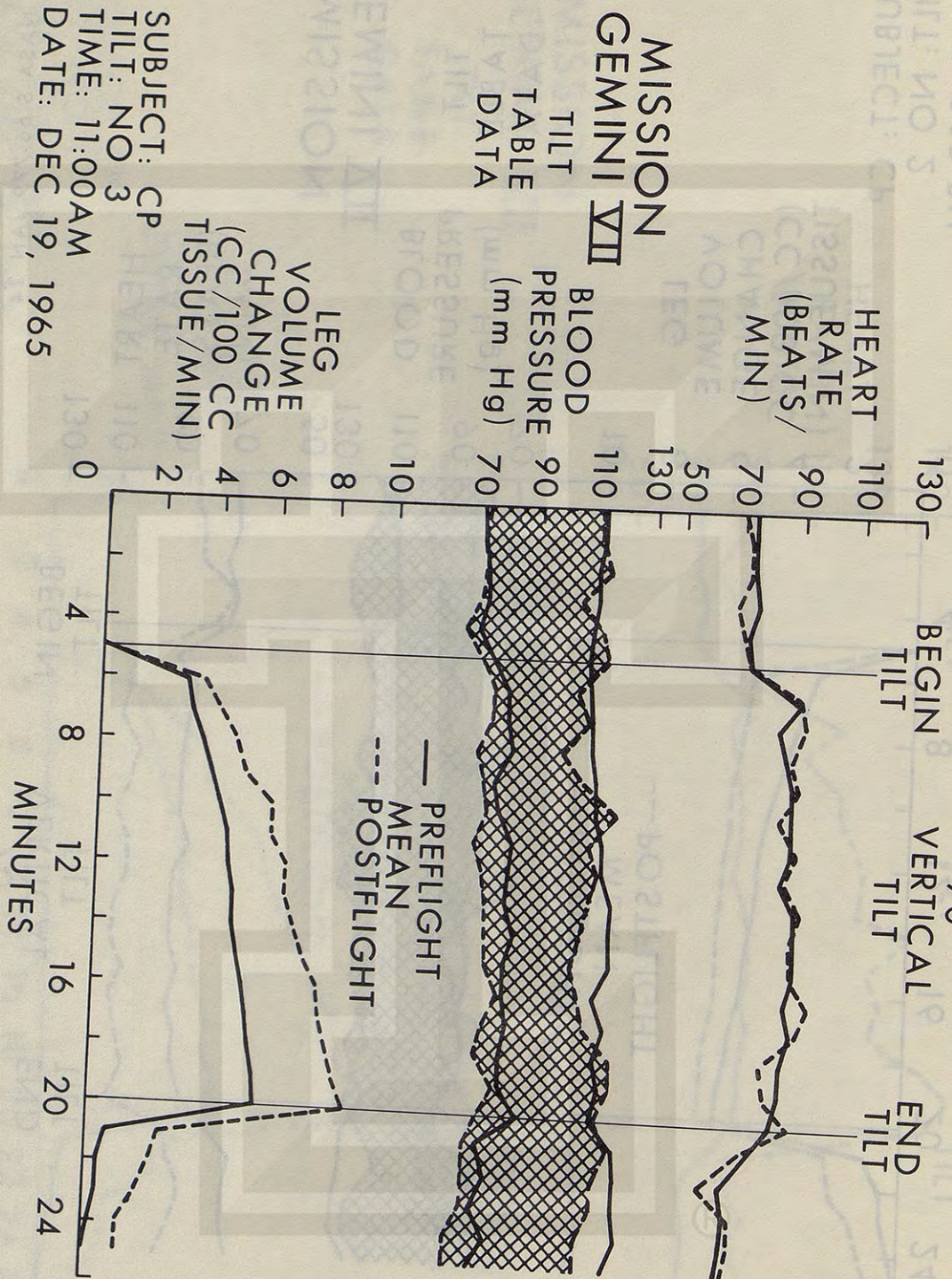


Fig.
39-13

MISSION GEMINI VII

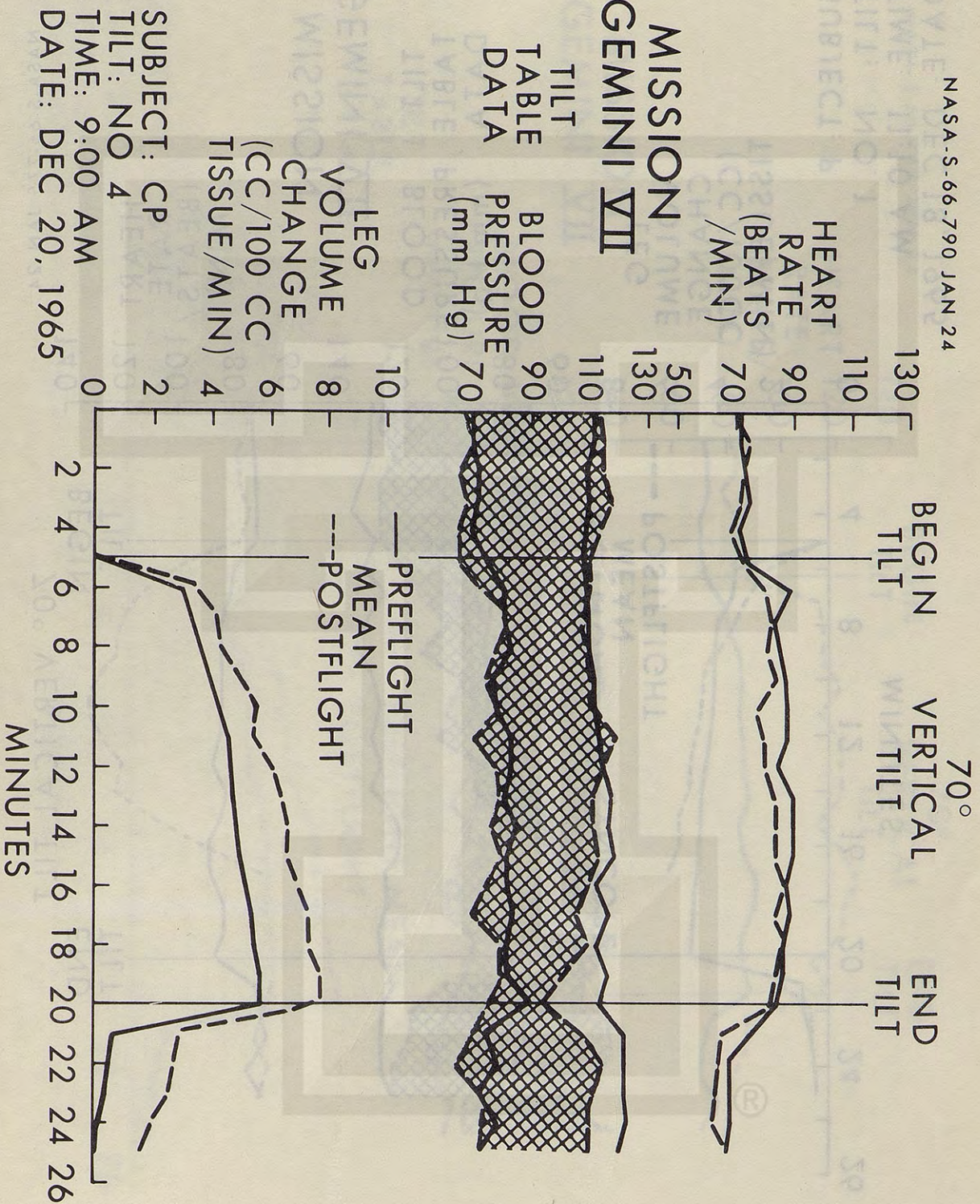


Fig. 39-14

NASA-S-66-775 JAN 24

MISSION GEMINI VII

TILT
TABLE
DATA
BLOOD
PRESSURE
(mm Hg)

HEART
RATE
(BEATS/
MIN)

LEG
VOLUME
CHANGE
(CC/100CC
TISSUE/MIN)

SUBJECT: P
TILT: NO. 1
TIME: 11:10 AM
DATE: DEC 18, 1965

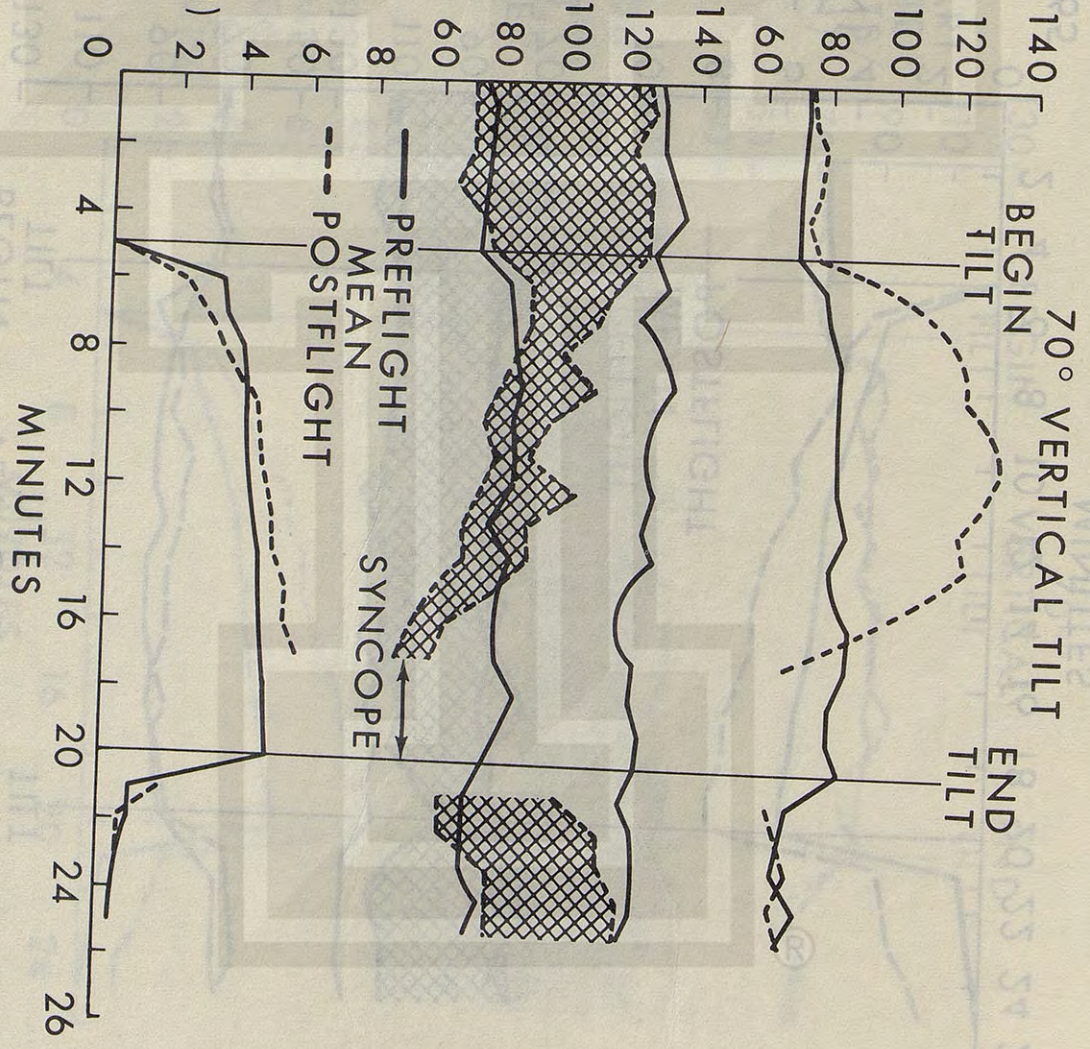


Fig.
39-15

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

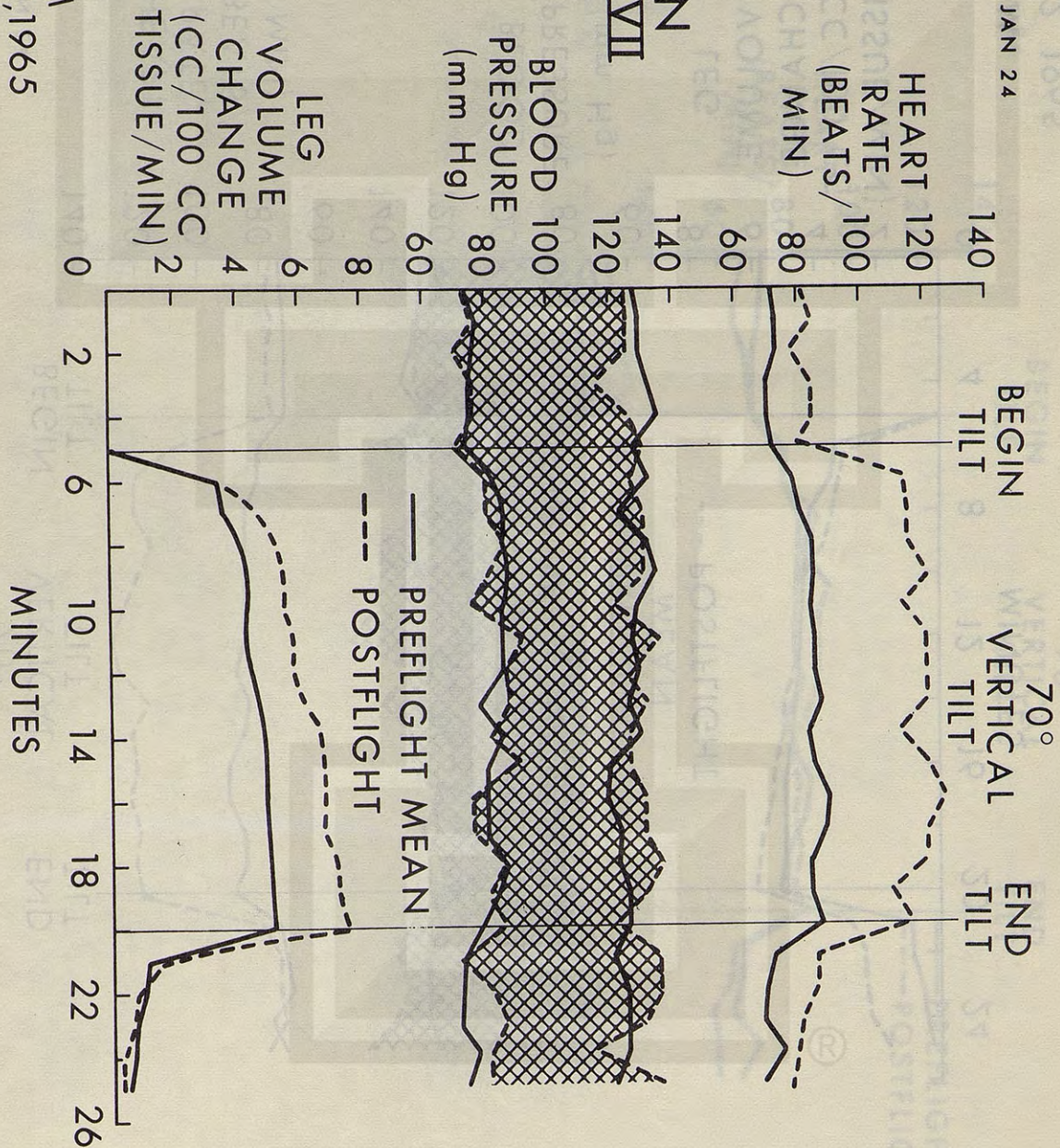


Fig 39-16

TILT: NO. 4
TIME: 11:10 A.M.
DATE: DEC 20, 1965

0 2 4 6 8 10 12 14 16 18 20 22 24 26
MINUTES

NASA-S-66-770 JAN 24

TIME: 9:00 PM

SUBJECT: P

MISSION GEMINI VII

TILT
TABLE
DATA

BLOOD
PRESSURE
(mm Hg)

LEG
VOLUME
CHANGE
(CC/100 CC
TISSUE/MIN)

SUBJECT: P
TILT: NO 3
TIME: 9:00 AM
DATE: DEC 12, 1965

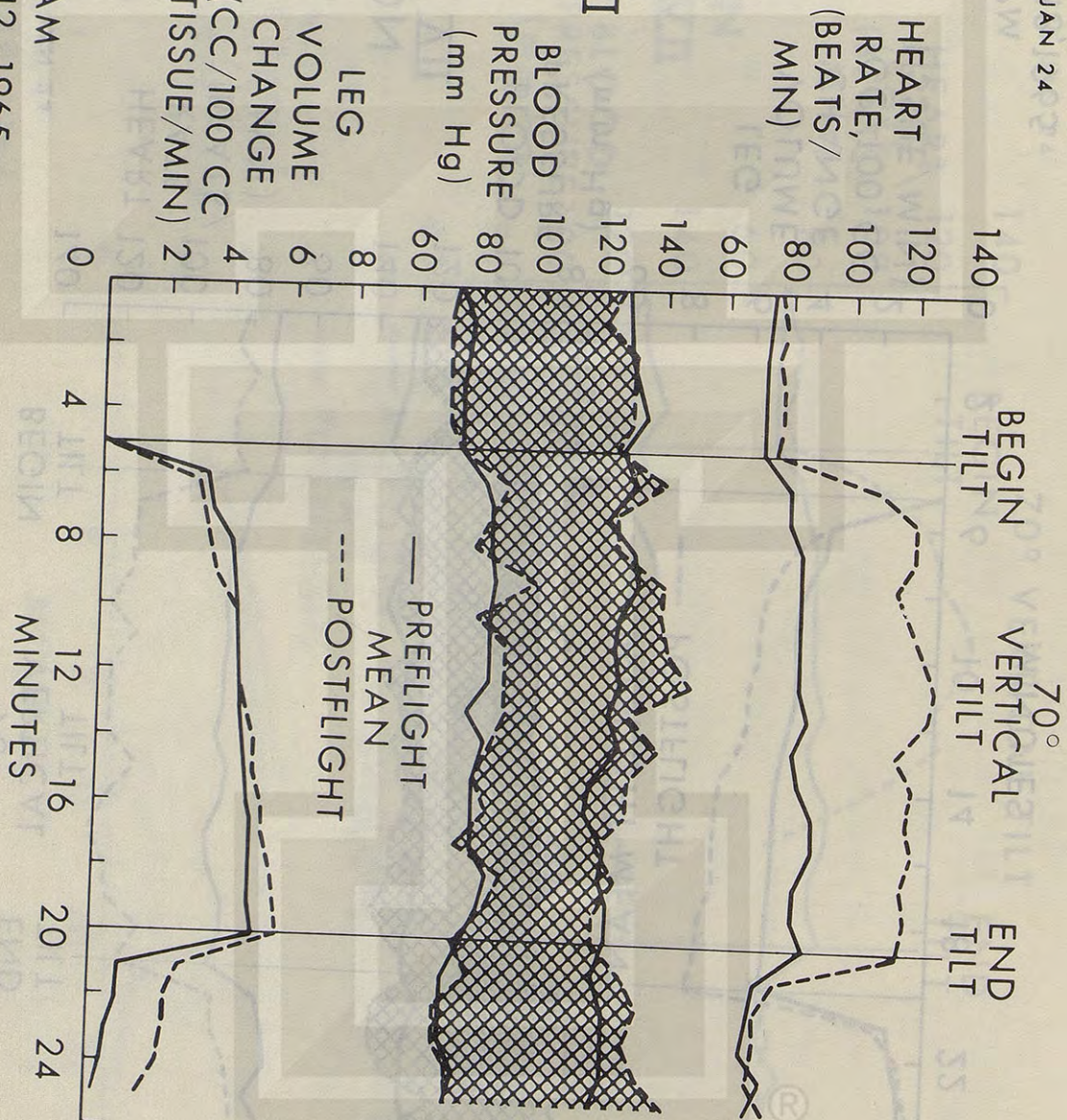
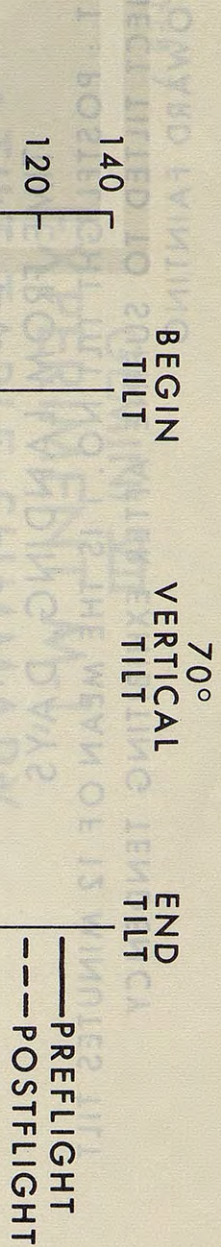


Fig 39-17



MISSION GEMINI VII

TILT
TABLE
DATA

BLOOD
PRESSURE
(mm Hg)

SUBJECT: P
TILT: NO. 4
TIME: 11:10 A.M.
DATE: DEC 20, 1965

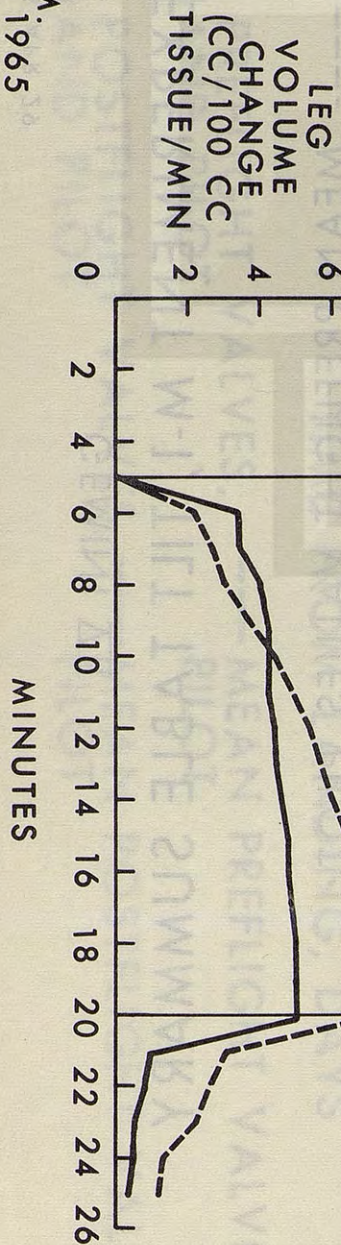


Fig
39-18

MEAN POSTFLIGHT
COMMAND PILOT

PILOT

NASA-S-66-4365 APR 29

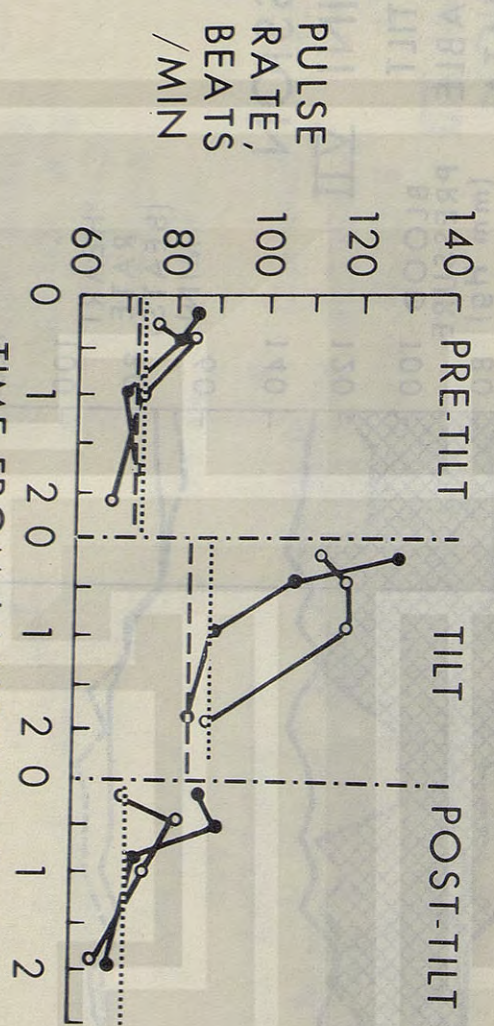
DATE: DEC 20 1965
TIME: 10:00
LIFT: NO. 4
SUBJECT: B-770 JAN 24

GEMINI VII

MINUTES

EXPERIMENT M-1, TILT TABLE SUMMARY

- MEAN PREFLIGHT VALUES, PILOT
- MEAN POSTFLIGHT VALUES, PILOT
- MEAN PREFLIGHT VALUES, C/P
- MEAN POSTFLIGHT VALUES, C/P



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

Fig. 39-19

GEMINI VII EXPERIMENT M-1, TILT TABLE SUMMARY

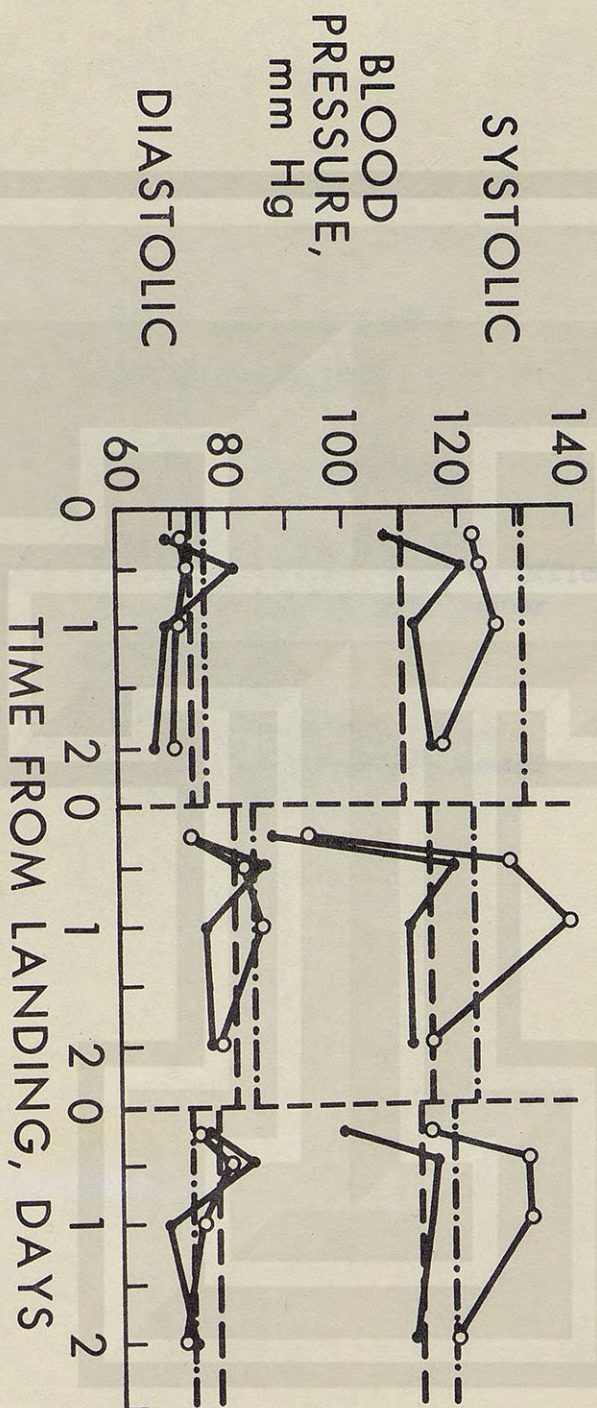


Fig 19
396

Medical Experiment M003

INFLIGHT EXERCISER

PRINCIPAL INVESTIGATORS:

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EXPERIMENT M-3, INFLIGHT EXERCISE - WORK TOLERANCE

by

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and

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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 crew-member. 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.)

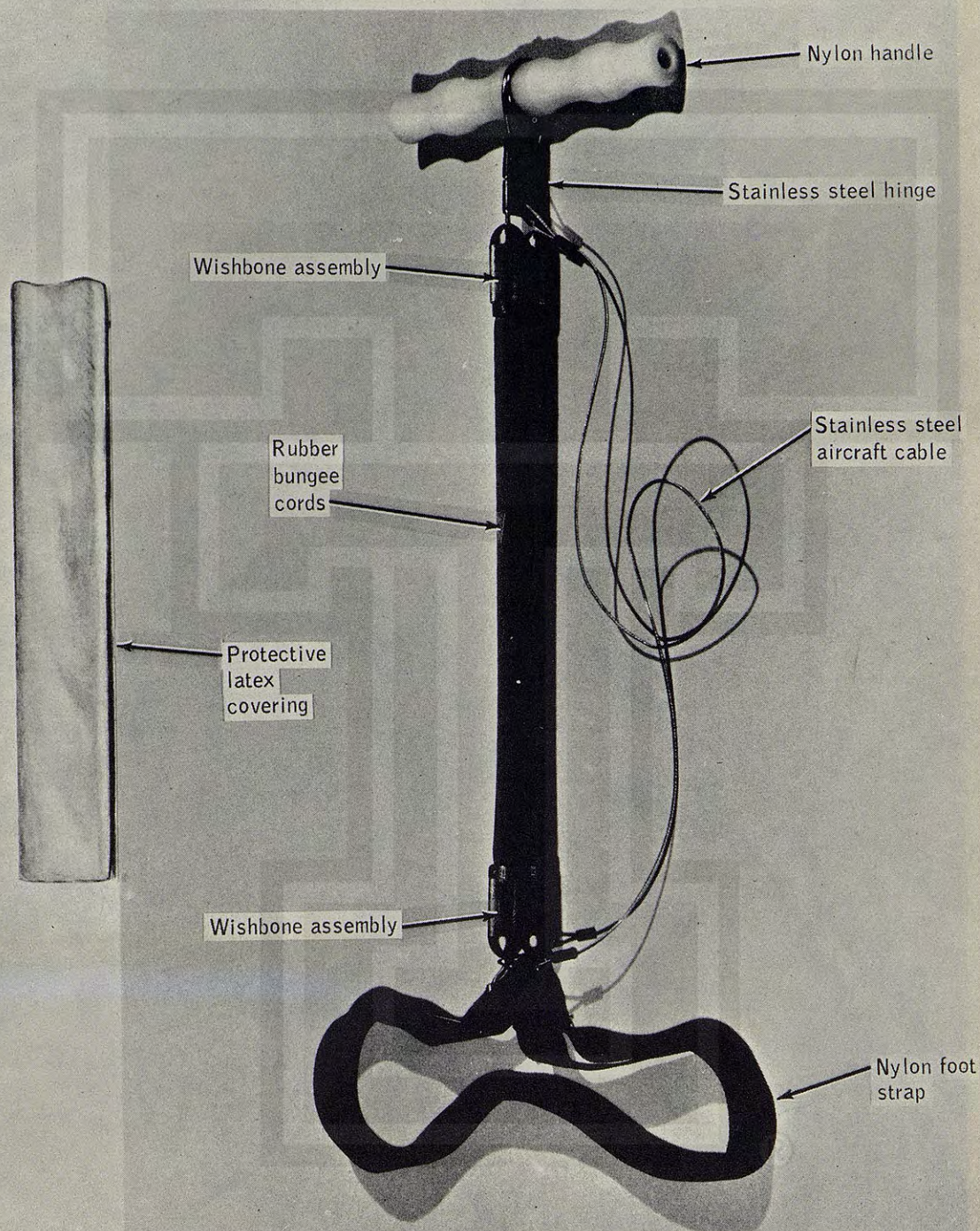
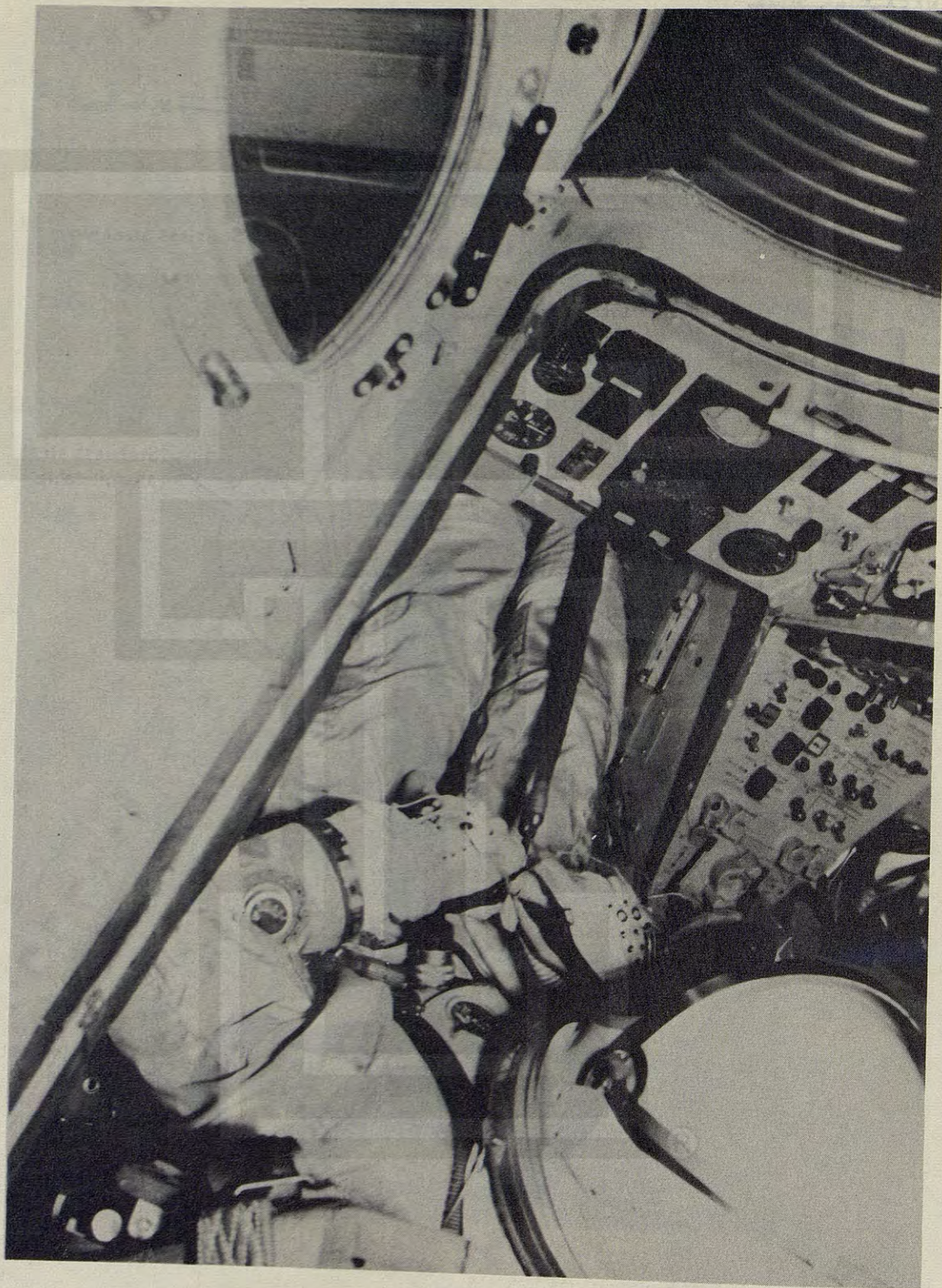


Fig. 1

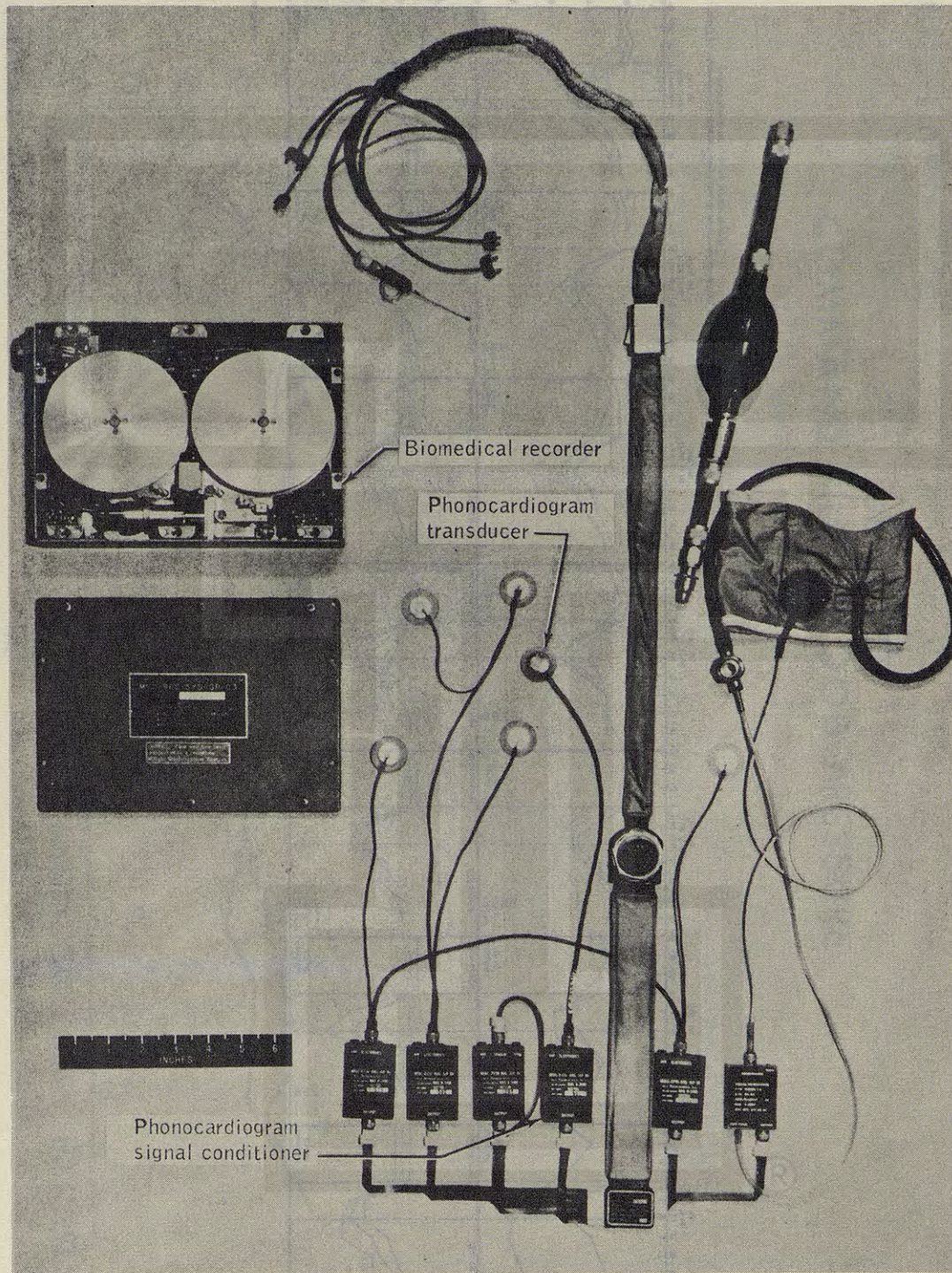
NASA-S-65-2854



Inflight exerciser in use by astronaut

Fig. 2

NASA-S-65-3507



GT-4 biomedical and communications harness

Fig. 3

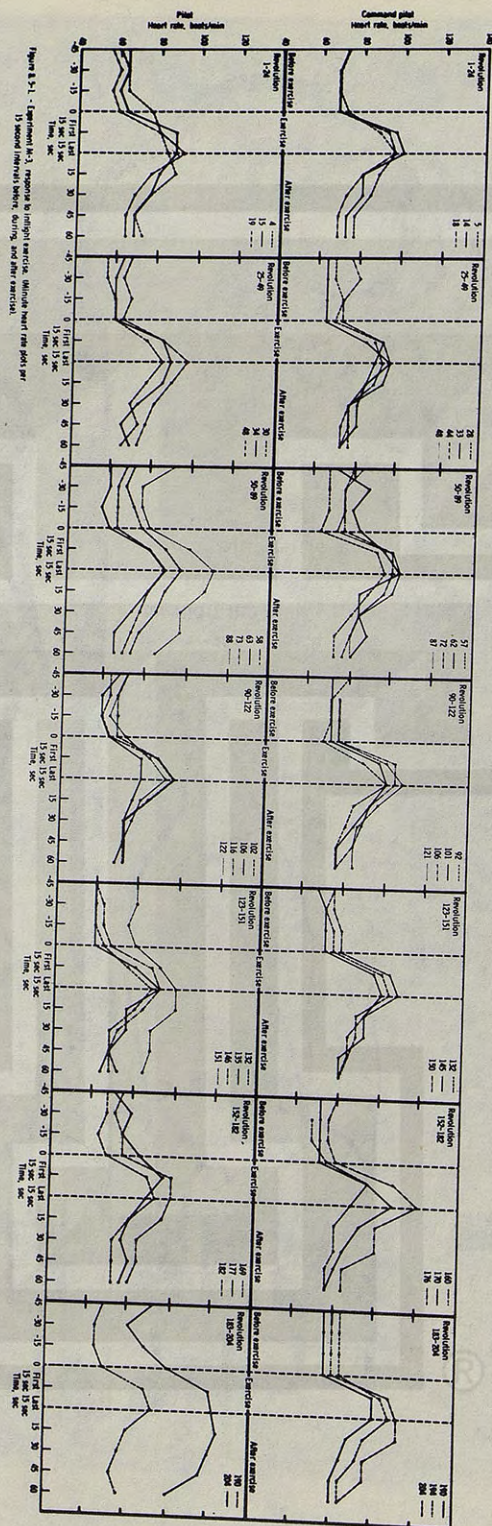


Fig. 4

GEMINI VII COMMAND PILOT BLOOD PRESSURE

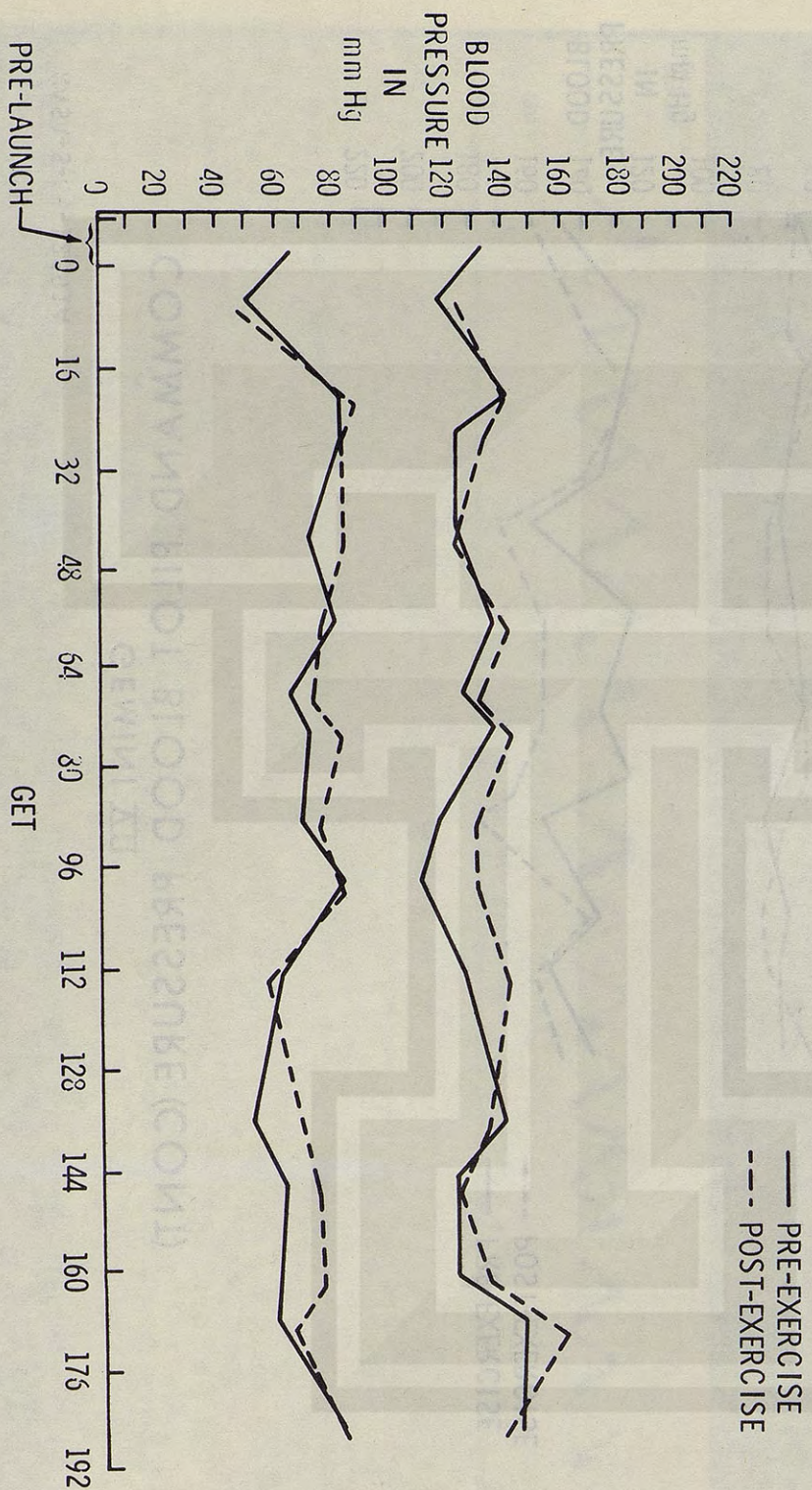


Fig. 5

GEMINI VII COMMAND PILOT BLOOD PRESSURE (CONT)

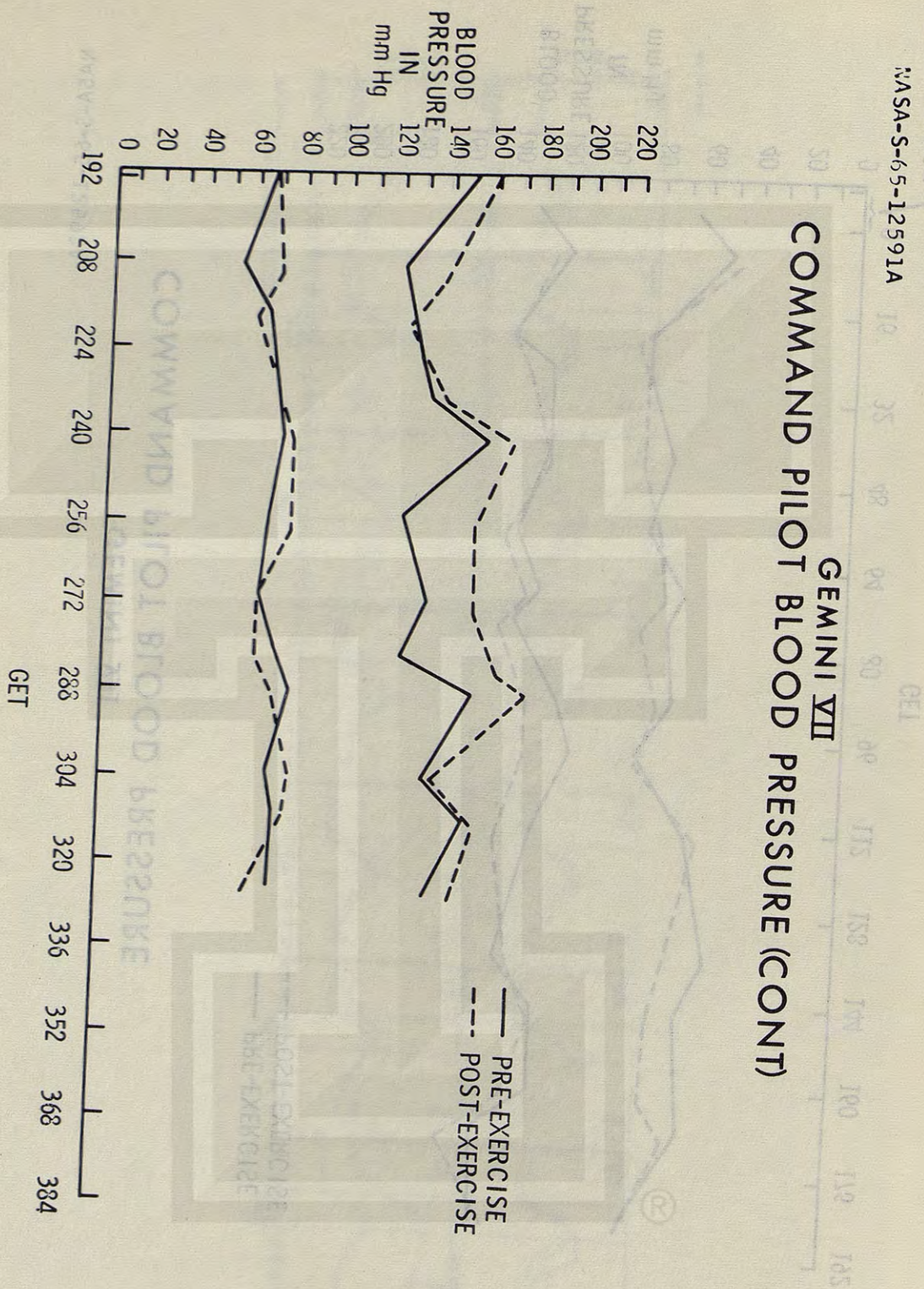
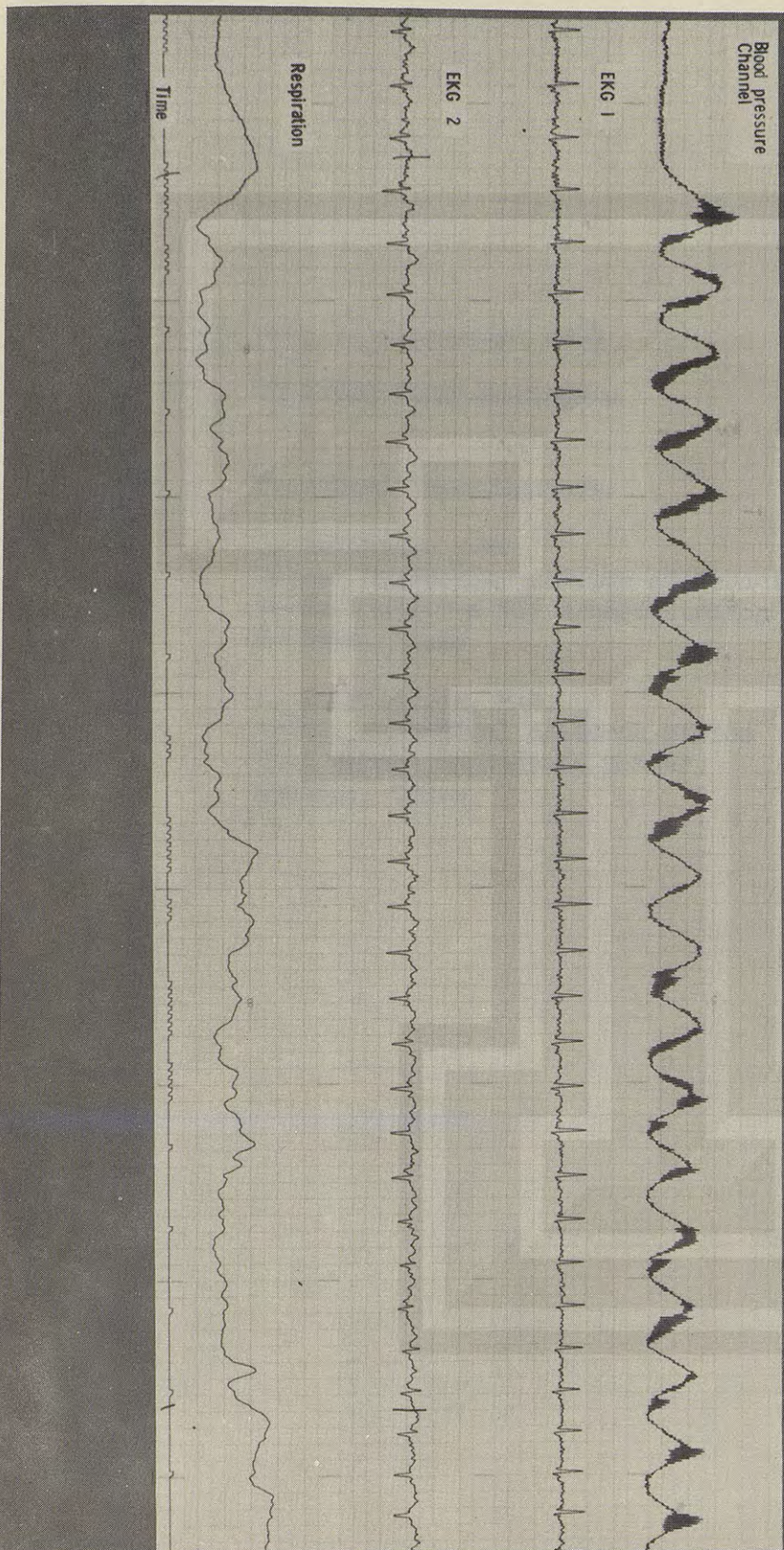


Fig. 6

NASA-S-66-1336 FEB 10

SAMPLE OF TELEMETERED PHYSIOLOGICAL DATA DURING INFIGHT EXERCISE



Medical Experiment M004

INFLIGHT PHONOCARDIOGRAM

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MO04 - INFLIGHT PHONOCARDIOGRAM

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

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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 (electromechanical delay), and the interval between the first and second heart sounds. The same program computed the means and standard deviations of these variables after each 15 consecutive beats (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 Holzmam, 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 electro-mechanical 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 electro-mechanical 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 electro-mechanical 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 electro-mechanical 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.

INFLIGHT PHONOCARDIOGRAM

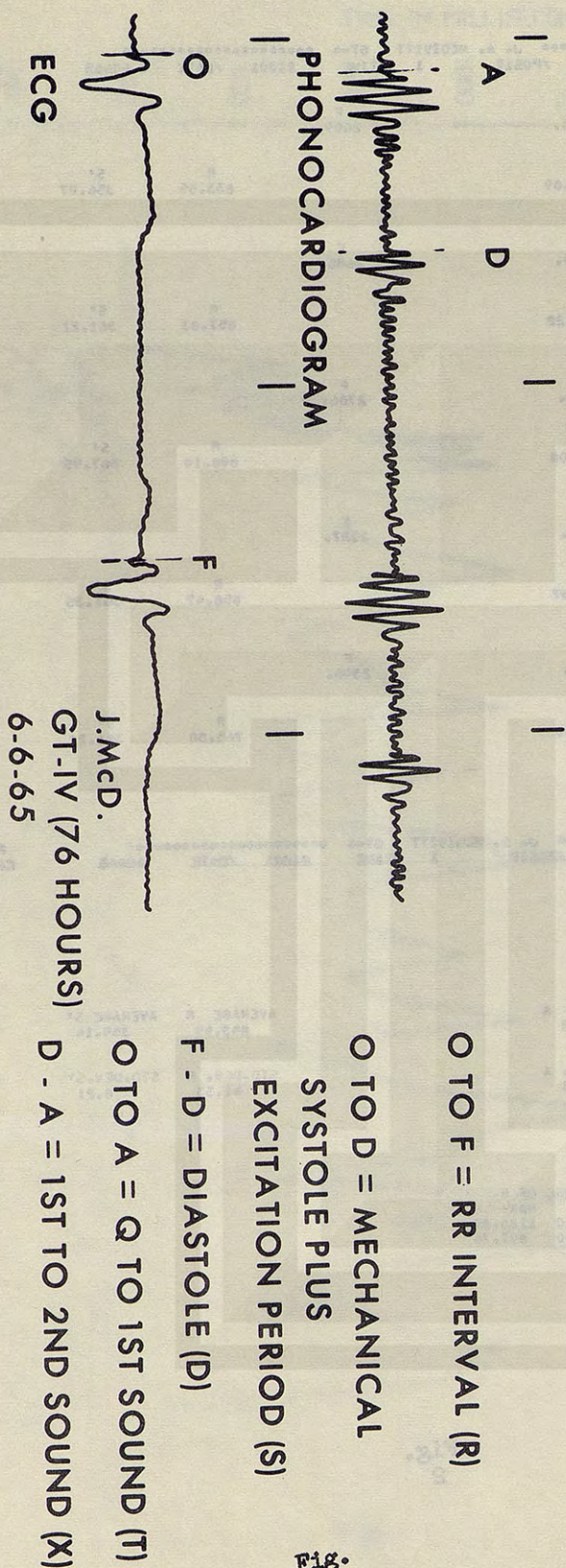


Fig.
1

192. -0. -0. J. A. MCDIVITT 70050 /POSIT 1 /TIME 81001 /DATE 60665 PAGE 1361
CALIB. 31301 .31999

OBSERVATION	A	T	S	D	X	F	R	S*
92.				1015.		2609.		
29.39			324.28		294.89		833.55	356.07
84.				983.		2685.		
26.84			314.06		287.22		857.83	361.21
92.				1025.		2786.		
29.39			327.48		298.08		890.10	367.95
98.				1015.		2687.		
31.31			324.28		292.97		858.47	361.35
137.				1004.		2596.		
43.77			320.77		277.00		765.50	341.22

192. -0. -0. J. A. MCDIVITT 70050 /POSIT 1 /TIME 81001 /DATE 60665 PAGE 1362
CALIB. 31301 .31999

AVERAGE FOR BEAT 1 TO 15

AVERAGE T	AVERAGE S	AVERAGE X	AVERAGE R	AVERAGE S*
30.33	320.65	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	
272.38	368.51	506.10	1180.89	
301.92	332.27	765.50	897.76	
CALCULATED		ACTUAL		

Fig. 2

0 1
20
40
60
80
100
120
140
160
180
20060- ELAPSED TIME FROM START OF MISSION (HOURS)

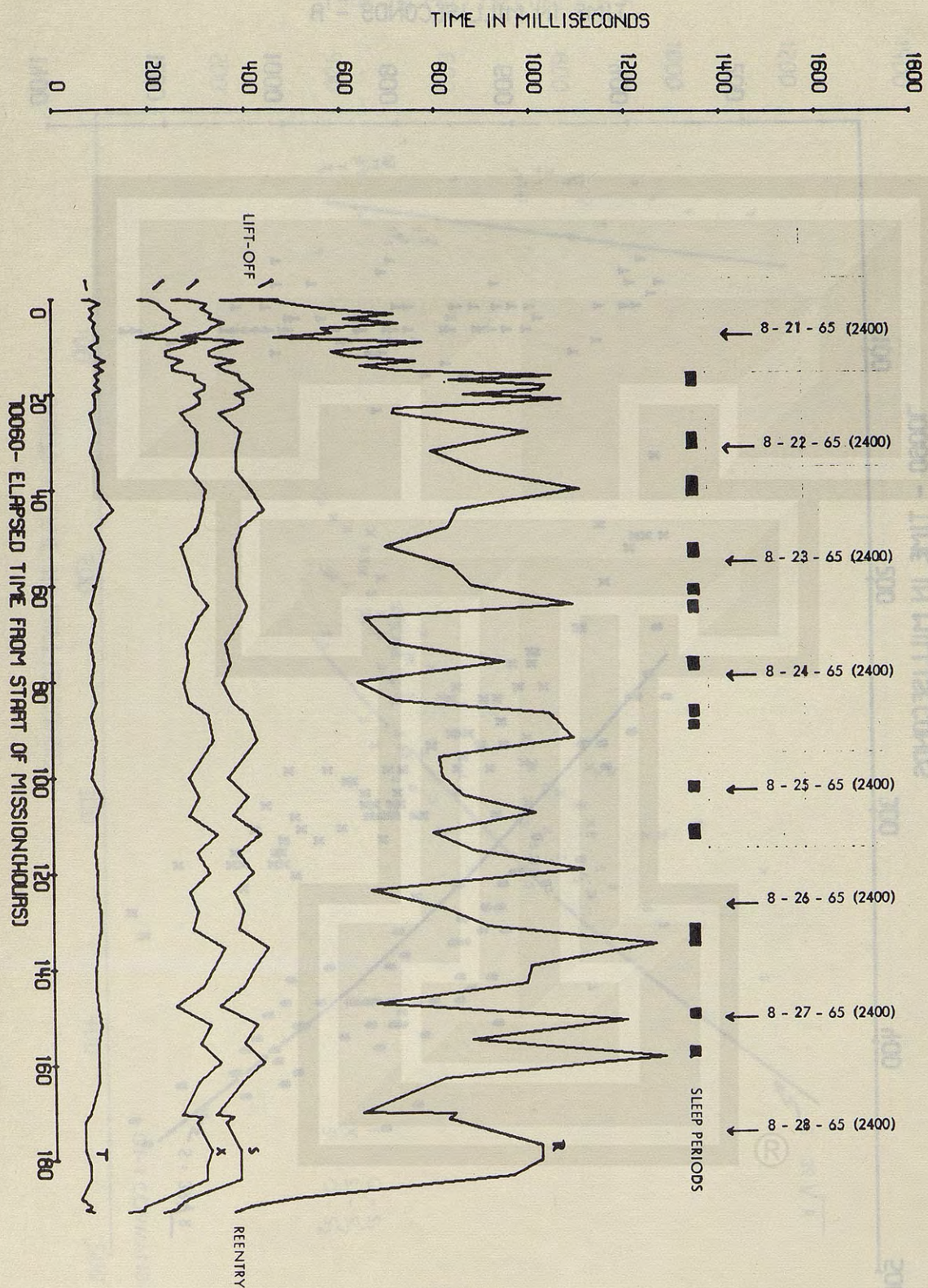


Fig.
3

TIME IN MILLISECONDS

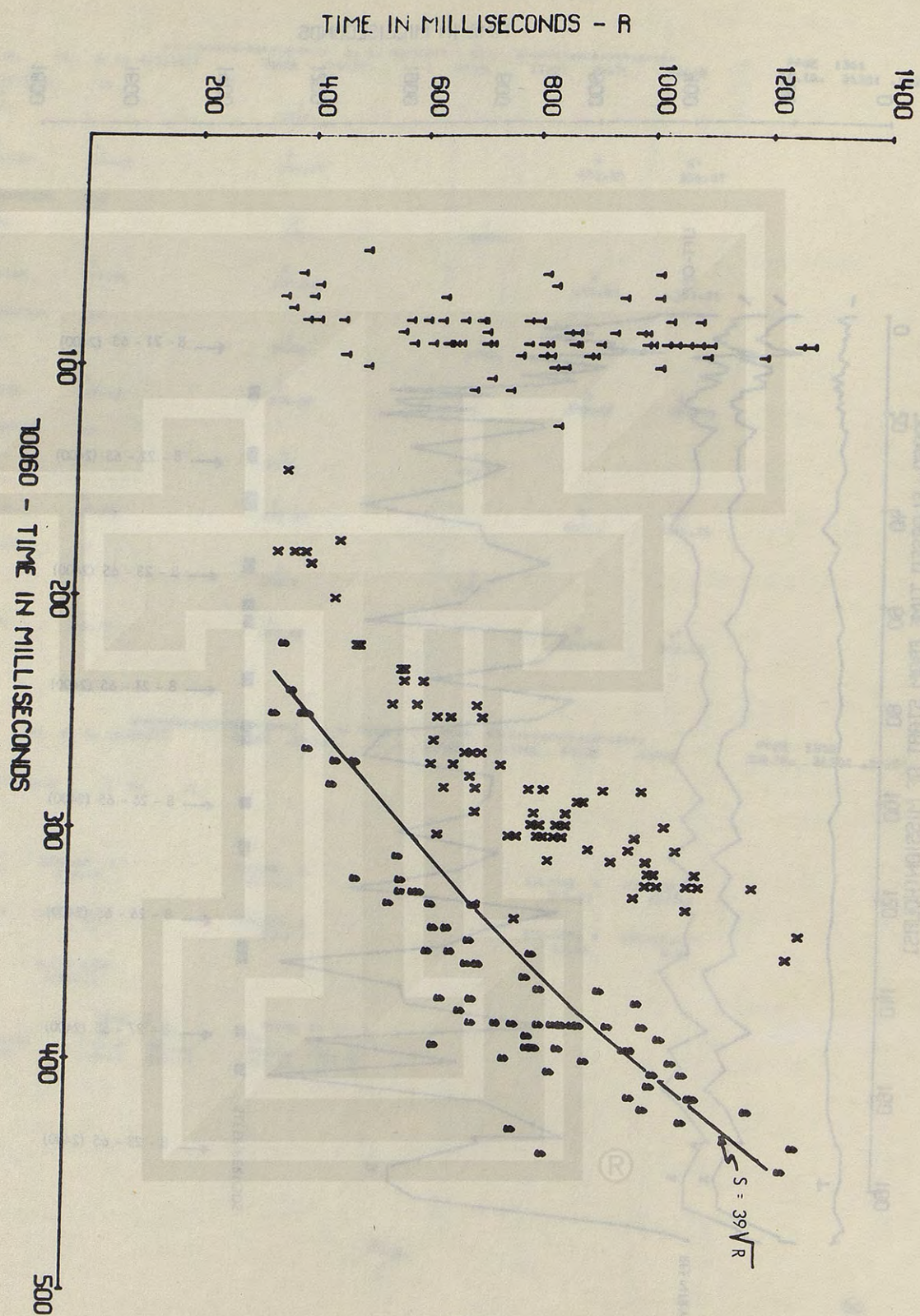


Fig. 4

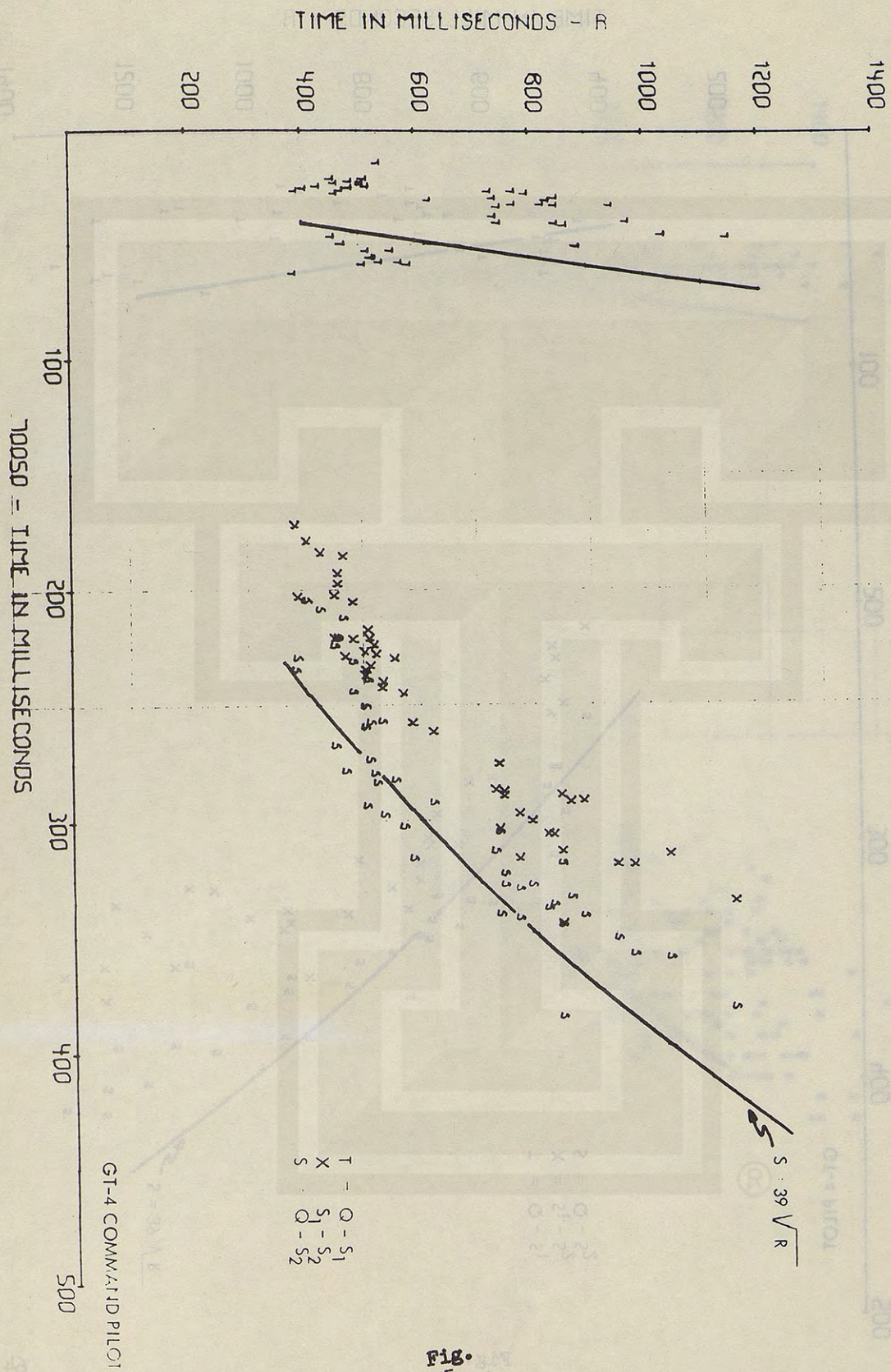


Fig. 5

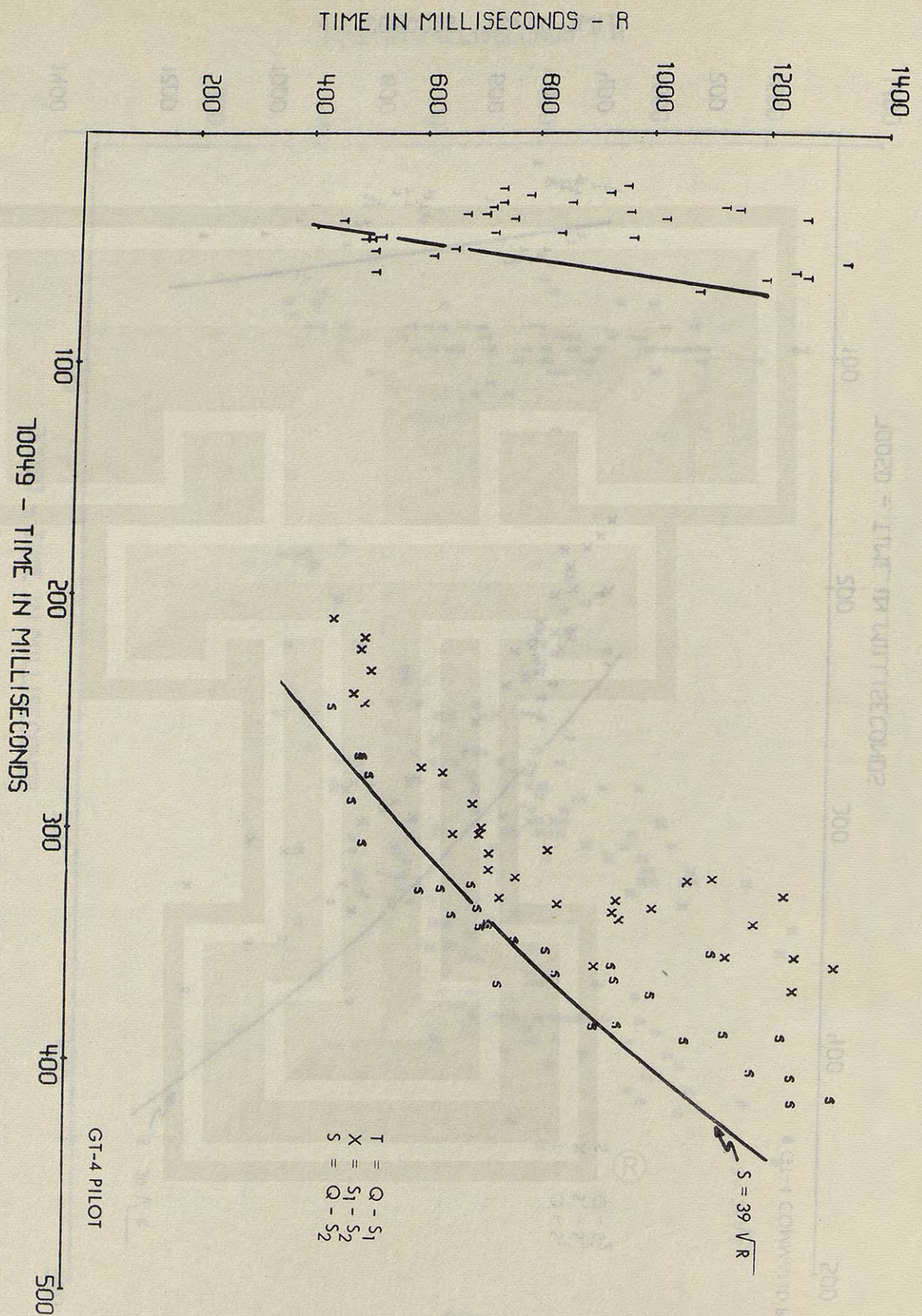


Fig.
6

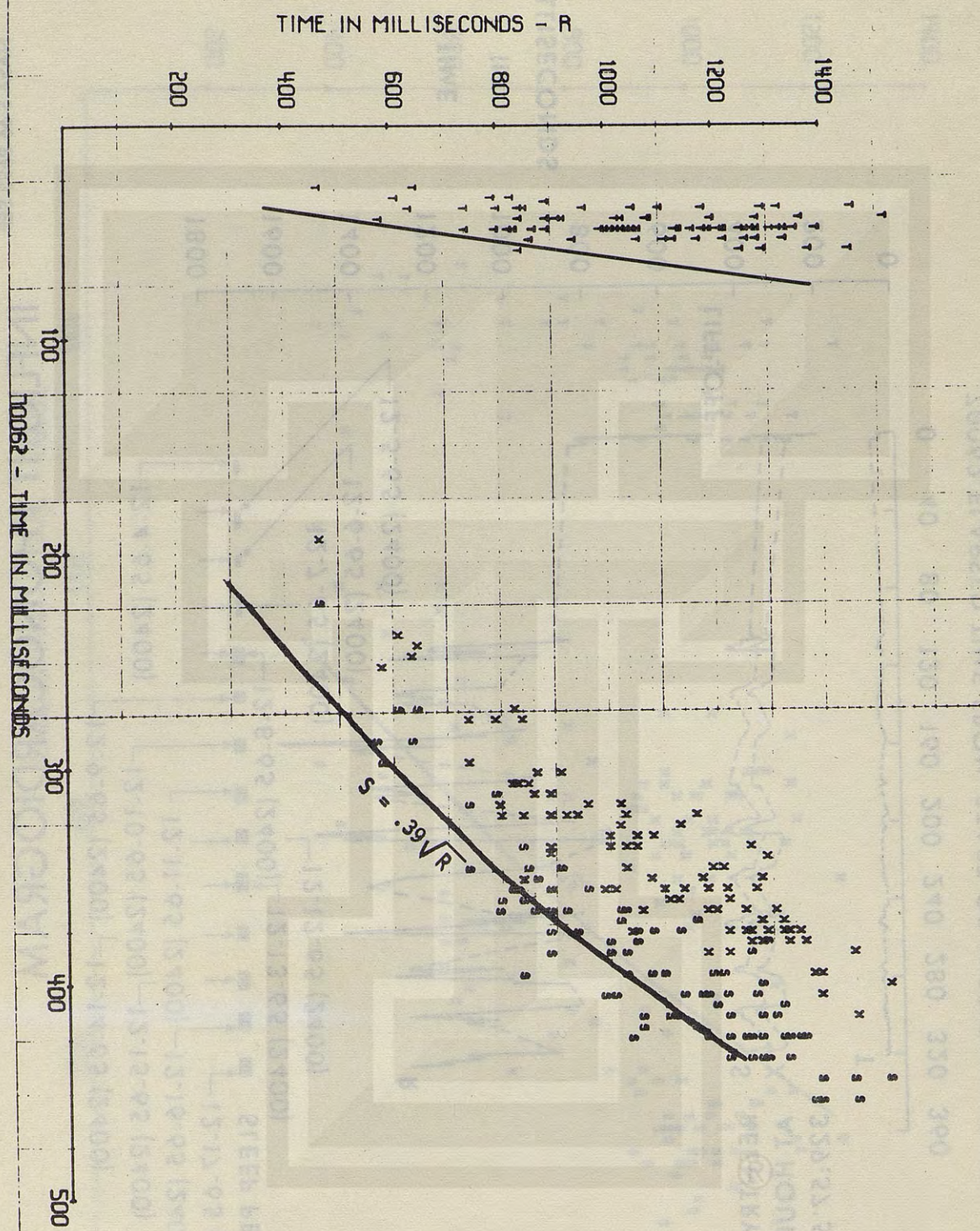
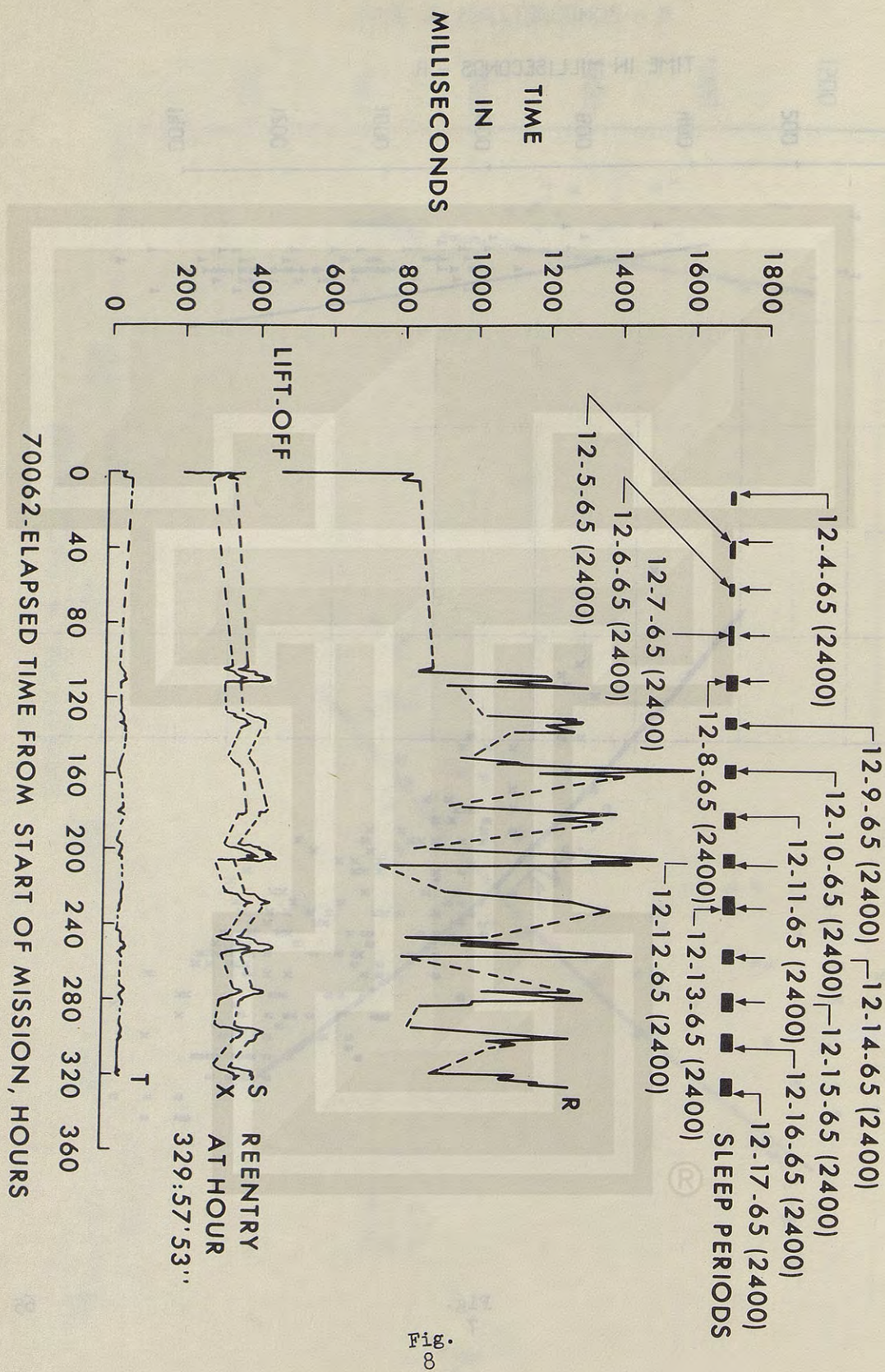


Fig.
7

INFLIGHT PHONOCARDIOGRAM

69



INFLIGHT PHONOCARDIOGRAM

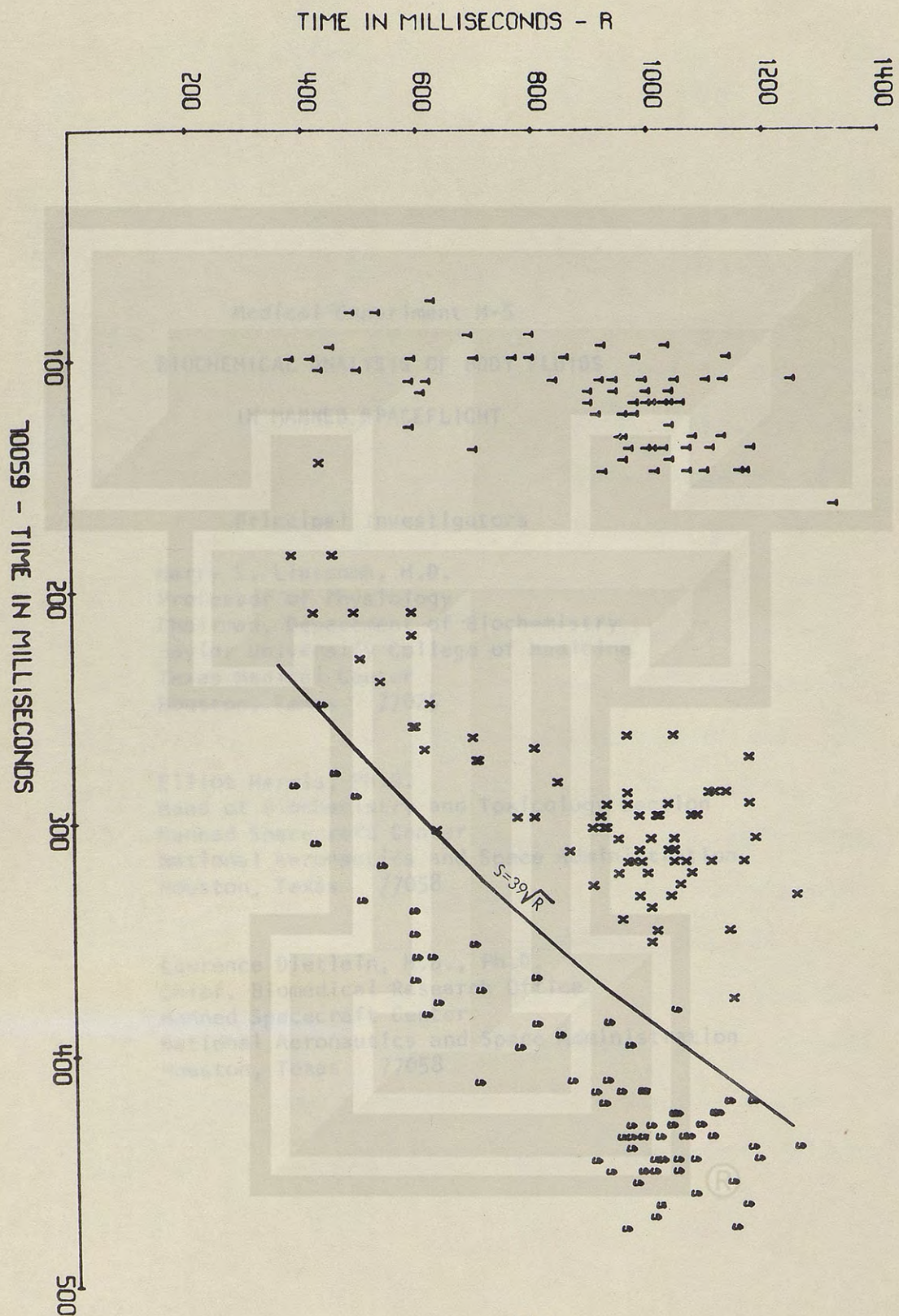


Fig.
9

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 pro-

tection 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 diagrammatic 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 norepinephrine 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.

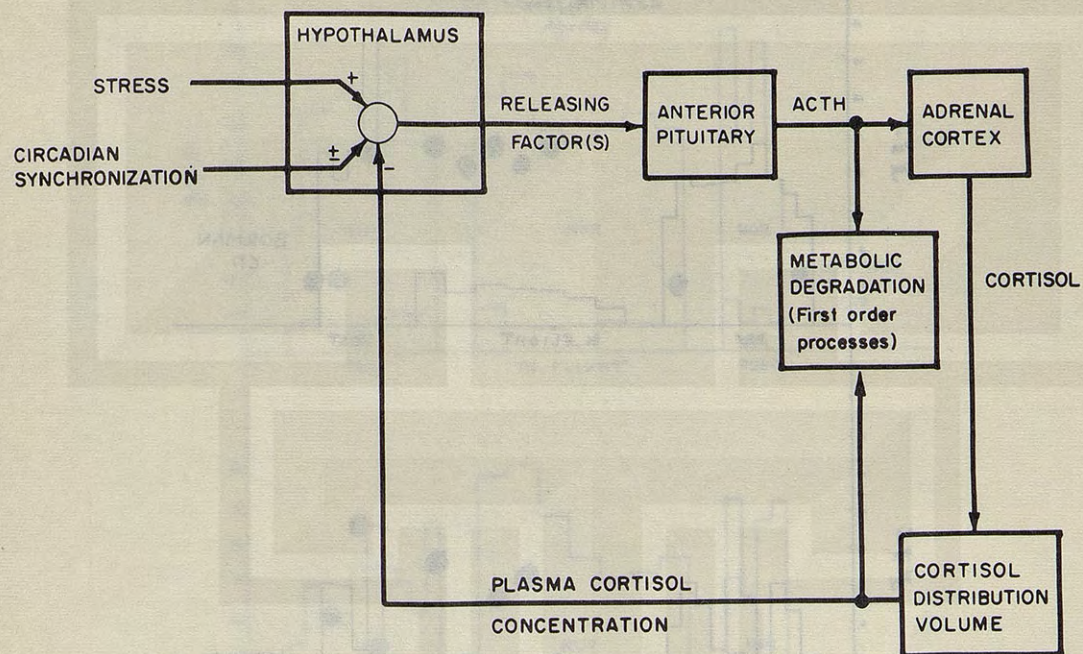


Fig.
2

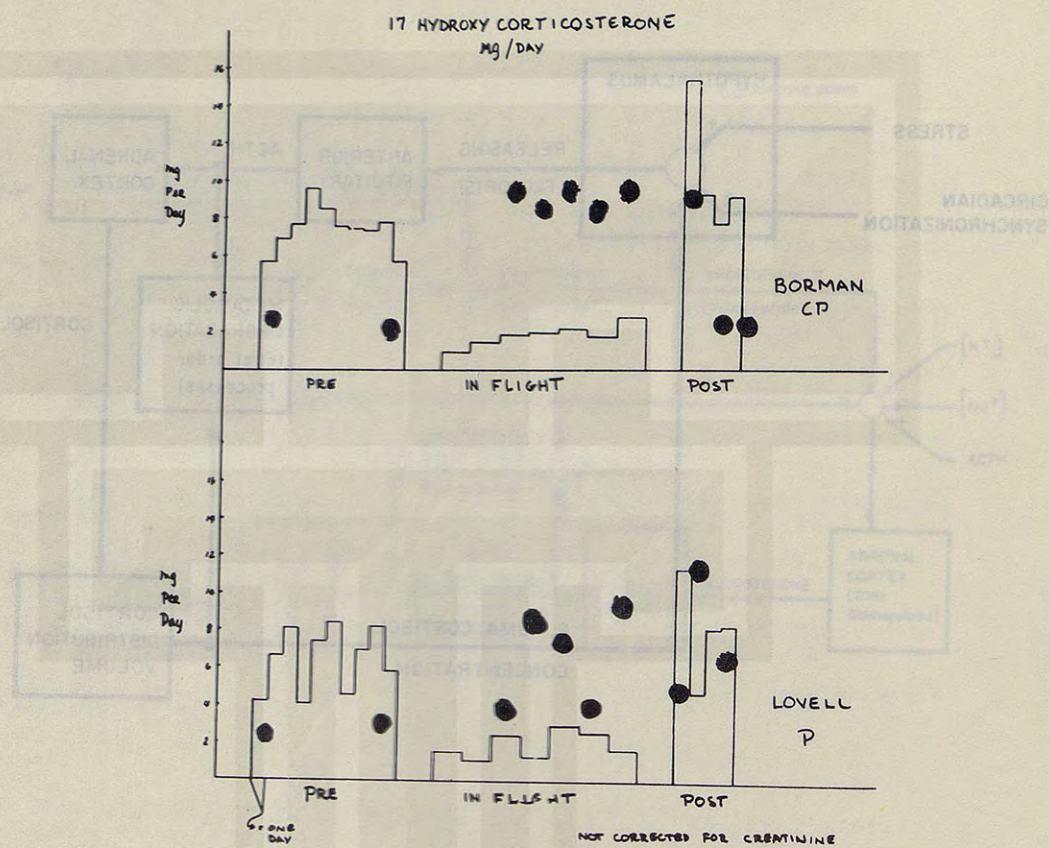


Fig.
3

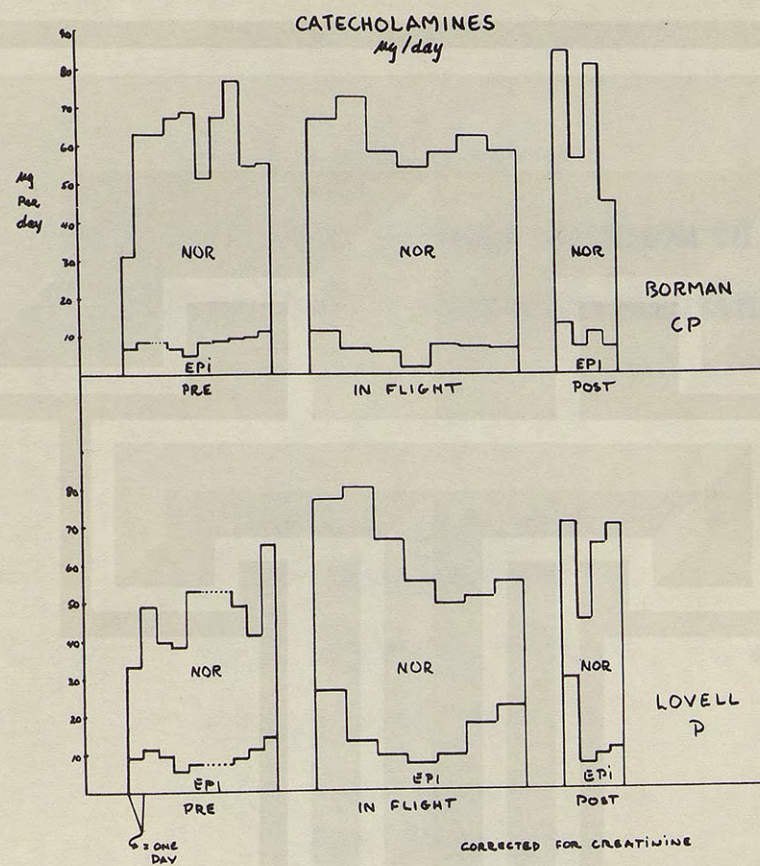


Fig.
4

MEDICAL EXPERIMENT M-6
REVIEW OF MEDICAL FINDINGS OF GEMINI VII
AND RELATED MISSIONS— BONE DEMINERALIZATION

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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.

Central os calcis section. - 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.

Multiple parallel os calcis evaluations. - 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 preflight. 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

	<u>Calcium Intake</u>	<u>Bone Density Change</u>
	(milligrams)	(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	<u>636</u>	<u>-3.59</u>
Mean of Bed Rest		
Subjects	651	-3.47

GEMINI V

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	<u>308</u>	<u>-8.06</u>
Mean of Bed Rest		
Subjects	302	-7.41

GEMINI VII

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	<u>930</u>	<u>-5.86</u>
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 below.....	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 below.....	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

15 mm above	-11.7	-5.1	-24.3	-14.7	-8.9	2.9
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

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)	
Conventional Os Calcis Section	Command Pilot	Pilot	Command Pilot	Pilot	Command Pilot	Pilot
Multiple Os Calcis Sections	-7.80	-10.30	-15.10	-8.90	-2.91	-2.84
Range of Changes in Multiple Os Calcis Sections	-6.82	-9.25	-10.27	-8.88	-2.46	-2.54
Section of Talus	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
Multiple Sections of Hand Phalanx 5-2	-10.69	-12.61	-13.24	-9.87	-7.06	-4.00
Range of Changes in Hand Phalanx 5-2	-11.85	-6.24	-23.20	-16.98	-6.78	-7.83
Multiple Sections of Hand Phalanx 4-2	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
Range of Changes in Hand Phalanx 4-2	-4.19	-8.65	-9.86	-11.80	-6.55	-3.82
Section of Capitate	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
	-4.48	-17.64	-17.10	-16.80	-4.31	-9.30

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

TABLE IV

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	-12.2
4 mm above	-10.1	-0.5	-20.6	-20.2	-12.1	-6.5
5 mm above	-10.2	-1.9	-19.6	-20.9	-6.8	-14.9
6 mm above	-9.8	-3.8	-21.3	-18.3	-3.5	-7.8
7 mm above	-6.2	-3.5	-21.9	-19.6	-1.8	-6.3
8 mm above	-4.4	-3.4	-23.3	-17.9	-3.3	-5.0
9 mm above	-3.5	-5.1	-23.1	-22.0	-4.7	-4.2
10 mm above	-7.6	-3.3	-23.5	-17.3	-4.3	-3.5
11 mm above	-7.8	-4.6	-23.5	-15.8	-3.8	-2.2
12 mm above	-10.7	-7.1	-24.2	-14.2	-4.9	-2.3
13 mm above	-12.2	-5.5	-26.1	-15.5	-6.2	-4.2
14 mm above	-10.6	-5.4	-24.3	-0.4	-10.7	-2.5
15 mm above	-11.7	-5.1	-24.3	-14.7	-8.9	-7.9
16 mm above	X	-7.5	-23.8	-16.5	-8.4	X
17 mm above	X	-8.4	-25.9	X	-7.1	X

TABLE III

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

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.

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Fig. 1

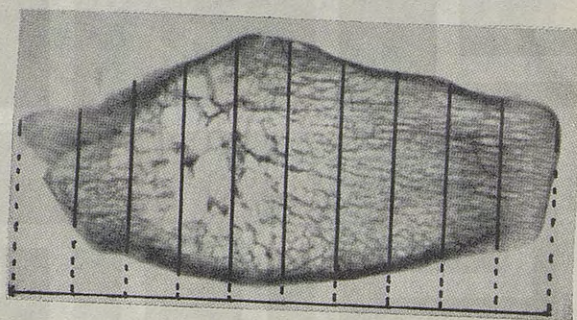


Fig. 2



Fig. 3

114

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



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

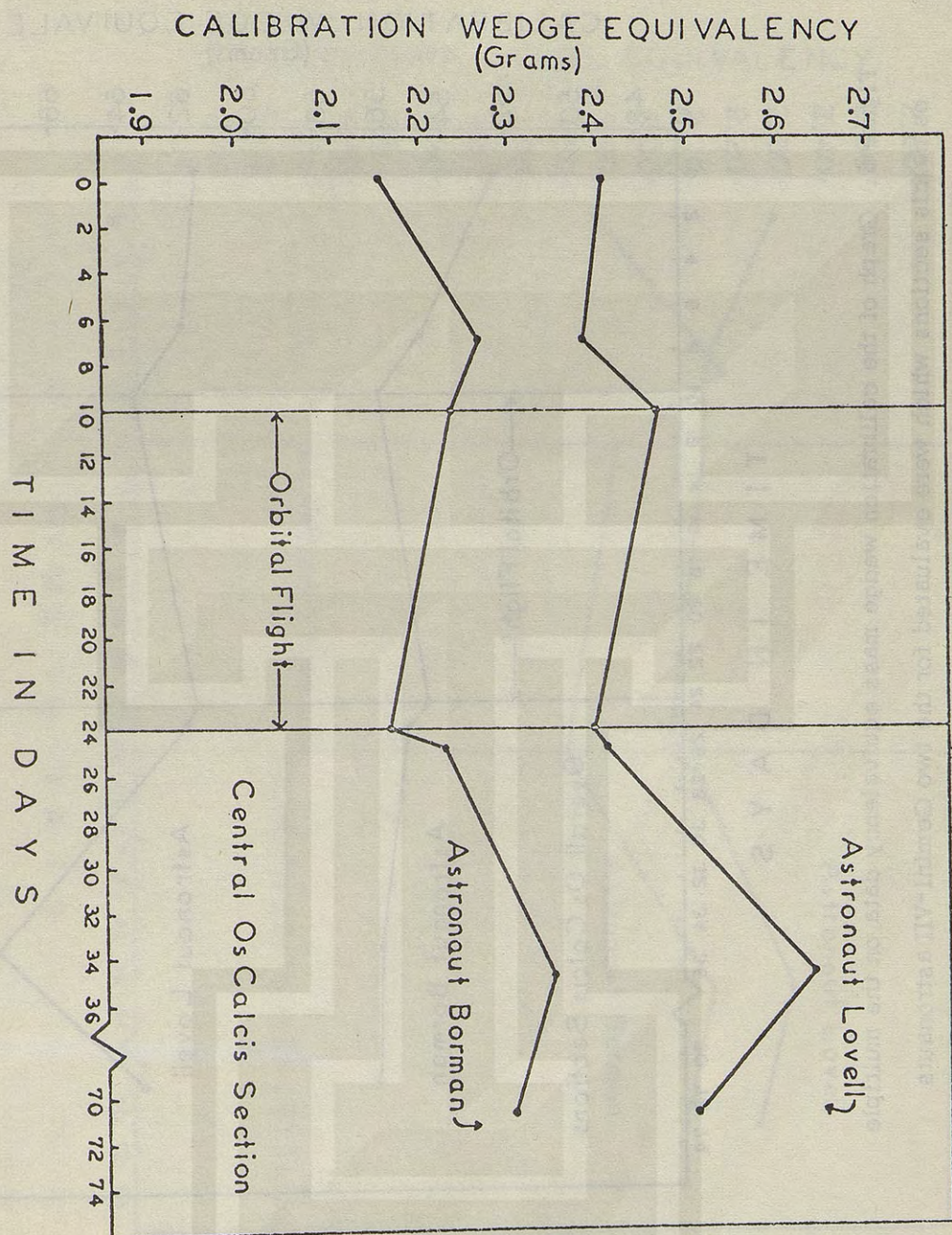


Fig. 5

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

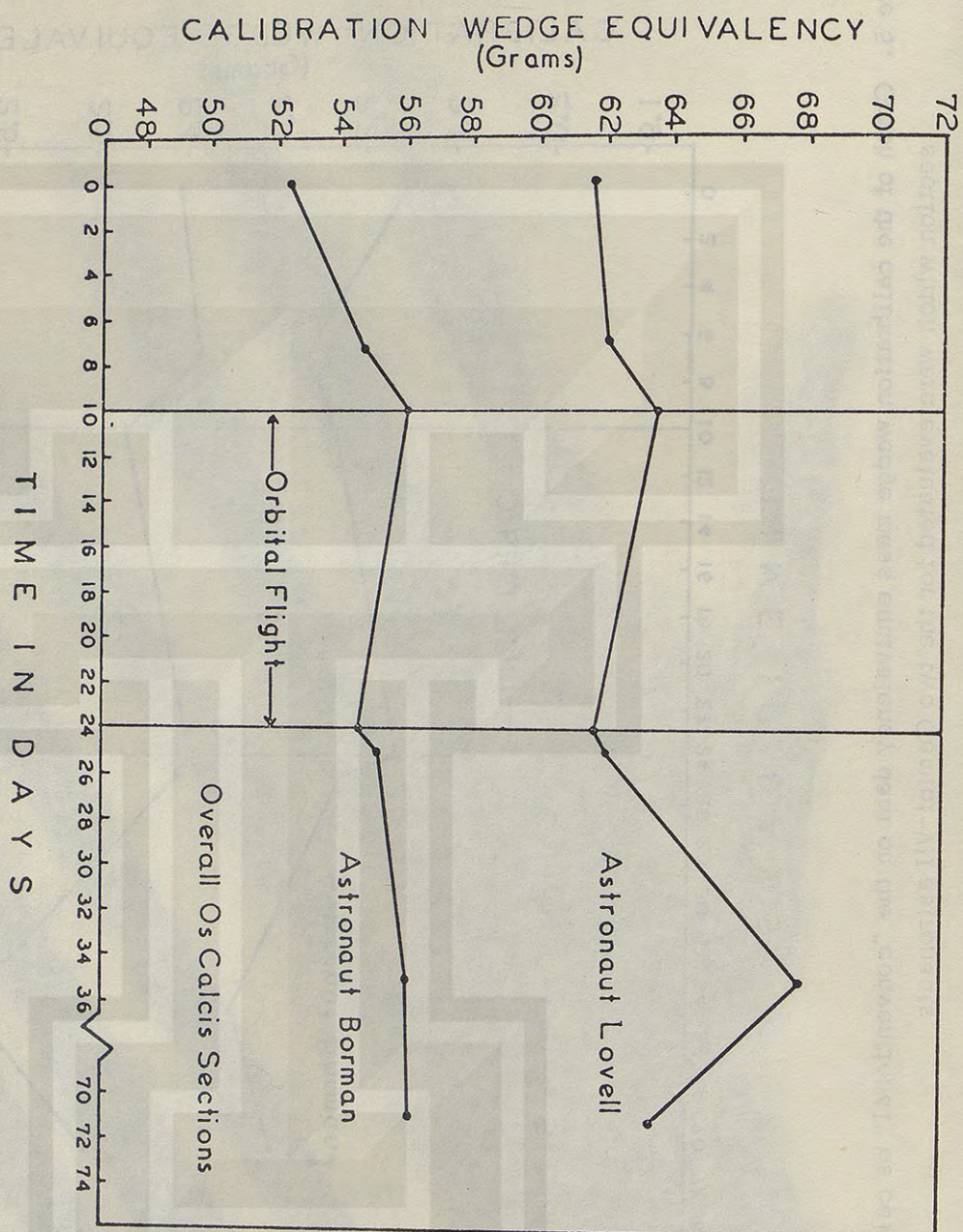


Figure 6. Graph of the calibration wedge mass equivalency data on the multiple os calcis sections which were evaluated for the two Gemini-VII astronauts

Fig. 6

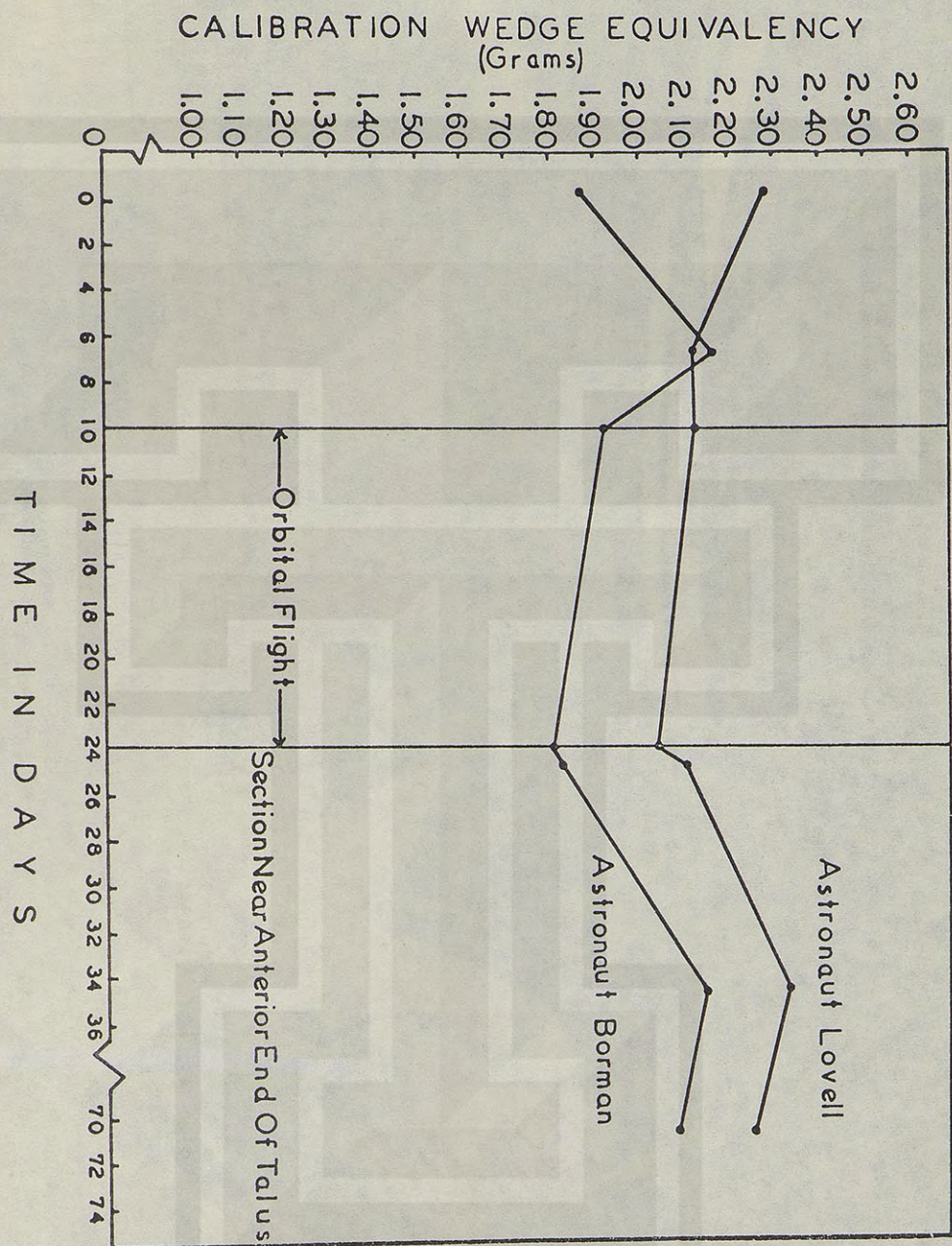


Fig. 7

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

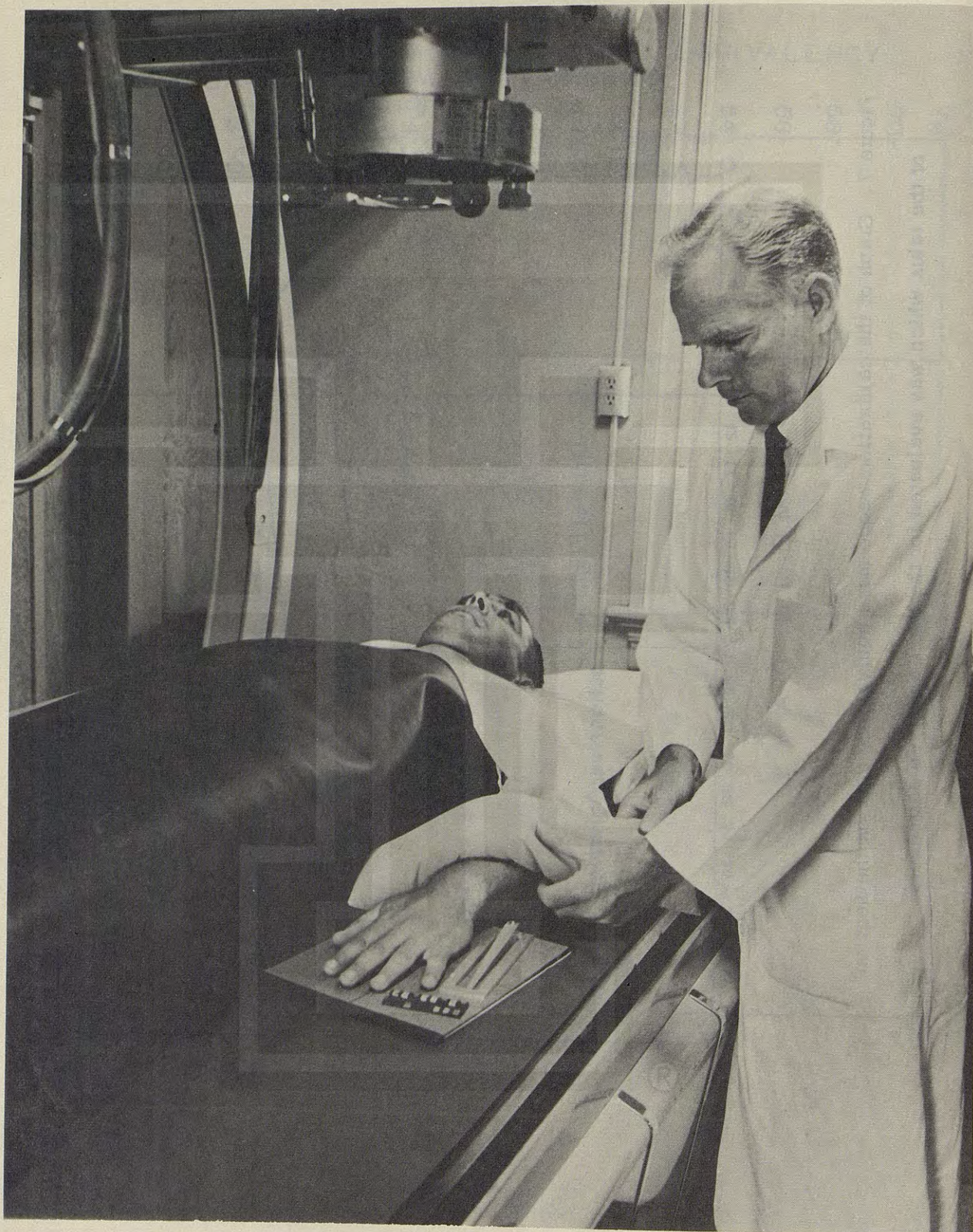


Fig. 8

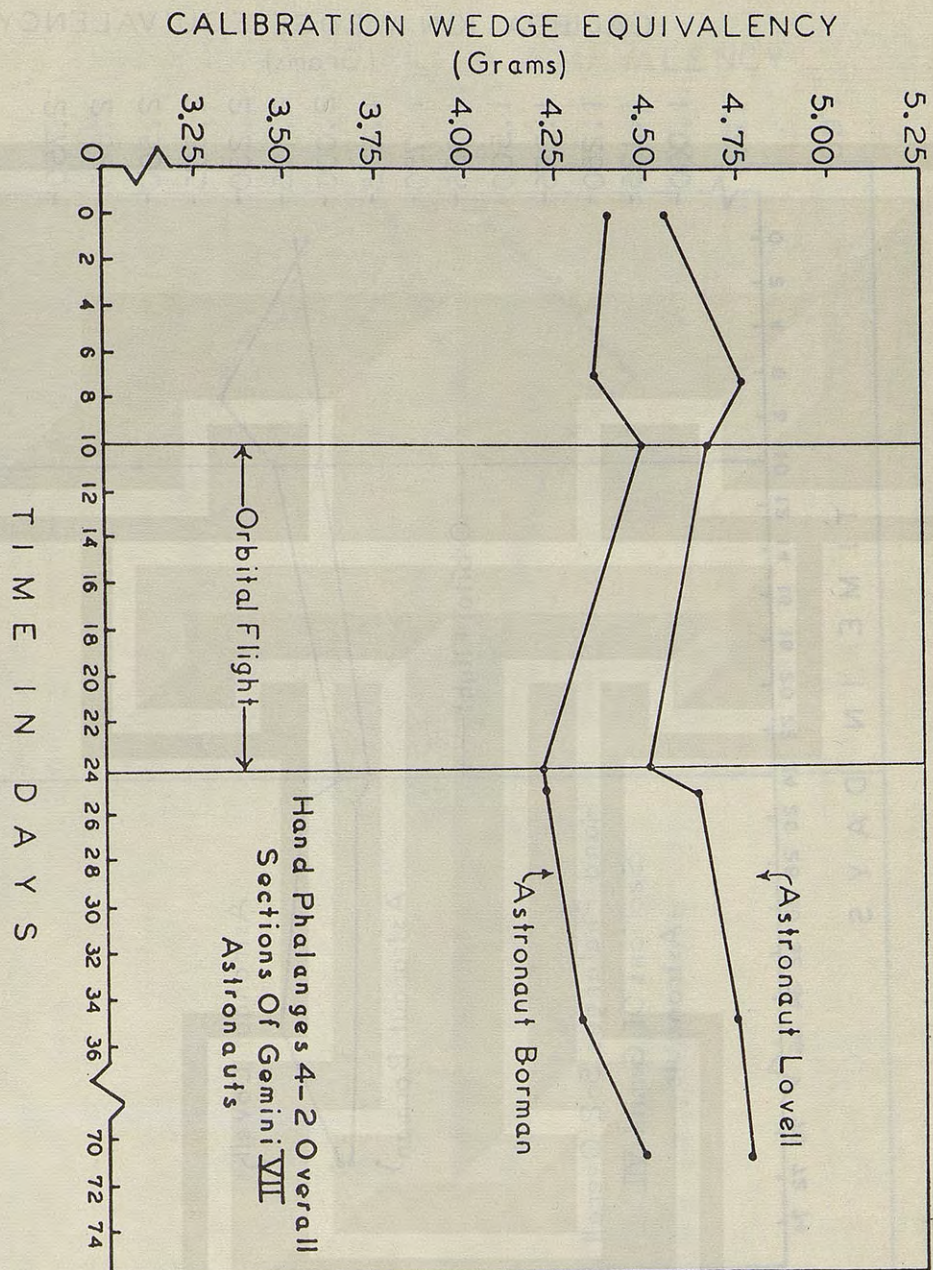


Fig. 9

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

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

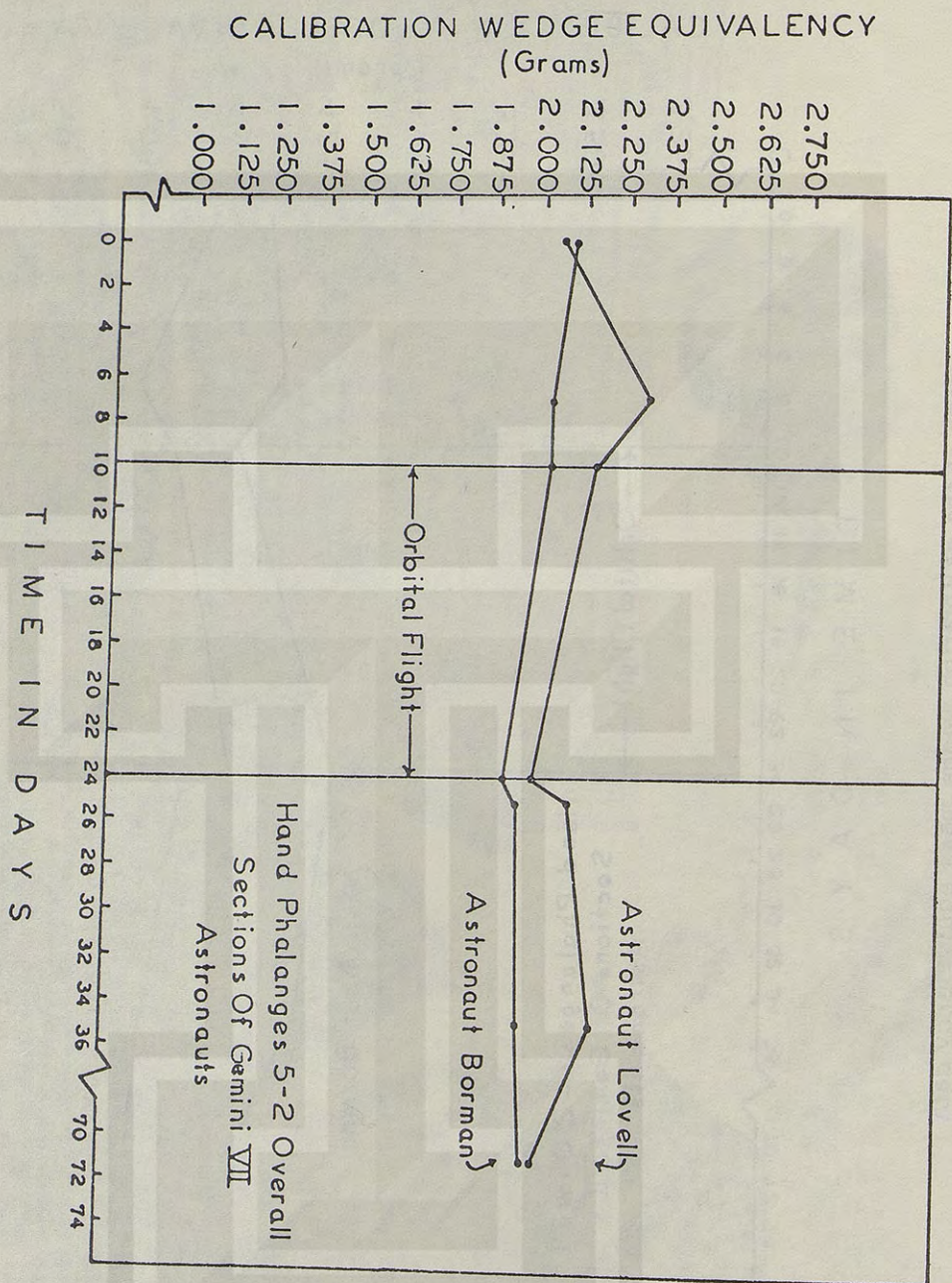
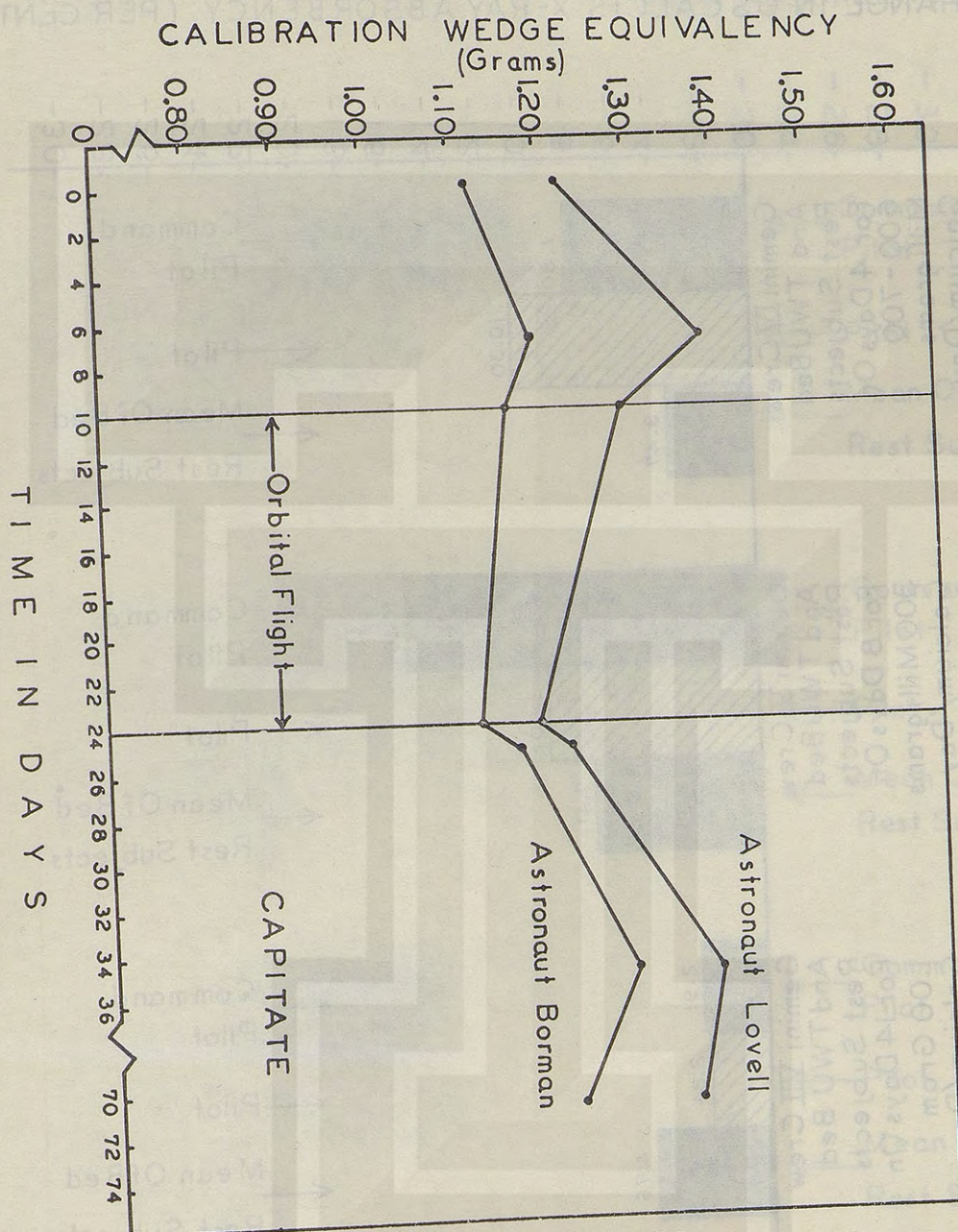


Figure 10. Graph of the calibration wedge mass equivalency data on hand phalanx 5-2 for the two Gemini-VII astronauts

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



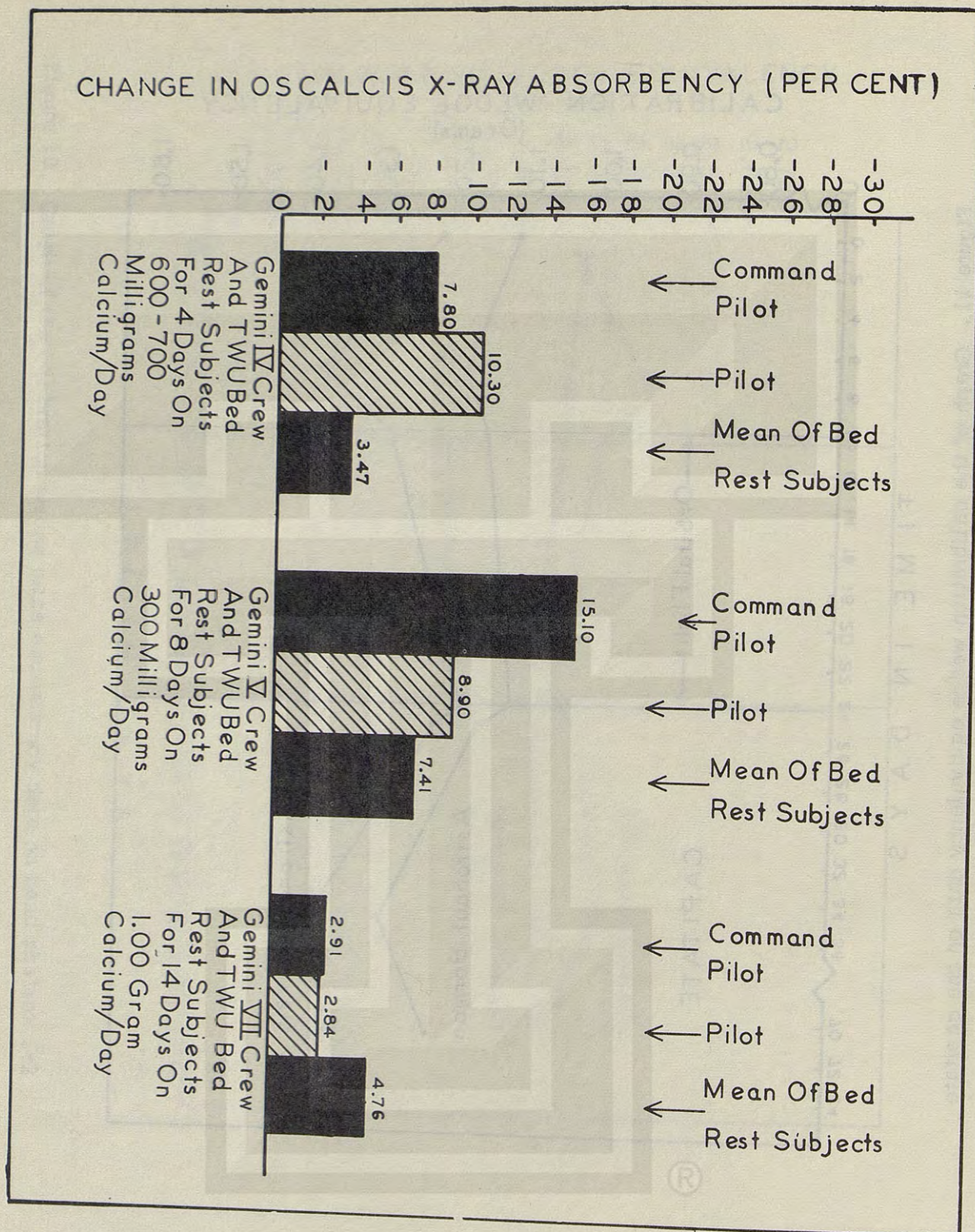


Fig. 12

CHANGE IN HAND PHALANX 5-2 X-RAY ABSORBENCY

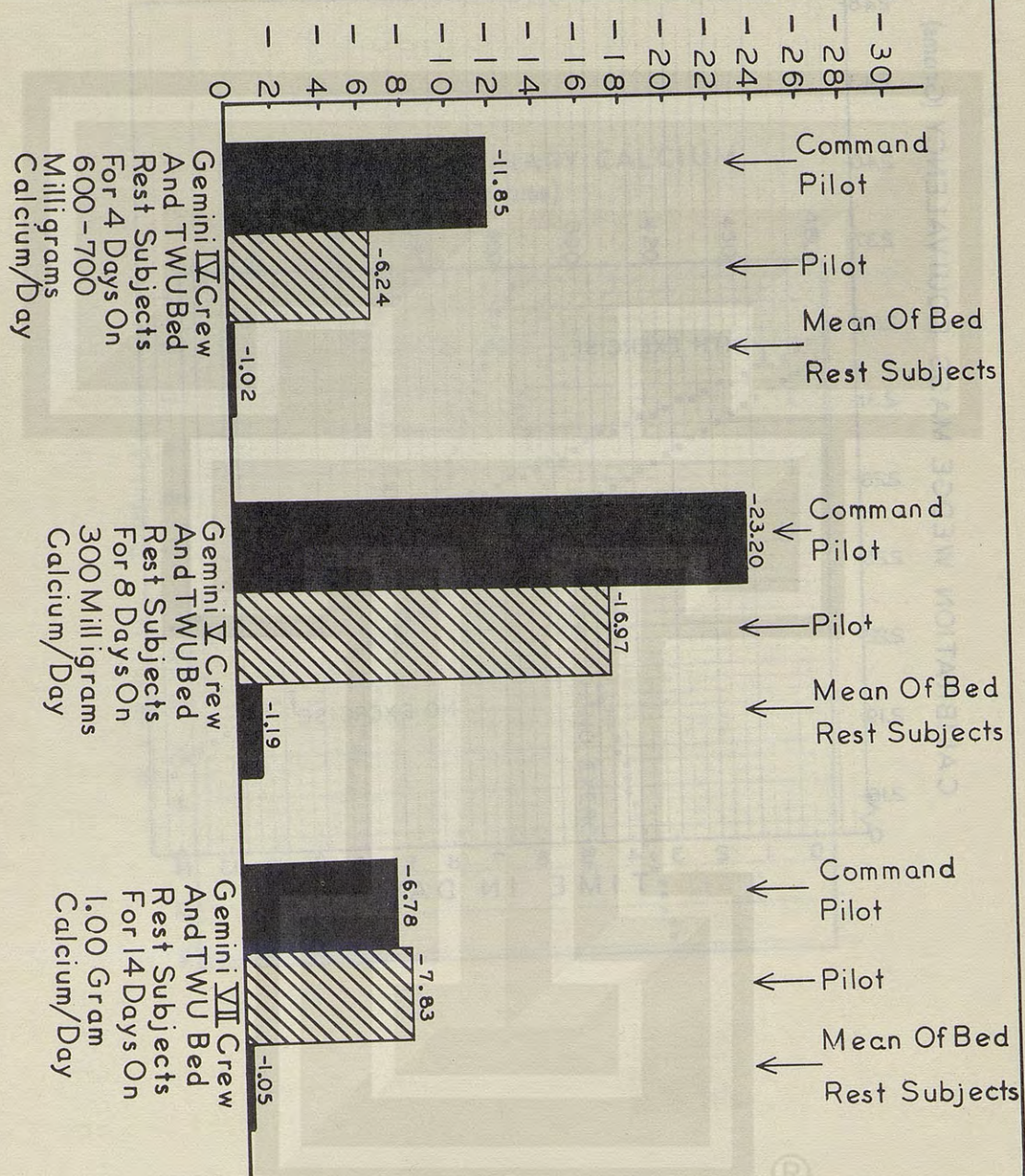


Fig. 13

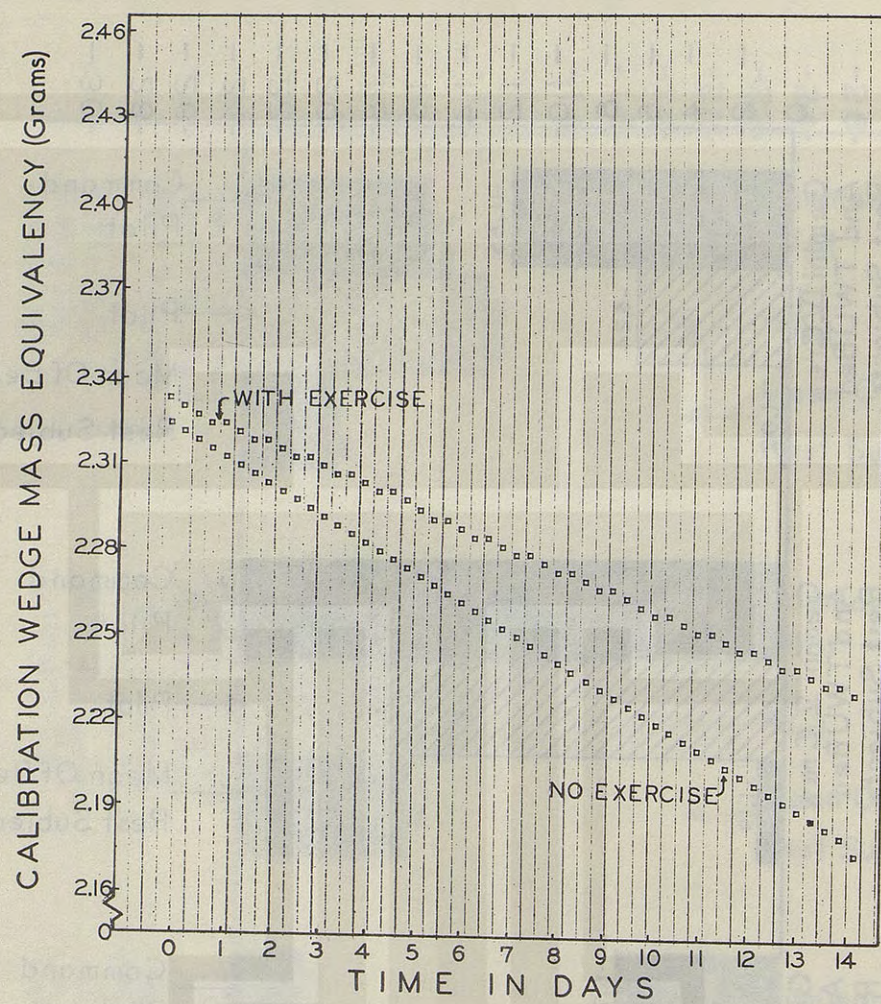


Fig. 14

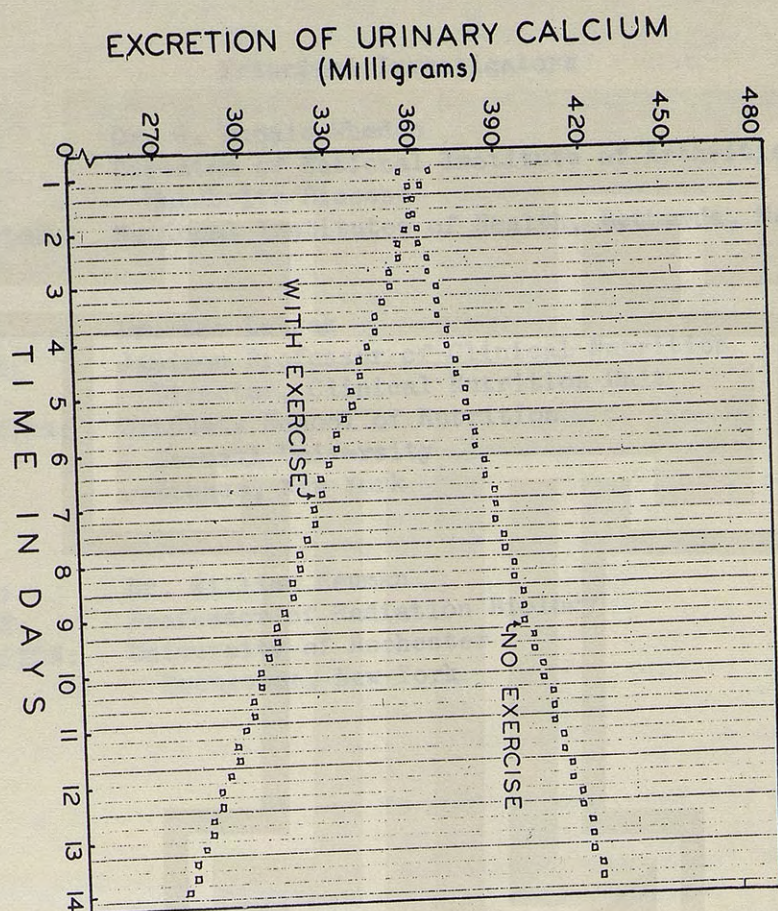


Fig. 15

Medical Experiment M7

CALCIUM AND NITROGEN BALANCE

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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 re-construct 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 wholly 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 Reifenshtein; 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 tendency 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

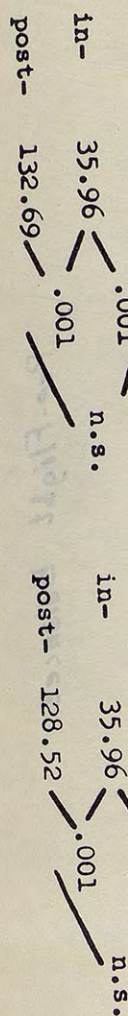


FIGURE 3

ANALYSES PERFORMED

ANALYSES	MATERIAL*	METHOD
Volume	U	a) Routine, pre- and post- flight b) T ₂ O 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	Autoanalyzer 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.

J.L.

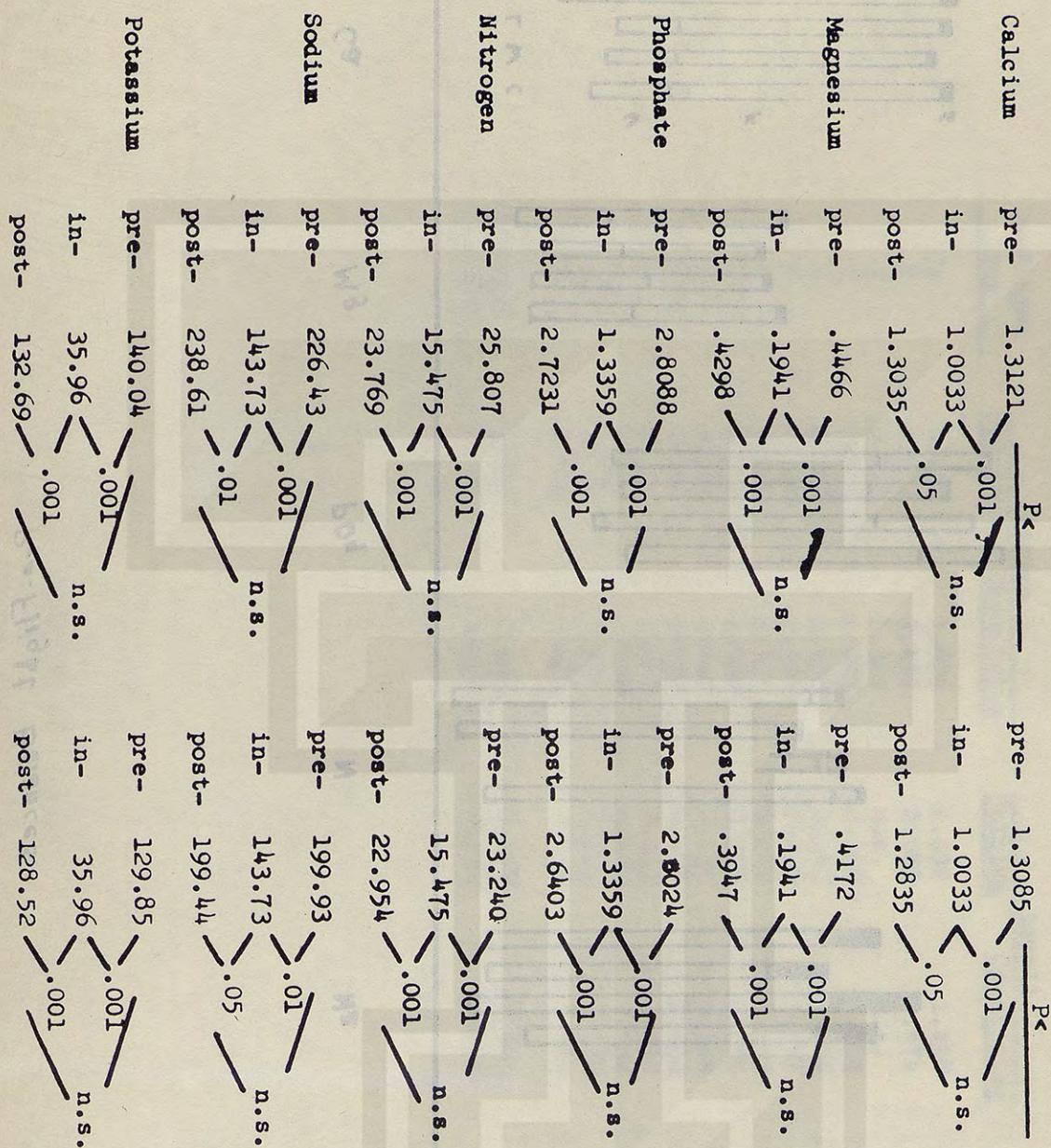


FIGURE 3

ANALYSES PERFORMED

ANALYSES

MATERIAL*

METHOD

FIGURE 5

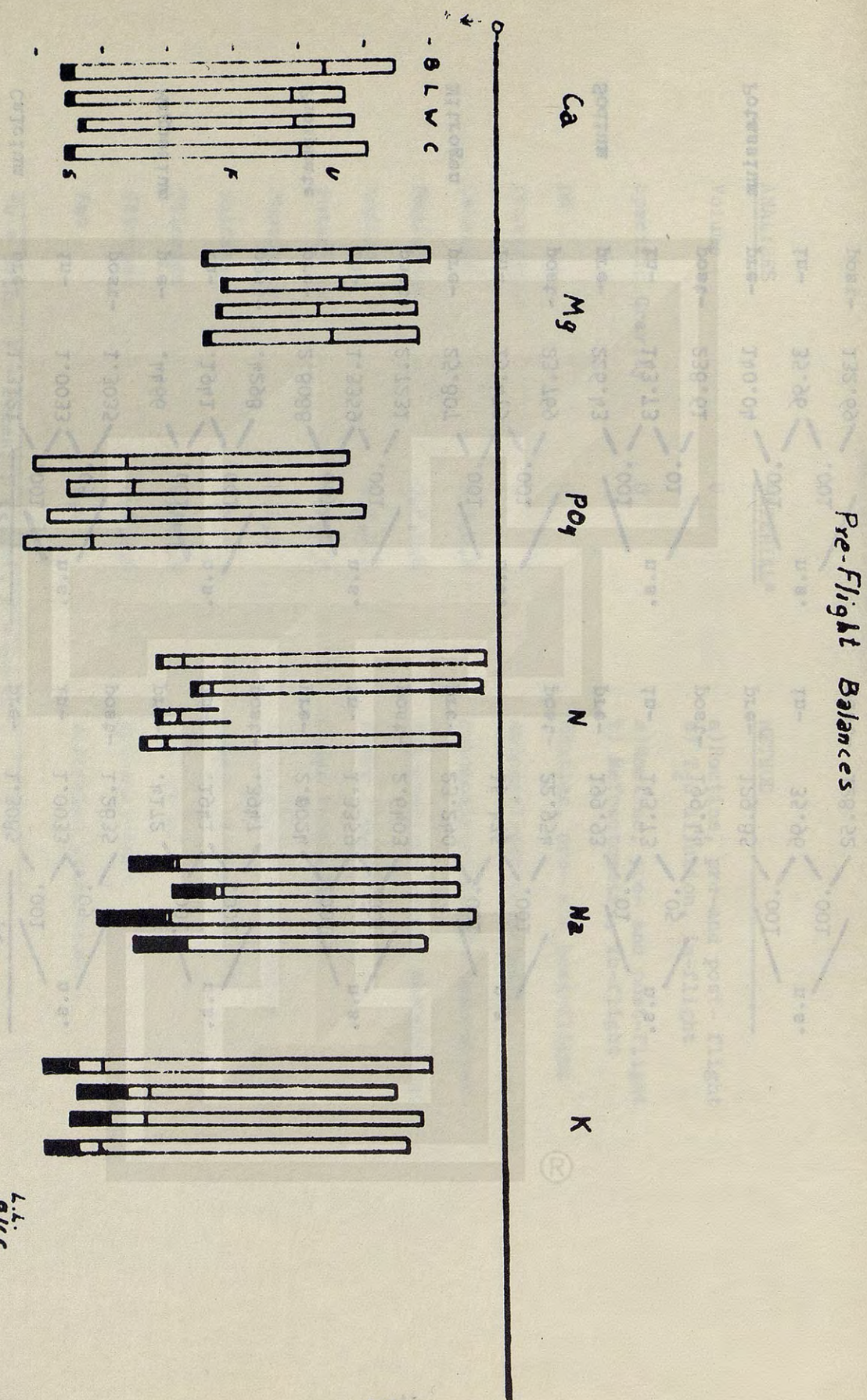


FIGURE 4

UNCORRECTED URINARY EXCRETIONS

In-Flight Day	Borman		Lovell	
	Calcium	Creatinine	Calcium	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

Pre-Flight Balances

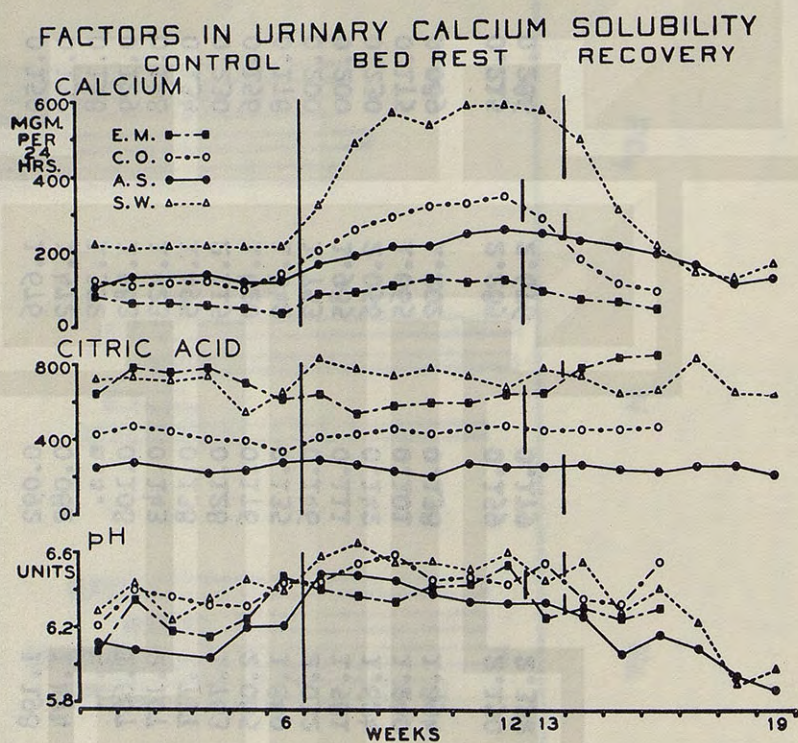
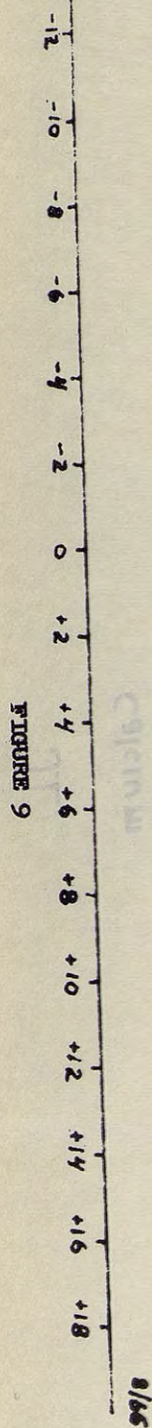


Fig. 118. Effect of immobilization on the urinary excretion of calcium and citric acid and on urinary pH in four normal male subjects. Daily calcium intake was 0.852 gm. for subject E.M., 0.920 gm. for subjects C.O., A.S. and S.W.



URINARY EXCRETION

F.B.

J.L.

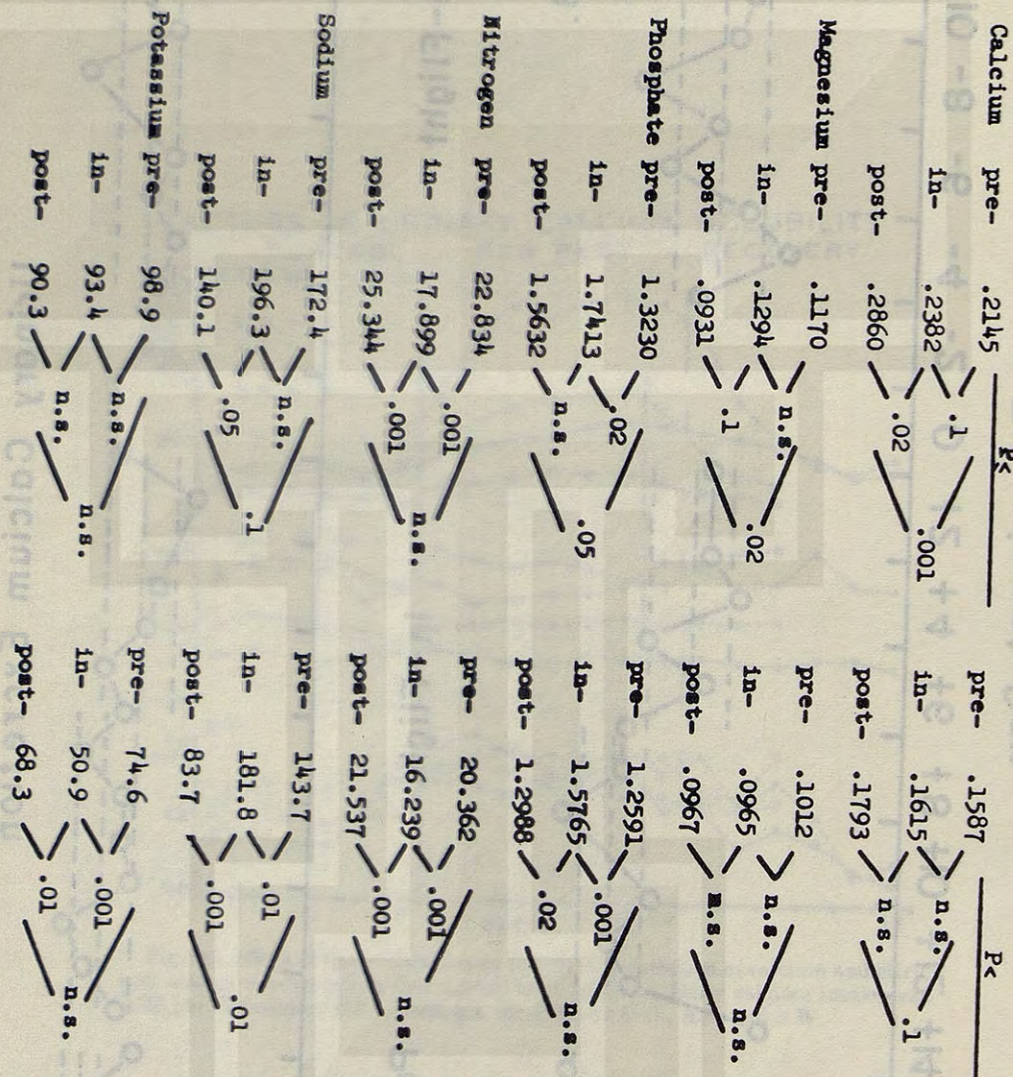


FIGURE 8

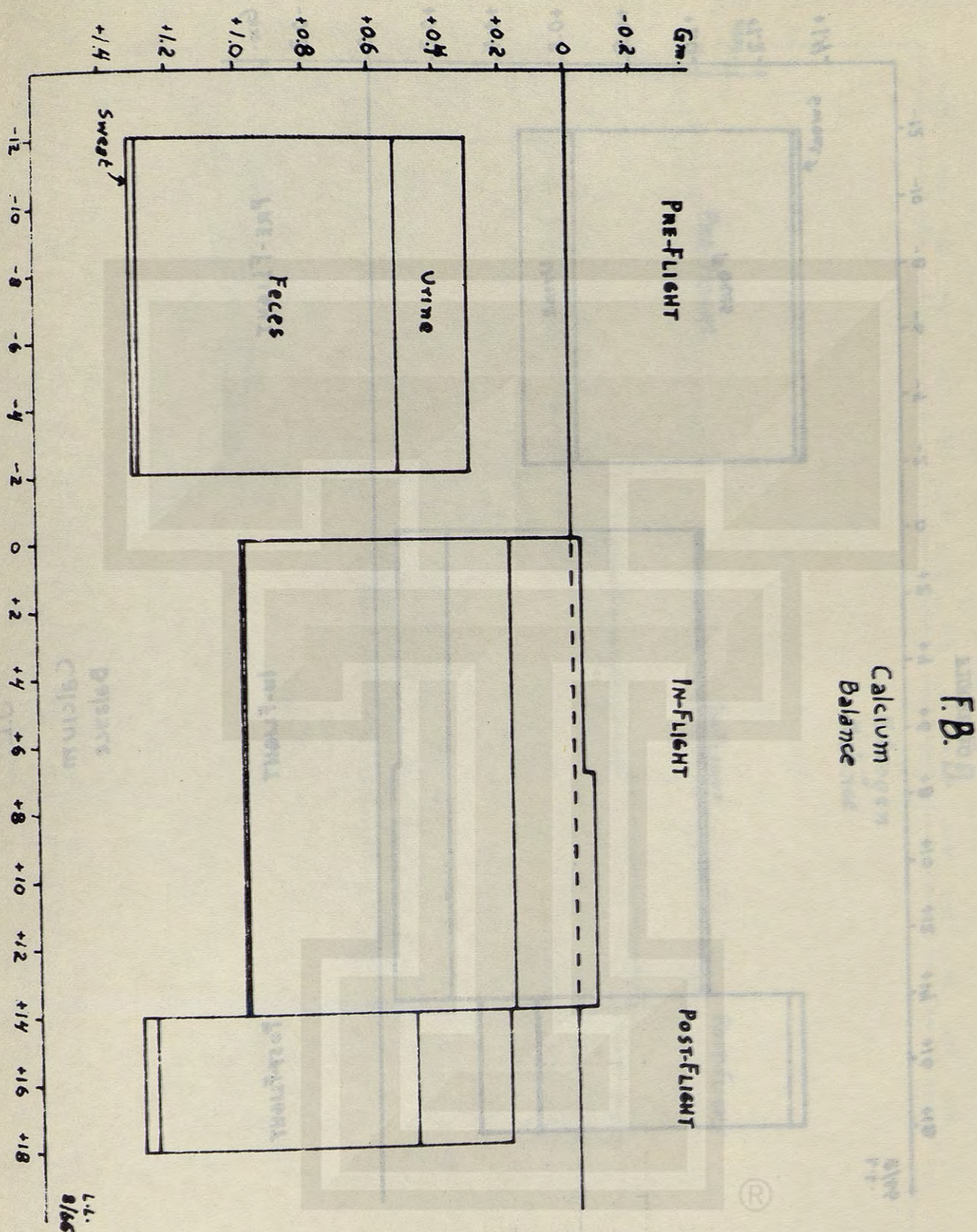


FIGURE 9

URINARY EXCRETION

F.B.

J.L.

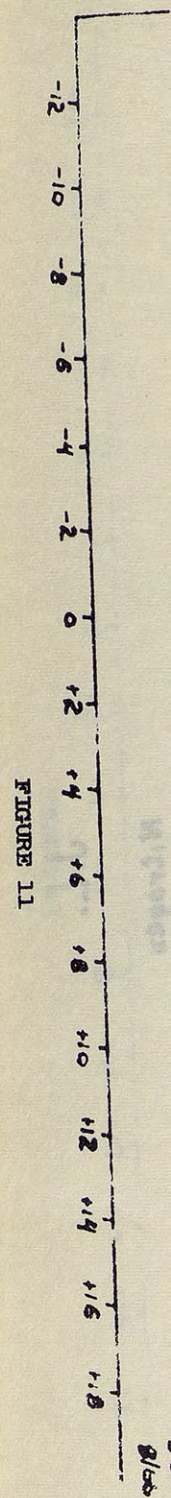


FIGURE 11

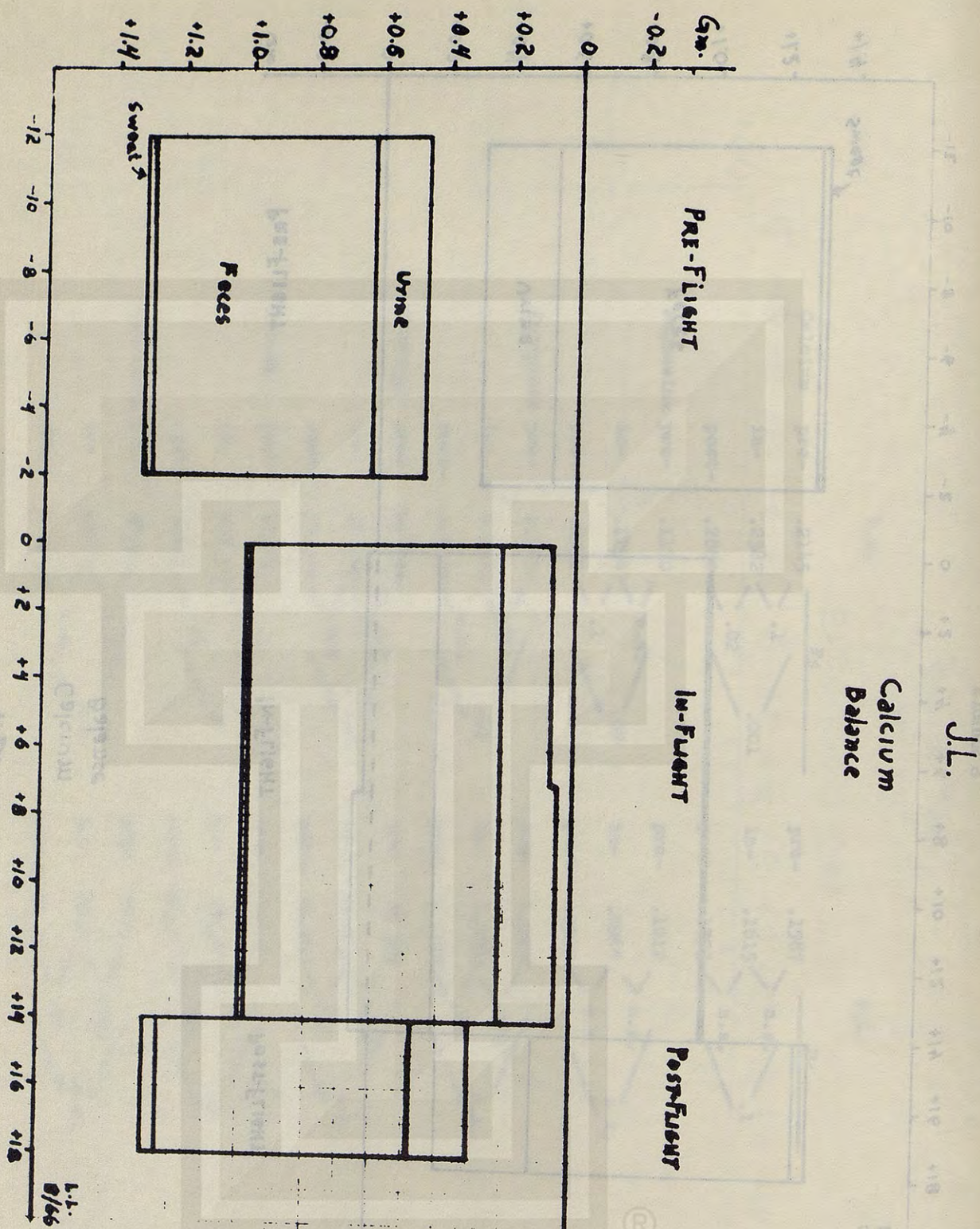


FIGURE 10

F.B. Nitrogen Balance

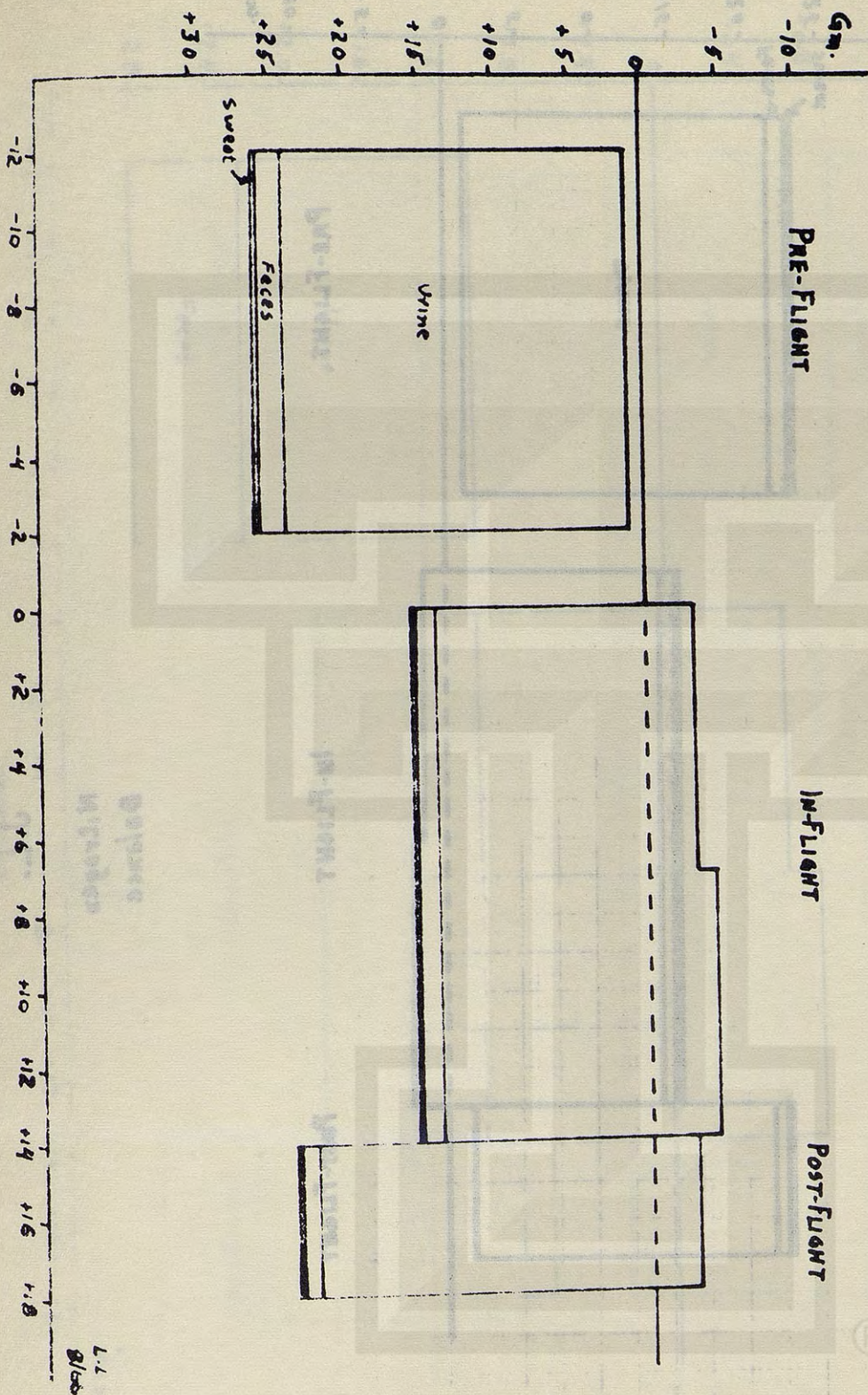


FIGURE 11

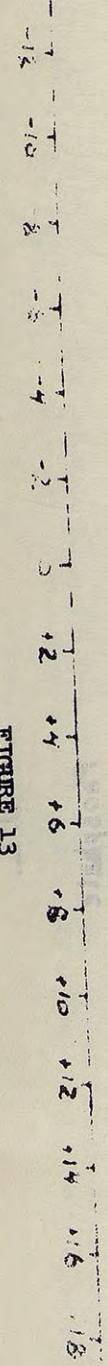


FIGURE 13

J.L.

Nitrogen
Balance

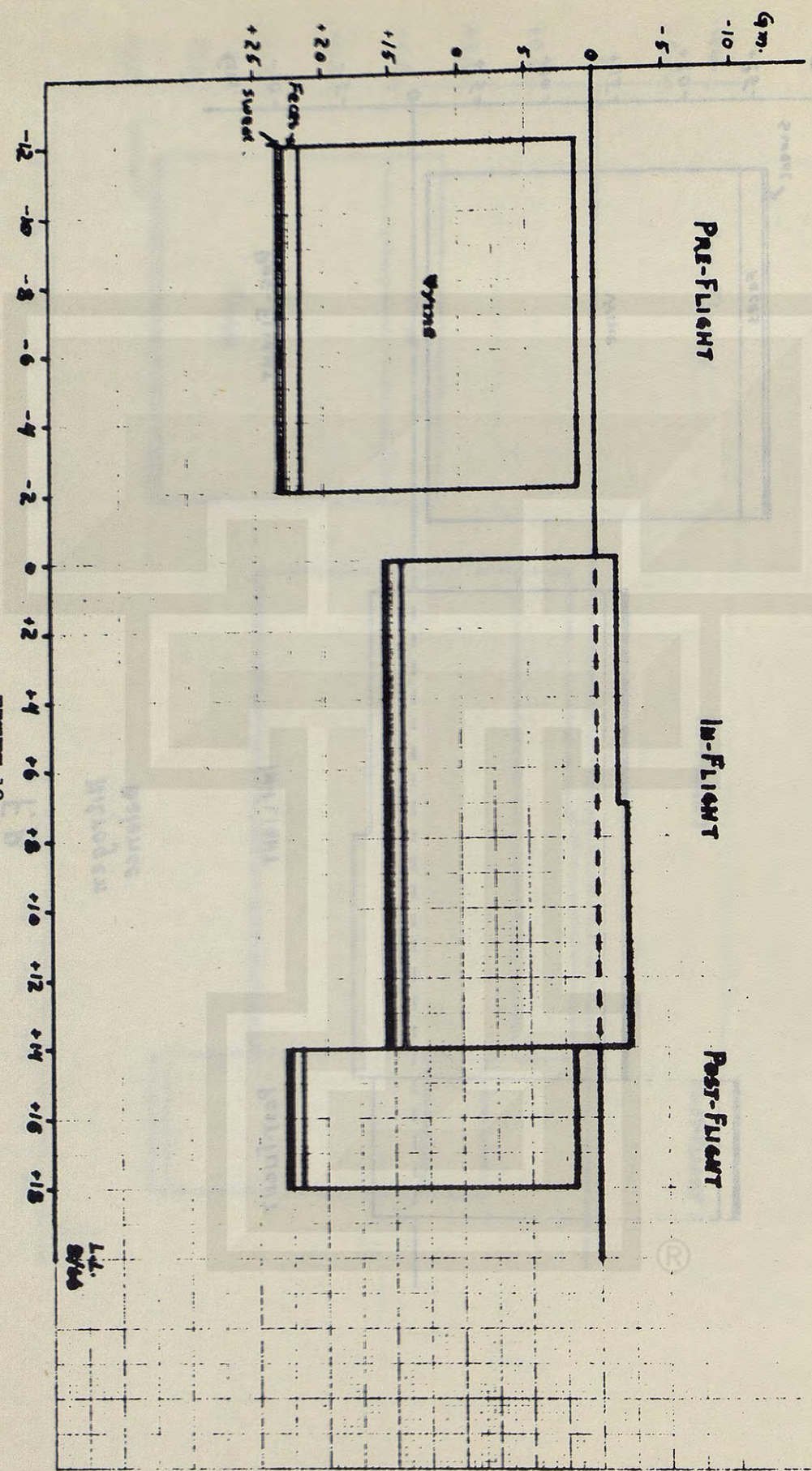


FIGURE 12

K-E ALBANESE & GUIDE LINE 10 5651
NON-REPRODUCIBLE 10 ± 10 TO THE 1/2 INCH

F.B.

Phosphate
Balance

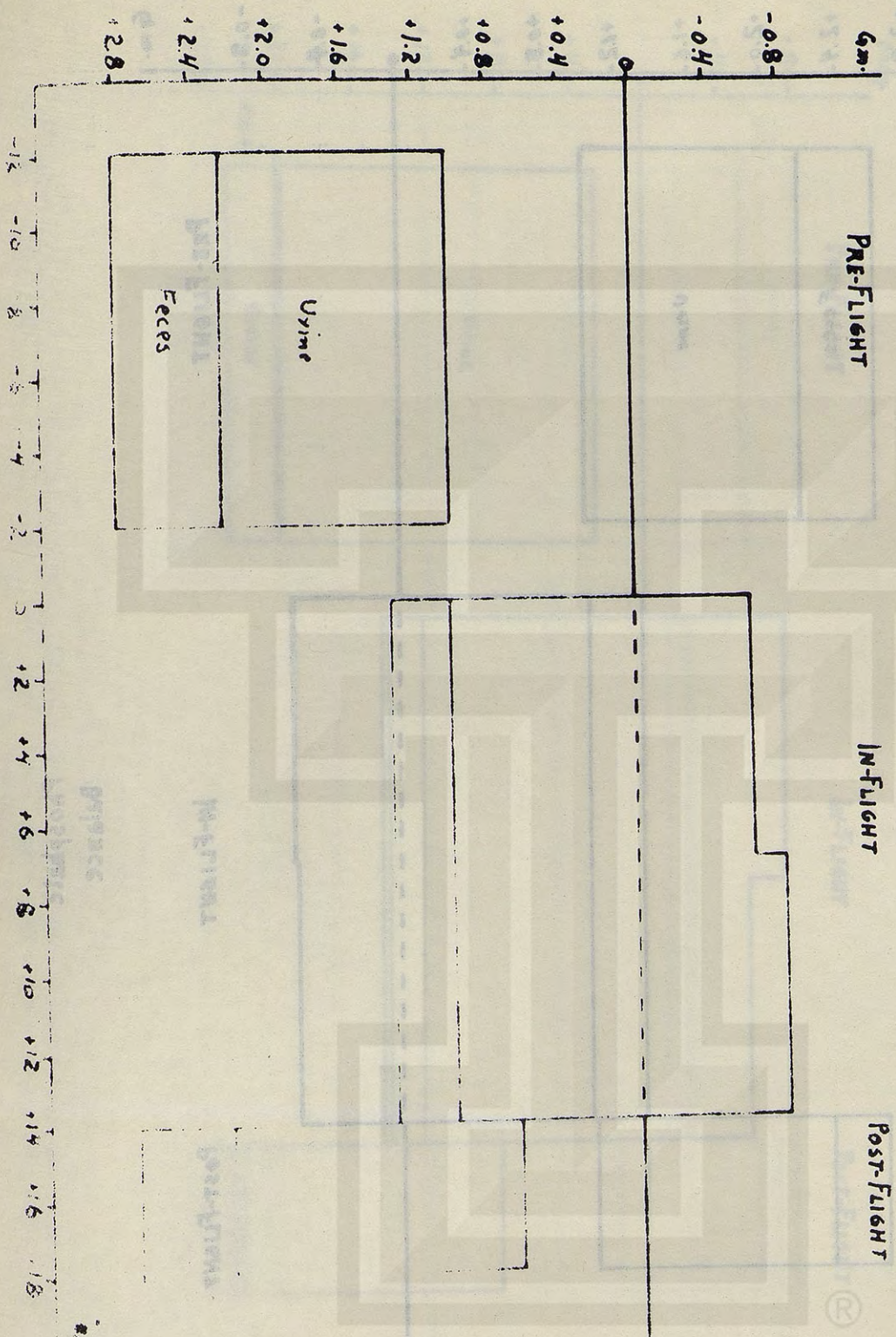


FIGURE 13

J.L.

Nitrogen

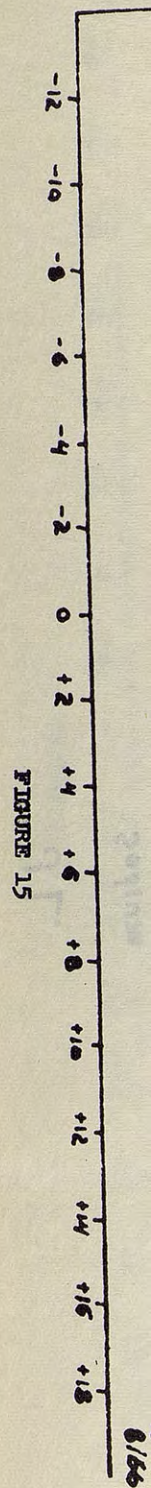


FIGURE 15

J.L.

Phosphate
Balance

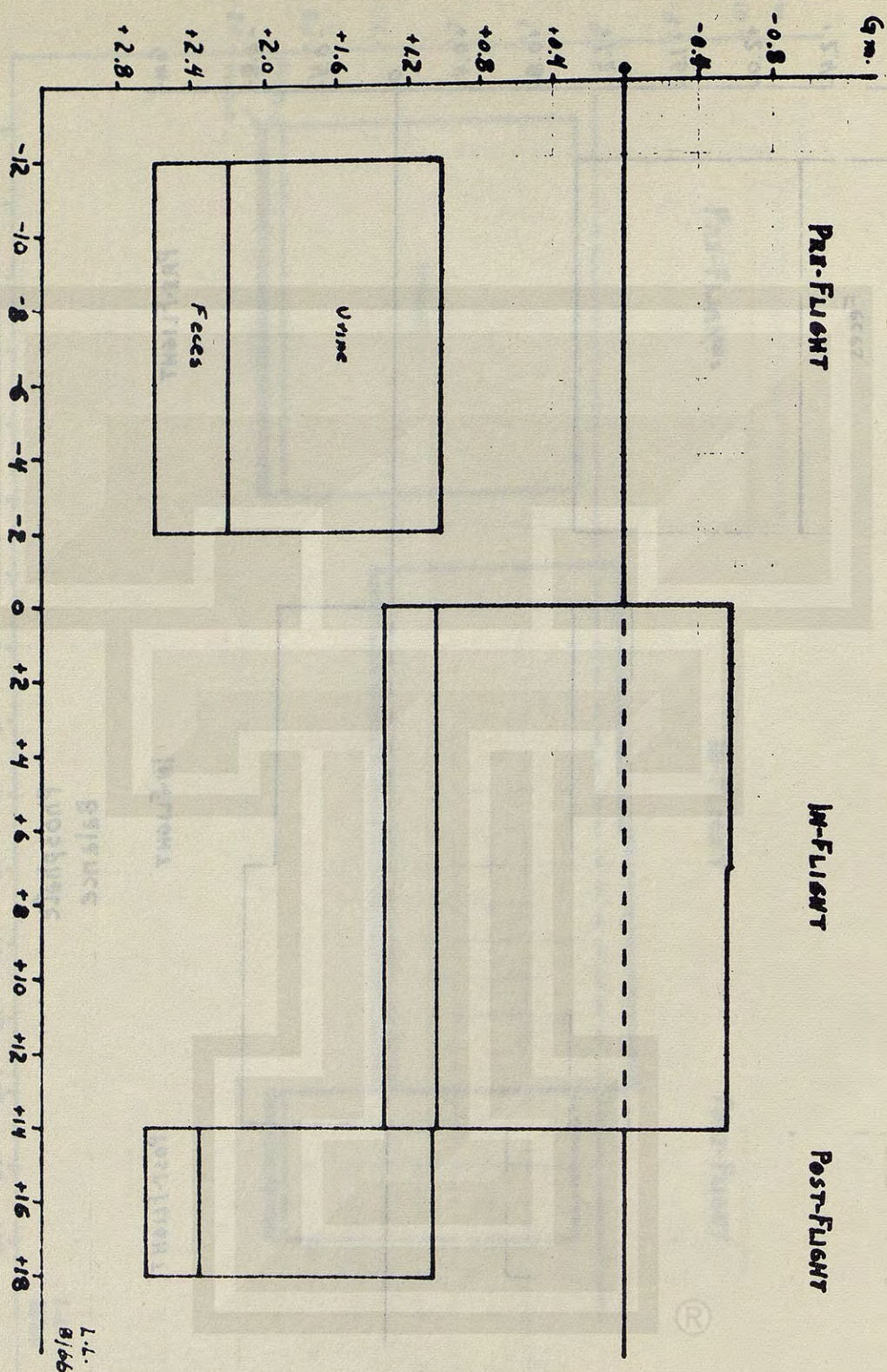


FIGURE 14

F.B.

Sodium
Balance

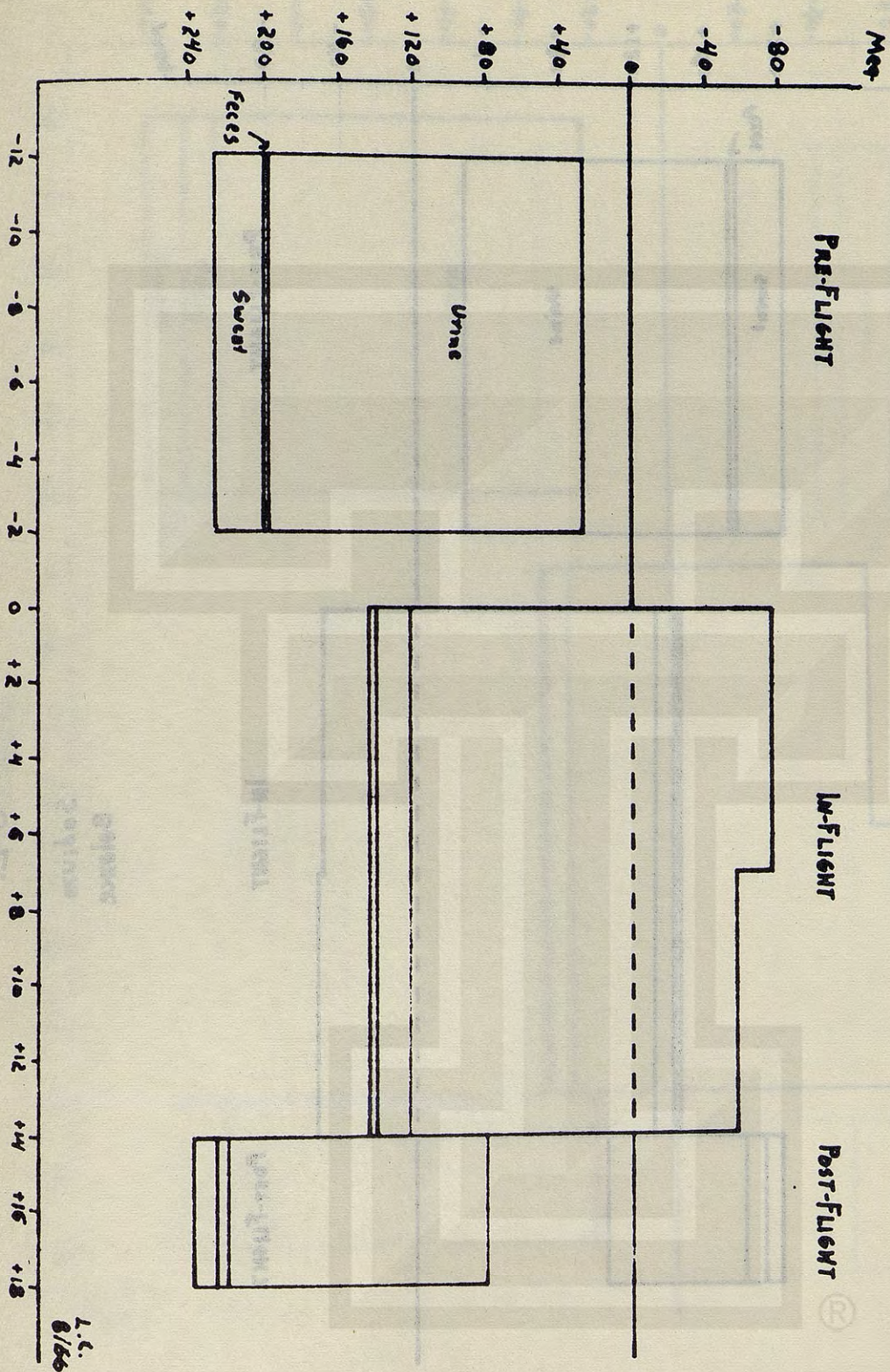


FIGURE 15

J.L.

Phosphate
Balance

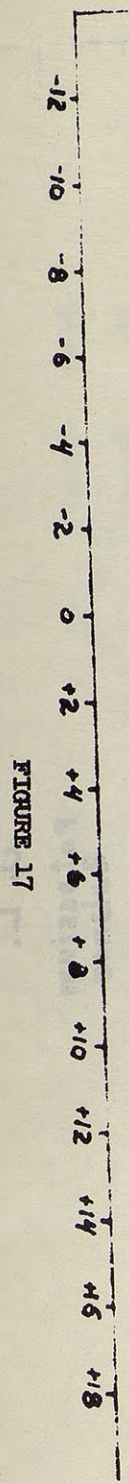


FIGURE 17

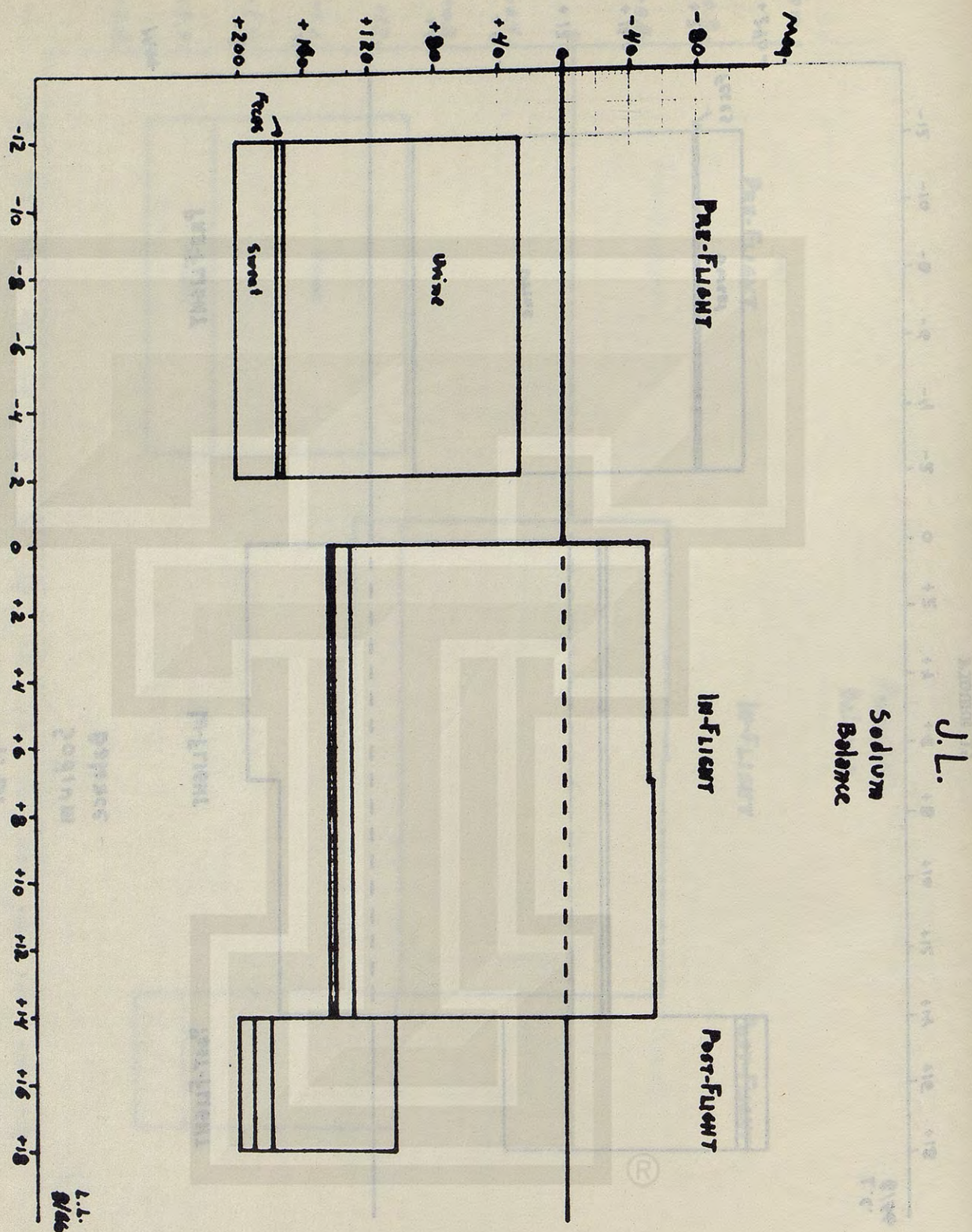


FIGURE 16

F.B.

Potassium
Balance

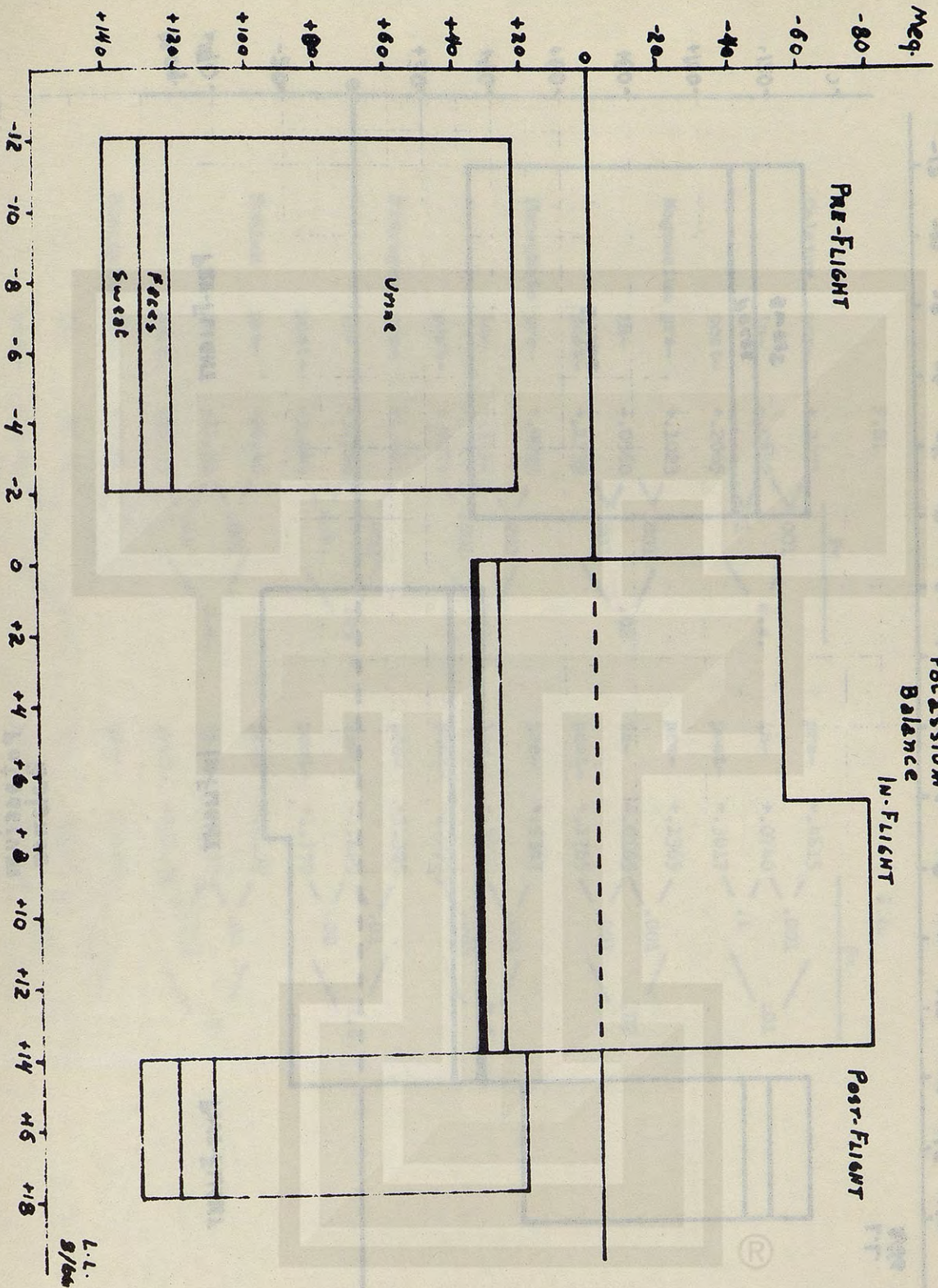


FIGURE 17

J.L.

Sodium

In- -65.46
 post- +21.86
 .01
 n.s.
 In- -23.91
 post- +46.54
 .001
 n.s.

FIGURE 19

J. L. Potassium Balance

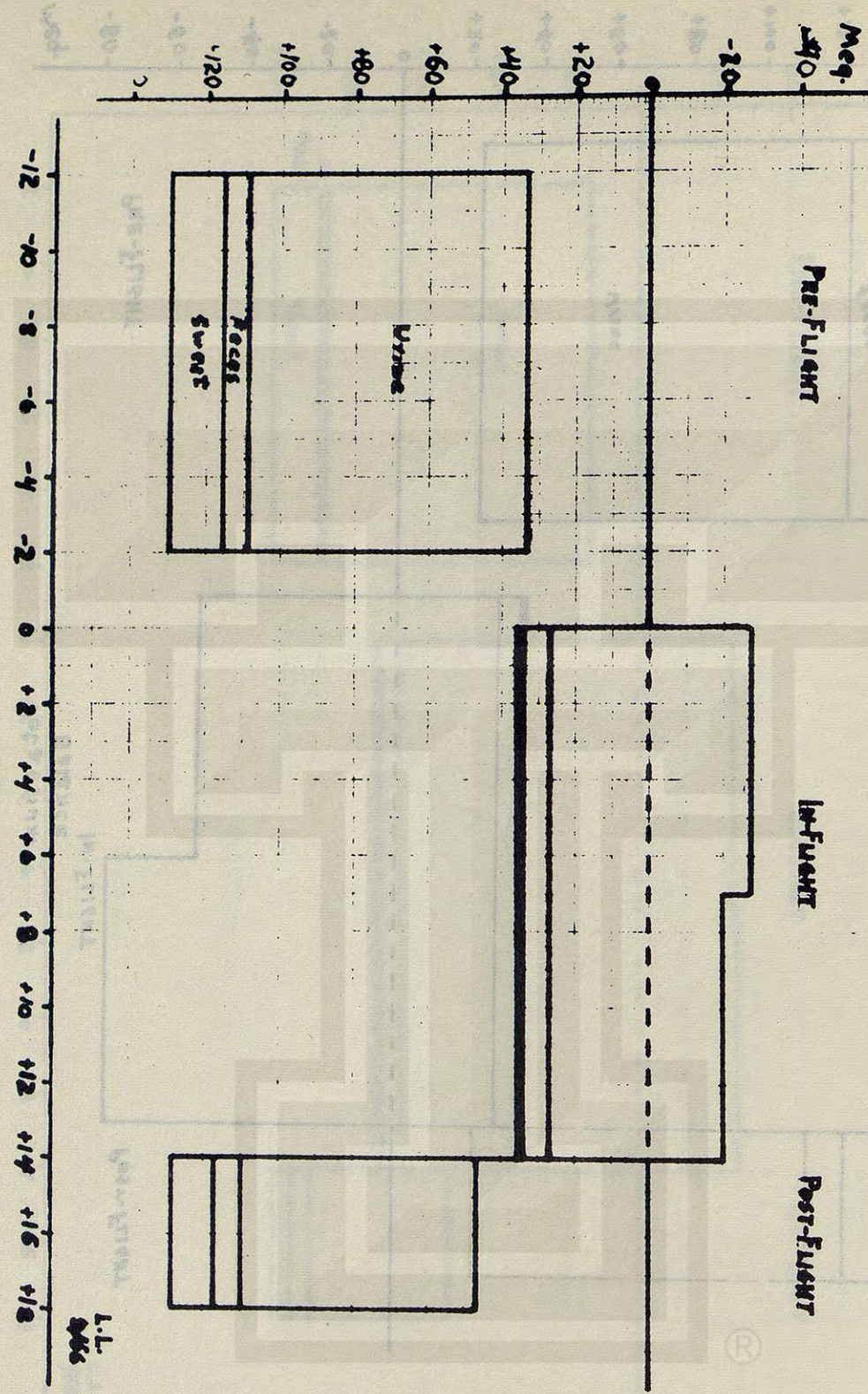


FIGURE 18

BALANCES

F.B.			J.L.		
			P<		
Calcium	pre-	+3.071	pre-	+4.615	
	in-	-0.0452	in-	+0.0740	
	post-	+2.065	post-	+3.017	
			P<		
Magnesium	pre-	+1.023	pre-	+1.1365	
	in-	-0.0560	in-	-0.0165	
	post-	+2.1739	post-	+1.1765	
			P<		
Phosphate	pre-	+0.9091	pre-	+0.9367	
	in-	-0.7161	in-	-0.5493	
	post-	+0.6574	post-	+1.0555	
			P<		
Nitrogen	pre-	+1.001	pre-	+1.305	
	in-	-3.768	in-	-1.629	
	post-	-3.044	post-	+1.770	
			P<		
Sodium	pre-	+26.40	pre-	+26.22	
	in-	-71.31	in-	-50.77	
	post-	+80.03	post-	+104.79	
			P<		
Potassium	pre-	+22.84	pre-	+33.08	
	in-	-65.46	in-	-23.91	
	post-	+21.86	post-	+46.54	

FIGURE 19

J. L.

Potassium
Balance