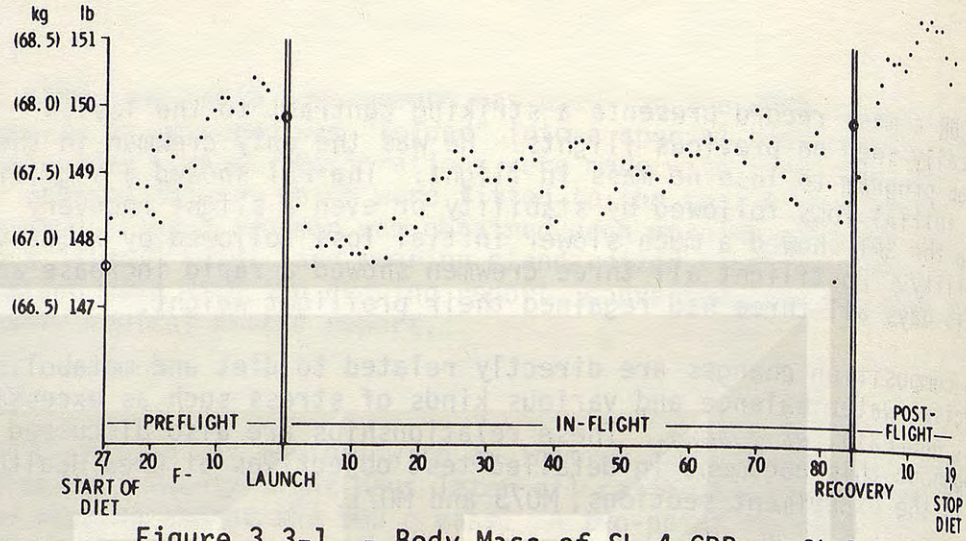



Figure 3.3-1. - Body Mass of SL-4 CDR on Skylab Diet.

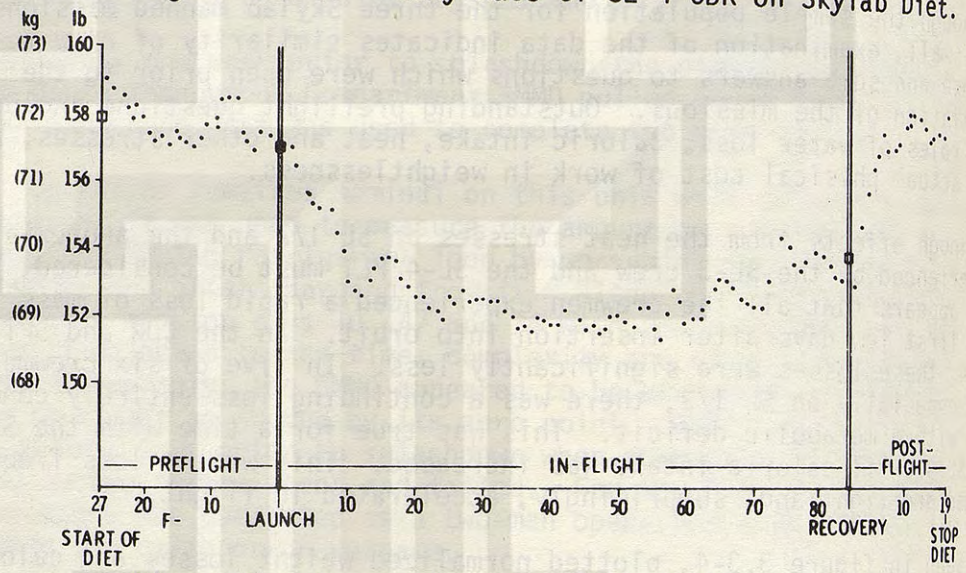



Figure 3.3-2. - Body Mass of SL-4 SPT on Skylab Diet.

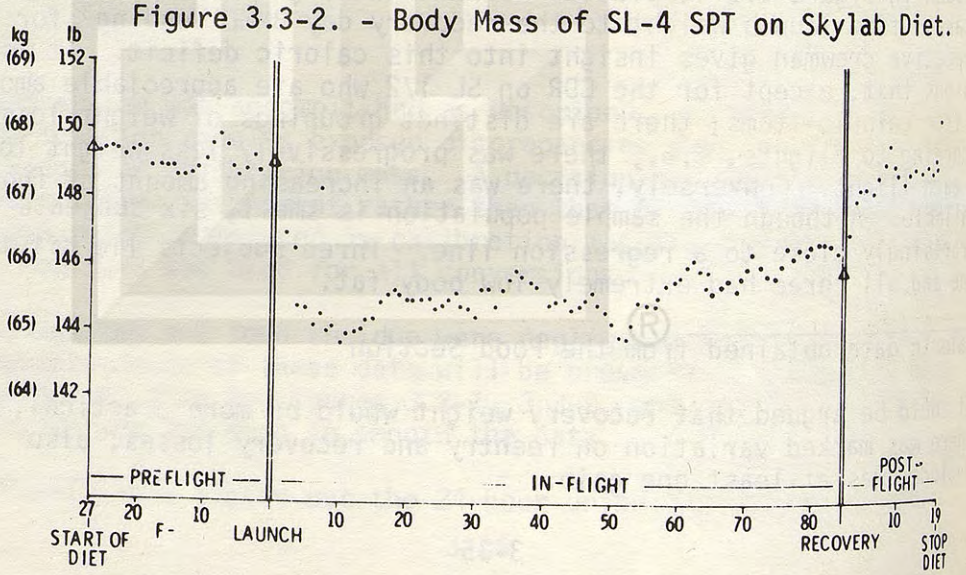



Figure 3.3-3. - Body Mass of SL-4 PLT on Skylab Diet.

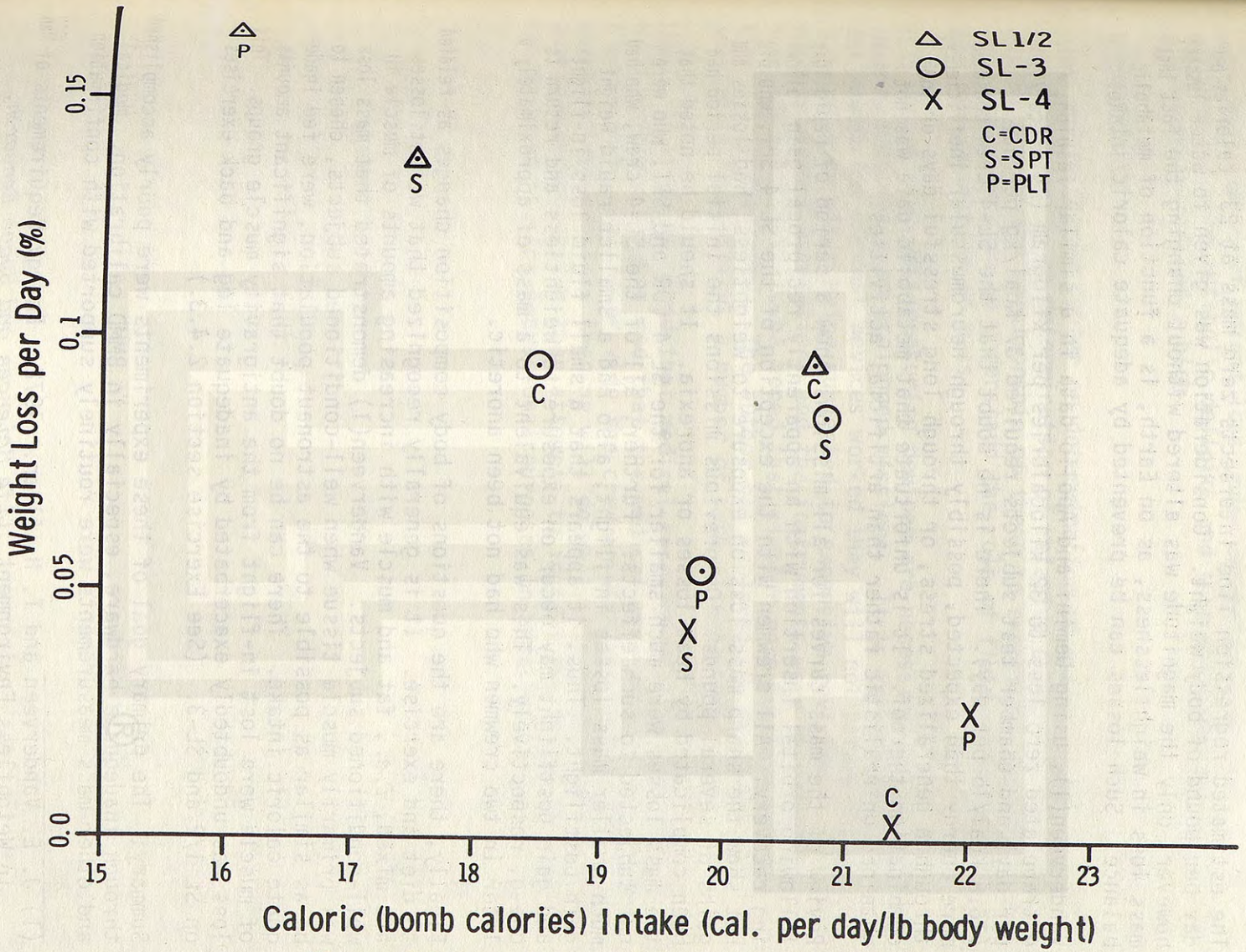



Figure 3.3-4. - Average Weight Loss *vs.* Caloric Intake For All Skylab Missions.

The estimated regression line intersects zero mass at 23+ calories per day per pound of body weight. Consideration was given to water losses; however, only the magnitude was altered without changing the fact that mass loss in weightlessness, as on Earth, is a function of metabolic balance. Such losses can be prevented by adequate caloric intake.

Vanderveen(1), using Gemini and Apollo data in a similar fashion, extrapolated zero loss to 32 kilocalories per kilogram (14.5 Kcal/lb per day) and chamber test subjects required 37 Kcal/kg per day (16.8 Kcal/lb per day). There is no doubt that the SL-4 crew consumed more energy than expected, possibly through neuromuscular inefficiency, through a generalized stress, or through long stressful days or some combination thereof. It is unfortuate that metabolic data was not obtained on realistic rather than artificial activities.

Review of the mass curves for all missions show a period of rapid loss following orbital insertion with an apparently reciprocal gain following recovery. All crewmen with the exception of the SL-4 SPT, who did not show the sharp mass loss on exposure to weightless, had losses and gains of several pounds. On previous missions the initial period had been complicated by heat losses or anorexia. It should be noted that the mass losses were much smaller for the SL-4 CDR and SPT, who were not subjected to such effects. Further, all of the SL-4 crew, who had much smaller mass losses in flight, also had a smaller rapid weight gain postflight. Thus, it appears that a small fluid loss in-flight and gain postflight may occur on exposure to weightless and return to one-g, respectively. This was equivalent to a mass of approximately a liter in two crewmen who had not been anoretic.

Finally, there are the questions of body composition changes as related to diet and exercise. It is generally recognized that weight losses are mixed, *i.e.*, fat and muscle with increasing amounts of muscle in well-conditioned subjects. Vanderveen(1) demonstrated that mass loss was primarily muscle tissue when well-conditioned subjects, chosen to be as similar as possible to the astronaut population, were fed inadequate caloric intake. There can be no doubt that significant amounts of muscle were lost in-flight from the antigravity muscle groups. This loss was undoubtedly exacerbated by inadequate leg and back exercises on SL 1/2 and SL-3. (See Exercise section 2.4.3.)

Summary: The primary goal of these experiments were poorly accomplished through inadequate hardware, especially in BMMD calibration. Medical and other mass measurements were routinely supported with confirmation

(1) J. E. Vanderveen and T. H. Allen. 1972. Energy Requirements of Man in Weightless Environment. *Life Sciences and Space Research*, COSPAR vol. X. Akademie-Verlag, Berlin.

that primary causes of weight loss under weightlessness were not obligatory but were metabolic deficits and that metabolic energy costs on SL-4 were unexpectedly high.

Recommendations

Future efforts should center on determination of energy costs in typical space flight tasks, in determination of relative changes in body composition, and in the relationship of these to exercise. Above all, effort should be made to understand the role of fluid shifts and their exact role in changes of mass.

It is obvious that mass measuring devices are necessary for any future research, especially on prolonged missions. It is to be hoped that just because the current devices worked they will not become the method of choice, even after being subjected to expensive revision. The method has severe limitations and the instruments were obsolete as flown. Rather, it is to be hoped that simpler more suitable alternatives will be developed. The author has explored, to the point of demonstrated feasibility, a number of such alternatives.

Finally, it is to be hoped that medical research will be used where needed in future flights and that the medical assurance gained on these flights will be used to provide the crewman with his requirements and provide for emergencies; then he will do well. In my opinion, nothing could be more regressive than attempts to install the Skylab BMMD, or some rehash of it, for operational purposes in Shuttle.

## 3.4 Experiment M078. Bone Mineral Measurement

*Principal Investigator: John M. Vogel, M.D.*
*Principal Coordinating Scientist: Michael Whittle, M.D.*

### Introduction

The probability of significant bone mineral loss being initiated by extended periods of weightlessness has been predicted on the basis of observations made in bed rested and immobilized subjects. The mineral loss occurs after short periods of delay whereas total body calcium deficit begins in the first week. Although very large mineral losses were documented for all bones measured during the short Gemini IV, V, VII, and Apollo VII and VIII missions, some of these measurements have been found to contain significant errors due to the techniques used.

Using the photon absorptiometric technique, studies of the radius, ulna and *os calcis* have shown no mineral losses in the upper extremity during Apollo 14, 15, 16, or SL 1/2 and SL-3, but there were variable losses in the *os calcis* in Apollo 15 and SL-3. These observations for the most part are in concert with bed rest studies undertaken with the same technique. However, as with all biologic data, unexplained variations do occur, *e.g.*, Apollo 15. Attempts to apply prediction terms relating initial bone mineral content and urinary hydroxyproline excretion of the bed rested subjects to the weightless state have largely been successful and were applied to the SL-4 crew.

### Data

The mineral content of the distal right radius and ulna and the central left *os calcis* was measured preflight at F-35, F-21, F-10 days and postflight at R+1, R+7, R+17, and R+32 days on each of the crewmen and on at least four ambulatory controls at each measurement. Additional *os calcis* measurements were made on R+95 days. The data for the crewmen of SL-4 and controls are delineated in the accompanying tables.

### Interpretation

No significant change in mineral content in the right radius and ulna was observed during the 84-day flight. Significant mineral loss from the left central *os calcis* was observed in the SPT (4.5%) and PLT (7.9%). No change was seen in the CDR (+0.7%). Although there appeared to be a reduction in the loss on R+4 days this was not sustained on R+7 days. Recovery in the *os calcis* mineral of the SPT and PLT was not complete at 95 days.

In a heterogenous group of 15 bed rested subjects, the mean mineral loss for 84 days was -11.3% with a standard deviation of 7.2%. The prediction terms for these subjects varied from 11.2 to 36.3. The current crew had prediction terms outside of these limits and therefore predictions for the crew based upon the bed rested data were not possible.

It was expected, however, that losses in the *os calcis* would not exceed 5%. The 7.9% loss in the PLT cannot be explained on this basis.

It is concluded that mineral losses do occur from the bones of the lower extremities during missions of up to 84 days and that in general, they follow the loss patterns of the bed rested situation. The levels of loss observed in the Skylab crews have been of no clinical concern. It is fortuitous that all of the SL-4 crewmen had high predication terms.

TABLE 3.4-I. BONE MINERAL MEASUREMENT (SL-4)

| Time, Days | CDR | SPT | PLT |
|---|---|---|---|
| | | *OS CALCIS* (mg/cm$^2$) | |
| Preflight Mean | 518.3 ±0.4%* | 708.1 ±1.6%* | 566.4 ±1.1%* |
| R+1 | 522.1 (+0.7)† | 676.4 (-4.5)† | 521.4 (-7.9)† |
| R+4 | 521.4 (+1.2) | 686.1 (-3.1) | 540.4 (-4.6) |
| R+7 | 525.0 (+1.3) | 675.8 (-4.6) | 526.1 (-7.1) |
| R+17 | 528.6 (+2.0) | 685.9 (-3.1) | 532.2 (-6.0) |
| R+32 | 509.9 (-1.6) | 655.5 (-7.4) | 517.0 (-8.7) |
| R+95 | 523.0 (+0.9) | 675.6 (-4.5) | 548.6 (-3.1) |
| | | RADIUS (g/cm) | |
| Preflight Mean | 1.125 ±1.1% | 1.226 ±0.8% | 1.338 ±0.6% |
| R+1 | 1.113 (-1.1) | 1.238 (+1.0) | 1.330 (-0.6) |
| R+4 | 1.104 (-1.9) | 1.228 (+0.2) | 1.329 (-0.7) |
| R+7 | 1.119 (-0.5) | 1.236 (+0.8) | 1.331 (-0.5) |
| R+16 | 1.112 (-1.2) | 1.224 (-0.2) | 1.342 (+0.3) |
| | | ULNA (g/cm) | |
| Preflight Mean | 0.631 ±0.6% | 0.692 ±0.4% | 0.663 ±0.9% |
| R+1 | 0.620 (-1.7) | 0.692 ( 0.0) | 0.672 (+1.4) |
| R+4 | 0.633 (+0.3) | 0.686 (-0.9) | 0.668 (+0.8) |
| R+7 | 0.613 (-2.9) | 0.687 (-0.7) | 0.668 (+0.8) |
| R+16 | 0.636 (+0.8) | 0.696 (+0.6) | 0.669 (+0.9) |

* ± 1 Std. Dev.

† Percent Change from Mean Baseline

## TABLE 3.4-II. BONE MINERAL MEASUREMENT (SL-4)

### Control Data

*OS CALCIS* (mg/cm²)

| Subject | Preflight Mean | R-2 | R+1 | R+4 | R+7 | R+17 | R+32 | R+95 |
|---|---|---|---|---|---|---|---|---|
| | | | DAYS | | | | | |
| | % | % | % | % | % | % | % | % |
| Alexander | 524.8 ±1.1 | 558.6 (+6.4) | 532.7 (+1.5) | 554.3 (+5.6) | 556.5 (+6.0) | 551.0 (+5.0) | 543.0 (+3.5) | - |
| Brown | 518.8 ±1.1 | 536.6 (+3.4) | 529.7 (+2.1) | - | 526.5 (+1.5) | - | 523.1 (+0.8) | 534.3 (+3.0) |
| Hordinsky | 411.1 ±1.4 | | - | - | - | - | 418.5 (+1.8) | 422.4 (+2.7) |
| LaPinta | 505.0 ±0.4 | | | - | 505.5 ( 0.0) | 506.5 (+0.3) | 499.7 (-1.1) | 502.5 (-0.5) |
| Silverstein | 481.7 ±1.5 | | 475.4 (-1.2) | 485.4 (+0.8) | 486.2 (+0.9) | 476.4 (-1.1) | 473.4 (-1.7) | - |
| Vogel | 611.3 ±1.0 | 614.7 (+0.6) | 617.1 (+0.9) | 594.5 (-2.7) | - | 621.8 (+1.7) | - | - |
| Whittle | 590.8 ±1.0 | | 591.4 (+0.1) | 587.2 (-0.6) | - | - | - | 583.5 (-1.7) |
| | | | | RADIUS (g/cm) | | | | |
| Alexander | 1.113 ±1.5 | | 1.081 (-2.9) | 1.119 (+0.5) | 1.109 (-0.4) | 1.099 (-1.3) | 1.110 (-0.3) | |
| Brown | 1.534 ±0.6 | | 1.542 (+0.5) | - | 1.539 (+0.3) | - | - | |
| Hordinsky | 1.364 ±1.1 | | - | - | - | - | 1.347 (-1.2) | |
| LaPinta | 1.304 ±0.3 | | | - | 1.290 (-1.1) | 1.281 (-1.8) | - | |
| Silverstein | 1.086 ±1.6 | | 1.078 (-0.7) | 1.090 (+0.4) | 1.090 (+0.4) | 1.097 (+1.0) | - | |
| Vogel | 1.481 ±0.4 | | 1.477 (-0.3) | 1.490 (-0.6) | - | 1.499 (+1.2) | - | |
| Whittle | 1.159 ±0.8 | | 1.153 (-0.5) | - | - | - | - | |
| | | | | ULNA (g/cm) | | | | |
| Alexander | 0.563 ±2.1 | | 0.545 (-3.2) | 0.559 (-0.7) | 0.545 (-3.2) | 0.538 (-4.4) | 0.544 (-3.4) | |
| Brown | 0.751 ±2.3 | | 0.743 (-1.1) | - | 0.761 (+1.3) | - | - | |
| Hordinsky | | | - | - | - | - | 0.709 (+1.9) | |
| LaPinta | 0.640 ±1.1 | | | - | 0.652 (+1.9) | 0.640 ( 0.0) | - | |
| Silverstein | 0.554 ±2.5 | | 0.558 (+0.7) | 0.574 (+3.6) | 0.574 (+3.6) | 0.553 (-0.2) | - | |
| Vogel | 0.682 ±1.0 | | 0.685 (+0.4) | 0.693 (+1.6) | - | 0.686 (+0.6) | - | |
| Whittle | 0.592 ±2.0 | | 0.580 (-2.0) | - | - | - | - | |

## 3.5 Experiment M092. Lower Body Negative Pressure

*Principal Investigators:* *R. L. Johnson, M.D.*
*G. W. Hoffler, M.D.*

### Preflight

Preflight baseline data were collected over a period of 4-1/2 months. Seven LBNP tests were performed on each crewman. Data from the CDR's sixth preflight test were lost. The fifth and seventh tests took place in the SML's while the other five were carried out in the one-g trainer.

Resting heart rates (HR) of the CDR were in the low sixties during his first three tests but later fell to the low fifties. Resting heart rates of the SPT and PLT ranged between 45 and 55 bpm in all preflight tests. Mean resting and stressed (-50 mm Hg) values for heart rate, systolic (SBP) and diastolic blood pressure (DBP), pulse pressure (PP) and percent leg volume increase at the end of the -50 mm Hg negative pressure phase during the preflight tests were:

| (bpm) | CDR | SPT | PLT |
|---|---|---|---|
| HR, Resting | 59.0 (4.5)* | 51.0 (3.1) | 48.0 ( 4.3) |
| HR, Stressed | 66.0 (6.7) | 65.0 (8.6) | 61.0 ( 5.6) |
| **(mm Hg)** | | | |
| SBP Resting | 94.0 (3.5) | 121.0 (5.1) | 118.0 ( 9.9) |
| SBP Stressed | 88.0 (3.0) | 113.0 (5.9) | 103.0 (10.7) |
| DBP Resting | 62.0 (2.6) | 71.0 (7.5) | 65.0 ( 9.5) |
| DBP Stressed | 63.2 (2.7) | 77.0 (5.9) | 68.0 (10.2) |
| PP, Resting | 32.0 (4.4) | 51.0 (3.6) | 53.0 ( 7.7) |
| PP, Stressed | 25.0 (3.9) | 37.0 (7.5) | 35.0 ( 4.1) |
| Percent Δ Leg Volume | 2.1 (0.35) | 3.6 (0.92) | 3.7 ( 1.03) |

*S.D. = Standard deviation

Preflight ranges for the same parameters were:

| (bpm) | CDR | SPT | PLT |
|---|---|---|---|
| HR, Resting | 52-64 | 47-55 | 45-56 |
| HR, Stressed | 58-71 | 54-78 | 55-71 |
| (mm Hg) | | | |
| SBP Resting | 89-98 | 113-126 | 106-133 |
| SBP Stressed | 83-91 | 104-122 | 87-120 |
| DBP Resting | 58-66 | 58-79 | 54-80 |
| DBP Stressed | 60-67 | 71-89 | 57-86 |
| PP, Resting | 26-36 | 45-55 | 43-67 |
| PP, Stressed | 20-31 | 25-48 | 30-39 |
| Percent Δ Leg Volume | 1.52-2.47 | 1.72-4.7 | 2.63-5.63 |

As can be seen from these data, the blood pressure of the PLT showed considerable lability. In each of the first six tests, systolic pressure increased progressively from 106 to 133 mm Hg, falling again in the seventh to 114 mm Hg. Diastolic pressure also varied through a range of from 55 to 80 mm Hg. The blood pressure of the SPT was also labile but to a lesser degree while that of the CDR was quite stable.

Typical preflight tests of the three crewmen are shown in figures 3.5-1, -2, and -3.

In-flight

During the 84-day flight, twenty-two M092 tests were performed on the CDR and SPT while the PLT was tested twenty-three times. The first in-flight test on the CDR on the morning of MD 5 (fig. 3.5-4) showed mean resting heart rate, resting systolic and pulse pressure slightly higher than, and diastolic pressure slightly below, preflight ranges. Stressed heart rate rose only slightly and blood pressure was well-maintained. The second and third tests were also well-tolerated although pulse pressure showed slightly more narrowing than during the first test. Leg volume increases measured in the range of four to five percent.

During the first 13 minutes of his fourth in-flight test on MD 16, the CDR's cardiovascular responses appeared quite similar to those of previous tests except for a greater increase than usual in leg volume at the lower levels of LBNP (fig. 3.5-5). Heart rate rose rather abruptly to about 80 bpm during the last two minutes of -40 mm Hg LBNP. When

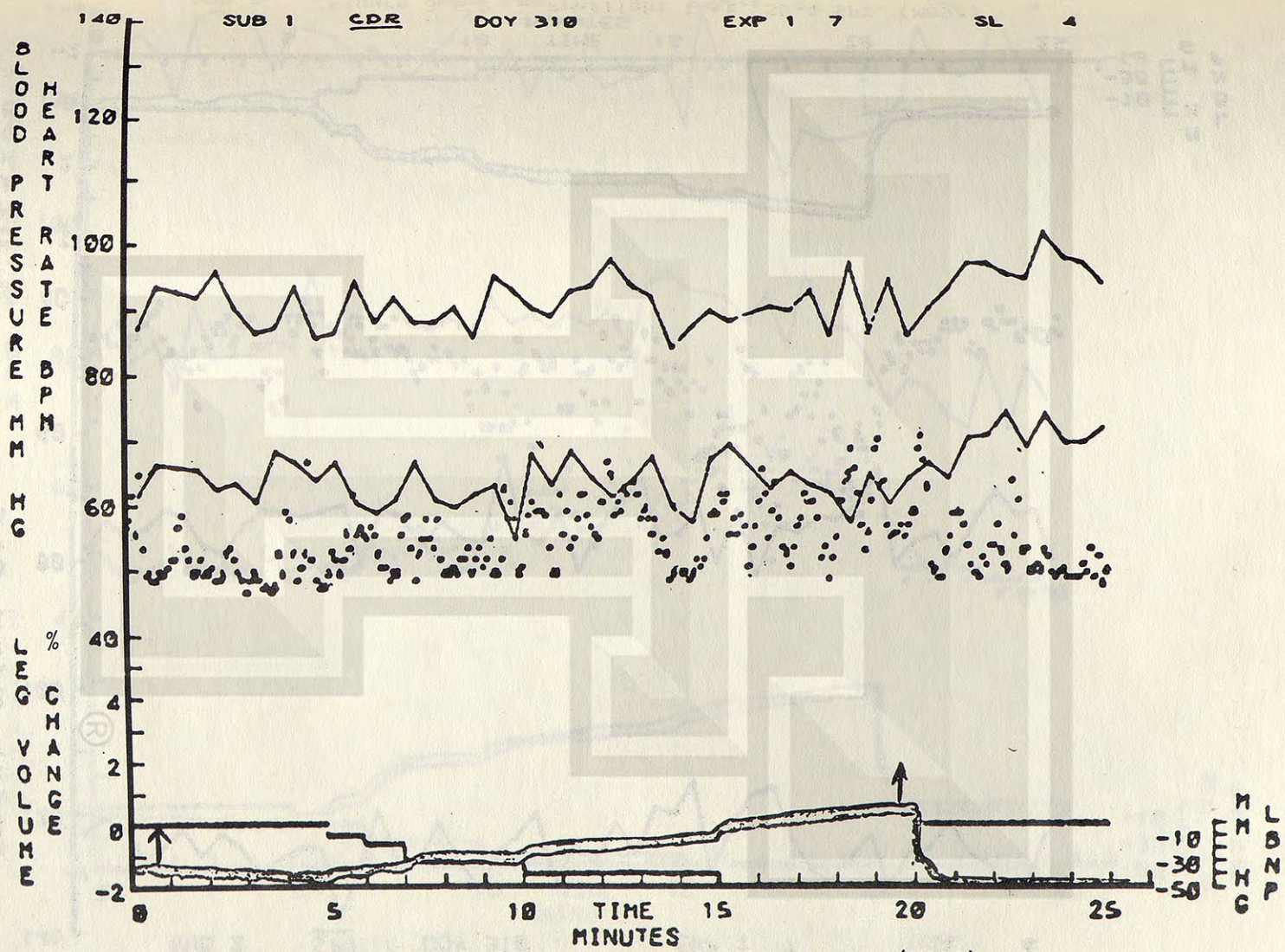



Figure 3.5-1. - Preflight Test, SL-4 CDR. (M092)

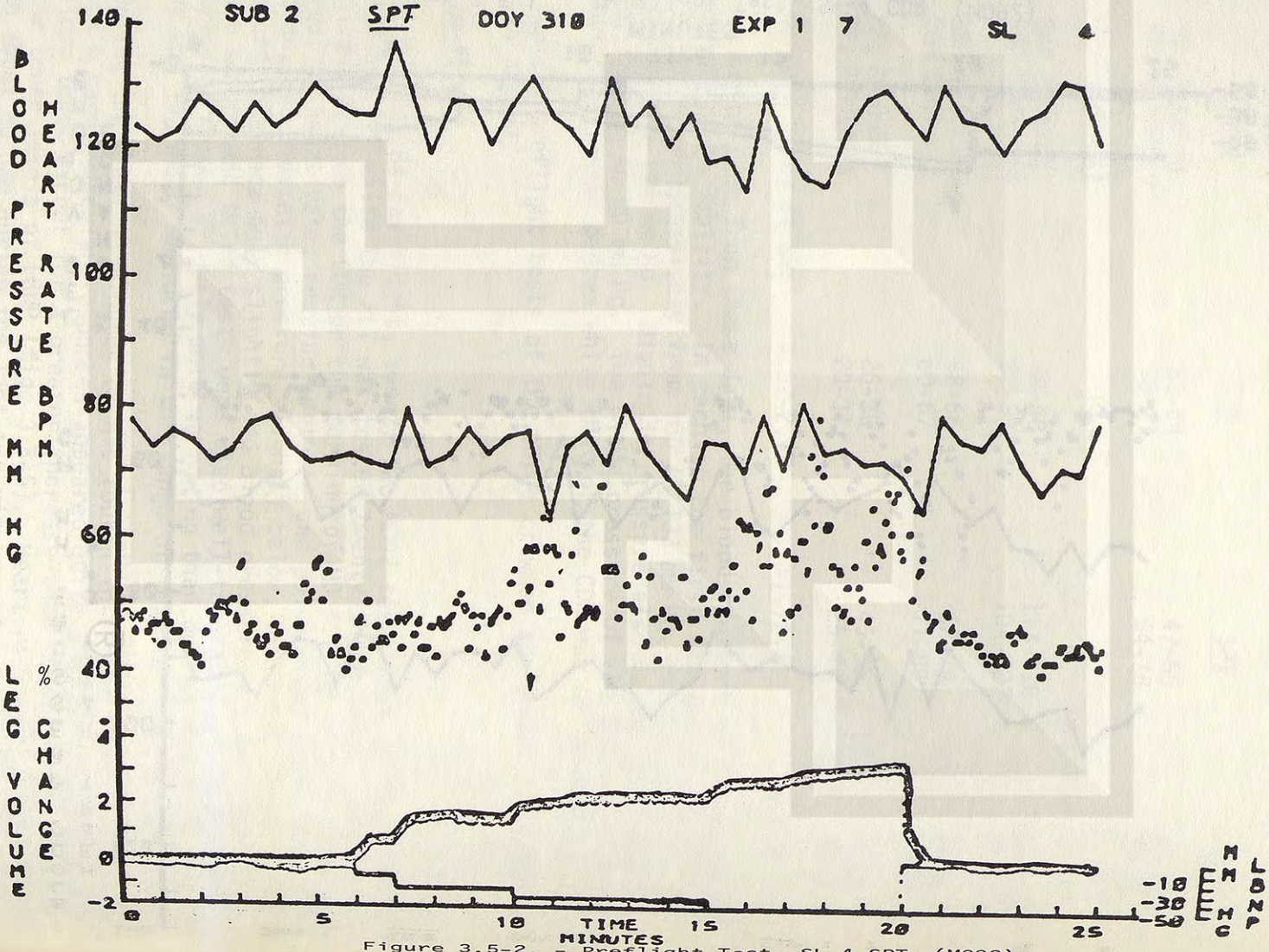
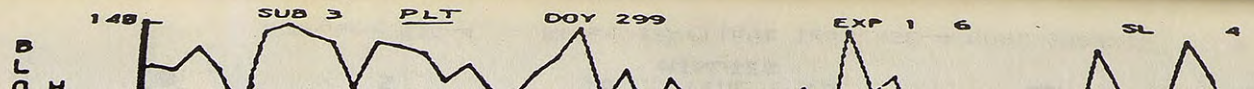



Figure 3.5-2. - Preflight Test, SL-4 SPT. (M092)



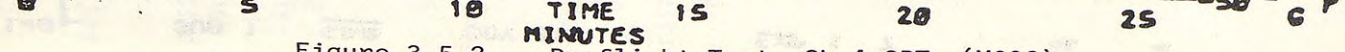



Figure 3.5-2. - Preflight Test, SL-4 SPT. (M092)

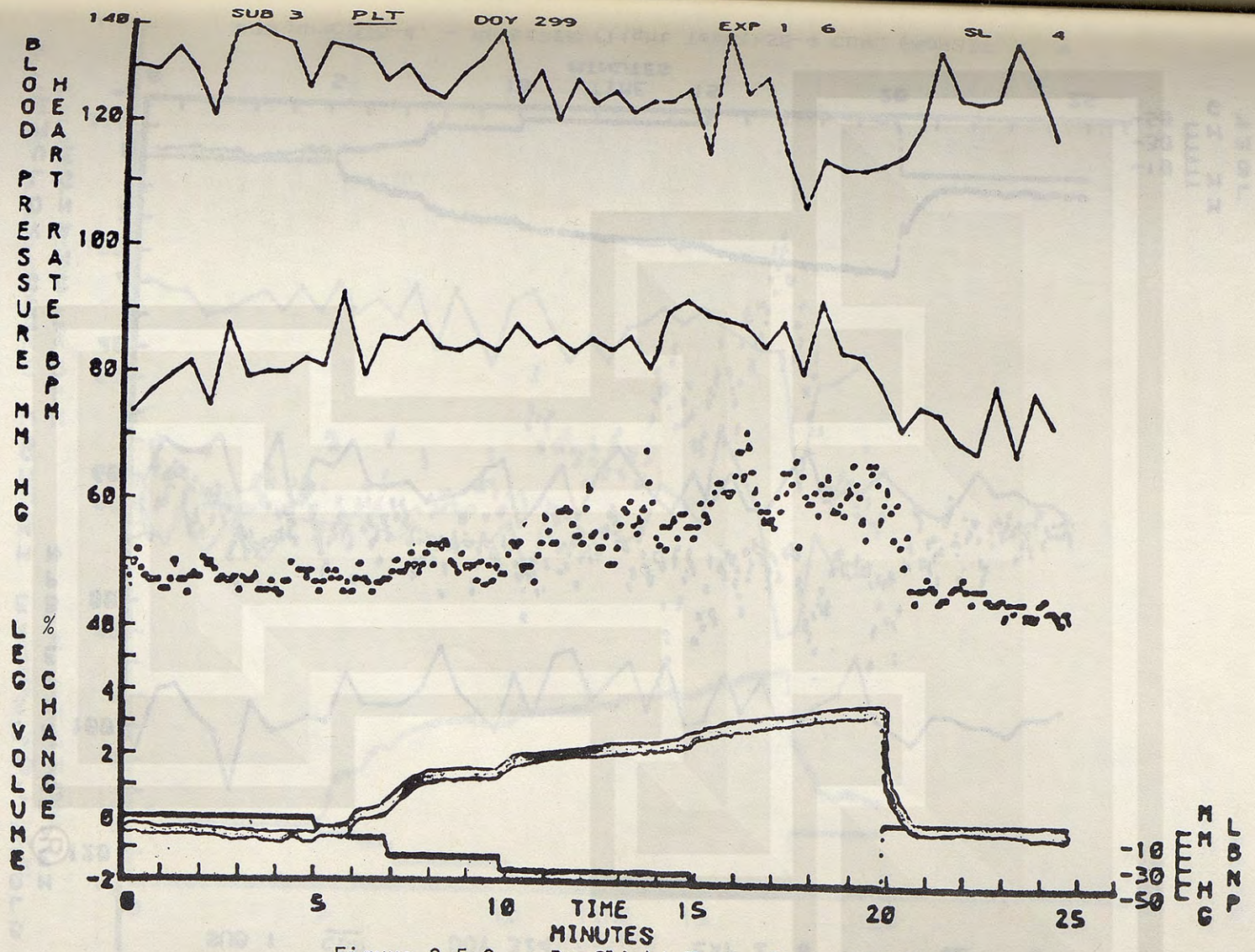



Figure 3.5-3. - Preflight Test, SL-4 PLT. (M092)

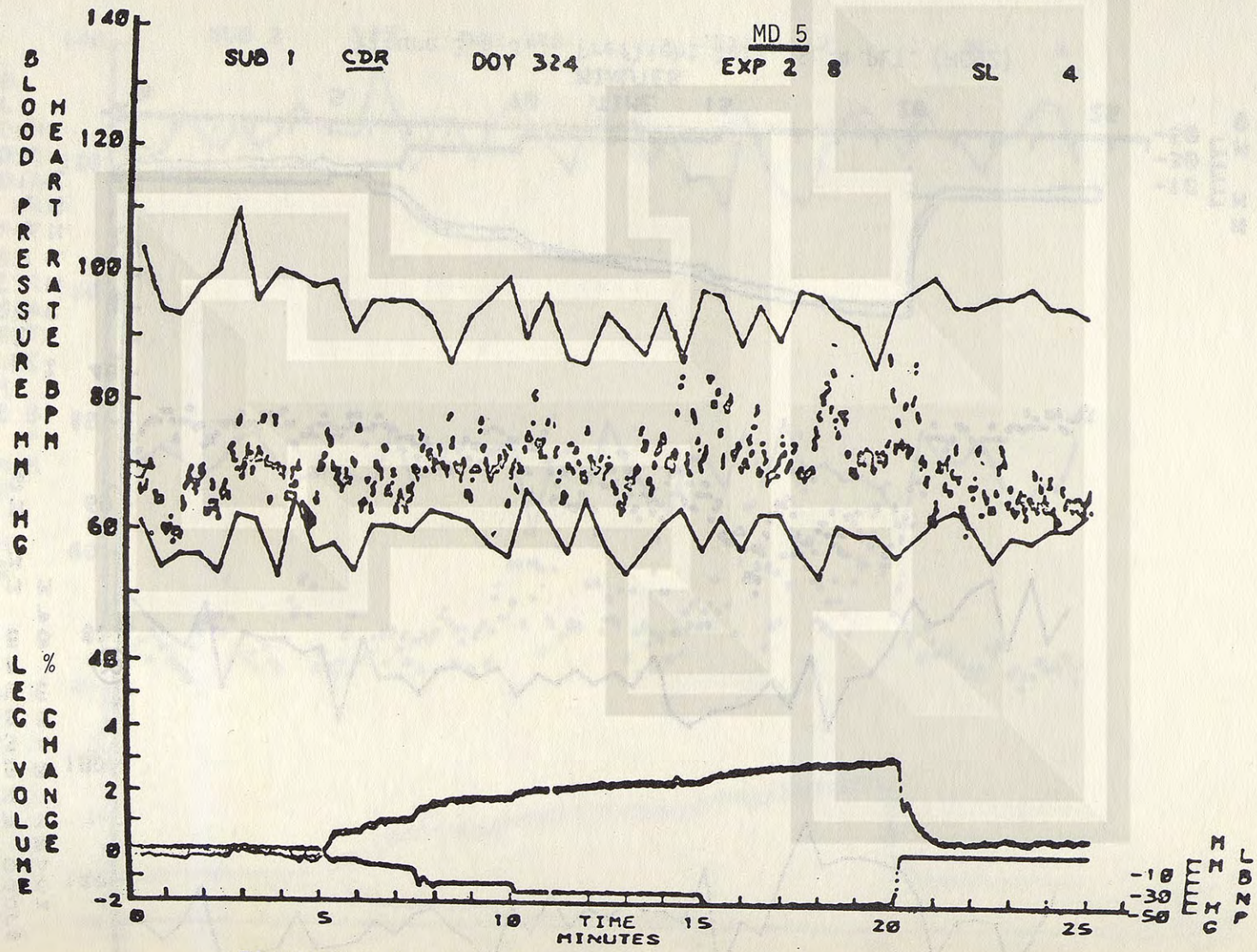



Figure 3.5-4. - First In-flight Test, SL-4 CDR. (M092)


Figure 3.5-4. - First In-flight Test, SL-4 CDR. (M092)

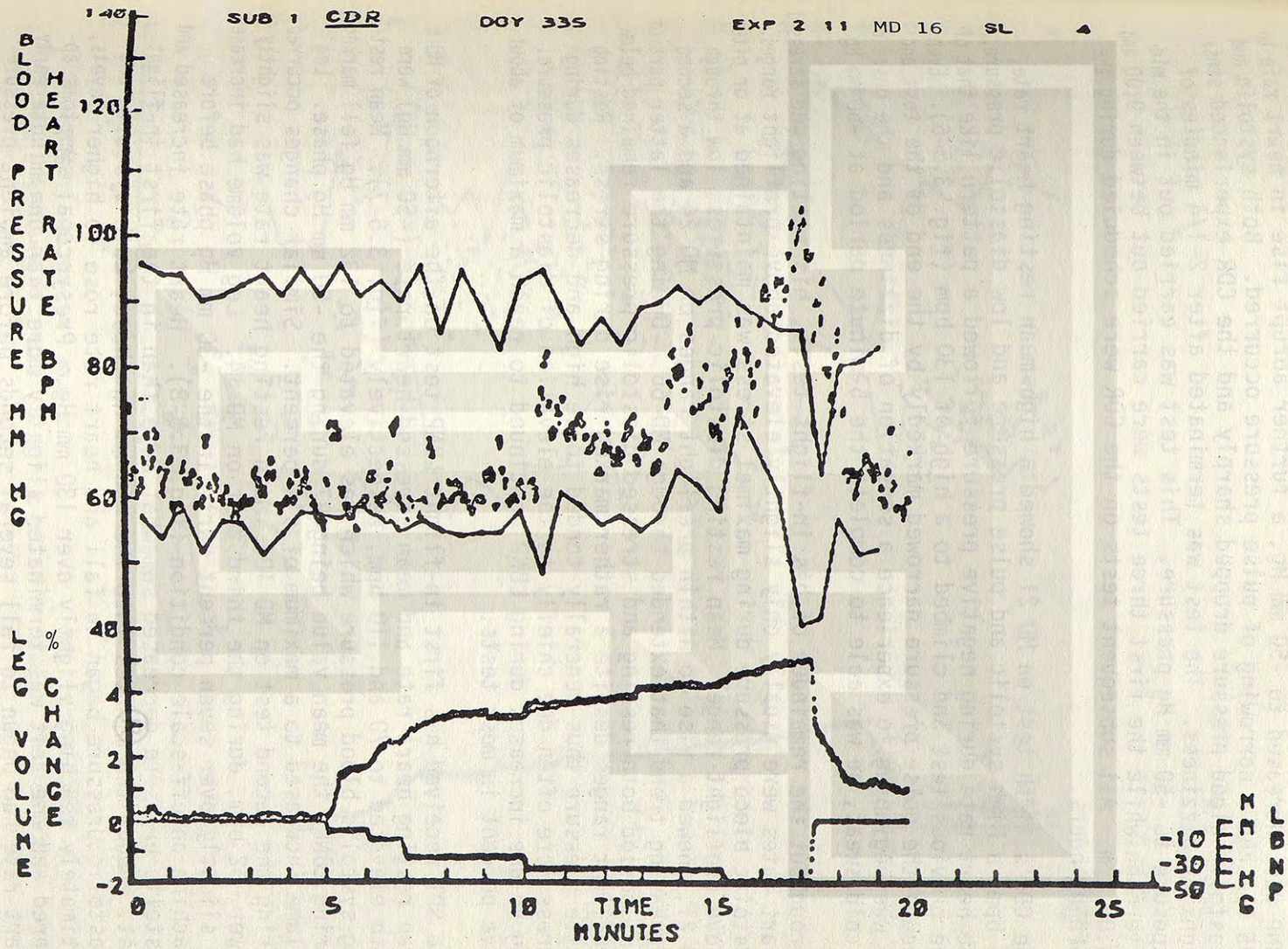



Figure 3.5-5. - Fourth In-Flight Test, SL-4 CDR.

LBNP was increased to -50 mm Hg, a further abrupt rise in heart rate to 105 bpm and a narrowing of pulse pressure occurred. Both systolic and diastolic blood pressure dropped sharply and the CDR experienced sensations of dizziness. The test was terminated after 2-1/4 minutes of exposure to -50 mm Hg pressure. This test was carried out in the mid-afternoon while the first three tests were carried out between 9:00 and 10:00 a.m. All subsequent tests on the CDR were scheduled during the morning hours.

The CDR's fifth test on MD 21 showed a high mean resting heart rate, 76 bpm, a high systolic and pulse pressure and low diastolic pressure. The heart rate during negative pressure followed a pattern like that of the previous test and climbed to a high of 130 bpm (fig. 3.5-6). Even though the pulse pressure narrowed markedly by the end of the test and he was beginning to experience a sensation of dizziness and the onset of a cold sweat, he was able to complete the 5-minute period at -50 mm Hg.

Throughout the remainder of his in-flight tests, his resting and stressed heart rates were usually only slightly elevated above preflight ranges. Systolic blood pressure during maximal stress was maintained at or often above preflight range. Mean resting diastolic pressures, low through MD 21, showed a rise to within preflight ranges on MD 24 and a second decreasing trend that extended through MD 66. During the latter part of this period both resting and stressed diastolic pressure remained below preflight ranges despite a rather marked rise during stress. Resting pulse pressure thus generally tended to be high and decreases during stress were often due chiefly to the elevation of diastolic pressure. Leg volume increases during LBNP continued to reach a maximum of about five percent in most tests.

The SPT received his first in-flight LBNP test on the afternoon of MD 6. Mean resting heart rate and mean stressed heart rate (-50 mm Hg) were both elevated to 70 and 110 bpm, respectively (fig. 3.5-7). Mean resting systolic blood pressure which was elevated to 132 mm Hg fell markedly during LBNP, the mean value being 97 during the -50 mm Hg phase. Leg volume increased to a maximum of six percent. Similar changes occurred during the second test on MD 10. Mean resting heart rate was slightly lower, 62 bpm, during the third test on MD 14. Leg volume had increased to slightly over seven percent early in the -30 mm Hg phase before reaching an off-scale condition (fig. 3.5-8). Heart rate increased and systolic pressure decreased somewhat more than in the first in-flight test. About two minutes into the -50 mm Hg phase, both systolic and diastolic pressure began to fall and heart rate rose to higher levels, ultimately reaching slightly over 130 mm Hg. Presyncopal symptoms appeared and the test was terminated slightly more than one minute early. Heart rate had begun to fall several seconds before ambient pressure was returned to the LBNPD, indicating that a vasovagal reaction was beginning.

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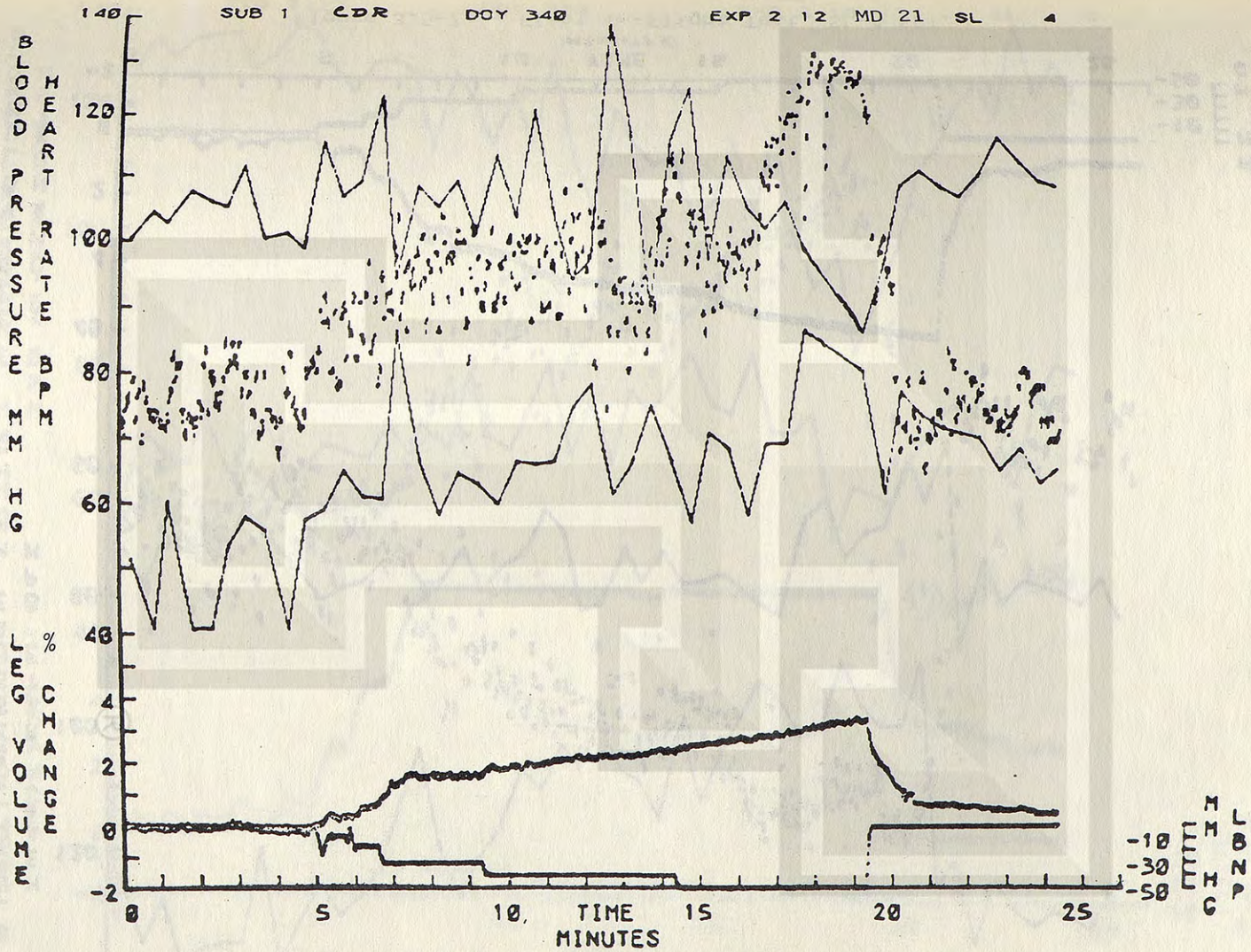



Figure 3.5-6. - Fifth In-flight Test, SL-4 CDR.

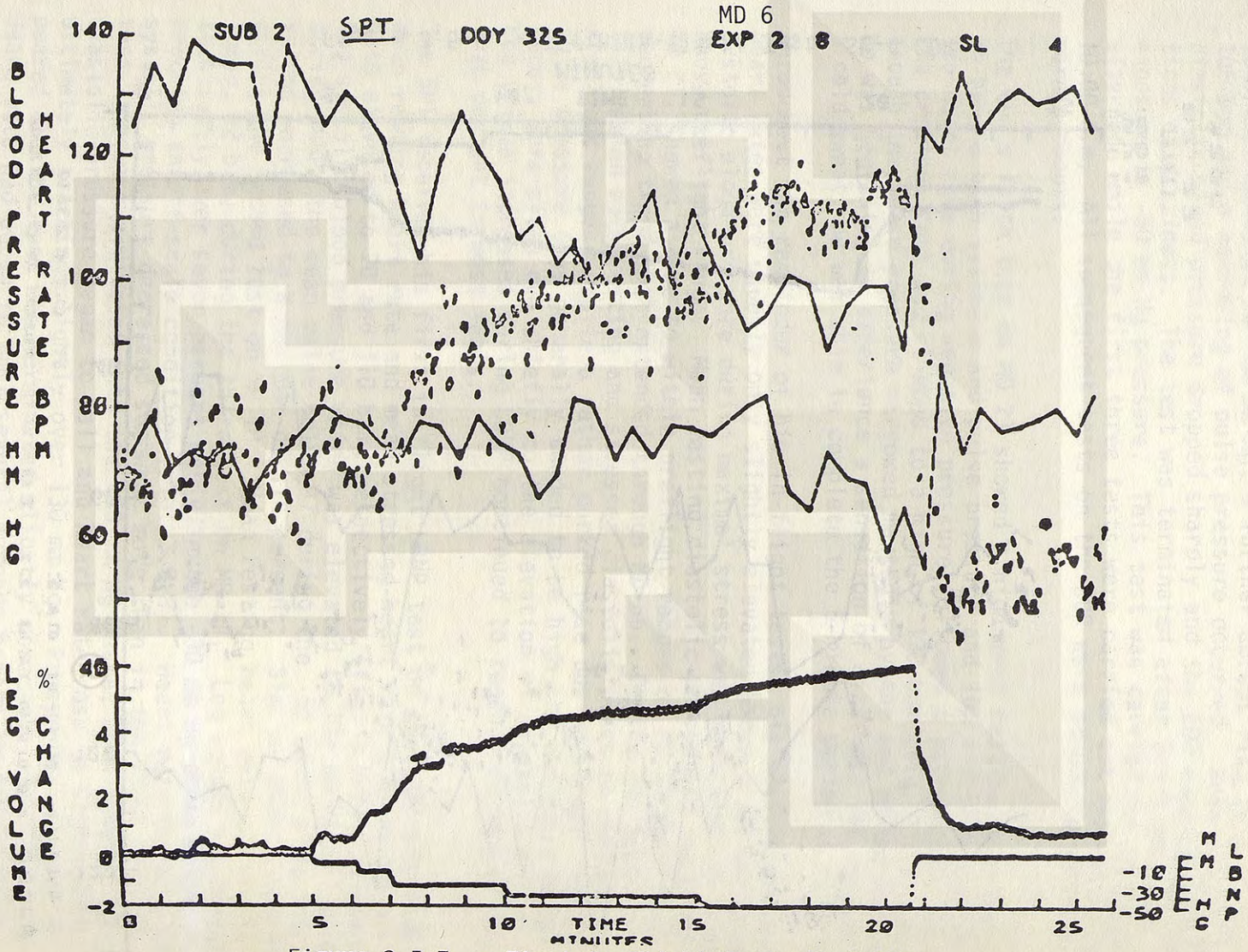



Figure 3.5-7. - First In-Flight Test, SL-4 SPT.



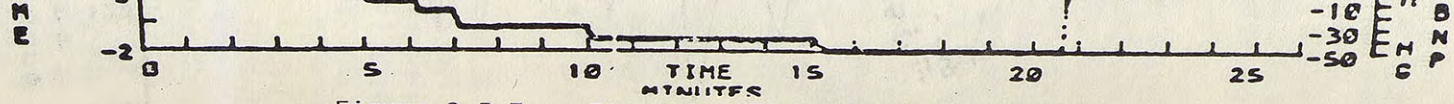



Figure 3.5-7. - First In-Flight Test, SL-4 SPT.

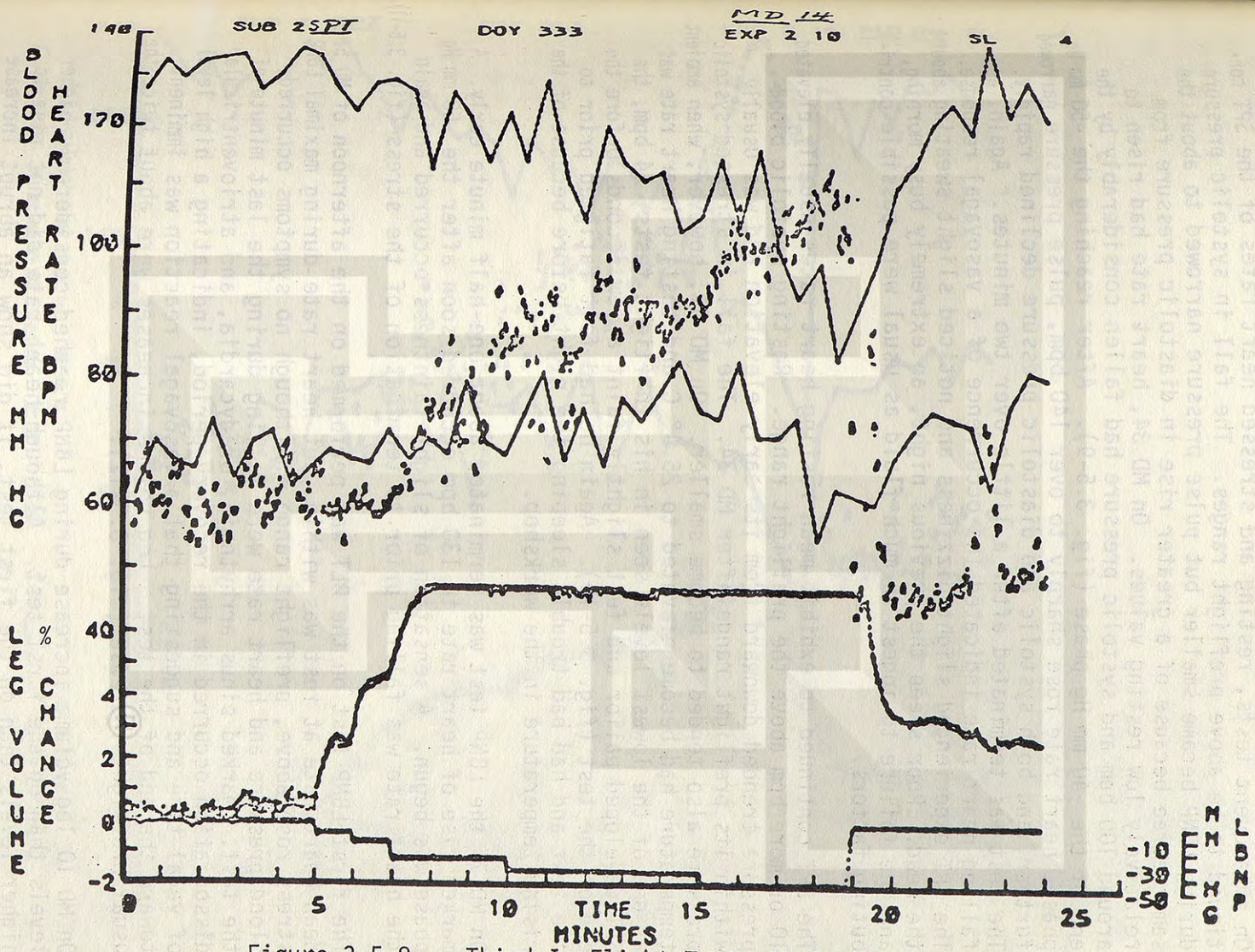



Figure 3.5-8. - Third In-Flight Test, SL-4 SPT.

On subsequent tests, resting and stressed heart rates of the SPT continued to be above preflight ranges. The fall in systolic pressure during LBNP became smaller but pulse pressure narrowed to about the same degree because of a greater rise in diastolic pressure from relatively low resting values. On MD 34, heart rate had risen to around 100 bpm and systolic pressure had fallen considerably by the end of the -40 mm Hg phase (fig. 3.5-9). After reaching the -50 mm Hg phase, heart rate rose sharply to over 140 bpm, pulse pressure narrowed further, and both systolic and diastolic pressure declined rapidly. The test was terminated after a little over two minutes. Again, a falling heart rate indicated the occurrence of a vasovagal response. The SPT experienced slight dizziness and noticed slight sweating about the head. Poor sleep the previous night, an extremely busy morning, and the failure to ingest as much fluid as usual were possible contributing factors.

The SPT continued to exhibit mean resting heart rates usually elevated 10 or more bpm above the preflight range. Resting systolic blood pressure trended downward from its early elevation and was usually within its preflight range after MD 34. The fall in stressed systolic pressure also tended to become smaller. On MD 61, however, when ambient temperature had become elevated to 26.4° C and resting heart rate was at one of the lowest levels seen in his in-flight tests, 54 bpm, the SPT developed pallor and felt slightly faint a few seconds before the end of the test (fig. 3.5-10). Again he had felt fatigued prior to the test and had had trouble sleeping the night before because of the rising temperature in the workshop.

On MD 71 the LBNP test was terminated about one-half minute early. A marked rise of heart rate to 130 bpm occurred soon after the -50 mm Hg phase was begun. A sensation of slight faintness occurred and again the heart rate was falling prior to termination of the stress (fig. 3.5-11).

The first LBNP test on the PLT was performed on the afternoon of MD 5. Mean heart rate at rest was within, but heart rate during maximal LBNP stress rose above, preflight range. Although no symptoms occurred, blood pressure and heart rate were falling during the last minute of the test. Marked sinus arrhythmia, bradycardia, and atrioventricular dissociation occurred in the recovery period, indicating a high level of vagal tone and suggesting that a vasovagal reaction was imminent toward the end of the test. Leg volume increases were about twice the usual preflight increase (fig. 3.5-12).

On MD 10 leg volume increase during LBNP reached considerably higher levels than on the first test. Although heart rate did not rise to higher levels than on the first test, it did show an abrupt increase after about two minutes of exposure to the -50 mm Hg phase. Concurrently, pulse pressure became more contracted. Soon heart rate,

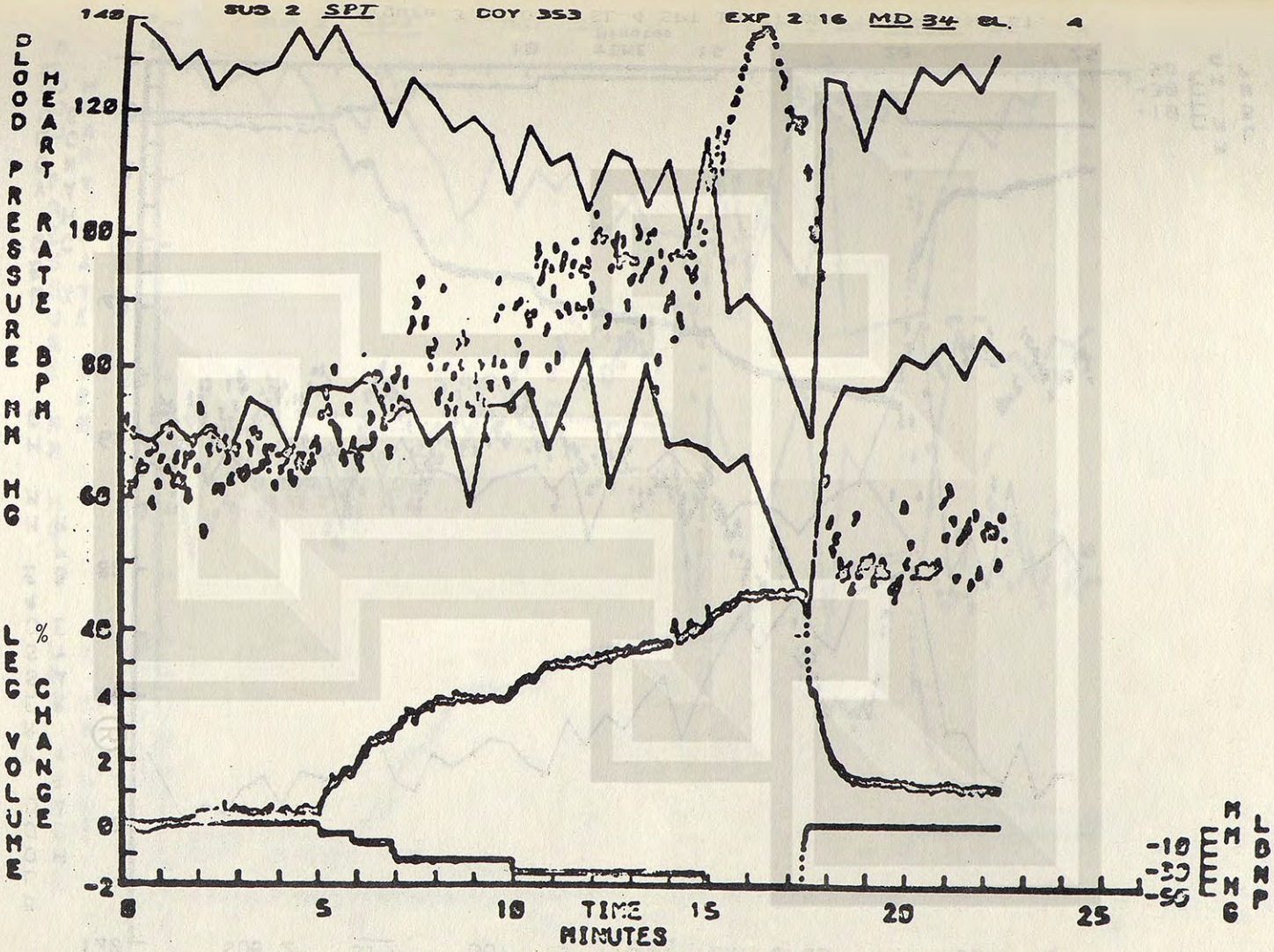



Figure 3.5-9. - SL-4 SPT In-Flight Test on MD 34.

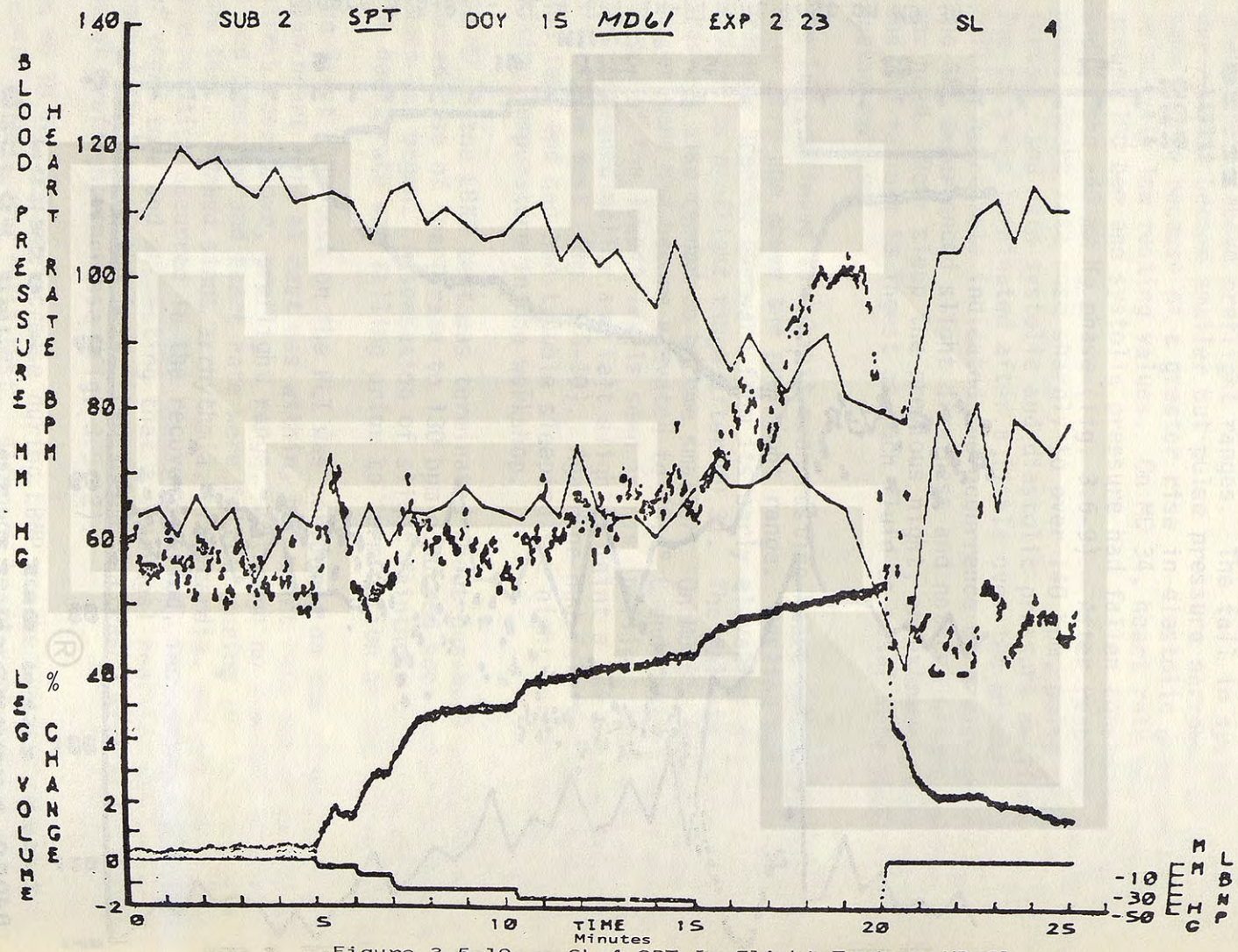



Figure 3.5-10. - SL-4 SPT In-Flight Test on MD 61.

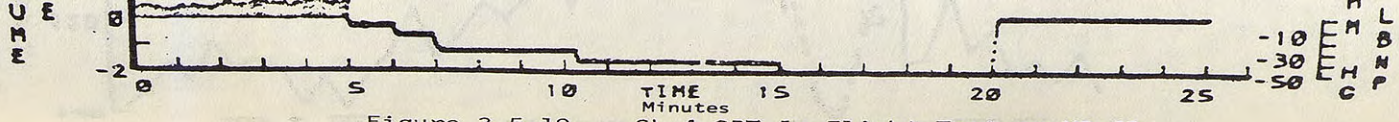



Figure 3.5-10. - SL-4 SPT In-Flight Test on MD 61.

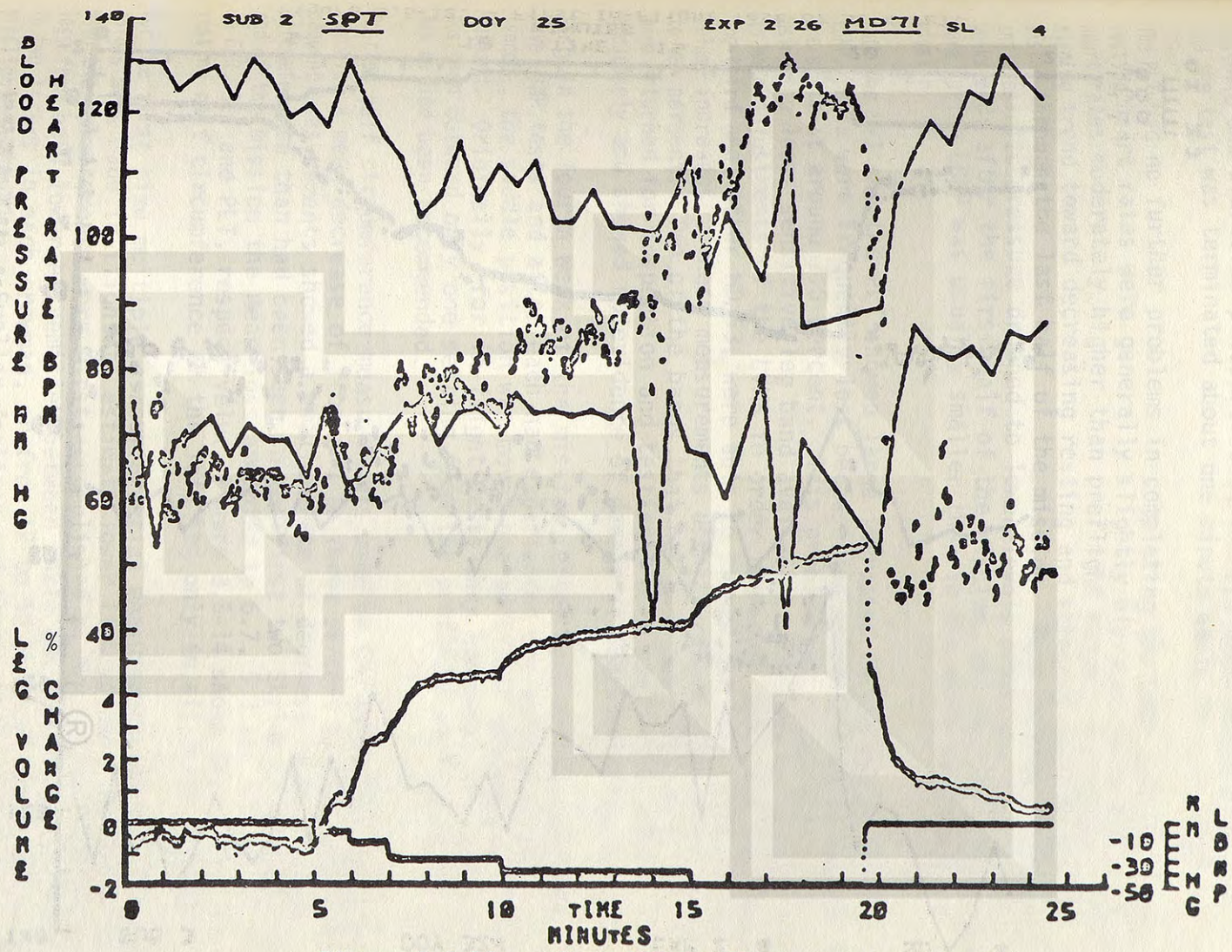



Figure 3.5-11. - SL-4 SPT In-Flight Test on MD 71.

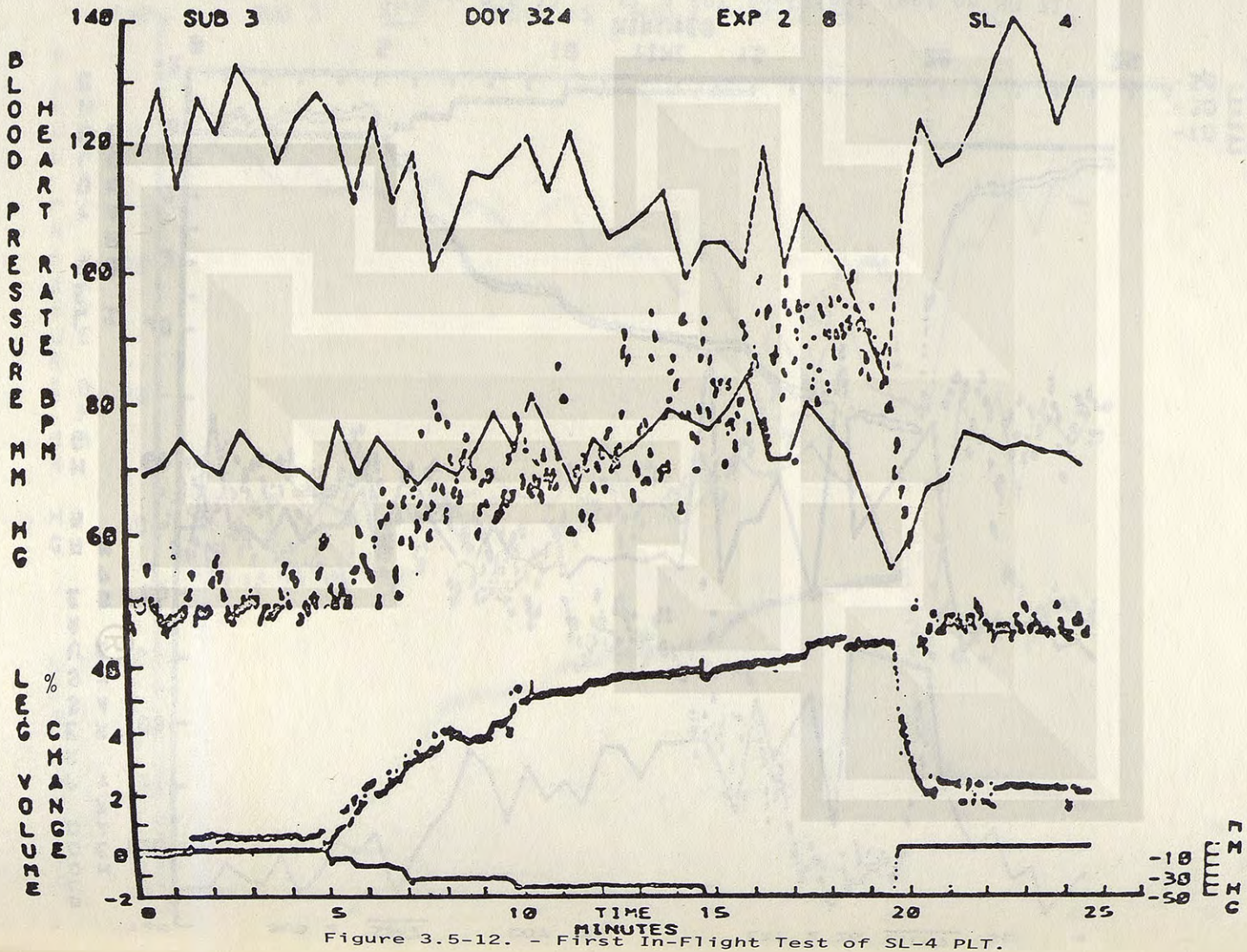



Figure 3.5-12. - First In-Flight Test of SL-4 PLT.

systolic and diastolic pressure fell, the PLT experienced dizziness and the test was terminated about one minute early (fig. 3.5-13).

The PLT had no further problems in completing the LBNP protocol. Mean resting heart rates were generally slightly elevated above and stressed heart rates moderately higher than preflight range. A slight but continuing trend toward decreasing resting and stressed heart rates persisted through the last half of the mission. Mean resting systolic and diastolic pressure dropped to lower levels after the first three weeks and, after the first half of the mission, the fall in pulse pressure during LBNP was usually smaller than in the early part of the mission.

Both the SPT and the PLT showed large increases in leg volume during LBNP. Data were frequently lost because leg volume increases exceeded the scale at around 7.5 percent. This problem was not eliminated by using the least sensitive leg band available. The crew was advised to make adjustments of the LVMS in order to reduce sensitivity by about one-third and, after MD 53, were able to record the full scale of leg volume increases. These measurements usually ranged from around eight to ten percent. Two of the bands that had been most frequently used were returned for inspection and testing. Both bands functioned accurately and showed no evidence of damage or degraded performance.

Early in the fourth week of the mission, after each crewman had received five LBNP tests and after each had experienced one episode of presyncope, the saddle position was moved one additonal setting, 3/4 inch, outward. Originally, for in-flight tests they had moved the saddle position outward only one setting from the preflight setting rather than two as had been recommended.

Resting calf circumference measurements made on the second day of flight revealed a mean decrease of from one to three percent by that time. Subsequent measurements showed a smaller rate of decrease in calf girth circumference than had been seen in the first two Skylab crews. By the end of the mission the mean loss amounted to 6.7, 5.3 and 7.0 percent in CDR, SPT and PLT, respectively. Figure 3.5-14 shows the course of resting calf circumference of the left leg only in all three crewmen.

For the first time multiple circumferential measurements of the legs and thighs were made in-flight to estimate lower limb volume. By the MD 3, when the measurements were first accomplished on the CDR and PLT, volume loss from both lower extremities between ankle and upper thigh amounted to two liters in each crewman, or from 12 to 13 percent loss from the preflight mean value. Smaller declines and fluctuations occurred in the four subsequent in-flight measurements. The left leg volume in liters for the three crewmen is shown in figure 3.5-15.



Figure 3.5-12. - MINUTES First In-Flight Test of SL-4 PLT.

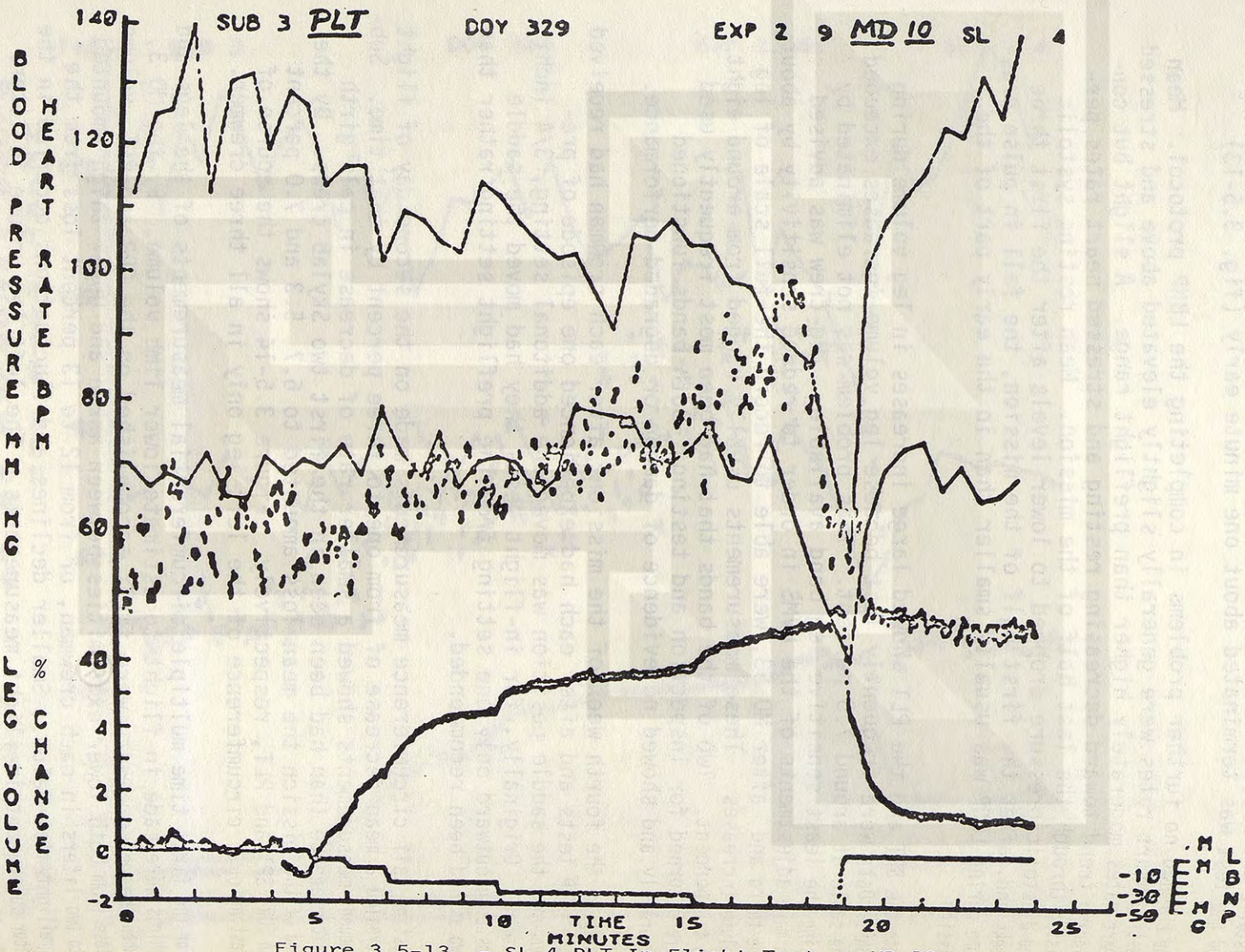



Figure 3.5-13. - SL-4 PLT In-Flight Test on MD 10.

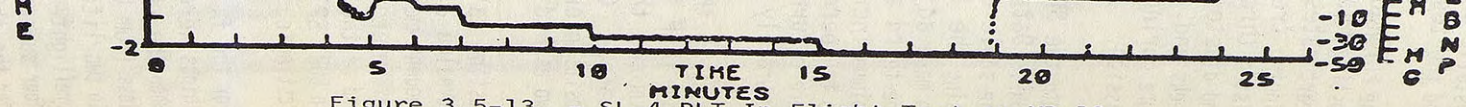



Figure 3.5-13. - SL-4 PLT In-Flight Test on MD 10.

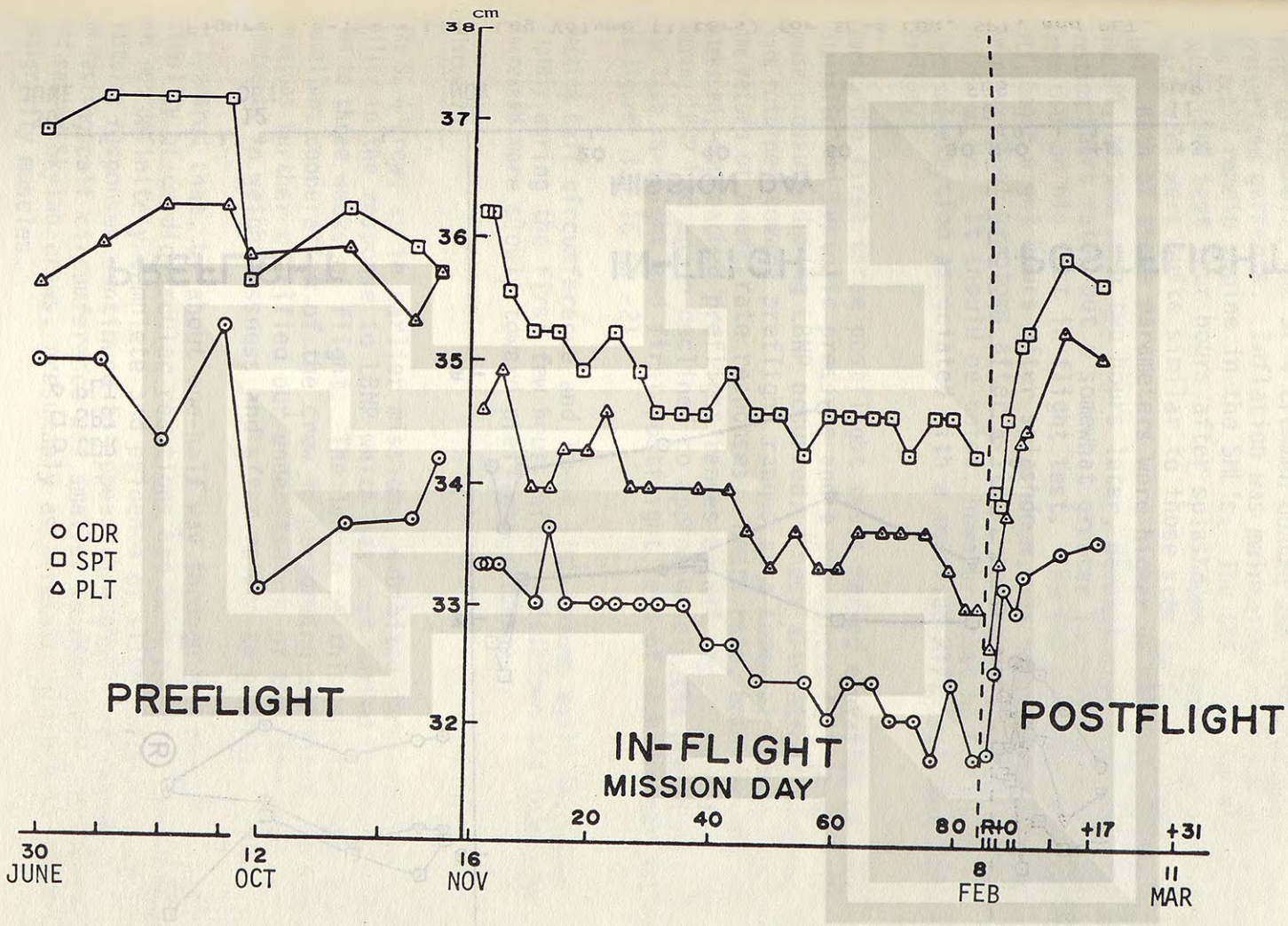



Figure 3.5-14. - Maximum Girth Left Leg, Resting, SL-4 CDR, SPT, and PLT.

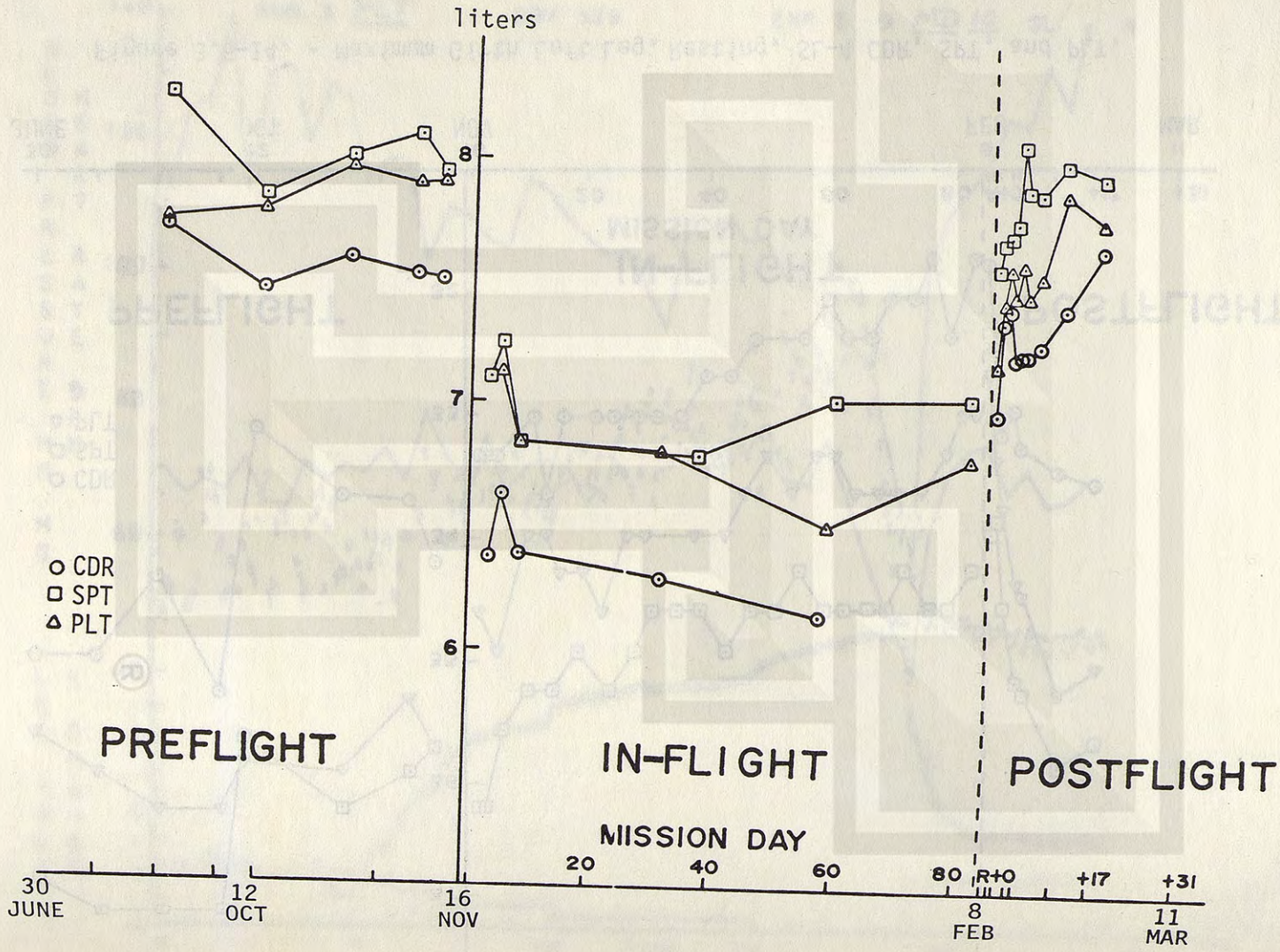



Figure 3.5-15. - Left Leg Volume (liters) for SL-4 CDR, SPT, and PLT.

Figure 3.5-15. - Left Leg Volume (liters) for SL-4 CDR, SPT, and PLT.

## Postflight

Prior to deorbit, the SL-4 crewmen donned and inflated their lower body pressurized garments. Inflation was maintained at least until the crewmen could remain supine in the SML's. The CDR received the first postflight LBNP test four hours after splashdown. Resting and stressed heart rates were quite similar to those seen during his last in-flight test. Both of these parameters were higher on R+1 than on R+0 day. The SPT, tested some two hours later, demonstrated a relatively low resting heart rate, but a somewhat greater increase in stressed heart rate than on his last in-flight test. The R+0 day LBNP test on the PLT, begun eight hours after splashdown, was terminated early because of presyncopal symptoms after a little more than a minute of exposure to -55 mm Hg. It should be noted, however, that he had performed mild physical exertion associated with a modified M171 test about two hours earlier.

During the first three postflight tests marked elevation of resting diastolic and systolic pressure and a pronounced fall in systolic and pulse pressure during LBNP occurred. These alterations in blood pressure returned toward preflight ranges at a somewhat slower pace than the return of heart rate responses. Heart rate, both resting and stressed, approached preflight ranges by R+4 day. Leg volume increase during LBNP had again declined to approximately the preflight values. The last in-flight and first postflight test of each crewman are shown in figures 3.5-16 to -21.

Resting calf circumference and lower limb volume again increased rapidly during the first few hours after splashdown and thereafter increased more slowly toward preflight values.

## Discussion

The SL-4 crew, as in earlier missions, exhibited cardiovascular instability in the response to LBNP which was most marked during the first two to three weeks of flight. The length of this mission plus the excellent cooperation of the crew in performing additional cardiovascular missions further clarified our understanding of the cardiovascular adjustments in weightlessness and after return to gravity.

It appeared that, by about one-half way through the mission, relative stability of cardiovascular reactions had been achieved. However, this was not definitely complete and evidence of slight change in cardiovascular responses continued to appear throughout the mission. The loss of resting calf circumference was smaller in magnitude than in the first and second Skylab crews, presumably as a result of exercise involving antigravity muscles.

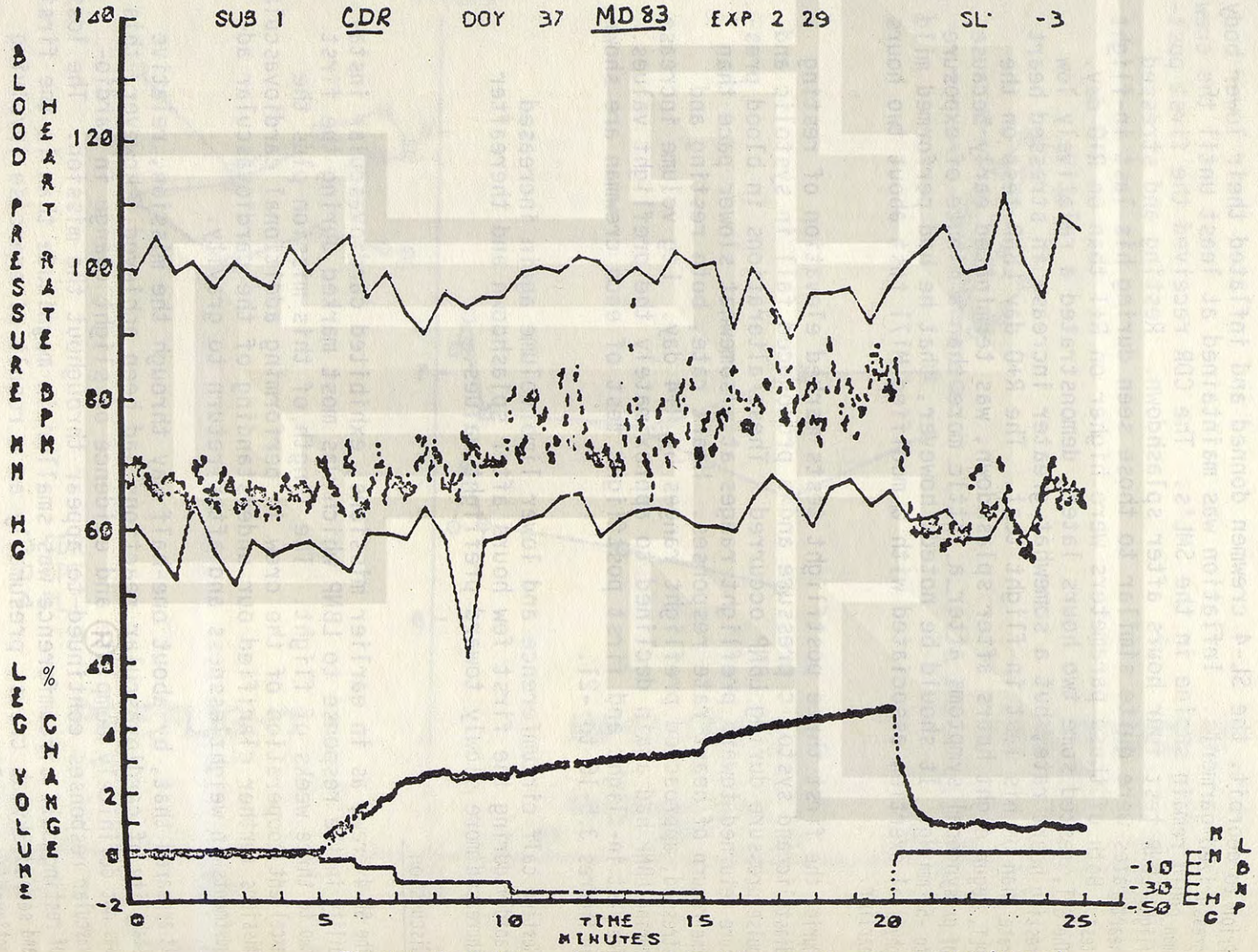



Figure 3.5-16. - Last In-Flight Test, SL-4 CDR.(M092)


Figure 3.5-16. - Last In-Flight Test, SL-4 CDR.(M092)

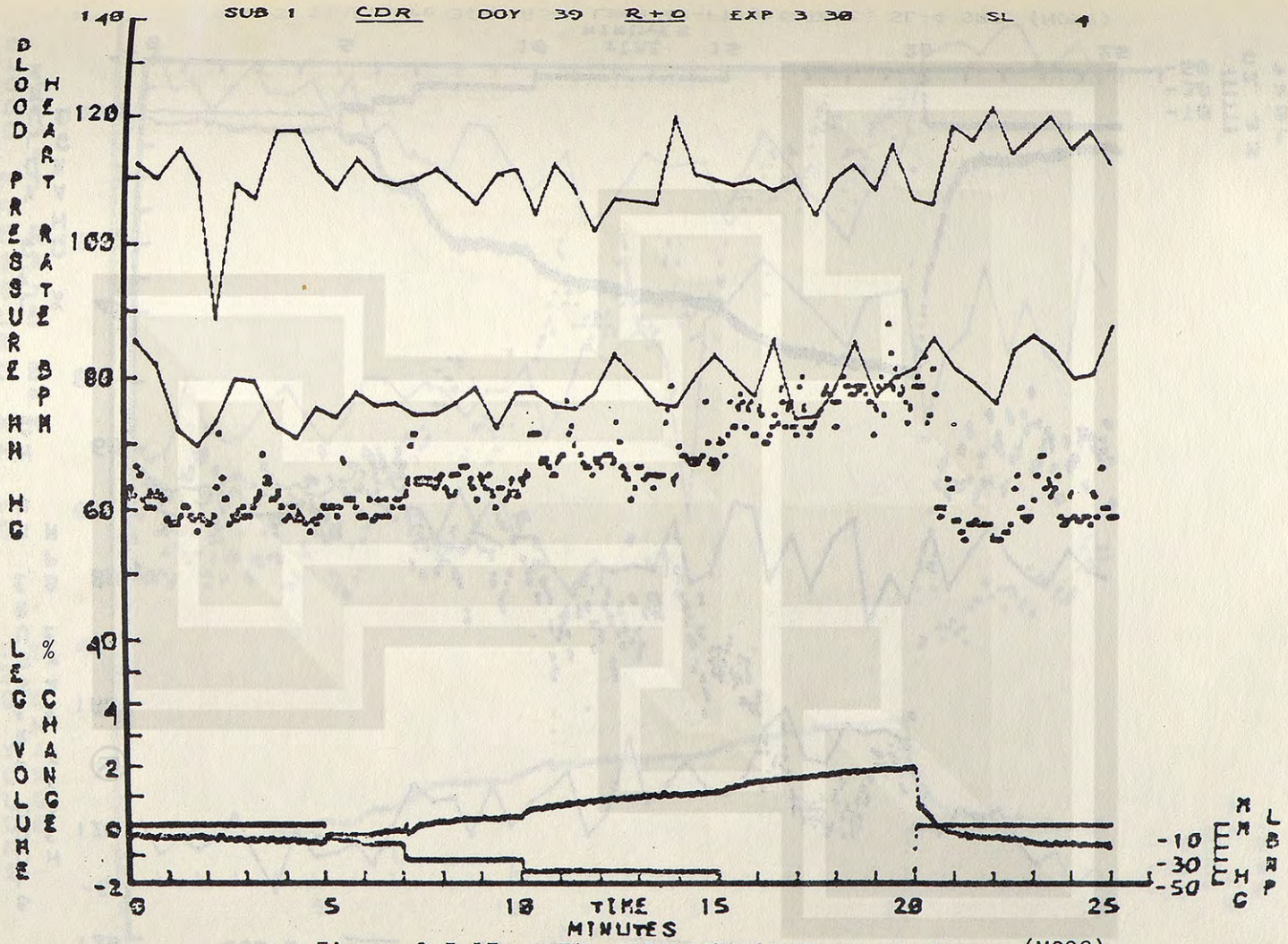



Figure 3.5-17. - First Postflight Test, SL-4 CDR. (M092)

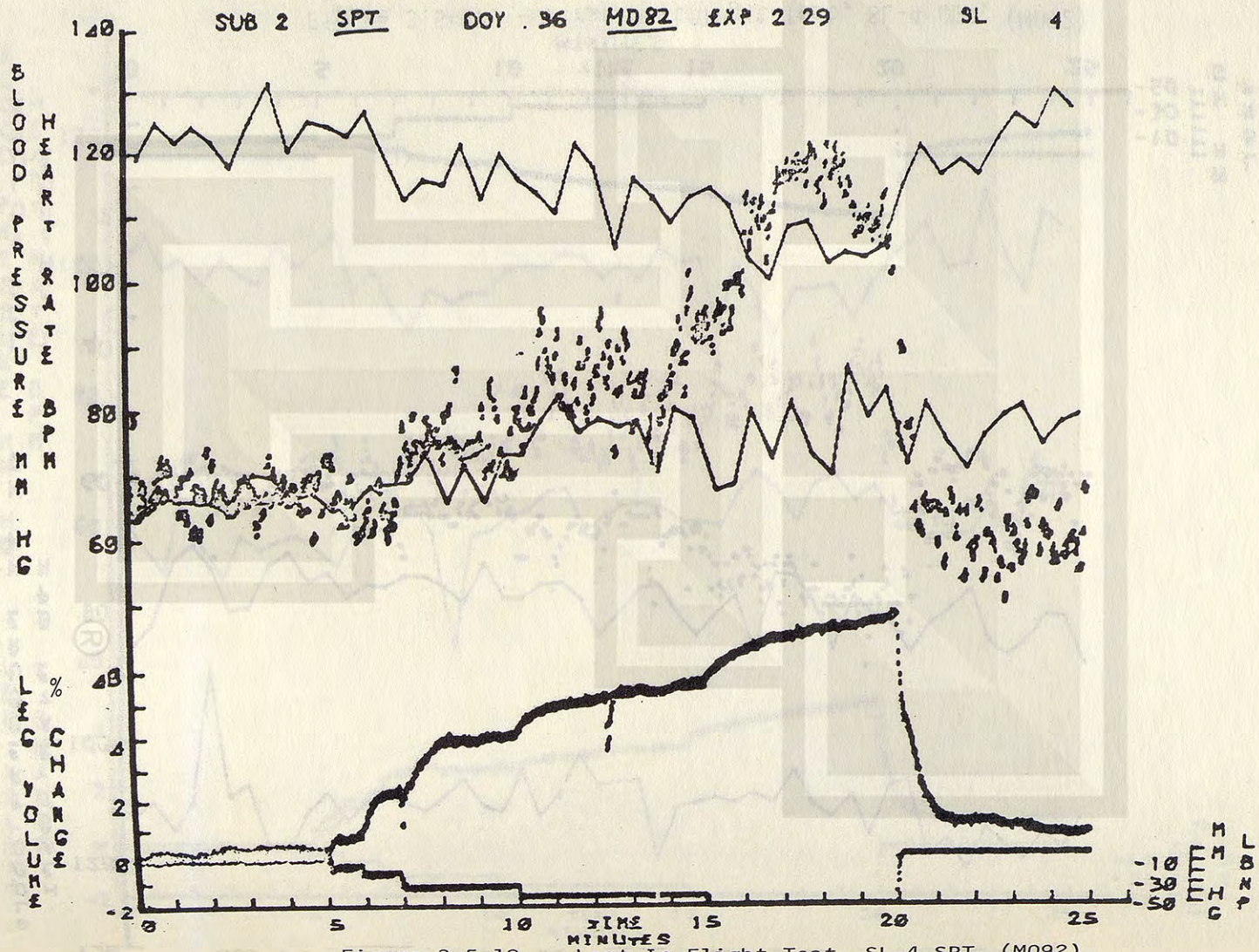



Figure 3.5-18. - Last In-Flight Test, SL-4 SPT. (M092)

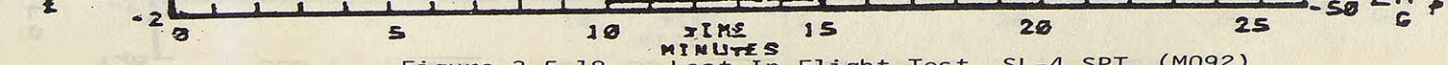



Figure 3.5-18. - Last In-Flight Test, SL-4 SPT. (M092)

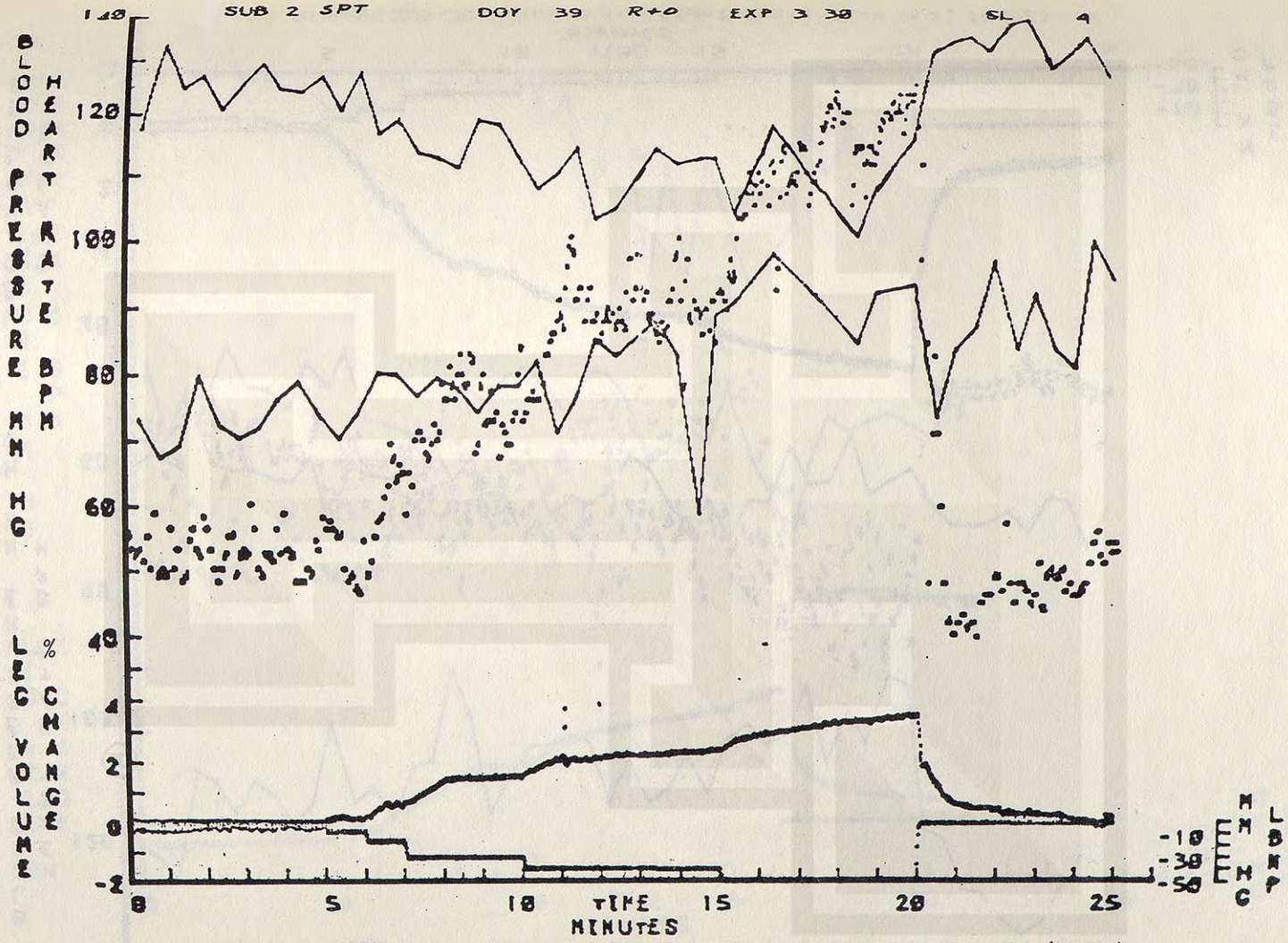



Figure 3.5-19. - First Postflight Test, SL-4 SPT. (M092)

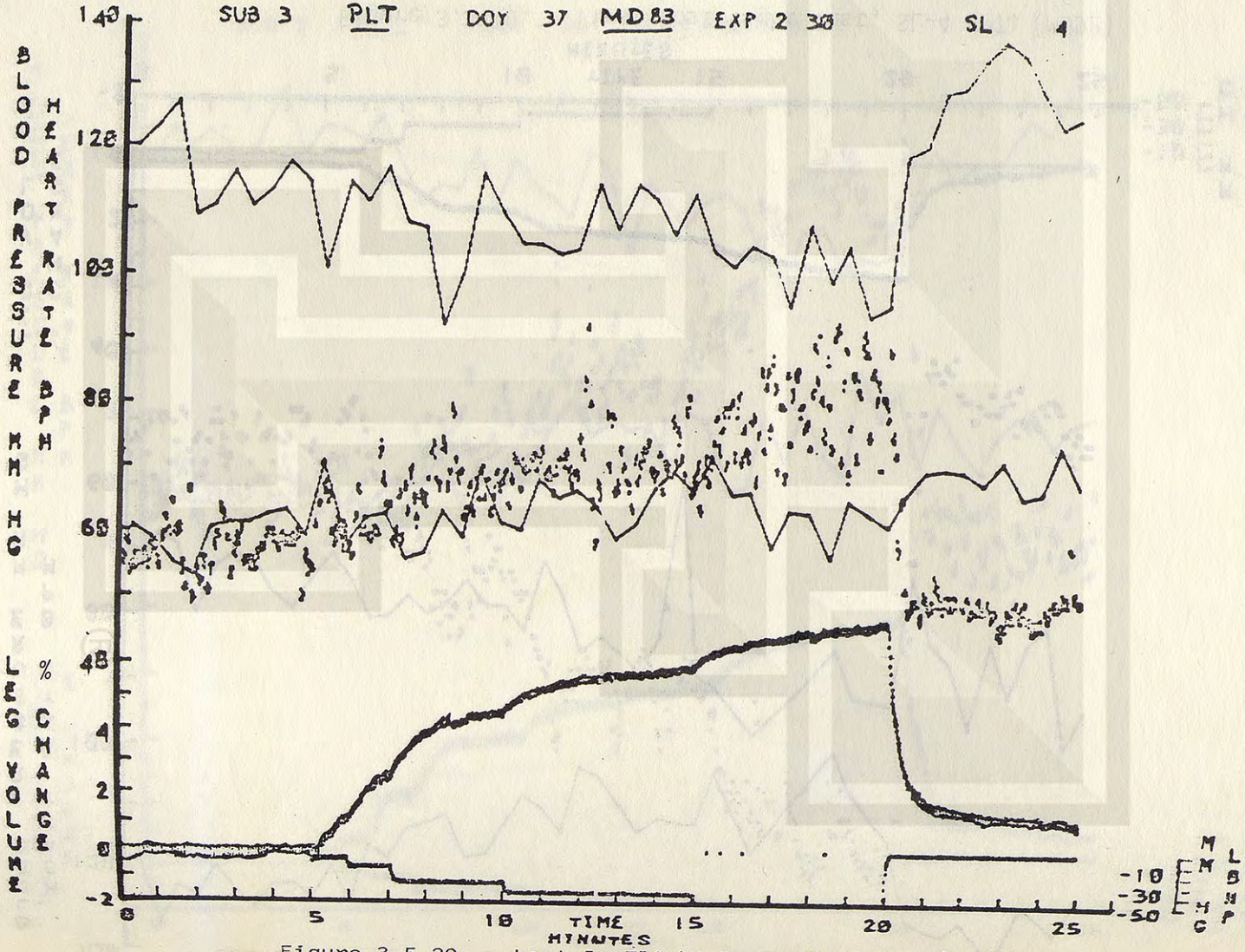



Figure 3.5-20. - Last In-Flight Test, SL-4 PLT. (M092)

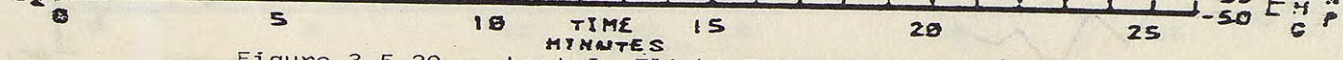



Figure 3.5-20. - Last In-Flight Test, SL-4 PLT. (M092)

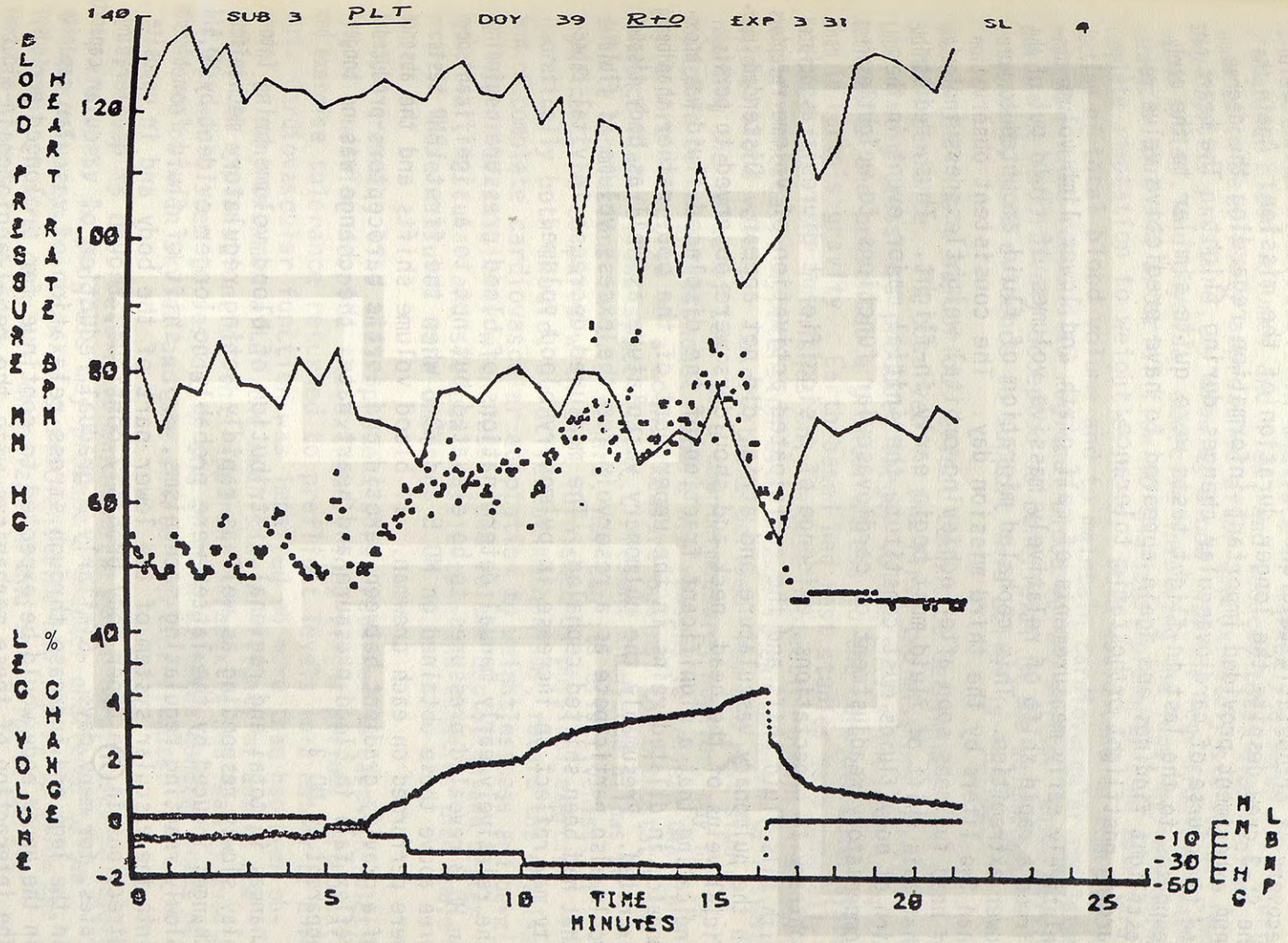



Figure 3.5-21. - First Postflight Test, SL-4 PLT.(M092)

Recovery of orthostatic tolerance occurred at least as rapidly as in the SL-3 crew despite the longer duration of the mission. Again the LBNP experiment provided important information regarding the degree and timecourse of cardiovascular changes during flight. The heart rate responses to the last in-flight tests were quite similar to the early postflight findings and again appeared to have predictive value regarding postflight orthostatic tolerance.

Relatively early measurements of calf girth and lower limb volume confirmed a rapid shift of relatively massive volumes of fluid out of the lower extremities. This cephalad migration of fluid amounted to more than two liters by the third mission day. The consistent observation of head fullness soon after achieving orbital weightlessness indicates that this shift of fluid must begin early in-flight. Thus, redistribution of body fluids must constitute the initial major event in the compensatory readjustment of cardiovascular functions to weightlessness.

Contrary to expectations, evidence of a significant diuresis associated with this fluid shift and the anticipated activation of volume receptors in the pulmonary vasculature and atria, did not appear. Distended superficial veins of the head, neck and shoulders were observed to persist, indicating that a significant fraction of the displaced fluid was accommodated in dilated veins in the upper part of the body rather than being excreted. Presumably the pulmonary vasculature as well as body tissues would also participate as a reservoir for the excess volume of fluid that had been shifted cephalad. The measured decrease in vital capacity may reflect an increase in pulmonary blood volume.

The relatively early manual determinations of blood pressure beginning on MD 3 revealed pressures to be elevated but not to a significant degree above those obtained on MD 5 and MD 6 when the first LBNP tests were performed on each crewman. If blood volume shifts and the absence of a gravity gradient between carotid and aortic baroceptors produced a reflex fall in blood pressure and heart rate, the change was no longer apparent by MD 3.

Changes in total and regional distribution of blood volume bring into play slowly responding as well as rapidly acting regulatory mechanisms. Changes induced by the latter were probably no longer evident by MD 5. Slowly reacting regulating mechanisms, *e.g.*, shift of fluid from tissues into the vascular system of the lower part of the body and in opposite directions in the upper body probably continue, though at decelerating rates, for many days. Similarly a gradual reduction of vascular capacity in the legs and increase through stress relaxation of vascular capacity in the upper body would be expected to continue for prolonged periods. The interaction of these mechanisms with the renal-angiotensin-aldosterone system and with other volume regulating renal mechanisms in zero gravity has not yet been defined.

Cardiovascular homeostasis in the face of markedly altered distribution of regional blood volumes and flow, and reduced total blood volume, appeared to be closely approached after approximately six weeks. Lower body negative pressure, by drawing blood into the legs from the central venous system, and physical exercise involving the legs, by increasing cardiac output and arterial flow to the legs, probably tend to retard complete adaptation to weightlessness. Both would tend to limit reduction of total blood volume and to maintain cardiovascular regulatory mechanisms that respond to regional blood volume shifts. While physical exercise is intuitively accepted as beneficial in the weightless environment, hard evidence to support this belief is lacking.

Whether LBNP has a salubrious effect cannot be determined from the Skylab experience. As observed in the first two missions, however, LBNP in weightlessness produced larger volume shifts into the lower extremeties and presented a greater stress to the cardiovascular system than in Earth's gravity. Earth-based bed rest studies have generally indicated that LBNP furnishes only modest protection against the development of orthostatic hypotension even though it can maintain or restore depleted blood volume. Observations derived from bed rest studies regarding the value of LBNP as a countermeasure, however, may not be applicable to weightlessness. There are reasons to believe that LBNP may be more effective as a countermeasure against the orthostatic intolerance that follows space flight. Present knowledge allows no definite conclusions in this regard, nor can its effectiveness, if significant, be compared with that furnished by physical exercise. Theoretically both should, by different mechanisms, retard the development of complete cardiovascular adaptation to weightlessness and permit achievement of stability with less blood volume depletion and better myocardial, vascular and skeletal muscle tone and function than would occur if these measures were omitted.

The SL-4 crewmen, like their predecessors, returned to Earth in relatively good condition despite the extremely long flight period. Orthostatic and exercise tolerance returned to preflight levels in a matter of a few days. Cardiovascular function was impaired no more than had been observed in many crewmen after the much shorter flights of Gemini and Apollo. An explanation for this apparent paradox is not readily available, but would seem to reside in one or more of three general areas of difference between Skylab and the shorter earlier flights.

First, it may be that return to Earth while major cardiovascular adjustments are still in progress may present a greater challenge to the cardiovascular system than if sufficient time had lapsed to allow the achievement of more complete organization and integrity of cardiovascular function. A second factor may reside in the physical exercise and possibly, LBNP exposure, that occurred during Skylab flights.

However, the physical effort associated with lunar activities had no clearly demonstrable beneficial effect on orthostatic tolerance in Apollo crewmembers. Third, the type of recovery used in Skylab, that is, shipboard egress, the use of pressurized lower body garments and minimal orthostatic exposure during the early postflight period may have altered the readaptive changes and the postflight physical condition. There seems little doubt, although concrete supporting evidence does not exist, that these measures do cushion or soften the impact of the readaptive changes necessary in gravity. The cardiovascular adjustments that occur on return to Earth's gravity must begin in response to relatively large fluid shifts from upper to dependent regions of the body. The protective measures used in Skylab slow these regional shifts of blood volume and minimize the stress placed upon the heart and blood vessels at a time when major compensatory responses would otherwise not only be necessary for circulatory integrity, but also would probably be least able to respond effectively.

### 3.5.1 Echocardiographic Studies in the SL-4 Crew

*Principal Investigators:* *W. Henry, M.D.*
*James Griffith*
*R. Goldstein, M.D.*
*S. Epstein, M.D.*
*Principal Coordinating Scientist:* *G. W. Hoffler, M.D.*

Echocardiographic studies were performed preflight on F-10 days and postflight on R+0, R+1, R+2, R+4, and R+11 days. From these ecnocardiograms the following measurements were made:

- Left ventricular transverse dimension at onset of systole
- Left ventricular transverse dimension at end systole
- Ventricular septal thickness at end diastole
- Posterobasal left ventricular free wall thickness at end diastole

Preflight measurements in the CDR revealed a left ventricular transverse dimension at the upper limit of normal, while that of the SPT and PLT were increased above the normal range. These findings in the SPT and PLT resemble that seen in trained distance runners. Wall thickness measurements were normal in all three crewmembers preflight.

Postflight basal studies were unchanged in the CDR at R+0 through R+11 days. In both the SPT and PLT, however, the left ventricular transverse dimension was decreased slightly. This decrease was noted on R+0 through R+11 days. Wall thickness measurements were unchanged.

Using the accepted assumptions, left ventricular volumes at end diastole and end systole were calculated for each crewmember. Stroke volume also was derived from these two values. In each crewmember the left ventricular stroke volume was appropriate for his end diastolic volume both preflight and postflight, indicating that no deterioration in ventricular function had occurred.

## 3.6 Experiment M093. Vectorcardiogram

*Principal Investigators:* *Raphael F. Smith, M.D.*
*Newton Allebach, M.D.*

Twenty-one in-flight exercise vectorcardiograms (VCG) were obtained on each crewman during SL-4. Twelve M171 protocols (figures 3.6-1 through -11) and nine M093 protocols were utilized on an alternating basis with approximately three-day centers. No significant protocol violations occurred in-flight and the quality of the data was generally excellent.

During the R+0 and R+1 day runs several protocol violations occurred that impact the data significantly. Supine exercise at a low level was performed on R+0 day and bears no resemblance to the preflight protocol. On R+1 day supine exercise was performed before upright exercise interjecting an additional stress between the M092 run and the M171 run. It will be difficult to determine whether the VCG changes noted during these early postflight runs reflect adaptive mechanisms or the protocol deviations.

As noted in SL 1/2 and SL-3, several VCG parameters differed statistically from preflight values. None of these deviations from preflight "norms" reached the level of being considered clinically abnormal. All of the changes were similar in direction and magnitude to changes noted in the previous Skylab crewmen. These changes are summarized on the accompanying tables, 3.6-I and 3.6-II.

VCG changes common to a majority of the Skylab crewmen include:

- An increase in the maximum QRS vector (QRS magnitude)
- A small increase in QRS duration
- An increase in P-R interval at rest, with no significant change during exercise
- An increase in T-wave magnitude at rest
- An anterior shift of the QRS max. vector

By R+4 days most of the in-flight changes had returned to (or were definitely approaching) preflight levels. Speculation as to the causes of the in-flight VCG changes must be deferred until the data can be correlated with fluid and electrolyte changes, EVA activity, endocrine activity, and other findings. It appears that there is fairly strong vagotonic stimulation (and probably sympathetic inhibition) during the in-flight resting or control periods. This would account for the A-V conduction delay (increased P-R interval) that has been noted during the control period.

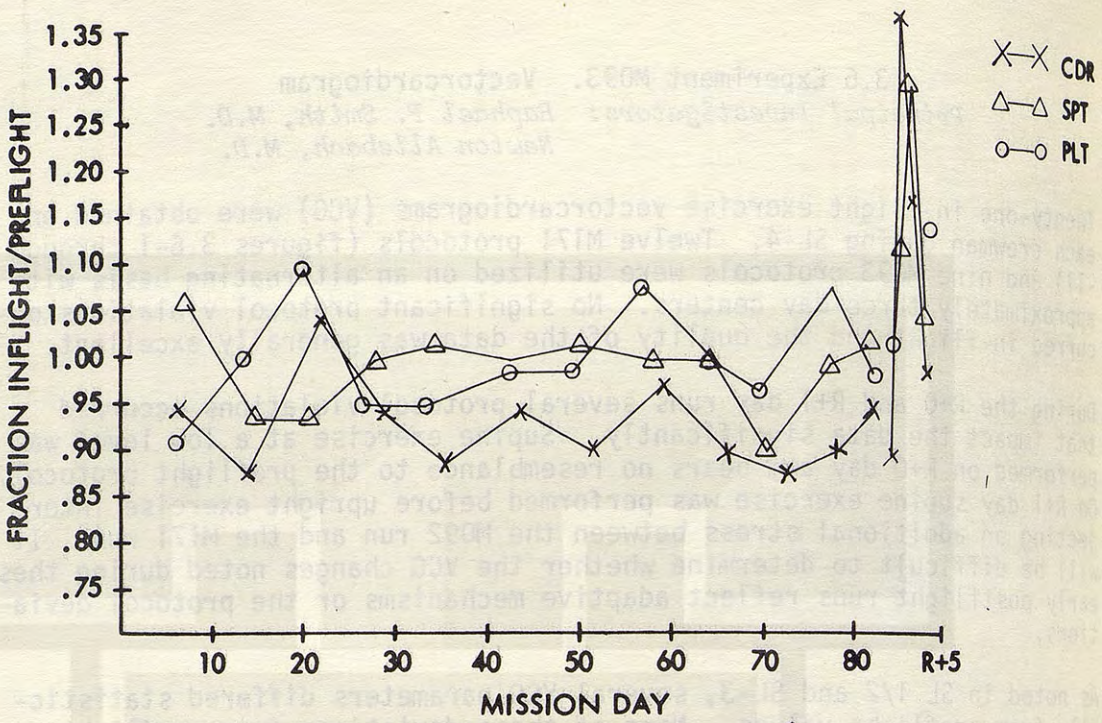



Figure 3.6-1. - Heart Rate, Rest, SL-4,(M093)

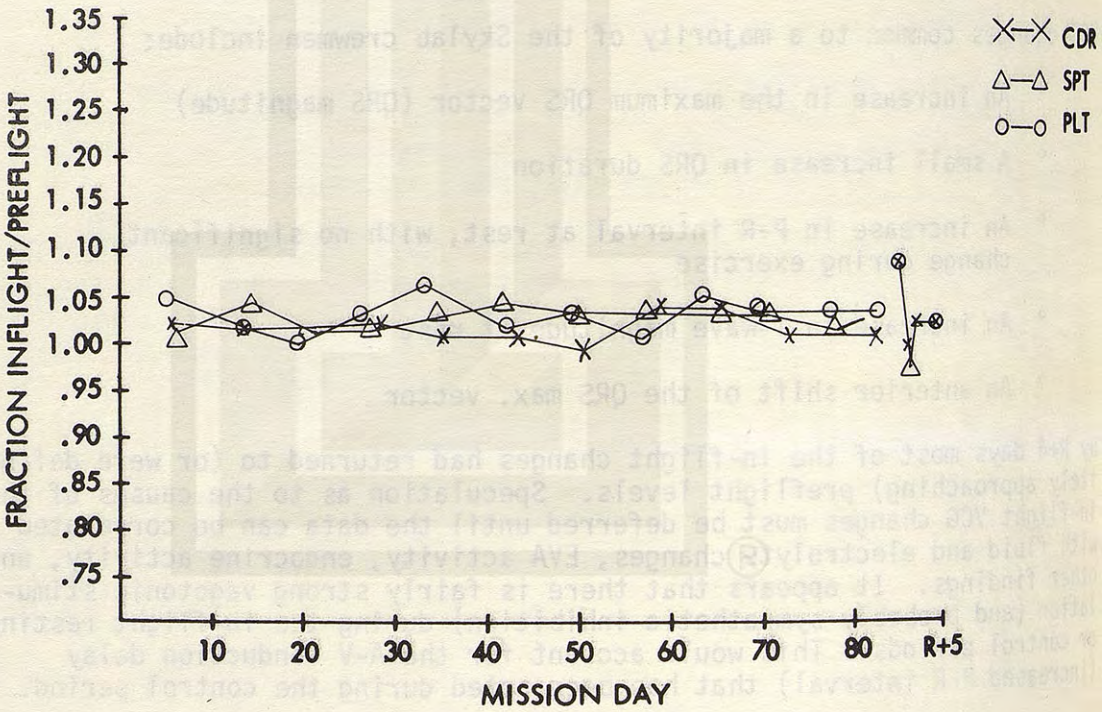



Figure 3.6-2. - QRS Duration, Rest, SL-4 (M093).

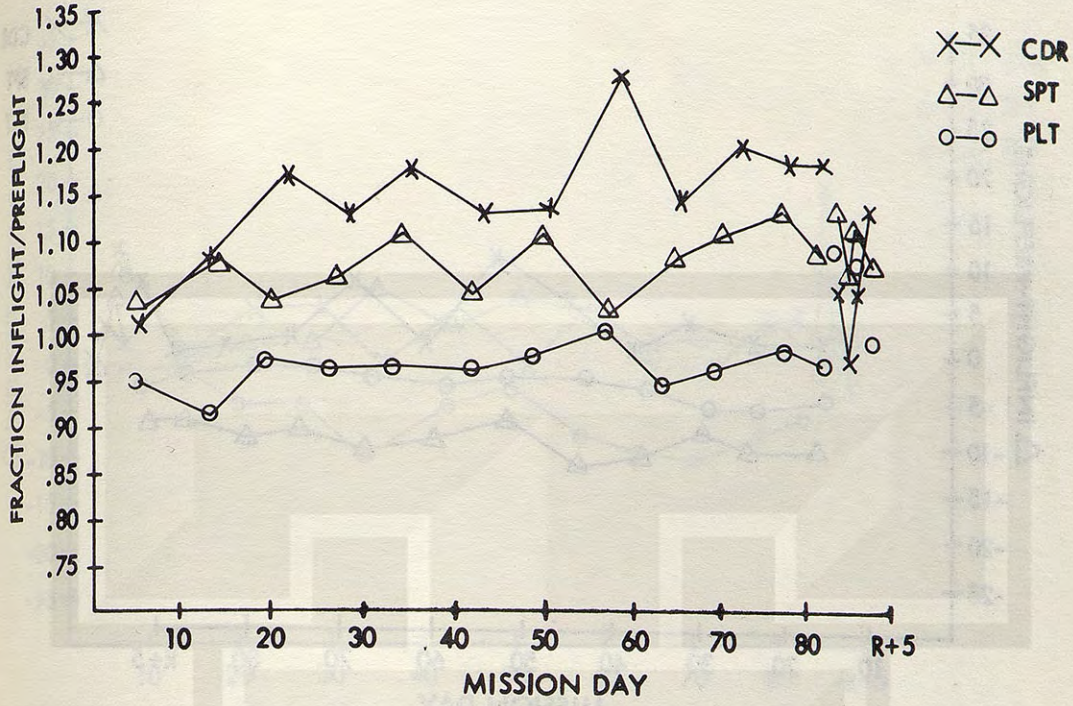



Figure 3.6-3. - QRS Magnitude, Rest, SL-4.

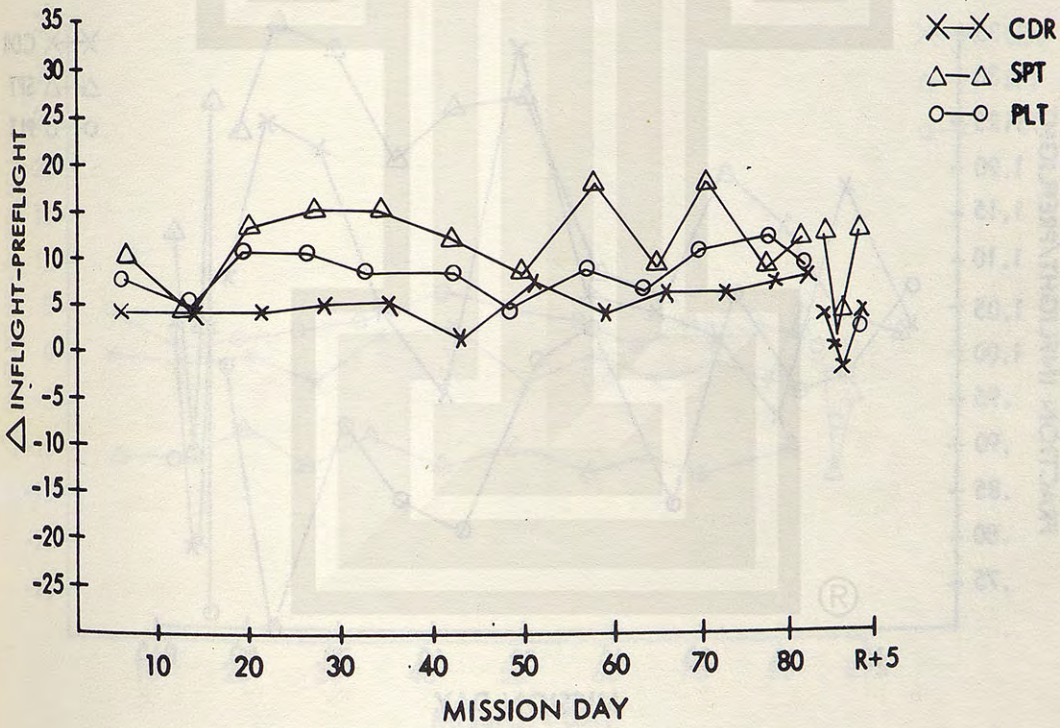



Figure 3.6-4. - QRS Azimuth, Rest, SL-4.

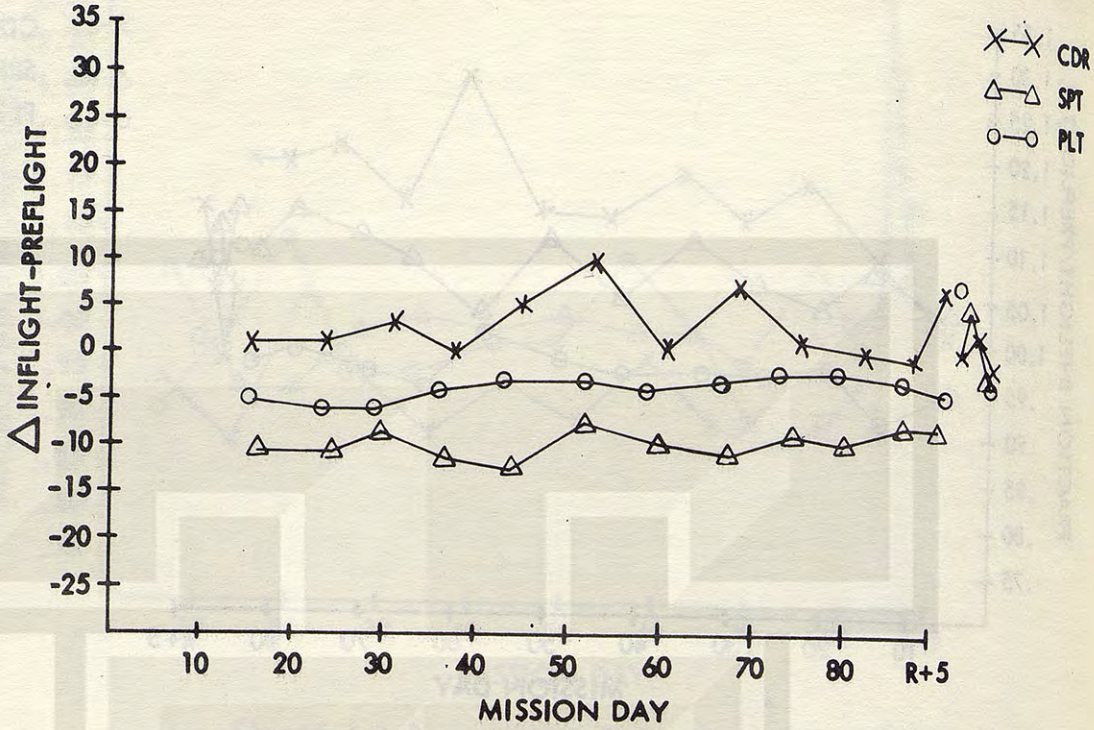



Figure 3.6-5. - QRS Elevation, Rest, SL-4.

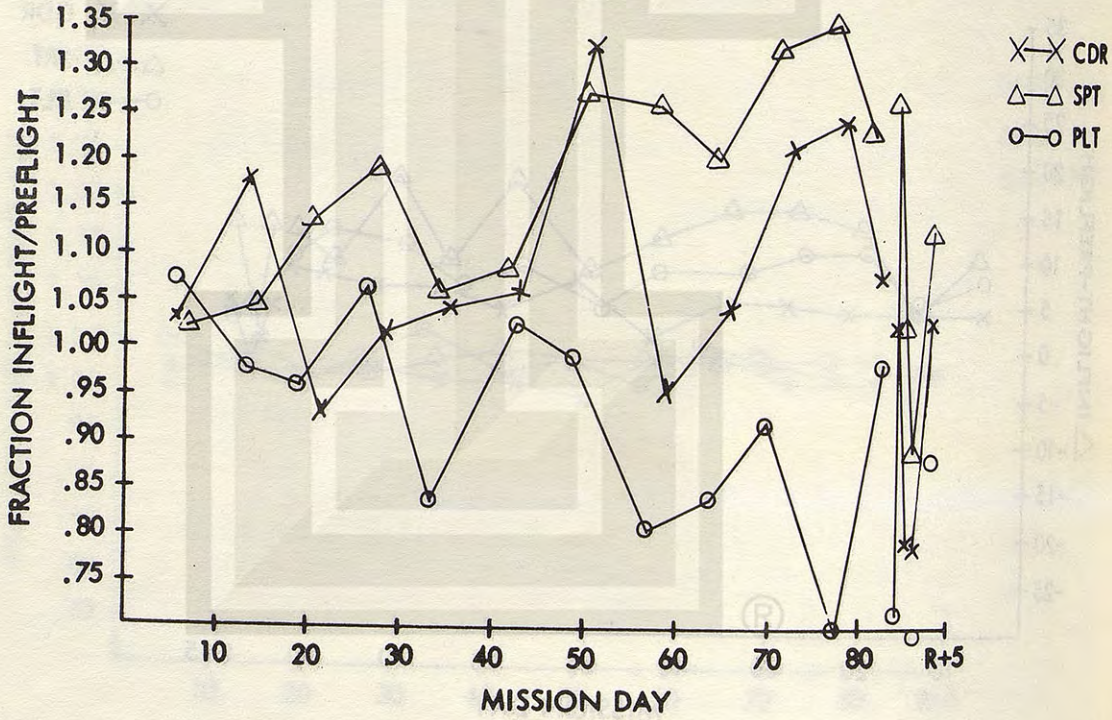



Figure 3.6-6. - T Magnitude, Rest, SL-4.

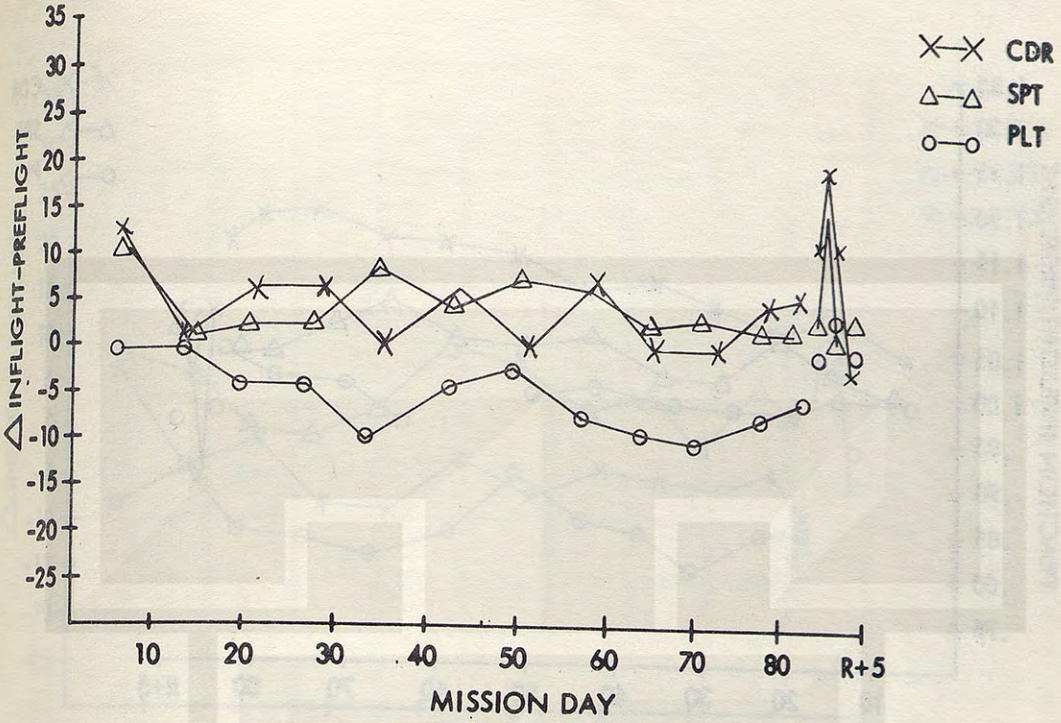



Figure 3.6-7. - T Azimuth, Rest, SL-4.

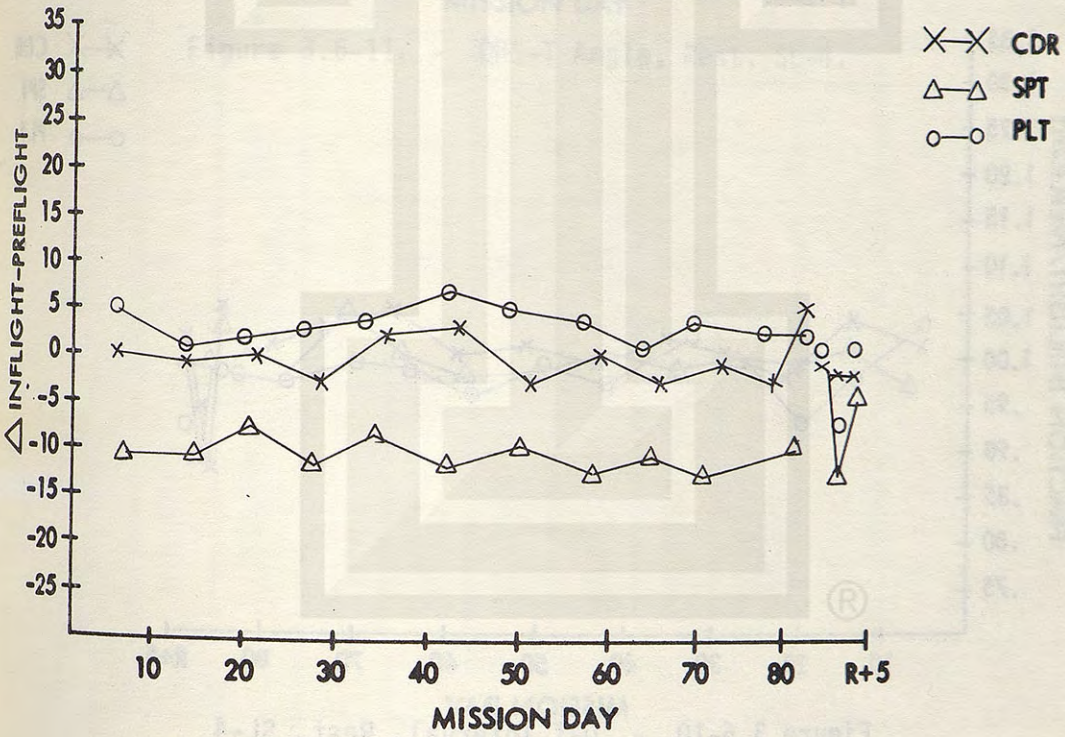



Figure 3.6-8. - T Elevation, Rest, SL-4

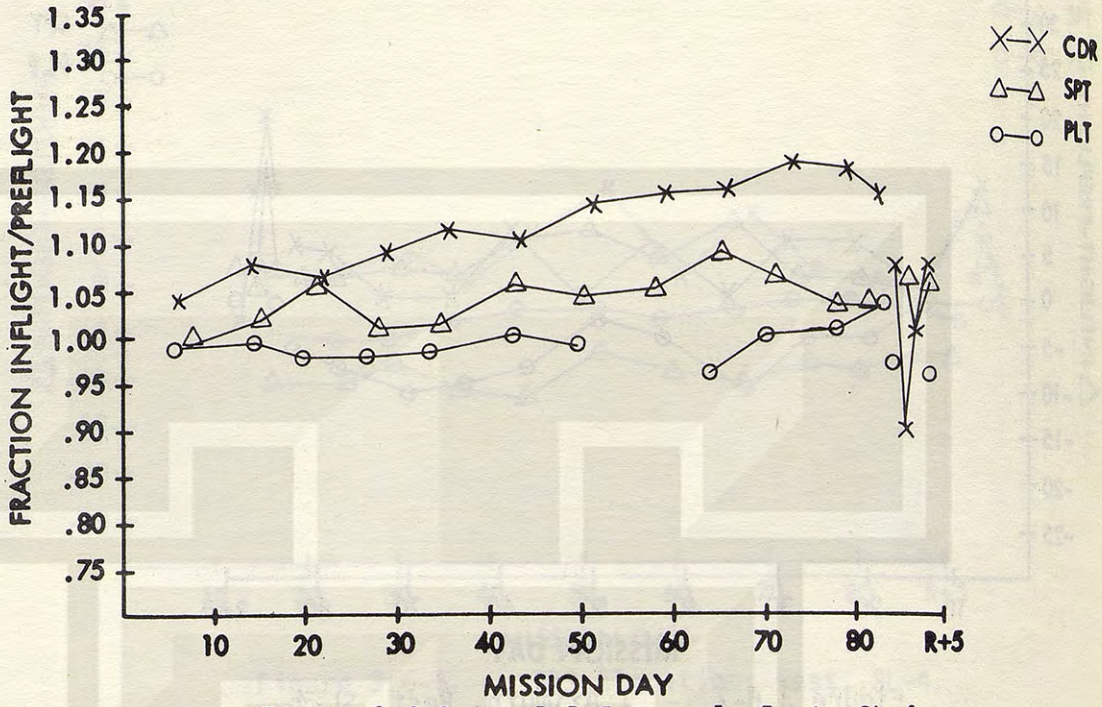



Figure 3.6-9. - P-R Interval, Rest, SL-4.

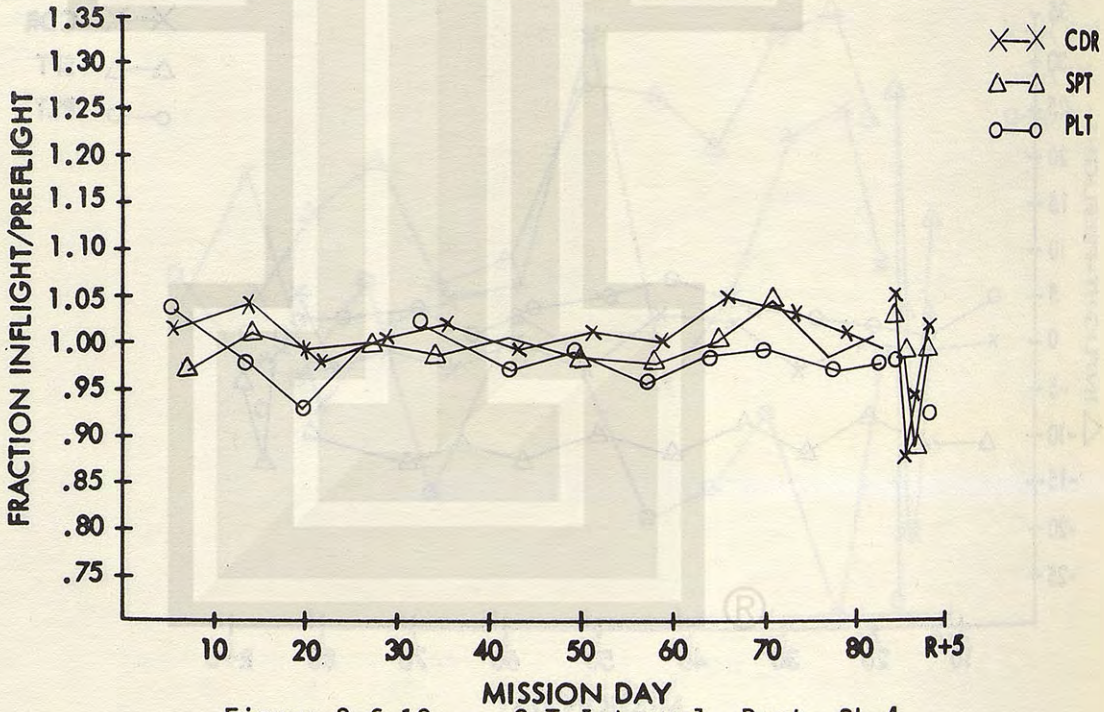



Figure 3.6-10. - Q-T Interval, Rest, SL-4.

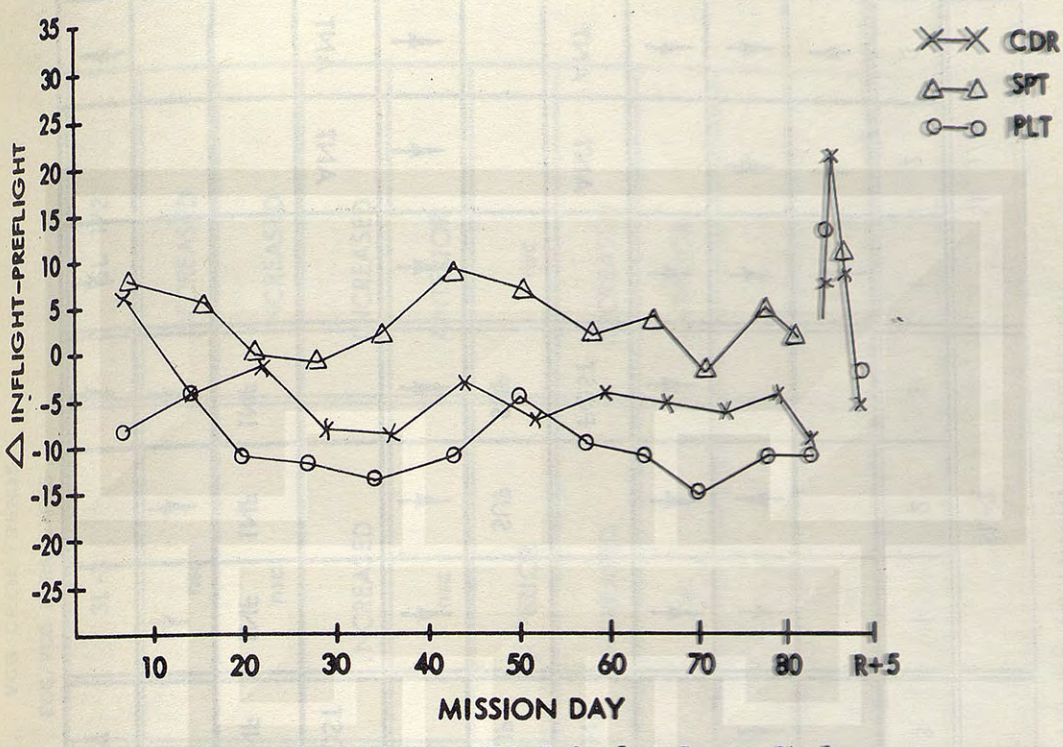



Figure 3.6-11. - QRS-T Angle, Rest, SL-4.

TABLE 3.6-I. VCG CREW TRENDS IN-FLIGHT *vs.* PREFLIGHT

| | SL-4 | | | SL-3 | | | SL 1/2 | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 1 | 2 | 3 | 1 | 2 | 3 |
| HEART RATE | | | | | | | ↓ | ↓ | ↓ |
| QRS DURATION | ↑ | ↑ | ↑ | ↑ | ↓ | | ↑ | ↑ | ↑ |
| QRS MAGNITUDE | ↑ | ↑ | | ↑ | ↑ | ↑ | ↑ | | ↑ |
| QRS AZIMUTH | ANT | ANT | ANT | | | POST | | ANT | ANT |
| QRS ELEVATION | INF | SUP | SUP | | SUP | SUP | | | |
| T MAGNITUDE | ↑ | ↑ | | ↑ | ↑ | ↑ | ↑ | ↑ | ↑ |
| T AZIMUTH | | | POST | | | | | ANT | ANT |
| T ELEVATION | | SUP | INF | INF | INF | INF | | | |
| P-R INTERVAL | ↑ | ↑ | | ↑ | ↑ | ↑ | | | |
| QRS-T ANGLE | | | ↓ | | | ↑ | ↑ | | ↓ |



TABLE 3.6-II. VCG CREW TRENDS

ECG/VCG PARAMETERS

TABLE 3.6-II. VCG CREW TRENDS

ECG/VCG PARAMETERS

| | SL-4 | SL-3 | SL 1/2 |
|---|---|---|---|
| HEART RATE | nsc | nsc | DECREASED |
| QRS DURATION | INCREASED | nsc | INCREASED |
| QRS MAGNITUDE | INCREASED | INCREASED | INCREASED |
| QRS AZIMUTH | ANTERIOR | nsc | ANTERIOR |
| QRS ELEVATION | SUPERIOR | SUPERIOR | nsc |
| T MAGNITUDE | INCREASED | INCREASED | INCREASED |
| T AZIMUTH | nsc | nsc | ANTERIOR |
| T ELEVATION | MIXED | INFERIOR | nsc |
| Q-T INTERVAL | nsc | nsc | INCREASED |
| P-R INTERVAL | INCREASED | INCREASED | nsc |
| QRS-T ANGLE | nsc | nsc | MIXED |

nsc = no significant change.

## 3.7 Experiment M111. Cytogenetic Studies of Blood

*Principal Investigator: L. H. Lockhart, M.D.*

Because of the time involved to adequately examine and analyze a sufficient number of cells, there are no data available at this time.

## 3.8 Experiment M112. Man's Immunity - *in vitro* Aspect

*Principal Investigator:* *S. E. Ritzmann, M. D.*
*W. C. Levin, M.D.*
*Principal Coordinating Scientist:* *S. L. Kimzey, Ph.D.*

A manuscript was not submitted.

## 3.9 Experiment M113. Blood Volume and Red Cell Life Span (SL-4)

*Principal Investigator: Philip C. Johnson, M.D.*
*Principal Coordinating Scientist: S. L. Kimzey, Ph.D.*

The data for experiment M-113 are attached on the accompanying tables 3.9-I through -IV.

### Methods

The methods used were identical to those for the SL 1/2 and SL-3 missions.

### Results

As in past missions, there was a decrease in red cell mass during this mission. The mean decrease of 6.8% was less than the decreases in SL 1/2 and SL 3. By R+31 days the crew's red cell masses had returned to above the premission levels. The mean plasma volume decrease, from blood samples taken as soon as possible after recovery, of 16% was greater than that of SL 1/2 (-3.4%), but essentially equal to SL-3 (-13%).

As in the other two missions the $^{51}Cr$ red cell T 1/2 was equal to the controls and showed no change. Mean iron turnover of the crew, 0.37, was above that of the controls, 0.25. For the three missions, the mean crew iron turnover from blood samples taken as soon as possible after recovery of 0.32 was not different statistically from the 0.30 of the controls. Iron reappearance was complete by R+14 days. This indicates that iron kinetics were normal at the time of recovery.

The mean $^{14}C$-glycine red cell life span was 123 days which was similar to the controls (121 days). Throughout the three missions, mean red cell life span was 123 days for crew and 118 days for controls.

### Discussion

These results confirm our original findings extending back to Gemini that decreases in red cell mass can be expected during weightless flight in the Gemini, Apollo and Skylab environments. The decrease in red cell mass is accompanied by proportional decreases in plasma volume so that a peripheral hematocrit is not a valid estimate of the red cell loss (mean pre, 43 and post, 43) at recovery.

In SL-4 a red cell mass was obtained at F-1 day. This indicated that the red cell mass decrease did not occur between F-14 and F-1 day(s). Skylab results show no evidence of a hemolytic event as the cause of the red cell mass decrease. Instead, the results are compatible with inhibition of erythropoiesis.

The mean percent decrease in red cell mass of SL 1/2 and SL-3 was greater than the 10% of the Apollo 14 to 17 crews. The crew of SL-4 showed a 7% decrease which is less than Apollo. This could represent difference in crew response. However, it raises the possibility that the inhibition of erythropoiesis during weightlessness is a temporary phenomena. There is no evidence to suggest that the red cell mass decrease is progressive.

As in past Skylab missions, the cooperation of the crew was outstanding. Their positive attitude and willingness to participate greatly improved this experiment.

TABLE 3.9-I SKYLAB 4 HEMATOLOGY DATA

| Time (Days) | CARR | GIBSON | POGUE | ALEXANDER | BURCHARD | WINKLER |
|---|---|---|---|---|---|---|
| | | | $^{51}$Cr Red Cell T 1/2 (Days) | | | |
| Preflight | 24.4 | 22.7 | 23.5 | 29.0 | 25.6 | 20.0 |
| Postflight | 27.4 | 24.5 | 21.8 | 26.7 | 24.8 | 20.1 |
| | | | Iron Turnover Rate (ml/kg per day) | | | |
| R+0 | 0.30 | 0.38 | 0.42 | 0.21 | 0.23 | 0.32 |
| | | | % Reappearance of $^{59}$Fe in Red Cells | | | |
| R+3 | 41 | 44 | 36 | 26 | 37 | 48 |
| R+7 | 100 | 75 | 98 | 94 | 93 | 99 |
| R+14 | 100 | 100 | 100 | 100 | 94 | 97 |
| | | | Peripheral Hematocrit (vol %) | | | |
| F-15 | 43 | 40 | 41 | 39 | 41 | 46 |
| F-1 | 41 | 39 | 42 | 39 | 41 | 45 |
| R+0 | 47 | 44 | 43 | 42 | 40 | 47 |
| R+14 | 38 | 37 | 38 | 40 | 40 | 45 |
| R+31 | 42 | 37 | 40 | | | |
| | | | Total Body Hematocrit (vol%) | | | |
| F-15 | 39 | 37 | 38 | 35 | 37 | 43 |
| F-1 | 37 | 35 | 38 | 35 | 37 | 41 |
| R+0 | 41 | 39 | 39 | 37 | 36 | 43 |
| R+14 | 35 | 33 | 34 | 35 | 37 | 41 |
| R+31 | 38 | 33 | 37 | | | |
| | | | Total Body to Peripheral Hematocrit Ratio | | | |
| F-15 | 0.91 | 0.92 | 0.93 | 0.90 | 0.90 | 0.93 |
| F-1 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.91 |
| R+0 | 0.87 | 0.89 | 0.91 | 0.88 | 0.90 | 0.92 |
| R+14 | 0.91 | 0.89 | 0.89 | 0.89 | 0.91 | 0.91 |
| R+31 | 0.91 | 0.89 | 0.91 | | | |
| | | | Mean RBC Life Span (Days) | | | |
| | 125 | 131 | 113 | 130 | 128 | 106 |

TABLE 3.9-II

SKYLAB 4

| | CARR | GIBSON | POGUE | ALEXANDER | BURCHARD | WINKLER |
|---|---|---|---|---|---|---|
| | | | Red Cell Mass (ml) | | | |
| F-15 | 1920 | 2039 | 1904 | 2119 | 2197 | 1817 |
| F-1 | 1891 | 2000 | 1962 | 2119 | 2258 | 1766 |
| R+0 | 1813 | 1851 | 1790 | 2096 | 2187 | 1845 |
| R+14 | 1829 | 1941 | 1826 | 2070 | 2175 | 1752 |
| R+31 | 1995 | 2066 | 2010 | | | |
| | | | Plasma Volume (ml) | | | |
| F-15 | 2949 | 3535 | 3129 | 3860 | 3736 | 2438 |
| F-1 | 3185 | 3706 | 3262 | 3919 | 3778 | 2563 |
| R+0 | 2585 | 2927 | 2784 | 3498 | 3859 | 2447 |
| R+14 | 3332 | 3889 | 3612 | 3807 | 3748 | 2554 |
| R+31 | 3264 | 4262 | 3384 | | | |
| | | | Red Cell Mass (ml/kg) | | | |
| F-15 | 28.4 | 28.5 | 28.0 | 27.4 | 29.7 | 24.2 |
| F-1 | 27.8 | 28.0 | 29.2 | 27.4 | 30.5 | 23.3 |
| R+0 | 26.6 | 26.4 | 27.0 | 27.8 | 29.4 | 24.2 |
| R+14 | 26.6 | 27.1 | 27.0 | 26.7 | 29.6 | 23.1 |
| R+31 | 28.8 | 27.8 | 28.8 | | | |
| | | | Plasma Volume (ml/kg) | | | |
| F-15 | 43.6 | 49.4 | 46.1 | 50.0 | 50.5 | 32.6 |
| F-1 | 46.8 | 52.0 | 48.6 | 50.8 | 51.0 | 33.8 |
| R+0 | 38.0 | 41.8 | 41.9 | 46.4 | 51.9 | 32.1 |
| R+14 | 48.4 | 54.4 | 53.4 | 49.1 | 51.0 | 33.7 |
| R+31 | 47.2 | 57.4 | 48.4 | | | |

TABLE 3.9-III

SKYLAB 4
PERCENT CHANGE FROM MEAN VALUE PREFLIGHT

| | CARR | GIBSON | POGUE | MEAN | ALEXANDER | BURCHARD | WINKLER | MEAN |
|---|---|---|---|---|---|---|---|---|
| | | | | **Red Cell Mass (ml)** | | | | |
| R+0 | - 4.8 | - 8.3 | - 7.4 | - 6.8 | - 1.1 | - 1.8 | + 3.0 | 0.0 |
| R+14 | - 4.0 | - 3.9 | - 5.5 | - 4.5 | - 2.3 | - 2.4 | - 2.2 | - 2.3 |
| R+31 | + 4.7 | + 2.3 | + 4.0 | + 3.7 | | | | |
| | | | | **Plasma Volume (ml)** | | | | |
| R+0 | -15.7 | -19.2 | -12.9 | -15.9 | -10.1 | + 2.7 | - 2.1 | - 3.2 |
| R+14 | + 8.6 | + 7.4 | +13.0 | + 9.7 | - 2.1 | + 3.9 | + 2.1 | + 1.3 |
| R+31 | + 6.4 | +17.7 | + 5.9 | +10.0 | | | | |

TABLE 3.9-IV

SKYLAB 4
PERCENT CHANGE FROM MEAN VALUE PREFLIGHT

| | CARR | GIBSON | POGUE | MEAN | ALEXANDER | BURCHARD | WINKLER | MEAN |
|---|---|---|---|---|---|---|---|---|
| | | | | Red Cell Mass (ml/kg) | | | | |
| R+0 | - 5.3 | - 6.5 | - 5.6 | - 5.9 | + 1.4 | - 2.3 | - 1.9 | - 0.9 |
| R+14 | - 5.3 | - 4.1 | - 5.6 | - 5.0 | - 2.6 | - 1.7 | - 2.7 | - 2.3 |
| R+31 | + 2.5 | - 1.6 | + 0.7 | + 0.5 | | | | |
| | | | | Plasma Volume (ml/kg) | | | | |
| R+0 | -15.9 | -17.6 | -11.5 | -15.0 | - 7.9 | + 2.3 | - 3.3 | - 3.0 |
| R+14 | + 7.1 | + 7.3 | +12.8 | + 9.1 | - 2.6 | + 0.5 | + 1.5 | - 0.2 |
| R+31 | + 4.4 | +13.2 | + 2.2 | + 6.6 | | | | |

## 3.10 Experiment M114. Red Blood Cell Metabolism

*Principal Investigator: Charles E. Mengel, M.D.*
*Principal Coordinating Scientist: S. L. Kimzey, Ph.D.*

The objectives of Experiment M114 are to determine if metabolic or membrane changes occur in red blood cells as a result of exposure to space and to gather information on the means by which glucose penetrates red blood cells, in-cell metabolism and its dependence on gravity.

Postflight measurements of cells which have spent the significant portions of their lives in a space environment have yielded the following which are the results of the initial analysis of Skylab 4 data and are to be considered preliminary.

Results

There were decreases of reduced glutathione, glucose 6 phosphate dehydrogenase, phosphofructokinase, and glyceraldehyde 3 phosphate dehydrogenase during flight. Before flight, astronauts and controls were identical. During flight, the above changes were observed. After flight, no significant changes were observed.

These changes are somewhat similar to previous observations made in our laboratory during the oxygen under high pressure studies in animals, the previous SMEAT study, and former Skylab studies.

## 3.11 Experiment M115. Special Hematologic Effects

*Principal Investigators:* *Stephen L. Kimzey, Ph.D.*
*Craig L. Fischer, M.D.*

The primary objective of this experiment is to examine critical physiochemical hematologic parameters relative to the maintenance of normal functions of the red blood cell, and to evaluate the effects of space flight upon these parameters. A secondary objective is to provide essential hematologic data which will assist in the interpretation of the present hematology/immunology experiments (M110 series).

Data of this nature are essential for the complete medical evaluation and qualification of man referable to his physiological performance during prolonged space flight. Data derived from this protocol along with the results of the other experiments in the M110 series are required for determination of the extent, time course, and etiology of observed hematological changes resulting from the exposure of man to the conditions of space flight.

### Results

The routine hematology data are presented in tables 3.11-I, -II and -III. The red cell count, hemoglobin concentration, and hematocrit were elevated on recovery as compared to preflight levels (figures 3.11-1 through -3). These hemoconcentration-dependent parameters began to decline by R+1 day and by R+3 days were significantly lower than preflight values. As in the SL-3 flight, these measurements gradually returned to within preflight limits. Red cell indices showed considerable variation postflight, but none significantly out of the established preflight limits (figures 3.11-4 through -6). Mean corpuscular hemoglobin concentration (MCHC), as would be expected, was for the most part extremely stable.

The white cell count was significantly elevated at R+0 day especially in the PLT and SPT (figure 3.11-7), but rapidly returned to preflight ranges in all three crewmen. Differential counts indicated that this elevation was due to an absolute increase in neutrophils (figures 3.11-8 and 3.11-9) with lymphocytes, though showing a decrease in percentage (figure 3.11-10), being maintained within preflight limits relative to absolute number (figure 3.11-11).

The reticulocyte percent and absolute count began to increase between R+3 and R+5 days in all three crewmen (figures 3.11-12, -13). The time course and magnitude of the response was comparable to that seen after SL-3. Classification of reticulocyte age based on the density of the ribosomal network showed no change even though there was an increased reticulocyte number (table IV). Specific gravity profiles of

# TABLE 3.11-I. SKYLAB 4 HEMATOLOGY DATA

## CDR

| DATE/MD (1973) | RBC COUNT million/ $mm^3$ | RETIC % | RETIC NUMBER $x10^3$ | Hb g/100 ml | HCT vol % | MCV cu μ | MCH μμg | MCHC % | PLATELET COUNT $x10^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Preflight | | | | | | | | | |
| 10-12/F-35 | 5.01 | 1.00 | 50.10 | 15.10 | 45.0 | 90.0 | 30.0 | 34.0 | 221.0 |
| 10-26/F-21 | 5.01 | 0.80 | 40.08 | 14.40 | 42.0 | 84.0 | 29.0 | 34.0 | 198.0 |
| 10-27/F-20 | 5.10 | 1.00 | 51.00 | 14.80 | 44.0 | 86.0 | 29.0 | 34.0 | |
| 11-2/F-14 | 4.55 | 1.00 | 45.50 | 14.50 | 42.0 | 92.0 | 32.0 | 35.0 | 215.0 |
| 11-10/F-6 | 4.52 | 1.10 | 49.72 | 14.70 | 42.0 | 93.0 | 33.0 | 35.0 | 243.0 |
| 11-15/F-1 | 4.34 | 1.20 | 52.08 | 14.10 | 42.0 | 97.0 | 32.0 | 34.0 | 250.0 |
| Mean | 4.76 | 1.02 | 48.08 | 14.6 | 42.8 | 90.3 | 30.6 | 34.3 | 225.4 |
| SD | 0.32 | 0.13 | 4.52 | 0.4 | 1.3 | 4.8 | 1.7 | 0.5 | 21.2 |
| Postflight (1974) | | | | | | | | | |
| 2-8/R+0 | 5.13 | 0.80 | 41.04 | 15.0 | 44.0 | 86.0 | 29.0 | 34.0 | 241.0 |
| 2-9/R+1 | 4.63 | 1.00 | 46.30 | 14.5 | 43.0 | 93.0 | 31.0 | 34.0 | 226.0 |
| 2-11/R+3 | 4.24 | 0.90 | 38.16 | 13.4 | 38.5 | 91.0 | 32.0 | 35.0 | 212.0 |
| 2-13/R+5 | 4.36 | 1.50 | 65.4 | 13.2 | 39.5 | 91.0 | 30.0 | 33.0 | |
| 2-15/R+7 | 4.41 | 1.50 | 66.15 | 13.3 | 38.5 | 87.0 | 30.0 | 35.0 | 207.0 |
| 2-19/R+11 | 4.55 | 1.80 | 82.80 | 14.0 | 40.0 | 88.0 | 31.0 | 35.0 | |
| 2-22/R+14 | 4.27 | 1.80 | 76.86 | 13.0 | 38.5 | 90.0 | 30.0 | 34.0 | 232.0 |
| 2-25/R+17 | 4.95 | 2.00 | 99.00 | 14.5 | 42.5 | 86.0 | 29.0 | 34.0 | |
| 3-1/R+21 | 4.53 | 1.70 | 77.01 | 13.6 | 40.0 | 88.0 | 30.0 | 34.0 | |
| 3-11/R+31 | 4.82 | 1.30 | 62.66 | 13.6 | 40.5 | 84.0 | 28.0 | 34.0 | |
| 4-17/R+68 | 5.40 | 0.90 | 48.60 | 15.9 | 47.0 | 87.0 | 29.0 | 34.0 | |

| DATE/MD (1973) | WBC COUNT thousands/ $mm^3$ | NEUT. COUNT thousands/ $mm^3$ | NEUT. PERCENT | LYMPH COUNT thousands/ $mm^3$ | LYMPH PERCENT | MONO PERCENT | EO PERCENT | BASO PERCENT | BANDS PERCENT |
|---|---|---|---|---|---|---|---|---|---|
| Preflight | | | | | | | | | |
| 10-12/F-35 | 4900 | 3283 | 67 | 1328 | 27 | 1 | 2 | 1 | 1 |
| 10-26/F-21 | 4200 | 2268 | 54 | 1638 | 39 | 2 | 4 | 0 | 1 |
| 11-2/F-14 | 4600 | 2576 | 56 | 1610 | 35 | 2 | 6 | 0 | 1 |
| 11-10/F-6 | 4200 | 2562 | 61 | 1260 | 30 | 3 | 3 | 0 | 3 |
| 11-15/F-1 | 4300 | 2279 | 53 | 1720 | 40 | 2 | 3 | 0 | 1 |
| Mean | 4440 | 2594 | 58.2 | 1510 | 34.2 | | | | |
| SD | 305 | 413 | 5.8 | 205 | 5.6 | | | | |
| Postflight (1974) | | | | | | | | | |
| 2-8/R+0 | 6400 | 4800 | 75 | 1344 | 21 | 1 | 1 | 1 | 1 |
| 2-9/R+1 | 5400 | 3294 | 61 | 1782 | 33 | 1 | 3 | 1 | 1 |
| 2-11/R+3 | 5000 | 2900 | 58 | 1700 | 34 | 1 | 5 | 1 | 1 |
| 2-15/R+7 | 5200 | 2964 | 57 | 1872 | 36 | 2 | 4 | | 1 |
| 2-19/R+11 | 4600 | 2346 | 51 | 1932 | 42 | 1 | 4 | | 2 |
| 2-22/R+14 | 3400 | 1972 | 58 | 1224 | 36 | 1 | 3 | 1 | 1 |
| 2-25/R+17 | 4500 | 2745 | 61 | 1575 | 34 | 1 | 1 | 1 | 1 |
| 3-1/R+21 | 3400 | | | | | | | | |
| 3-11/R+31 | 3400 | 2142 | 63 | 986 | 29 | 1 | 7 | 0 | 0 |
| 4-17/R+68 | 5500 | 3630 | 66 | 1540 | 28 | 1 | 3 | 1 | 1 |

# TABLE 3.11-II. SKYLAB 4 HEMATOLOGY DATA

## SPT

| DATE/MD (1973) | RBC COUNT million/ $mm^3$ | RETIC % | RETIC NUMBER $x10^3$ | Hb g/100 ml | HCT vol.-% | MCV $cu\mu$ | MCH $\mu\mu g$ | MCHC % | PLATELET COUNT $x10^3$ |
|---|---|---|---|---|---|---|---|---|---|
| Preflight | | | | | | | | | |
| 10-12/F-35 | 4.60 | 0.9 | 41.40 | 13.8 | 41.65 | 90.0 | 30.0 | 33.0 | 169 |
| 10-26/F-21 | 4.67 | 0.7 | 32.69 | 13.1 | 39.65 | 85.0 | 28.0 | 33.0 | 202 |
| 10-27/F-20 | 4.70 | 1.1 | 51.70 | 13.4 | 41.65 | 88.0 | 29.0 | 32.0 | |
| 11-2/F-14 | 4.49 | 1.1 | 49.39 | 13.1 | 39.65 | 88.0 | 29.0 | 33.0 | 248 |
| 11-10/F-6 | 4.81 | 0.9 | 43.29 | 13.9 | 41.65 | 86.0 | 29.0 | 33.0 | 285 |
| 11-15/F-1 | 4.22 | 0.9 | 39.98 | 12.6 | 38.00 | 90.0 | 30.0 | 33.0 | 256 |
| Mean | 4.58 | 0.9 | 43.08 | 13.3 | 40.33 | 87.8 | 29.2 | 32.8 | 232 |
| SD | 0.21 | ±0.2 | 6.85 | 0.5 | 1.65 | 2.0 | 0.8 | 0.4 | 46 |
| Postflight (1974) | | | | | | | | | |
| 2-8/R+0 | 4.72 | 0.8 | 37.76 | 14.0 | 42.00 | 89.0 | 30.0 | 33.0 | 283 |
| 2-9/R+1 | 4.48 | 1.0 | 44.80 | 12.7 | 40.00 | 89.0 | 28.0 | 32.0 | 258 |
| 2-11/R+3 | 4.03 | 1.2 | 48.36 | 11.6 | 35.65 | 88.0 | 29.0 | 33.0 | 262 |
| 2-13/R+5 | 4.06 | 1.7 | 69.02 | 11.0 | 35.00 | 86.0 | 27.0 | 31.0 | |
| 2-15/R+7 | 3.96 | 1.4 | 55.44 | 11.0 | 33.55 | 85.0 | 28.0 | 33.0 | 246 |
| 2-19/R+11 | 4.15 | 1.7 | 78.20 | 11.7 | 35.55 | 86.0 | 28.0 | 33.0 | |
| 2-22/R+14 | 4.40 | 2.0 | 88.00 | 12.3 | 37.55 | 85.0 | 28.0 | 33.0 | 244 |
| 2-25/R+17 | 4.38 | 1.9 | 83.22 | 12.7 | 38.55 | 88.0 | 29.0 | 33.0 | |
| 3-1/R+21 | 4.34 | 1.8 | 78.12 | 12.6 | 38.00 | 88.0 | 29.0 | 33.0 | |
| 3-11/R+31 | 4.18 | 1.9 | 79.42 | 12.4 | 37.00 | 89.0 | 30.0 | 34.0 | |
| 4-17/R+68 | 5.29 | 1.2 | 63.48 | 14.4 | 44.00 | 83.0 | 27.0 | 33.0 | |

| DATE/MD (1973) | WBC COUNT thousands/ $mm^3$ | NEUT. COUNT thousands/ $mm^3$ | NEUT. PERCENT | LYMPH COUNT thousands/ $mm^3$ | LYMPH PERCENT | MONO PERCENT | EO PERCENT | BASO PERCENT | BANDS PERCENT |
|---|---|---|---|---|---|---|---|---|---|
| Preflight | | | | | | | | | |
| 10-12/F-35 | 4 900 | 2597 | 53 | 1911 | 39 | 4 | 1 | 0 | 3 |
| 10-26/F-21 | 4 500 | 2610 | 58 | 1665 | 37 | 1 | 3 | 0 | 1 |
| 11-2/F-14 | 5 700 | 3363 | 59 | 2052 | 36 | 3 | 0 | 0 | 2 |
| 11-10/F-6 | 5 100 | 3519 | 69 | 1275 | 25 | 1 | 3 | 2 | 0 |
| 11-15/F-1 | 4 500 | 2610 | 58 | 1710 | 38 | 1 | 2 | 1 | 0 |
| Mean | 4 940 | 2940 | 59.4 | 1723 | 35 | | | | |
| SD | 498 | 461 | 5.9 | 295 | 5.77 | | | | |
| Postflight (1974) | | | | | | | | | |
| 2-8/R+0 | 10 000 | 8100 | 81 | 1400 | 14 | 2 | 1 | 1 | 1 |
| 2-9/R+1 | 7 500 | 4875 | 65 | 2025 | 27 | 3 | 2 | 1 | 2 |
| 2-11/R+3 | 6 200 | 4526 | 73 | 1364 | 22 | 1 | 1 | 1 | 2 |
| 2-15/R+7 | 4 100 | 2501 | 61 | 1435 | 35 | 1 | 3 | | |
| 2-19/R+10 | 4 600 | 2668 | 58 | 1518 | 33 | 1 | 3 | | |
| 2-22/R+14 | 4 400 | 2948 | 67 | 1276 | 29 | 1 | 1 | 1 | 1 |
| 2-25/R+17 | 5 000 | 3000 | 60 | 1800 | 36 | 1 | 1 | 1 | |
| 3-1/R+21 | 4 200 | | | | | | | | |
| 3-11/R+31 | 4 600 | 2898 | 63 | 1610 | 35 | 0 | 1 | 1 | 1 |
| 4-17/R+68 | 4 800 | 2400 | 50 | 2112 | 44 | 2 | 2 | 1 | 0 |

## TABLE 3.11-III. SKYLAB 4 HEMATOLOGY DATA

### PLT

| DATE/MD (1973) | RBC COUNT million/mm3 | RETIC % | RETIC NUMBER x10^3 | Hb g/100 ml | HCT vol % | MCV cu μ | MCH μμg | MCHC % | PLATELET COUNT x10^3 |
|---|---|---|---|---|---|---|---|---|---|
| **Preflight** | | | | | | | | | |
| 10-12/F-35 | 4.70 | 0.9 | 42.30 | 14.4 | 41.5 | 88.0 | 31.0 | 35.0 | 183 |
| 10-26/F-21 | 4.58 | 0.9 | 41.22 | 14.4 | 41.0 | 91.0 | 32.0 | 33.0 | 200 |
| 10-27/F-20 | 4.56 | 1.1 | 50.16 | 15.3 | 43.0 | 94.0 | 34.0 | 36.0 | |
| 11-2/F-14 | 4.36 | 1.0 | 43.60 | 14.3 | 41.0 | 94.0 | 33.0 | 35.0 | 228 |
| 11-10/F-6 | 4.74 | 0.9 | 42.66 | 14.5 | 41.0 | 86.0 | 31.0 | 35.0 | 259 |
| 11-15/F-1 | 4.45 | 1.0 | 44.50 | 14.5 | 41.5 | 93.0 | 33.0 | 35.0 | 218 |
| Mean | 4.57 | 1.0 | 44.07 | 14.6 | 41.5 | 91.0 | 32.3 | 34.8 | 217.6 |
| SD | 0.14 | 0.1 | 3.19 | 0.4 | 0.8 | 3.4 | 1.2 | 1.0 | 28.9 |
| Postflight (1974) | | | | | | | | | |
| 2-8/R+0 | 4.42 | 0.9 | 39.78 | 14.9 | 44.0 | 100.0 | 34.0 | 34.0 | 236 |
| 2-9/R+1 | 4.45 | 1.5 | 66.75 | 13.6 | 41.5 | 93.0 | 31.0 | 33.0 | 252 |
| 2-11/R+3 | 3.82 | 0.8 | 30.56 | 12.7 | 36.5 | 96.0 | 33.0 | 35.0 | 194 |
| 2-13/R+5 | 4.06 | 1.5 | 60.90 | 13.4 | 39.0 | 96.0 | 33.0 | 34.0 | |
| 2-15/R+7 | 4.24 | 1.7 | 72.08 | 13.7 | 38.0 | 91.0 | 32.0 | 36.0 | 219 |
| 2-19/R+11 | 4.76 | 2.3 | 109,71 | 14.8 | 42.0 | 88.0 | 31.0 | 35.0 | |
| 2-22/R+14 | 4.13 | 2.0 | 82.60 | 13.3 | 38.0 | 92.0 | 32.0 | 35.0 | 220 |
| 2-25/R+17 | 4.44 | 2.1 | 93.24 | 14.2 | 40.5 | 91.0 | 32.0 | 35.0 | |
| 3-1/R+21 | 4.38 | 2.0 | 87.60 | 13.4 | 39.0 | 89.0 | 31.0 | 34.0 | |
| 3-11/R+31 | 4.06 | 1.6 | 64.96 | 13.8 | 39.0 | 96.0 | 34.0 | 35.0 | |
| 4-17/R+68 | 4.66 | 1.4 | 65.24 | 14.8 | 42.0 | 90.0 | 32.0 | 35.0 | |

| DATE/MD (1973) | WBC COUNT thousands/mm3 | NEUT. COUNT thousands/mm3 | NEUT. PERCENT | LYMPH COUNT thousands/mm3 | LYMPH PERCENT | MONO PERCENT | EO PERCENT | BASO PERCENT | BANDS PERCENT |
|---|---|---|---|---|---|---|---|---|---|
| **Preflight** | | | | | | | | | |
| 10-12/F-35 | 6 400 | 3 840 | 60 | 2112 | 33 | 4 | 3 | 0 | 0 |
| 10-26/F-21 | 5 100 | 2 805 | 53 | 2091 | 41 | 1 | 3 | 0 | 0 |
| 11-2/F-14 | 5 800 | 3 074 | 53 | 2436 | 42 | 3 | 2 | 0 | 0 |
| 11-10/F-6 | 8 200 | 6 150 | 75 | 1640 | 20 | 1 | 2 | 1 | 1 |
| 11-15/F-1 | 5 800 | 3 422 | 59 | 2146 | 37 | 3 | 1 | 0 | 0 |
| Mean | 6 260 | 3 858 | 60 | 2085 | 34.6 | | | | |
| SD | 1 178 | 1 339 | 9 | 285 | 8.9 | | | | |
| Postflight (1974) | | | | | | | | | |
| 2-8/R+0 | 13 200 | 11 220 | 85 | 1584 | 12 | 1 | 1 | 0 | 1 |
| 2-9/R+1 | 6 500 | 4 550 | 70 | 1560 | 24 | 3 | 2 | 1 | 0 |
| 2-11/R+3 | 6 200 | 3 472 | 56 | 2170 | 35 | 1 | 5 | 1 | 2 |
| 2-15/R+7 | 5 800 | 3 364 | 58 | 2083 | 36 | 2 | 1 | 1 | 2 |
| 2-19/R+11 | 6 900 | 3 243 | 47 | 3243 | 47 | 2 | 4 | | |
| 2-22/R+14 | 5 200 | 3 068 | 59 | 1820 | 35 | 1 | 2 | 1 | 2 |
| 2-25/R+17 | 5 500 | 2 750 | 50 | 2530 | 46 | 2 | 1 | 1 | |
| 3-1/R+21 | 5 200 | | | | | | | | |
| 3-11/R+31 | 5 600 | 3 304 | 59 | 2016 | 36 | 1 | 2 | 1 | 1 |
| 4-17/R+68 | 4 700 | 2 444 | 52 | 2021 | 43 | 1 | 2 | 0 | 2 |

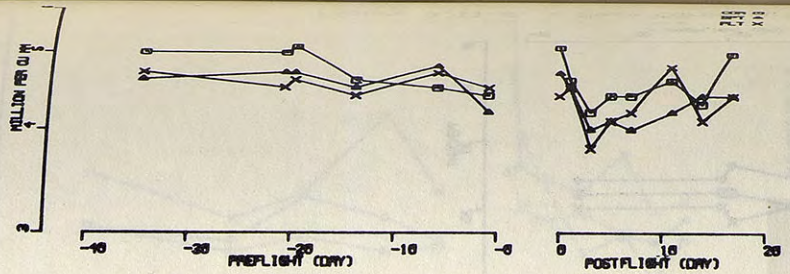



Figure 3.11-1. - RBC Count (SL-4).

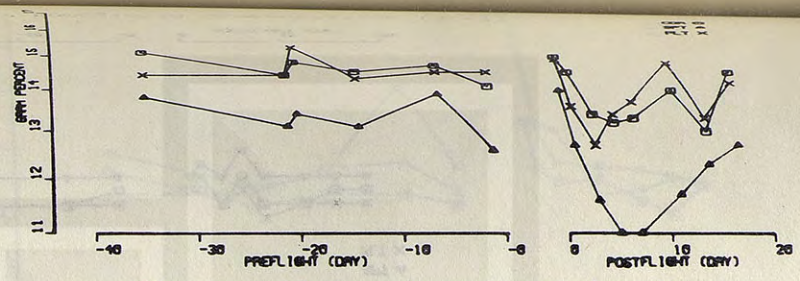



Figure 3.11-2. - Hemoglobin (SL-4).

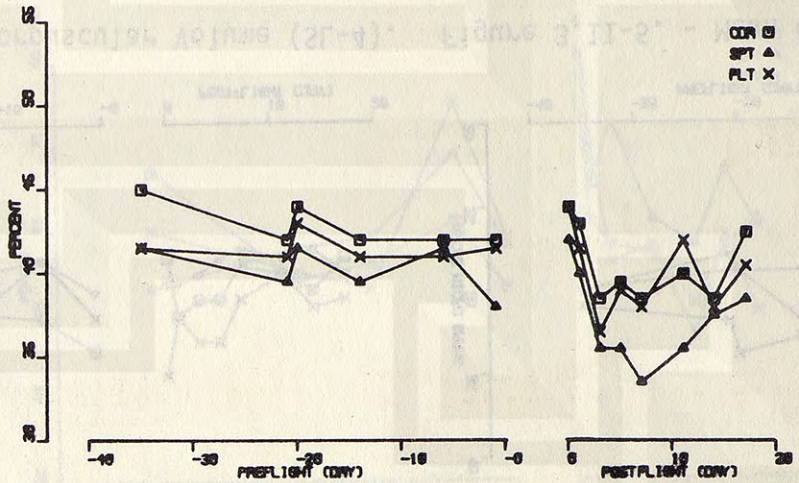



Figure 3.11-3. - Hematocrit (SL-4).

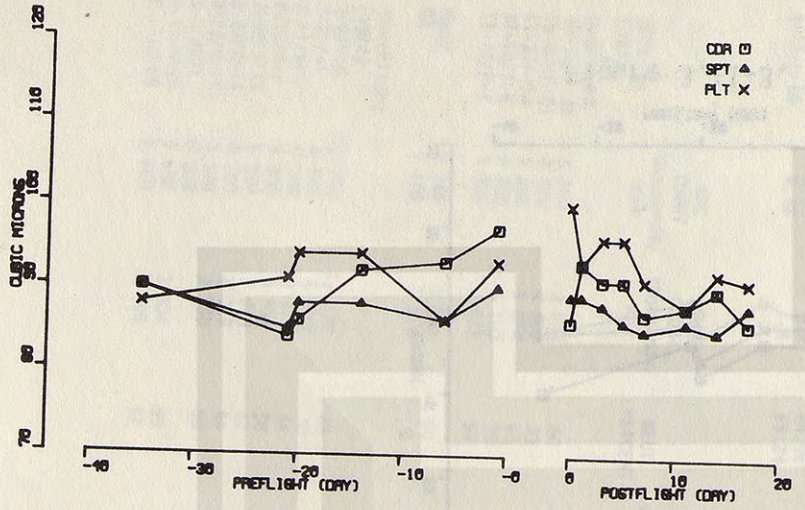



Figure 3.11-4. - Mean Corpuscular Volume (SL-4).

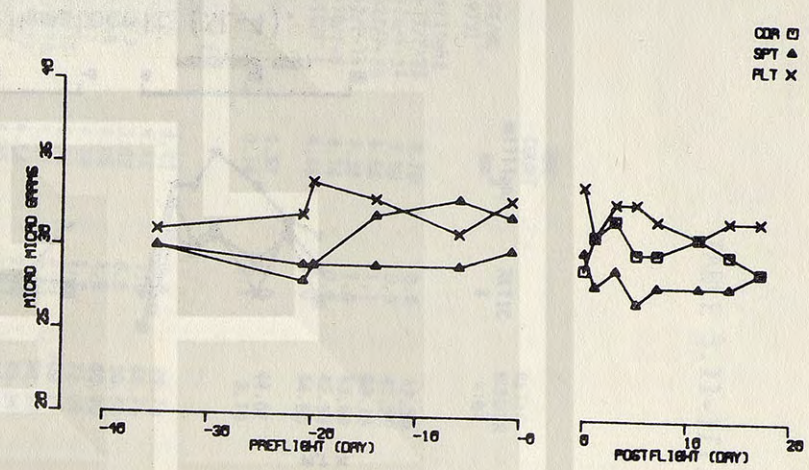



Figure 3.11-5. - Mean Corpuscular Hemoglobin (SL-4).

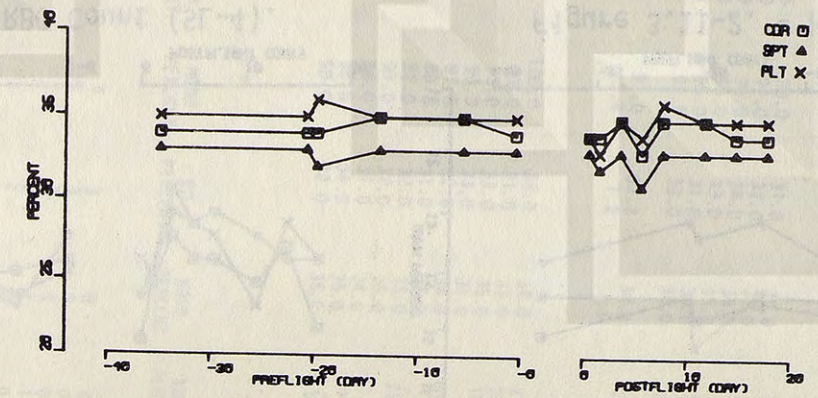



Figure 3.11-6. - Mean Corpuscular Hemoglobin Concentration (SL-4).

Figure 3.11-6. - Mean Corpuscular Hemoglobin Concentration (SL-4).

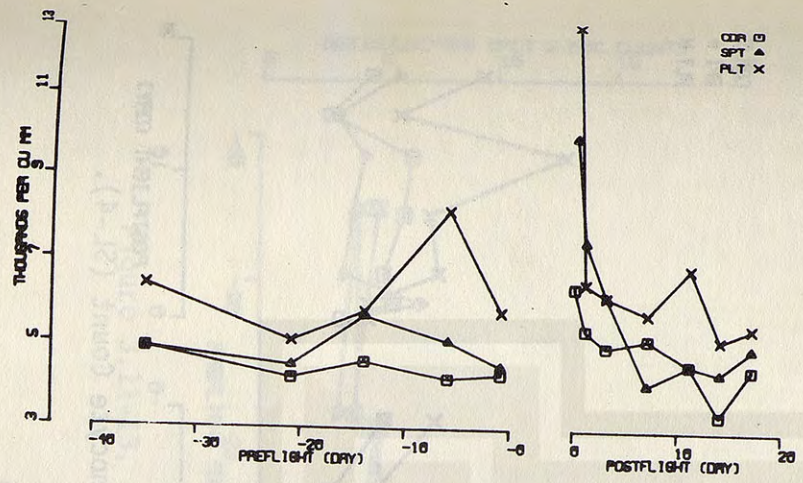



Figure 3.11-7. - WBC Count (SL-4).

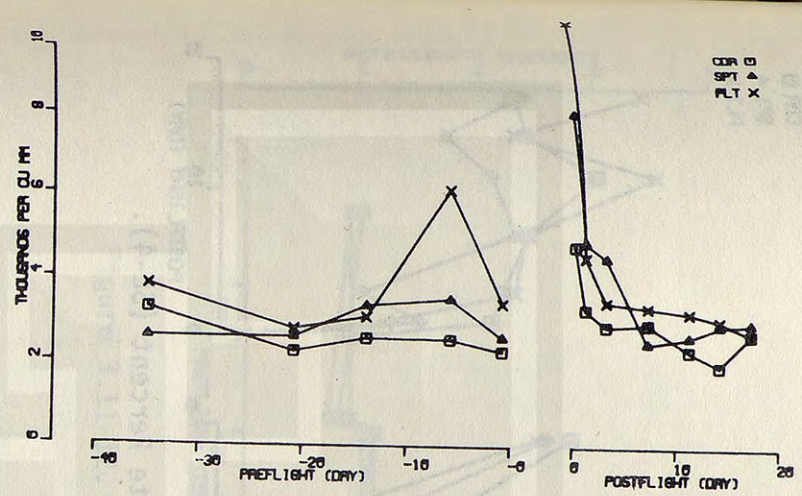



Figure 3.11-8. - Neutrophil Count (SL-4).

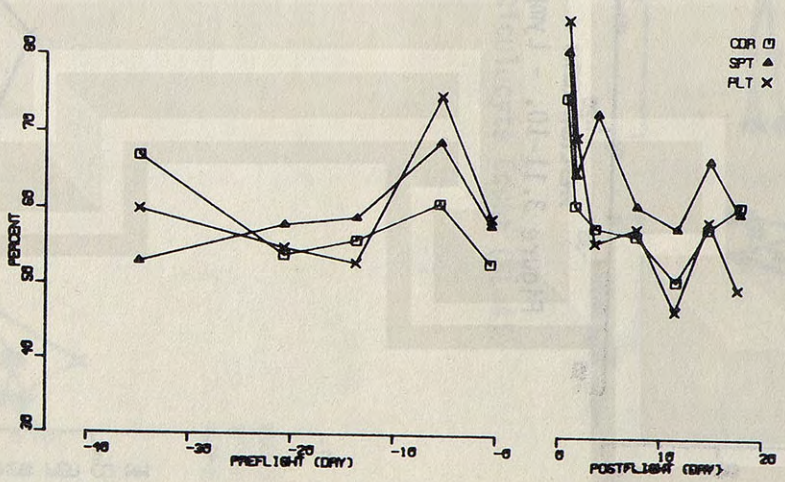



Figure 3.11-9. - Neutrophil Percent (SL-4).

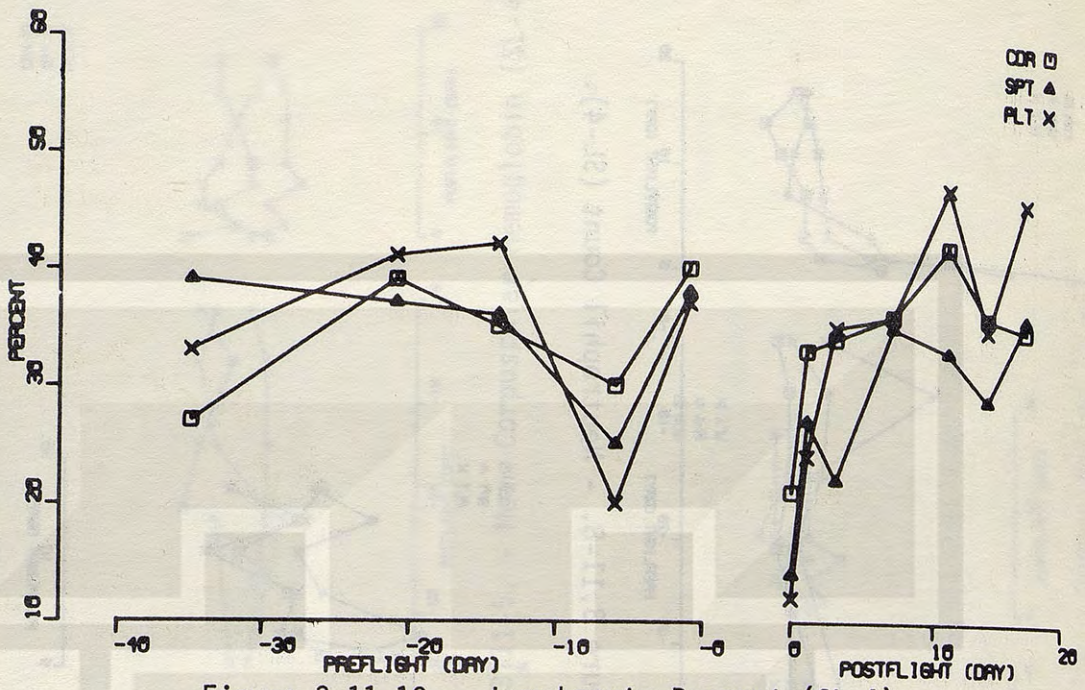



Figure 3.11-10. - Lymphocyte Percent (SL-4).

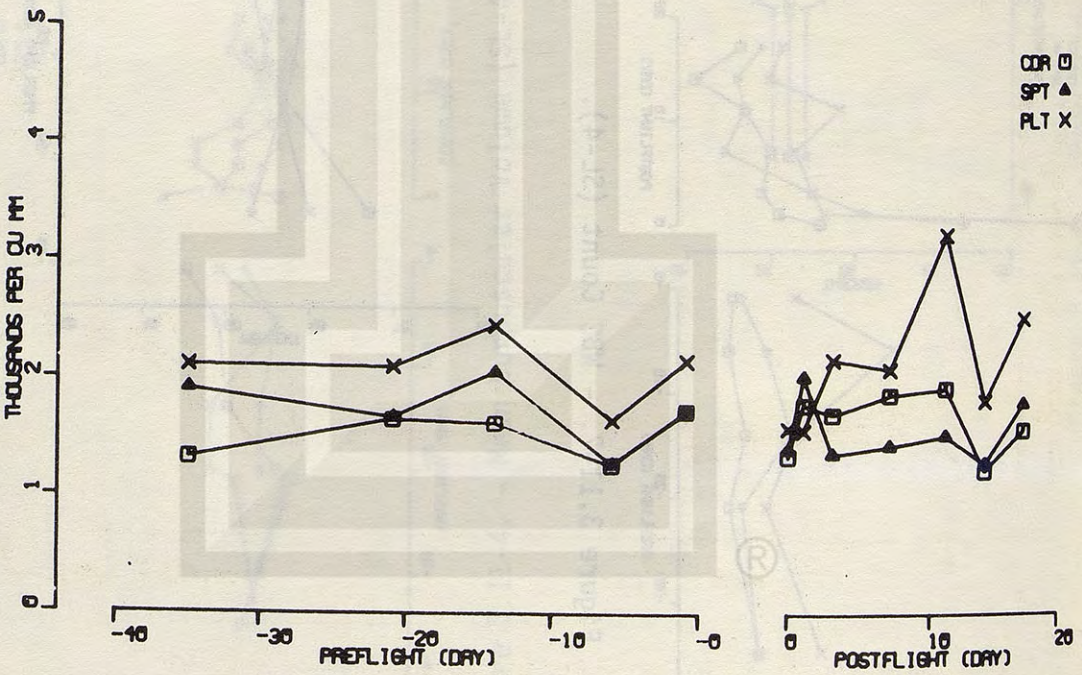



Figure 3.11-11. - Lymphocyte Count (SL-4).

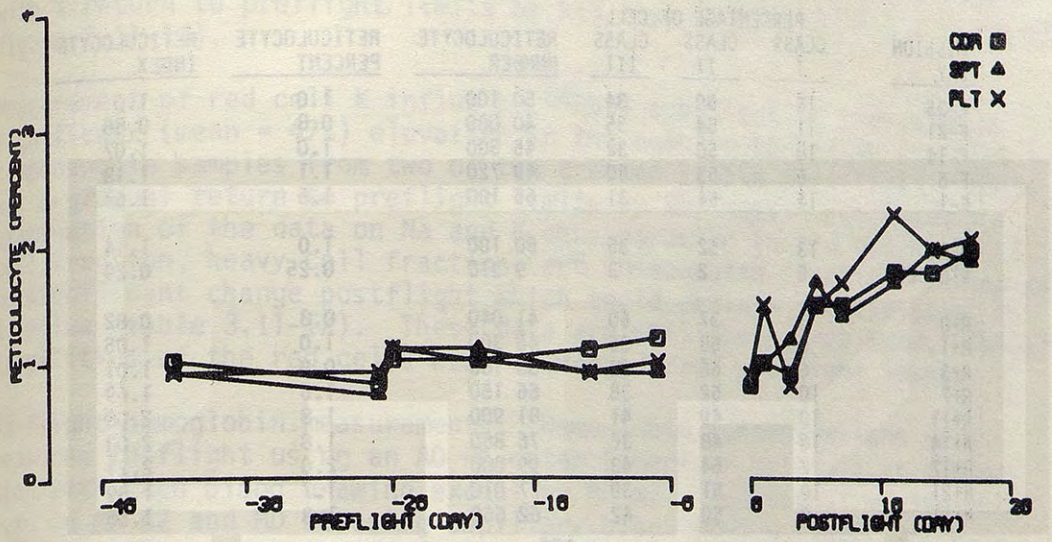



Figure 3.11-12. - Reticulocyte Count (SL-4).

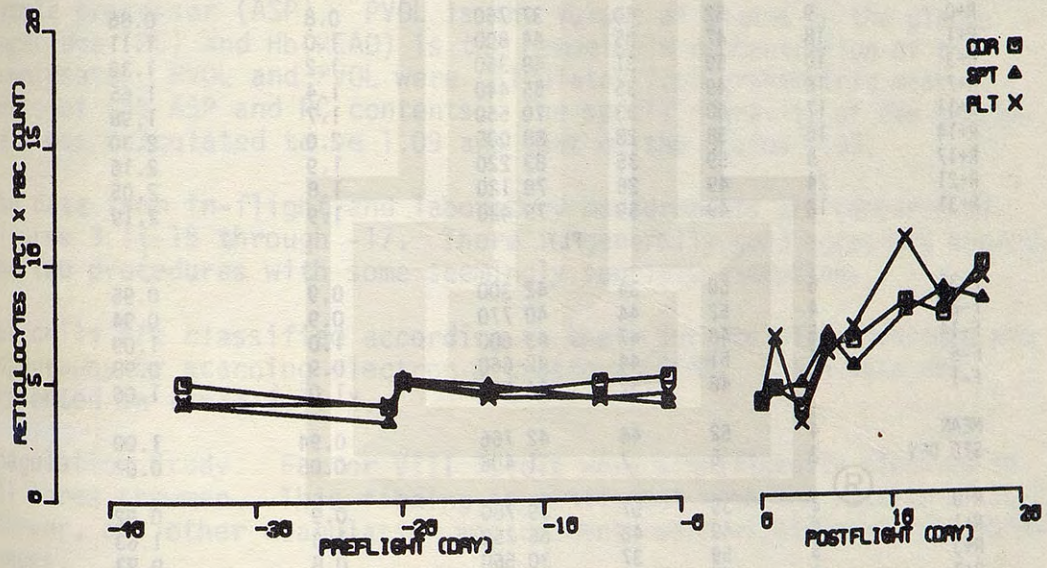



Figure 3.11-13. - Reticulocyte Number (SL-4).

TABLE 3.11-IV RETICULOCYTE CLASSIFICATION, SKYLAB 4

CDR

| MISSION DAY | PERCENTAGE OF CELL CLASS I | CLASS II | CLASS III | RETICULOCYTE NUMBER | RETICULOCYTE PERCENT | RETICULOCYTE INDEX |
|---|---|---|---|---|---|---|
| F-35 | 16 | 50 | 34 | 50 100 | 1.0 | 1.0 |
| F-21 | 11 | 54 | 35 | 40 080 | 0.8 | 0.86 |
| F-14 | 18 | 50 | 32 | 45 500 | 1.0 | 1.07 |
| F-6 | 6 | 53 | 40 | 49 720 | 1.1 | 1.18 |
| F-1 | 14 | 54 | 31 | 65 100 | 1.5 | 1.61 |
| MEAN | 13 | 52 | 35 | 50 100 | 1.0 | 1.14 |
| STD DEV | 5 | 2 | 3 | 9 310 | 0.25 | 0.29 |
| R+0 | 3 | 37 | 60 | 41 040 | 0.8 | 0.82 |
| R+1 | 6 | 58 | 36 | 46 300 | 1.0 | 1.05 |
| R+3 | 6 | 66 | 28 | 38 160 | 0.9 | 1.01 |
| R+7 | 10 | 52 | 38 | 66 150 | 1.5 | 1.69 |
| R+11 | 10 | 49 | 41 | 81 900 | 1.8 | 2.00 |
| R+14 | 16 | 48 | 36 | 76 860 | 1.8 | 2.03 |
| R+17 | 2 | 54 | 43 | 99 000 | 2.0 | 2.21 |
| R+21 | 10 | 51 | 39 | 77 010 | 1.7 | 1.89 |
| R+31 | 8 | 50 | 42 | 62 660 | 1.3 | 1.56 |
| | | | | SPT | | |
| F-35 | 10 | 52 | 38 | 41 400 | 0.9 | 0.95 |
| F-21 | 7 | 57 | 36 | 32 690 | 0.7 | 0.77 |
| F-14 | 15 | 54 | 30 | 49 390 | 1.1 | 1.21 |
| F-6 | 13 | 56 | 30 | 43 290 | 0.9 | 0.95 |
| F-1 | 7 | 57 | 35 | 37 980 | 0.9 | 1.03 |
| MEAN | 11 | 55 | 34 | 40 950 | 0.9 | 0.98 |
| STD DEV | 4 | 2 | 3 | 6 204 | 0.14 | 0.16 |
| R+0 | 9 | 52 | 40 | 37 760 | 0.8 | 0.86 |
| R+1 | 18 | 47 | 35 | 44 800 | 1.0 | 1.11 |
| R+3 | 10 | 59 | 31 | 48 360 | 1.2 | 1.39 |
| R+7 | 16 | 49 | 35 | 55 440 | 1.4 | 1.65 |
| R+11 | 17 | 50 | 33 | 70 550 | 1.7 | 1.98 |
| R+14 | 15 | 58 | 28 | 88 000 | 2.0 | 2.30 |
| R+17 | 9 | 59 | 35 | 83 220 | 1.9 | 2.16 |
| R+21 | 24 | 49 | 28 | 78 120 | 1.8 | 2.05 |
| R+31 | 12 | 49 | 39 | 79 420 | 1.9 | 2.19 |
| | | | | PLT | | |
| F-35 | 6 | 60 | 34 | 42 300 | 0.9 | 0.95 |
| F-21 | 4 | 52 | 44 | 40 770 | 0.9 | 0.94 |
| F-14 | 5 | 48 | 47 | 43 600 | 1.0 | 1.09 |
| F-6 | 4 | 51 | 44 | 42 660 | 0.9 | 0.98 |
| F-1 | 2 | 46 | 52 | 44 500 | 1.0 | 1.06 |
| MEAN | 4 | 52 | 44 | 42 766 | 0.94 | 1.00 |
| STD DEV | 2 | 6 | 7 | 1 406 | 0.05 | 0.07 |
| R+0 | 3 | 39 | 57 | 39 780 | 0.9 | 0.92 |
| R+1 | 6 | 49 | 46 | 66 750 | 1.5 | 1.63 |
| R+3 | 5 | 59 | 37 | 30 560 | 0.8 | 0.93 |
| R+7 | 5 | 47 | 48 | 72 080 | 1.7 | 1.94 |
| R+11 | 19 | 58 | 23 | 109 480 | 2.3 | 2.47 |
| R+14 | 8 | 46 | 46 | 82 600 | 2.0 | 2.28 |
| R+17 | 9 | 45 | 46 | 93 240 | 2.1 | 2.32 |
| R+21 | 9 | 44 | 47 | 87 600 | 2.0 | 2.25 |
| R+31 | 9 | 50 | 41 | 64 960 | 1.6 | 1.80 |

the red cells shifted toward a lighter population at R+0 and R+1 days with a return to preflight limits by R+3 days (tables 3.11-V through VII, figure 3.11-14).

Measurement of red cell K influx by $^{86}$RbCl substitution indicated a significant (mean = 47%) elevation in the ouabain-sensitive ("active") component in samples from two of the crewmen (table 3.11-VIII). There was a gradual return to preflight limits by R+7 days. Preliminary examination of the data on Na and K concentration in red cells (light cell fraction, heavy cell fraction, and unseparated fraction) indicates no significant change postflight which could explain the elevation in K influx (table 3.11-IX). These data are still being reviewed. Osmotic fragilities of the red cells were unchanged from preflight levels.

In-flight hemoglobin measurements. Hemoglobin concentrations were measured in-flight using an AO Hb-meter (American Optical) in conjunction with each blood drawing except on MD 82. Additional measurements were on MD 62 and MD 68 using capillary blood from a finger dermal puncture. Measurements of the hemoglobin concentration in each of the in-flight samples were made postflight using the cyanmethemoglobin procedure. Calculation of the grams percent hemoglobin (Hb) in the whole blood sample were made using the following equation:

$$Hb = Hb(READ) \times HVOL/(HVOL + PVOL)$$

where HVOL is the volume of the hemolysate returned in the automatic sample processor (ASP). PVOL is the volume of plasma in the plasma cartridge (PC) and Hb(READ) is the hemoglobin concentration of the hemolysate. HVOL and PVOL were calculated from gravimetric measurements of the ASP and PC contents. The specific gravity of the hemolysate was calculated to be 1.09 and that of the plasma 1.03.

The data from in-flight and laboratory measurements are compared in figures 3.11-15 through -17. There is generally good agreement between the two procedures with some seemingly spurious exceptions.

Red cells are classified according to their surface ultrastructure and topography by scanning electron microscopy (SEM). These data are presented in table 3.11-X.

Coagulation Study. Factor VIII levels were significantly elevated in all three crewmen. This finding is consistent with the results of SL-3. However, all other coagulation measurements were within preflight normal ranges.

TABLE 3.11-V. RED BLOOD CELL SPECIFIC GRAVITY DISTRIBUTION

SL-4 CDR

| SPECIFIC GRAVITY | PREFLIGHT* | POSTFLIGHT (DAY) R+0 | R+1 | R+3 to R+14* |
|---|---|---|---|---|
| 1.136 | 0 | 0 | 0 | 0 |
| 1.120 | 0.72±0.23 | 1.26 | 0.43 | 0.81±0.57 |
| 1.116 | 1.94±0.54 | 3.12 | 1.32 | 2.81±1.16 |
| 1.112 | 6.66±1.12 | 6.16 | 4.88 | 7.49±2.52 |
| 1.108 | 19.58±3.21 | 14.74 | 8.73 | 19.09±6.02 |
| 1.104 | 59.72±5.29 | 41.72 | 23.24 | 54.04±13.46 |
| 1.100 | 93.43±3.83 | 85.84 | 56.16 | 89.80±6.58 |
| 1.096 | 99.55±0.01 | 97.80 | 93.12 | 98.33±1.65 |
| 1.092 | 100.0 | 99.12 | 98.70 | 99.83±0.29 |
| 1.088 | 100.0 | 99.56 | 99.56 | 100.0 |
| 1.084 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1.080 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1.057 | 100.0 | 100.0 | 100.0 | 100.0 |

*$\bar{x}$ ± S.D.

TABLE 3.11-VI. RED BLOOD CELL SPECIFIC GRAVITY DISTRIBUTION

SL-4 SPT

| SPECIFIC GRAVITY | PREFLIGHT* | POSTFLIGHT (DAY) R+0 | R+1 | R+3 to R+14* |
|---|---|---|---|---|
| 1.136 | 0 | 0 | 0 | 0 |
| 1.120 | 0.54±0.18 | 0.22 | 0.50 | 0.45±0.17 |
| 1.116 | 1.24±0.39 | 1.36 | 0.93 | 1.24±0.39 |
| 1.112 | 3.58±1.08 | 2.96 | 2.12 | 3.14±0.55 |
| 1.108 | 10.59±3.40 | 6.42 | 4.49 | 8.40±1.02 |
| 1.104 | 38.02±13.89 | 19.81 | 11.45 | 27.49±5.43 |
| 1.100 | 88.13±7.66 | 53.20 | 28.88 | 75.27±4.36 |
| 1.096 | 99.02±0.27 | 96.04 | 86.08 | 97.04±2.69 |
| 1.092 | 99.63±0.23 | 99.09 | 98.72 | 99.29±0.29 |
| 1.088 | 100.0 | 99.56 | 98.62 | 100.0 |
| 1.084 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1.080 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1.057 | 100.0 | 100.0 | 100.0 | 100.0 |

*$\bar{x}$ ± S.D.

TABLE 3.11-VII. RED BLOOD CELL SPECIFIC GRAVITY DISTRIBUTION

SL-4 PLT

| SPECIFIC GRAVITY | PREFLIGHT* | POSTFLIGHT (DAY) R+0 | R+1 | R+3 to R+14* |
|---|---|---|---|---|
| 1.136 | 0.23±0.27 | 0 | 0 | 0 |
| 1.120 | 1.92±0.58 | 1.74 | 0.46 | 1.68±0.53 |
| 1.116 | 6.24±1.75 | 4.30 | 4.40 | 5.46±1.01 |
| 1.112 | 18.54±4.62 | 9.73 | 11.94 | 16.35±3.69 |
| 1.108 | 48.88±11.04 | 20.47 | 29.71 | 40.91±7.09 |
| 1.104 | 88.05±6.65 | 55.76 | 62.52 | 79.45±6.17 |
| 1.100 | 97.72±1.25 | 84.84 | 89.32 | 95.12±2.88 |
| 1.096 | 99.54±0.01 | 98.58 | 98.83 | 99.15±0.29 |
| 1.092 | 100.0 | 99.06 | ND | 100.0 |
| 1.088 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1.084 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1.080 | 100.0 | 100.0 | 100.0 | 100.0 |
| 1.057 | 100.0 | 100.0 | 100.0 | 100.0 |

*$\bar{X}$ ± S.D.

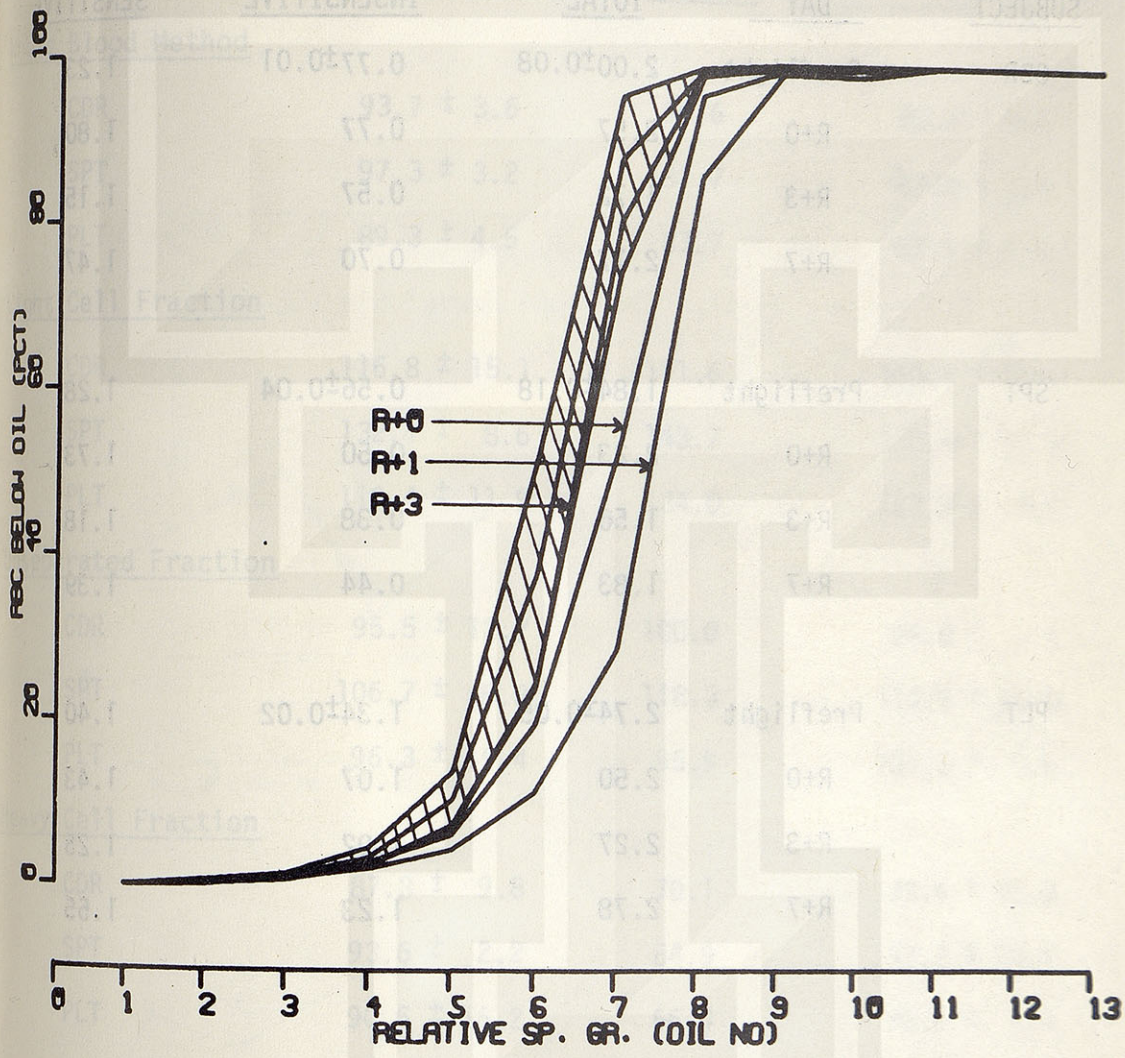



Figure 3.11-14. - RBC Density Distribution (SL-4).

TABLE 3.11-VIII. K INFLUX ($^{86}$RbCl INCORPORATION) INTO ERYTHROCYTES

| SUBJECT | MISSION DAY | TOTAL | OUABAIN INSENSITIVE | OUABAIN SENSITIVE |
|---|---|---|---|---|
| CDR | Preflight | 2.00±0.08 | 0.77±0.01 | 1.23 |
| | R+0 | 2.57 | 0.77 | 1.80 |
| | R+3 | 1.72 | 0.57 | 1.15 |
| | R+7 | 2.17 | 0.70 | 1.47 |
| SPT | Preflight | 1.84±0.18 | 0.56±0.04 | 1.28 |
| | R+0 | 2.23 | 0.50 | 1.73 |
| | R+3 | 1.56 | 0.38 | 1.18 |
| | R+7 | 1.83 | 0.44 | 1.39 |
| PLT | Preflight | 2.74±0.05 | 1.34±0.02 | 1.40 |
| | R+0 | 2.50 | 1.07 | 1.43 |
| | R+3 | 2.27 | 1.02 | 1.25 |
| | R+7 | 2.78 | 1.23 | 1.55 |

TABLE 3.11-IX. RED BLOOD CELL K CONCENTRATION

| | PREFLIGHT ± 1 S.D. | R+0 DAY | POSTFLIGHT ± 1 S.D. |
|---|---|---|---|
| Whole Blood Method | | | |
| CDR | 93.7 ± 3.6 | 96.6 | 89.9 ± 6.6 |
| SPT | 97.3 ± 3.2 | 91.7 | 87.5 ± 3.6 |
| PLT | 89.3 ± 4.5 | 87.7 | 87.1 ± 2.4 |
| Light Cell Fraction | | | |
| CDR | 116.8 ± 15.1 | 111.6 | 135.1 ± 13.9 |
| SPT | 132.1 ± 8.6 | 143.7 | 133.4 ± 17.2 |
| PLT | 118.4 ± 11.9 | 134.0 | 128.4 ± 15.0 |
| Unseparated Fraction | | | |
| CDR | 95.5 ± 12.7 | 100.0 | 96.8 ± 1.4 |
| SPT | 106.7 ± 6.8 | 118.3 | 114.6 ± 16.8 |
| PLT | 96.3 ± 15.4 | 95.9 | 105.3 ± 9.6 |
| Heavy Cell Fraction | | | |
| CDR | 87.8 ± 9.8 | 70.1 | 92.4 ± 15.0 |
| SPT | 93.6 ± 2.2 | 84.9 | 92.2 ± 20.7 |
| PLT | 90.5 ± 16.2 | 66.4 | 86.6 ± 3.4 |

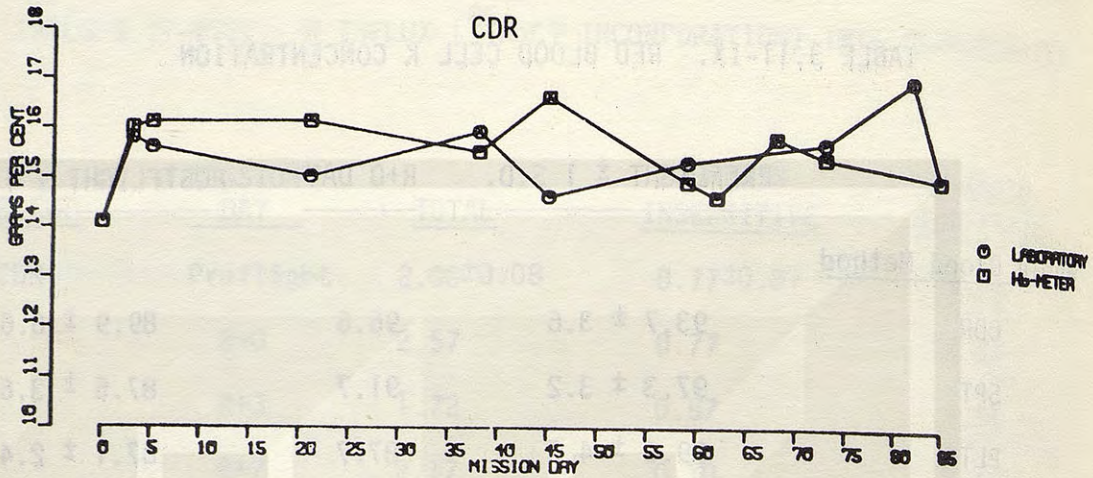



Figure 3.11-15.- In-Flight Hemoglobin (SL-4).

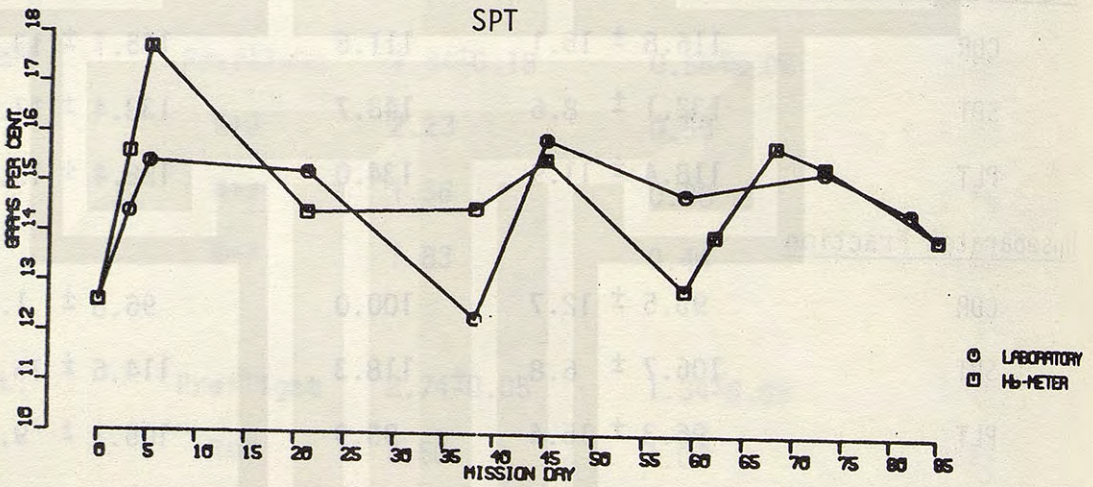



Figure 3.11-16.- In-Flight Hemoglobin (SL-4).

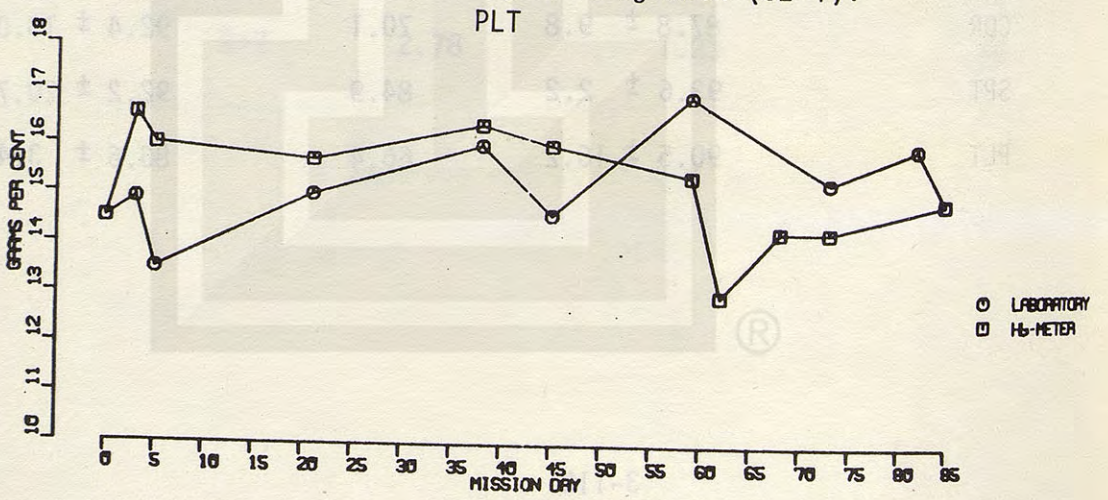



Figure 3.11-17.- In-Flight Hemoglobin (SL-4).



TABLE 3.11-X
SEM CLASSIFICATION OF ERYTHOROCYTES

TABLE 3.11-X
SEM CLASSIFICATION OF ERYTHOROCYTES
SKYLAB 4

| SUBJECT | MISSION DAY | CLASS I DISCOCYTE | CLASS IIA LEPTOCYTE | CLASS IIB CODOCYTE | CLASS IIIA STOMATOCYTE | CLASS IIIB KNIZOCYTE | CLASS IV ECHINOCYTE | CLASS V OTHER |
|---|---|---|---|---|---|---|---|---|
| CDR | F-1 | 76.5 | 7.3 | 3.8 | 10.7 | 1.7 | 0 | 0 |
| | 3 | 68.2 | 13.8 | 6.2 | 5.1 | 4.8 | 1.9 | 0 |
| | 82 | 68.3 | 7.3 | 0.5 | 2.4 | 5.7 | 15.7 | 0 |
| | R+0 | 72.6 | 10.8 | 4.2 | 10.5 | 1.6 | 0.2 | 0 |
| SPT | F-1 | 79.4 | 9.8 | 5.3 | 3.3 | 2.2 | 0 | 0 |
| | 3 | 68.6 | 12.7 | 6.0 | 8.4 | 4.1 | 0.3 | 0 |
| | 82 | 82.8 | 11.6 | 0.3 | 1.0 | 3.3 | 1.0 | 0 |
| | R+0 | 74.3 | 9.3 | 5.5 | 9.0 | 1.8 | 0 | "ghosts" |
| PLT | F-1 | 60.9 | 15.5 | 9.7 | 9.2 | 4.8 | 0 | 0 |
| | 3 | 60.8 | 26.7 | 5.5 | 1.0 | 4.2 | 1.8 | 0 |
| | 82 | 35.4 | 50.3 | 4.0 | 4.3 | 1.7 | 4.3 | 0 |
| | R+0 | 71.1 | 15.9 | 4.3 | 7.3 | 1.4 | 0 | 0 |

## Discussion

The changes observed postflight in the red cell count, hematocrit, and hemoglobin are indicative of the changing state of the circulating plasma volume. The high values at recovery, even with a significant loss of red cell mass, indicate a reduced plasma volume. This indirect measurement was confirmed by direct determination of plasma volume using $^{125}$I-albumin (see Experiment M113 report, sec. 3.9). The drop in these parameters observed at R+3 days was accompanied by a significant gain in body weight of several pounds. These changes are consistent with the changing state of hydration of the crew during the first few days following recovery (see Experiments M071 and M073 reports, sections 3.1 and 3.2).

The elevation in the metabolic-dependent component of K influx is greater than that observed after SL-3, but its significance is still unknown. Measurements of red cell adenosine triphosphate (ATP) and utilization of ATP during the flux incubation are incomplete at this time.

The rapid return to normal rates may be interpreted as a response of the cells to a transient condition which has somehow altered the dynamic state of equilibrium existing across the cellular membrane with respect to electrolytes and water. A permanent elevation would be suggestive of membrane damage resulting in a more permeable cell. The osmotic stress has not been compromised during the mission.

Contrary to both SL 1/2 and SL-3, the specific gravity profile at R+0 day was shifted towards lighter cells. On the previous two missions, this shift has been in the opposite direction. These data are still being evaluated.

The reticulocyte response observed after this mission is almost identical to that seen after SL-3. In contrast to SL-3, the reticulocyte count and number were not reduced at R+0 day. Evidently the reticulocyte response was not great enough to cause a significant change in the density of the ribosomal network. These evaluations were done by subjective classification using light microscopy. It is possible that the change in average age of the reticulocytes was too subtle to be detected by this technique.

Scanning electron microscope examinations of the surface topography of red cells from preflight, in-flight, and postflight samples indicates that there are changes in the cell structure during flight. The most obvious change is an increase in the number (and percentage) of echinocytes (crenated cells) especially in the CDR at MD 82. The PLT

had a striking shift to leptocytic cells in-flight. Most of the shifts observed were only in the in-flight samples with the R+0 day SEM differential not differing significantly from the preflight. The significance of these changes is not known at present, but the same type of shifts have been observed on all three flights.

Summary

There is a striking similarity between the data from SL-3 and SL-4 (with the one exception of the specific gravity shifts). There would appear to be no major biochemical problems associated with red blood cell structure and function after 84 days of space flight. Much of the data is preliminary and must be completed and compared to that from SL 1/2 and SL-3 before the final significance of long duration space flight with respect to hematologic functions can be determined.

## 3.12 Experiment M131. Human Vestibular Function

*Principal Investigators:* *Ashton Graybiel, M.D.*
*Earl F. Miller II, Ph.D.*
*Principal Coordinating Scientist:* *J. L. Homick, Ph.D.*

### Introduction

Experiment M131, Human Vestibular Function, compares in-flight with preflight and postflight measurements of:

- susceptibility to motion sickness
- the perception of angular acceleration as indicated by the oculogyral illusion
- the perceived direction of internal and external space.

The purpose of this report is to provide a preliminary summary of SL-4 findings through R+31 days that have been analyzed at this time. All equipment throughout the three missions performed without fault. One major equipment usage factor, the pressure of the $N_2$ system (1200 lb) that isolates the brush-type motor, remained well above the critical level (about 200 lb).

In analyzing vestibular side effects reported during the orbital weightless portion of the SL-4 mission, it is important to distinguish between motion sickness susceptibility under operational and experimental conditions.

### Operational Conditions

As a result of the incidence of motion sickness among the SL-3 crew, the SL-4 crew was instructed to use antimotion sickness drugs according to the schedule outlined in table 3.12-I (through MD 4 at 0600 hours c.s.t. and additionally as required). It is to be noted that on MD's 8, 33 and 82 the SPT took the recommended drug combination B as a soporific rather than for its antimotion sickness properties. In spite of these measures, the PLT and possibly the CDR experienced symptoms of motion sickness during the first three days of the mission. The CDR's symptoms were mild and restricted to epigastric awareness prior to meals whereas those of the PLT were severe and included vomiting. The PLT also greatly restricted his activities at least during the first day of the mission. Since drugs were employed, the precise effect of weightlessness upon motion sickness susceptibility during the early part of the mission cannot be assessed for any of the crew. Assuming the drugs were always helpful, the PLT must have been highly susceptible to motion sickness, the CDR slightly to moderately susceptible.

TABLE 3.12-I. SKYLAB 4 ANTIMOTION SICKNESS MEDICATION

| MISSION EVENT | APPROX TIME (Hours, c.s.t.) | Commander | Scientist Pilot | Pilot |
|---|---|---|---|---|
| LAUNCH DAY (MD 1) AFTER INSERTION | 0900 | | A | B |
| AFTER NC-1* | 1100 | A | | |
| AFTER DOCKING | 1600 | B | B | B |
| | 2030 | | | B |
| MD 2 & MD 3 ON ARISING | 0600 | A | A | B |
| | 1000 | A | A | |
| | 1400 | B | B | B |
| MD 4 ON ARISING | 0600 | A | A | B |
| | 1400 | | | B |
| MD 8 | BEDTIME | | B† | |
| MD 33 | BEDTIME | | B† | |
| MD 82 | BEDTIME | | B† | |
| MD 84 ABOUT 2 HOURS PRIOR TO SPLASH (ENTRY) | | A | A | A |

A SCOPOLAMINE/DEXTROAMPHETAMINE SULFATE (0.4/5.0 mg)
B PROMETHAZINE/EPHEDRINE (25/50 mg)
* FIRST PHASING MANEUVERS
† USED AS A SOPORIFIC

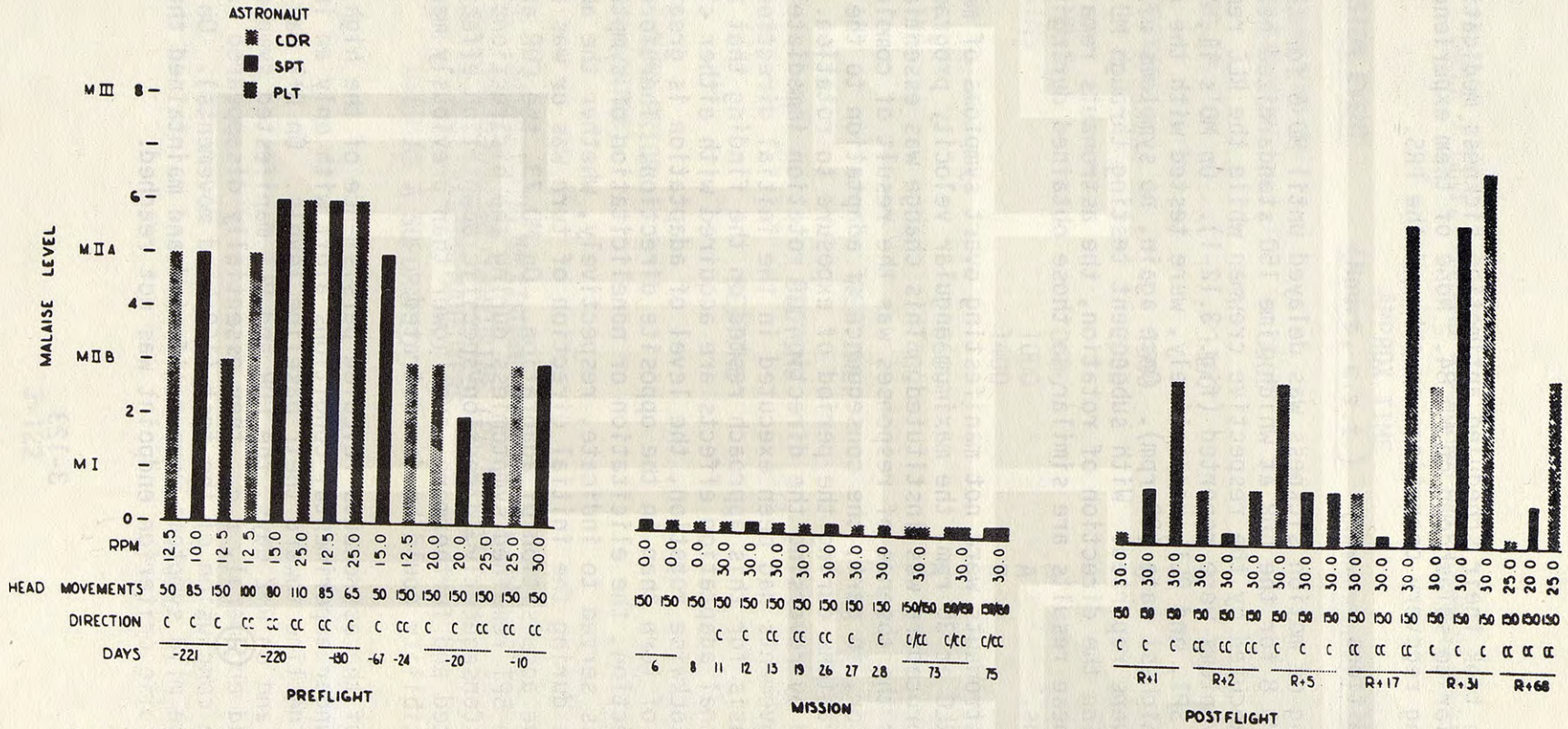
All three crewmen took their scheduled antimotion sickness medication about 2 hours prior to splashdown on MD 84. None of them experienced seasickness during recovery operations or onboard the PRS.

Experimental Conditions

Systematic testing of motion sickness was delayed until MD 6 for the SPT and PLT and MD 8 for the CDR at which time 150 standardized head movements were executed by the respective crewman while the RLC remained stationary; no symptoms were reported (fig. 3.12-1). On MD's 11, 12, and 13, the CDR, SPT, and PLT, respectively, were tested with the chair rotating at its highest rate (30 rpm). Once again, no symptoms of motion sickness were reported. With subsequent testing through MD 28, each time reversing the direction of rotation, the astronauts remained symptom free. These results are similar to those obtained during the first two missions.

Since the SL-4 astronauts were not manifesting overt symptoms of motion sickness in the RLC at 30 rpm, the maximum angular velocity programed, a change in the procedure was instituted. This change was essential to determine whether the absence of responses was the result of complete insusceptibility or, in part, the consequence of adaptation to the stressful accelerations during the period of exposure to rotation. The latter was tested by reversing the direction of rotation immediately after 150 head movements had been executed in the initial direction of rotation. The basis for this approach rested on the finding that although bidirectional adaptation effects are acquired with either clockwise or counterclockwise rotation, the level of adaptation is greater in the direction of turn than in the opposite direction. Therefore, by reversing direction, the elicitation or nonelicitation of symptoms of motion sickness served to indicate, respectively, whether the absence of symptoms during the initial direction of turn was or was not due in part to the acquisition of adaptation. On MD 73, the CDR and PLT, and on MD 75, the SPT remained symptomless during the bidirectional test procedure. Consequently, direction-specific adaptation effects were not manifested and furthermore, even lower than previously measured levels of susceptibility could be demonstrated.

Postflight each of the astronauts revealed persistence of the high tolerance found under experimental conditions aloft with only an indication of possible decline toward their baseline levels. On R+1 day, the SPT and PLT, and on R+2 days, the CDR and PLT manifested symptoms that were mild and ephemeral, *i.e.*, they essentially disappeared sometime prior to the conclusion of the test (150 head movements). On R+5 days, although the mild symptoms were manifested and maintained throughout the test, the malaise criterion endpoint was not reached.




C = CLOCKWISE
CC = COUNTERCLOCKWISE

Figure 3.12-1. - Testing for Motion Sickness, (SL-4).

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On R+31 days the SPT and PLT reached M IIA after 60 and 80 head movements, respectively, while rotating at the highest rotational rate (30 rpm) while the CDR manifested slight sweating during the execution of 150 head movements at this rate. Each astronaut reported, however, that the same stimulus conditions of the prior postflight tests which evoked only slight or no symptoms had a clear and substantial stressor effect on R+31 days. On day 68 postflight the rpm were reduced to 25 rpm and none reached the motion sickness endpoints.

Spatial Localization

Preliminary inspection of the findings indicates no gross changes in spatial perception, but further comments on the rod/sphere data must be reserved until a later date since the analysis has just been initiated.

Oculogyral Illusion (OGI)

The oculogyral illusion thresholds of response, a highly sensitive indicator of canal function, are presented in figure 3.12-2 for the three crewmen. The preflight and postflight "frequency of seeing" curves as a function of the step level of angular acceleration (steps 1, 4, 8, 10, 14, 18, equal angular accelerations of 0.20, 0.038, 0.096, 0.150, 1.380, 0/950°/sec$^2$) are represented as broken lines. The curves obtained through MD's 8 through 81 are portrayed as solid lines. Gross inspection reveals little or no significant changes in the thresholds of canal response as a function of time in-flight for the CDR, whereas the SPT and particularly the PLT display rather marked and progressive increases in their thresholds. In this regard, it is to be noted the PLT reported in the latter part of the flight much more difficulty in perceiving this illusion under weightless Skylab conditions than on the ground.

Postflight, the CDR revealed similar, the SPT, decreased; and the PLT markedly decreased thresholds of response (increased "frequency of seeing"). For as yet unexplained reasons, the PLT showed a curious reversal in slope of his resultant curve on the last mission test day and the first test postflight. In the second test postflight his perception of the OGI was excellent, comparable to his best performance preflight and far exceeding his scores made after MD 12.

Postural Equilibrium

Postural equilibrium was measured in terms of the duration in which the subject could stand on the floor and on rails of various widths with his feet tandemly arranged and arms folded. On R+1 day the test results were comparable to those of preflight, but only when visual orientation cues were present. With eyes closed, severe disequilibrium was demonstrated. The amount of disequilibrium, however, decreased substantially by R+4 days and by R+11 days postural balance was nearly the same as preflight.

Figure 3.12-2. - OGI Threshholds of Response, (SL-4).

## 3.12.1 Electronystagmography

*Principal Investigators: J. L. Homick, Ph.D.*
*M. F. Reschke, Ph.D.*

### Background and Introduction

Nystagmus is generally defined as any rhythmic movement of the eyes which is normally designed to maintain the retinal image in the same position on the retina. Nystagmus may be induced by a variety of experimental or operational conditions involving stimulation of the vestibular apparatus or movements of the visual field. Nystagmus may also be clinical in nature and occur as the result of some acute or chronic abnormality of the vestibular system. Clinical nystagmus may be present continuously and spontaneously and/or it may occur only when the head is moved to a particular postion. Assuming that functional alterations might occur in the vestibular apparatus of the SL-4 crewmen, either as a result of 85 days of exposure to zero-g or the sudden transition back to one-g, procedures were implemented to measure for the presence of spontaneous and positional nystagmus.

### Protocol

At the beginning of each session miniature electrodes were placed at the outer canthus of each eye and a ground electrode was attached to the center of the crewman's forehead. Following eye movement calibration, the subject was blindfolded and then instructed to lie in a supine position on an examination table. An attempt was then made to elicit nystagmus in several different positional modes. The first procedure was patterned after standard clinical positional electronystagmography. Starting from a seated upright position, the crewman turned his head up over the right shoulder and then while maintaining this head positon, the head was lowered back over the edge of the examination table. This head-down position was maintained for approximately 10-15 seconds after which the crewman was returned to the seated upright position. The maneuver was repeated with the head tilted straight back and turned up over the left shoulder. For purposes of this report the procedures just described are referred to as Type I positional nystagmus. Following the Type I maneuvers the crewman was required to lie passively on the examination table for a period of 30 seconds during which time eye movements were monitored for the presence of spontaneous nystagmus. Finally, while lying supine on the examination table, the crewman was instructed to rotate his head 90° to the right (and left) positon and after a 5-10 second pause, back to center. The head turns were made at a slow, moderate, and fast rate of speed. This latter head movement procuedure is referred to as Type II positional nystagmus. It should be noted that the Type II procedure as described is not a true positional nystagmus. The required

rotary head movements in effect created a momentary angular acceleration which could be expected to elicit nystagmus if it were of sufficient magnitude. All of the procedures described above were performed with each crewman on F-5, R+1, and R+11 days.

## Results and Discussion

Careful examination of the electronystagmographic records obtained indicated that essentially no Type I positional nor spontaneous nystagmus occurred in any of the crewmen during any of the measurement periods. Type II positional nystagmus was observed with some regularity; the results are summarized in table 3.12.1-I which gives the average slow phase velocity (deg/sec$^2$) and frequency (beats/sec) of nystagmus recorded during each of the stimulus conditions. Empty cells in the table mean that no data were obtained for that condition. From the data presented it can be seen that no Type II positional nystagmus was elicited from the CDR during any of the examination periods. Although Type II positional nystagmus was present in the SPT and PLT, no overall trends are apparent which convincingly demonstrate that nystagmus was more easily produced during the immediate postflight period. It should be recognized that the positional nystagmus methods employed were not sensitive to any subtle changes that may have been present postflight. It is clear, however, that no gross vestibular dysfuction was revealed by these measurements.



Table 3.12.1-I. Preflight and Postflight Type II Positional Nystagmus Elicited From The SL-4 CDR, SPT, and PLT

Values are mean slow phase velocity (deg/sec$^2$) and frequency (beats/sec), latter in parenthesis.

Table 3.12.1-I. Preflight and Postflight Type II Positional Nystagmus Elicited From The SL-4 CDR, SPT, and PLT

Values are mean slow phase velocity (deg/sec$^2$) and frequency (beats/sec), latter in parenthesis, of nystagmus recorded during slow, medium, and fast head turns to the right and left.

| | | SLOW (4 sec) | | | | MEDIUM (2 sec) | | | | FAST (1 sec) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | DAY | C-R | R-C | C-L | L-C | C-R | R-C | C-L | L-C | C-R | R-C | C-L | L-C |
| CDR | F-5 | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | R+1 | 13.2(3) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | R+11 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| SPT | F-5 | | | | | 5.6(3) | 9.2(3) | 8.6(3) | 11.6(3) | 42.6(5) | 0 | 0 | 51.3(7) |
| | R+1 | 0 | 27.7(3.5) | 22.1(2) | 16.0(3) | 0 | 0 | 46.4(4.5) | 48.6(4) | 0 | 0 | 0 | 0 |
| | R+11 | 19(2) | 0 | 22(3) | 19(4) | 25(6) | 38(4) | 24(2) | 42(3) | 51(4) | 52(6) | 37(2) | 20(3) |
| PLT | F-5 | | | | | 9.4(3) | 8.8(2) | 0 | 0 | 13.2(3) | 27.3(5) | 0 | 24.0(5) |
| | R+1 | 10.3(4) | 7.4(3) | 7.1(3) | 4.5(2) | 11.6(3) | 9.5(3) | 15.6(3) | 17.0(4) | 46.6(4) | 35.1(6) | 32.0(6) | 68.8(6) |
| | R+11 | 18(4) | 0 | 0 | 16(3) | 29(4) | 0 | 18(3) | 29(3) | 63(4) | 43(6) | 0 | 54(5) |

C = Center
R = Right
L = Left

## 3.13 Experiment M133. Sleep Monitoring

*Principal Investigator: James D. Frost, Jr., M.D.*
*Principal Coordinating Scientist: William H. Shumate, Ph.D.*

### Introduction

Prior to Skylab, very little objective information had been obtained concerning man's ability to sleep in space. Since sleep deprivation is known to be associated with degradation of performance, the objective data provided by the M133 study is intended to provide useful information for determining optimal work/rest schedules and for planning for future space missions.

The M133 Experiment was successfully carried out during the 29-day first manned Skylab mission (SL 1/2). Some degradation of data quality occurred because of hardware damage resulting in high temperatures present in the OWS during the first 10 days of this flight. The data indicated that although the SPT experienced significant decrease in total sleep time, it was a result of voluntarily reducing his rest time and it was not due to difficulty in sleeping nor frequent awaking.

During Skylab 3, the second manned mission, the SPT was not greatly affected by the weightless environment and no changes in total sleep time or sleep latency were evident while Stage 4 and Stage REM dropped slightly.

The Skylab 4 flights provided an opportunity to observe sleep characteristics in a third subject over a longer period of time (84 days).

### Method

The complete sleep-analysis system designed for this experiment included data-acquisition hardware, onboard analysis components, and a capability for real-time telemetry.

Onboard equipment accomplished automatic analysis of the electroencephalogram (EEG), electro-oculogram (EOG), and head-motion signals. The system's output, consisting of sleep-stage information, was telemetered in near real time to Mission Control, where a profile of sleep stage versus time was accumulated. The analog signals (EEG, EOG, and head motion) were also preserved by onboard magnetic-tape recorders, thus allowing a more-detailed postflight analysis.

## Flight Hardware

The astronaut wore a recording cap containing electrodes for detecting EEG and EOG activity. A preamplification unit, attached to the cap near the vertex of the head, amplified the signals, and a dual-axis accelerometer, placed within the preamplifier housing, provided information concerning lateral (side-to-side) and vertical (up-down) movement of the subject's head. A flexible cable connected the preamplifier with a control-panel assembly mounted on the wall in the subject's sleep compartment, within easy reach of the sleep restraint. Within the control-panel assembly, additional circuitry accomplished automatic electrode testing, sleep analysis, and generation of the telemetry output signal, indicative of the subject's current level of consciousness. Two tape recorders, attached to the rear of the control-panel assembly, provided an analog record of the subject's sleep.

The recording cap made of an elastic-type fabric, stretches to conform comfortably to the subject's head. Inside the cap, sponge-type electrodes prefilled with gelled, conductive electrolyte, are attached at the positions necessary for acquisition of EEG and EOG signals; wires join the electrodes to a miniature electrical connector at the vertex of the cap, enabling rapid linkage with the preamplifier/accelerometer assembly. The cap contains seven electrodes, arranged such that four provide a composite EEG channel, two provide one EOG channel, while the seventh electrode serves as a ground.

The cap is stored in a plastic bag until needed. The donning procedure requires less than five minutes of the subject's time prior to bed, and since each cap is used only once, postrecording breakdown is limited to removal of the cap, disconnection of the preamplifier/accelerometer unit, and disposal of the cap.

At bedtime, after the astronaut dons the recording cap, each electrode is automatically tested to insure proper function. The control-panel front, easily visible from the sleep restraint, contains indicator lamps arranged in a configuration simulating the position of the recording electrodes on the head.

Continuous monitioring of EEG, EOG, and head-motion signals is done during the sleep period. As the monitoring sessions progress, the data-analysis circuitry within the control-panel assembly supplies sleep-stage information in near real time to observers in Mission Control. Onboard, the EEG, EOG, and head-motion signals are processed in real time. EEG alone determines stages Awake, 1, 2, 3, and 4 of sleep; EEG and EOG signals differentiate stage REM. Signals likely to be contaminated by artifacts do not reach the analysis section, since the EEG and accelerometer circuits specifically exclude them.

The analysis-circuitry output continuously displays one of seven possible states: awake; stages 1 through 4 and REM of sleep; or stage 0, indicating the absence of adequate data. This output, essentially a three-bit code, arrives at Mission Control in real-time as the space craft passes over tracking stations. Between stations, the digital signals are recorded onboard and then transmitted at a high rate during a subsequent tracking-station pass.

## Ground-Based Data Analysis

During a sleep monitoring session, true real-time data was available only during the few minutes when the spacecraft was passing over a ground tracking station. Throughout the frequent periods when the spacecraft was out of communication range, the spacecraft telemetry recorder accumulated sleep-stage data and transmitted it to the ground at a high rate during a subsequent tracking-station pass. The tracking stations, in turn, relayed the information to Mission Control. Consequently, the data ultimately received during a sleep period was somewhat sporadic, ranging from actual real time to delays of up to several hours. Data-processing equipment in Mission Control collated the incoming data so that the time relationships were preserved, and eventually a complete tabulation of sleep stage versus elapsed time evolved.

Although data was telemetered at a rate of 1.25 sleep-stage samples per second (75 samples per minute), a subject's sleep stage does not typically change more often than two or three times each minute, and it is often stable for several minutes. The data-processing system was therefore programed to indicate only the time and the sleep stage when a change of sleep level occurred. The resultant listing of sleep-stage information versus time was transferred to The Methodist Hospital, where the computer facilities of the Neurophysiology Laboratory and the Baylor Institute of Computer Science were employed to provide the final data analysis.

The end product was a compact graphic plot showing the complete profile of sleep stage versus time over the course of a sleep period. A statistical summary of the all-night data was also supplied for each sleep period, and values for the following parameters were included: total rest-period time, total sleep time, total awake time, sleep latency, number of arousals, accumulated time in each sleep stage, percentage of total sleep time occupied by each sleep stage, and REM latency.

At the conclusion of each Skylab mission, the onboard data tapes were returned by the crew, and this data was then analyzed by conventional visual scoring techniques after playback onto a graphic recorder.

## Experimental Design

One crew member participated in the sleep monitoring activities during each Skylab flight. Baseline data was obtained on the participating subjects preflight during three consecutive nights of sleep monitoring, using portable apparatus functionally identical to the onboard hardware. The astronaut studied during the 29-day mission was recorded in his own home two months prior to launch, while the subjects of the 59- and 84-day missions were monitored in the preflight quarantine facility two weeks before their respective launches. In addition, a standard clinical electroencephalogram was performed on each subject prior to the flight to permit precise EEG amplitude determinations for calibration of the flight hardware.

In-flight monitoring was accomplished during 12 selected nights of the 29-day mission (nights 5, 6, 7, 10, 11, 15, 17, 19, 21, 24, 25, and 26), during 20 nights of the 59-day mission (nights 7, 8, 9, 12, 15, 18, 21, 24, 27, 29, 33, 36, 39, 42, 45, 48, 52, 55, 56, and 57), and during 18 nights of the 84-day flight (nights 3, 4, 10, 14, 19, 24, 29, 34, 40, 45, 50, 55, 60, 72, 77, 80, 81, and 82). Operational factors associated with the activation and function of various spacecraft systems prevented recordings during the initial period of each flight.

Crew bedtime was typically at 2200 hours, and the scheduled sleep period terminated at 0600 hours, although occasional deviations from this schedule were necessitated by work requirmments not associated with the sleep monitoring experiment. During the last week of the 29- and 59-day missions, sleeping schedules were adjusted forward by a total of four hours (*i.e.*, typical bedtime became 1800 hours). An adjustment of two hours was made on days 20 and 22 of the 29-day mission, and there was a similar change of two hours on days 51 and 53 of the 59-day mission. During the 84-day mission, schedule alterations were made during the last three days only, and consequently only one day (day 82) of sleep monitoring was affected. On this day, the bedtime was advanced approximately two hours (approximately 2000 hours), and the subject was permitted a 10-hour total rest time (*i.e.*, the time of awakening remained approximately 0600 hours). These scheduled alterations were necessitated by the activities associated with spashdown and recovery operations, which required early awakening on the final day of the mission.

Upon return to Earth, postflight baseline studies were performed on each sleep monitoring participant. After the 29-day mission, recordings were done on nights 4, 6, and 8, and in the case of the 59-day mission, on the second, fourth, and sixth nights following splashdown. Following the 84-day flight, recordings were made on the first, second, and fifth nights.

## Operational Factors

Partial dehydration of several recording-cap electrodes from the elevated temperatures in the OWS during the first mission necessitated the use of caps intended for subsequent flights. The SL-3 crew took a repair kit with them to refurbish the damaged recording caps by injection of supplementary electrolyte gel prior to use. As there were not enough caps remaining to permit use of a new unit for each recording session on the final, SL-4 84-day flight, the subject reused a cap several times and injected additional electrolyte gel into the sponge electrodes before donning the cap each night. These techniques were successful for the respective flights and the data quality remained high.

Despite the unforeseen problems, however, successful near-real-time monitoring was accomplished on nine of the 12 attempted recording nights during the 29-day mission, on 18 of the 20 nights attempted on the 59-day mission, and on 17 of the 18 attempted sessions of the 84-day flight. Postflight return of the analog tapes permitted visual confirmation of the results on two of the nine nights of the 29-day mission, on 12 of the 18 nights of the 59-day mission, and on 17 of the 18 nights of the 84-day mission.

## Statistical Analysis

The results are, when possible, those obtained by visual analysis of the tape-recorded EEG, EOG, and head motion signals, since this method is considered the most reliable and the least influenced by various artifactual components that may be present. In the instances where this was not possible due to loss of recorded data on several nights, the results of onboard automatic analysis have been utilized after application of certain corrective factors based upon past performance of the system and, in the case of the 59-day flight, upon correlation of the in-flight results with those of visual analysis for the nights on which both types of information were available (MA. Table 3.13-I). In most cases automatic analysis gave satisfactory estimates of the actual value. Regression analysis, after correlation of automatic and visual results, provided a means for further modifying the results of automatic analysis (MCA. Table 3.13-II) for those six nights of the 59-day mission unconfirmed by visual analysis (*i.e.*, nights 42, 45, 48, 52, 56, and 57, for which the analog-tape data was lost).

These statistical maneuvers provided a consistent means for utilizing all the available information. The values obtained are included in the results to be presented and were subjected to further statistical analysis along with the visual-analysis results, although it was determined that the overall significance of the results was the same, whether or not these values were included.

TABLE 3.13-I.

29-DAY MISSION

| | PREFLIGHT | | | AVG. | | IN-FLIGHT | | | | | | | | | AVG. | | POSTFLIGHT | | | AVG. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MISSION DAY | -60 | -59 | -58 | | | 5 | 6 | 10 | 15 | 17 | 19 | 21 | 24 | 26 | | | +3 | +5 | +7 | |
| ANALYSIS TYPE | V | V | V | | | V | V | MA | MA | MA | MA | MA | MA | MA | | | V | V | V | |
| TOTAL REST TIME | 7.3 | 7.3 | 8.7 | 7.8 | | 6.6 | 6.3 | 7.7 | 7.4 | 5.6 | 7.7 | 6.5 | 8.0 | 6.0 | 6.86 | | 9.3 | 9.0 | 8.5 | 8.9 |
| TOTAL SLEEP TIME | 6.5 | 6.5 | 7.7 | 6.9 | | 6.1 | 5.4 | 5.3 | 7.0 | 5.2 | 6.6 | 6.2 | 7.2 | 5.4 | 6.04 | | 9.0 | 8.5 | 8.0 | 8.5 |
| TOTAL AWAKE TIME | 0.74 | 0.81 | 0.96 | 0.84 | | 0.31 | 0.85 | 2.43 | 0.45 | 0.47 | 0.81 | 0.25 | 0.67 | 0.26 | 0.72 | | 0.26 | 0.45 | 0.44 | 0.38 |
| SLEEP LATENCY | 0.46 | 0.70 | 0.73 | 0.63 | | 0.35 | 0.33 | 0.28 | 0.35 | 0.18 | 0.76 | 0.06 | 0.10 | 0.30 | 0.30 | | 0.17 | 0.24 | 0.16 | 0.19 |
| STAGE 1% | 7.4 | 4.3 | 4.2 | 5.3 | | 6.8 | 9.5 | 9.8 | 8.3 | 7.7 | 1.1 | 5.4 | 4.4 | 0.6 | 5.95 | | 4.0 | 6.5 | 4.8 | 5.1 |
| STAGE 2% | 60.3 | 49.6 | 54.5 | 54.8 | | 60.2 | 56.4 | 43.4 | 56.4 | 26.7 | 50.9 | 43.8 | 28.9 | 24.0 | 43.4 | | 58.5 | 53.8 | 57.4 | 56.6 |
| STAGE 3% | 12.8 | 17.9 | 13.8 | 14.8 | | 18.3 | 14.6 | 10.0 | 12.6 | 8.8 | 13.1 | 11.2 | 28.0 | 27.8 | 16.0 | | 11.8 | 11.1 | 13.7 | 12.2 |
| STAGE 4% | 2.9 | 3.4 | 2.4 | 2.9 | | 4.6 | 0.8 | 12.6 | 17.1 | 14.9 | 14.5 | 16.5 | 27.7 | 41.6 | 16.7 | | 1.0 | 1.0 | 1.3 | 1.1 |
| STAGE REM % | 16.6 | 24.8 | 25.1 | 22.2 | | 10.1 | 18.6 | 24.1 | 5.5 | 41.9 | 20.4 | 23.2 | 11.0 | 5.9 | 17.9 | | 24.7 | 27.5 | 22.8 | 25.0 |
| REM LATENCY | 1.24 | 1.24 | 1.91 | 1.46 | | 2.31 | 1.66 | | | | | | | | 1.98 | | 0.93 | 1.18 | 1.11 | 1.07 |
| NO. OF AWAKENINGS | 19 | 16 | 24 | 19.7 | | 10 | 14 | | | | | | | | 12 | | 20 | 20 | 26 | 22 |



TABLE 3.13-II.

TABLE 3.13-II.

59-DAY MISSION

| | PREFLIGHT | | | AVG. | | IN-FLIGHT | | | | | | | | | | | | | | | | | | | | AVG. | | POSTFLIGHT | | | AVG. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MISSION DAY | -15 | -14 | -13 | | | 7 | 8 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 29 | 33 | 36 | 39 | 42 | 45 | 48 | 52 | 55 | 56 | 57 | | | +1 | +3 | +5 | |
| ANALYSIS TYPE | V | V | V | V | | V | V | V | V | V | V | V | V | V | V | V | V | $M_{C_A}$ | $M_{C_A}$ | $M_{C_A}$ | $M_{C_A}$ | $M_{C_A}$ | $M_{C_A}$ | $M_{C_A}$ | $M_{C_A}$ | | | V | V | V | |
| TOTAL REST TIME | 7.7 | 8.4 | 6.5 | 7.5 | | 6.90 | 6.59 | 8.23 | 7.14 | 7.32 | 7.05 | 6.95 | 7.27 | 7.87 | 8.90 | 7.19 | 7.38 | 7.21 | 7.23 | 7.55 | 7.68 | 6.82 | 6.78 | 7.32 | 6.61 | 7.32 | | | 7.09 | 8.44 | 7.77 |
| TOTAL SLEEP TIME | 6.4 | 7.6 | 5.2 | 6.4 | | 5.95 | 6.08 | 6.94 | 6.24 | 6.86 | 5.75 | 5.47 | 6.50 | 7.03 | 6.96 | 6.46 | 6.99 | | 6.16 | 6.47 | 6.14 | 5.04 | | 6.48 | 6.44 | 6.31 | | | 5.77 | 7.38 | 6.58 |
| TOTAL AWAKE TIME | 1.3 | 0.8 | 1.3 | 1.1 | | 0.95 | 0.51 | 1.28 | 0.90 | 0.46 | 1.30 | 1.49 | 0.77 | 0.87 | 1.94 | 0.73 | 0.38 | | 1.07 | 1.08 | 1.54 | 1.78 | | 0.84 | 0.17 | 1.00 | | | 1.32 | 1.06 | 1.19 |
| SLEEP LATENCY | 0.3 | 0.09 | 0.2 | 0.2 | | 0.21 | 0.24 | 0.32 | 0.32 | 0.13 | 0.15 | 0.06 | 0.15 | 0.26 | 0.36 | 0.19 | 0.12 | | 0.14 | 0.37 | 0.12 | 0.36 | 0.10 | 0.16 | 0.17 | 0.21 | | 0.08 | 0.15 | 0.24 | 0.16 |
| STAGE 1 (%) | 8.3 | 7.6 | 10.6 | 8.8 | | 7.5 | 5.9 | 11.2 | 10.6 | 8.7 | 11.9 | 11.6 | 9.5 | 11.3 | 13.5 | 4.3 | 5.0 | | 7.5 | 9.4 | 10.5 | 7.3 | | 6.4 | 8.8 | 8.9 | | | 10.4 | 9.9 | 10.2 |
| STAGE 2 (%) | 57.3 | 58.3 | 53.3 | 56.3 | | 59.5 | 57.4 | 63.2 | 60.4 | 60.7 | 57.8 | 49.2 | 62.4 | 63.6 | 56.6 | 60.8 | 59.1 | | 61.0 | 60.5 | 59.6 | 60.9 | | 61.0 | 60.1 | 59.7 | | | 57.1 | 58.4 | 57.8 |
| STAGE 3 (%) | 18.0 | 16.4 | 17.7 | 17.4 | | 19.1 | 13.5 | 13.8 | 17.2 | 18.6 | 15.8 | 24.6 | 13.9 | 15.1 | 20.0 | 19.1 | 19.4 | | 15.4 | 17.9 | 16.2 | 16.6 | | 17.4 | 21.1 | 17.5 | | | 12.0 | 8.2 | 10.1 |
| STAGE 4 (%) | 3.1 | 4.9 | 0.3 | 2.8 | | 1.8 | 1.9 | 0.8 | 1.6 | 1.5 | 1.0 | 3.1 | 1.3 | 0.8 | 1.3 | 1.1 | 1.4 | | 1.3 | 1.3 | 1.3 | 1.3 | | 1.3 | 1.3 | 1.4 | | | 0.4 | 0.4 | 0.4 |
| STAGE REM (%) | 13.2 | 12.7 | 18.2 | 14.7 | | 12.1 | 21.3 | 11.0 | 10.2 | 10.7 | 13.4 | 11.5 | 13.0 | 9.2 | 8.6 | 14.7 | 15.1 | | 11.8 | 13.2 | | 10.8 | | 8.5 | 10.1 | 12.1 | | | 20.1 | 23.0 | 21.6 |
| REM LATENCY | 1.6 | 2.2 | 1.8 | 1.87 | | 1.5 | 1.8 | 2.3 | 2.6 | 2.2 | 2.1 | 1.6 | 2.2 | 2.3 | 2.9 | 1.6 | 1.6 | | 2.0 | | | | | | | 2.05 | | 0.8 | 1.1 | 0.7 | 0.87 |
| NO. OF AWAKENINGS | 37 | 51 | 34 | 40.7 | | 39 | 32 | 70 | 52 | 62 | 43 | 21 | 51 | 44 | 25 | 8 | 25 | | | | | | | | | 39.3 | | | 26 | 31 | 28.5 |

Finally, for each mission, preflight, in-flight, and postflight conditions for each parameter were treated by an analysis of variance. *A posteriori* comparisons were made in cases where the overall F test reached conventional levels of statistical significance ($P<0.05$).

For the 84-day mission, all 17 nights are based on the results of visual analysis.

Data Quality

Data quality, as evaluated by visual inspection of the signals played back from the analog tapes returned at the conclusion of each mission, was generally excellent. Although recorder malfunctions occurred during the 29- and 59-day missions, the data recorded prior to the failures was, in both instances, of high quality. During the 84-day flight, the recorded signals were of clinical quality throughout.

Selected examples of the EEG, EOG, and head-motion signals, as played back from the onboard tapes, are shown in figure 3.13-1. This figure illustrates the transition from the awake, alert state through the various stages of sleep for the Scientist Pilot on day 3 of the 84-day mission.

Results

Sleep Latency.

The amount of elapsed time from the onset of the sleep period (*i.e.*, bedtime) until the first appearance of stage 2 sleep is defined as sleep latency. Sleep-latency characteristics observed during the three Skylab missions are summarized in figure 3.13-2 and Table 3.13-I, -II, and -III. Average in-flight, preflight, and postflight figures for this parameter are indicated in the tables. Sleep latency varied considerably during the 29-day mission, ranging from a low value of 3.6 minutes on day 21 to a maximum of 45 minutes on day 19. Day 19 was, however, the only instance in which the latency exceeded the preflight values, and the average in-flight value of 18 minutes actually represents a decrease of 20 minutes as compared to the preflight average of 37.8 minutes. Postflight values were all relatively low but well within the in-flight range. Statistically, the in-flight and postflight latencies were less than the preflight values ($P<0.01$).

No statistically significant changes in sleep latency were noted during the 59-day mission although on several days the values were somewhat above the preflight average of 12 minutes. This parameter ranged from a low of 4 minutes on day 21 to a maximum of 24 minutes on day 45. A cyclic fluctuation of sleep latency was suggested, with maxima near

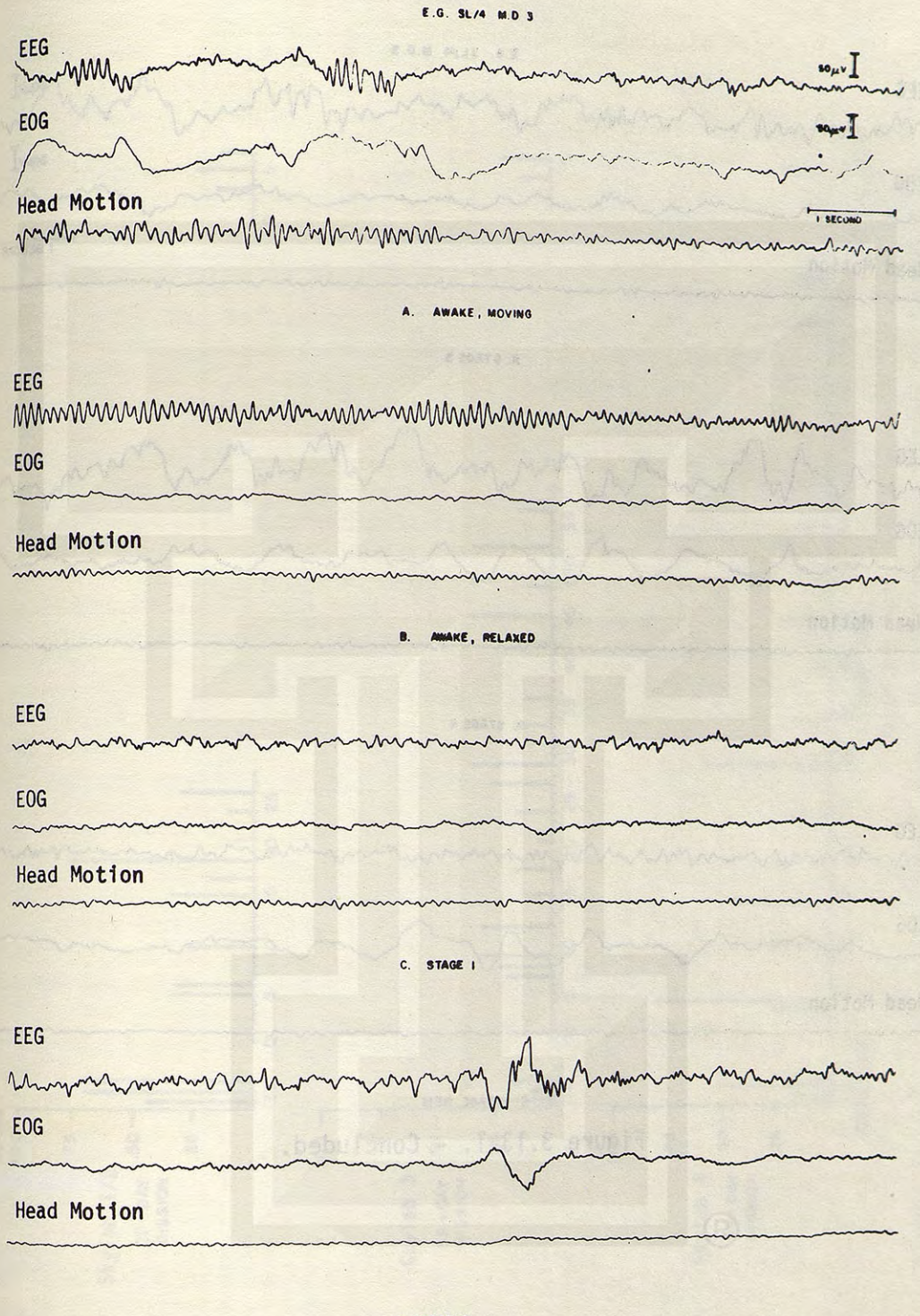


Figure 3.13-1. - Transitions of SL-4 SPT from awake through the various stages of sleep, MD 3.

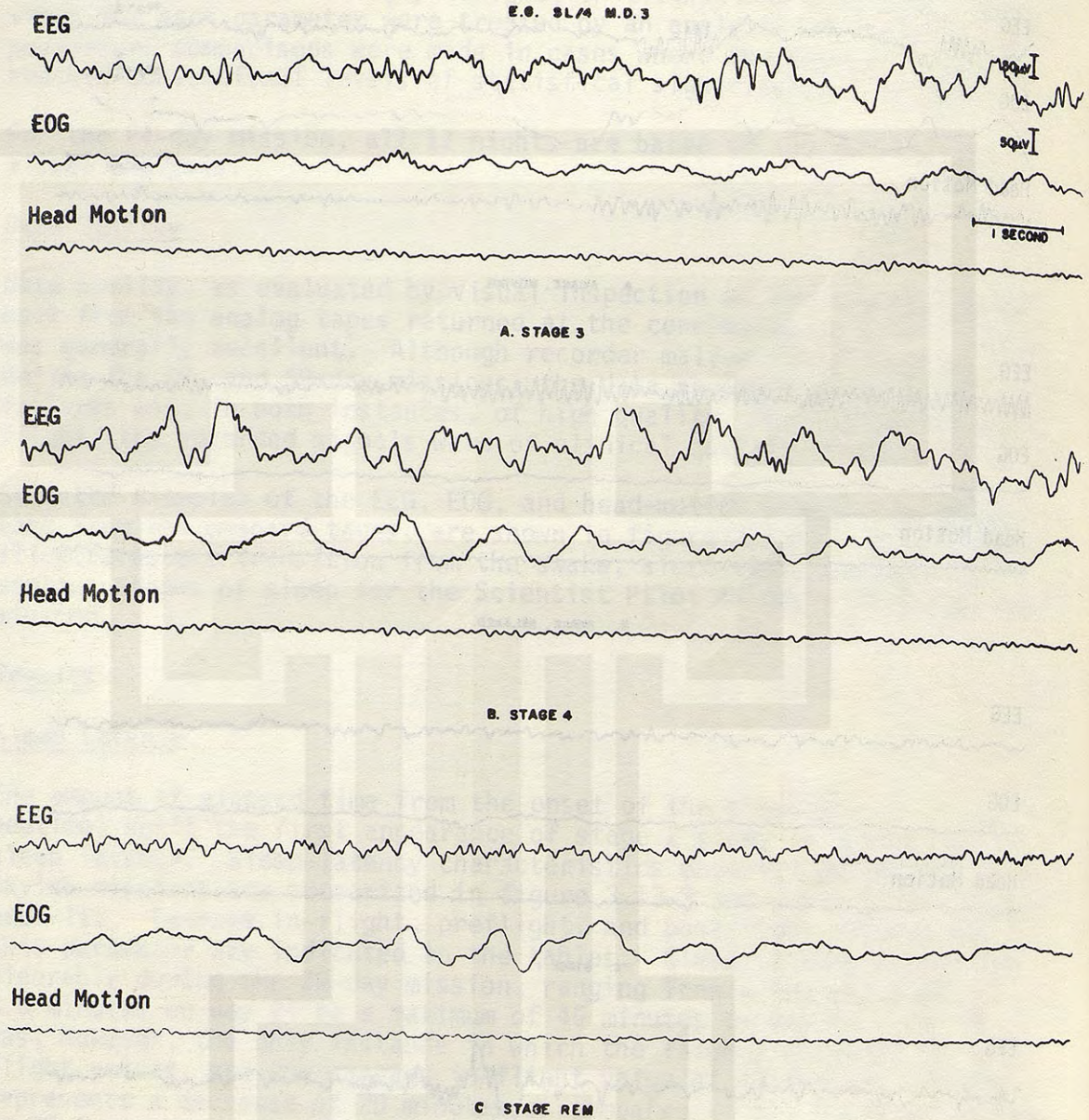


Figure 3.13-1. - Concluded.

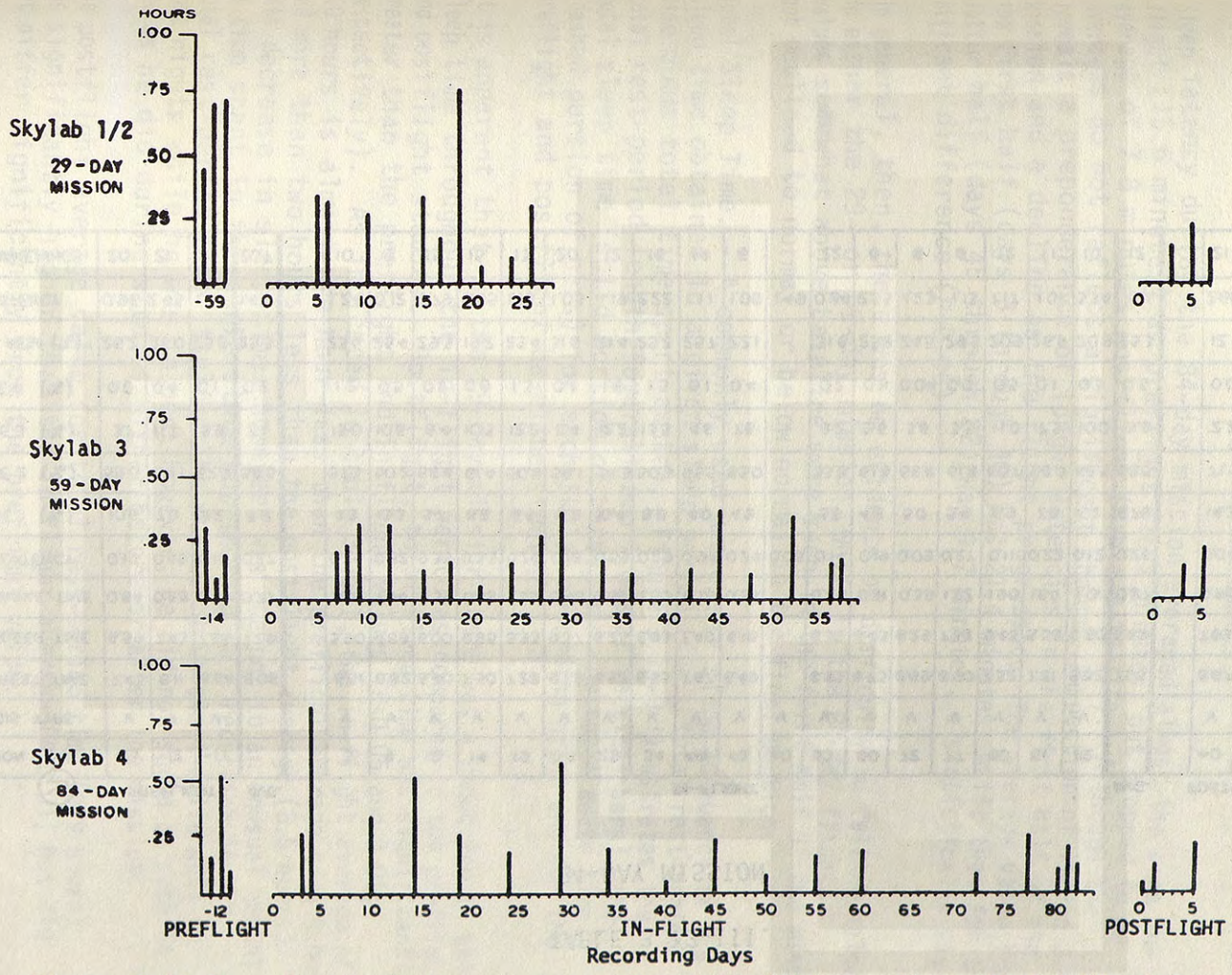


Figure 3.13-2. - Observed Sleep Latency Characteristics. Three Skylab Missions.

TABLE 3.13-III.

84-DAY MISSION

| | PREFLIGHT | | | AVG. | IN-FLIGHT | | | | | | | | | | | | | | | | | | AVG. | POSTFLIGHT | | | AVG. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MISSION DAY | -13 | -12 | -11 | | 3 | 4 | 10 | 14 | 19 | 24 | 29 | 34 | 40 | 45 | 50 | 55 | 60 | 72 | 77 | 80 | 81 | 82 | | +0 | +1 | +5 | |
| ANALYSIS TYPE | V | V | V | | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | | V | V | V | |
| TOTAL REST TIME | 7.43 | 8.11 | 8.64 | 8.06 | 6.51 | 6.82 | 6.40 | 7.30 | 7.28 | 9.78 | 6.92 | 8.33 | 7.67 | 6.49 | | 8.65 | 6.73 | 6.69 | 8.60 | 7.32 | 7.21 | 9.82 | 7.56 | 8.67 | 6.25 | 8.09 | 7.67 |
| TOTAL SLEEP TIME | 6.59 | 7.43 | 7.85 | 7.29 | 5.90 | 4.88 | 6.00 | 6.65 | 5.93 | 9.37 | 6.26 | 6.83 | 7.49 | 6.16 | | 8.39 | 6.43 | 6.29 | 7.38 | 5.43 | 5.58 | 8.80 | 6.69 | 7.69 | 4.50 | 7.40 | 6.53 |
| TOTAL AWAKE TIME | 0.84 | 0.68 | 0.78 | 0.77 | 0.61 | 1.94 | 0.39 | 0.65 | 1.35 | 0.40 | 0.66 | 1.50 | 0.18 | 0.33 | | 0.26 | 0.31 | 0.39 | 1.22 | 1.90 | 1.64 | 1.01 | 0.87 | 0.98 | 0.78 | 0.69 | 0.82 |
| SLEEP LATENCY | 0.16 | 0.55 | 0.10 | 0.27 | 0.26 | 0.82 | 0.33 | 0.53 | 0.26 | 0.18 | 0.59 | 0.20 | 0.04 | 0.24 | 0.08 | 0.14 | 0.19 | 0.09 | 0.27 | 0.11 | 0.22 | 0.12 | 0.26 | 0.04 | 0.13 | 0.23 | 0.13 |
| STAGE 1 (%) | 10.6 | 7.8 | 8.2 | 8.9 | 4.9 | 13.3 | 5.7 | 8.6 | 6.4 | 6.8 | 10.4 | 8.8 | 4.0 | 4.9 | | 5.3 | 4.6 | 5.0 | 5.4 | 6.9 | 7.8 | 6.2 | 6.76 | 14.2 | 7.0 | 7.0 | 9.4 |
| STAGE 2 (%) | 59.5 | 54.1 | 62.0 | 58.5 | 57.3 | 50.2 | 58.4 | 61.4 | 50.8 | 56.1 | 54.3 | 50.9 | 65.5 | 65.0 | | 53.8 | 61.6 | 66.8 | 61.8 | 60.7 | 58.0 | 62.5 | 58.5 | 71.5 | 71.1 | 55.8 | 66.1 |
| STAGE 3 (%) | 3.7 | 11.7 | 5.9 | 7.1 | 13.0 | 10.6 | 6.4 | 10.3 | 12.2 | 5.4 | 12.2 | 13.5 | 4.6 | 7.6 | | 9.2 | 9.5 | 3.6 | 3.3 | 11.0 | 7.3 | 10.0 | 8.8 | 2.2 | 3.3 | 2.5 | 2.7 |
| STAGE 4 (%) | 0.0 | 0.4 | 0.1 | 0.2 | 1.2 | 0.5 | 0.2 | 0.6 | 1.3 | 0.1 | 1.6 | 1.5 | 0.1 | 0.4 | | 0.2 | 0.5 | 0.04 | 0.0 | 0.5 | 0.1 | 0.3 | 0.5 | 0.0 | 0.1 | 0.04 | 0.05 |
| STAGE REM (%) | 26.2 | 26.0 | 23.8 | 25.3 | 23.6 | 25.4 | 29.3 | 19.2 | 29.4 | 31.6 | 21.4 | 25.2 | 25.7 | 22.1 | | 31.6 | 23.8 | 24.5 | 29.5 | 20.9 | 26.8 | 20.9 | 25.3 | 12.1 | 18.6 | 34.6 | 21.8 |
| REM LATENCY | 0.96 | 2.45 | 1.01 | 1.47 | 1.24 | 0.12 | 0.79 | 0.95 | 1.15 | 1.03 | 1.19 | 2.22 | 1.11 | 1.08 | 1.49 | 0.84 | 2.55 | 1.23 | 1.13 | 1.17 | 1.01 | 3.34 | 1.31 | 2.68 | 0.79 | 0.90 | 1.46 |
| NO. OF AWAKENINGS | 20 | 21 | 21 | 20.7 | 10 | 8 | 15 | 15 | 13 | 20 | 12 | 16 | 14 | 6 | | 22 | 6 | 6 | 8 | 12 | 11 | 10 | 12 | 21 | 11 | 24 | 18.7 |

days 10, 29, 45, and 52. The in-flight average value (12.6 minutes), however, was almost exactly the same as the preflight value. The postflight latencies, averaging 9.6 minutes, were only slightly less than either the preflight or in-flight measurements.

Sleep latency during the 84-day mission averaged almost the same in-flight (15.6 minutes) as preflight (16.2 minutes) but dropped to an average of 7.8 minutes postflight (table 3.13-III). Although the averages do not reflect a significant change, inspection of figure 3.13-2 reveals a preponderance of longer latencies in the first half of the mission and a decline as the flight progressed. The average value for the first half (days 3 through 40) was 21.4 minutes, while that for the latter half (days 45 through 82) was 9.7 minutes, a statistically significant difference ($P<0.05$).

In general, then, there was no evidence of difficulty in falling asleep in either the 29- or 59-day mission, while in the 84-day flight, values somewhat above baseline were seen in the first half of the mission but declined to normal or below normal in the final portion.

Total Sleep Time. - A commonly used measure of sleep adequancy is the total sleep time obtained in a given sleep period (*i.e.*, total rest-period time minus total time spent awake). Figure 3.13-3 illustrates the total rest-period length (overall amplitude of vertical bars), the total sleep time (solid portion of bars), and the total awake time (dashed portion of bars) for each Skylab recording night and for the preflight and postflight baseline studies.

It is apparent that in the 29-day mission there was a reduction in total sleep time throughout the in-flight period as compared to the preflight and postflight studies. Postflight, total sleep time was significantly greater than the preflight and in-flight values ($P<0.05$ and 0.01; respectively). As indicated in table 3.13-I, the in-flight average of 6.0 hours is almost one hour less than the preflight average of 6.9 hours and more than two hours less than the postflight average (8.5 hours). This decrease in sleep time, however, was due not to an unusual amount of time spent in the awake state but instead to a reduction in the total rest-period time itself. The subject thus slept quite well on most nights while he was in bed; however, he did not spend as much in bed as he did during studies either before or after the mission.

The postflight average value for total rest-period time (8.9 hours) was significantly higher than the in-flight average ($P<0.01$) but did not differ significantly from the preflight value.

No significant changes in the total sleep/total rest characteristics were obtained during the 59-day mission, as shown graphically in figure 3.13-3. The total rest time which averaged 7.3 hours

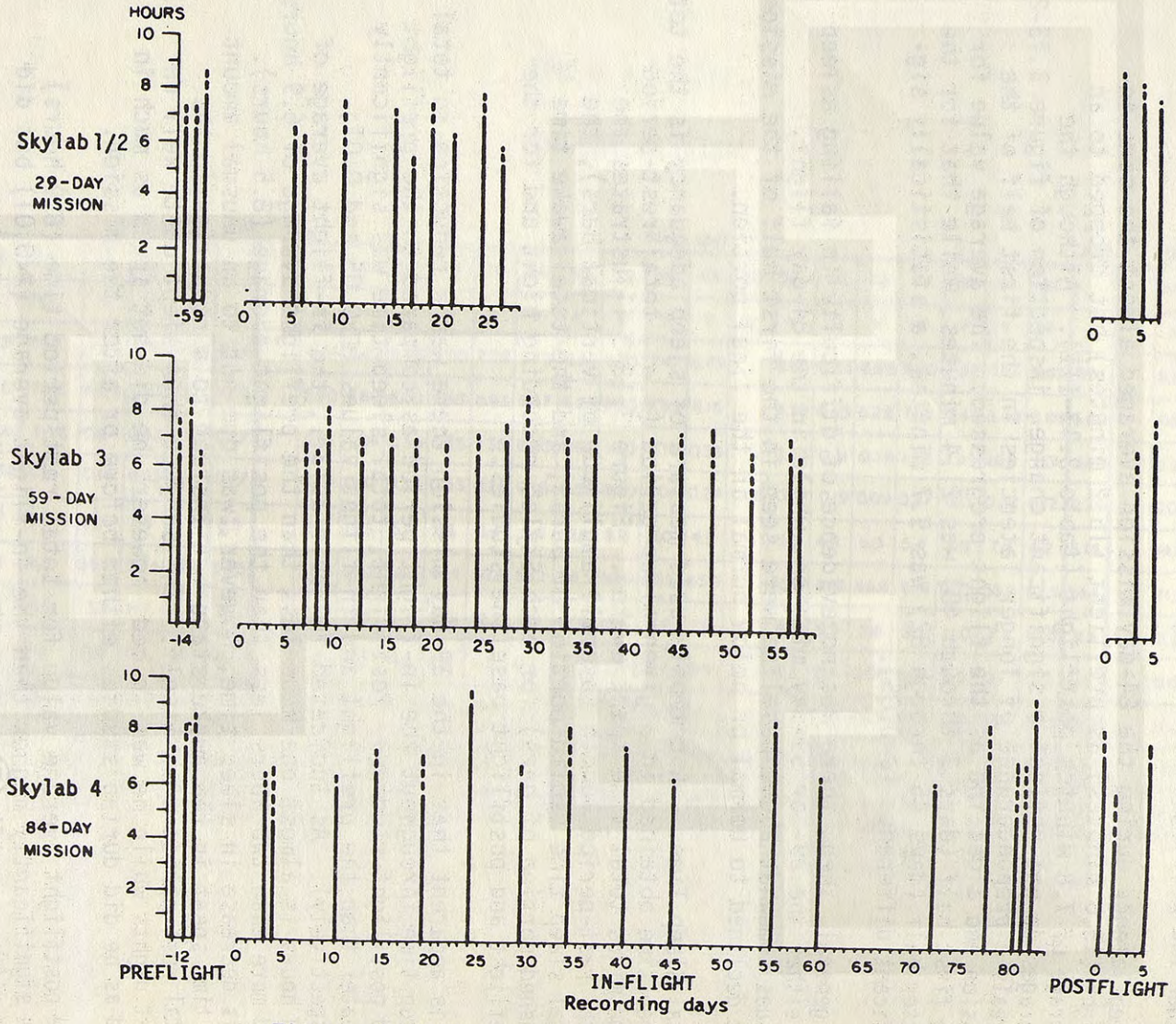


Figure 3.13-3. - Total Sleep Time, Three Skylab Missions

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in-flight (table 3.13-II), was only slightly lower than either the preflight average of 7.5 hours or the postflight value of 7.8 hours. In terms of total sleep time, although there was considerable fluctuation, only one day (52) was below the range established during the preflight series, and the subject obtained in excess of 5 hours' sleep on all other nights. The in-flight average value of 6.3 hours (table 3.13-II) is nearly the same as the preflight average (6.4 hours) and slightly lower than the postflight results (average, 6.6 hours)

A wide range of variation in the total rest and total sleep times was seen during the 84-day mission (figure 3.13-3). Total rest time ranged from a minimum of 6.4 hours on day 10 to a maximum of 9.8 hours on days 24 and 82. This parameter averaged 8.06 hours preflight, dropped by 30 minutes to 7.56 hours in-flight, and then rose to 7.67 hours postflight; but these variations were not statistically significant. Although most of the in-flight period was marked by considerable variation from one recording session to the next, there was a consistently lowered total rest time during the observations of the first 19 days. The five values of this period averaged 6.86 hours, or 1.2 hours below the preflight average.

Total sleep time tended to parallel total rest time, and thus long periods of time spent awake during the night were, in this mission as in the others, rare. Sleep time ranged from a low of 4.88 hours on day 4 to a high of 9.37 hours on day 24. The in-flight average value of 6.69 hours is about 36 minutes below the preflight average of 7.29 hours, but it is approximately 10 minutes higher than the postflight result of 6.53 hours. As in the case of total rest time, although the overall averages were not significantly altered, total sleep time was considerably lower during the first 19-day period. During this time, the average value was 5.87 hours, or 1.42 hours below the preflight average.

It is of interest that, while the initial 19-day period was characterized by a reduced time in bed and correspondingly reduced total rest time, it was also marked by a higher value for total awake time (0.99 hours average) compared to either the preflight average (0.77 hours) or the overall in-flight average (0.87 hours).

Sleep Stage Characteristics. - Sleep stage characteristics for the three missions (expressed as percentages of the total sleep time for each recording night) are illustrated in figures 3.13-4, 3.13-5 and 3.13-6. Average percent figures for the various stages in the preflight, in-flight, and postflight periods are listed in tables 3.13-I, -II, and -III. Comparisons of individual stage characteristics for the three missions are illustrated in figures 3.13-7 through 3.13-11.

Figure 3.13-3. - Total Sleep Time, Three Skylab Missions

Recording days

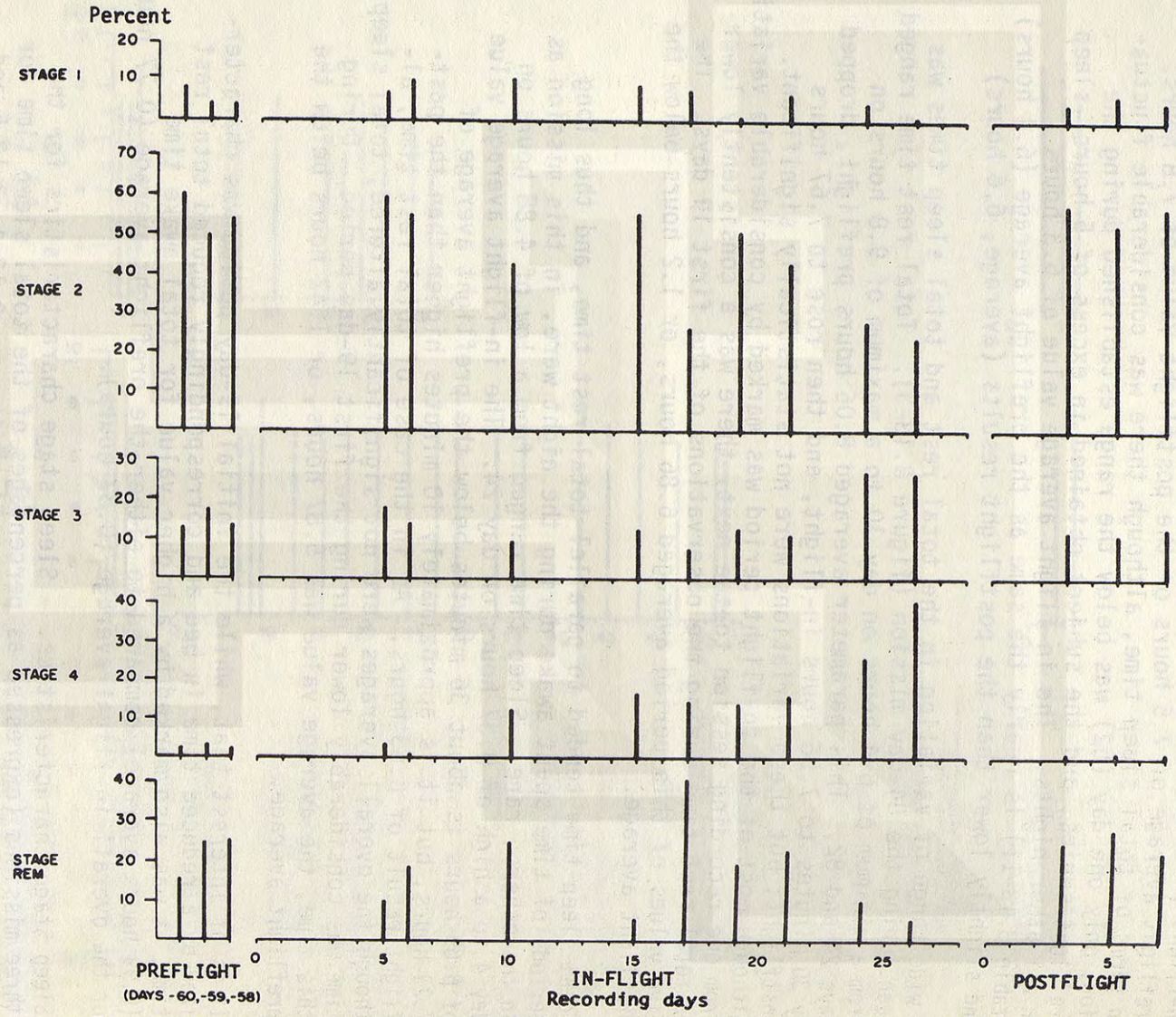
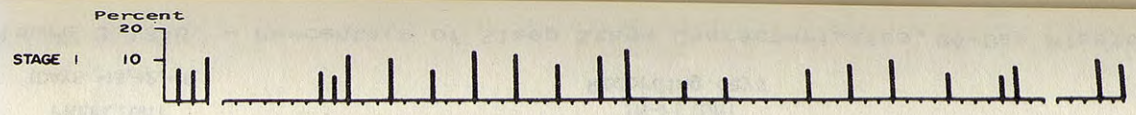



Figure 3.13-4. - Percentage of Sleep Stage Characteristics, 29-Day Mission.



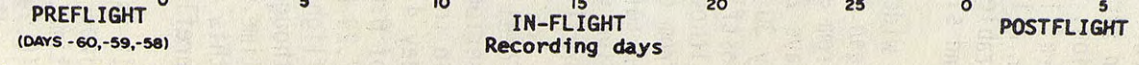



Figure 3.13-4. - Percentage of Sleep Stage Characteristics, 29-Day Mission.

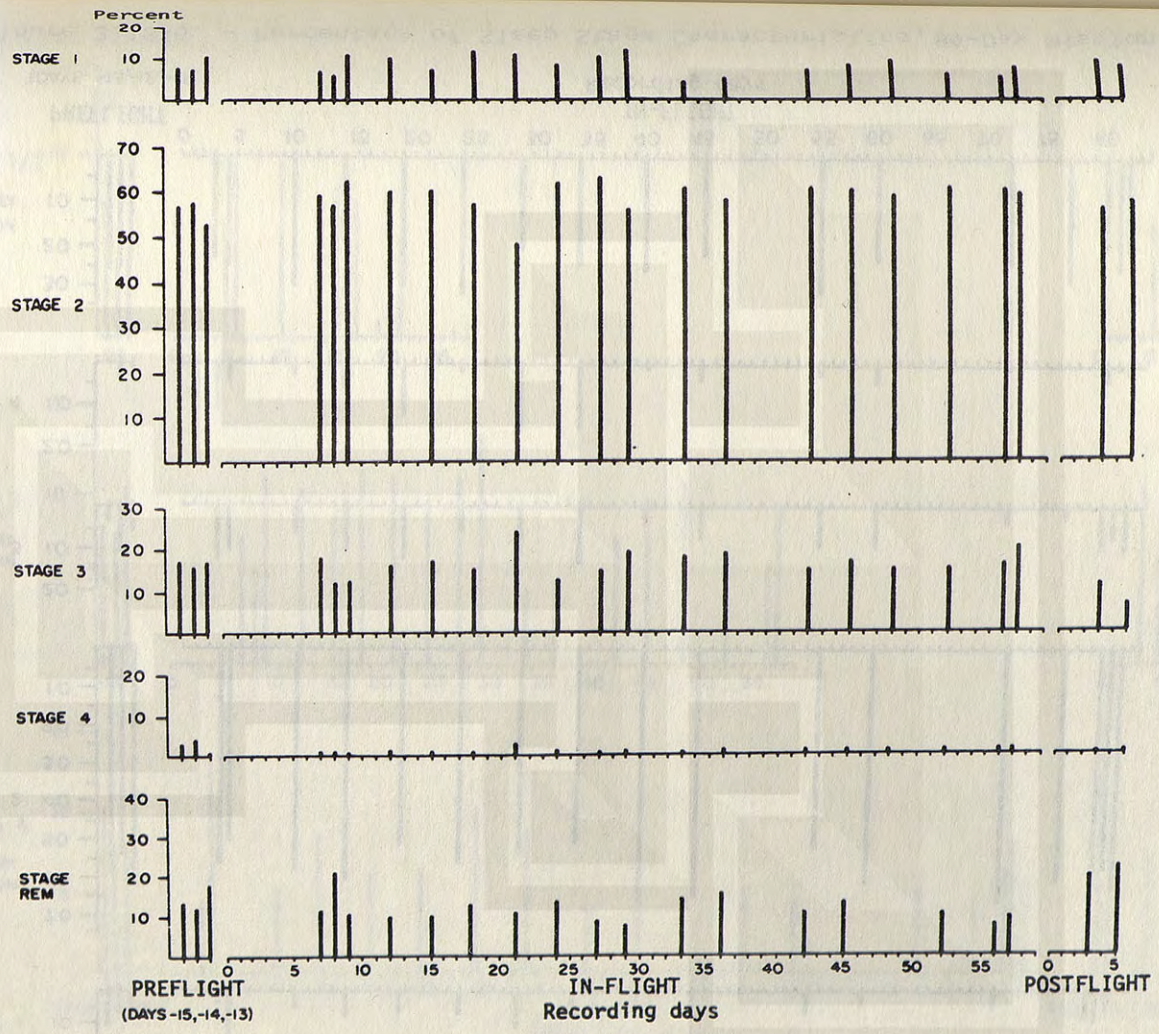



Figure 3.13-5. - Percentage of Sleep Stage Characteristics, 59-Day Mission.

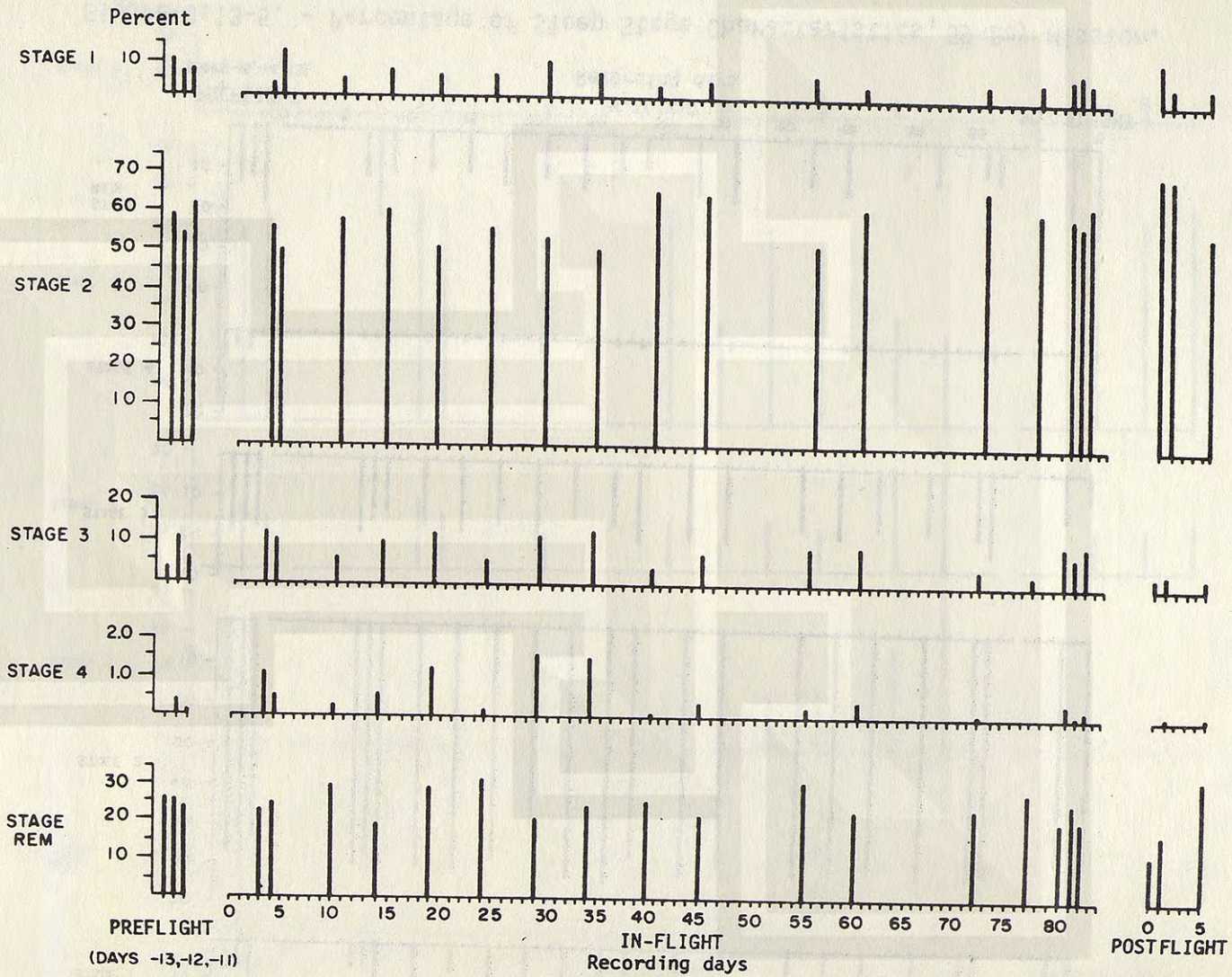



Figure 3.13-6. - Percentage of Sleep Stage Characteristics, 84-Day Mission.

(DAYS -13,-12,-11) Recording days

Figure 3.13-6. - Percentage of Sleep Stage Characteristics, 84-Day Mission.

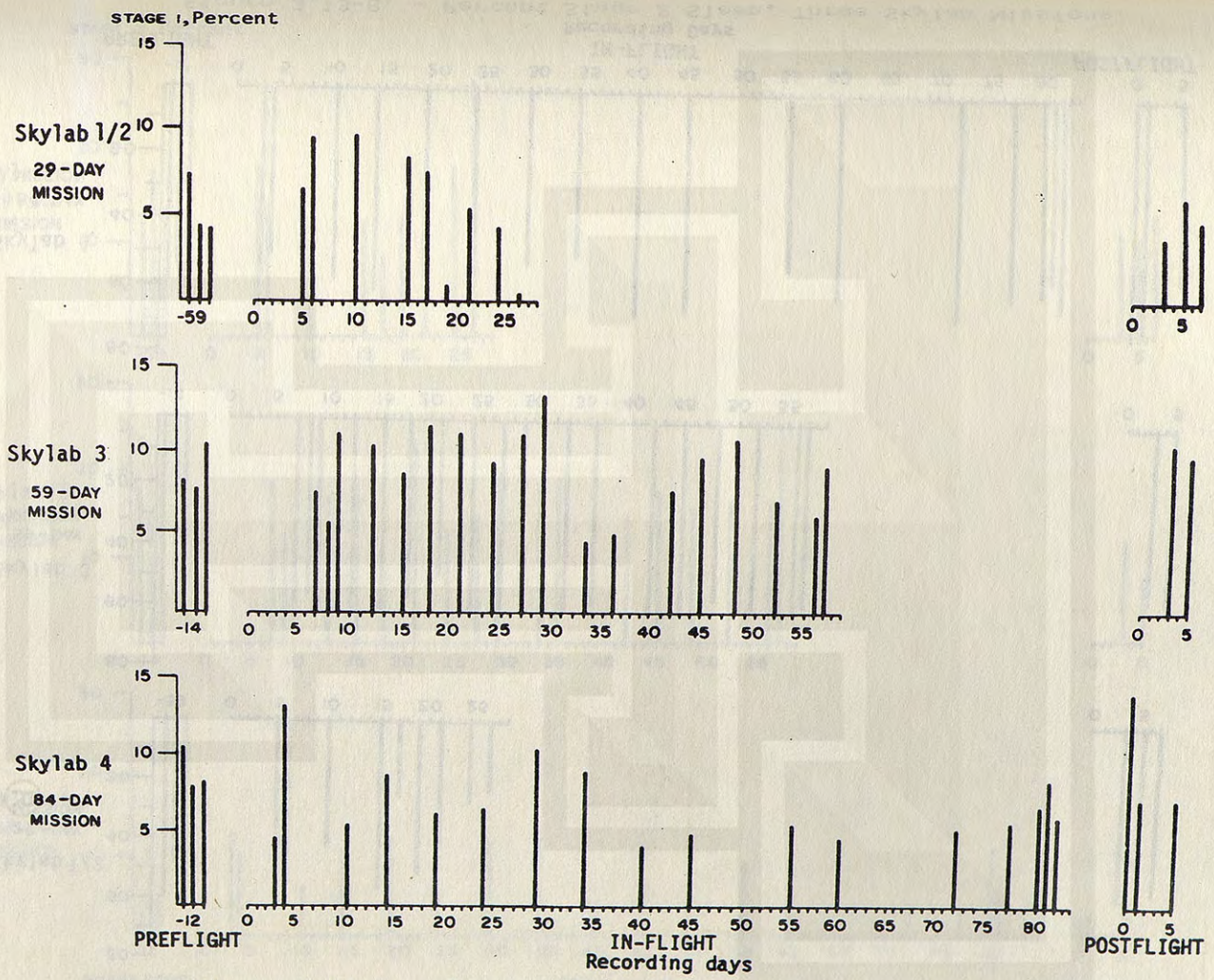



Figure 3.13-7. - Percent Stage 1 Sleep, Three Skylab Missions.

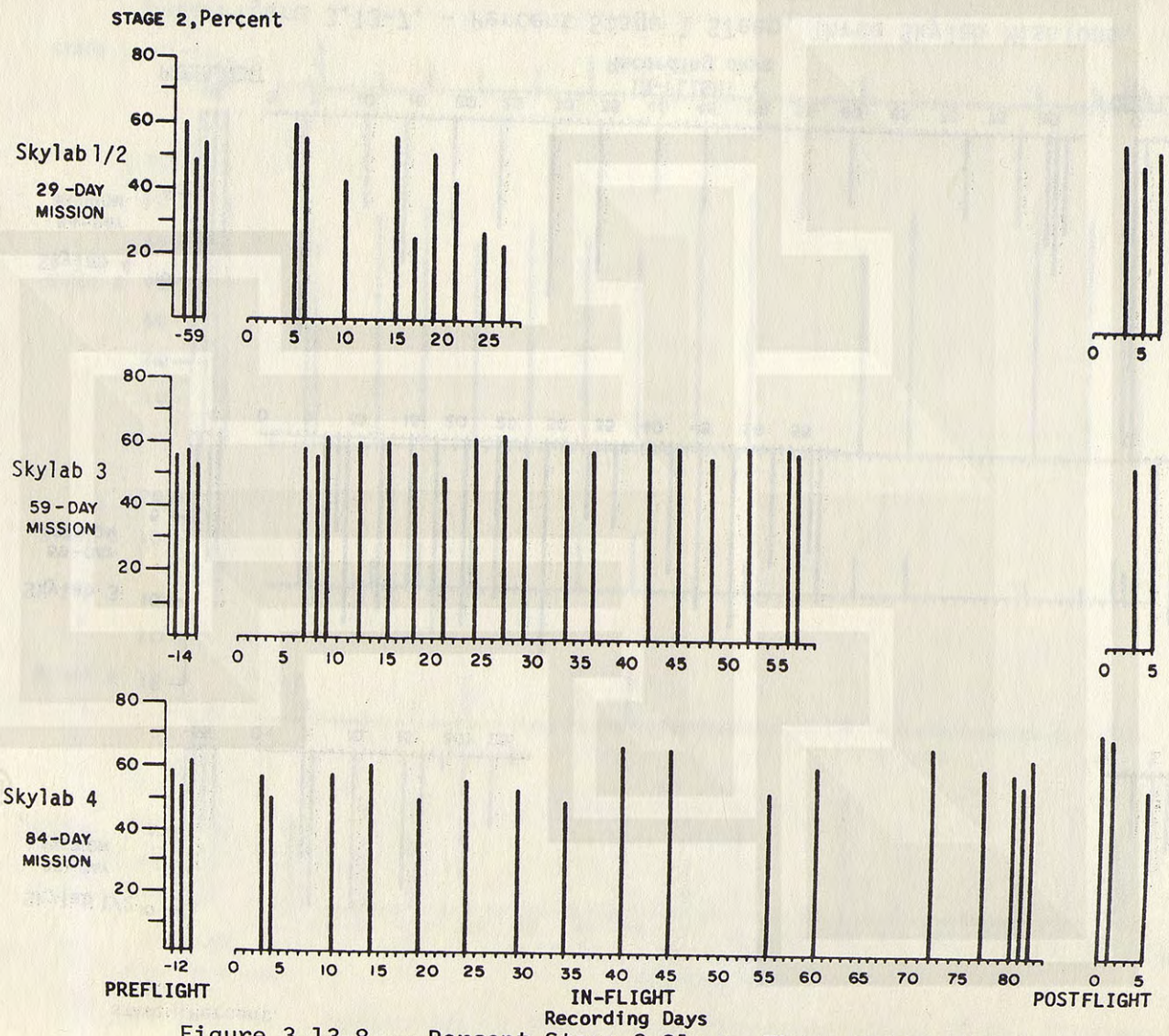
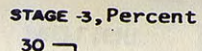



Figure 3.13-8. - Percent Stage 2 Sleep, Three Skylab Missions.





Recording Days

Figure 3.13-8. - Percent Stage 2 Sleep, Three Skylab Missions.

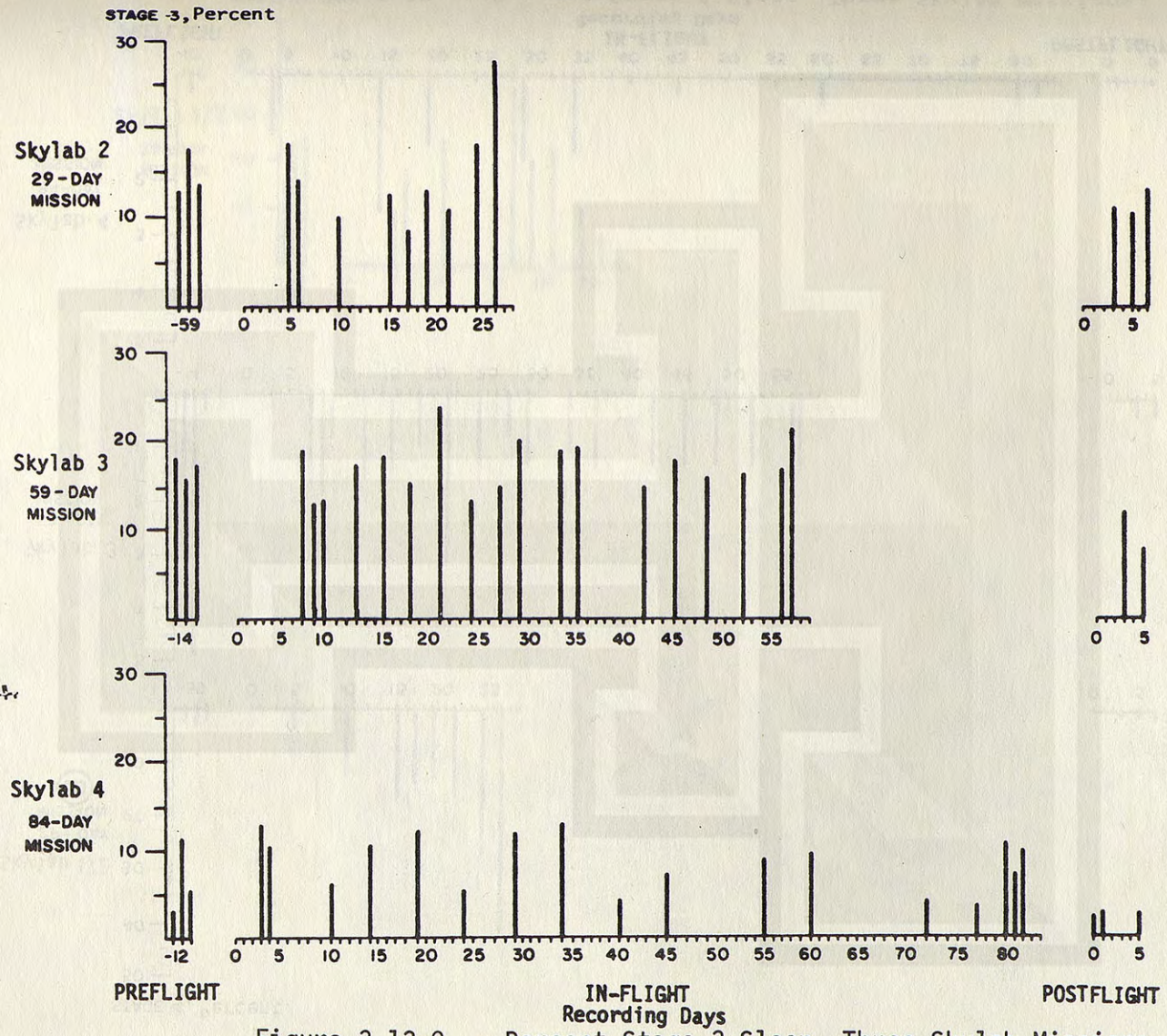



Figure 3.13-9. - Percent Stage 3 Sleep, Three Skylab Missions.

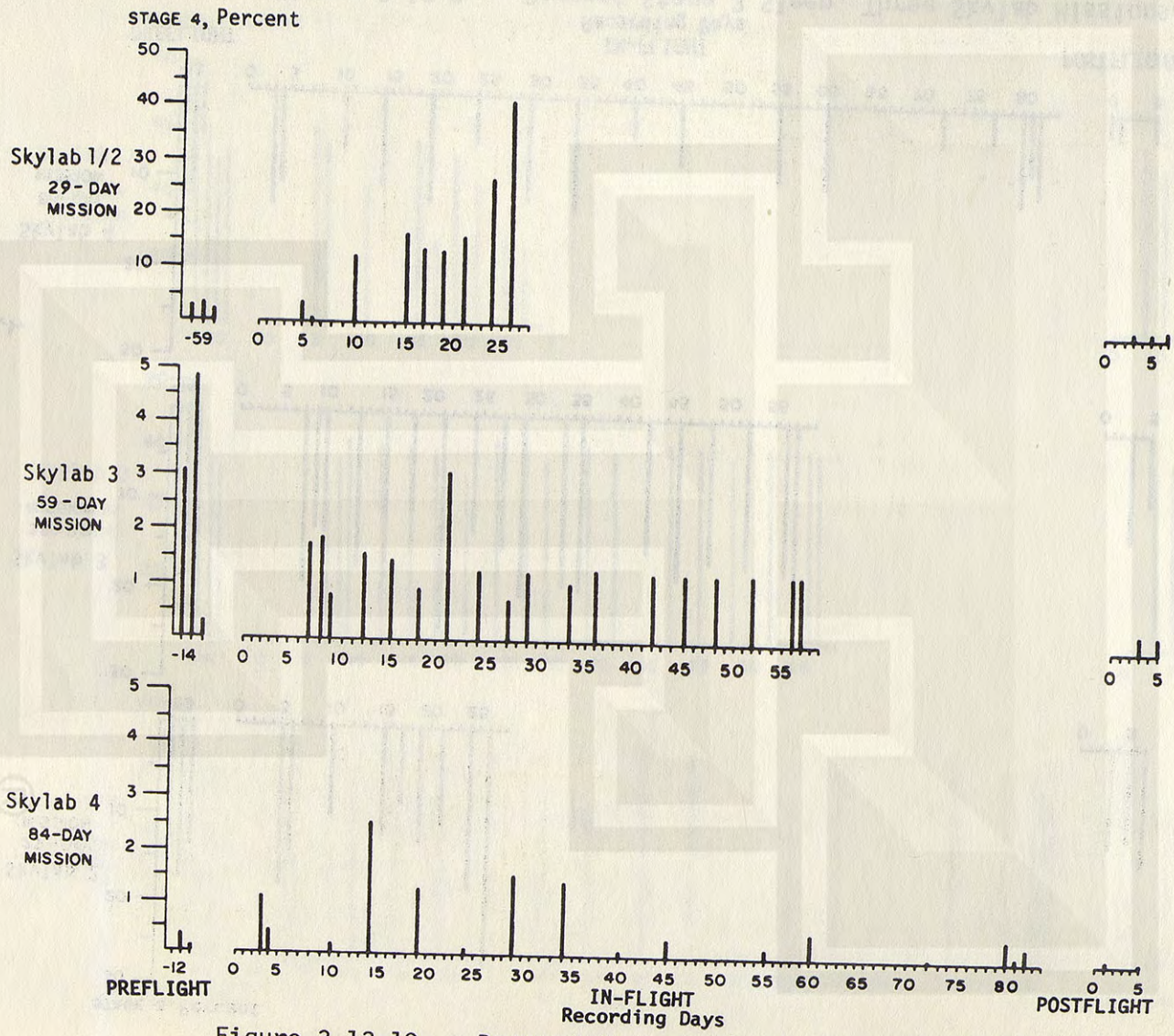
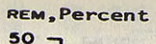



Figure 3.13-10. - Percent Stage 4 Sleep, Three Skylab Missions.





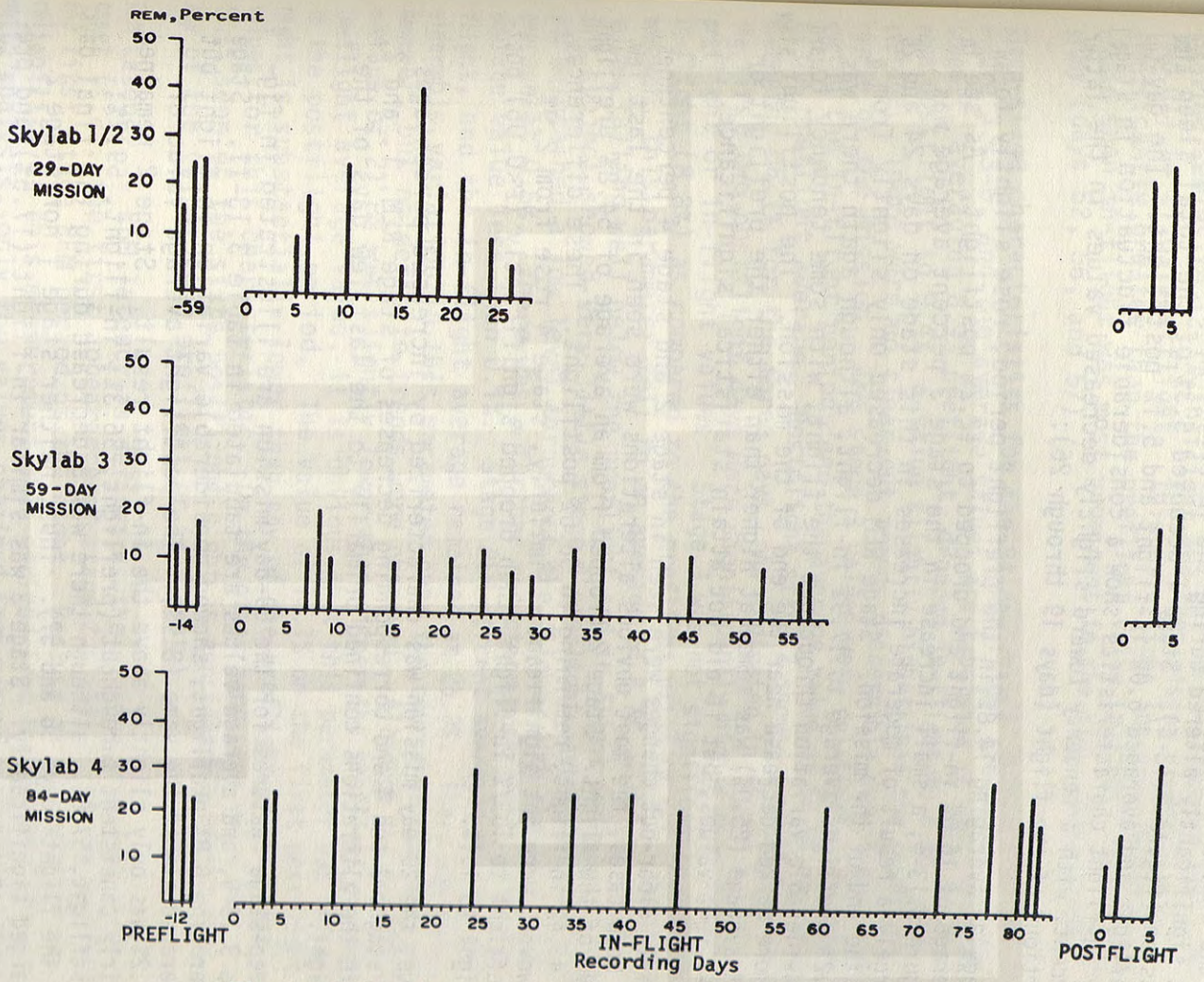



Figure 3.13-11. - Percent Stage REM, Three Skylab Missions.

If the average values are considered, stages 1, 2, 3, and REM were not significantly altered during the in-flight period of the 29 day mission (figure 3.13-4). Stage 1 occupied 5.3% of the total sleep time preflight and averaged 6.0% in-flight and 5.1% postflight. The day-to-day in-flight characteristics show a considerable fluctuation in stage 1 percent, with a tendency toward slightly decreased values in the latter portions of the flight (days 19 through 26).

Stage 3, averaging 14.8% in the preflight period, rose slightly to an average of 16.0% in-flight and dropped to 12.2% postflight. As see in figure 3.13-4, a small increase in the stage 3 percent average was largely a result of moderate increases in this stage on days 24 and 26 at the end of the mission. Stage REM decreased only slightly from a 22.2% preflight average to 17.9% in-flight, although again there was considerable variation throughout the flight, with some tendency toward a more marked decrease near the end of the mission. The postflight stage REM average (25.0%) was somewhat higher than either the preflight or in-flight values, but it did not attain statistical significance.

Fairly clear-cut changes were seen in stage 2 and stage 4 percentages. In both cases, the most obvious alterations were seen in the last few days of the flight. Stage 2 dropped from an average of 54.8% preflight to 43.4% in-flight, returning to 56.6% postflight. These differences, however, were not significant. Similarly, stage 4 rose from 2.9% preflight to 16.7% in-flight, then dropped significantly ($P<0.05$) post-flight to 1.1%.

Thus, the 29-day mission was characterized by increased percentages of stages 3 and 4 and corresponding decreases of stage REM, 1, and 2, with the alterations confined primarily to the last few days of the flight.

Sleep-stage features for the 59-day mission are illustrated in figure 3.13-5, and average values are tabulated in table 3.13-II. Stage 1, averaging 8.8% preflight, showed considerable variation in-flight but averaged almost the same (8.9%). The postflight average value of 10.2% was only slightly above the in-flight result. Stage 2 remained fairly consistent throughout (preflight, 56.3%; in-flight, 59.7%; postflight, 57.8%), although there was a decrease during the final days of the flight (days 56 and 57). Thus, neither stage 1 nor stage 2 changed significantly. Stage 3 was similar in-flight (17.5%) and preflight (17.4%) and also exhibited a change near the termination of the flight, tending to increase slightly. The postflight average of 10.1%, however, was significantly lower ($P<0.01$) than either the preflight or in-flight values. This subject showed very little stage 4 sleep in his preflight study (2.8%), and this parameter decreased significantly ($P<0.05$) in-flight (1.4%) and postflight (0.4%) ($P<0.05$). Stage REM

showed the greatest alteration, dropping from 14.7% during the preflight baseline series to 12.1% in-flight and then rising significantly ($P<0.01$) to 21.6% postflight. This postflight increase in REM was also significantly greater than the preflight value ($P<0.05$). The REM decrease seen in-flight was most prominent in the final phase of the study (days 52, 56, and 57).

Sleep-stage characteristics for the 84-day flight are summarized in figure 3.13-6, and the average values are tabulated in table 3.13-III. Stage 1, averaging 8.9% preflight, dropped in-flight to 6.8%, then rose postflight to 9.4%, a value slightly higher than the preflight average. There were no clear-cut trends discernible over the in-flight course of the mission. The stage 2 values were relatively consistent during the in-flight period, and the average value of 58.5% was identical to the preflight average. Postflight stage 2 showed a small increase, averaging 66.1% for the three days. As indicated in figure 3.13-6, the first two postflight days were significantly higher than any of the preflight or in-flight values. Stage 3 was not significantly different in-flight (8.8%) as compared to the preflight value (7.1%). Postflight, however, this parameter fell to an average of 2.7%, with all three values falling well below the preflight and in-flight averages ($P<0.01$). This subject showed very little stage 4 preflight, averaging only 0.2%, and maintained a low level throughout the flight, with the in-flight average at 0.5%. There was a further reduction postflight, with the average value less than 0.1%. Stage REM percent averaged 25.3% preflight, and the in-flight average remained at 25.3%. There was considerable variation in this parameter over the course of the mission, however, but no definite trends were observed. Although the postflight average of 21.8% was slightly lower than either the preflight or the in-flight average value, it is obvious that this parameter was not stable in the postflight period. The value of 12.1% on the first postflight night is substantially lower than any of the preflight or in-flight values for this characteristic. On the other hand, the value of 34.6% seen on the sixth postflight night is considerably higher than any of the values seen preflight or in-flight.

REM Latency. - REM latency is defined as the elapsed time from sleep onset (*i.e.*, the first appearance of stage 2 sleep) until the onset of the first stage REM period of the night. Because of the relative unreliability of this measurement when derived from the results of automatic analysis, only the values obtained from visual analysis have been reported below. Compared to preflight values, this measure was shortened during the postflight period of the 29- and 59-day missions. During the 29-day mission (figure 3.13-12), the REM latency averaged 1.5 hours preflight and 1.1 hours postflight, or a decrease of 24 minutes. Although substantial, this decrease was not statistically significant. The phenomenon was more apparent during the 59-day mission,

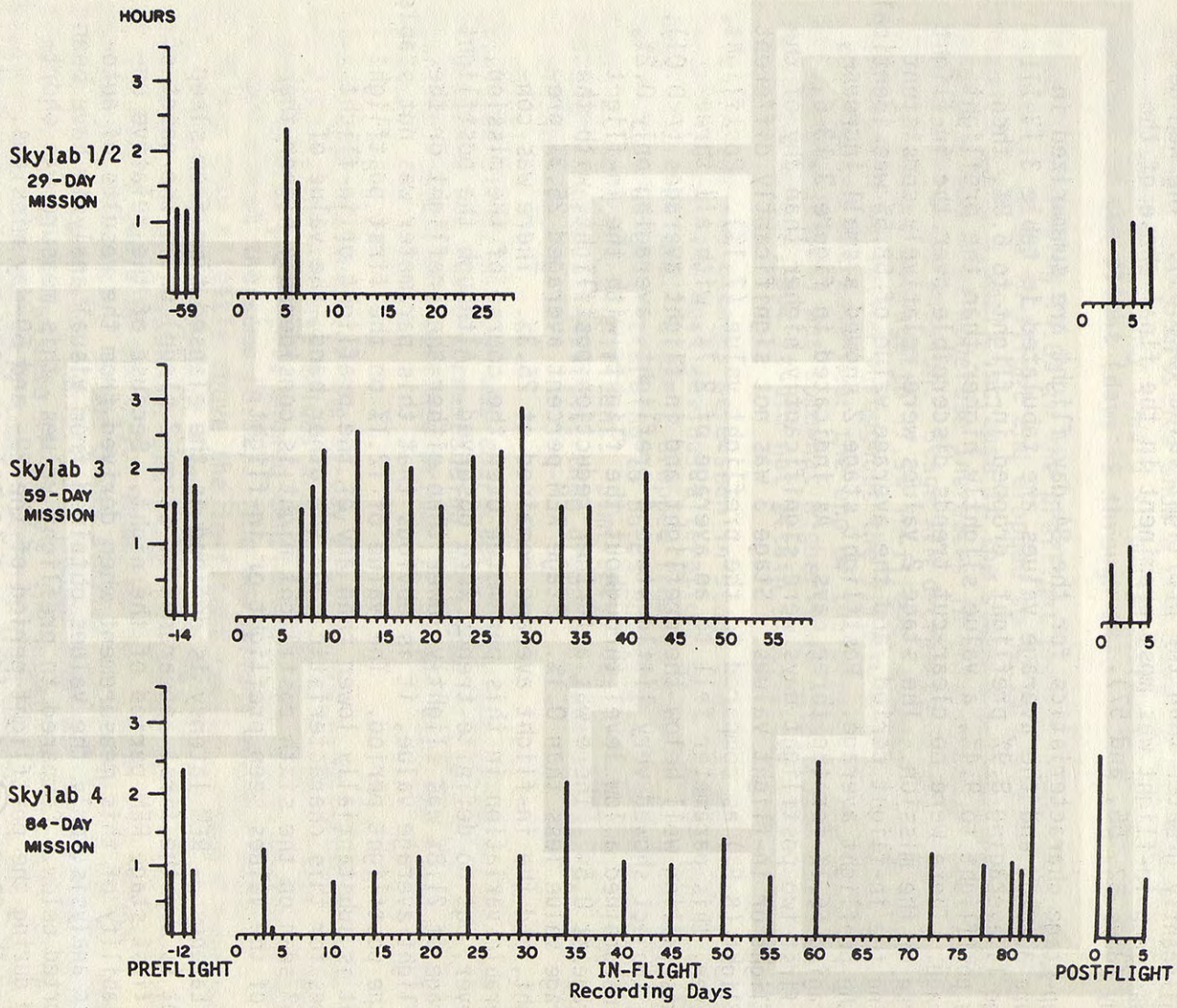



Figure 3.13-12. - REM Latency,Three Skylab Missions.

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as illustrated in figure 3.13-12. In the preflight baseline period, the values ranged from 1.6 to 2.2 hours, with an average latency of 1.9 hours. The in-flight values showed considerable fluctuation, but the average of 2.1 hours was not significantly different compared to the preflight results. In the postflight period, however, the latency dropped to 0.9 hours, which represented a decrease of 1 hour below the preflight findings. This postflight REM latency was significantly ($P<0.01$) less than both preflight and in-flight values.

REM latencies during the 84-day mission (figure 3.13-12) showed little change in the in-flight period compared to either preflight or postflight studies. The in-flight average value of 1.31 hours is not significantly different from the 1.47 hours figure seen preflight, while the value of 1.46 hours seen postflight is almost identical to the preflight result. It is worthy of note that the first postflight night exhibited a relatively long REM latency, while the second and third postflight nights were marked by much shorter periods.

Number of Awakenings. - The number of awakenings per night was calculated for the data based upon human visual analysis only, and this information is presented comparatively in figure 3.13-13.

The 29-day flight was characterized in the preflight period by an average of 19.7 awakenings per night, with a range of 16 to 24. Postflight, the average was 22, with a range of 20 to 26. Although only two in-flight nights are available for comparison, in both instances the number of awakenings was below the preflight and postflight levels.

The number of awakenings during the preflight baseline series for the 59-day mission ranged from 34 to 51, with an average of 40.7. In-flight, a greater range was seen, extending from a low of eight on day 33 to a high of 70 on day 9, with an average of 39.3. Postflight, the average number of awakenings dropped to 28.5, with a range of 26 to 31. The number of arousals seen during the in-flight portion of this mission peaked at day 9 and showed a tendency to decline toward baseline or sub-baseline levels as the flight progressed.

In the 84-day mission, the number of awakenings declined from a preflight average of 20.7 (20 to 21) to an in-flight average value of 12, with a range of 6 to 22 ($P<0.01$). Postflight, the level rose to an average of 18.7, with a range of 11 to 24 ($P<0.05$). Although the in-flight period was characterized by a good deal of variation in this measure, there was no consistent trend noticeable.

Figure 3.13-12. - REM Latency, Three Skylab Missions.

Recording Days

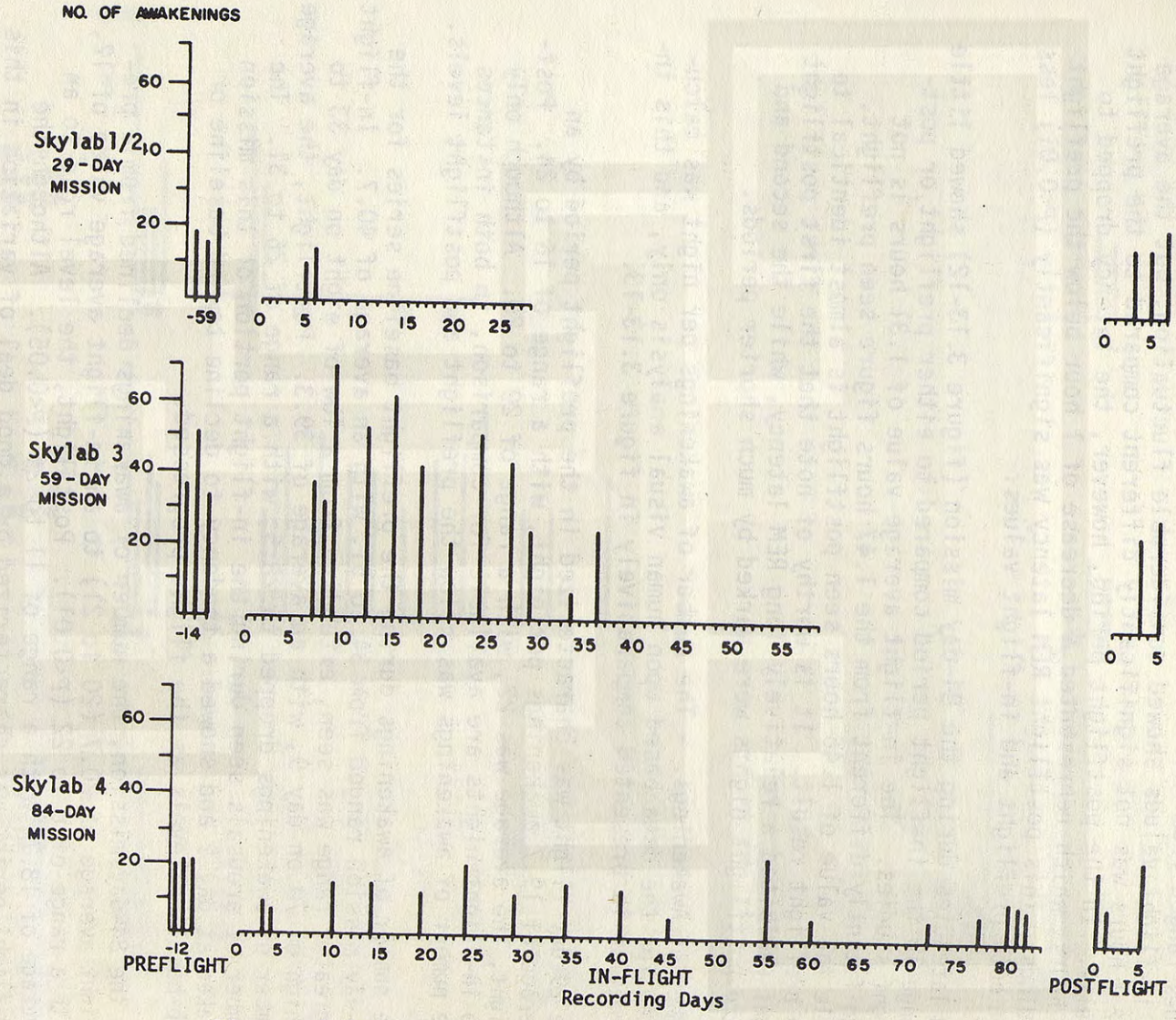


Figure 3.13-13. - Number of Awakenings, Three Skylab Missions.

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Figure 3.13-13. - Number of Awakenings, Three Skylab Missions.

Recording Days

## Discussion

Sleep Latency. - The three Skylab flights differed with respect to sleep latency characteristics. No significant changes in the parameter were noted during the 59-day mission. In the 29-day mission, the in-flight and postflight latencies were significantly lower than the pre-flight values. The 84-day flight was characterized by relatively long sleep latencies in the early portion, with the return to values typical of the preflight and postflight periods in the latter half of the mission.

The alterations seen during the 29-day mission are apparently explainable, at least in part, by a difference in the subject's routine rather than by a direct influence of the environment. This individual typically spent a few minutes reading in bed prior to falling asleep during preflight studies in his own home. However, he did not continue this practice either during the flight or in the postflight period.

In only the initial portion of the 84-day mission was a degradation in sleep latency seen. As illustrated in figure 3.13-2, even in this case the magnitude of the alterations seen was not great, and on only two nights were the values outside the range seen during the preflight studies. In addition, it is significant that these alterations occurred in the early portion of the study and thus cannot be attributed to the longer duration of this mission. Consequently, it appears reasonable to conclude that spaceflight and the associated weightless condition do not significantly interfere with the process of falling asleep, although in some individuals there may be an adaptive period during which some difficulty is experienced.

Sleep Time. - The greatest overall change in total sleep time occurred during the 29-day mission, when a decrease of approximately one hour was seen in-flight compared to preflight. As indicated previously, this was a voluntary reduction in sleep time by the subject himself and thus cannot be considered as insomnia. The subject did not complain of sleep loss and apparently was sleeping as much as he actually required. No significant changes in sleep times were noted during the 59- or 84-day missions. If the initial portion of the 84-day flight is considered separately, however, it is evident that the subject experienced some difficulty in sleeping in this time. Sleep was also more of a problem subjectively to this individual, and he indicated on several occasions that his sleep was not adequate. Sleeping medication was occasionally used by the subject, although not on the nights which were monitored.

Of the three subjects, then, only the one studied during the 84-day flight experienced real difficulty in terms of total sleep time. In this case, the problem diminished with time, although sleeping medication was used sporadically throughout the flight. In terms of any

possible adverse effect upon performance capability, it seems that only during the initial period of the 84-day mission would this have been likely to be caused by sleep loss. This cannot be precisely assessed because of the long sample intervals; however, even generalizing the worst case (4.9 hours on day 4), a severe influence upon performance would not be expected.

Stage Characteristics. - Several changes in sleep-stage characteristics were common to all three flights. Stage 3 (figure 3.13-7), which was significantly elevated during the in-flight portion of the 29-day mission, also rose in-flight in the 59- and 84-day missions. Postflight, the stage 3 (figure 3.13-9) and stage 4 (figure 3.13-10) values were below the preflight average in all three flights. A consistent elevation of stage REM (figure 3.13-1) was seen in the late postflight period of all flights and was accompanied by a shortening of REM latency.

Number of Awakenings. - Although this measure was highly variable, in general the in-flight period of all missions was characterized by no overall increase in number of arousals, and in the case of the 84-day mission, there were significantly fewer awakenings.

Significance of Results. - The results obtained during the three Skylab missions suggest that prolonged spaceflight, with its accompanying weightless state, is not directly associated with major adverse changes in sleep characteristics. The alterations in sleep patterns that were observed were not of sufficient magnitude to result in significant degradation of performance capability. These conclusions were somewhat unsuspected, since previous studies of confinement, social isolation, and unusual environments involving polar explorers (1-4), underwater habitats (5), long-duration flight operations (6), and astronauts (7) have all reported sleep loss and/or disturbances of sleep.

Early in the manned spaceflight program, speculation arose that the zero-g state might, itself, in some way disrupt the normal sleep/wakefulness mechanisms. It had been suspected that the altered sensory input to the central nervous system associated with weightlessness might interfere with sleep onset and result in prolongation of sleep latency and lead to long periods of wakefulness following arousals from sleep. The Skylab results, however, show that in none of the missions was sleep latency a significant problem over the course of the flight, and in only one case, that of the 84-day flight, was it even a temporary difficulty. Furthermore, there was no evidence of consistently increased amounts of time spent awake during the night; in fact, the number of awakenings tended to decrease in-flight. The results indicate that during spaceflights of long duration, it is possible to obtain adequate amounts of sleep during regularly scheduled eight-hour rest periods.

The most consistent and most significant changes were actually observed in the postflight period of all flights and pertained to sleep-stage characteristics. Thus, stages 3 and 4 tended to be decreased in the postflight period as compared to both preflight and in-flight results, while stage REM was elevated in the late postflight period (after day R+3) and was accompanied by a shortening of REM latency.

The postflight changes in stage REM are worthy of further consideration. Since such findings are typical of the rebound effect seen following periods of relative deprivation of stage REM (8), the question of a significant deprivation in-flight arises. This question is, however, somewhat difficult to accurately assess. When the overall averages are considered, there appears to be no significant decrease in REM in-flight. However, when the individual data points are considered (figure 3.13-11), there is a suggestion that perhaps REM percent did decline in the terminal portion of the flights. This tendency is most prominent in the case of the 29-day mission, where a relatively steady decline in stage REM percent is evident after day 17. Such a trend is less obvious in the case of the 59-day mission, although the last two days are below the preflight average value. In the case of the 84-day flight, the latter portion of the mission shows only a slight indication of a decrease in stage REM. Even though the results appear to argue against a prior period of REM deprivation in-flight as a contributing factor, it must be emphasized that recordings were not made during the last two nights of each mission, and consequently this situation cannot be full assessed.

A shortening of REM latency was observed in the late postflight period of all missions and accompanied the increase in REM percent noted during that time. This phenomenon has also been reported as a manifestation of a prior period of REM deprivation. Arguing against REM deprivation as a causative agent of this change is that no lessening of the effect was evident even on the sixth night following recovery of the 59- and 84-day missions nor after the eighth night following the 29-day mission. Similarly, it seems unlikely that the changes in stage REM can be attributed to alterations in the astronauts' sleep schedules (*i.e.*, the advances in bedtime near the termination of each mission). It has been reported that delaying sleep periods by four hours results in a shortening of REM latency, but such findings have not been reported with comparable advances in sleep onset. Furthermore, while delaying sleep periods had been found to increase REM percent, advancing sleep periods resulted in a decrease in REM percent (9).

Postflight data from the 84-day mission further suggests that the increase in REM percent seen late postflight is actually a delayed phenomenon and follows a period of relative REM suppression in the immediate recovery period. In fact, the REM percent value of 12.1%

on the first night following recovery is well below any REM percent value seen either preflight or in-flight. The value seen on day R+5 in the late postflight period is correspondingly well above any value seen either preflight or in-flight. Delayed REM rebound is not a typical finding in experimental situations involving REM deprivation. It had been reported following periods of total sleep deprivation, in which case there is an elevation of stage 4 in the first recovery night and a later elevation of stage REM (10). However, in none of the three Skylab flights was a postflight elevation of stages 3 and 4 noted, and in fact these parameters tended to decline. Consequently, in these cases a delayed REM rebound appears to argue against prior sleep deprivation as the cause of the postflight REM changes.

In view of these findings, it seems plausible that the decreased REM latency and increased REM percent represent a true influence of the reinstated one-g condition and that this signifies a basic alteration in the sleep/wakefulness mechanism of the central nervous system.

It has been postulated that sleep, and in particular the REM stage, may be of importance in the organization and maintenance of memory (11-14). According to this view, REM may be involved in consolidation or reprograming of short-term memory into a more permanent or long-term form. If this hypothesis is correct, then it might be predicted that tasks associated with acquisition of new motor skills and coordinated motor activity might be associated with an increased need for stage REM sleep.

In support of this hypothesis, it has been found that during the period of adaptation to an inverted visual field, REM time was increased (7, 14). After declining to relatively normal levels after adaptation, reverting the visual field to normal was again accompanied by an increase in REM-sleep amount. The situation in spaceflight may be analogous, since the withdrawal of gravitational cues and the decrease in proprioceptive input and altered vestibular input place a considerable burden upon the visual system as the sole means of maintaining spatial orientation. Following the mission, the return to Earth similarly requires a period of adaptation to the one-g condition. It might be speculated, then, that the increase in REM time seen postflight was a manifestation of this hypothesized mechanism. There is no evidence in the Skylab data that adaptation to zero-g is accompanied by an increase in REM time; in fact, the in-flight values were either the same or lower than preflight values. The hypothesis cannot, however, be adequately evaluated, since no sleep data was obtained prior to day 3 in any of the flights; thus, pertinent changes could conceivably have been missed. If such in-flight changes were present, however, they evidently were of shorter duration than those seen postflight, where changes were seen until day R+8.

## Conclusions

The objective results of these sleep monitoring experiments indicate that one is able to obtain at least adequate sleep over prolonged periods of time in space and during regularly scheduled eight-hour sleep periods. The alterations in sleep patterns which were observed during these missions were not of the type, nor of sufficient magnitude (with the possible exception of the initial portion of the 84-day mission), to result in significant degradation of performance capability. The most notable changes seen actually occurred in the postflight period, and this suggests that perhaps the readaptation to one-g is somewhat more disruptive to sleep than the adaptation to zero-g. Yet, even in this case, the alterations seen were those of sleep quality and not quantity. It is also worthy of emphasis, particularly with respect to the results seen during prior spaceflights, that none of the Skylab crewmen complained excessively of sleeping difficulties. In fact, most reported no problems with respect to sleep, and some expressed the opinion that sleep was perhaps better in space. Viewed overall, these results are somewhat surprising because of the frequent complaints of insomnia during pre-Skylab missions. Apparently, the problems encountered during earlier spaceflights were not simply due to the imposed zero-g environment. The Skylab orbiting laboratory differed considerably from spacecraft of the Apollo and Gemini types, although the gravitational and atmospheric factors were the same in all cases. The working volume of the spacecraft is most likely the influential factor in terms of sleep. Skylab provided adequate room for separate eating, exercising, working, and sleeping areas within 12 763 $ft^3$ of living area. The Apollo spacecraft measured only approximately 3% of this volume, while the Gemini craft contained less than 1%. In these smaller spacecraft, all daily tasks were more difficult, and the astronauts undoubtedly had a greater sense of confinement. In addition, Skylab allowed the establishment of a daily routine which was, in most respects, directly comparable to ground-based, everyday activity. The crewmen maintained their Houston-based time reference throughout the flights and, for the most part, worked during conventional hours. The individual sleeping compartments were a definite improvement over the prior spacecraft systems, and this undoubtedly greatly minimized or eliminated interference with sleep caused by activity of other crewmen. In general, the element of risk or danger present in all spaceflights seemed to be minimized in Skylab by the presence of a daily routine, and this also may have contributed to the improvement in sleeping conditions.

The results also suggest areas for future study with respect to the acquisition of scientific data and in terms of one's overall adaptation to life in space. As indicated previously, the changes in sleep-stage characteristics seen postflight possibly do represent a direct influence of the altered gravitational factors upon the sleep/wakefulness

mechanisms. Future experiments, if properly designed, could provide information of basic importance to our understanding of sleep. In terms of human capabilities, we feel confident that flights of two to three months will not be jeopardized by sleeping difficulties, but beyond this point we must continue to proceed with caution.

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## 3.14 Experiment M151. Time and Motion Study

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*Edward J. McLaughlin, Ph.D.*
*Principal Coordinating Scientist:* *W. E. Fedderson, Ph. D.*

### Introduction

The general format for the present report follows that presented for the SL 1/2 and SL 3 data. The initial section focuses on the objectives set for experiment M151. This is followed by a graphic presentation of representative activities. The third section outlines a series of statistical analyses of the effect the Skylab environment has on task performance, namely,

- the first in-flight task performance
- the return of in-flight performance to preflight baseline
- the pattern of activity in task performance as affected by zero-g.

In the fourth section the use of voice telemetry as an indication of task performance time is explored. This is followed by demonstrating the pronounced affect change in method has on performance time. A similar effect is shown in the conduct of "suit donning". Finally, performance during the latter part of the mission is studied for evidence of performance deterioration.

### Mission Objectives

The basic objective of experiment M151 was to evaluate astronaut work and task performance in the zero-g Skylab environment. As a meaningful contrast, in-flight performance was compared with that observed in the one-g preflight training environment. Most of the analyses were studied by means of the adaptation function, namely, the relation of the amount of time it takes to perform the same task in successive trials. The adaptation function was used to differentiate among various types of tasks, to evaluate the effect of the Skylab environment on task performance, and to develop criteria for possible deterioration of performance in long duration space flights.

### Graphic Results

One of the simplest, and in many ways most effective, methods of presenting experimental results is through graphic display. Graphs in figures 3.14-1 through -4 depict the adaptation function for the basic activities involved in experiment M092 Lower Body Negative Pressure (sec. 3.5) which was performed on the three manned Skylab missions. Training data comprise the left-side section of each graph; the right side portion presents the in-flight results.

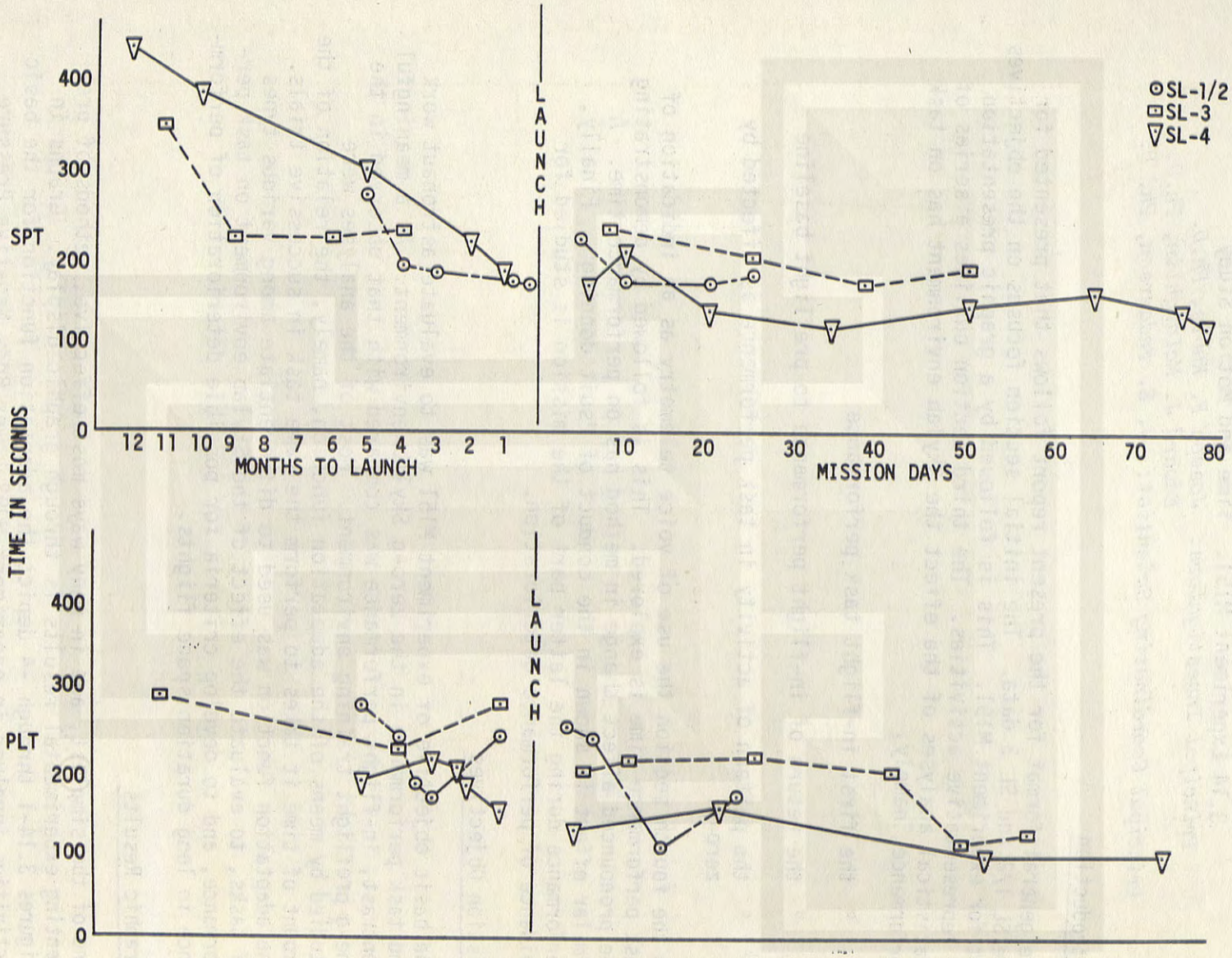


Figure 3.14-1. - Time to Perform Basic M092 Subject Activity at Prerun.

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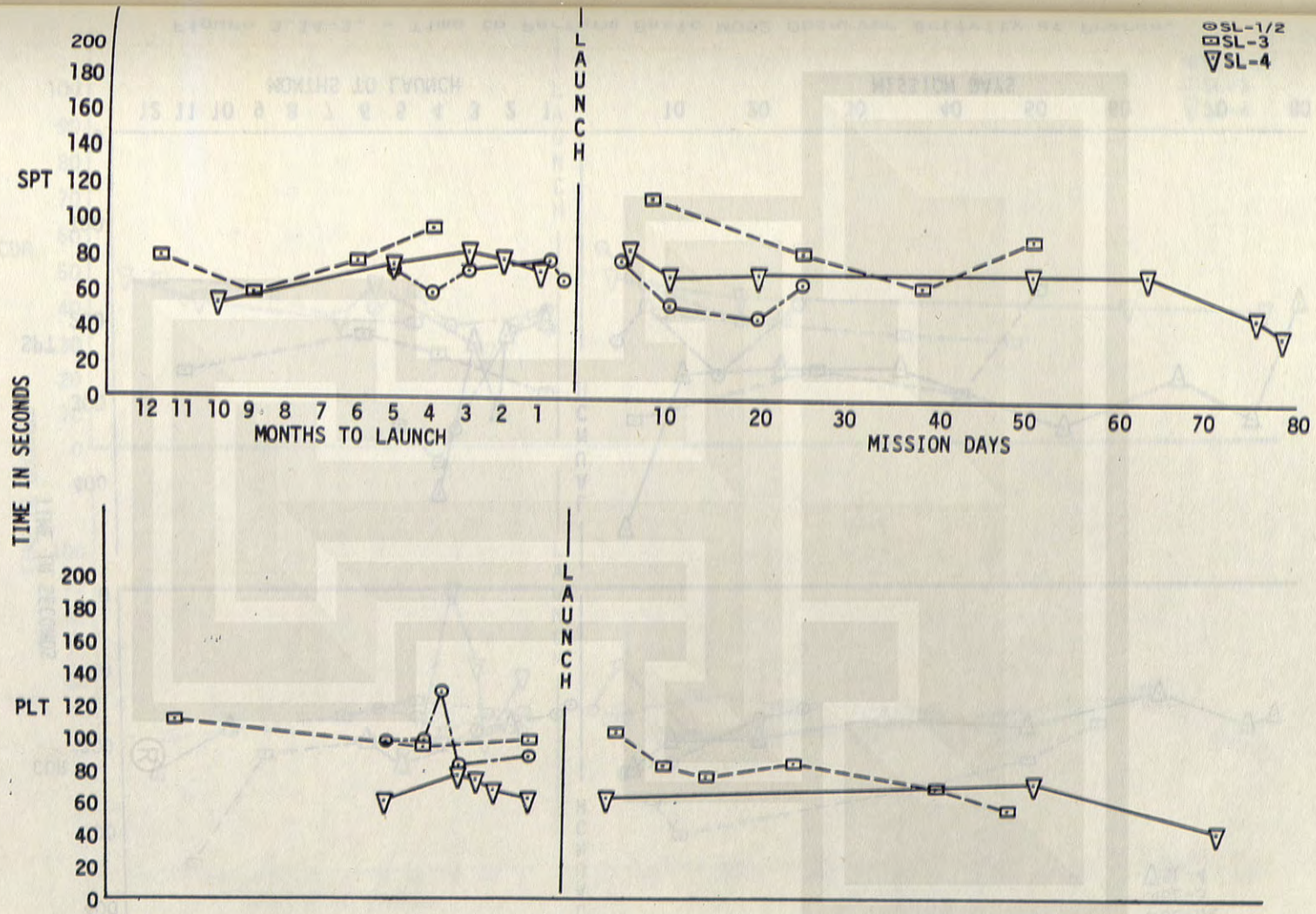



Figure 3.14-2. - Time to Perform Basic M092 Subject Activity at Post Run.

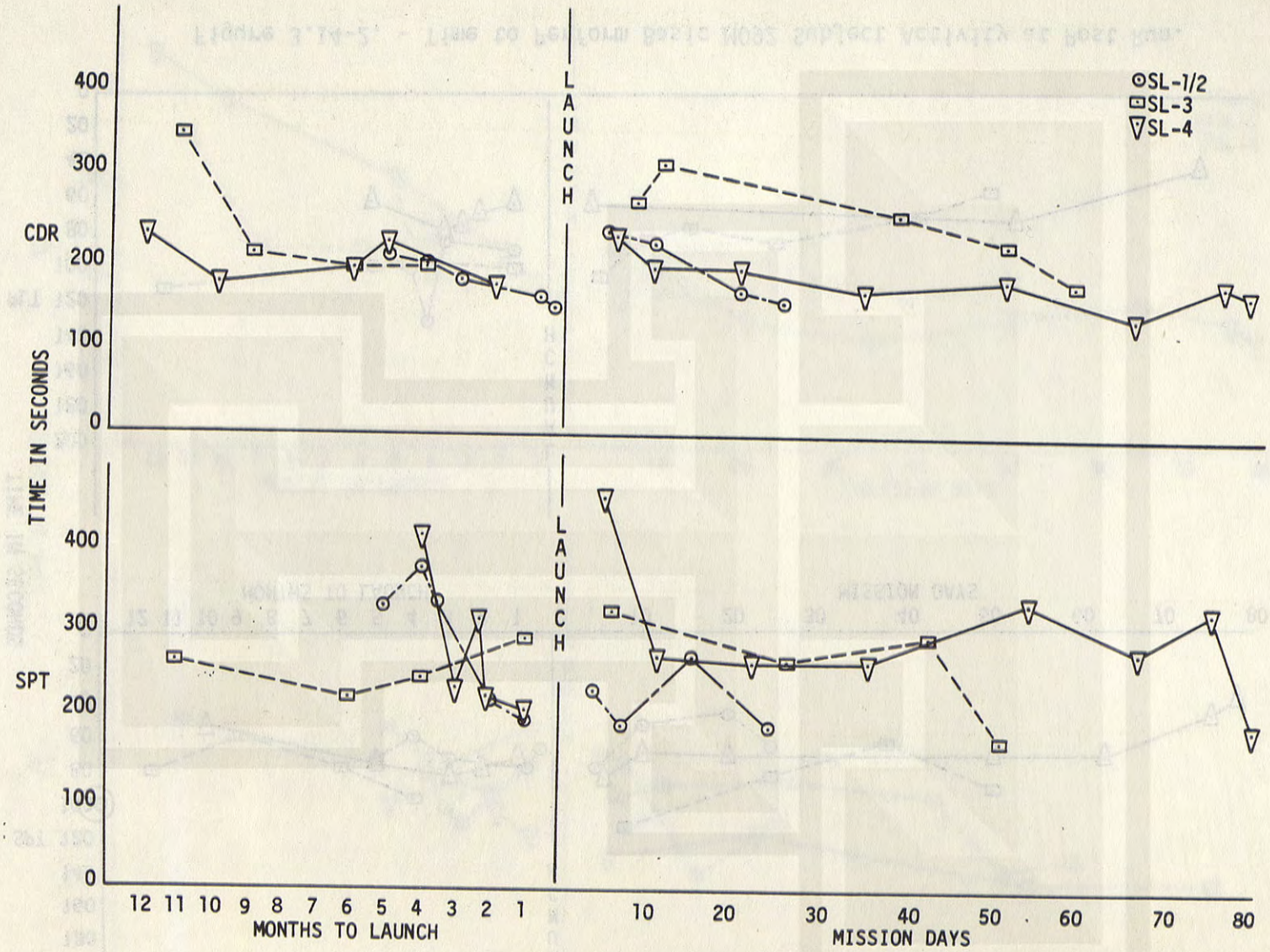



Figure 3.14-3. - Time to Perform Basic M092 Observer Activity at Prerun.

Figure 3.14-3. - Time to Perform Basic M092 Observer Activity at Prerun.

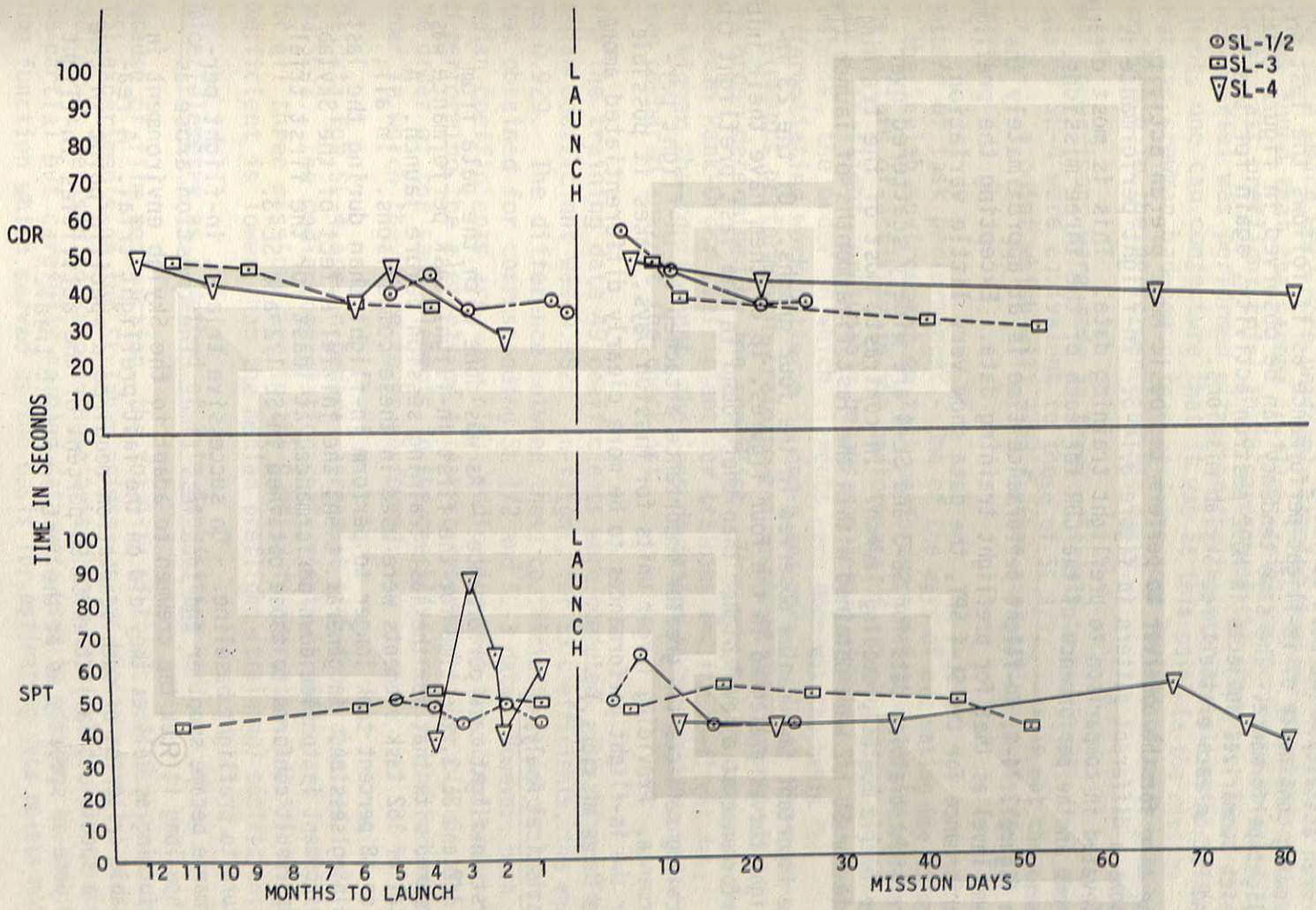



Figure 3.14-4. - Time to Perform Basic M092 Observer Activity at Post Run.

Figure 3.14-1 shows the results for the SPT and PLT as subjects in M092 prerun activity. The most striking feature of these graphs is the seeming continuity of in-flight performance as it follows the last pre-flight performance. The same tendency can be observed in figure 3.14-2 which summarizes subjects in M092 postrun activity, again for the SPT and PLT on each of the three Skylab missions.

The time for the observer to perform the basic M092 prerun activity shows a different pattern in figure 3.14-3. In-flight performance is elevated in comparison to preflight training data. This is most clearly shown in the performance of the CDR for each of the three missions.

In figure 3.14-4, in-flight performance time is at approximately the same level as that for preflight training data. Excepting the preflight performance for the SL-4 SPT, the data show very little variation.

Preflight training data for SL-3 and SL-4 are widely scattered over the twelve months preceding launch. In contrast, most of the training data for SL 1/2 were obtained within the last five months of launch time.

One important fact can be observed in the four graphs. Of the 23 in-flight curves presented in the four figures, 18 of them have their initial performance at a level higher than that found in the last preflight trial.

(Scaling reflects the greater importance attached to in-flight performance. Providing larger units for Mission Days, makes it possible for the in-flight performances to be more clearly differentiated among the three missions.)

Statistical Analyses

First in-flight task performance. - As was done with the data from SL 1/2 and SL-3, the time for the first in-flight task performance was compared with that for the last training session before launch. A total of 162 task elements were used in these comparisons. In all, 94 or 58 percent took longer to perform in-flight than during the last training session. In general, then, the initial effect of the Skylab environment is to slow down performance, at least for the first trial. This result conforms to those obtained in SL 1/2 and SL-3.

Return to preflight baseline. - On successive trials, in-flight performance became smoother and took less time. The question arose as to how long it took the crewmen to adapt to the Skylab environment in performing as well as they did on the last preflight trial. A reasonable criterion of such adaptation required a specific point in time (or a specific trial) at which 50 percent of the activities in-flight are done as speedily as at the last preflight trial.

With the use of this criterion and with the analysis confined to the M092 data which were more uniformly sampled than any other set of data, it was found that the second in-flight trial was performed as speedily as the last preflight trial in 48 percent of the elements. Since the second trial was performed either on the tenth or the eleventh day in-flight, one can conjecture that it was at this point in the mission that the crewman had begun to experience some feeling of mastery and confidence in the performance of his tasks.

When comparisons were made in terms of trials to reach criterion, the data of SL-4 were equivalent to those of SL 1/2. This is not the case for SL-3, a point which will need further explanation in the final report.

Pattern of task performance. - One of the ways of evaluating the effect of the Skylab environment on task performance was to determine whether the pattern of activity in the performance of a task changed significantly in-flight, presumably because of zero-g effects. In the present analysis, the order in which elements were done was the basis for differentiating work patterns in one-g and zero-g. Thus, the order of the elements performed in training and in-flight was compared with the order determined by the checklist. This was done by computing the Spearman Rank-Order Coefficient for training and for in-flight data. The higher the coefficient, the less deviation in the performance pattern when compared against the checklist.

With the training data 49 coefficients were computed. The value of the median coefficient was 0.982. In-flight, for 53 coefficients, the median was 0.929. The difference between these coefficients is larger than that obtained for corresponding SL 1/2 and SL-3 data. However, both median coefficients are very high, indicating that the actual order of performing the elements of a task corresponded rather closely with the order of the same elements in the checklist, namely, the nominal order in which they were to be performed.

The data for SL-4 are in general agreement with those obtained in SL 1/2 and SL-3. The median correlation coefficients (training and in-flight) for all three missions are in the 0.90's; further, the median in-flight coefficient is lower than the median preflight (training) coefficient.

Voice/Telemetry as a Method of Data Acquisition

Because of film restriction, the totality of trials comprising each of M151 experiments on the Skylab missions was not photographed. A procedure was devised to sample those trials most critical to M151 objectives. The partial but carefully sampled data were used to generate the adaptation function which served as the basis for estimating data points not

sampled by M151 film procedures. Data for the complete set of trials would have been highly desirable; they were, however, unobtainable because of the limited amount of film available to M151.

The cooperation of the SL-4 crew to gather and report data on the performance of an M151 task that was done repeatedly and regularly over the entire 85-day mission was fortunate. These tasks involved the major medical experiments: M092, Lower Body Negative Pressure: M093, Vectorcardiogram; and M171, Metabolic Activity. These experiments were scheduled back-to-back in combinations of M092/M093 or M092/M171 and were performed within three or four day cycles with each crewman as subject. The result was that virtually every mission day from MD 5 to MD 83 had at least one of the combinations M092/M093 or M092/M171 as part of the daily flight plan. The only exceptions were the days the crew rested or performed EVA. Also twice during the mission, two major medical runs were made in one day to free another day for multiple Earth Resource passes. Although subjects were scheduled on a regular basis, this was not the case for the observers. By the end of SL-4, the CDR was the observer for M092 a total of 26 times, the PLT a total of 23 times, and the SPT only 18 times.

Performance time was obtained from the voice records and these indicated the points at which crewmen began or finished a task. In the course of the experiment, telemetry automatically recorded other events, such as calibrations, and these time points provided a check on possible discrepancies in the voice records.

No attempt was made to factor out anomalies or task interruptions present during the nominal run of the experiment. Interruptions caused by air-to-ground communications or other crewmen were considered, in the present analysis, as part of the total time required to perform the task. Other factors, however, not associated with the experiment proper, were eliminated from the tape-recorded time interval assigned to the experiment. These were the special tests which were introduced either late in SL-3 or in SL-4. They included Limb Blood Flow, Leg Blood Pressure, Facial Photos and Anthropometric Measurements to study body fluid shifts, venous compliance, and changes in body size due to prolonged zero gravity. In some tests, such as Limb Blood Flow, the time required could be factored out on the basis of telemetry associated with the test. In others, an estimate was determined from baseline data or from in-flight photos taken from M151 data. Early in SL-4, the special tests had significant impact on performance because the crew had little or no training on these tests prior to flight.

The performance data, expressed as averages of the three crewmen, are presented in graphs relating performance time and mission day. This functional relationship, termed the adaptation function, is dependent upon several variables such as the nature of the task, the amount and

type of training prior to launch, frequency of performance in-flight, and the unique style and tempo of individual crewmen. As found for data obtained in the two earlier flights, the fitted function is monotonically decreasing, and generally exponential in form. In other words, as the number of trials increase, the time to perform them decreases with the largest drop occurring in the earlier trials.

Figure 3.14-5 presents the M092 data. Task proficiency in M092 depended on subject-observer cooperation in electrode donning and LBNPD ingress. As estimated from the fitted function, performance time for the first trial was 45.1 minutes; that for the last trial was 22.2 minutes. Increase in proficiency was expressed in terms of how much time was reduced in performing the task. This decrement was 22.9 minutes, a time reduction of 51 percent with respect to initial performance.

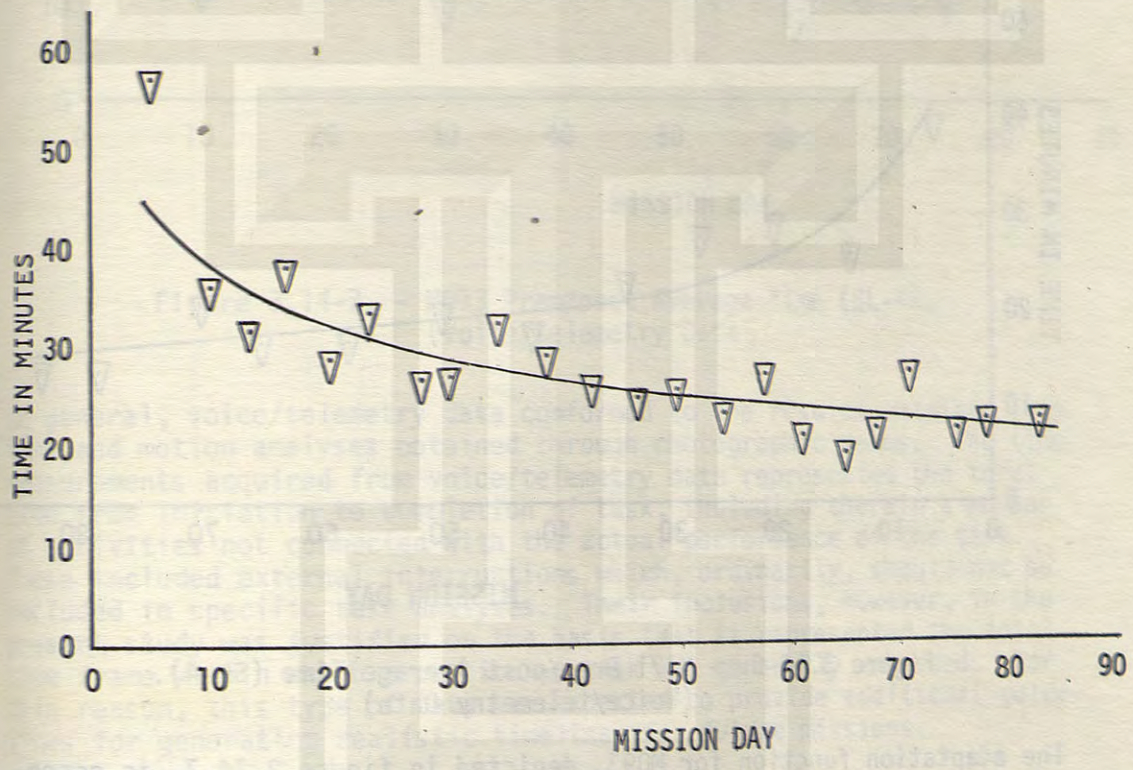



Figure 3.14-5. - M092 Prep/post Average Time (SL-4).
(Voice/telemetry Data)

Figure 3.14-6 presents similar data from experiment M171. Although the M171 performance did not rely so heavily on subject-observer interaction as that required in M092, the observer was engaged in a relatively complicated setup and calibration of the Metabolic Analyzer while the subject remained passive on the ergometer. The corresponding initial (41.3 minutes) and final (15.3 minutes) values obtained from the adaptation function indicated a reduction in time of approximately 63 percent over the mission. Proficiency in M171 task performance, as expressed by this number, appeared to be somewhat better than that reported for M092. The increase in M171 proficiency was gained by the crew in performing some of the Metabolic Analyzer setup during the period when M092 data were being collected.

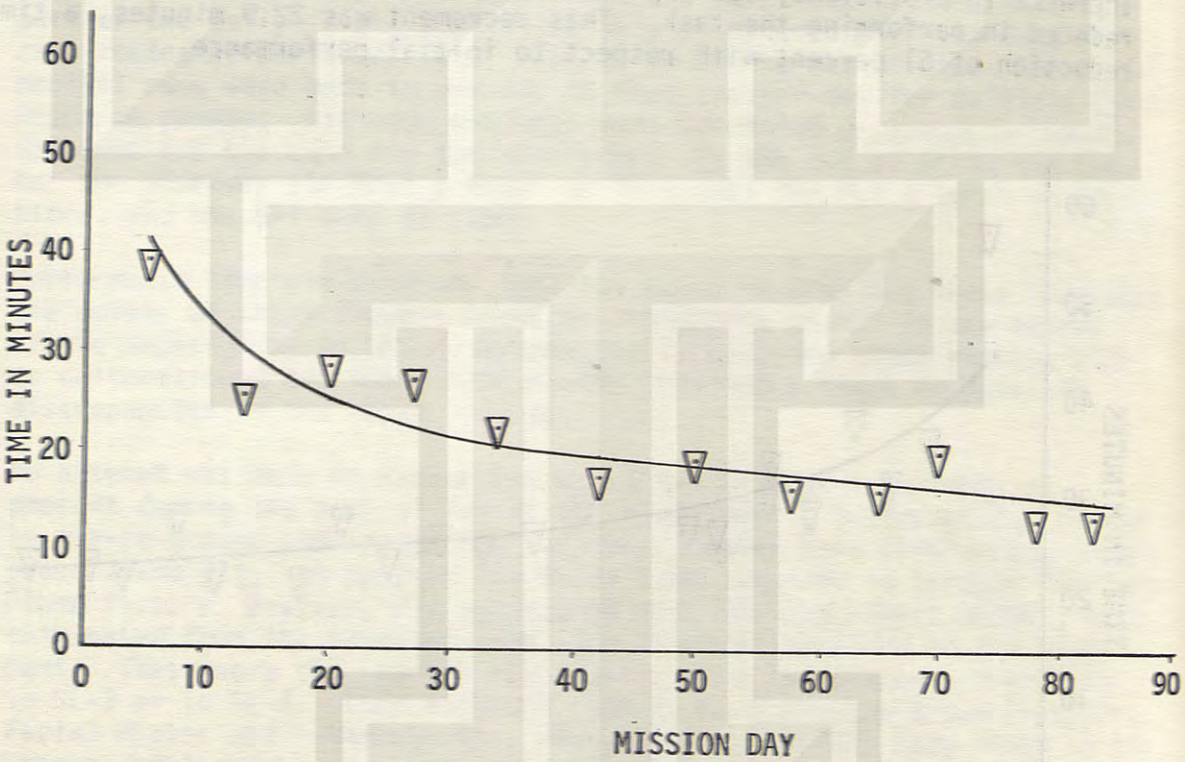



Figure 3.14-6. - M171 Prep/post Average Time (SL-4).
(Voice/telemetry Data)

The adaptation function for M093, depicted in figure 3.14-7, is essentially linear in character. The estimated initial and final values, 14.1 and 9.4 minutes respectively, indicated a time reduction of about 33 percent over the mission. The small reduction in time probably reflected the relative simplicity of the observer task requirements.

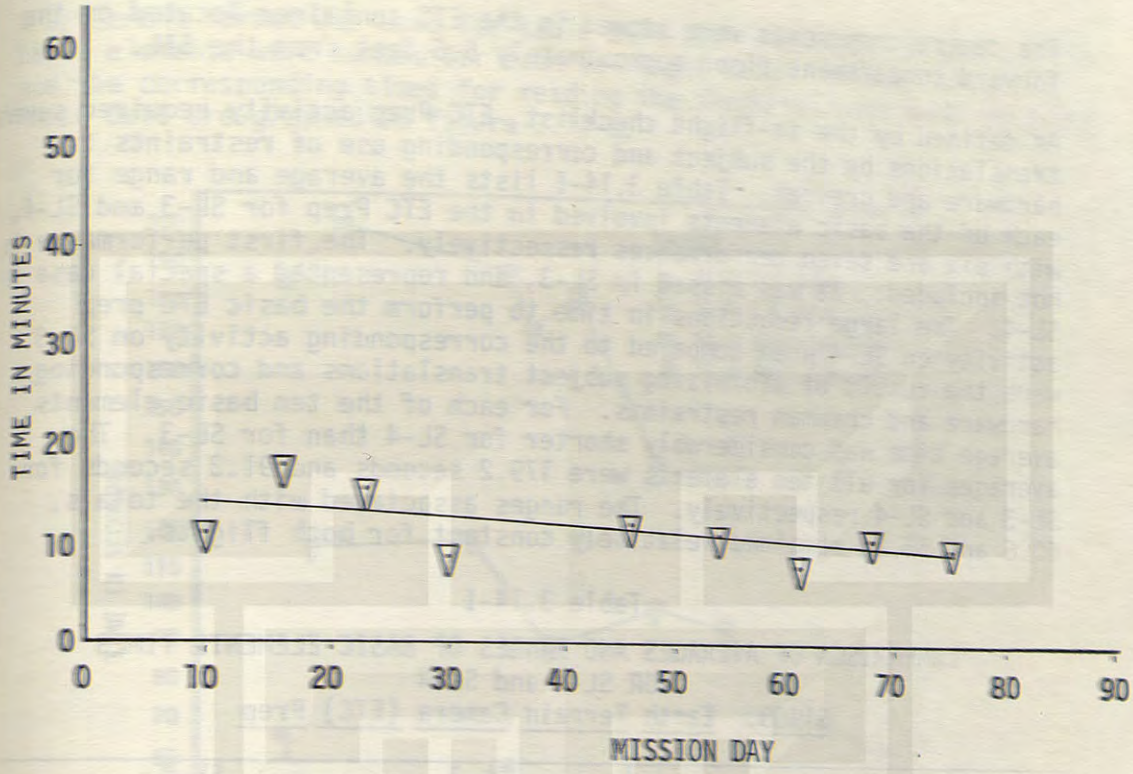



Figure 3.14-7. - M093 Prep/post Average Time (SL-4).
(Voice/telemetry Data

In general, voice/telemetry data conformed to the results obtained from time and motion analyses obtained through photographic means. The time measurements acquired from voice/telemetry data represented the total time from initiation to completion of task, including therein a number of activities not connected with the actual performance of the task. These included external interruptions which, ordinarily, should not be included in specific task analyses. Their inclusions, however, in the present study was justified on the basis that it represented the total time frame within which a particular task was generally embedded. For this reason, this type of data was expected to provide additional guidelines for generating realistic timelines for future missions.

Time Reduction Resulting From In-flight Method Change

One of the principal differences between SL-3 and SL-4 performance of S190B: Earth Terrain Camera (ETC) Prep was the change in method to perform the activity. Essentially the activity consisted of assembling the Earth Terrain Camera components in the Scientific Airlock (SAL).

The camera components were stowed in the ETC container located on the forward compartment floor approximately 5.5 feet from the SAL.

As defined by the in-flight checklist, ETC Prep activity required several translations by the subject and corresponding use of restraints for hardware and crewman. Table 3.14-I lists the average and range for each of the basic elements involved in the ETC Prep for SL-3 and SL-4, with six and seven performances respectively. The first performance is not included: it was missed in SL-3, and represented a special case in SL-4. The large reductions in time to perform the basic ETC prep activity on SL-4 when compared to the corresponding activity on SL-3 were the result of minimizing subject translations and corresponding hardware and crewman restraints. For each of the ten basic elements average time was considerably shorter for SL-4 than for SL-3. The averages for all ten elements were 179.2 seconds and 91.3 seconds for SL-3 and SL-4 respectively. The ranges associated with the totals, 60.6 and 55.4, remained relatively constant for both flights.

Table 3.14-I

COMPARISON OF AVERAGES AND RANGES OF BASIC ELEMENTS TIMES FOR SL-3 and SL-4

S190B: Earth Terrain Camera (ETC) Prep

| | SL-3 | | SL-4 | |
|---|---|---|---|---|
| Element Description | Avg.* (s) | Range (s) | Avg.* (s) | Range (s) |
| Remove/stow SAL window | 33.9 | 24.4 | 14.9 | 11.2 |
| Remove/stow square cover | 13.8 | 17.4 | 7.9 | 16.5 |
| Place ETC window in SAL | 24.7 | 42.3 | 14.1 | 19.0 |
| Remove/stow round cover | 12.9 | 9.3 | 4.9 | 6.2 |
| Xlate to F573 from -Z SAL | 5.7 | 8.0 | 4.1 | 4.0 |
| Open F573 | 18.6 | 10.8 | 9.7 | 13.8 |
| Position ETC in F473 | 16.6 | 9.3 | 7.2 | 4.2 |
| Remove/stow lens cover | 8.8 | 5.1 | 7.6 | 8.1 |
| Xfer ETC to -Z SAL | 17.8 | 21.5 | 6.2 | 7.7 |
| Install ETC in -Z SAL | 26.0 | 16.5 | 14.7 | 18.7 |
| Total | 179.2 | 60.6 | 91.3 | 55.4 |

*Excludes performance no. 1

A different format was used for table 3.14-II. The times to perform the basic elememts were summed for each in-flight trial (trial 1 excluded) and the corresponding times for reading the checklist were also included. These data are graphed in figure 3.14-8.

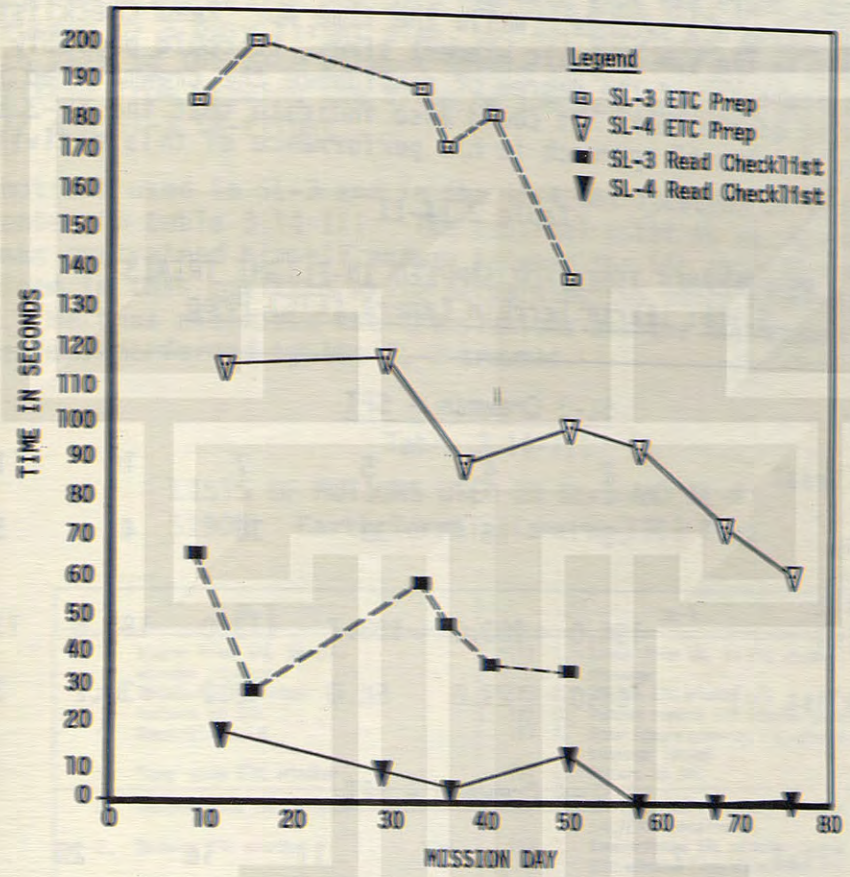



Figure 3.14-8. - Sum of Basic Elements for In-flight ETC Prep and Corresponding Read Checklist Times.

The outstanding feature of table 3.14-II (and figure 3.14-8) is the marked difference in time per trial between the SL-3 and SL-4 crewmen, a fact which reflects a similar time difference noted in table 3.14-I. In the case of SL-3, performance time remained relatively constant until trial 15 (MD 50) where a sharp reduction of about 24 percent occurred. A similar reduction (22 percent) occurred much earlier for SL-4, namely, at trial 9 (MD 37).

Another important feature of table 3.14-II is the difference observed between SL-3 and SL-4 crewmen in reading the checklist. The times for the SL-4 crewman were appreciably shorter for corresponding in-flight trials. The average for SL-3 across the entire mission was 38.7 seconds. In SL-4, however, after the first trial during which the crewman took 91.0 seconds, there was very little time required for checklist reading, the average being 6.2 seconds. While the time for "Read Checklist" was not included in the sum of basic element times, it could probably be used as an indicator of the degree of confidence the crewman had in his understanding of the task. It could also indicate that the SL-3 crewman took a more "cookbook" approach in his performance of this activity.

Table 3.14-II

PERFORMANCE TIMES FOR SAMPLED IN-FLIGHT TRIALS
S190B: Earth Terrain Camera (ETC) Prep

| | | | | | | |
|---|---|---|---|---|---|---|
| **SL-3 Crewman - SPT** | | | | | | |
| In-flight Trial | 2 | 4 | 5 | 7 | 10 | 15 |
| Mission Day | 9 | 15 | 33 | 36 | 41 | 50 |
| Sum of Basic Elements (s) | 184.0 | 200.0 | 188.7 | 173.0 | 182.6 | 139.4 |
| Read Checklist (s) | 65.0 | 29.0 | 58.0 | 48.0 | 36.2 | 34.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **SL-4 Crewman - SPT** | | | | | | | |
| In-flight Trial | 2 | 8 | 9 | 11 | 16 | 20 | 26 |
| Mission Day | 12 | 29 | 37 | 50 | 58 | 67 | 76 |
| Sum of Basic Elements (s) | 115.1 | 116.8 | 89.5 | 100.2 | 95.5 | 74.5 | 61.4 |
| Read Checklist (s) | 18.8 | 8.0 | 2.3 | 12.5 | 0 | 0 | 1.5 |

Specifically, the SPT on SL-3 followed the checklist with only one modification (stowage of the ETC window covers in a bag rather than fastening them to the OWS wall), and he worked at a "nominal" pace, double-checking activities involving the scientific airlock as he performed the task. On the other hand, the SL-4 SPT used the checklist

very rarely after his initial trials and from trial 1 on he began to modify the normal method of doing the task. His pace was faster and his actions were smooth and sure. He seemed to know what came next and did not have to check to verify what should be done. He also used zero-g to his advantage by leaving hardware free-floating while he opened a box or put something away. His pace may have been greater because he truly was rushed by a busy flight plan, but his knowledge of the task allowed him to keep up the pace without making errors. Finally, he may have benefitted from viewing the films of the same activity as performed on SL 1/2 and S1-3 in-flight.

The motions used in SL-3 and in the SL-4 modification of the task are presented in table 3.14-III. The critical point is no. 6 where the SL-4 crewman restrained himself midway between the SAL and ETC container and remained in this position while performing the other elements of the task. He thus minimized the translations and the corresponding restraint operations performed by the SL-3 crewman.

Table 3.14-III

LISTS OF MOTIONS USED IN SL-3 AND SL-4
S190B: Earth Terrain Camera (ETC) Prep

| SL-3 | SL-4 |
|---|---|
| 1. Xlate from SAL to ETC window stowage | *(1) 1. Xlate from SAL to ETC window stowage |
| 2. Obtain ETC window | (2) 2. Obtain ETC window |
| 3. Return to SAL | (8) 3. Remove square ETC window cover |
| 4. Restrain self | (9) 4. Stow square cover at ETC window stowage locker |
| 5. Temp stow ETC window | (3) 5. Return to SAL |
| 6. Remove/stow SAL window | (4) 6. Restrain self (midway between SAL/ETC container) |
| 7. Obtain ETC window | (6) 7. Remove/stow SAL window (leave ETC window free-floating) |
| 8. Remove square ETC window cover | (11) 8. Remove round TEC window cover (leave free-floating) |
| 9. Stow square cover | (10) 9. Install ETC window in SAL |
| 10. Install ETC window in SAL | (new) 10. Obtain round cover |
| 11. Remove round ETC window cover | (new) 11. Lean-back-open ETC container |
| 12. Stow round cover | (17) 12. Remove ETC |
| 13. Release restraint | (19) 13. Remove ETC lens cover |
| 14. Xlate to ETC container | (new) 14. Stow ETC lens cover and round window cover |
| 15. Restrain self | (20) 15. Obtain ETC |
| 16. Open ETC container | (new) 16. Lean forward-position/lock ETC in SAL |
| 17. Remove ETC | |
| 18. Position ETC in container | |
| 19. Remove/stow ETC lens cover | |
| 20. Obtain ETC | |
| 21. Release restraint | |
| 22. Xlate to SAL with ETC | |
| 23. Restrain self | |
| 24. Position/lock ETC in SAL | |

*Comparable SL-3 number

The data presented demonstrate the importance of method in task performance, and the impact of familiarity with, or confidence in performance of the task. Also the pressure of the flight plan schedule may be considered a more pronounced factor in the SL-4 performance, as compared with the SL-3 performance. Finally, this may have been one of the in-flight tasks the SL-4 crewman decided to modify in order to reduce the time required, thus freeing himself for other activities.

Suit Donning

Suit donning is of vital concern to crew safety and operation during EVA. In addition, this activity (as well as suit doffing) has always been of interest to M151 because it requires the full scope of the crewman's capabilities from fine motor dexterity, such as the precise alignment of connectors, to gross activities such as placing the helmet and gloves for later use. Crewman interaction was also involved, primarily during the zipper closures of the pressure garment assemblies. As later crews studied the M151 films of earlier crews, it was anticipated that significant changes in method from crew to crew would develop. Suit donning was nominally to be performed early, middle, and late in the mission on SL-3 and SL-4, thus providing some indication of zero-g adaptation.

The Skylab crewmen wore their suits for many different types of training in preparation for their respective missions. In most cases, they received assistance from suit technicians in donning and doffing the suits and as a result had a minimal number of training sessions where they actually simulated the donning and doffing procedures required for the Apollo telescope mount EVA's. However, from the exposure of having the suits custom fitted and from having the suits on for various exercises, the crewmen became familiar with the components required for EVA. During Skylab training, a maximum of only four EVA suit donning (and doffing) sessions were recorded by M151 for any crew. Table 3.14-IV presents a summary of Skylab preflight training, with total time shown for 21 basic (and common) elements which must occur in the suit donning activity. The performance number refers to the crewman donning the suit.

Figure 3.14-9 presents the graphs of the averaged data in table 3.14-IV. The outstanding characteristic of the three functions is the terminal point, the time for the last training session before flight. Whatever the differences in the initial training session, and these were large among the three crews, the final training performance required about the same amount of time (800-850 s) for the different crews. Although there was some inconsistency in the pairing of crewmen during the training sessions, it was felt that this had a minimal impact on the total times. There is certainly every indication that proficiency consistently improved.

Table 3.14-IV
EVA SUIT DONNING TRAINING SUMMARY
(Sum of Basic Elements)

| Flight | Perf No. | Time to Launch (months) | Crewman | Assisting Crewman | (Avg.) | Time (s) |
|---|---|---|---|---|---|---|
| SL-1/2 | 1 | 9 | CDR | PLT | | 763 |
| | 1 | 9 | PLT | CDR | | 1043 |
| | | | | | (Avg.) | 903 |
| | 1 | 7 | SPT | CDR | | 1231 |
| | 2 | 7 | CDR | PLT | | 811 |
| | | | | | (Avg.) | 1021 |
| | 2 | 3 | SPT | CDR | | 1061 |
| | 3 | 3 | CDR | PLT | | 864 |
| | | | | | (Avg.) | 962 |
| | 3 | 1 | SPT | CDR | | 874 |
| | 4 | 1 | CDR | PLT | | 715 |
| | | | | | (Avg.) | 795 |
| SL-3 | 1 | 11 | CDR | SPT | | 1334 |
| | 1 | 11 | SPT | CDR | | 1089 |
| | | | | | (Avg.) | 1211 |
| | 1 | 8 | PLT | CDR | | 912 |
| | 2 | 8 | CDR | PLT | | 1159 |
| | 2 | 6 | SPT | PLT | | 1072 |
| | | | | | (Avg.) | 1048 |
| | 3 | 6 | CDR | PLT | | 1030 |
| | 3 | 6 | PLT | CDR | | 879 |
| | | | | | (Avg.) | 955 |
| | 4 | 1.5 | CDR | PLT | | 796 |
| | 4 | 1.5 | PLT | CDR | | 914 |
| | | | | | (Avg.) | 855 |
| SL-4 | 1 | 5 | SPT | CDR | | N/A |
| | 1 | 5 | CDR | SPT | | N/A |
| | 2 | 4 | SPT | PLT | | 1666 |
| | 1 | 4 | PLT | SPT | | 1194 |
| | | | | | (Avg.) | 1430 |
| | 4 | 2 | CDR | PLT | | 938 |
| | 4 | 2 | PLT | CDR | | 730 |
| | | | | | (Avg.) | 834 |

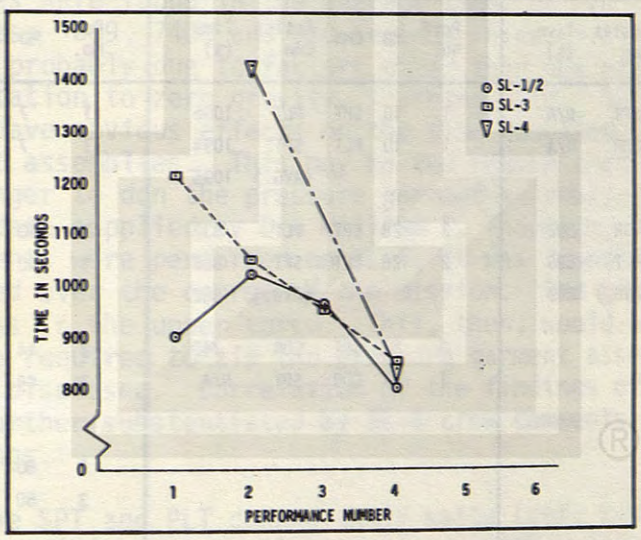



Figure 3.14-9. - Preflight Suit Donning Average Time.
(Sum of Basic Elements)

Although all three crewmen donned the pressure garment assemblies prior to each EVA, only the two crewmen who would actually perform the EVA donned the necessary items specific to EVA. The third crewman did gain the additional experience of donning and doffing the basic part of the suit but did not participate to the extent of the two EVA crewmen. The performance number alluded to in this section refers to an assignment as EVA crewman.

Table 3.14-V and figure 3.14-10 which follow summarize the in-flight suit donning performances. Only one performance (on MD 25) was filmed for SL 1/2, but it was the second time the CDR had donned his suit prior to EVA, while it was the first suit donning for the PLT as an EVA crewman. An earlier EVA on MD 14, involving the CDR and SPT, was required on SL 1/2 during which the PLT performed a non-EVA suit don. Three trials were recorded during SL-3 and SL-4, but not always with the same pair of crewmen. The effect of total number of performances, difficulties (on SL-4) with the zipping operation because of snug-fitting suits, occasional intrusions of the non-EVA crewmember into the operation, and the small number of observations, created difficulties in identifying relationships between the timing (number of months or days, before launch) of training sessions and the timing of in-flight performances.

Table 3.14-V

EVA SUIT DONNING IN-FLIGHT SUMMARY
(Sum of Basic Elements)

| SL 1/2 | | | | | SL-3 | | | | | SL-4 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Perf No. | MD | CMN | Assist Cmn | Time (s) | Perf No. | MD | CMN | Assist Cmn | Time (s) | Perf No. | MD | CMN | Assist Cmn | Time (s) |
| 1 | 14 | CDR | SPT | N/A | 1 | 10 | SPT | PLT | 1096 | 1 | 7 | SPT | PLT | 1192 |
| 1 | 14 | SPT | CDR | N/A | 1 | 10 | PLT | SPT | 1094 | 1 | 7 | PLT | SPT | 818 |
| | | | | | | | | (AVG.) | 1095 | | | | (AVG.) | 1005 |
| 1 | 25 | PLT | CDR | 802 | 2 | 28 | SPT | PLT | 837 | 2 | 40 | PLT | CDR | N/A |
| 2 | 25 | CDR | PLT | 536 | 2 | 28 | PLT | SPT | 866 | 1 | 40 | CDR | PLT | N/A |
| | | | (AVG.) | 669 | | | | (AVG.) | 852 | | | | | |
| | | | | | 3 | 57 | SPT | CDR | 740 | 2 | 44 | CDR | SPT | 1036 |
| | | | | | 1 | 57 | CDR | SPT | N/A | 2 | 44 | SPT | CDR | 1057 |
| | | | | | | | | | | | | | (AVG.) | 1046 |
| | | | | | | | | | | 3 | 80 | CDR | SPT | 980 |
| | | | | | | | | | | 3 | 80 | SPT | CDR | 840 |
| | | | | | | | | | | | | | (AVG.) | 910 |

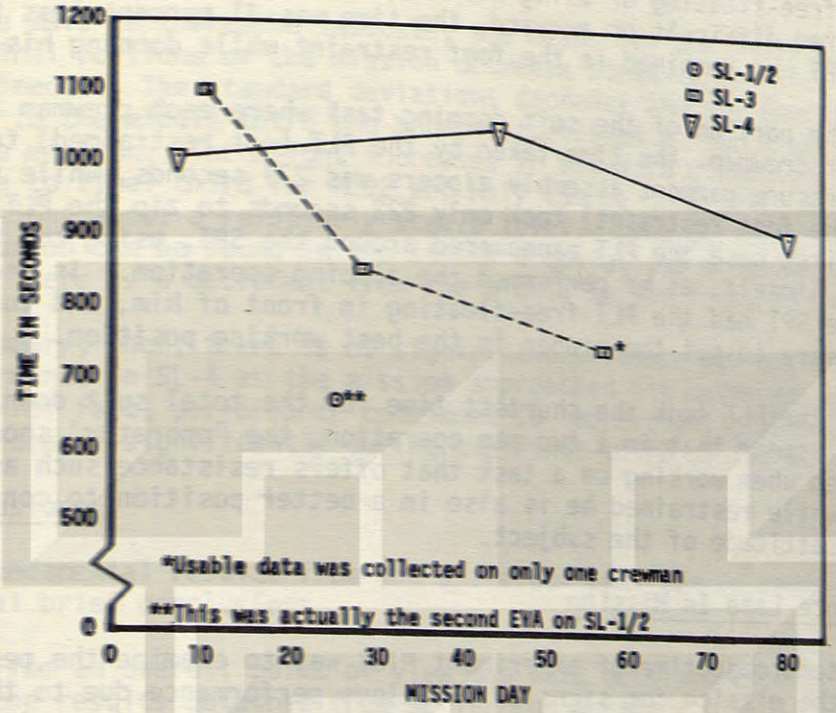



Figure 3.14-10. - In-flight Suit Donning Average Time. (Sum of Basic Elements)

Large differences were found in the average times of EVA crewmen for the last performances: 669, 740, and 910 seconds respectively. These differences are probably due to factors other than the effect of training schedules, adaptation to zero gravity, learning, etc. Suit fit, for example, could have obvious effects on the time required to don the pressure garment assemblies. This may be the reason that the SL-4 crewman took longer to don the pressure garment assembly late in the mission. From data supplied by Dr. William E. Thornton, whose anthropometric measurements were performed on SL-4, it was found that heights of crewmen increased over the course of the mission. The greater part of this increase was in the upper torso. This, then, would explain the much longer time required to zip the pressure garment assembly, a fact which M151 data disclosed. Correlation of the findings of Dr. Thornton and M151 were further substantiated by SL-4 crew comments in their post-flight debriefings.

On SL-4 MD 7, the SPT and PLT donned their suits (ref. table 3.14-V) with considerable difference in time required (1192 s for SPT, 818 s for PLT). During this EVA preparation the PLT seldom used the portable foot restraint while donning his own suit. He accomplished the suit

donning free-floating or using his hands as a restraint system. Although it appeared difficult or awkward, the time was 31 percent less than that of the SPT who remained in the foot restraint while donning his suit.

During the portion of the suit donning task where each crewman assisted the other crewman, the time taken by the PLT (not restrained) to zip the SPT's pressure garment assembly zippers was 279 seconds, while the SPT (using the foot restraint) took only 222 seconds to zip the PLT's zippers. In the first case the PLT maneuvered around the SPT, using the SPT to restrain himself, as he performed the zipping operation. In the second case, the SPT had the PLT free-floating in front of him, and turned him as necessary to put the zipper in the best working position.

Although the PLT took the shortest time for the total suit donning task, it would appear that in a two man operation, the "operator" should be restrained when working on a task that offers resistance such as a zipper; while restrained he is also in a better position to control the physical attitude of the subject.

Performance Late In Mission

An important objective of experiment M151 was to examine the performance late in the mission for signs of anomalous performance due to the long exposure of the Skylab environement. In terms of the adaptation function an anomalous result would be either a significant increase in time to perform tasks or a significant increase in variability towards the latter part of the mission.

To determine whether these two effects were operating on the SL-4 mission, the voice/telemetry data for M092, M171, and M093 were divided into thirds: the initial third, the middle third, and the final third of the SL-4 mission. These data, in the form of means and standard deviations, are presented in table 3.14-VI.

Table 3.14-VI
MEANS AND STANDARD DEVIATIONS OF TASK PERFORMANCE FOR THE INITIAL, MIDDLE, AND FINAL THIRDS OF THE SL-4 MISSION

| | Initial Third | | Middle Third | | Final Third | |
|---|---|---|---|---|---|---|
| | $\bar{X}$ | SD | $\bar{X}$ | SD | $\bar{X}$ | SD |
| M092 | 34.7[α] | 6.3 | 27.2 | 2.8 | 23.3 | 3.1 |
| M171 | 30.2 | 5.4 | 19.0 | 2.4 | 15.9 | 2.9 |
| M093 | 14.9 | 2.9 | 10.7 | 1.6 | 9.7 | 1.2 |

[α] in minutes

As the data in the table indicate, the means for the initial, middle, and final portions of the mission decrease steadily for the three experiments. The standard deviations decrease sharply from the initial third to the middle third and become stabilized at about this period of the mission. The slight increases in standard deviation from the middle to final third for M092 and M171 can be considered as random variations about a relatively stable level. Some substantiation for this conclusion can be found in the standard deviations observed in M093 where there is a decrement from the middle to the final third.

In summary, then, there is no significant evidence for deterioration of performance on SL-4 as the mission approached its culmination. As a matter of fact, performance continued to improve while variability did not increase significantly during the final third of the SL-4 mission.

## Conclusions

The fundamental results from the above analyses can be summarized in several brief conclusions.

- From an overall point of view the data obtained from SL-4 confirm the results obtained from SL 1/2 and SL-3.
- Two exploratory studies indicate that (a) voice/telemetry is a valuable adjunct in data acquisition, and (b) change in method of task performance can yield a significant reduction in performance time.
- Behavioral performance on SL-4 continued to improve from beginning to end of mission.
- There is no evidence of anomalous performance that could be attributed to the effects of long duration exposure to the Skylab environment.

## 3.15 Experiment M171. Metabolic Activity

*Principal Investigators: E. L. Michel*
*J. A. Rummel, Ph.D.*
*Project Scientist: C. F. Sawin, Ph.D.*
*Principal Coordinating Scientist: E. L. Michel*

### Methods

Experiment M171 is an exercise response test which utilizes a bicycle ergometer to study man's metabolic effectiveness during quantitative mechanical work. The test protocol is 25 minutes in duration consisting of a five-minute rest followed by three five-minute periods of increasing exercise approximating 25, 50, and 75 percent of the individual crewman's maximum oxygen consumption. This is followed by a five-minute recovery period. The physiological parameters measured are heart rate, blood pressure, oxygen consumption, carbon dioxide production, minute volume and vectorcardiogram. Additionally, cardiac output, vibrocardiogram, and carotid pulse measurements were made during the preflight and postflight tests. Each crewman performed the M171 experiment eight times preflight, twelve times in-flight, and seven times postflight. Vital capacity measurements were performed twelve times in-flight on each crewman.

### Results

Tables 3.15-I, -II, and -III summarize qualitatively the results observed in-flight and postflight as compared to the preflight baseline tests. As can be seen, there were no significant changes in any of the in-flight parameters which would indicate a decrement in response to exercise. The SL-4 crew responses differed in some ways from those observed in the SL 1/2 and SL-3 crews. These differences will be discussed in the next section of the report.

The postflight data acquired at R+0, R+1, R+2, R+4, R+5, R+11, and R+17 days demonstrate that all crewmen had a decreased tolerance for mechanical work immediately postflight. The significant changes observed postflight included elevated resting heart rates (figs. 3.15-1, -2, and -3), elevated resting minute volumes in the SPT and PLT (figs. 3.15-4 and -5), and decreased cardiac output (fig. 3.15-6) and decreased stroke volume (fig. 3.15-7) in the CDR.

As can be seen in figures 3.15-8, -9, and -10, the vital capacity measurements revealed in-flight decreases (2 to 10%) in all crewmen. Vital capacities for the CDR and PLT were below their preflight baseline range during the entire mission.

## TABLE 3.15-I. PRELIMINARY SL-4 M171 DATA SUMMARY, (REST - COMPARED TO PREFLIGHT DATA)

| VARIABLE* | COMMANDER In-flight | COMMANDER Postflight† | SCIENTIST PILOT In-flight | SCIENTIST PILOT Postflight† | PILOT In-flight | PILOT Postflight† |
|---|---|---|---|---|---|---|
| Heart Rate | No Change | Significantly Increased | No Change | Significantly Increased | No Change | Significantly Increased |
| Systolic Blood Pressure | No Change | No Change | Slightly Decreased | No Change | No Change | No Change |
| Diastolic Blood Pressure | Slightly Decreased | No Change | No Change | No Change | No Change | No Change |
| Oxygen Consumption | No Change | No Change | No Change | No Change | No Change | No Change |
| Minute Volume | No Change | No Change | Slightly Increased | Significantly Increased | Slightly Increased | Significantly Increased |

* = All measurements were obtained in sitting position.
† = Postflight data reflects immediate postflight measurements.

## TABLE 3.15-II. PRELIMINARY SL-4 M171 DATA SUMMARY, (LEVEL 3 EXERCISE - IN-FLIGHT; COMPARED TO PREFLIGHT)

| VARIABLE* | COMMANDER In-flight | COMMANDER Postflight† | SCIENTIST PILOT In-flight | SCIENTIST PILOT Postflight† | PILOT In-flight | PILOT Postflight† |
|---|---|---|---|---|---|---|
| Heart Rate | No Change | Significantly Increased | No Change | Significantly Increased | No Change | Significantly Increased |
| Systolic Blood Pressure | No Change | Slightly Increased | No Change | No Change | No Change | No Change |
| Diastolic Blood Pressure | Significantly Decreased | No Change | No Change | No Change | No Change | No Change |
| Oxygen Consumption | No Change | No Change | No Change | No Change | Slightly Decreased | Slightly Decreased |
| Minute Volume | No Change | No Change | Slightly Increased | Significantly Increased | No Change | No Change |

* = All measurements were obtained in sitting position.
† = Postflight data reflects immediate postflight measurements.

## TABLE 3.15-III. PRELIMINARY SL-4 M171 DATA SUMMARY, (RECOVERY PERIOD - COMPARED TO PREFLIGHT)

| VARIABLE* | COMMANDER In-flight | COMMANDER Postflight† | SCIENTIST PILOT In-flight | SCIENTIST PILOT Postflight† | PILOT In-flight | PILOT Postflight† |
|---|---|---|---|---|---|---|
| Heart Rate | Significantly Decreased | No Change | Slightly Decreased | No Change | Significantly Decreased | Slightly Increased |
| Systolic Blood Pressure | Slightly Decreased | Slightly Increased | No Change | No Change | No Change | No Change |
| Diastolic Blood Pressure | No Change | No Change | No Change | No Change | No Change | No Change |
| Minute Volume | No Change | No Change | Slightly Increased | Significantly Increased | No Change | No Change |

* = All measurements were obtained in sitting position.
† = Postflight data reflects immediate postflight measurements.

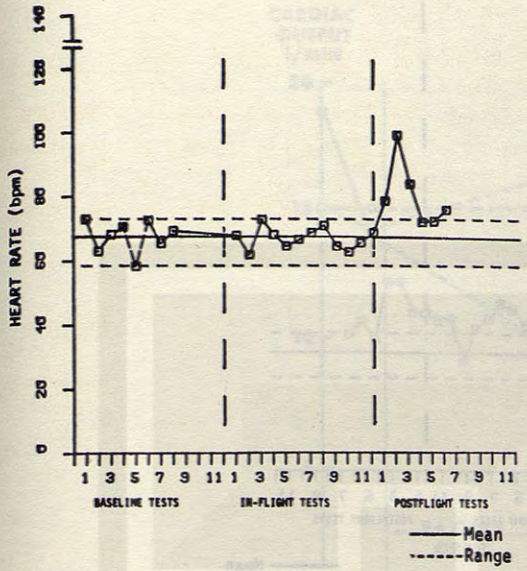



Figure 3.15-1. - SL-4 CDR Resting Heart Rate. (M171)

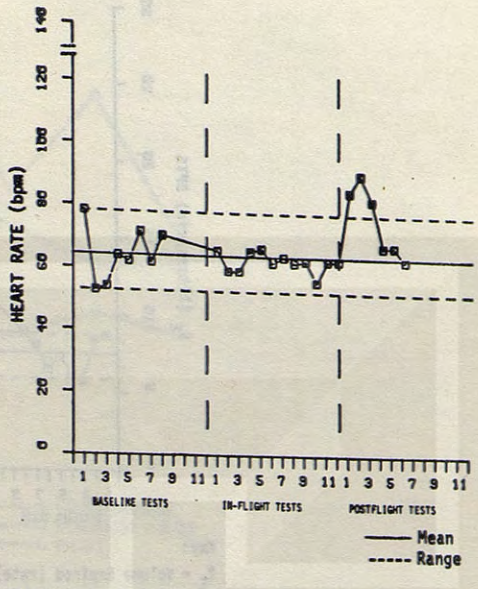



Figure 3.15-2. - SL-4 SPT Resting Heart Rate. (M171)

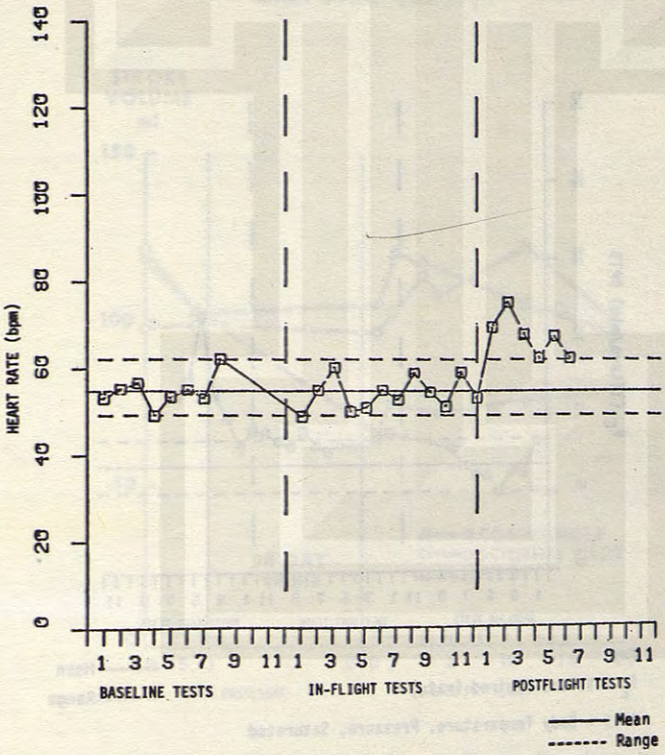
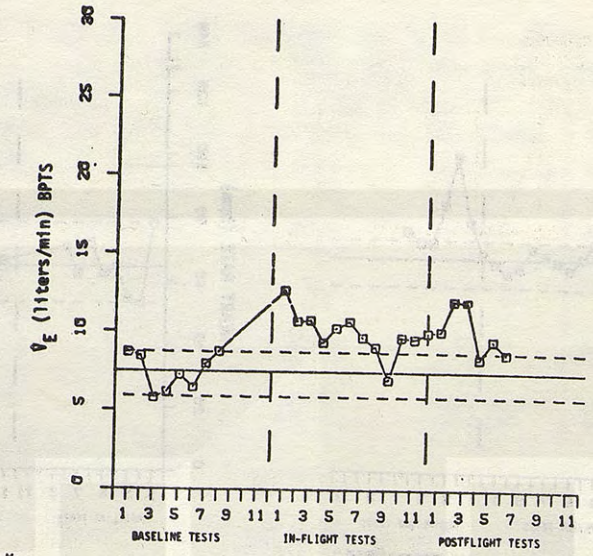



Figure 3.15-3. - SL-4 PLT Resting Heart Rate. (M171)




Key:

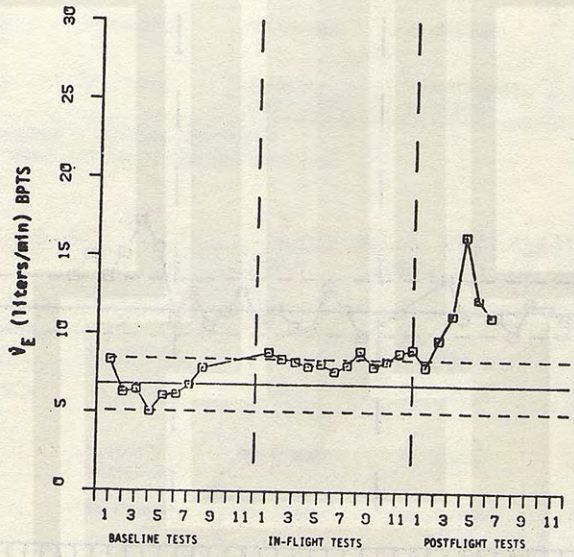
$\dot{V}_E$ = Volume Expired (rate)

BPTS = Body Temperature, Pressure, Saturated

——— Mean

------- Range

Figure 3.15-4. - SL-4 SPT Resting Minute Volume.




Key:

$\dot{V}_E$ = Volume Expired (rate)

BPTS = Body Temperature, Pressure, Saturated

——— Mean

-------Range

Figure 3.15.5. - SL-4 PLT Resting Minute Volume.

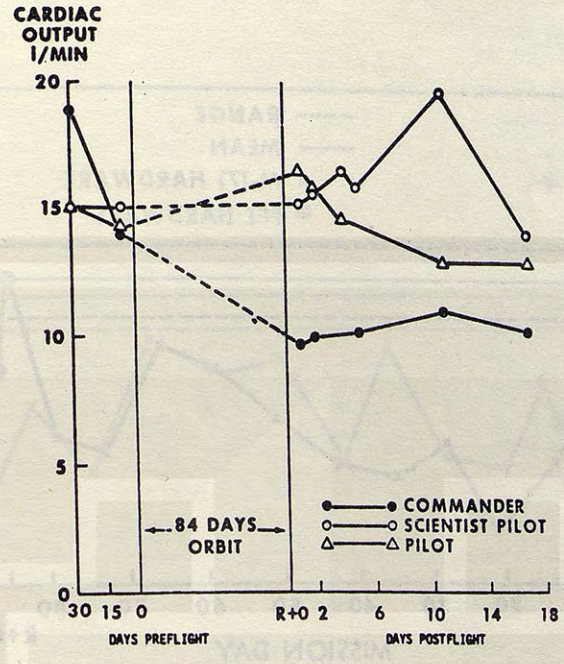



Figure 3.15-6. - Cardiac Output During Submaximal Exercise (SL-4).

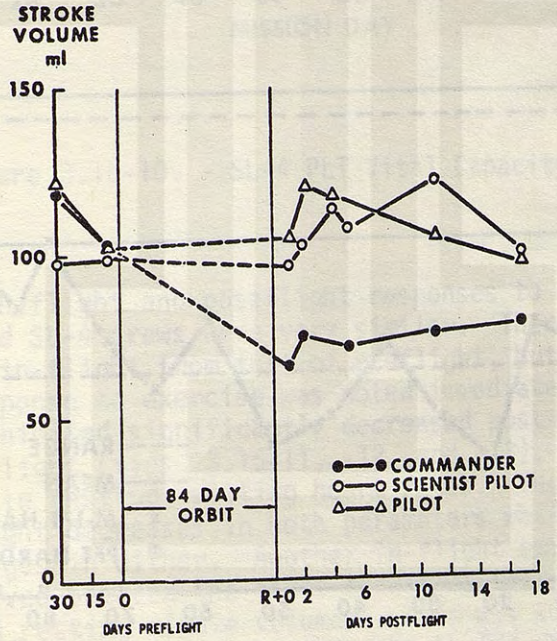



Figure 3.15-7. - Mean Stroke Volume During Submaximal Exercise (SL-4).

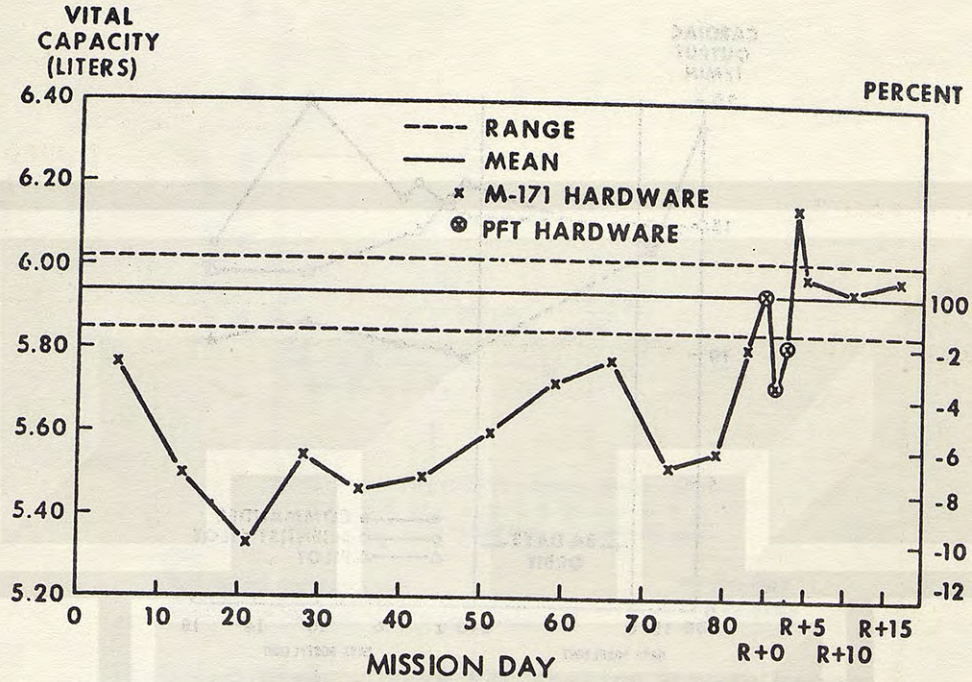



Figure 3.15-8. - SL-4 CDR Vital Capacity.

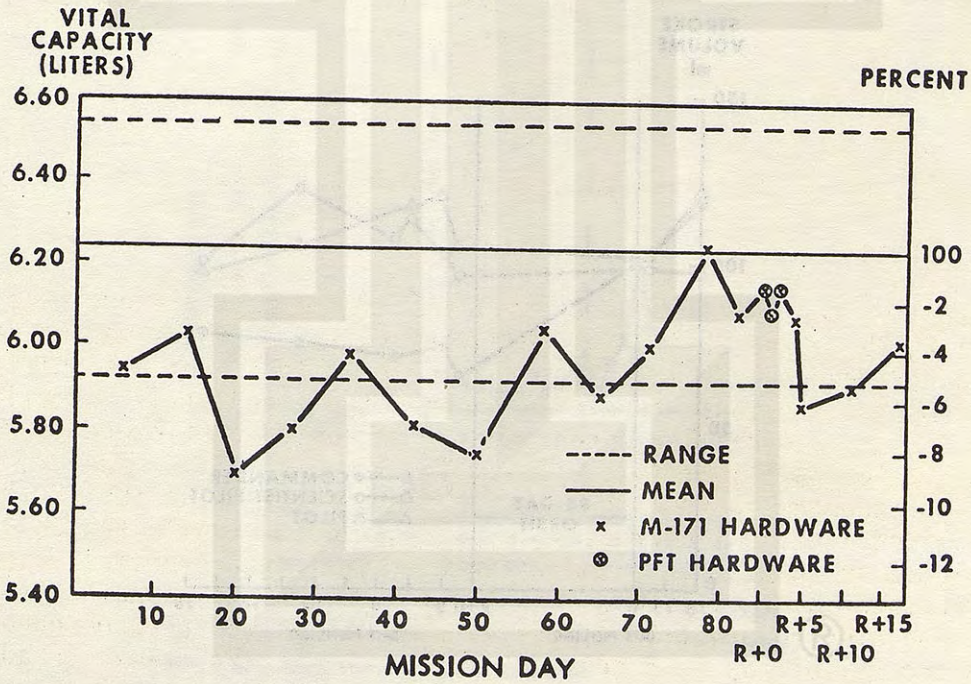



Figure 3.15-9. - SL-4 SPT Vital Capacity.

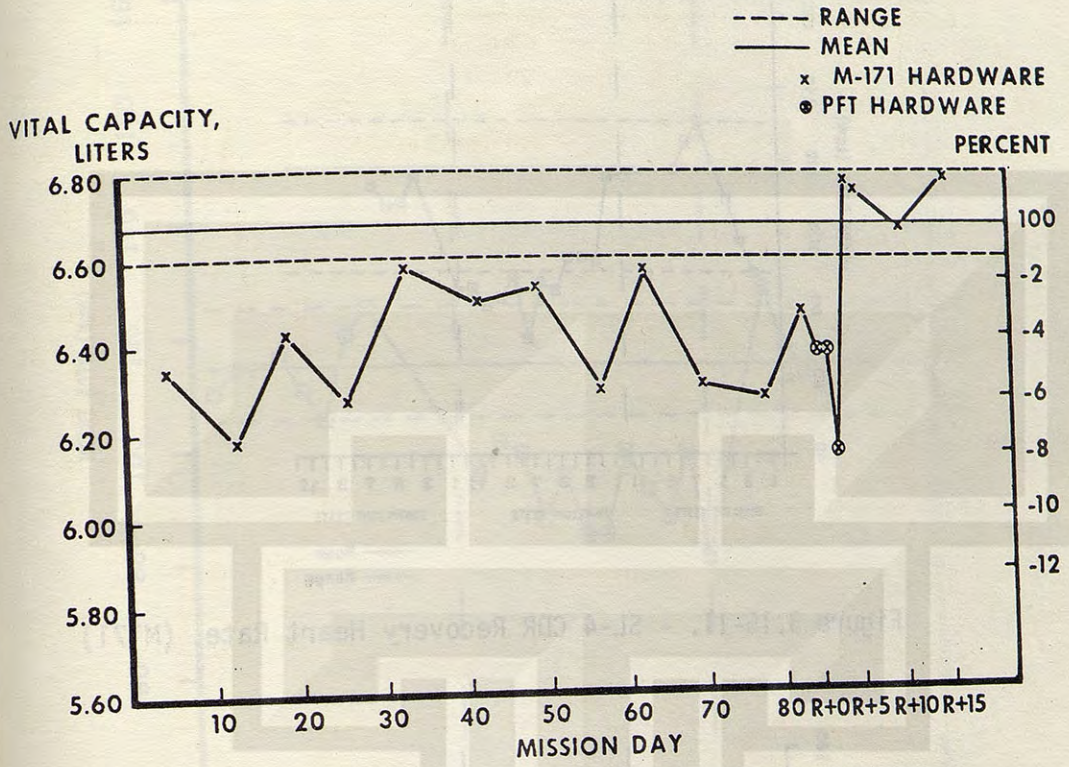



Figure 3.15-10. - SL-4 PLT Vital Capacity.

Discussion

Generally, the in-flight and postflight responses to exercise by the SL 1/2, SL-3, and SL-4 crews were very similar. There was no significant difference in-flight from that of preflight, but a significant decrement in response to exercise was noted immediately postflight. The SL-4 crew exhibited significantly decreased post-exercise recovery heart rates in-flight (figs. 3.15-11, -12, and -13). However, there were no changes in resting, sitting heart rates. The SL 1/2 crew exhibited in-flight decreases in both parameters while the SL-3 crew exhibted no changes in either. Another in-flight exercise response difference observed between the three crews was that the SL-4 SPT and PLT had elevated resting minute volumes. This was also observed in the CDR and PLT of the SL-3 crew but not in the SL 1/2 crew. In addition, most crewmen showed a trend toward decreased diastolic blood pressure during exercise in-flight.

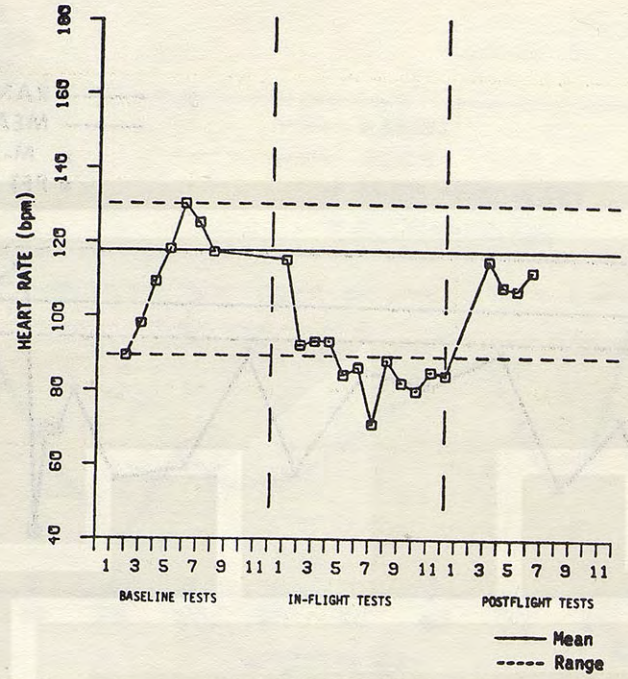



Figure 3.15-11. - SL-4 CDR Recovery Heart Rate. (M171)

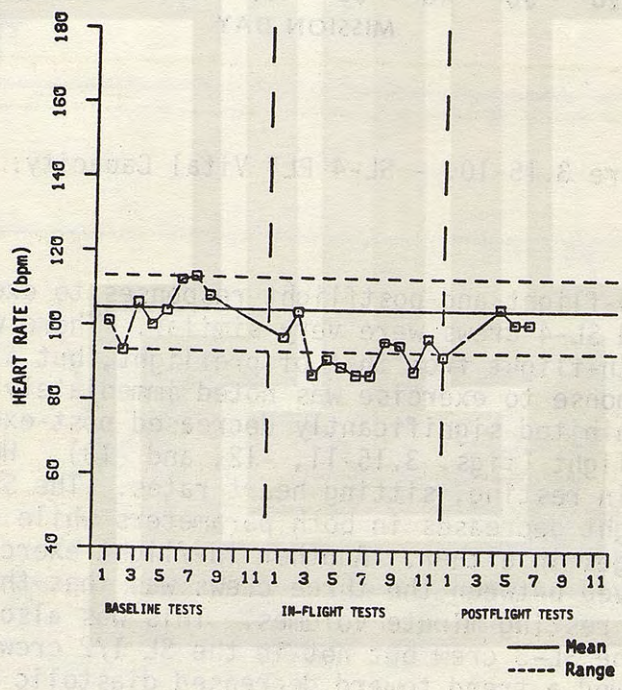



Figure 3.15-12. - SL-4 SPT Recovery Heart Rate. (M171)

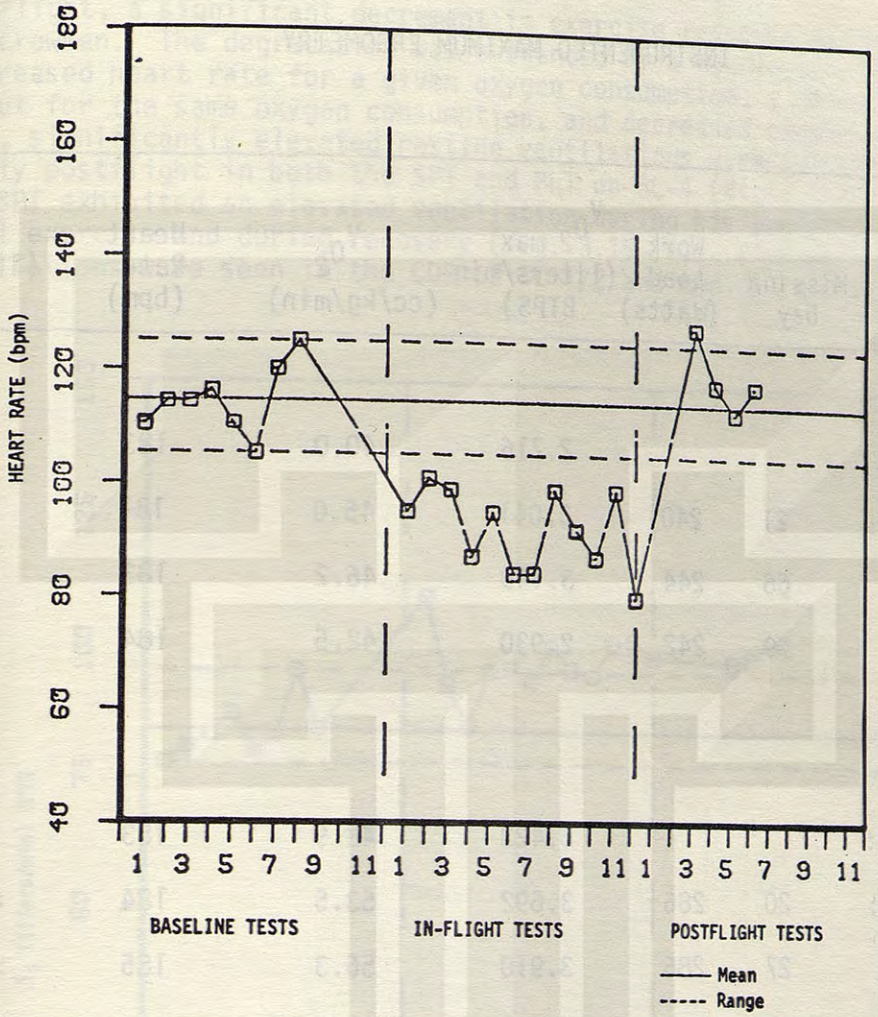



Figure 3.15-13. - SL-4 PLT Recovery Heart Rate.(M171)

Maximum effort in-flight ergometry with full M171 bioinstrumentation was performed by all SL-4 crewmen. The peak work loads (watts), $V_{O_2}$, heart rates, and minute volumes are summarized in table 3.15-IV, together with representative preflight data. All crewmen showed increased $\dot{V}_{O_2}$ max in-flight. It should be noted that these in-flight data for SPT and PLT may be slightly lower than actual because their minute volumes reached or exceeded the maximum measurement capability of the metabolic analyzer ($V_E \geq 150$ liters min, BTPS).

Table 3.15-IV

INSTRUMENTED MAXIMUM ERGOMETRY

| Crewman | Mission Day | Work Load (watts) | $\dot{V}_{O_2\ max}$ (liters/min BTPS) | $\dot{V}_{O_2}$ (cc/kg/min) | Heart Rate (bpm) | $\dot{V}_E$ (liters/min BTPS) |
|---|---|---|---|---|---|---|
| CDR | | | | | | |
| Preflight: | | | 2.716 | 40.0 | 183 | 083 |
| In-flight: | 21 | 240 | 3.041 | 45.0 | 181 | 106 |
| | 66 | 244 | 3.149 | 46.2 | 183 | 121 |
| | 79 | 242 | 2.930 | 42.5 | 184 | 115 |
| SPT | | | | | | |
| Preflight: | | | 3.423 | 48.9 | 183 | 089 |
| In-flight: | 20 | 286 | 3.692 | 53.5 | 184 | >142 |
| | 27 | 286 | 3.910 | 56.3 | 185 | >138 |
| | 42 | 286 | 3.855 | 55.3 | 183 | >150 |
| | 65 | 286 | 4.235 | 60.5 | 183 | >140 |
| | 82 | 286 | 3.801 | 54.2 | 185 | >147 |
| PLT | | | | | | |
| Preflight: | | | 3.182 | 47.0 | 183 | 119 |
| In-flight: | 63 | 244 | 3.584 | 53.8 | 183 | >150 |
| | 83 | 286 | 3.366 | 50.5 | 185 | >150 |

Postflight, a significant decrement in exercise response was noted in all crewmen. The degradation was evidenced by a decreased oxygen pulse (increased heart rate for a given oxygen consumption, a decreased cardiac output for the same oxygen consumption, and decreased stroke volume). Also, significantly elevated resting ventilations were evidenced immediately postflight in both the SPT and PLT on SL-4 (figs. 3.15-4 and -5). The SPT exhibited an elevated ventilation during his postflight third level exercise and during recovery (fig. 3.15-14). Elevated postflight ventilations were seen in the CDR of SL 1/2 and the CDR and PLT of SL-3.

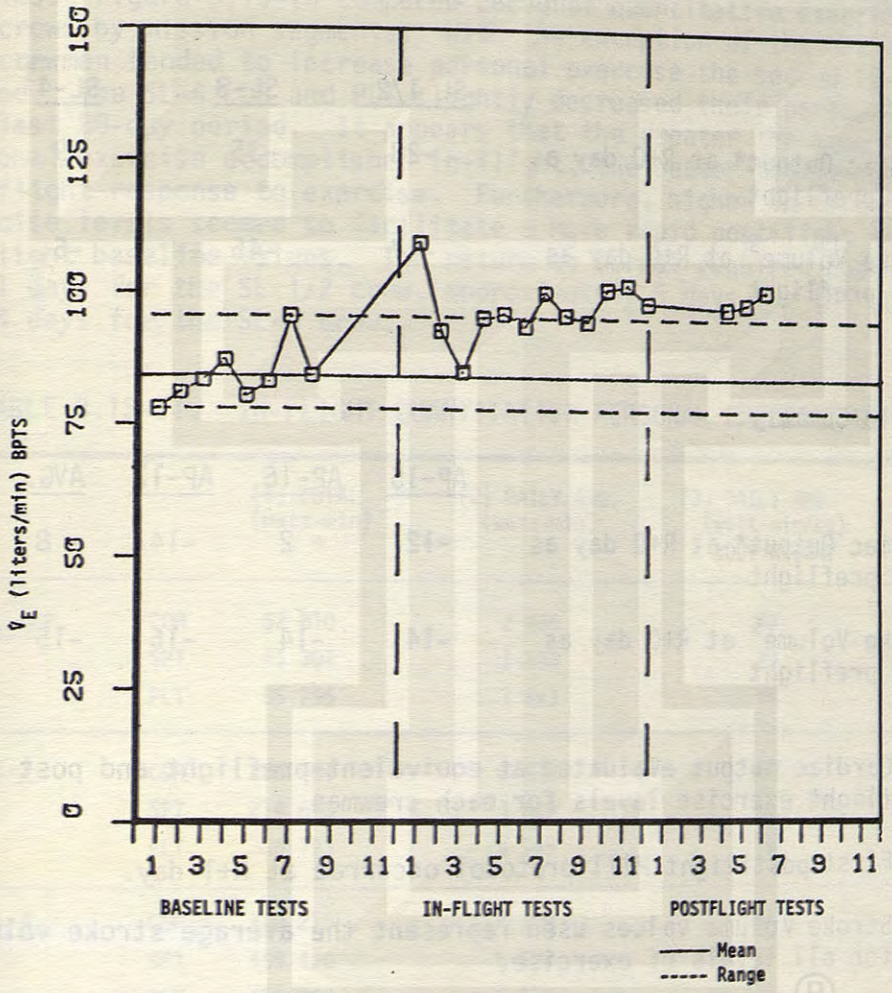



Figure 3.15-14. - SL-4 SPT Level 3 Exercise.(M171)

Table 3.15-V summarizes the Skylab cardiac output and stroke volume data together with those observed immediately postflight in the last Apollo missions. As can be seen, the SL-4 data closely resemble those obtained during postflight Apollo testing; however, this is misleading in that the CDR was the only SL-4 crewman who had decreased cardiac output and stroke volume. The CDR's values were essentially similar to those of SL 1/2 and SL-3 crewmen.

TABLE 3.15-V. SKYLAB EXERCISE CARDIAC OUTPUT DATA EVALUATION AS OF 3/7/74

| | SL 1/2 | SL-3 | SL-4† |
|---|---|---|---|
| Cardiac Output* at R+0 day as % of preflight | -28 | -35 | -9 |
| Stroke Volume§ at R+0 day as % of preflight | -47 | -45 | -6 |

Apollo Summary:

| | AP-15 | AP-16 | AP-17 | AVG. |
|---|---|---|---|---|
| Cardiac Output* at R+0 day as % of preflight | -12 | + 2 | -14 | - 8 |
| Stroke Volume§ at R+0 day as % of preflight | -14 | -14 | -16 | -15 |

* = Cardiac output evaluated at equivalent preflight and post flight exercise levels for each crewman.

† = First postflight M171 protocol occurred at R+1 day.

§ = Stroke volume values used represent the average stroke volume for all levels of exercise.

The levels of personal exercise accomplished by the SL-4 crew were higher than either of two previous crews. Table 3.15-VI compares the quantitative exercise (that done on the bicycle ergometer) accomplished by these crews. Reference to the far right column, showing these exercise data normalized to the crewman's body weight, reveals that the SL-3 crew exercised about 107% more than the SL 1/2 crew and the SL-4 crew 130% more than the 1/2 crew. As stated previously, these figures compare only quantitative bicycle ergometer exercise; additionally, the SL-3 crew exercised with a "mini-gym" and a metal spring set. The SL-4 crew used all these exercisers plus a "treadmill" which was added for their mission to provide a means of exercising some of the antigravity muscles. Figure 3.15-15 compares personal quantitative exercise of the crews by mission segments. With the exception of the SPT on SL-4, all crewmen tended to increase personal exercise the second 28-day period. The SL-4 CDR and PLT slightly decreased their personal exercise the last 28-day period. It appears that the greater the amount of personal exercise accomplished in-flight, the better the immediate postflight response to exercise. Furthermore, higher in-flight personal exercise levels seemed to facilitate a more rapid postflight return to preflight baseline values. The return to normal required approximately 18-21 days for the SL 1/2 crew, approximately 5 days for the SL-3 crew, and 4 days for the SL-4 crew.

TABLE 3.15-VI. IN-FLIGHT QUANTITATIVE PERSONAL EXERCISE SUMMARY

| | | (1) TOTAL (watt-min) | (2) DAILY AVG. (watt-min) | (3) DAILY AVG. (watt-min/kg) BODY WEIGHT | |
|---|---|---|---|---|---|
| SL 1/2 | CDR | 62 810 | 2 855 | 47 | |
| | SPT | 45 307 | 1 618 | 21 | 31 AVG. |
| | PLT | 55 795 | 1 993 | 26 | |
| SL-3 | CDR | 228 581 | 3 874 | 58 | |
| | SPT | 214 645 | 3 638 | 62 | 65 AVG. |
| | PLT | 386 193 | 6 545 | 75 | |
| SL-4 | CDR | 349 210 | 4 108 | 61 | |
| | SPT | 469 420 | 5 523 | 79 | 71 AVG. |
| | PLT | 414 760 | 4 879 | 74 | |

(1) Includes M171 Experiment Tests and Personal Exercise

(2) Based on 29-Day SL 1/2 Mission, 59-Day SL-3 Mission, and 84-Day SL-4 Mission

(3) Based on Mean In-Flight Body Weight

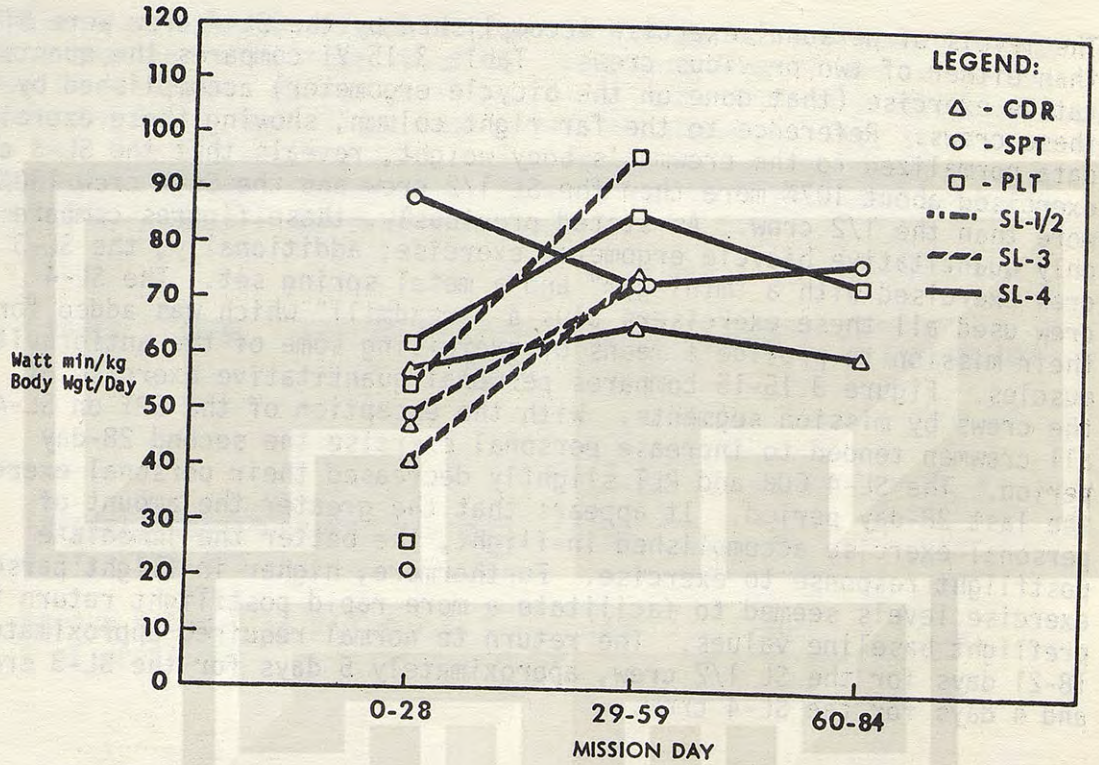



Figure 3.15-15. - Quantitative Exercise During Skylab.

It seems that the physiologic responses evidenced immediately postflight were a composite result of readaptation to one-g. It appears that these responses resulted principally from decreased venous return which in turn was due to an altered fluid balance/blood volume state with a possible reduction in venous vascular tone.

Upon exposure to the weightless environement, the crews have commented on a feeling of "fullness in the head" and sinus problems which never fully subsided during their stay in zero-g. The bicycle ergometer exercise provided subjective relief from this feeling of head fullness. Heavy leg exercise facilitated circulation in the lower extremities and apparently relieved their symptoms. It is evident that upon exposure to weightlessness some blood leaves the lower part of the body and is redistributed in the upper torso, perhaps explaining the reduced vital capacities which might result from engorgement of the pulmonary vessels with blood redistributed from the lower extremities.

## 3.16 Skylab 4 Pulmonary Function Testing

*Charles F. Sawin, Ph.D., Arnauld E. Nicogossian, M.D. and A. Paul Schachter, Ph.D.*

### Introduction

Comprehensive pulmonary function testing was done for the first time in the Skylab program during SL-4 preflight and postflight examinations. The purpose for these measurements may be concisely stated as follows:

- To provide supplementary information needed for rational interpretation of the single breath cardiac output data (ref. sec. 3.15, M171),
- To test the hypothesis that there is in-flight body fluid redistribution with possible increased pulmonary capillary blood volume, and
- To document postflight time course of return to preflight levels.

All pulmonary function tests were noninvasive and were designed to provide maximum information with minimum testing time (15 minutes per protocol). The resulting information consisted of:

- Static lung volumes (1, 6),
- Expiratory flow rates (2, 3, 9),
- Intrapulmonary gas distribution (7, 8), and
- Indirect measurement of small airway mechanics (4, 5, 10).

### Methods and Equipment

The pulmonary function test equipment layout is shown in figure 3.16-1. A metabolic analyzer (11) was modified to compute nitrogen production. Aviator oxygen was supplied to the inspiration spirometer through a standard oxygen demand regulator. These modifications permitted residual volume determinations by open circuit washout of pulmonary nitrogen during oxygen breathing.

A respiratory mass spectrometer monitored $P_{N_2}$ continuously at the mouthpiece assembly. An XY plotter provided continuous $P_{N_2}$ (ordinate) as a function of time (abscissa) during residual volume measurements.

An analog tape recorder was used to provide a permanent record of the flow, nitrogen production rate, and volume.

A stripchart recorder was used to provide a tape system for the data to provide an adequacy of the data.

Closing volumes were measured by respective equipment. The equipment has been proposed for use in the Skylab in the way mechanical equipment was used in the single-breath method.

In addition, a digital voltmeter was used to permit digitization of the data.

Residual volumes were measured by the subject's breathing through the measurement of the maximum inspiration and the primary expiration.

## Results

The primary results of the pulmonary function test on F-10, R+0 day, and PLT are shown and PLT are shown. These data are shown.

CDR - The CDR was the first single subject. Principal differences were on R+0 day. The measurement were within.

SPT - The SPT to his F-10 and the results are not abr.

Ventilatory appeared to ations.

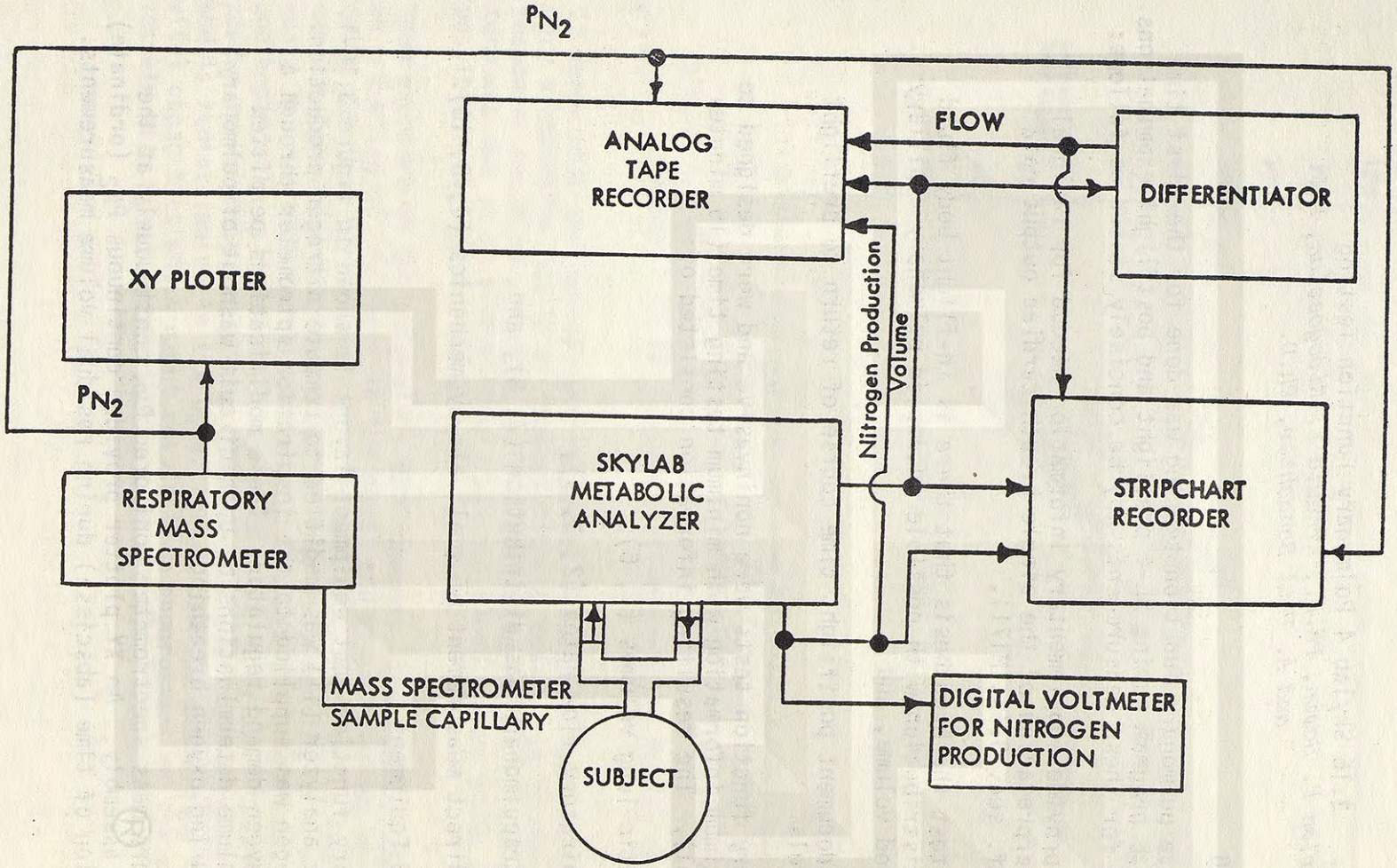



Figure 3.16-1. - Pulmonary Function Test Equipment.

An analog tape recorder was used during all testing to provide a permanent record of $P_{N_2}$ at the mouthpiece assembly, tidal volume, flow rate, and nitrogen production.

A stripchart was used to record the same parameters as the analog tape system. This record permitted immediate assessment of the adequacy of the prior measurement/maneuver.

Closing volume (CV) and closing capacity (CC), together with their respective ratios to the vital and total lung capacities (TLC), have been proposed as a sensitive means for detecting changes in small airway mechanics. For this reason, closing volumes were determined by the single breath oxygen washout technique.

In addition, slow and forced vital capacities (VC, FVC) were measured to permit calculation of commonly reported flow and volume parameters.

Residual volume (RV) and closing volume measurements were made with the subject in the sitting position. All slow and forced vital capacity measurements were made with the subject standing. This permitted maximum inspiratory and expiratory maneuvers with subject effort being the primary variable.

Results

The primary and derived measurements obtained during the SL-4 pulmonary function testing are shown in table 3.16-I. The tests were performed on F-10, R+0, R+1, R+2, and R+5 days. Reduced data for the CDR, SPT, and PLT are presented in tables 3.16-II, -III, and -IV, respectively. These data are best summarized for each crewman as follows:

CDR - The CDR exhibited a vasovagal response on R+0 days during his first single breath $N_2$ washout test. This had been anticipated by the Principal Investigators and was handled by the medical staff without major difficulty. No further pulmonary function testing was performed on R+0 day. A hardware failure in the metabolic analyzer prevented measurment of CDR's RV on R+1 day. All other data obtained for CDR were within normal ranges.

SPT - The SPT had slightly increased RV on R+0 and R+2 days relative to his F-10 day control value. The small absolute value of this increase and the resultant RV/TLC percent indicate that these increased values are not abnormal.

Ventilatory equivalent ($V_A$/RV) for the SPT was quite variable. This appeared to be a reflection of variable tidal volume during RV determinations.

PLT - All data were extremely consistent and on the high side of normal in the case of VC and flow rates.

Table 3.16-I. SL-4 PULMONARY FUNCTION TESTING

| MEASUREMENT | INFORMATION OBTAINED |
|---|---|
| 1) RESIDUAL VOLUME BY OXYGEN WASHOUT OF PULMONARY NITROGEN | ° RV<br>° TOTAL LUNG CAPACITY (RV + VC)<br>° VENTILATORY EQUIVALENTS ($V_A$/RV) |
| 2) SINGLE BREATH PULMONARY NITROGEN WASHOUT WITH OXYGEN | ° DISTRIBUTION OF INSPIRED GAS<br>° STATUS OF SMALL AIRWAYS<br>° CLOSING VOLUME<br>° CV/VC AND CC/TLC |
| 3) SLOW VITAL CAPACITY | ° VC |
| 4) FORCED VITAL CAPACITY | ° FVC/VC%<br>° $FEV_{1-SEC}$<br>° MMFR (25-75% FVC)<br>° MEFR<br>° $\dot{V}$ (60% TLC) |

MEFR = Maximum Expiratory Flow Rate

TABLE 3.16-II. SL-4 RESULTS OF PULMONARY FUNCTION TESTS

CDR

| PARAMETER | Time, Day(s) F-10 | R+0 | R+1 | R+2 | R+5 |
|---|---|---|---|---|---|
| Height cm | 175 | | | | |
| Weight kg | 70 | | | | |
| B.S.A. $m^2$ | 1.85 | | | | |
| VC (liters) | 5.83 | 5.94 | 5.72 | 5.82 | 5.94 |
| RV (liters) | 1.40 | 1.53 | -- | 1.31 | 1.43 |
| TLC (liters) | 7.23 | 7.47 | -- | 7.13 | 7.37 |
| RV/TLC (%) | 20 | 21 | -- | 18 | 19 |
| TV (liters/breath) | 1.07 | 1.20 | 1.00 | 1.15 | 0.92 |
| $V_A$/RV | 30 | 23 | -- | 33 | 16 |
| FVC (liters) | 5.61 | -- | 5.56 | 5.71 | 6.05 |
| FVC/VC (%) | 99 | -- | 97 | 98 | 102 |
| $FEV_1$ (liters/sec) | 4.62 | -- | 4.29 | 4.59 | 4.70 |
| $MMFR_{25-75}$(l/sec) | 4.32 | -- | 4.30 | 4.39 | 4.14 |
| MET (sec) | 0.65 | -- | 0.64 | 0.65 | 0.73 |
| MEFR (liters/sec) | 12.4 | -- | 12.0 | 12.4 | 12.3 |
| $\dot{V}$ (60% TLC) (l/sec) | 4.74 | -- | 3.88 | 4.61 | 5.50 |
| CV (liters) | 0.80 | 0.88 | 0.83 | 0.56 | 0.76 |
| CC (liters) | 2.20 | 2.41 | -- | 1.87 | 2.18 |
| CV/VC (%) | 14 | 15 | 16 | 10 | 13 |
| CC/TLC (%) | 30 | 32 | -- | 28 | 30 |

TABLE 3.16-III. SL-4 RESULTS OF PULMONARY FUNCTION TESTS

SPT

| PARAMETER | Time, Day(s) F-10 | R+0 | R+1 | R+2 | R+5 |
|---|---|---|---|---|---|
| Height cm | 175 | | | | |
| Weight kg | 70 | | | | |
| B.S.A. $m^2$ | 1.84 | | | | |
| VC (liters) | 6.11 | 6.16 | 6.00 | 6.16 | 6.26 |
| RV (liters) | 1.53 | 2.18 | 1.27 | 2.43 | 1.65 |
| TLC (liters) | 7.64 | 8.28 | 7.27 | 8.59 | 7.92 |
| RV/TLC (%) | 20 | 26 | 18 | 28 | 21 |
| TV (liters/breath) | 2.48 | 2.83 | 1.87 | - - | 1.48 |
| $V_A$/RV | 48 | 28 | 48 | 27 | 16 |
| FVC (liters) | 5.83 | 5.77 | 5.39 | 5.88 | 6.21 |
| FVC/VC (%) | 96 | 94 | 90 | 96 | 99 |
| $FEV_1$ (liters/sec) | 4.35 | 4.61 | 4.24 | 4.37 | 4.54 |
| $MMFR_{25-75}$(l/sec) | 3.17 | 5.15 | 3.69 | 3.43 | 3.65 |
| MET (sec) | 0.92 | 0.56 | 0.73 | 0.86 | 0.85 |
| MEFR (liters/sec) | 10.5 | 11.0 | 10.5 | 10.9 | 10.8 |
| $\dot{V}$ (60% TLC) (l/sec) | 3.70 | 4.74 | 3.67 | 3.73 | 4.87 |
| CV (liters) | 1.02 | 0.99 | 0.99 | 0.49 | 0.81 |
| CC (liters) | 2.55 | 3.18 | 2.26 | 2.92 | 2.46 |
| CV/VC (%) | 17 | 16 | 17 | 8 | 13 |
| CC/TLC (%) | 33 | 38 | 31 | 34 | 31 |

TABLE 3.16-IV. SL-4 RESULTS OF PULMONARY FUNCTION TESTS

PLT

| PARAMETER | Time, Day(s) F-10 | R+0 | R+1 | R+2 | R+5 |
|---|---|---|---|---|---|
| Height cm | 175 | | | | |
| Weight kg | 69.5 | | | | |
| B.S.A. $m^2$ | 1.84 | | | | |
| VC (liters) | 6.49 | 6.38 | 6.38 | 6.05 | 6.64 |
| RV (liters) | 2.20 | 1.67 | 2.00 | 2.20 | 1.53 |
| TLC (liters) | 8.69 | 8.05 | 8.38 | 8.24 | 8.17 |
| RV/TLC (%) | 26 | 21 | 24 | 27 | 19 |
| TV (liters/breath) | 2.23 ??? | 0.92 | 0.94 | 0.82 | 0.80 |
| $V_A$/RV | 23 | 21 | 17 | 18 | 16 |
| FVC (liters) | 6.22 | 6.22 | 5.72 | 6.27 | 6.32 |
| FVC/VC (%) | 96 | 97 | 90 | 104 | 95 |
| $FEV_1$ (liters/sec) | 5.50 | 5.50 | 5.39 | 5.49 | 5.29 |
| $MMFR_{25-75}$(l/sec) | 6.61 | 7.06 | 7.73 | 6.82 | 5.10 |
| MET (sec) | 0.47 | 0.44 | 0.37 | 0.46 | 0.62 |
| MEFR (liters/sec) | 11.6 | 11.6 | 11.0 | 12.2 | 11.4 |
| $\dot{V}$ (60% TLC) (l/sec) | 7.76 | 7.55 | 7.33 | 7.46 | 5.72 |
| CV (liters) | 0.72 | 0.89 | 0.50 | 0.45 | 0.59 |
| CC (liters) | 2.91 | 2.56 | 3.43 | 2.64 | 2.12 |
| CV/VC (%) | 11 | 14 | 8 | 7 | 9 |
| CC/TLC (%) | 34 | 32 | 32 | 33 | 25 |

## Discussion

No significant decrement in pulmonary function was shown by any crewman during any examination. It should be mentioned that the reserve capacity of the pulmonary system is extremely high and subtle changes may have gone undetected by the standard clinical methods employed in these examinations.

Vital capacity was the only parameter measured preflight, in-flight and postflight. Minor decreases in vital capacity were observed in-flight (ref. sec. 3.15, M171). These decreases likely resulted from a cervical shift of the diaphragm, body fluid redistribution, or a combination of both. Based upon our data we can state that in-flight changes, if any, returned to normal in a short time postflight without any significant impact on crew health status.

The instrumented personal exercise data obtained in-flight for all crewmen provided indirect evidence that there was no serious in-flight disturbance in pulmonary function. $\dot{V}_E$ max data for all crewmen were higher in-flight than preflight, probably as a result of decreased air density in-flight, which in turn led to more laminar respiratory gas flow. A second contributing factor may have been an increased ventilatory requirement resulting from decreased convective cooling in the less dense, low air flow Skylab environment.

In the future, in order to document pulmonary function in the weightless environment, it will be desirable to conduct in-depth in-flight testing. Additional measurements would be desirable in order to study ventilation-perfusion relationships. These are expected to change with the removal of the dependent regions in the thoracic cavity concomitant with exposure to zero-g. The improvement in $\dot{V}O_2$ max observed for all SL-4 crewmen in-flight may represent a summation of physical training effects and improved ventilation-perfusion relationships.

In summary, it was clearly shown that an 84-day, zero-g normoxic exposure was well tolerated by all crewmen with respect to pulmonary function. However, one must remember that these crewmen maintained vigorous daily personal exercise programs throughout the mission and for this reason their successful adaptation does not preclude difficulty in more sedentary passengers proposed for future Shuttle flights.

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# 4.0 MEDICAL EXPERIMENTS HARDWARE AND BIOMEDICAL OPERATIONAL EQUIPMENT FOR SKYLAB 4

# 4.0 MEDICAL EXPERIMENTS HARDWARE AND BIOMEDICAL OPERATIONAL EQUIPMENT FOR SKYLAB 4

## 4.1 Skylab Biomedical Experiments Hardware Performance

*William J. Huffstetler*

The series of biomedical experiments planned for the third manned mission were accomplished as planned, with additional approved special tests in some cases.

All biomedical experiment hardware performed nominally with only minor intermittent problems.

Experiment M074/M172 - Specimen and Body Mass Measurement

Two experiment M074 (specimen mass measuring) devices were utilized to measure masses of fecal samples and food residues. Body mass measuring (M172) was accomplished daily by each crewman.

In-flight calibration of each mass measuring device was accomplished three times during the mission. Three of the four M074 mass measuring device calibration weights were misplaced early in the mission leaving two point (zero and 500 gram) calibration for this device. No degradation in calibration was noted in any of the mass measuring devices during the mission.

On MD 78, the crew reported the thumb release mechanism inoperative on the M172 device requiring use of the side release lever for actuation.

On MD 81, the rubber specimen restraint separated from the frame on the M074 device located in the waste management compartment. The M074 unit located in the wardroom was utilized for the remaining three days of the mission.

Experiment M092 - Lower Body Negative Pressure

Experiment M092 was performed on the CDR and SPT 22 times and on the PLT 23 times. Special testing in conjunction with M092 was also conducted as detailed test objectives. Infrared facial photographs during M092 were accomplished six times on the CDR and PLT and five times on the SPT. Post M092 limb blood flow testing was performed seven times on the CDR and PLT and six times on the SPT.

Vacuum source modifications of M092 were accomplished prior to the first experiment run. This modification allowed the M092 lower body negative pressure device vacuum source to be provided from the SIVB

LOX tanks through a crew plumbing modification. The effect of this modification was to preclude propulsive venting vehicle disturbances noted during previous missions. Operation of this system was satisfactory throughout the mission.

On MD 37, a reference leg band (designated AX) exhibited off-scale high readings and was subsequently replaced with a backup band.

On MD 75, the crew was unable to obtain blood pressure readings utilizing blood pressure cuff SN 011. The problem was attributed to a broken lead in the microphone and a backup cuff was utilized during the remainder of the mission.

Experiment M093 - Vectorcardiogram

Experiment M093 was conducted nine times for each crewman specifically per experiment protocol. Runs of M171 provided the necessary vectorcardiogram data to satisfy M093 requirements another 12 times for each crewman, thus providing 21 M093 data points per crewman.

No hardware problems were evident during the conduct of M093 experimentation.

Experiment M110 - In-flight Blood Collection

Blood withdrawal and centrifugal separation of plasma was accomplished eight times per crewman. Special blood hemoglobin determinations were performed nine times and urine specific gravity tests were accomplished four times. No hardware problems occurred relative to the M110 blood collection.

Experiment M131 - Human Vestibular Function

Oculogyral illusion testing was performed six times on each crewman. Spatial localization tests were run twice on the SPT and three times each on the CDR and PLT. Motion sensitivity tests were accomplished six times by the CDR and five times by the SPT. No hardware problems were encountered during any of the test operations.

Experiment M133 - Sleep Monitoring

Experiment M133, originally scheduled for eight runs, was actually conducted 18 times during the mission. This increase in number of tests required double and in some cases triple usage of the electrode cap assemblies. The SPT refilled the previously used electrodes with electrolyte each second (and in some cases third) run with ground data indicating completely acceptable results.

On MD 15, the SPT reported erratic calibration check readings when the preamplifier cable was moved. The cable was replaced with a spare and operation was satisfactory.

Experiment M151 - Time and Motion Study

All photography was accomplished with the exception of one M509 (Astronaut Maneuvering Unit) run. Four M092/M093/M171 experiment runs were photographed over and above M151 experiment requirements.

Experiment M171 - Metabolic Activity

Twelve M171 runs per crewman were accomplished. The ergometer additionally was utilized on a daily basis by each crewman for exercise.

All hardware associated with M171 functioned nominally throughout the mission.

## 4.2 Biomedical Operational Evaluation

*William J. Huffstetler and William H. Bush*

### 4.2.1 Food

The extension of the third visit to 84 days required 146 pounds of additional food to be launched to support the mission. Because of launch weight restrictions, the Skylab menus for the 28 additional days were modified to include new high caloric density foods and to make maximum use of foods available on the Orbital Workshop. To provide a 10-day contingency rescue capability at the end of the extension, 21.5 pounds of survival bars were also launched.

A resupply of salt was required due to increased consumption of salt on the first and second missions. Crystal salt was packaged in modified Apollo beverage packages. Salt was rehydrated in-flight and syringes were used to dispense the rehydrated salt as required by the crew menus and the M070 experiment.

As a result of previous crew experiences with conventional shaker and bottle-type condiment dispensers, a dispenser with a collapsible inner bag was designed to be used for liquid pepper, Tabasco sauce, and liquid garlic. Powdered horseradish was provided in an Apollo rehydratable spoon bowl package.

The Skylab Food System and ancillary equipment experienced problems in several areas.

Rehydratable Package problems were:

- Seepage through the zipper closure on the spoon bowl package, when kneading.
- Spontaneous closing of spoon bowl package during meals caused food particles to be released into the air.
- Split of one rehydration valve tube because the water passage hole was either omitted or heat sealed shut during manufacture.

Beverage Package problems were:

- Mislabelling of four black coffee items as coffee with sugar.
- The tension of the bellows (body) tended to expand the package and introduce gas into the beverage.

- Lid seam failures were reported in one can of pineapple and one can of peanut butter.

- The salt dispenser nozzle plugged with dried salt causing one salt dispenser bag to split when force was applied in an attempt to remove the salt solution from the bag.

- Surface tension caused the liquid pepper to cling to the outside of the dispenser nozzle instead of dispensing in a stream.

Specific items noted by the crew were:

- The chili was messy.

- A need for more ready-to-eat, quick energy-type foods.

- The liquid pepper could be used by dispensing the liquid on the back of a spoon and then spreading it on the food.

- Liquid condiments worked best when dispensed from a syringe-type device similar to the salt dispenser.

The following items were left on board the OWS at the end of the third manned mission:

| Food Item | Quantity |
|---|---|
| Applesauce | 2 |
| Asparagus | 28 |
| Beef hash | 5 |
| Biscuit | 1 |
| Bread | 23 |
| Butterscotch pudding | 2 |
| Catsup | 22 |
| Chicken and Gravy | 2 |
| Coffee with Sugar | 18 |
| Creamed Peas | 7 |
| Cream Style Corn | 24 |
| German Potato Salad | 2 |
| Grape Drink | 10 |
| Grapefruit Drink | 0 |
| Green Beans | 12 |
| Lemonade | 16 |
| Macaroni and Cheese | 1 |
| Mashed Sweet Potatoes | 3 |
| Pea Soup | 1 |
| Peach Ambrosia | 5 |

| Food Item | Quantity |
|---|---|
| Peaches | 1 |
| Pears | 1 |
| Pineapple | 1 |
| Pork and Scalloped Potatoes | 1 |
| Potato Soup | 1 |
| Rice Krispies | 1 |
| Scrambled Eggs | 1 |
| Shrimp Cocktail | 11 |
| Sliced Dried Beef | 1 |
| Spaghetti with Meat Sauce | 3 |
| Stewed Tomatoes | 2 |
| Sugar Coated Corn Flakes | 1 |
| Tea with Lemon and Sugar | 5 |
| Tuna Sandwich Spread | 13 |
| Turkey and Gravy | 1 |
| Turkey Rice Soup | 5 |
| Veal and Barbeque Sauce | 8 |
| Grape Drink (A) | 1 |
| Survival Bar | 120 |

As originally proposed, the Skylab Food System was designed to provide 128 crew days of food in the OWS and five crew days of food in each Command Module (one crew day includes three meals plus snacks for three crewmen) plus 20% excess food on a calorie basis.

At the completion of the third mission, the food system had performed reliably and had, by launching approximately 150 pounds (68.1 kg) extra food, supported 31 additional extended-mission days. In addition to the mission extensions, the average caloric intake for all nine crewmen was approximately 250 calories per man per day greater than planned. Excluding the catsup package failures, the failure rate on all missions was less than 0.1 percent.

### 4.2.2 In-flight Medical Support System

No problems were encountered relative to in-flight medical support system hardware.

### 4.2.3 Operational Bioinstrumentation System

The operational bioinstrumentation was utilized during launch, EVA, M590 suited runs and entry with satisfactory electorcardiogram and impedance pneumograph data obtained. No data loss occurred.

### 4.2.4 Exercise

The Mark I exerciser sustained three return spring failures during this mission. The first two on mission days 19 and 74 were corrected by the crew through replacement of the return spring. The final spring failure on MD 80 was not repairable and usage of the unit was discontinued for the remaining four days of the mission.

### 4.2.5 Atmospheric Analysis

An atmospheric volatile concentration measurement device was utilized on this mission for the first time. This device collected and trapped volatile organic molecules from the workshop environment in small tubes. The tubes were subsequently capped and returned for quantitative analysis. At this time, samples from the beginning, middle and end of mission have been subjected to high resolution gas chromatographic analysis. The samples indicate the presence of at least 150 organic volatile compounds. The term "volatile compounds" refers to those chemicals which can be desorbed from the porous polymer in the sample tubes and can be chromatographed directly at 175°.C. In essence, this means that compounds which are not gases under normal conditions can be separated and detected at the parts per billion level. These consist of chemicals (aldehydes, ketones, alcohols, and hydrocarbons) of molecular weight range up to 200. Mass spectrometric analysis is presently underway to determine concentration of these compounds.

# 5.0 RECOMMENDATIONS AND CONCLUSIONS: POST SKYLAB 4

# 5.0 RECOMMENDATIONS AND CONCLUSIONS: POST SKYLAB 4

*J. R. Hordinsky, M.D.*

## 5.1 Recommendations

- Crew Surgeons should have a co-equal vote with the Flight Directors on a crew status board, or before the FMT.

- The MOCR Surgeons must be given instructions in all the Skylab hardware and experiments in the preflight period, especially in performance, the unique stresses involved, and unique human factors problems. The instructions must be coordinated by LSD and the appropriate program office.

- The interface between LSD and the BEO/Med Systems/Med-Data people (all Flight Ops Directorate personnel) must be defined more clearly. Flight operations personnel must not look upon the MMT as an absolute necessity for approval, as any MOCR Surgeon should be explicitly charged with the authority to effect decisions in real-time.

- Crew Surgeons must have mission communication monitoring capability at their offices and at their homes. Continued Comm capability with the crew should be maintained on the Recovery Ship. Private Comm capability should be possible from the Crew Surgeons' homes.

- The Crew Surgeon should be provided independent data handling support.

- Any data that needs charting or graphing for crew health evaluations should be as near real-time as possible.

- There should be an actively maintained call schedule of medical and experiment consultants to allow for better real-time decision making.

- Choice of brands of drugs and of monitoring of packaging of medical equipment must be more closely supervised by the operational medicine people.

- Checking medical equipment function in zero-g must have the same priority status as any medical experiment.

- In-flight mandatory medical monitoring could safely be reduced to seven days.

- Exercise periods of 1.5 hours should be continued, with better devices and systematization of protocols required.

- Onboard flight planning is the preferred method, with ground providing a long-term recommendation of tasks, surveillance of performance, and tabulations of achievements.

- Onboard personnel should include at least one medical doctor, or highly trained paramedic, with one other person trained in basic emergency functions as a backup to this prime medical person.

- Improvements of onboard hygiene and habitability levels must be continued per the various crews' inputs.

- Recovery day protocol should continue to be reduced; a 4-hour maximum is recommended.

## 5.2 Conclusions from the Mission

- Physiological stability was well maintained throughout the 84-day flight, and in the postflight period.

- The Crew Surgeon-Deputy Crew Surgeon task force orientation is excellent for coordinating and monitoring crew activities. Three-day sequences on duty for the Crew Surgeon followed by a three-day sequence for the Deputy Crew Surgeon is a very workable arrangement even for missions of 84-day duration or longer.

- The efficacy of antimotion sickness medications is not established either for the onset or the termination of a flight.

- Single block circadian shifts are easiest to effect physiologically and operationally.

- Whenever many laboratories or large numbers of equipment items are involved, a separate coordinator is extremely useful preflight and at recovery.

- Although much valuable experimental and operationaly useful data was provided by the onboard medical experiments (as well as supplementing preflight and postflight experiments), extensive experimentation is still needed to define the physiological changes induced by zero-g as well as to determine the efficacy of simulated gravity, partial or full one-g, even intermittently, for arresting the observed changes and improving the subjective feeling and work capability for prolonged space flights.

# APPENDIXES

## APPENDIX A - ACRONYMS AND ABBREVIATIONS

## ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| A/G | Air-to-Ground |
| ALSA | Astronaut Life Support Assembly |
| AM | Airlock Module |
| ASP | Automatic Sample Processor |
| ATM | Apollo Telescope Mount |
| A-V | Atrioventricular |
| BASO | Basophil |
| b.i.d. | Twice a day |
| BMMD | Body Mass Measuring Device |
| BP | Blood Pressure |
| bpm | Beats per minute |
| BPMS | Blood Pressure Measuring System |
| BT | Burn Time |
| BTMS | Body Temperature Measuring System |
| BTPS | Body Temperature, Pressure, Saturated |
| CAAD (CAD) | Computation and Analysis Division |
| CBRM | Charger/Battery/Regulator/Module |
| CDR | Commander |
| CM | Command Module; Center of Mass |
| CM/SM | Command Module/Service Module |
| CO | Carbon Monoxide |
| $CO_2$ | Carbon Dioxide |
| COMM | Communication |
| CPD | Crew Passive Dosimeter |
| CRP | C-reactive protein |
| CSD | Crew Systems Division |
| CSM | Command and Service Module |

ACRONYMS AND ABBREVIATIONS (cont.)

| | |
|---|---|
| DAC | Data Acquisition Camera |
| DB | Biomedical Research Division |
| ECG | Electrocardiogram |
| e.d.t. | Eastern Daylight Time |
| EDTA | Ethylenediaminetetracetic Acid |
| EEG | Electroencephalogram |
| EMG | Electromyogram |
| EMU | Extravehicular Mobility Unit |
| EO | Eosinophil |
| EOG | Electro-oculogram |
| EPS | Electrical Power System; Electron-Proton Spectrometer |
| ESS | Experiment Support System |
| EVA | Extravehicular Activity |
| EV2 | Identification of Extravehicular Crewman |
| F | Flight |
| F- | Preflight |
| FCOD | Flight Crew Operations Directorate |
| F-0 | Launch Day |
| FAS | Fixed Airlock Shroud |
| FCHSP | Flight Crew Health Stabilization Program |
| FCS | Flight Control System; Food Containment System |
| FMT | Flight Management Team |
| FOD | Flight Operations Directorate |
| G.E.T. | Ground Elapsed Time |
| G.m.t. | Greenwich Mean Time |
| Hb | Hemoglobin |
| HCT | Hematocrit |
| HHMU | Hand-held Maneuvering Unit |
| HR | Heart Rate |
| IBCS | In-flight Blood Collection System |

ACRONYMS AND ABBREVIATIONS (cont.)

| | |
|---|---|
| IMSS | Inflight Medical Support System |
| IR Sensitivity | Infrared Sensitivity |
| IVA | Intravehicular Activity |
| IV/CSM | Intravehicular/Command Service Module |
| J | Joules |
| JSC | Lyndon B. Johnson Space Center |
| K | Potassium |
| KSC | John F. Kennedy Space Center |
| LBNP | Lower Body Negative Pressure |
| LBNPD | Lower Body Negative Pressure Device |
| LCG | Liquid Cooled Garment |
| LEB | Lower Equipment Bay |
| LPH | Landing Platform Helicopter |
| LSD | Life Sciences Directorate |
| LSU | Life Support Umbilical |
| LVMS | Leg Volume Measuring System |
| MA | Metabolic Analyzer |
| MAK | Medical Accessory Kit |
| MAP | Mean Arterial Pressure |
| MCC | Mission Control Center |
| MCH | Mean Corpuscular Hemoglobin |
| MCHC | Mean Corpuscular Hemoglobin Concentration |
| MCV | Mean Corpuscular Volume |
| MD | Mission Day |
| MDA | Multiple Docking Adapter |
| MDRS | MCC Data Retrieval System |
| MMT | Medical Management Team |
| MOCR | Mission Operations Control Room |

ACRONYMS AND ABBREVIATIONS (cont.)

| | |
|---|---|
| MONO | Monocyte |
| MRD | Mission Requirements Document |
| MS | Motion Sensitivity |
| MSFC | George C. Marshall Space Flight Center |
| N | Newton |
| Na | Sodium |
| NC1:NC2 | Phasing Adjustment Rendezvous Maneuvers 1 and 2 |
| RLC | Rotating Litter Chair |
| rpm | Revolutions per minute |
| RSM | Radiation Survey Meter |
| S | Subject |
| SAA | South Atlantic Anomaly |
| SAS | Solar Array System |
| S.D. | Standard Deviation |
| SE | Standard Error of the Mean |
| SEVA | Standup Extravehicular Activity |
| SFCHSP | Skylab Flight Crew Health Stabilization Program |
| SL 1/2 (SL2) | First Manned Skylab Flight |
| SL 1 | First Unmanned Skylab Flight |
| SML | Skylab Mobile Laboratories |
| SMMD | Specimen Mass Measuring Device |
| SMEAT | Skylab Medical Experiments Altitude Test |
| SPAN | Solar Particle Alert Network |
| SPE | Serum Protein Electrophoresis |
| SPS | Service Propulsion System; Samples Per Second |
| SPT | Scientist Pilot |
| SRAS | Space Radiation Analysis Section |
| SSR | Medical Staff Support Room |

ACRONYMS AND ABBREVIATIONS (concluded)

| | |
|---|---|
| STDN | Spacecraft Tracking and Data Network |
| STS | Structural Transition Section; Skylab Terminal Section |
| SV | Stroke Volume |
| TACS | Thruster Attitude Control System |
| TDI | Toluene Diisocyanate |
| t.i.d. | Three times a day |
| TLD | Thermoluminescent Dosimeter |
| TP | Teleprinter |
| TPI | Terminal Phase Initiate |
| TPF | Terminal Phase Final |
| TSP | Total Serum Proteins |
| VABD | Van Allen Belt Dosimeter |
| VC | Center Work Station |
| VCG | Vectorcardiogram |
| VS | Ventilation System; Sun-End (of ATM Canister)<br>Work Station (for EVA's) |
| VT | Viewfinder Tracking |
| WBC | White Blood Cell |
| WCIU | Workshop Computer Interface Unit |
| WR | Ward Room |
| WMC | Waste Management Compartment |
| -Z SAL | Minus Z Scientific Airlock |

# APPENDIX B

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