PHYSIOLOGICAL MASS MEASUREMENTS ON SKYLAB 1/2 AND 1/3

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During Skylab, mass measurement of crewmen and other objects in space became a more or less routine procedure. This was the first time such measurements have been made in space. Conversely, they have been needed since the early days of manned flight for one of the consistent post-flight changes has been weight loss[1,2]. Although the rate of loss was ~~greater~~ with ~~shorter~~ duration missions and such losses were rapidly replaced, there was generally a continuing loss on longer duration missions and a portion of this loss remained several days after recovery. The major questions of concern were the mechanism of the loss and whether it could be prevented on longer missions.

There have been several theories concerning the mechanism of these losses including (1) a shift of fluids cephalad under weightlessness with removal of this apparent excess by diuresis[3,4], (2) excessive fluid loss by heat and other stresses, and (3) inadequate food and liquid intake[5,6].

In 1965 it was obvious that daily in-flight crew body mass with intake/output mass determinations would be required to serially document these changes to determine the mechanisms responsible. It was also obvious that such measurements were absolutely dependent upon nongravimetric instruments which were not available. At the Air Force's Aerospace Medical Division we concluded that development of a nongravimetric mass measuring device was of first priority to investigation of this fundamental problem, and the author began such development. By 1966 a device for measuring mass of specimens over the range of 25 grams to 1 kilogram, and a larger one covering the range of 1/2 to 100 kilograms, were completed. Skylab has been the first opportunity to demonstrate their performance in flight. Since the method of mass measurement used is a fundamental departure from weighing machines, the technique will be briefly described.

Man has been using the gravimetric balance or scales for at least 5,000 years. It is such a simple, efficient, and accurate method that no alternative devices were available or needed. The only practical alternative for mass determination is some measure of the mass' inertial property. In 1965 the mass dependent spring/mass oscillator, limited to translational motion, was chosen as an alternative method. This choice was heavily biased by size and weight requirements and by previous experience of the author and is not necessarily the current method of choice.

Figure 1 is a schematic of the method used. A sample mass, M, is constrained to linear motion between the two springs, K. If the mass is displaced by a distance X from its rest position X_0 and released, it will undergo virtually undamped natural oscillation whose period T is a function only of the mass and spring constants, K, as shown in the equation. An opto-electronic detector and counter times each crossing of the zero displacement point, X_0, providing an accurate measurement of the period of oscillation. By calibrating the device with a series of known masses, the mass of an unknown sample can be determined from its period of oscillation.

Such a technique allows reasonable accuracies with solid masses--for example, it is not particularly difficult to obtain .01% or better. Conversely, this technique has several inherent limitations. Any motion (jitter) of the supporting mechanism or of the specimen or any nonrigidity of specimen (slosh) which allows secondary oscillations near the primary frequency will produce errors, thus measurement of items such as liquids and of the human body require special arrangement.

Although existing vibration studies of the human body show that it behaves as a single rigid mass below one cycle per second, this proved to be only approximately true. The frequency of oscillation had to be lowered to less than one-half cycle second, and the body folded into the most rigid configuration possible (see figure 4) to obtain the required accuracies. All voluntary motion by the subject, including respiration, was stopped. With such precautions, the results shown in figure 2 were obtained under 1-G at three locations using as subjects anyone who could get into the scale.

For Skylab, three mass measuring devices were flown--one specimen device (SMMD) in the wardroom (figure 3) to measure all food residue left from standard portions and another in the waste management compartment to measure all fecal samples and any vomitus. A body mass measuring device (BMMD) (figure 4) is located in the orbital workshop and each crewman makes a basal measurement each morning after awakening and voiding.

Both SMMD and BMMD used the passive spring/mass oscillator described. The springs, in this case, are eight elastic flexure pivots which both constrain the specimen mass to translational motion and supply the required restoring forces for oscillation. The specimen mass measurement devices have a flat tray to which the specimen is held by the perforated elastomer sheet. A single electronics package times the period of three oscillations to 10^{-5} second and displays this by six digital light emitting diode units. Operation consists of rotating a lever, holding it until timing is complete and reading and recording for transmission to ground the oscillation period values for the mass. This time value is then converted to mass.

The BMMD has the subject seat suspended between flexure pivots and in addition to the hand/foot restraint has a pair of padded shoulder straps to constrain the body firmly in the seat under weightlessness. The same electronics display package is used. Operation consists of the subject strapping himself into the seat, actuating a lever which cocks the oscillator, i.e., displaces the seat from equilibrium and latches it, and then manually releasing it to oscillate by means of a trigger on the hand/foot restraint bar. The oscillation period data is recorded and analyzed as with the SMMD. Periodic in-flight calibration of all instruments is done with fixed masses.

Experiments M-074/172 were also intended to explore the complete envelope of performance of this method, but since this was only of interest to the investigator this aspect will not be mentioned except to say that accuracies obtained are more than adequate for any current medical investigations--a few grams for food residue and approximately ± .1 pound repeatability for body mass with absolute body mass accuracy between + .25 to + 1.0 pound, and probably closer to the lower figure.

Operation on Skylab has been more or less routine. There was a loss of data for the first few days on Skylab-2 during vehicle repairs. Virtually no uneaten food has been left to measure. Two small vomitus samples, on the order of 100 milligram were produced by one crewmember on Skylab-3. All fecal samples were routinely measured. Other mass measurements have been routinely made in support of spacecraft operations, including urine pools and the amount of coolant fluid added to the refrigerant system.

All portions of food were accurately pre-weighed and analyzed. All water used and urine produced was accurately measured volumetrically and all fecal material measured for mass, dehydrated, and subsequently analyzed. These data will allow a complete mass balance study, but time has not yet allowed it. However, simply plotting the body masses has provided considerable insight into the general mechanisms of weight loss.

For a baseline, three crewmen were placed in a ground based chamber simulation of a 56-day Skylab mission using the same food and atmosphere.* Plots of the crewmen's body weights during this test are shown in figures 5, 6, and 7. The CDR showed a stable preflight and postflight test period while on the diet with a small continuing loss in flight. Losses for the SPT were large and continuing throughout the mission and post mission until the diet was sharply increased some 4 days postflight. No significant trend is present in the PLT's data. Since no pathology or unusual stresses were present, this data is consistent with a significant metabolic loss in one, a slight loss in another, and metabolic balance in the third test crewman.

* SMEAT

Results of crew mass measurements from Skylab are shown in figures 8 through 17. Daily basal measurements are plotted for the entire period while on the diet. Preflight and postflight measurements were made gravimetrically with a standard calibrated clinical scale and were probably accurate and repeatable to ± .25 pounds or less. Figure 8 is a plot of the raw data from the CDR of Skylab 2 for comparison with the other plots which have been smoothed by taking a 3 day sliding average. This has the advantage of making trends less "noisy" while still allowing significant and rapid changes to appear. It produces a slight phase lag or delay.

Weights on beginning the diet, on launch, and on recovery are accentuated. The Skylab-2 CDR's loss curve is typical of two crewmen on this mission. There was a small but definite loss during the control period (i.e., while on the Skylab diet and in quarantine). After launch this rate of increase accelerated but remained more or less constant except for sharp drops associated with EVA's. Following recovery there was a rapid increase, accompanied by an overshoot which, although not shown here, plateaued to a value some two plus pounds below launch weight. This rapid postflight gain is marked by two horizontal lines and may represent fluid changes. the PLT's curve (figure 11) has the same general shape without the postflight overshoot while the SPT's curve (figure 10) is more variable.

There were marked differences from Skylab-2 curves in two of the Skylab-3 crewmen--CDR and PLT (figures 12 and 14). After the first day of the preflight stabilization period there was no loss or possibly a slight gain. In flight there was an initial loss followed by a long stable period until just prior to the end of the mission when a rapid rate of loss occurred. the SPT (figure 13) has a slight loss during the control period, a slow loss which continued in flight after a marked decrement over the first few days. After recovery we see the "typical" rapid increase followed by a plateau or inflection.

Skylab-4 conditions were different from Skylab-3 and the results obtained reflected these differences. Caloric allowances had again been increased for this crew and the CDR actually returned from this longest of missions with no mass loss. Only the PLT had an initial period of anorexia. To more clearly demonstrate the effects of this, the percentage of mass lost and gained for 10 days after orbital insertion and recovery are plotted[1] in figures 18 and 19 for Skylab-3 and Skylab-4. On Skylab-3 all three

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[1]A 2-day sliding average is used here, e.g., average value for day N + (N + 1) are plotted on day (N + 1)

crewmen, and especially the PLT, were anoretic for the first few days of flight. All three showed a remarkably similar loss curve which stabilized at an initial loss of 4 to 4 percent. By recovery this increased to 4-1/2 to 5-1/2 percent. After 1-2 days post recovery there was a sharp, apparently reciprocal, gain of 3-4 percent. This data would appear to fit a picture of rapid fluid loss and gain on being exposed to weightlessness and gravity respectively. The gains and losses seem to match and the difference could be interpreted as tissue loss. Looking now at the Skylab-4 crew's data in which only the PLT was initially sick, one sees a different picture. While the sick PLT has a loss curve virtually identical to that of the Skylab-3 crew the CDR shows a slight initial loss while the SPT started a downward trend that was apparently halted later in the mission by increased caloric intake. Postflight the CDR showed virtually no gain while the PLT had the usual rapid gain but only of some 2 percent. The SPT also had a sharp gain which did not plateau but continued at a slower rate, a picture which seems consistent with a positive metabolic balance the rate of which subtracted from the rapid gain would have an initial gain of some 1-1/2 percent. Another major difference in the crew is the much smaller total in-flight loss, consistent with increased food.

This latter question deserves particular attention. If one plots the calories/day/unit mass versus the percentage of total in-flight mass lost for each crewman on the mission, a linear relation results, i.e., total weight lost was a direct function of caloric intake, which is not surprising. What was surprising is the high caloric intake required to maintain zero loss in flight.

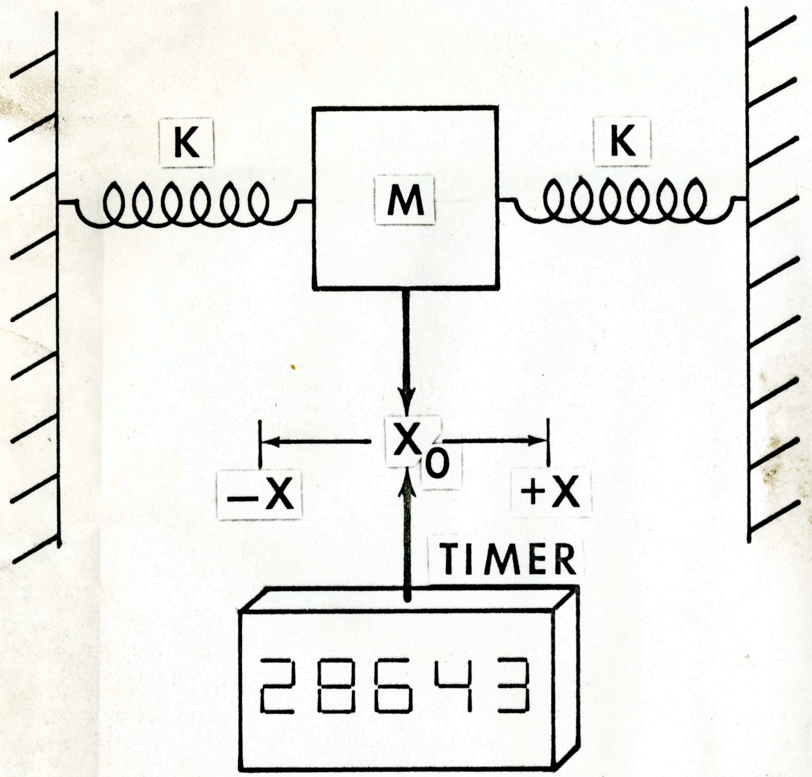
Although the sample is far too small for definitive results, the following statements seem consistent with the data to date. (1) There appears to be a small rapid gain and loss on exposure to weightlessness and reexposure to gravity consistent with a fluid shift and amounting to 1-2 percent in subjects in metabolic balance. Although larger shifts were seen in crewmen they were anoretic initially and had lost 5 percent or more body mass postflight. While one associates rapid mass change with fluid changes, significant tissue mass may also be lost in several days. (2) The major loss in mass is consistent with a metabolic loss pattern. (3) There are small rapid gains and losses associated with obvious stresses such as EVA and preparation for reentry.

Thus we seem to have come full circle and confirmed the role of all three postulated mechanisms of loss of body mass under weightlessness. We have better defined both the relative roles of each mechanism as well as indicated the areas of future concern. For example, what is the cause of increased metabolic cost under weightlessness? A new set of feeding criteria is obviously required. What tissue is being lost, i.e., how much is fat and how much is muscle from disuse atrophy and how may this be prevented? This latter question is dealt with further in the paper on Anthropometric Studies and in "Measurement and Prevention of Muscular Deconditioning."

Finally, there is the question of mass measurement itself on future missions--missions that may not have almost unlimited resources. The mass measurement devices flown on Skylab are relatively crude, obsolescent, and expensive. In the intervening 7 years since their design, we have developed a series of smaller, simpler, and cheaper alternatives which should allow mass measurements on virtually any object in almost any spacecraft.

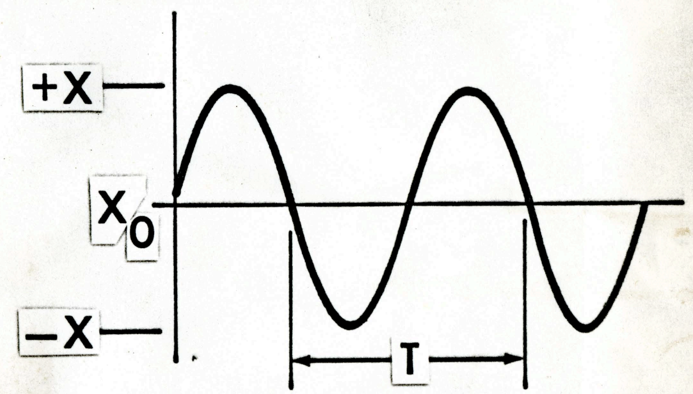
NASA-S-74-4748

SCHEMATIC SPRING MASS/OSCILLATOR



MOTION EQUATION

$$T = C\sqrt{\frac{M}{2K}}$$



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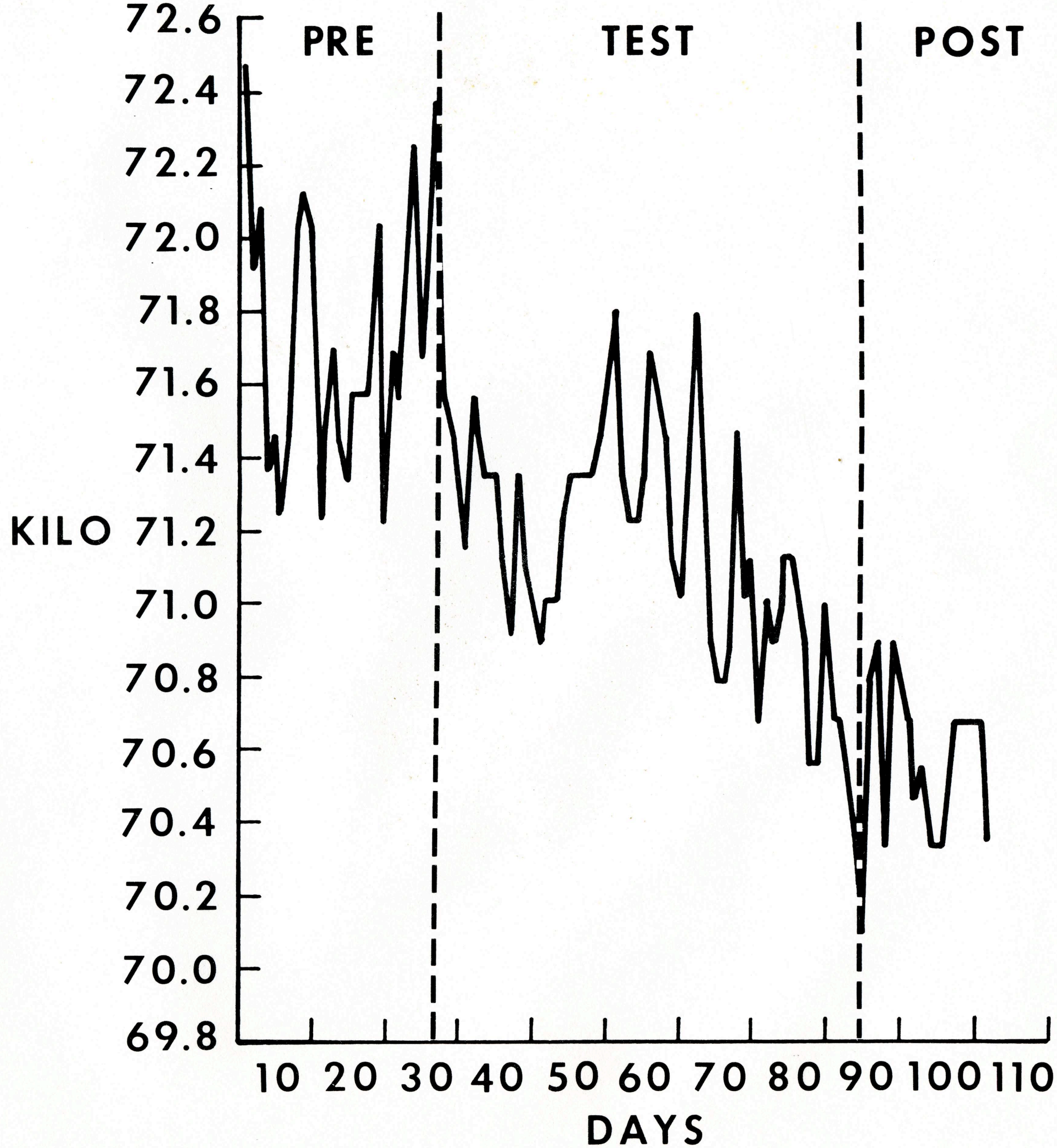
SMEAT CDR WEIGHT



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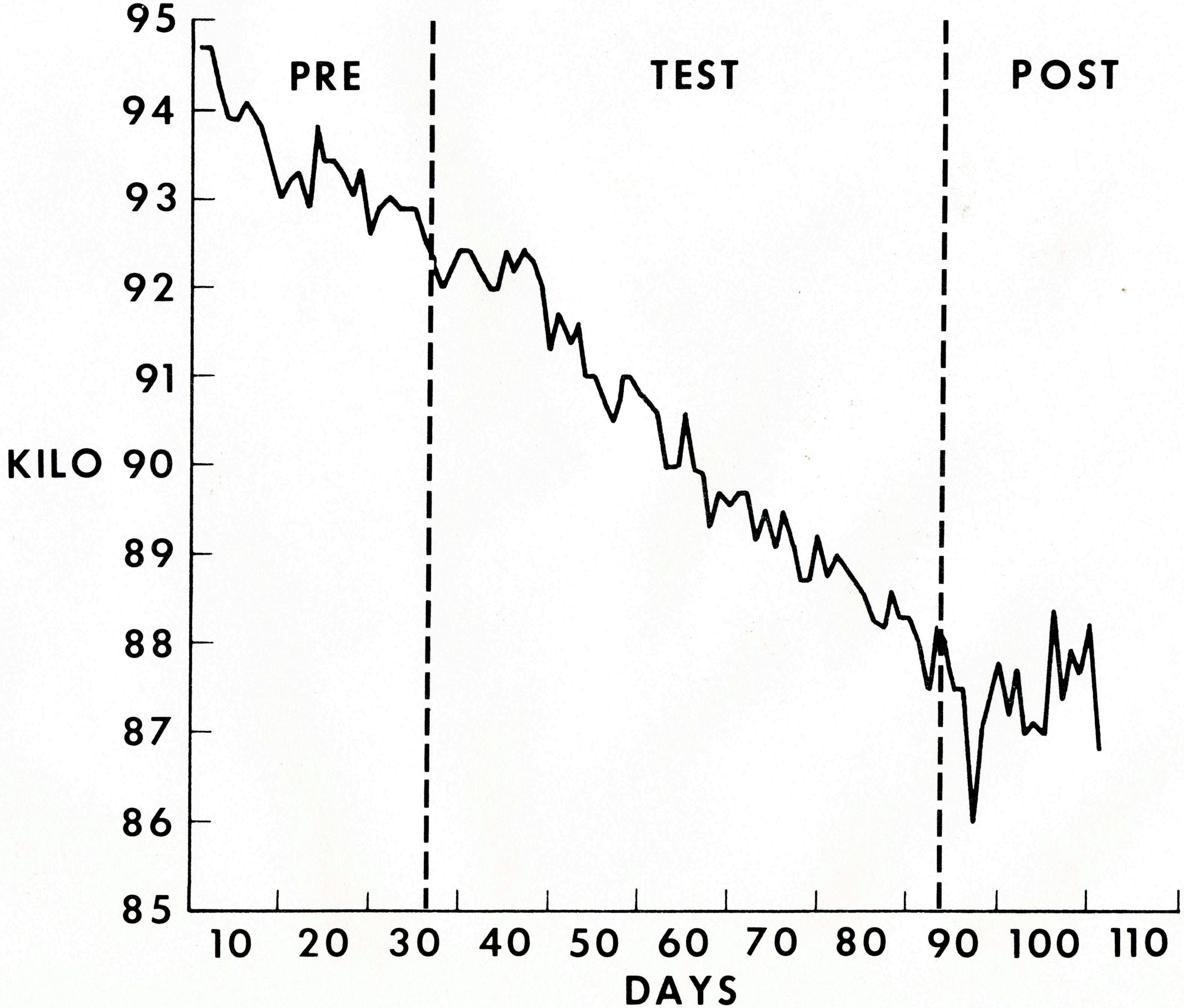
SMEAT SPT WEIGHT



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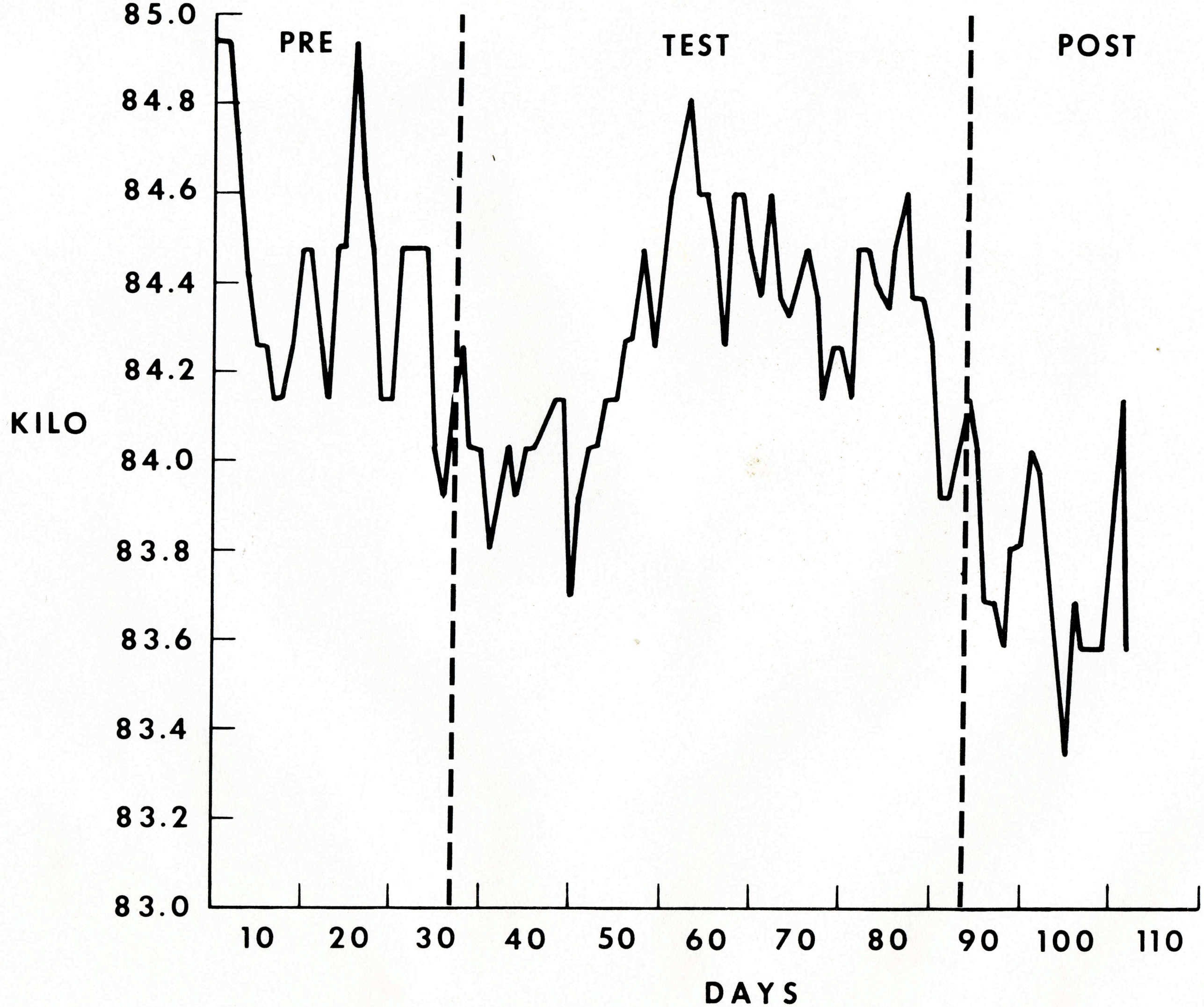
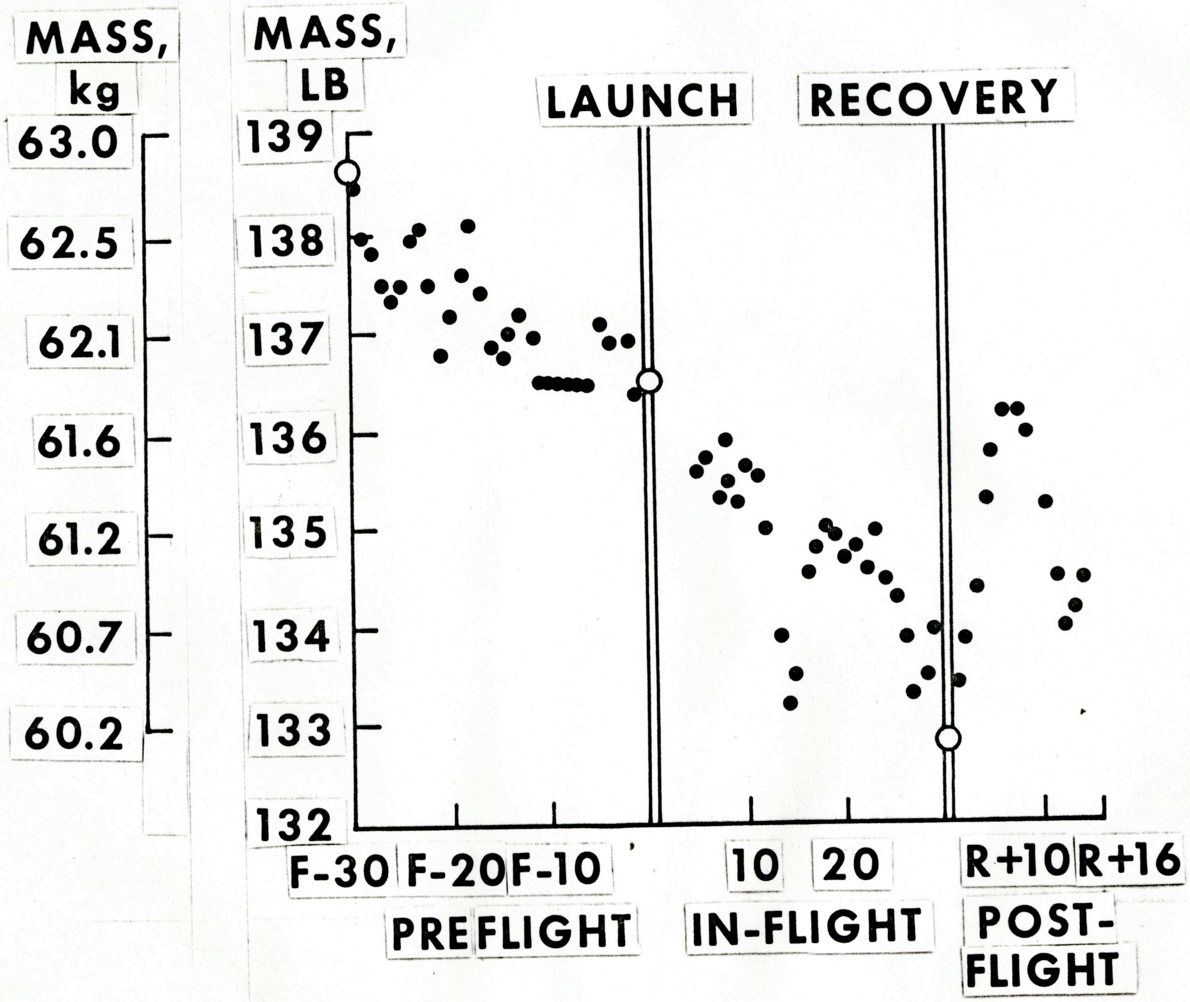
SMEAT PLT WEIGHT



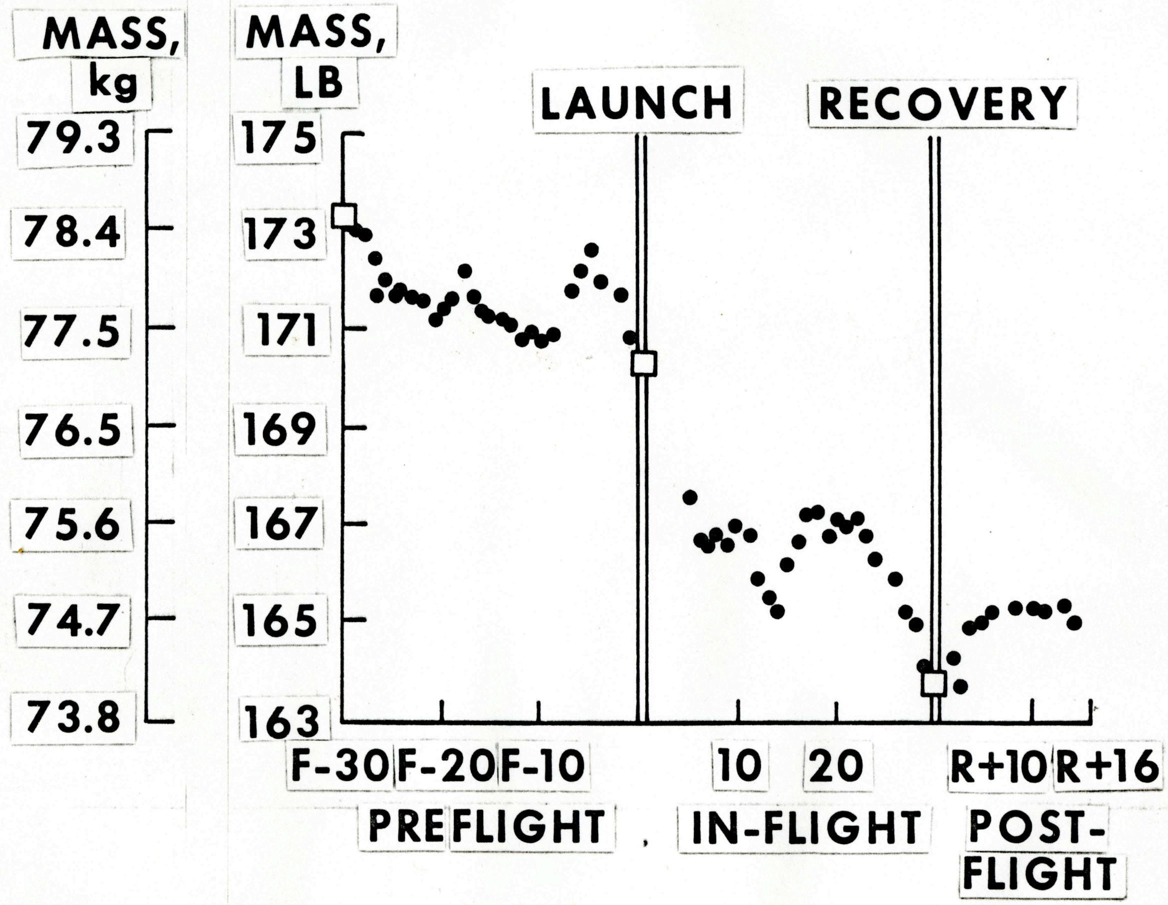
NASA-S-74-4756

BODY MASS OF SL-2 CDR ON SKYLAB DIET



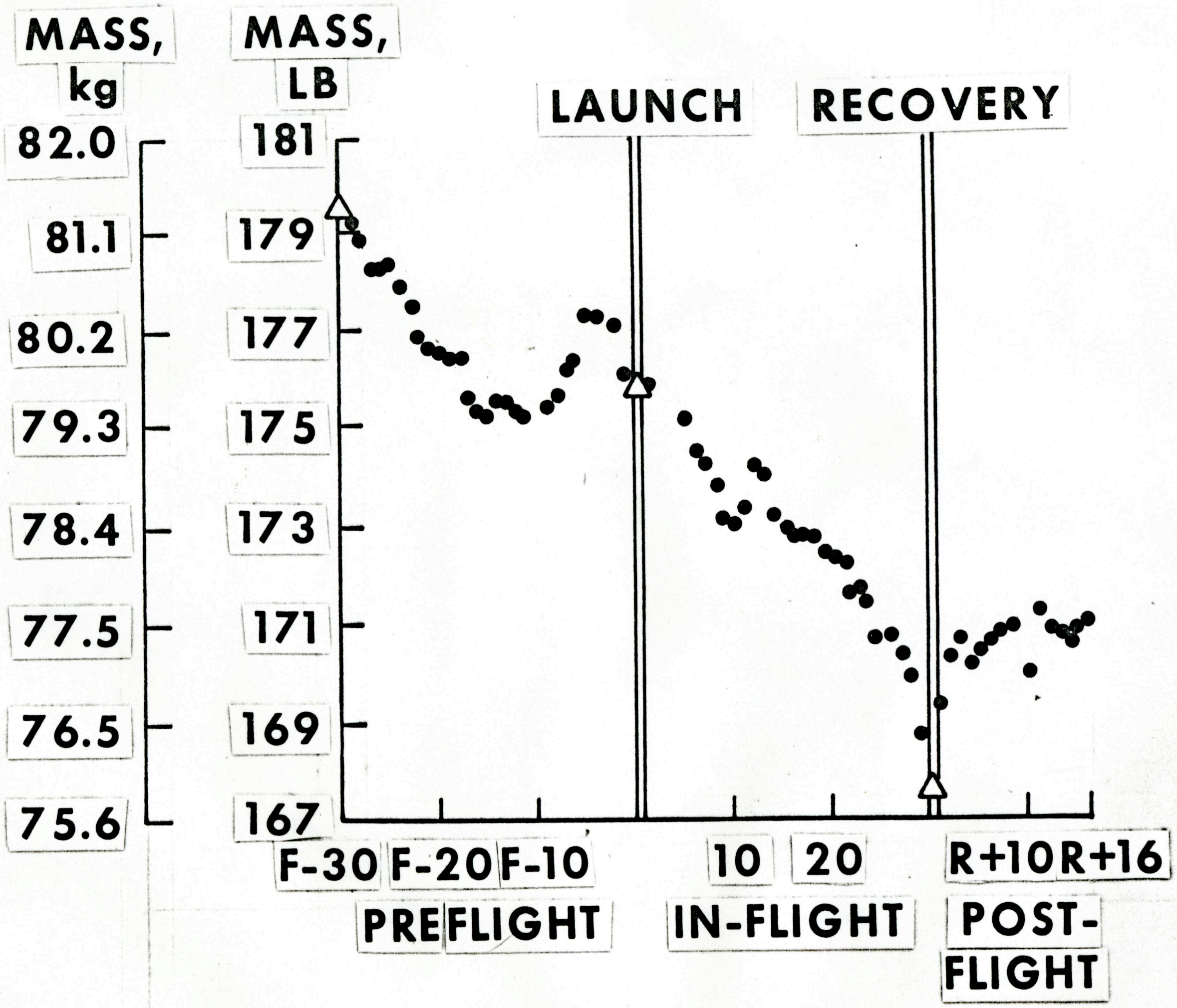
NASA-S-74-4757

BODY MASS OF SL-2 SPT ON SKYLAB DIET



NASA-S-74-4758

BODY MASS OF SL-2 PLT ON SKYLAB DIET



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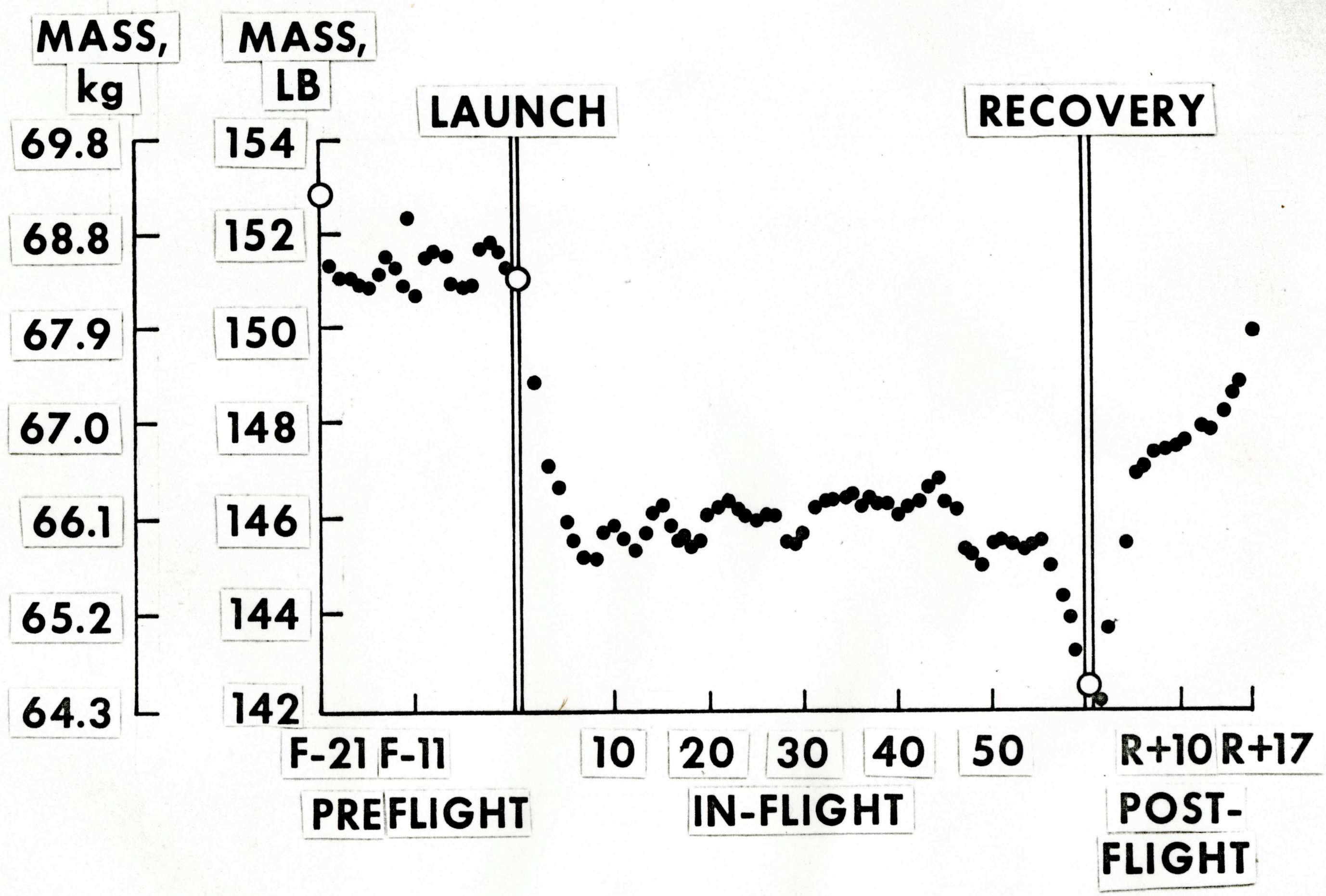
BODY MASS OF SL-3 CDR ON SKYLAB DIET



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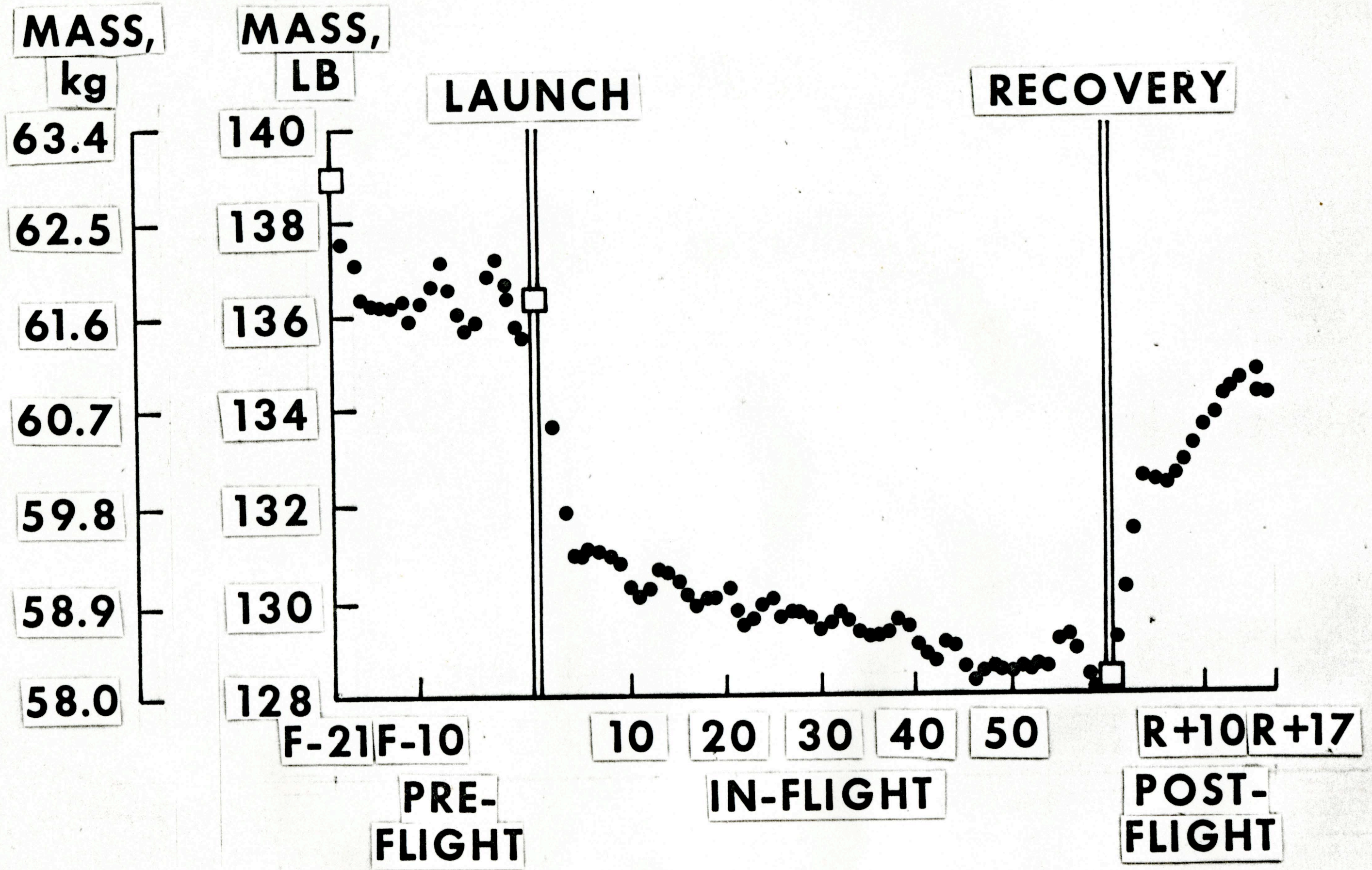
BODY MASS OF SL-3 SPT ON SKYLAB DIET



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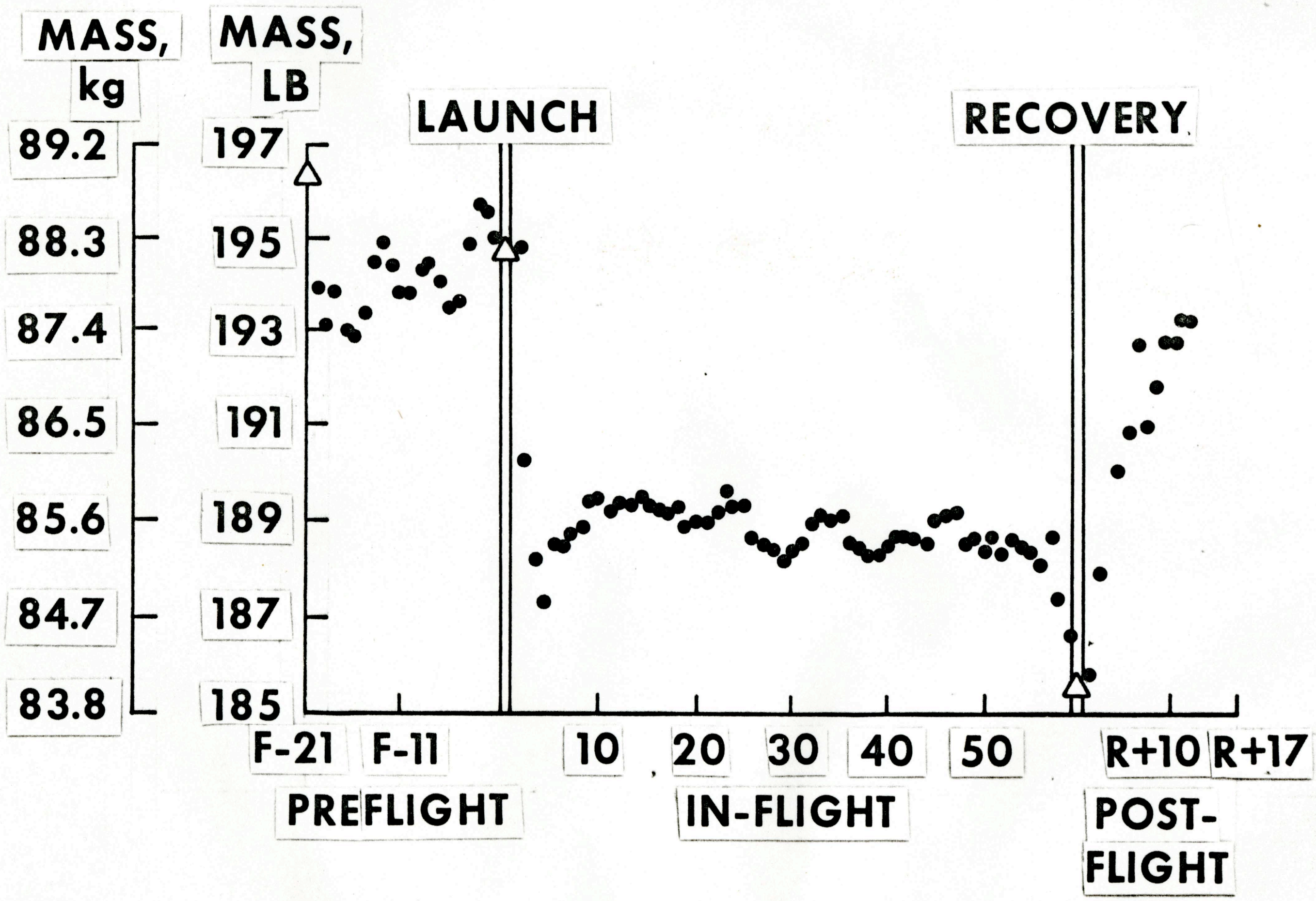
BODY MASS OF SL-3 PLT ON SKYLAB DIET



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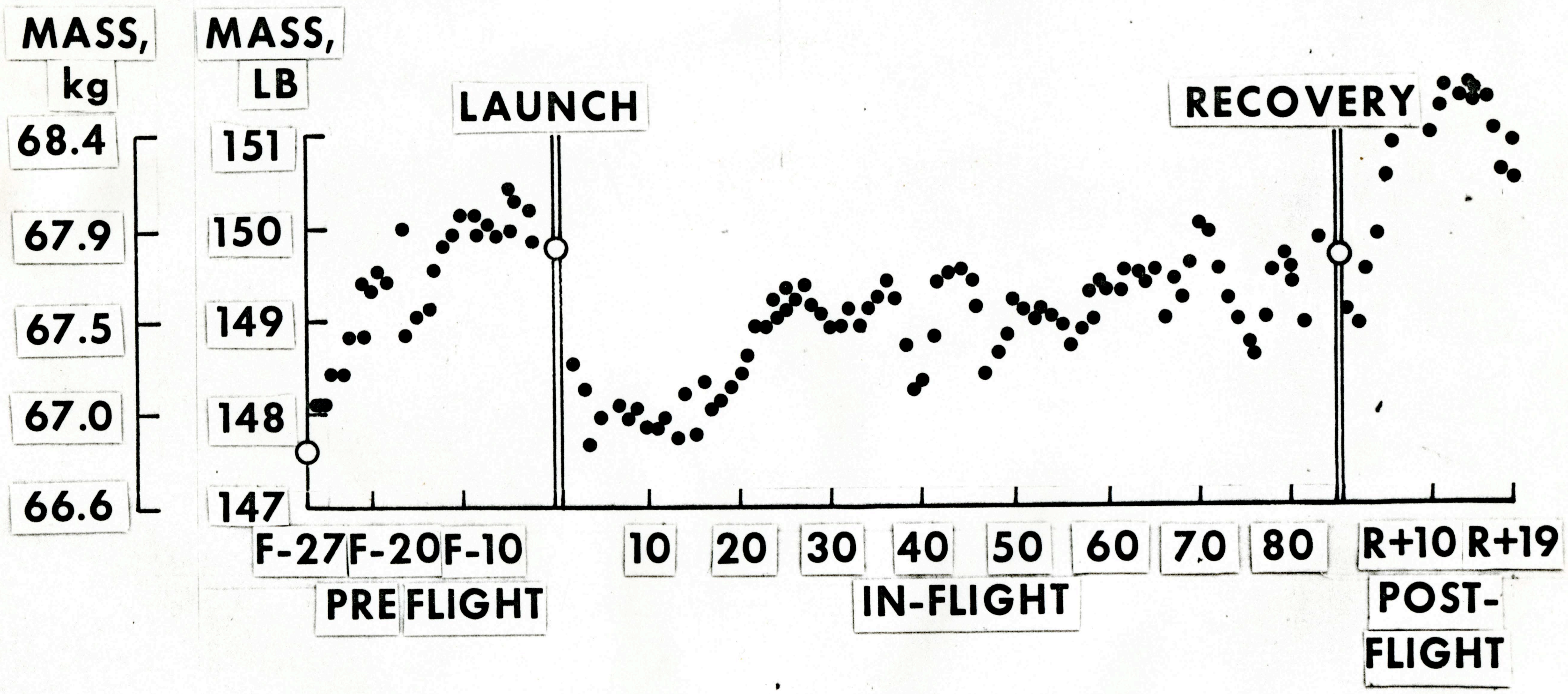
BODY MASS OF SL-4 CDR ON SKYLAB DIET



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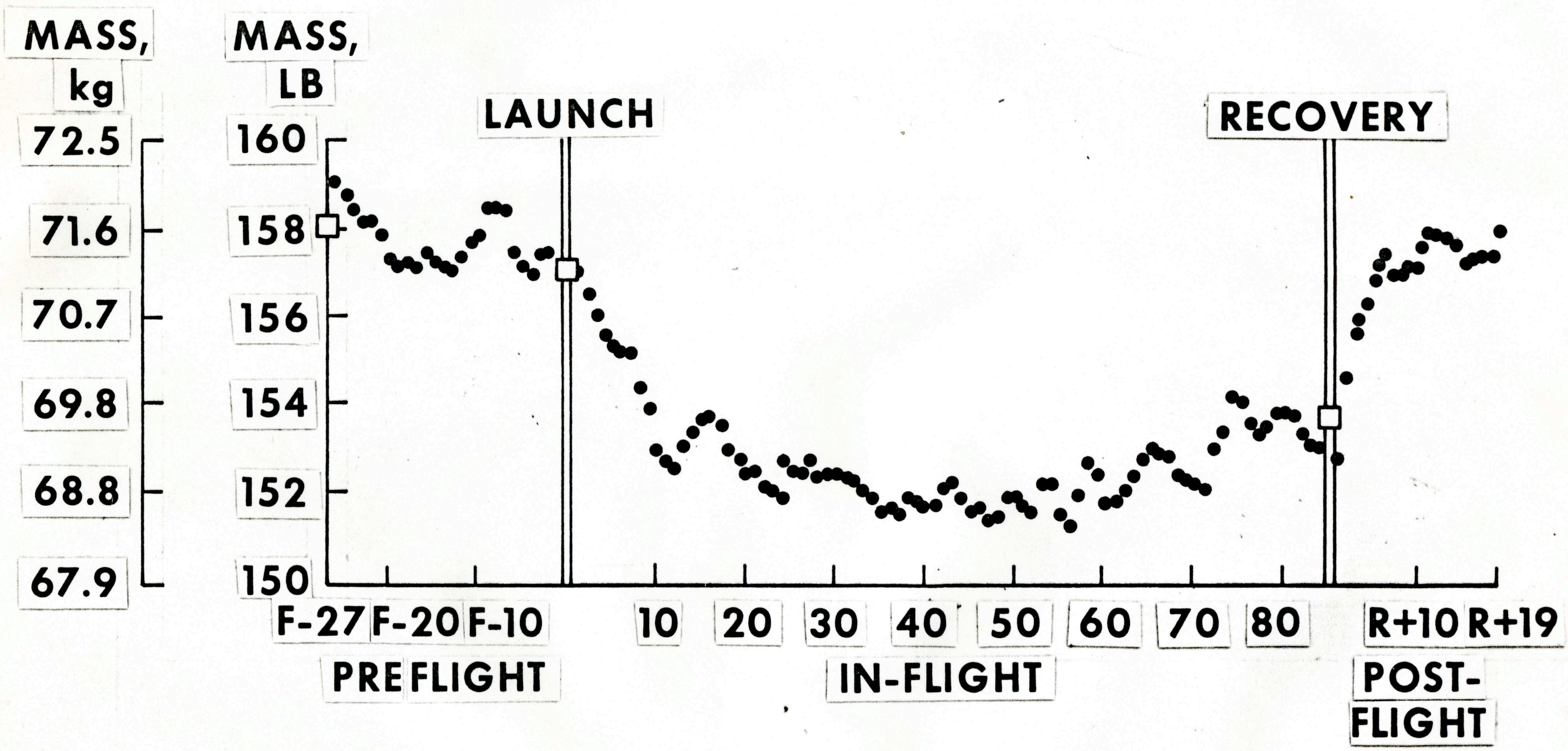
BODY MASS OF SL-4 SPT ON SKYLAB DIET



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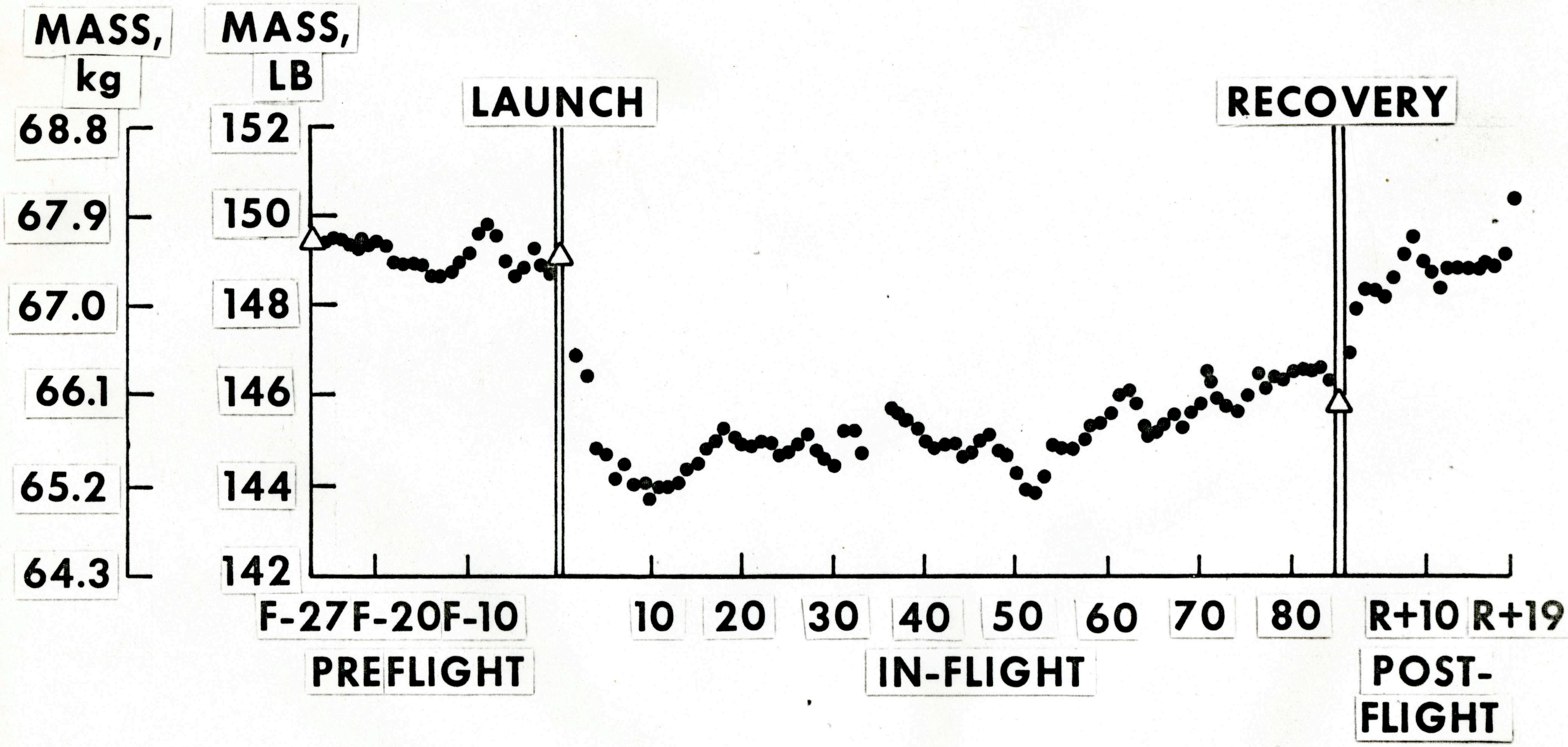
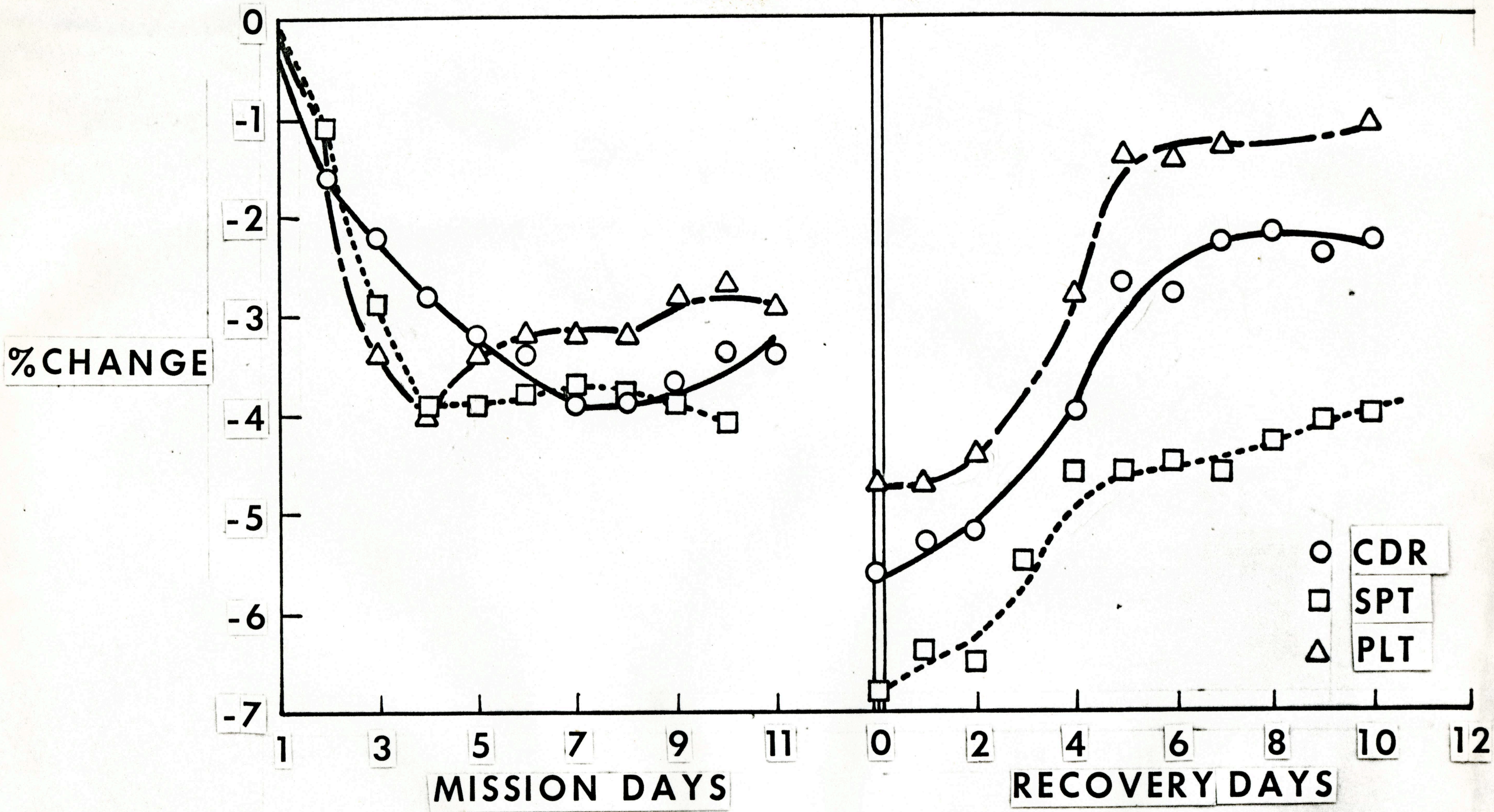
BODY MASS OF SL-4 PLT ON SKYLAB DIET



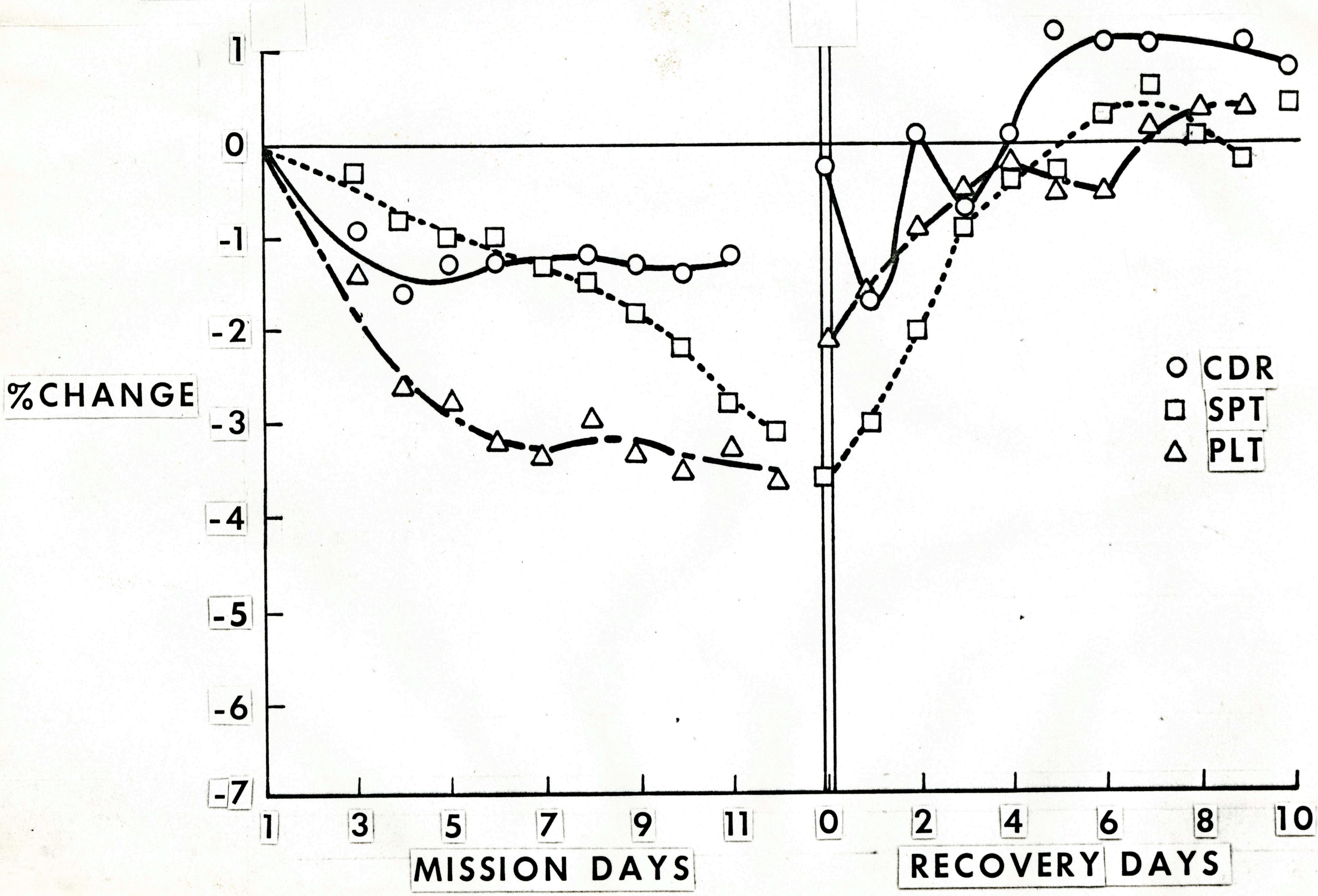
NASA-S-74-4764

BODY WEIGHT CHANGE
SL-3 INSERTION AND RECOVERY



NASA-S-74-4765

BODY WEIGHT CHANGE
SL-4 INSERTION AND RECOVERY



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