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

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ABSTRACT

Mass measurements of crewmen and ~~other~~ objects were made for the first time in space during Skylab. A description of the new devices designed for such measurements and of the technique of their use is detailed. Results from ground-based chamber simulation tests and from those during Skylab II and III show similar patterns of simple metabolic deficits, of a rapid loss during the first few days of flight followed by a reciprocal gain for the first few postflight days, and other transient changes. It is concluded that two major causes of weight loss are present: (1) a fluid redistribution and loss, and (2) metabolic losses. Added to these are short-term changes from transient stress. Smaller, simpler, and cheaper devices have since been designed which should allow mass measurements on virtually any object in almost any spacecraft.

Introduction

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 space flight for one of the consistent postflight changes has been weight loss [1, 2].

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 [2, 5].

In 1965 it was obvious that daily inflight 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 senior 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.

Technique and Apparatus

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

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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 senior author and is not necessarily the current method of choice.

Fig. 1 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 a virtually undamped natural oscillation whose period T is a function only of the mass and spring constants, K, as shown in the equation. An optoelectronic 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 0.01% 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 to obtain the required accuracies. All voluntary motion by the subject, including respiration, was stopped. With such

Fig. 1 precautions, the results shown in Fig. 2 were obtained under 1-G at three locations, using as subjects anyone who could get into the scale.

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For Skylab, three mass-measuring devices were flown—one specimen device (SMMD) in the wardroom (Fig. 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) (Fig. 4) is located in the orbital workshop, and each crewman makes a basal measurement each morning after awakening and voiding.

In both the SMMD and BMMD the passive spring/mass oscillator was used. The springs, in this case, are eight elastic flexure pivots, which constrain the specimen mass to translational motion and, also, 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.

On the BMMD the subject seat is suspended between flexure pivots, and in addition to the hand/foot restraint there is 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 a trigger on the hand/foot restraint bar. The oscillation period data are recorded and analyzed as with the SMMD. Periodic inflight 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 $\pm$ 0.1 pound repeatability for body mass with absolute body mass between +0.25 to +1.0 pound, and probably closer to the lower figure.

(i) Results

Operation on Skylab has been more or less routine. There was a loss of data for the first few days on Skylab II during vehicle repairs. Virtually no uneaten food has been left to measure. Two small vomitus samples, on the order of 100 milligrams, were produced by one crewmember on Skylab III. 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. As of this time the complete balance study of all mass intake and output has not been performed; however, simply plotting the body masses has been most revealing.

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 Figs. 5-7. The commander table preflight and postflight test period while on the diet, with a small continuing loss in flight. Losses for the scientist pilot (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 pilot's (PLT) data. Since no pathology or unusual stresses were present, these data are consistent with a significant metabolic loss in one, a slight loss in another, and metabolic balance in the third test crewman.

Figs. 5-7

Next are shown the results from Skylab II (Figs. 8-10). The data have been smoothed by plotting a 3-day sliding average. Weights on beginning the diet, on launch, and on recovery are accentuated. The Skylab II 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 in loss 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

Figs. 8-10

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weight. This rapid postflight gain is marked by two horizontal lines and may represent fluid changes. The PLT's curve has the same general shape without the postflight overshoot, while the SPT's curve is more variable.

In the Skylab III crewmen (Figs. 11-13) there were marked differences from Skylab II curves in two of the crewmen – CDR and PLT (Figs. 11 and 13). After the first day of the preflight stabilization period there was no loss, or possibly a slight gain. Inflight 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 (Fig. 12) had a slight loss during the control period and a slow loss which continued inflight after a marked decrement over the first few days. After recovery we see the typical rapid increase followed by a plateau or inflection.

With at least three crewmen there is one obvious and consistent pattern of simple metabolic deficit which was also seen in the control study. There are more subtle patterns, especially the rapid shifts which must be interpreted in conjunction with a great deal of other data which are not complete at this time.

A second pattern appears to be a rapid loss during the first few days of flight followed by a reciprocal gain for the first few postflight days. This is consistent with a redistribution and gain and loss of fluid. It cannot be forgotten that both crews were subjected to abnormal stresses during the first few inflight days – Skylab II to excessive heating and Skylab III to anorexia from vestibular disturbance. Note in every case, however, that a significant deficit remains after the postflight redistribution, which must represent a tissue loss. The average deficit is larger in Skylab II than in Skylab III, which is consistent with the increased caloric intake of Skylab III.

Finally, there are other transient changes, such as those associated with EVA and the increased rate of loss prior to reentry which was seen in most crewmen. This period is one of increased activity in preparation for reentry, and for individuals on a fixed caloric intake such a loss is reasonable.

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Conclusions

It now appears that two major causes of weight loss are present: (1) a fluid redistribution and loss, and (2) metabolic losses. Added to these are short-term changes from transient stress. Thus it seems that all three theories proposed years ago are operational in varying degrees. There still remains considerable work to be done in defining and controlling these changes.

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.

(1)

References

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FIGURE 1. Schematic of spring/mass oscillator.

Mass is displaced from rest position along longitudinal axis of springs and released to oscillate along this axis.

~~FIGURE 2.~~

Fig. 2. Difference in mass determination by mass scale and gravimetric scales—all subjects who were measured the first time were included at 3 locations, San Antonio, Los Angeles and Houston. Repeat measurements are typically ± .05%.

FIGURE 3. Wardroom specimen mass measurement device.

Device in use on SL-1/3. Period readout is above specimen tray which oscillates left to right in this photo. Specimen is held to tray by perforated elastomer sheet.

FIGURE 4. CDR of SL-1/3 making daily mass measurement in Body Mass Measurement Device.

Axis of oscillation is front to back of crewman, with an amplitude of a few millimeters.

FIGURE 5. Daily mass (gravimetric) of commander (CDR) during altitude simulation of Skylab mission while on Skylab diet.

FIGURE 6. Daily mass of scientist pilot (SPT) during simulated Skylab mission while on diet. Quantity of food was increased sharply at day 97.

FIGURE 7. Daily mass of pilot (PLT) during simulated Skylab mission.

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1st dark circle

Fig. 8. Body Mass SL-1/2 CDR.

- Circles with crosses are BMMD measurements
- Circles without crosses are from standard gravimetric scales
- Double circles are start and/or finish values for a test period
- A three-day sliding average was used to smooth these data, yet allow major variations to appear

A = Minimum weight

Fig. 9. Body Mass SL-1/2 SPT.

- Circles with crosses are BMMD measurements
- Circles without crosses are from standard bravimetric scales
- Double circles are start and/or finish values for a test period
- A three-day sliding average was used to smooth these data, yet allow major variations to appear

A = Minimum weight

Fig. 10. Body Mass SL-1/2 PLT.

- Circles with crosses are BMMD measurements
- Circles without crosses are from standard bravimetric scales
- Double circles are start and/or finish values for a test period
- A three-day sliding average was used to smooth these data, yet allow major variations to appear

A = Minimum weight

Fig. 11. Body Mass of SL-3 CDR.

- Solid circles are BMMD measurements
- Double circles are start and/or finish values for test period
- Non-solid circles are from standard gravimetric scales
- A three-day sliding average was used to smooth these data, yet allow major variations to appear

A = Minimum weight

Fig. 12. Body Mass of SL-3 SPT.

- Solid ~~xxxxx~~ circles are BMMD measurements
- Double circles are start and/or finish values for test period
- Non-solid circles are from standard gravimetric scales
- A three-day sliding average was used to smooth these data, yet allow major variations to appear

A = Minimum weight

Fig. 13. Body Mass of SL-3 PLT.

- Solid circles are BMMD measurements
- Double circles are start and/or finish values for test period
- Non-solid circles are from standard gravimetric scales
- A three-day sliding average was used to smooth these data, yet allow major variations to appear

A = Minimum weight

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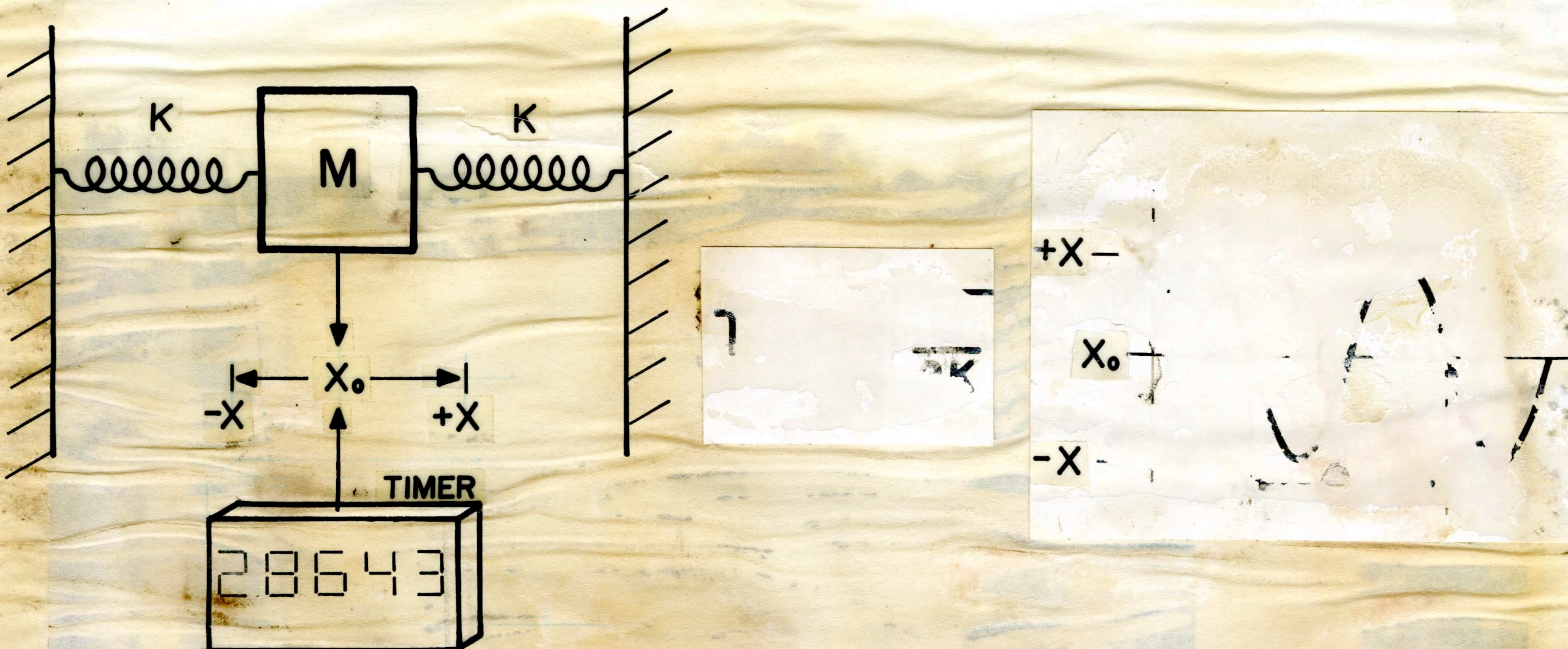
Schematic of spring mass oscillator



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