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SPECIMEN MASS MEASUREMENT
M074 in SMEAT

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Revision 2 ?

This is the first time I've seen this — W.T.

SPECIMEN MASS MEASUREMENT (M074)

Introduction

Mass determination is one of the cornerstones of engineering and scientific operations. The only devices previously available for such determination were gravimetric and unusable in the weightless conditions of space flight.

The specimen mass measurement device (SMMD), which operates independently of gravity, is being used for the first time in Skylab as a means of determining mass ~~and, therefore, weight.~~

Prior to Skylab, the SMEAT M074 experiment was conducted to demonstrate the capacity of the SMMD to accurately weigh masses as great as 1,000 grams in a zero-g environment, or 500 grams in a 1-g environment. The SMMD was operated throughout the SMEAT test in a close simulation of the 56-day Skylab mission. The device was installed so that the oscillation of the springs was parallel to the ground, and the springs were constructed so as to be heavy enough that the deflection caused by gravity could be ignored.

The experiment was also intended to develop and validate operational SMMD procedures. Periodic calibrations of the device were performed to determine long term stability and repeatability.

Equipment

Mechanics

The SMMD employs a mechanical (rectilinear) spring/mass oscillator in which the period of oscillation is a function of the mass coupled into the system. It measures and records the time associated with the period of a plate-fulcra, spring-supported pendulum that has a fixed displacement.

The mass to be measured is located on a tray under an elastic sheet. The sheet is necessary because of the irregular shape and variable consistency of the substances to be measured. The mass is accelerated uniformly by a repeatable restoring force that is set into the plate-fulcra springs; periods of the pendulum are timed to 10^{-5} seconds accuracy by a crystal-controlled digital timer with a six place readout. An electro-optical transducer sends a signal to the logic circuit of the device each time the tray crosses the midpoint in its oscillating cycle. After two cycles have been completed to allow transients to decay, the total elapsed time for the next three cycles in tens of microseconds appears on a digital display.

The displacement and release of the mass is controlled by a single-loaded control level which locks the mechanical oscillator, and on manual rotation displaces and releases the tray and specimen mass to oscillate. A reset button on the electronic package sets the time to zero. The electronics unit has a switch-selected temperature function with a sensor in its base. Figure 1 shows the basic mechanics of the SMMD.

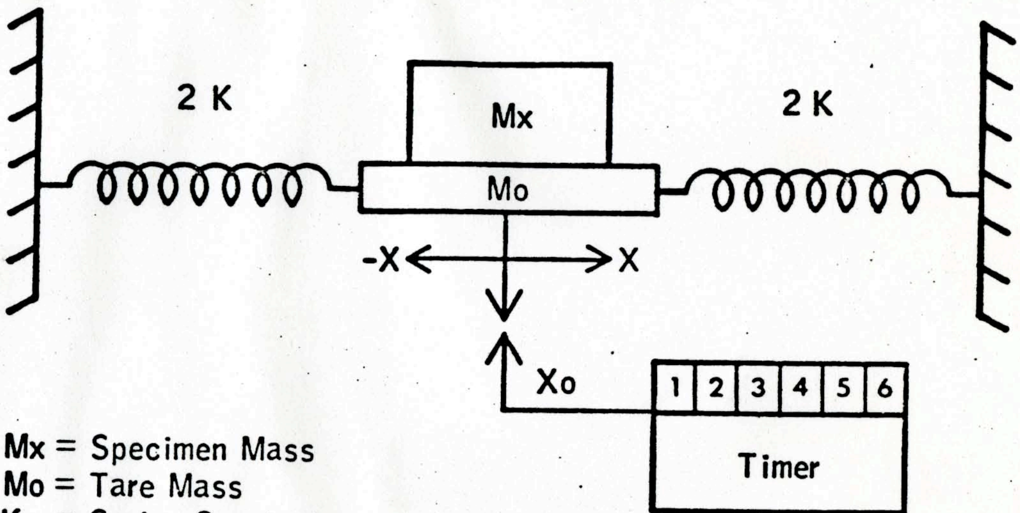
Error Sources

The SMMD is susceptible to the following sources of error:

A. External vibrations which have components close enough to the natural frequency of oscillation to cause an error in period. Since the SMMD oscillation amplitude has been kept small, very low levels of external oscillation may cause appreciable period disturbances.

B. Any nonrigidity, or "slosh," either in specimen mass or in coupling the specimen to the tray. Slosh may cause secondary oscillations which, if the frequency is near the fundamental frequency, result in errors. This is the major limitation in the utility of this type of mass measurement.

C



Mx = Specimen Mass
Mo = Tare Mass
K = Spring Constant
Xo = Position of rest
Xo = Maximum Displacement
T = Period of Oscillation

$$T = C\sqrt{\frac{Mx + Mo}{K}}$$

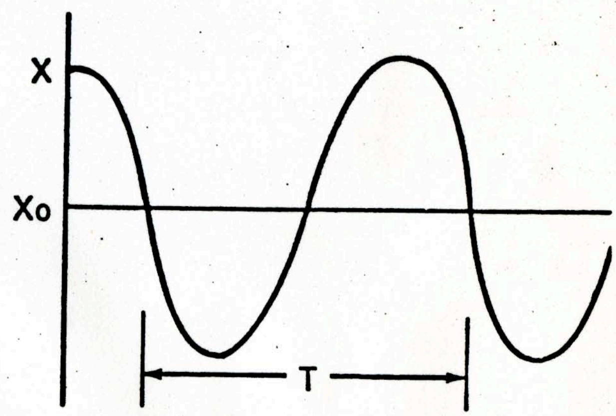


Figure 1.- ~~A simple spring/mass oscillator and its equation of motion~~.
Basic mechanics of the SMMD

C. Any lack of rigidity in either the mounting or supporting structure of the device. This can produce either coupled compliances or resistances which may alter oscillation periods.

D. Deviations of the plane of oscillation from a position normal to gravity. This occurs in a 1 g environment and results in a pendulum effect with shifts in period; hence the need for careful leveling of the SMMD during SMEAT.

E. Errors caused by the "tare mass" or mass of the specimen tray and associated structure. Overall accuracy is limited by tare mass as follows. The maximum SMMD resolution available is ΔM, a relatively fixed value of M_o (tare mass). However, the error of interest is the fraction of specimen mass M_x or $\Delta M/M_x$; thus, when M_x is small compared to M_o (tare mass), appreciable errors can result as in the case of measurement of small food residues.

F. Miscellaneous errors from environmental sources, design features, and manufacturing tolerances. These might include air streams, mechanical interference, and errors in the spring/plate-fulcra, the counting circuit, or the zero-crossing detector.

SMEAT SMMD Mounting

During the SMEAT test, the SMMD was mounted in a replica of a set of Skylab wardroom cabinets vertically oriented in the SMEAT chamber head. Actual mounting in the cabinet consisted of supporting the SMMD base plate on the ends of vertical vernier bolts at four corners for leveling. These bolts fitted recesses in the plate, and contact was maintained by the large weight of the mounting plate and SMMD. Neither cabinet nor mountings were as rigid as Skylab. Figure 2 illustrates the SMMD.

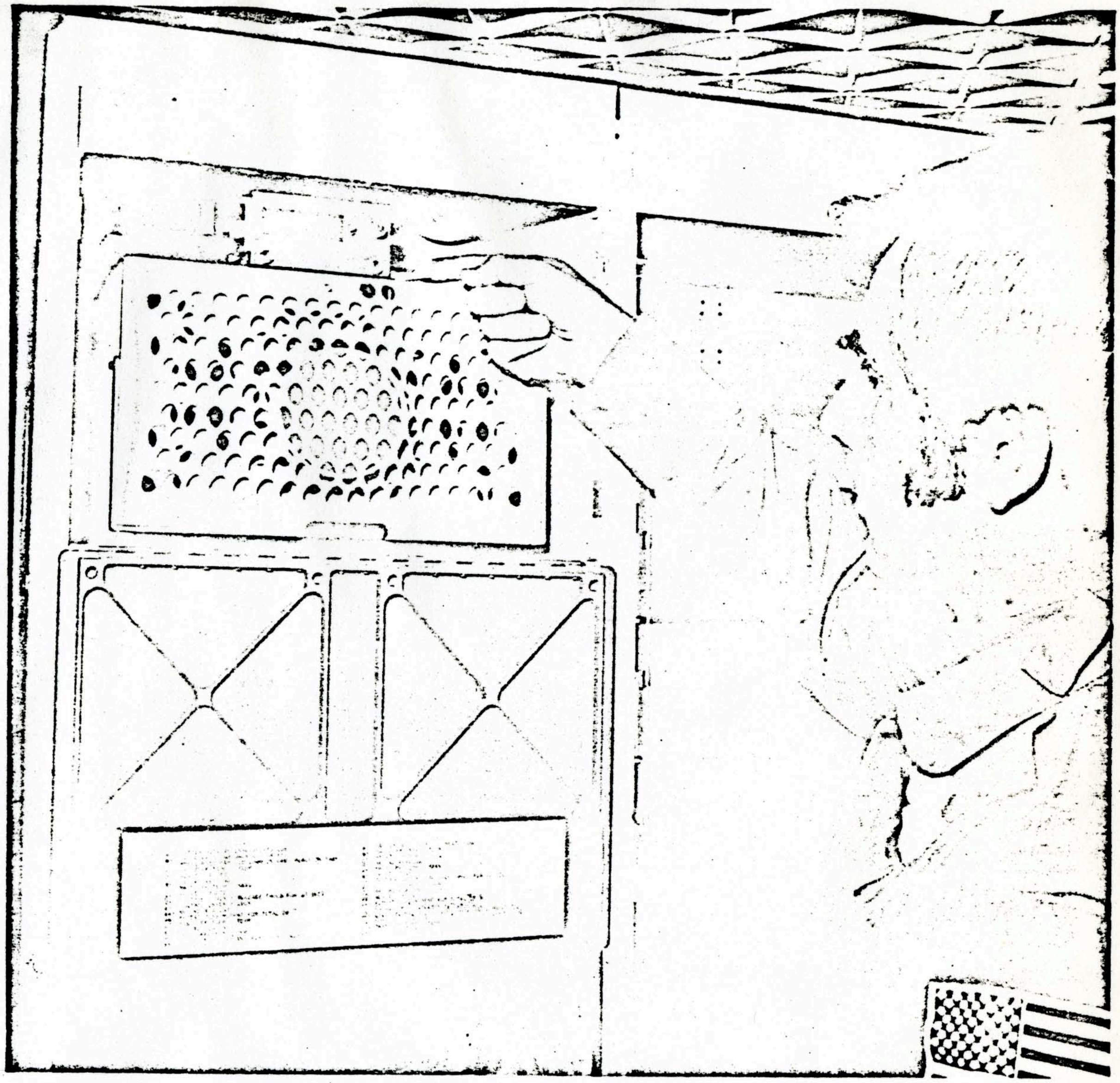


Figure 2.- S/L SMMD installation. Control lever is being held in operate position.

Procedures

Calibration

Since the SMMD is a comparative rather than an absolute unit, it requires calibration. The complete unit, therefore, includes a series of calibration masses.

During the experiment, the calibration was periodically re-checked to verify the amount of change, if any.

Calibration masses in SMEAT were: 9, 50, 100, 150, 250, 300, 400, and 500 grams, the range of masses capable of being measured by the SMMD at 1 g.

Calibration of the SMMD in the SMEAT chamber consisted of:

1. Verifying level by visual inspection of the bubble level.
2. Obtaining a starting temperature reading from the SMMD and independent sensors.
3. Inserting the proper mass in the center of the specimen tray.
4. Zeroing the electronic timer.
5. Releasing the tray to oscillate.

The displayed period and the start and stop temperatures were recorded on the log sheet. This procedure was repeated five times for each mass unless unusual crew acceleration or other activity produced a period readout of more than 200 microseconds (20 counts) difference from the average of the five readings obtained. In this event, the measurement was repeated.

Temperature Measurement

Since the SMMD has a large temperature coefficient, its mass determinations must be corrected for temperature. Temperature measurements were taken before and after calibration so that temperature-corrected time periods could be used to make the calibration curves. The experimenters had planned to use the SMMD's internal temperature measurement system, but the system proved inaccurate. Several alternative methods were tried, including air probe sensors, a digital thermometer, and the ambient chamber temperature measured by the environmental control system. Temperatures from the ~~latter~~ first two devices were taken from structures as close to the spring supports as possible. Temperatures close to the spring supports did not deviate from the ambient chamber temperature, which turned out to be the most practical measurement.

Data Collection

During the experiment, both fecal and food residue masses were to be measured. Since the crewmen ate all the food provided during SMEAT, food residues had to be simulated. Several measurement techniques were tried in order to adopt the most satisfactory procedures for Skylab.

The fecal samples were collected in a bag with self-adhesive surfaces covered by a plastic backing which is removed when the bags are used. Six wipes were normally used and placed in the bag along with the feces.

Five readings on the SMMD were always recorded for each mass determination to allow for statistical treatment. If drift or some overt instability was present, the sequence was repeated as necessary. Specimens were remeasured on a platform-beam balance to check for differences between the SMMD and a gravimetric scale.

Data Analysis

Calibration curve coefficients were generated outside the chamber using regression equations. Mass conversions were performed inside on a small digital computer. The following equation was employed:

$$\text{Mass} = A + BT^2$$

where: A and B are the calibration coefficients and T is the period of oscillation.

To examine more carefully how well the SMMD determines the mass of an unknown sample as compared to the sample's true mass, a series of higher order equations ~~were~~ was generated to fit the calibration curves more closely. They are of the form:

$$\text{Mass} = A + BT + CT^2 + DT^3 \ldots XT^n$$

Specimens weighed on the gravimetric balance were corrected in accordance with the weight of the calibration masses on the scale. The gravimetric scale was obviously sensitive to the location of weights on the pan. This was its largest error source and could easily be 1/3 gram or more without careful centering, especially with large objects. Resolution to .05 grams was possible with this scale, although 0.1 gram would be a more conservative figure. Discrepancies between the actual and measured weights amounted to some 1/10 to 2/10 of a percent at masses above 100 grams and slightly less than that at lower masses.

Results

The SMMD performed satisfactorily as a nongravimetric instrument within the accuracies required for the associated medical tests. It was reasonably quick and easy to use.

Calibration

The root-mean-square errors for third and fourth order calibration curves were similar and the practical best accuracy which could be obtained was .0238 percent error with a -.009 percent minimum at 500 grams to .0244 percent error with a maximum of 0.3464 percent at 100 grams. This compares reasonably well to prototype errors on the order of .01 percent. Resolution at 250 grams using calibration masses was typically 3.95 times 10^{-2} percent or .0989 grams. Drift over a ten-day period averaged 5.329 times 10^{-2} percent or .1332 grams. The worst error over a ten-day period at 250 grams, therefore, should not exceed .256 grams or .102 percent. Short term resolution at small masses was on the order of 100 milligrams.

Fecal Masses

Table 1 contains values from three representative periods of fecal mass measurement, early, mid, and late in the test. The estimated fecal mass was obtained by subtracting 110 grams for bag and wipes from the total gross mass. The percent of fecal mass error was then calculated from the result.

Fecal masses had typical net errors of .05 to .75 percent with normal samples, but occasionally small samples exceeded two percent. Gross fecal samples, including both wipes and bag as well as the feces themselves, were typically less than .5 percent with occasional errors on the order of two percent.

The most likely source of errors in fecal measurement was accounting for the number of wipes used. The wipes themselves were consistent in weight within a given lot. Bag weights were another source of error. The bags weighed during SMEAT were apparently handled in lots which resulted in large variation in the accuracy of recorded weights.

Food Residue Masses

Table 2 shows the results of several simulated food residue measurements. It was found that liquid in a container with an air interface was measured with large errors. Oddly enough, small samples of more viscous material (corn, sauces, etc.) produced surprisingly large errors which could never be explained. Larger, more liquid samples with tissue entrapment, were measured accurately.

The procedures used to measure food residues showed that it was important to secure the object to the SMMD specimen tray in such a way as to prevent sloshing. The most promising of the restraint methods tried with a variety of simulated food residues seemed to be placement of the residue in a mylar bag which was folded to prevent spillage. It was also clear that the masses of

TABLE 1

ACCURACY OF FECAL SAMPLE MASS DETERMINATIONS

Date	Sample Number	Gravimetric[1] Mass Grams	SMMD Mass Grams	Error Grams	% Gross Error	Fecal mass Error %	Period Resolution Sec.x10^{-5}
209	FC 1547	246.84	247.70	+.86	.35	.59	23
	FC 1544	275.41	275.26	-.15	-.054	-.091	11
	FC 1549	212.39	212.75	.26	.12	.25	50
210	FC 1545	254.1	255.2	1.1	.43	.77	23
	FC 1542	187.15	188.87	.72	.38	.74	9
211	FC 1541	165.91	169.33	3.42	2.06	6.1	27
	FC 1529	277.51	278.28	.77	.28	.46	8
	FC 1528	170.3	172.85	2.55	1.49	4.2	14
212	FC 1527	257.59	257.08	.48	.19	.30	17
	FC 1526	188.65	188.58	-.07	0.037	0.039	23
	FC 1524	207.4	209.2	1.8	.87	1.8	19
230	FD 1783	174.12	178.3	-.18	.10	.28	38[2]
	FD 1786	278.88	278.41	-.47	.17	.28	14
	FD 1787	144.45	143.99	-.46	.32	1.35	16
	FD 1788	183.6	184.05	.45	.25	.61	36
231	FD 1790	206.50	206.79	-.29	.14	.30	21
	FD 1804	198.00	199.16	1.16	.59	1.32	15
	FD 1805	191.43	191.08	-.35	.18	.43	10
260	FD 1751	159.3	160.21	.91	.57	1.86	27
	FC 1517	231.6	233.74	2.14	.92	1.75	42
	FC 1516	173.83	175.58	+1.74	1.00	4.14	19
262		179.92	181.59	1.67	.93	2.38	48

[1]Corrected to SMMD calibration mass.

TABLE 2

FOOD RESIDUE DETERMINATIONS

Item	Mass Gravimetric Grams	Mass SMMD Grams	Error Grams	Error %
Drink #DBC379 [1]	39.70	41.25	+1.55	3.9
Drink #DBC275 [1]	46.70	47.77	+1.07	2.29
Drink #DBC474 [1]	44.31	45.23	.92	2.69
Spaghetti + Sauce	45.39	45.99	+ .6	1.33
Asparagus	43.54	44.78	+1.24	2.7
Cream Corn	43.39	44.41	+1.02	2.3
Veal [2]	163.8	165.04	+1.54	.94
Pineapple A -	155.32	158.76	+3.44	
B - [2]	163.25	163.58	+ .33	2.02×10^{-1}

1 - Liquid in Skylab drink containers.

2 - Tissues used to constrain liquid.

the containers and wipes had to be accounted for in order to determine the mass of the actual food residues.

<u>Equipment Limitations</u>

The SMMD has a large temperature coefficient and lacks a workable temperature sensing system. This results in the requriement for an independent temperature determination during calibration.

The large tare mass of the specimen tray makes high resolution studies impossible. The SMMD performs well as regards drift, but shows moderate sensitivity to mass position, undoubtedly a by-product of the large specimen tray and plate-fulcra design.

The fact that the SMMD lacks direct mass readings made operation of the instruments very time consuming. The data had to be recorded and transmitted verbally, and then the time periods had to be translated into mass. For Skylab, three rather than five measurements for each specimen are recommended.

Conclusions

In spite of some difficulties with the temperature measurement system, the SMMD worked well. The device is more accurate when measuring large calibration masses. Maximum resolution is on the order of 50 milligrams at small masses. Stability for ten-day periods is on the order of 175 milligrams.

Careful documentation of can and bag weights and number of wipes used is necessary in order to measure fecal and food residue masses accurately. Sloshing must be prevented during measurement or it will upset the period of oscillation.

Although mass determination is a ~~fundamental~~ cornerstone of engineering + scientific operations, no such measurements have been ~~so~~ made in space flight to date since all weighing machines are gravimetric devices. Skylab, for the first time, will ~~ma~~ routinely make mass measurements using a mechanical mass controlled ocillator. ~~which is operates One such device,~~ the The S.L. Specimen Mass Measurement Device was included in S meat to allow realistic operations in ~~determ~~ measurements of food residue + fecal samples ~~and to~~ as well as ~~demonstrate~~ evaluate performance ~~operation~~ of the device and develop operational procedures under realistic conditions. ~~The Evaluation of and~~

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~~evaluate its performance~~

Equipment:

The S.M.M.D. is a rectilinear spring mass oscillator whose performance closely approximates that of the idealized arrangement shown in Fig. 1. A ~~specimen~~ tray or platform has an elastic cover sheet to hold specimens to it. This tray is supported by and constrained to approximately linear motion by a flexure pivot (as* shown in Fig. 2) which also applies a restoring force when ~~off~~ the ~~dept~~ tray is displaced from a neutral position. add * here. X

~~lever a~~ Motion of an operate lever first displaces the tray a small fixed distance and then releases it allowing virtually undamped

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oscillation on the order of 1 cycle/sec. ~~of the tray~~ Period ~~s~~ of this oscillation, ~~the~~ which is a function of the specimen mass, is measured ~~by timing successive~~ and an electronics system ~~which~~ times ~~to + displays 6 decades of the zero crossings to 10 microsecs~~ + displays ~~6 successive~~ the period of 3 cycles to a resolution of 10 micro-seconds. ~~By~~ After periodic calibration with known masses ~~the mass of~~ specimens mass may be calculated or determined graphically. Since the devices ~~were not~~ as constructed had ~~a~~ considerable temperature effects an integral temperature measurement system was included in the

Summary: The SkyLab Specimen Mass Measurement Device, ~~a non-gravimetric~~ a spring mass oscillator ~~which is opera~~ to be used for mass determination of food residue, vomitus & feces on Skylab, was used in ~~the~~ Smeat to determine operational suitability + determine procedures. ~~It~~ Until the unit was damaged by heat sterilization after an external repair, the unit demonstrated measurement ~~is~~ ~~fecal sample~~ accuracies of ~1% ~~and food res~~ for fecal samples + 2% for food residues. Accuracies with solid masses was on the order of ≤1% and stability was ~~on~~ approx. 175 mgm - for 10 day periods. ~~It~~ With procedures developed it should be suitable for support of Sklab ~~mass~~ medical requirements.