M074 in SMEAT

WILLIAM THORNTON, M.D.	-	PRINCIPAL INVESTIGATOR, CB, NASA - MSC
JACK ORD, COL., USAF	-	CO-PRINCIPAL INVESTIGATOR, USAF HOSPITAL, CLARK AFB
RAY MCKINNEY	-	PROJECT ENGINEER, DE/4 NASA - MSC

M074 - INTRODUCTION

Mass determination forms one of the cornerstones of engineering and scientific operations. The only devices previously available for such determination were gravimetric; hence, unusable in space flight to date. Skylab will, for the first time, attempt to make mass measurements in space with experiment M074/172. These experiments will use spring/mass oscillators for both investigation of the device's performance as well as routine measurements of food residue, waste and human mass. They form an integral portion of several other major experiments and as such are essential to their success.

The SMMD (specimen mass measurement device) was selected for inclusion in SMEAT to investigate its performance under conditions realistic of S.L. (Skylab). Stated objectives of the DTO were:

a. "Demonstrate mass measurement of the mass measuring device during the SMEAT chamber test."

b. "Perform periodic calibrations of the mass measurement device during the SMEAT test to ascertain long-term stability and repeatability."

Although not a stated objective, this test was used to develop and validate operational SMMD procedures. All Skylab conditions except weightlessness were present, and this was partially stimulated by placing the device in a plane such that gravity effects on the instrument's operation were virtually negated.

Installation and operation closely followed those planned for Skylab. Calibrations were performed more frequently, and several modes of residue and fecal measurement were tried to allow selection of the most suitable for Skylab operation.

This is a report of the methods used, results obtained, and their implications for Skylab. Although not strictly a part of this investigation, a number of factors affecting the overall accuracy of measurement of food and fecal samples were investigated and are presented in appendices.

Valuable assistance in data reduction was given by Ronald R. Lanier of the Flight Control Division, NASA - MSC.

DESCRIPTION OF APPARATUS

Skylab mass measuring devices all use a mechanical (recti-linear) spring/mass oscillator in which the period of oscillation is a function of the mass coupled into the system. After calibration with a series of known masses, sample masses may be calculated from the period of oscillation produced.

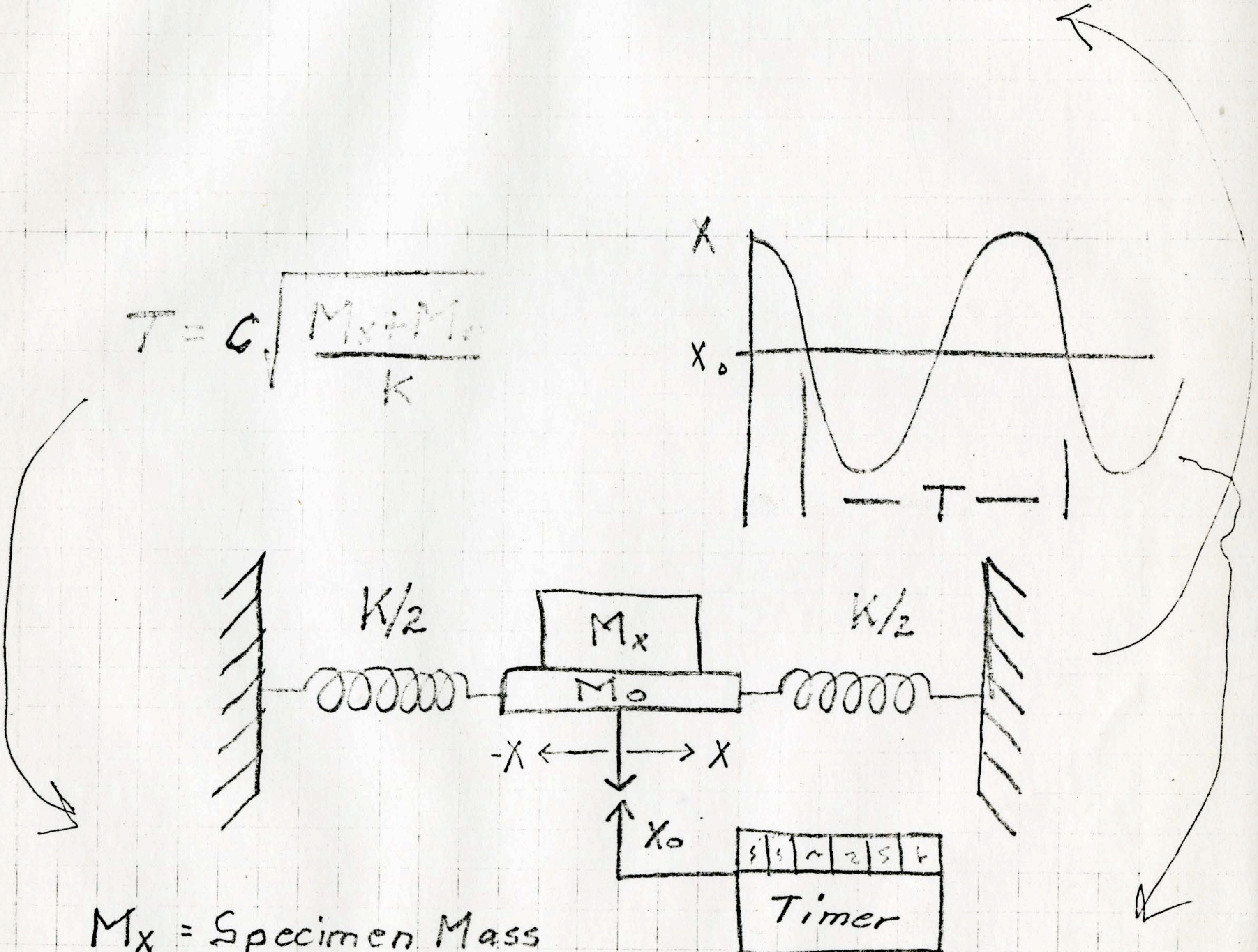
Figure 1 is a schematic of such an oscillator. If the masses are displaced a small distance X_1 from rest position X_0 and released, it will undergo undamped sinusoidal oscillation whose period (T) is measured by a timer. This period is given by the equation while the mass (M) may be calculated from:

$$M = A + BT^2 \qquad \text{Eqn. 1}$$

...where constants A and B are most easily determined from calibration of the system with known masses.

Such an oscillating system is approximated by the SMMD design. See Figure 2. A flexure pivot or plate fulcra made of spring material both supports and constrains the mass to approximately translational motion as well as provides restoring force when displaced. Timing to 10^{-5} seconds is accomplished by a crystal controlled digital timer with a six place readout. An electro-optical transducer sends a signal to the device's logic circuit each time the tray crosses the midpoint in its oscillating cycle. After two cycles have been completed to allow transients to decay, Fig 1. A simple spring/mass oscillator and its equation of motion -

$$T = C\sqrt{\frac{M_x + M_o}{K}}$$



M_X = Specimen Mass

M_o = Tare Mass

K = Spring Constant

X_o = Position of rest

X_o = Maximum Displacement

T = period of Oscillation

the total elapsed time for the next three cycles in tens of microseconds appears on the device's digital display.

The displacement and release of the mass is controlled by a single spring-loaded control lever which normally 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. Since these SMMD's were not designed with a zero temperature coefficient, temperature was to be internally measured. The electronics unit has a switch-selected temperature measurement function with a sensor in its base for this purpose. A large flat tray with an elastomeric cover sheet is used to couple specimens into the oscillator system. The complete SMMD includes a series of solid calibration masses.

Operation consisted of turning the device's power on, resetting the electronics readout to zero, placing the specimen to be measured on the tray under the elastic sheet, and rotating and holding the operating lever until the counting cycle is complete. This reading was manually recorded for verbal transmission during a schedule report.

The SMMD was mounted in a replica of a set of Skylab wardroom cabinets vertically oriented in the SMEAT chamber head. See Figure 3. 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 mounting plate and SMMD. Neither cabinet nor mountings were as rigid as Skylab. A potential error source was the large amount of low frequency vibration in chamber structure generated by the environmental control system blower. This could be expected to increase the random errors. There was virtually no air flow or other potential error sources in the SMMD area.

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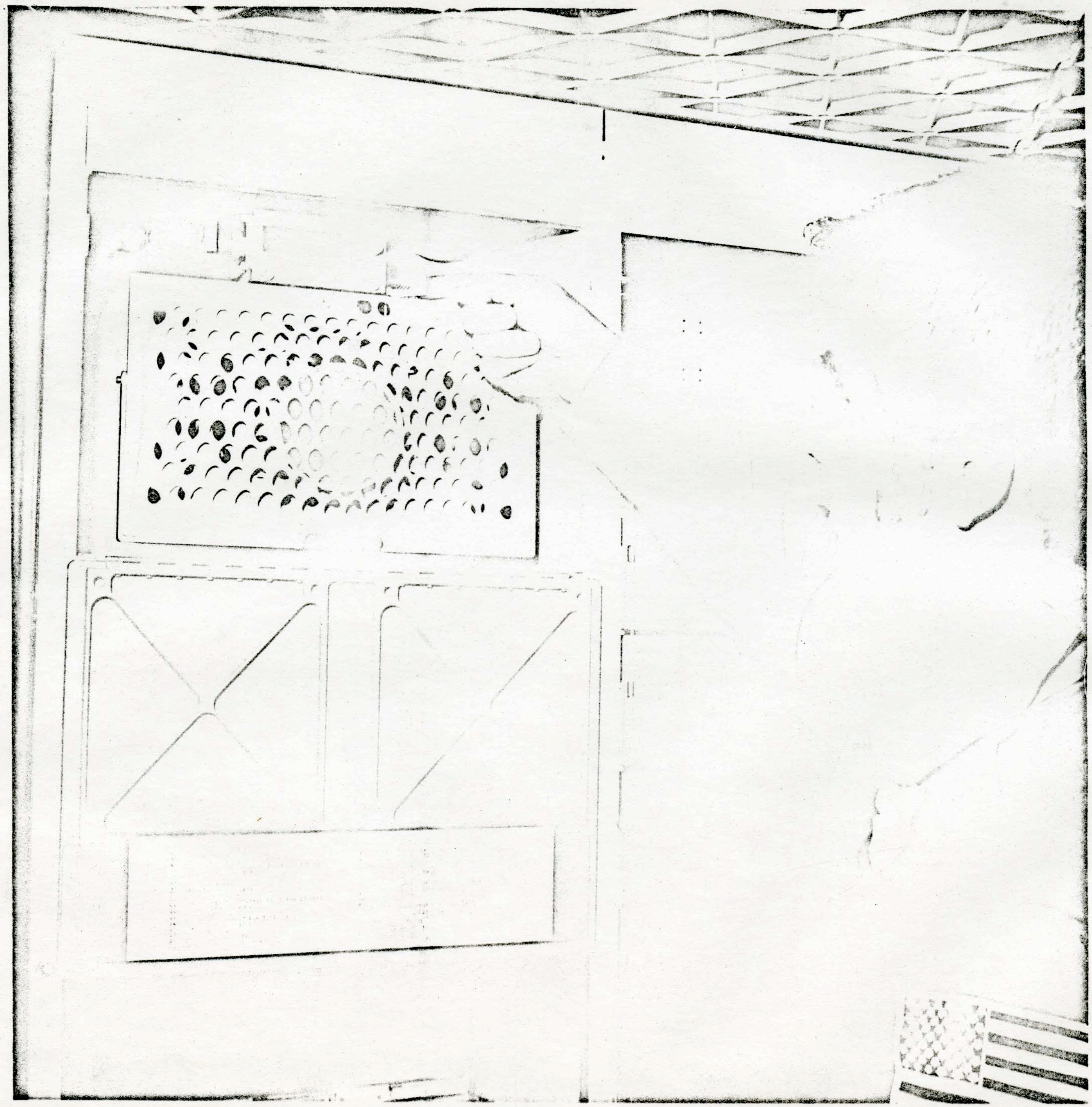
Fig 3



S/L SMMD Installation. ~~Operate handle is being released~~, Control lever is being held in operate position.

All weights other than the calibration masses were determined with an ordinary laboratory platform/beam balance scale (NASA T00837) placed in a cabinet immediately above the SMMD. The SMMD used in this test was a DVTU (development test unit) part #2837-002-01, Serial #DH-1. It was essentially identical to flight hardware.

DATA COLLECTION

Since the device is a comparative rather than absolute unit, calibration is required at least once every 10 days both for operation as well as evaluation of the instrument. Briefly, 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, and (5) releasing the tray to oscillate. The displayed period and the start and stop temperatures are recorded on the log sheet (see Figure 4). 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 simply repeated. Calibration masses were: 0, 50, 100, 150, 250, 300, 400 and 500 grams, the range of masses capable of being measured by the SMMD at 1-g versus a maximum of 1,000 grams at 0-g.

At the beginning of the test, it had been planned to use the internal temperature measurement but its inaccuracies prevented this, and a variety of work-arounds were tried including use of the air probe sensors and digital thermometer from M-487 and using air temperature measured by the environmental control system. Temperatures from these devices were taken from structure as close to spring supports as possible. These data are presented and discussed subsequently in this report. Since chamber temperature was constant and there were no significant heat sources in the associated structure, ambient chamber temperature proved to be the most practical.

Fig. 4 Original to be supplied for print as required.

SMMD MASS MEASUREMENTS

SMMD TEMP		SMMD READOUT					
[illegible]RNTON			BOBKO				

DATE 7/10/72

M074 SMMD CALIBRATION

[illegible]N - 11 T.							TIME -	HR		MIN		TEMP	
[illegible] OF YEAR				1	9	3	START	1	2	3	7	7	[illegible]
[illegible] UNIT - SMEAT							STOP	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MASS	SMMD READOUT						MASS	SMMD READOUT					
SEQ 1 0g	1	9	4	2	7	6	SEQ 6 300g	2	[illegible]	7	3	1	2
					6	7						8	2
	$\overline{6}$	$\overline{7}$			7	2						1	1
					6	6						3	[illegible]
	1	9	4	2	6	7		2	[illegible]	7	3	2	[illegible]
SEQ 2 50g	2	0	2	5	2	4	SEQ 7 400g	2	5	2	0	0	1
					2	3		[illegible]	[illegible]	9	9	2	[illegible]
					2	1						[illegible]	9
					1	0						2	7
	[illegible]	[illegible]	2	5	2	0		[illegible]	[illegible]	[illegible]	9	[illegible]	[illegible]
SEQ 3 100g	2	0	3	3	0	6	SEQ 8 500g	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
					6	6					[illegible]	4	[illegible]
					0	4						4	[illegible]
				8	9	3						6	1
	2	0	3	3	2	0					9	6	0
SEQ 4 150g	2	1	7	0	7	8	SEQ 9 0g	1	9	4	8	4	0
				3	6	6						5	3
				0	7	7		$\overline{5}$	$\overline{4}$			[illegible]	[illegible]
				4	6	9						[illegible]	[illegible]
				6	7	2						[illegible]	[illegible]
SEQ 5 250g	2	[illegible]	[illegible]	7	6	5	Start Temp	6		7	0		
					2	7	Sensor Elect Pkg (1) + Plat. preamp (2) *	6		7	1°		
	$\overline{5}$	$\overline{8}$			[illegible]	9		6		7	1		
					3	2		6		7	1		
					4	6							

*21 [illegible] probe

Fig 4. Typical Calibration Record of SMMD - Barred numbers are calculated means.

It was originally intended to measure all food residue and feces, but no residue was ever available, and only fecal mass measurements were made. Several food residues were simulated. A variety of methods of folding or manipulating fecal bags were tried during the test. Although this has no effect on errors shown, which is gross mass of bag and contents, large errors in fecal masses can result from uncontrolled variations in packaging techniques. A discussion of these is given in Appendix 1. Several food residue measurement techniques were also tried, and these are discussed in Appendix 2. Since fecal mass measurement is interrelated with collection, the methods and probable errors given are discussed later.

It had been originally planned to verbally pass the calibration and sample period data from the chamber and have all calibration curve generation and mass conversion performed externally. Rough inchamber conversions were to be made graphically. Gravimetric mass determinations of all samples were made inchamber and also verbally passed out as were the actual samples which were then to be remeasured with high resolution balances and differences checked. Just prior to entry a tiny digital computer (HP-35) became available and made mass conversions using externally generated curve coefficients a simple enough task to be done inchamber.

DATA REDUCTION

Analysis - Ultimate performance of the SMMD is simply how closely it determines the mass of any unknown sample as compared to the samples' true mass. This difference is designated Δ M. (Equation 1 is an approximation adequate for operational measurements.)

$$\text{Mass} = A + BT^2 \qquad \text{Eqn. 1}$$

A and B are coefficients determined by calibration with known solid masses using the regression equations 4a and b on page 9.

For examination of ultimate performance a series of equations of higher orders are generated to fit the calibration points more closely. They are of the form:

$$\text{Mass} = A + BT + CT^2 + DT^3 \text{ -- } XT^n \qquad \underline{\text{Eqn. 2}}$$

Errors in mass M are related to period errors by:

$$\frac{\Delta M}{M} = \frac{2 \Delta T}{T} \qquad \underline{\text{Eqn. 3}}$$

where: T is time of period(s), Δ T is error or variation in this time.

Errors, Δ T (hence Δ M), may be considered from several aspects, and the ones examined here are defined as:

Resolution is variation in recorded periods with a given sample in place and with repeated operations of the scale. This value determines the ultimate SMMD performance which may be expected and is a function of all short-term errors in the unit such as zero crossing resolution as well as externally induced disturbances such as vibration.

Repeatability is determined by removing a mass, replacing it on the tray, and repeating the measurement immediately.

Drift is error over a longer period of time and is determined by measurements of the same mass separated by days or weeks of time.

Although omitted in the above discussion, temperature is assumed to be constant in the previous measurements. These devices were fabricated with appreciable temperature coefficients, so this error source must also be considered.

Since the primary objectives of M074 are evaluation of its performance as a non-gravimetric mass measurement device, MMD (Mass Measurement Device) error source analysis is crucial. Expected sources include:

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 non-rigidity, i.e., "slosh", either in specimen mass or in coupling the specimen to the tray may result in secondary oscillations which, if the frequency is near the fundamental frequency, will cause errors. This is the major limitation in the utility of this type of mass measurement.

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

d. Any mechanical or other disturbance to the tray such as air streams or mechanical interference are fairly obvious error sources.

e. In 1-g use the plane of oscillation must be normal to gravity, or a pendulum effect with shifts in period will otherwise occur; hence, the need for careful leveling.

f. "Internal" errors determine ultimate accuracy available and include errors of spring/plate fulcra (which cannot be separated from overall mechanical design) such as spring rate drift, hysteresis, creep, and temperature effects.

g. Accuracy of the counting circuit and the resolution of the zero-crossing detector determine ultimate resolution and accuracy.

h. Not so obvious an error source is 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 when compared to M_o (tare mass), appreciable errors can result as in the case of measurement of small food residues.

i. Second and third order errors include buoyancy generated in gravimetric mass determination and a virtual mass of air which moves with an object at low velocities.

Data was analyzed as follows. Calibration masses were accurate to five significant places and thus assumed to have negligible error and became standards. All other sample masses were determined from the gravimetric balance which was in turn compared to the calibration masses as shown in Table 1. Weighed sample masses were corrected to the calibration masses. The gravimetric scale was obviously sensitive to location of weights on the pan. This was its largest error source and could easily be 1/3 gm. or more without careful centering and small objects. Resolution to .05 gm. was possible with this scale, although 0.1 gm. would be a more conservative figure. Discrepancies between the standard and measured weights amounted to some one to two tenths of a percent at masses above 100 gms. and slightly less than that at lower masses.

A calibration record sheet is shown in Figure 4, and a Figure 5 is a sample record sheet. The first five readings were always recorded to allow study of maximum period variation. If drift or some overt instability were present, a sequence would be repeated as necessary.

Straight line calibration curve coefficients were calculated from:

a. $$B = \frac{\sum XY - \bar{X}\sum Y}{\sum X^2 - \bar{X}\sum X}$$ b. $$A = \bar{Y} - A\bar{X}$$ Eqn. 4 a&b

$X = T\ (\text{period})^2$

$\bar{X}$ = average X

Y = mass

$\bar{Y}$ = average Y

A computer program was used to generate a curve to empirically calculate a series of equations of the form shown in Eqn. 2 up to the fifth order.

TABLE 1

INDICATED WEIGHTS FROM GRAVIMETRIC BALANCE$_1$ VS. CALIBRATION MASSES

Calibration Mass Grams	Scale Reading Grams	Date J.D.	Difference %
0.0	0.00	179	0.0
50.00	50.04	179	$8. \times 10^{-2}$
100.00	100.03	179	$3. \times 10^{-2}$
150.00	150.3	179	2×10^{-1}
250.00	250.28	179	1.12×10^{-1}
300.00	300.50	179	1.66×10^{-1}
400.00	400.58	179	1.45×10^{-1}
500.00	500.62	179	1.24×10^{-1}
100.00	100.05_2	203	$5. \times 10^{-2}$
100.00	100.06_3	203	$6. \times 10^{-2}$
100.00	100.35_4	203	3.5×10^{-1}
100.00	100.10	222	1×10^{-1}
90.00_5	90.08	222	8.9×10^{-2}
95.00_5	95.08	222	8.4×10^{-2}

1 - NASA Scale #T00837

2 - X 10 Scale

3 - X 1 Scale

4 - ≈ 6 cm. Off Center

5 - Laboratory Standard Masses

Fig. 5 Original to be supplied for print as required.

DAY 204   10 7.4   SMMD MASS MEASUREMENTS

CM	ITEM T	ITEM ID	TIME HR	TIME MIN	SMMD TEMP	SMMD READOUT
B	F	FC1547	18	50	[illegible]	[illegible]
						[illegible]
		247.14 g				[illegible] 7
		247.70				[illegible]
						2 3 [illegible]
T	F	FC1546	19	26	7 4	2 1 [illegible]
		166.7 G				[illegible]
		101.7				[illegible]
		232.66	126.2			1 7 [illegible]
		7 wipes				[illegible]
C	F	FC1544	19	45	7 4	2 7 9 1 [illegible]
						2 [illegible]
		275.71[illegible]				1 9 5
		275.26				2 [illegible]
						[illegible]
T	F	FC1549	14	79	1 2	2 2 [illegible]
						[illegible] 2
		212.60				[illegible] 1
		2 wipes				[illegible]
		212.75 M				[illegible]

URINE VOIDS	6 CRIPPEN 3	7 THORNTON 3	7 BOBKO 7
	[illegible]	[illegible]	[illegible]

DATE 7/10/72

Fig 5 - Sample Record Sheet for SMMD

Each curve was then used to calculate masses at each calibration point. Best fit was selected by comparing calculated to actual values.

Determination of and subsequent compensation for temperature was a problem. Table 2 shows a series of indicated temperature readings by the SMMD versus either measured temperatures on structure near the springs felt to be in equilibrium with them, or else ambient temperature if it had been stable for several days. The first temperature on a given day was taken immediately after the SMMD power has been turned on while the second is just prior to power being turned off.

Until day 240 the SMMD temperature seems to bear a relatively constant though erroneous relationship to that which actually existed but after that, there was little relation between the two. A second problem with the SMMD internal thermometer is that the electronics' heat induces errors after a short period of usage.

Calibrations were first made with and without temperature corrections. Such corrections were based on indicated temperatures and a temperature coefficient supplied by the fabricator and apparently derived using the SMMD internal temperature measurement and, as such, produced errors. The temperature was measured independently at each calibration and data was not "corrected" to some standard temperature but rather the apparent differences in mass were used to generate an accurate temperature coefficient. This latter figure is of interest in defining temperature coefficients but is not required to meet operational sample measurements. Measurements shown here are not temperature corrected.

Table 3 is a tabulation of several aspects of all calibrations and includes the average of all periods at zero mass both at the beginning and end (0_1 and 0_2) of the calibration period, of the 250 gm. calibration sequence, the total variation in period at each sequence (resolution)

TABLE 2

SMMD INDICATED VS. MEASURED TEMPERATURE

Date	Time	Indicated Temperature °F.	Measured Temperature °F.	Temperature Error °F.	Indicated Temperature Rise °F.
179	1423	70	67	+3	
	1425	73	67	+6	3
182	1346	74	71	+3	
	1405	77	71	+6	3
192	1745	73	70.5	+2.5	
	1800	76	70.5	+55	3
227	1503	77	73	+4.	
	1531	80	73	+7.	3
240	1456	82	77	+5	
	1509	83	77	+8	1
248	0307	75	68.5	+6.5	
	0320	77	68.5	+8.5	2
251	1440	77	68	+9	
	1455	78	-	-	-
	1507	79	68	+11	2
256	0346	74	68	+6	-

TABLE 3

SOME VALUES OF SMMD CALIBRATIONS

Date	Mass Grams	Average Period (T) Seconds	Drift Long $Sec.x10^{-5}$	Drift Short $Sec.x10^{-5}$	Resolution $Sec.x10^{-5}$	Measured Temp F^o	Calibration Curve Coefficients A	B
182_T	0_1	1.94902			29	71	-618.477	162.962
	0_2	1.94873		-29	9			
	250	2.30767			3			
192_T	0_1	1.94855	-47		9	70.5	-618.354	163.002
	0_2	1.94833	-40	-22	6			
	250	2.30721	-46		7			
193_T	0_1	1.94867	-35		10	71.	-618.684	162.944
	0_2	1.94854	-19	-12	9			
	250	2.30758	-9		21			
203_T	0_1	1.94889	-13		16	71	-618.243	162.931
	0_2	1.94866	-19	23	13			
	250	2.30748			13			
206_T	0_1	1.94881	-21		8	70	-618.190	162.931
	0_2	1.94858	-15	23	14			
	250	2.30740	-27		10			

TABLE 3

(Continued)

-2-

Date	Mass Grams	Average Period (T) Seconds	Drift Long $Sec. x10^{-5}$	Drift Short $Sec. x10^{-5}$	Resolution $Sec. x10^{-5}$	Measured Temp F^{o}	Calibration Curve Coefficients A	B
208_T	0_1	1.94891	-11		13	70	-162.961	-618.394
	0_2	1.94862	-11	-29	14			
	250	2.30755	-12		7			
212_T	0_1	1.94904	+2		12	69	162.915	-618.302
	0_2	1.94868	+5	-36	19			
	250	2.30778	+11		5			
217_B	0_1	1.94881	-21		5	69	162.966	-618.326
	0_2	1.94843	-30	-38	7			
	250	2.30738	-29		16			
218_T	0_1	1.94882	-20		5	70	162.947	-618.271
	0_2	1.94855	-18	-27	9			
	250	2.30745	-22		8			
227_T	0_1	1.94784	-118		39	73	162.983	-617.874
	0_2	1.94749	-124	-35	4			
	250	2.30633	-134		15			

TABLE 3

(Continued)

Date/Grams	Mass	Average Period(T) Seconds	Drift Long Sec.x10^{-5}	Drift Short Sec.x10^{-5}	Resolution Sec.x10^{-5}	Measured Temp F^{o}	Calibration Curve Coefficients A	B
229_T	0_1	1.94781	-121		5	73	163.185	-168.570
	0_2	1.94751	-122	-30	9			
	250	2.30633	-134		14			
240_T	0_1	1.98371			8	77	158.191	-622.005
	0_2	1.98334		37	9			
	250	2.34704			9			
248_T	0_1	1.98824	+453		14	68.5	157.376	-621.655
	0_2	1.98785	+451	39	6			
	250	2.35254	+550		21			
251_T	0_1	1.98753	+382		20	68	157.554	-621.559
	0_2	1.98797	+463	44	9			
	250	2.35151	+447		11			
256_T	0_1	1.98829	+458		13	68	157.578	-622.469
	0_2	1.98767	+433		44			
	250	2.35241	+537		39			

TABLE 3

(Continued)

Date/Grams	Mass	Average Period(T) Seconds	Drift Long $Sec.x10^{-5}$	Drift Short $Sec.x10^{-5}$	Resolution $Sec.x10^{-5}$	Measured Temp F^{o}	Calibration Curve Coefficients A	B
257_c	0_1	1.98810	+439		20	68	157.566	-622.139
	0_2	1.98733	+399		11			
	250	2.35180	+476		8			

Crewmen performing calibration.

c = Cdr.

B = Plt.

T = Spt.

differences between O_1 and O_2 during a calibration period (short-term drift), and differences in the average periods of O_1, O_2 and 250 mass sequence from the initial calibration (long-term drift), temperature as measured by independent methods, and the straight line calibration curve constants A and B. The initial calibrations were separated since on day 240 and after the SMMD had been altered as described under discrepancies. It would be more accurate to take the mode rather than mean period of oscillation if a sufficiently large number of cycles had been available to select a mode.

Table 4 contains values from three representative periods of fecal mass measurement, early, mid and late in the test. Values include date and sample identification, gravimetric mass, gravimetric mass approximately corrected to SMMD standard masses, mass difference and percentage difference of fecal mass plus bag and wipes and percentage of estimated fecal mass. The latter was obtained by subtracting an estimated 110 gms. for bag and wipes from total gross. The SMMD mass is calculated from Eqn. 1 using the required number of significant figures. No temperature corrections were used since a calibration curve at the stable temperature of each period was available.

Table 5 shows the results from several simulated food residue measurements. Table 6 shows the accuracy of fit of various calibration curves from Eqns. 1 and 2.

RESULTS - The RMS errors for third and fourth order calibration curves were similar and the practical best accuracy which could be obtained was .0238% and .0244% RMS error respectively with a range of -.009% minimum at 500 gms. to +.03464% maximum at 100 gms. This compares reasonably well to prototype errors on the order of .01%. Resolution at 250 gms. using calibration masses was typically 3.95×10^{-2}% or .0989 gms. Drift over a 10-day period averaged 5.329×10^{-2}% or .1332 gms.

TABLE 4

ACCURACY OF FECAL SAMPLE MASS DETERMINATIONS

Date	Sample Number	Gravimetric[1] Mass Grams	SMMD Mass Grams	Error Grams	% Gross Error	Net 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 5

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.

TABLE 6

SMMD CALIBRATION CURVE ERRORS

Equation:	1		2 2nd Order		2 3rd Order		2 4th Order		2 5th Order	
Calibration Mass Grams	Calculated Mass Error Grams	Error %	Calc. Mass Error Grams	Error %	Calc. Mass Error Grams	Error %	Calc. Mass Error Grams	Error %	Calc. Mass Error Grams	Error %
0	.493		-.0565	-	-.00291	-	-.00796	-	-.01556	-
50.00	.066	$1.32.10^{-1}$	.0085	.0169	-.01189	-.02374	-.00992	-.01983	-.03670	-.07340
100.00	-.314	$-3.14.10^{-1}$	.08094	.08094	.03464	.03464	.03887	.03887	.04433	.04433
150.00	-.525	$-3.50.10^{-1}$	.06131	.04087	.02055	.01370	.02411	.01607	.06552	.04368
250.00	-.739	$-2.96.10^{-1}$	-.07136	-.02854	-.05959	-.02384	-.06077	-.02431	-.02324	-.00930
300.00	-.647	$-2.16.10^{-1}$	-.09595	-.03198	-.05831	-.01944	-.06161	-.02054	-.06741	-.02247
400.00	-.054	$-1.35.10^{-2}$	-.07829	-.01957	.12531	.03133	.12151	.03038	.03029	.00757
500.00	.757	$1.51.10^{-1}$	-.00502	-.00100	-.04756	-.00951	-.04412	-.00882		
0_2										

COEFFICIENTS

Curve Order	A_0	A_1	A_2	A_3	A_4	A_5
2^o	-680.622	55.3633	150.790			
3^o	-619.382	-25.8604	186.502	-5.02546		
4^o	-629.091	-11.0189	178.282	-3.25681	-.163.544	
5^o	-371.619	-291.605	160.605	125.669	-55.8359	7.33240

Eqn. 1 - $M = -618.477 + 162.962\ T^2$ (Cal. from Day 208)

Eqn. 2 - $M = A_0 + A_1T + A_2T^2 \text{ X } A_3T^3 + A_4T^4 + A_5T^5$

A worst case error over a 10-day period at 250 gms. should thus not exceed .256 gms. or .102%. Short-term resolution at small masses was on the order of 100 mgm. Temperature coefficient appears to be on the order of 45 counts/^{o}F. or .125%/^{o}F. at 250 gms. (.313 gms.).

Fecal masses had typical net errors of .5 - .75% with normal samples, but occasionally small samples exceeded 2%. Gross fecal samples (wipes + bag) were typically less than 0.5% with occasional errors on the order of 2%.

The food residue measurements shown are not exhaustive and in fact a number of additional determinations were made. These of course must be supplemented with a great many more runs with the definitive flight procedures prior to flight. Free liquid, i.e, liquid with a large air interface or in a container with large dimensions in the plane of oscillation will produce large errors. Conversely, the small samples of more viscous materials (corn, sauces, etc.) produced surprisingly large errors on the order of two grams which could never be explained. Larger, more liquid samples with tissue entrapment were measured accurately.

DISCUSSION - The SMMD performed satisfactorily as a non-gravimetric instrument for mass measurement within the accuracies required for support of the associated medical tests. It was reasonably quick and easy to use. The chief operational problem was recording and verbally transmitting considerable amounts of time data which then required translation into mass, i.e., the device was not direct reading as such an operational instrument should have been.

As a tool for rigorously investigating a new method, it had predictable limitations. Lack of a workable temperature sensing system can probably be worked around, but this is a problem with the instrument's large temperature coefficient. The large tare mass of the specimen tray makes high resolution studies impossible. It performed well as regards drift, but showed moderate sensitivity to mass position, undoubtedly a byproduct of the large specimen tray and plate fulcra design.

Some care will be required in measurement of food residue to prevent slosh and resulting errors. An overbag and enough tissues to soak up liquids will produce acceptable results here. Careful accounting will be required to insure that no errors in adding wipes to fecal and food samples occur.

DISCREPANCIES - The temperature measurement system was inaccurate and unreliable.

After some 10 days of use, the elastomer specimen hold-down sheet began to pull loose from its lower clamping rail. It pulled completely loose at several points by day 234, and was passed from the chamber where the sheet and clamping rail were replaced. The mechanical portion of the unit was autoclaved twice before being returned which apparently stressed springs or structure such that performance was markedly different from the first portion of the test. After return on day 240, period readings were erratic, and there was a frequent large drift. This is not so readily apparent from the recorded data since that was filtered prior to recording, i.e., the crew would wait until the worst drift was over or not record obviously spurious readings. In addition, the zero-crossing detector was found to be loose after the chamber run. For these reasons data from day 240 onward is not considered representative.

The replacement clamping rail for the elastic sheet was a heavier, more rigid element than the original which was thin and flexible and did not distribute pressure evenly resulting in stress points on the sheet. This replacement appeared to solve the problem.

SUMMARY - The Skylab specimen mass measurement device was operated throughout the SMEAT test in close simulation of the 56-day Skylab mission. It performed operational specimen measurements well until it was passed out of the chamber for replacement of the specimen hold-down and was autoclaved prior to return. Performance after this is not considered representative.

Fecal measurements were typically made with less than 1% error with small samples occasionally exceeding this. No food residue was available but simulations were made. By using a mylar bag for containment and paper wipes to entrap liquids, measurements of less than 2% are routine.

Present Skylab procedures are adequate for calibration but the specimen mass determinations should be reduced to three readings without temperature. Careful documentation of number of wipes, etc., will be required to maintain overall accuracy.

This SMMD performed well as regards to stability and period resolution. It has a large (for rigorous analysis) temperature coefficient and this, coupled with a faulty temperature measurement, requires an independent temperature determination during calibration.

This temperature problem and a very heavy specimen tray limits its utility as an investigative tool. With larger calibration masses it has reasonably good accuracy, on the order of .05%. Maximum resolution is on the order of 50 mgm. at small masses. Stability for 10-day periods was on the order of 175 mgms.

APPENDIX I

Although mass determination is an obvious error source, other much larger errors can easily accrue to make worthless the efforts to obtain a good MMD instrument. Some of these errors in fecal specimen measurement are examined.

FECAL - Fecal samples are collected in a bag with self-adhesive surfaces which prior to use are covered with plastic backing. In addition, six wipes are nominally used and placed in the bag but more than this may be required.

Several possibilities of error present themselves. First, the bag weight must be known. Table 1a is a typical listing of 17 bags. It appears that the bags were handled in lots for as shown by this sampling there was large variation in accuracy of recorded weights. Some lots were close to marked weights while others showed typical errors recorded.

Table 1b shows the consistency of mass of the total amount of adhesive backing tape. Variation from maximum to minimum weight is 0.29 grams. As expected, this die-cut material is very constant, and a fixed average value can be used with negligible error, so long as all of it is consistently accounted for, i.e., the same procedure use be used each time. Portions of this backing weigh approximately 2.5 grams each.

The most likely source of error is accounting for the number of wipes used. Table 1c shows some typical wipe weights. As would be expected, they are very consistent in weight from item to item, but there were at least two lots of wipes used in SMEAT. Another sample of 63 wipes averaged 2.798 gms. An error of wipe count is likely and one - two wipes can cause appreciable errors. This plus errors in bag weights and possible differences in techniques of adhesive backing disposal can easily produce errors of 10 grams or more.

It is recommended for Skylab that:

(1) The sources of bag weight error be found and corrected.

(2) A fixed procedure for removal of adhesive backing be instituted and followed.

(3) Wipe weight determination be made and wipe count rechecked on return.

(4) Most importantly, personnel using specimen data become aware of error sources and take appropriate precautions.

TABLE 1.A.

MEASURED VS. RECORDED FECAL BAG WEIGHT

Bag I.D.#	Measured Weight * Grams	Recorded Weight (on bag) Grams	Weight Error Grams	Error %
FD 1790	97.77	99.90	2.13	2.18
88	96.90	97.00	.10	.10
87	96.30	97.30	1.0	1.04
86	96.08	99.70	3.62	3.76
5	95.15	95.65	.50	.53
4	97.68	100.03	2.35	2.41
3	97.18	99.58	2.40	2.47
FD 1858	96.72	97.10	.38	.39
49	99.22	99.48	.26	.26
31	95.22	95.11	-.11	-.12
30	96.36	96.15	-.21	-.22
29	99.44	99.45	.22	.22
28	95.55	95.36	-.19	-.20
27	96.93	96.54	.39	.40
25	96.60	96.55	-.05	-.52
FD 1791	95.32	97.40	2.08	2.18
1792	97.14	100.11	2.97	3.05

*Corrected to cal. weight.

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APPENDIX II

Measurement of food residue samples, like fecal sample measurement, will depend very much upon procedures used. At the moment these have not been delineated. The following is a resumé of error sources and recommendation of procedures.

Food packages vary widely including: beverage containers, an accordion-folded plastic cylinder with a push-pull valve, several can arrangements with pull ring top removal including small cans of custards, candies and peanuts, a separate larger can with plastic internal container and a water valve for rehydration, with a plastic diaphragm for large cans of wet packed foods such as fruits in syrup and applesauce, and large cans with frozen foods such as filets, shellfish in sauce and ice cream. Apparently a new design for dehydrated foods will be used for flight. It will have a semi-rigid section to fit the larger cans with a sealable plastic membrane extension.

Regardless of food residue, two requirements must be met for satisfactory mass determination. The object(s) must be secured to the SMMD specimen tray. They must be prevented from sloshing. Of all the schemes tried the following was the most practical. Small custard cans with or without the lid may be placed directly on the scale. A plastic bag with some form of liquid-tight closure is required for other measurements. Those cans with particulate materials such as candies and peanuts should be emptied into the plastic bag which is then placed on the specimen tray such that all contained particles are under pressure by the elastomer sheet.

Depending upon the final container configuration, the plastic inner containers should be removed from the cans and either sealed or placed in the plastic bag which is sealed. Any homogenous food can be measured directly since they are viscous enough not to slosh. Most of the wet packed foods (with the possible exception of applesauce) and the frozen items should be placed in the bag with its can and sufficient wipes to absorb any free liquid and the assembly placed under the specimen restraint. Using these procedures, accuracie sufficient for support of the metabolic analysis should be obtained.

Equally or even more important than mass measurement technique is the accounting of all objects in the gross mass figure, i.e., type and number of containers and wipes. It is equally important to insure that an accurate known mass is available for all of these items, i.e., can weights and wipe weights should be accurately known. Both cans (and their lids) and wipes have uniform weights to a small fraction of a gram. It is assumed that any plastic bags used will also be uniform or else weighed and stamped.

If such procedures are instituted and followed, accuracies adequate to support the metabolic experiments will be attained.

CONCLUDING REMARKS

With adequate procedures and careful adherence to them, the S/L SMMD should provide accuracies of 2% or better for specimen measurements with occasional exceptions for small samples. It will allow only a limited degree of exploration of the ultimate operational limitations of this method of mass measurement. At the moment measurement of temperature will probably be the limiting factor.

Gp 5

APPENDIX III

Although not directly associated with M074 and the SMMD, there was opportunity to verify a crucial component of M0172 (body mass measurement experiment) during the SMEAT test. In this experiment food trays are to be used as calibration masses. One might reasonably expect some change in these masses either through evaporation of volatiles or through addition of food residue. To determine magnitude of such changes all four[1] food trays were accurately measured by the NASA calibration lab using balances #41689 and CO 3586 and mass sets #46994 and CO 2731. Results are shown in Table 2b.

Tray Serial Number	Pre-test Mass Kilograms	Post-test Mass Kilograms	Difference Grams	Difference %
4904[2]	10.95175	10.94848	-3.27	-2.99×10^{-2}
4910	11.03376	10.97474	-59.02	-5.35×10^{-1}
4911	11.10955	11.10888	-0.67	-6.03×10^{-3}
4912	11.00278	10.99907	-3.71	-3.37×10^{-2}

In the absence of any consistent trend no valid conclusions can be drawn.

One could postulate that both evaporative losses and residue additions had occurred. The magnitude of loss would be negligible except for 4901. This should produce an error well above the resolution of the BMMD (body mass measuring device) for analytical studies; hence, bias them and if such a loss continued for two flights would produce a detectable and variable bias in the body weights.

2 Spare unit

1 Three trays were used and one was kept in the chamber as a spare.

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TABLE 1 B&C

1B Fecal Bag I.D.#	Adhesive Tape Backing Total
—	10.52
FD 1848	10.60
1830	10.25
1831	10.47
1838	10.43
1787	10.48
1805	10.42
1806	10.31
—	10.35
—	10.35
1846	10.50
	10.474 Avg.

1C - Weight of Wipes
2.6 gm.
2.5
2.5
2.6
2.65
2.57 Avg.

Average weight of another sample of 63 wipes was:

2.798 gm.

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— insert — (1)

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