Ruell Solberg, Jr.

DESIGN, DEVELOPMENT, AND FABRICATION OF MASS MEASUREMENT INSTRUMENTS

PHASE 1 FINAL REPORT
EVALUATION PHASE

By

R. F. Solberg, Jr.
W. E. Oakey

Phase 1 Final Report
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($M = AT^B$), and hyperbolic

$$\left(M = A + \frac{B}{T},\ M = \frac{1}{A + BT},\ \text{and } M = \frac{T}{A + BT} \right)$$

equations. These equations did not give good matches to early data and were not utilized further. In addition, the equation of $M = CT^2 + D$, used often in the past, was used to compare with the other equations.

A sliding power function equation will also be referenced. This equation is the same as the power function equation described in this section except that it uses only three calibration masses at a time to solve for the coefficients and exponent instead of all of the calibration masses. The three calibration masses chosen are those with periods closest to the period measured for a specimen or unknown mass.

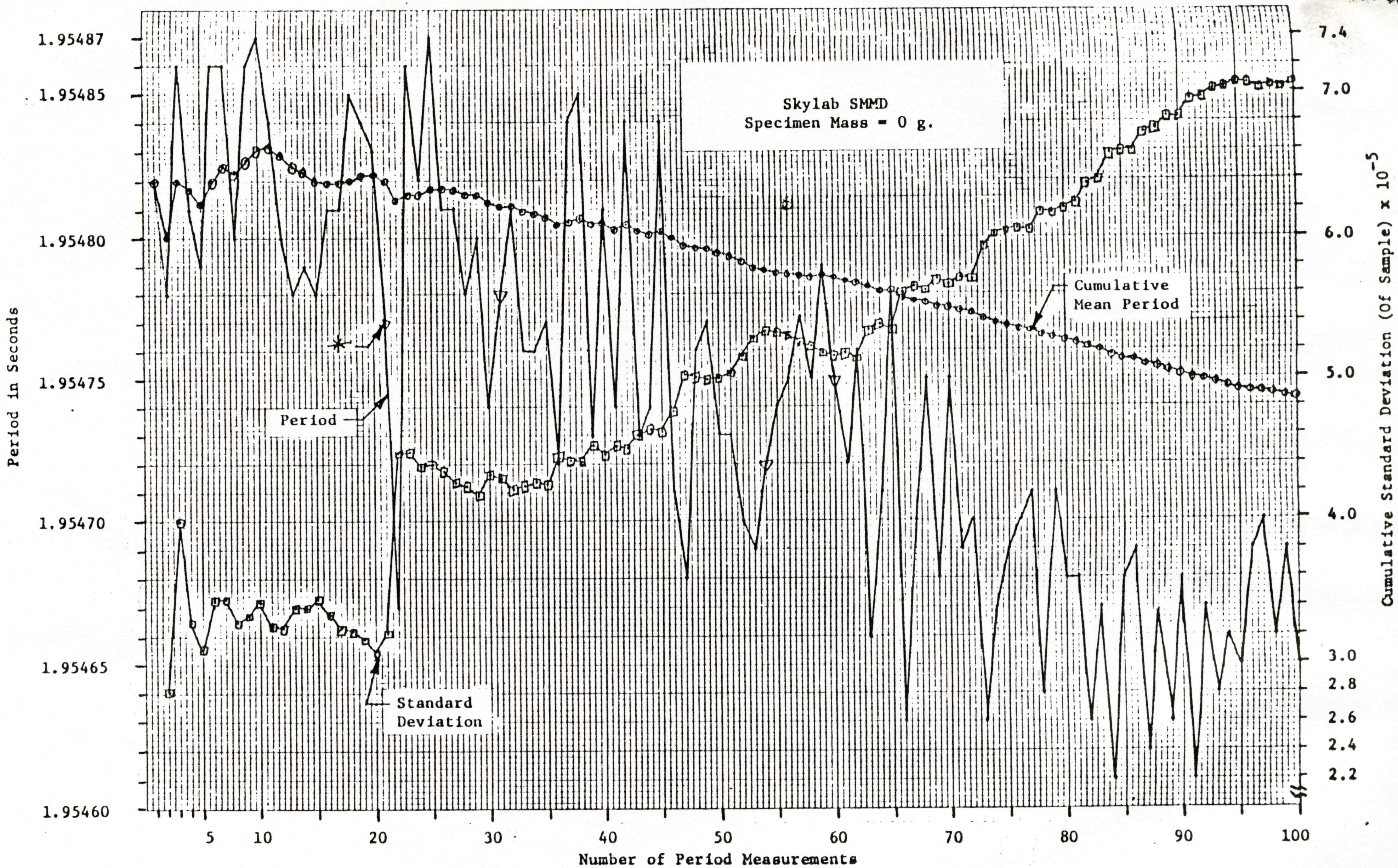
Most of the evaluation of the equations with the data was aided by computer analysis. A number of computer programs were developed and several existing programs were also utilized.

3.3.2 Drift

A rather low level drift of the period measurements was detected primarily only when very large numbers of measurements were taken consecutively. While this drift may have been acceptable for previous accuracy requirements (it was at least partially corrected), it is considered unacceptable for the accuracy goals of this program. The effect of the drift must be corrected through the instrument itself or it must be eliminated. Both directions were pursued during the Phase 1 work.

A number of tests were performed to define better and understand the drift. Figures 3-13 and 3-14 indicate the drift for the tare mass only and for a specimen solid mass of 100 grams. Each graph has three items plotted as a function of the number of period measurements: (1) individual period measurements, (2) cumulative mean period, and (3) cumulative standard deviation. The consecutive period measurements have some randomness superimposed on the downward drifts while the cumulative mean tends to null out the randomness effects. The standard deviation increases after several measurements because of the effect of additional individual periods being farther from their mean. As shown by Figure 3-15, the drift is at least partially a function of temperature. The data for this graph was obtained by raising the temperature of the SMMD and its cubicle, and then taking measurements as the temperature naturally decreased. This data was obtained without 3 specimen mass on the weighing tray.

The Skylab SMMDs were calibrated in terms of a base ambient temperature with an adjustment made when the temperature was different from the standard value. However, the data indicates that a theoretical correction will not provide the necessary adjustment for the accuracies now desired.



Note: Triangles on period graph are simply to show location of a point if it might be hard to see.

FIGURE 3-13. DRIFT DATA

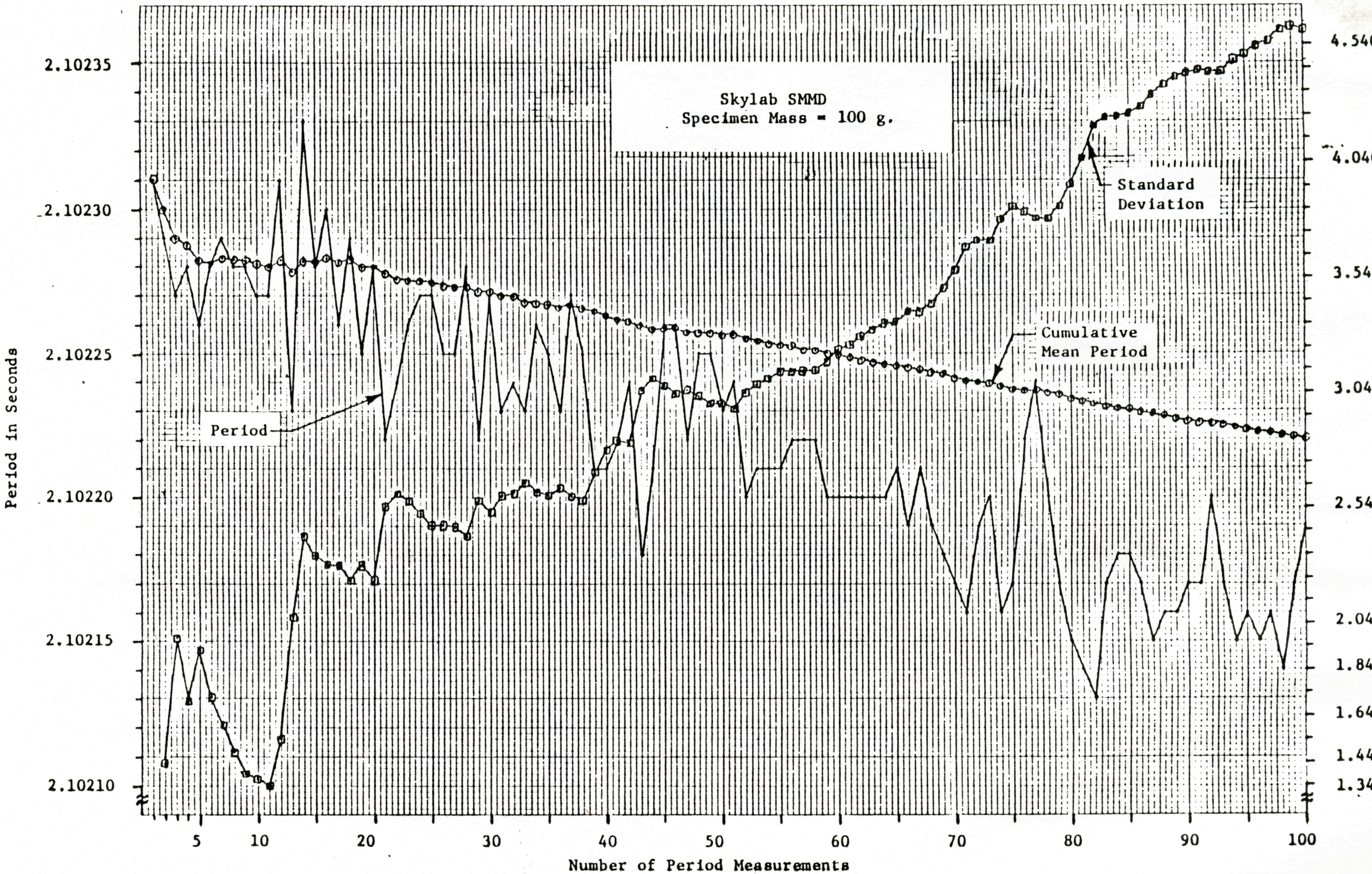


FIGURE 3-14. DRIFT DATA

SPECIMEN MASS = 0 g

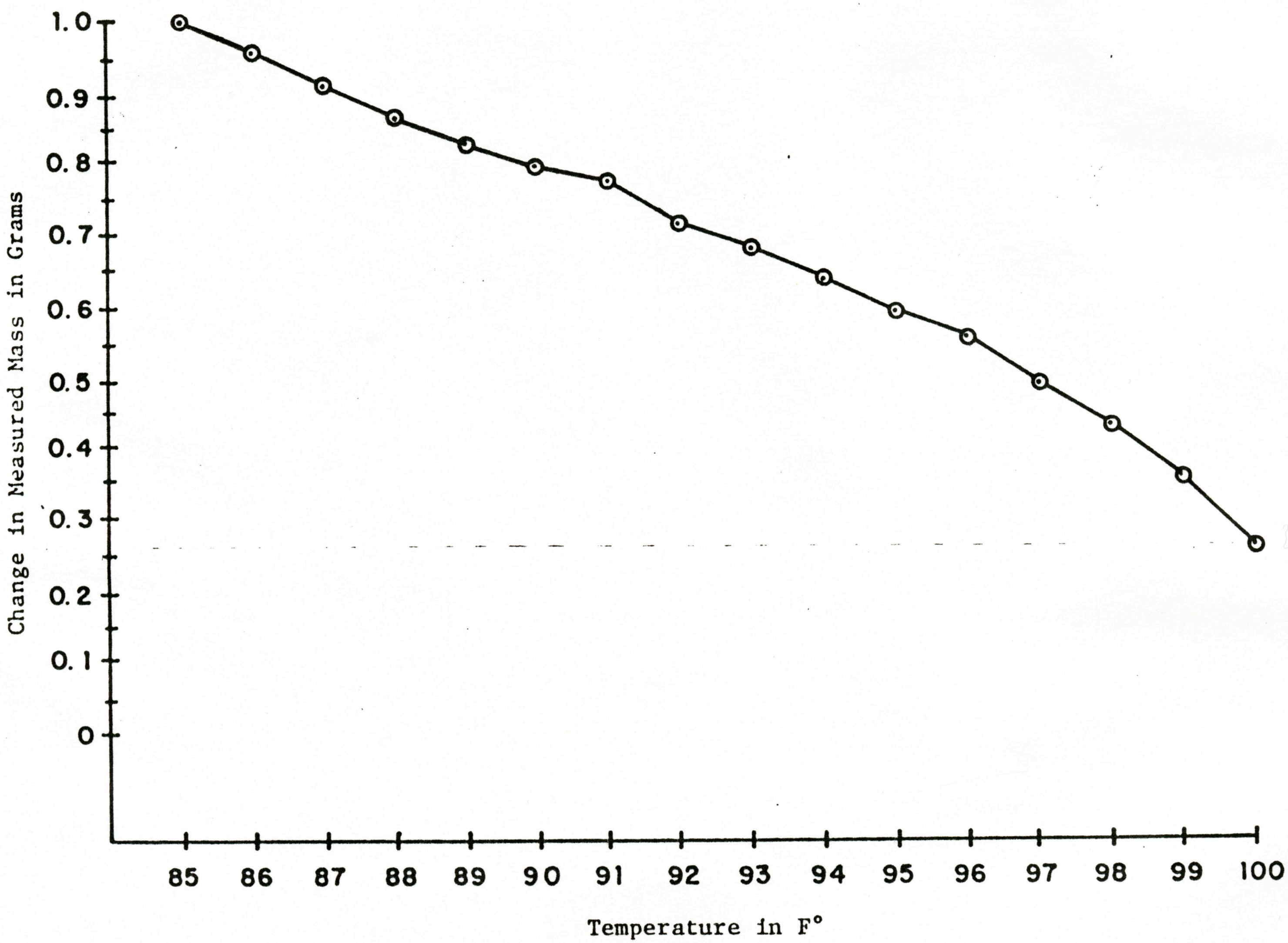


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FIGURE 3-15. CHANGE OF MASS CORRELATION WITH AMBIENT TEMPERATURE

Several representative figures are presented of plots of mass error for several solid specimen masses at several ambient temperatures and times. The data was obtained so that the temperature was not monotonically increasing or decreasing. The measurements were made at various times with the temperatures and times being recorded. Sometimes the temperature was increasing and other times it was decreasing, which would be closer to expected usage of the equipment. All of this data was taken for the plate spring configuration. Figure 3-16 is a graph of three specimen masses in the highest mass range. It, and the following graphs, indicate that a nice, smooth temperature effect is not likely under the conditions of nonmonotonically increasing or decreasing temperature. A temperature hysteresis effect probably is large enough to be of concern and may partially explain the somewhat erratic behavior.

Figure 3-17 is a plot similar to Figure 3-16 except that it is for different specimen masses. Figure 3-18 uses the same data and is plotted as a function of time. Figures 3-19 and 3-20 are similar plots for smaller specimen masses. The temperature plots indicate definite trends of drift related to temperature. However, as additional temperature and error values are added to the graphs, the curves become much less smooth, supporting a hysteresis effect.

The drift as a function of time plots indicates that the drift tends not to be related to the specimen masses. The plots for the different specimen masses tend to follow each other. The plot of Figure 3-18 begins one day later than that of Figure 3-20.

Hysteresis greatly complicates corrections based on temperature because it must be known where on the hysteresis curve the instrument is at that time. For example, whether the temperature was increasing or decreasing would be required. Particularly if the temperature changes more than small amounts, it would be necessary to know the maximum and minimum limits of that cycle. A very large number of hysteresis curves would also be required to be stored and retrievable so that the specific temperature history could be matched to the appropriate hysteresis data.

In addition, mechanical hysteresis of the spring materials is likely to affect an instrument which is as sensitive as this type, particularly in 1-g. Mechanical hysteresis tends to be cumulative when materials are repeatedly stressed. Some recovery or relaxation likely occurs, particularly when the instrument is at rest under temperature cycling. Heavy specimens used under 1-g conditions cause much higher and different states of stresses in the tops of the springs compared to the bottoms, which probably affects the springs and the period measurements. Fortunately, much of this nonsymmetrical loading and stresses will not be present during normal orbital flight. Improved performance of the instruments in 0-g is, therefore, anticipated.

There may be hysteresis effects caused by other environments and conditions. The cumulative effect of them makes this aspect very difficult to analyze and adequately predict or theoretically correct.

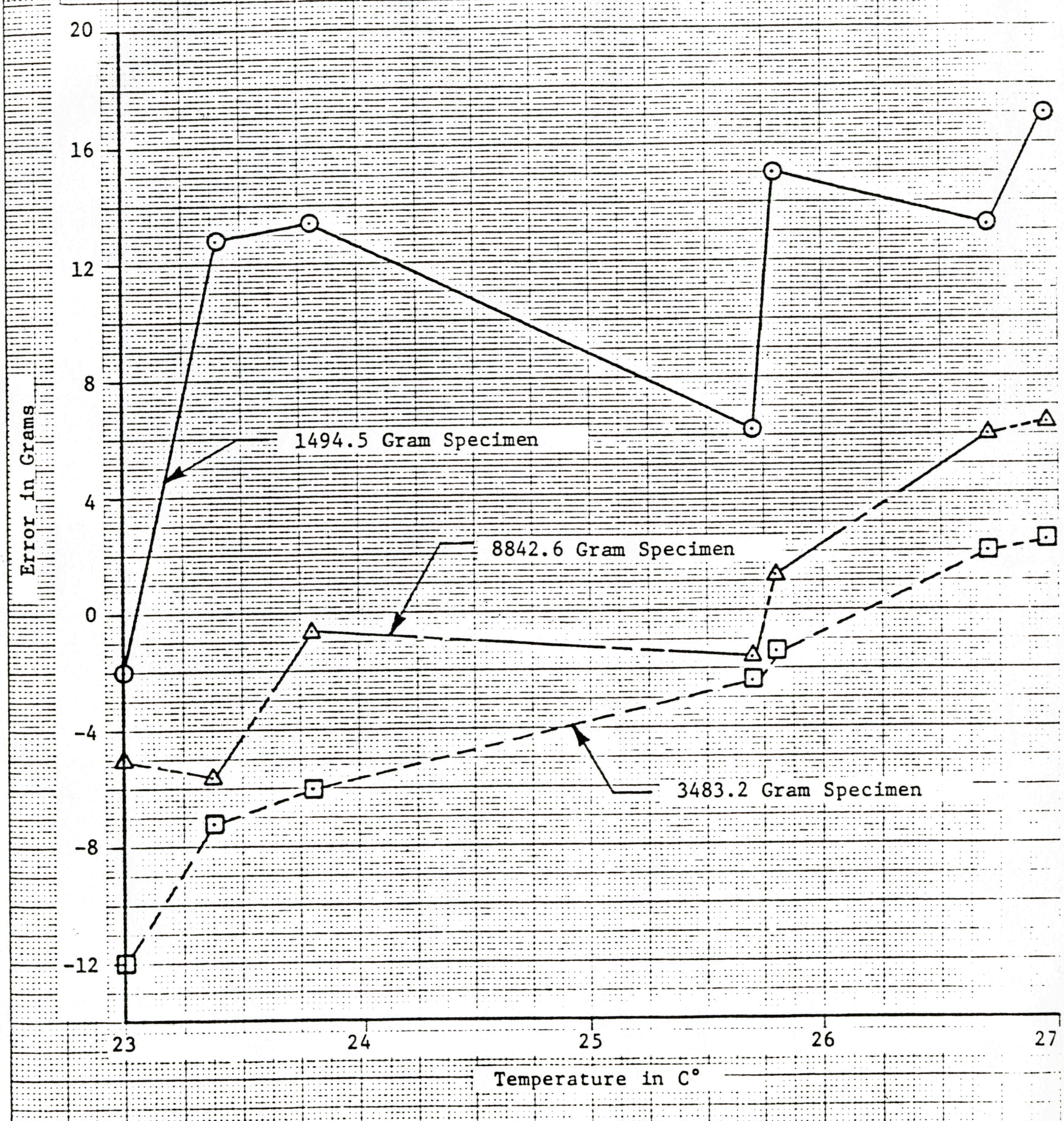


FIGURE 3-16. DRIFT-TEMPERATURE RELATIONSHIP

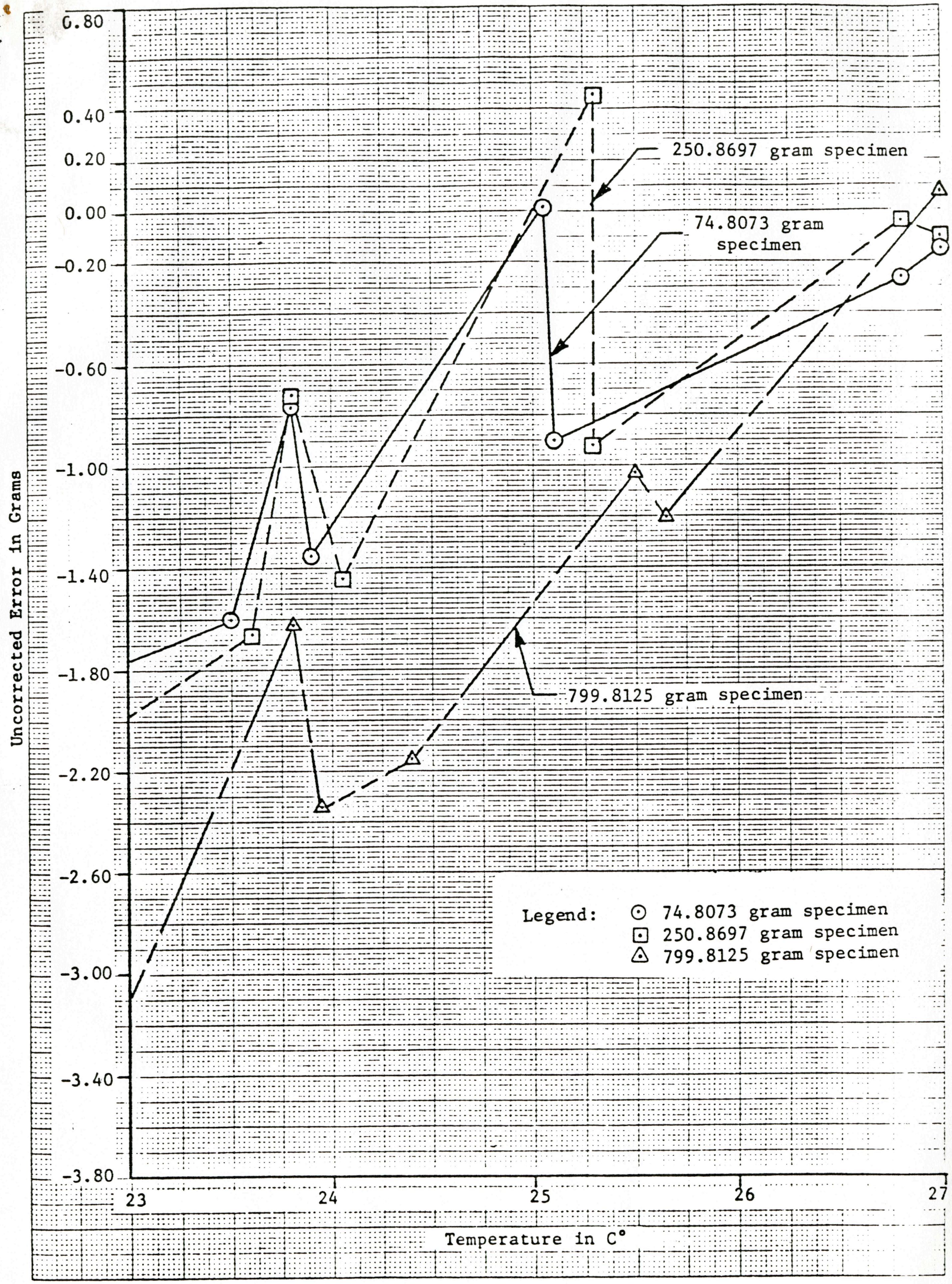


FIGURE 3-17. DRIFT-TEMPERATURE RELATIONSHIP

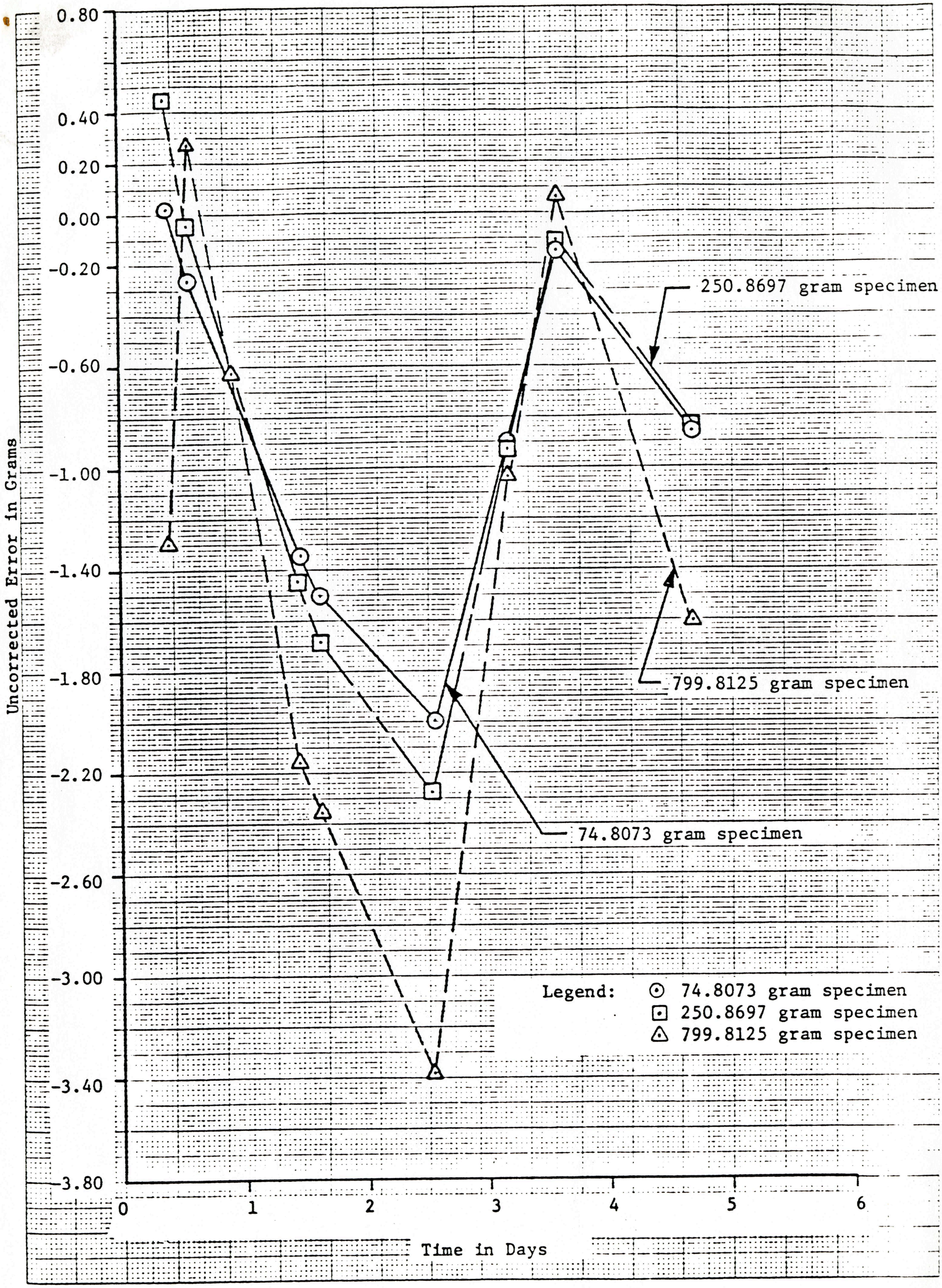


FIGURE 3-18. DRIFT-TIME RELATIONSHIP

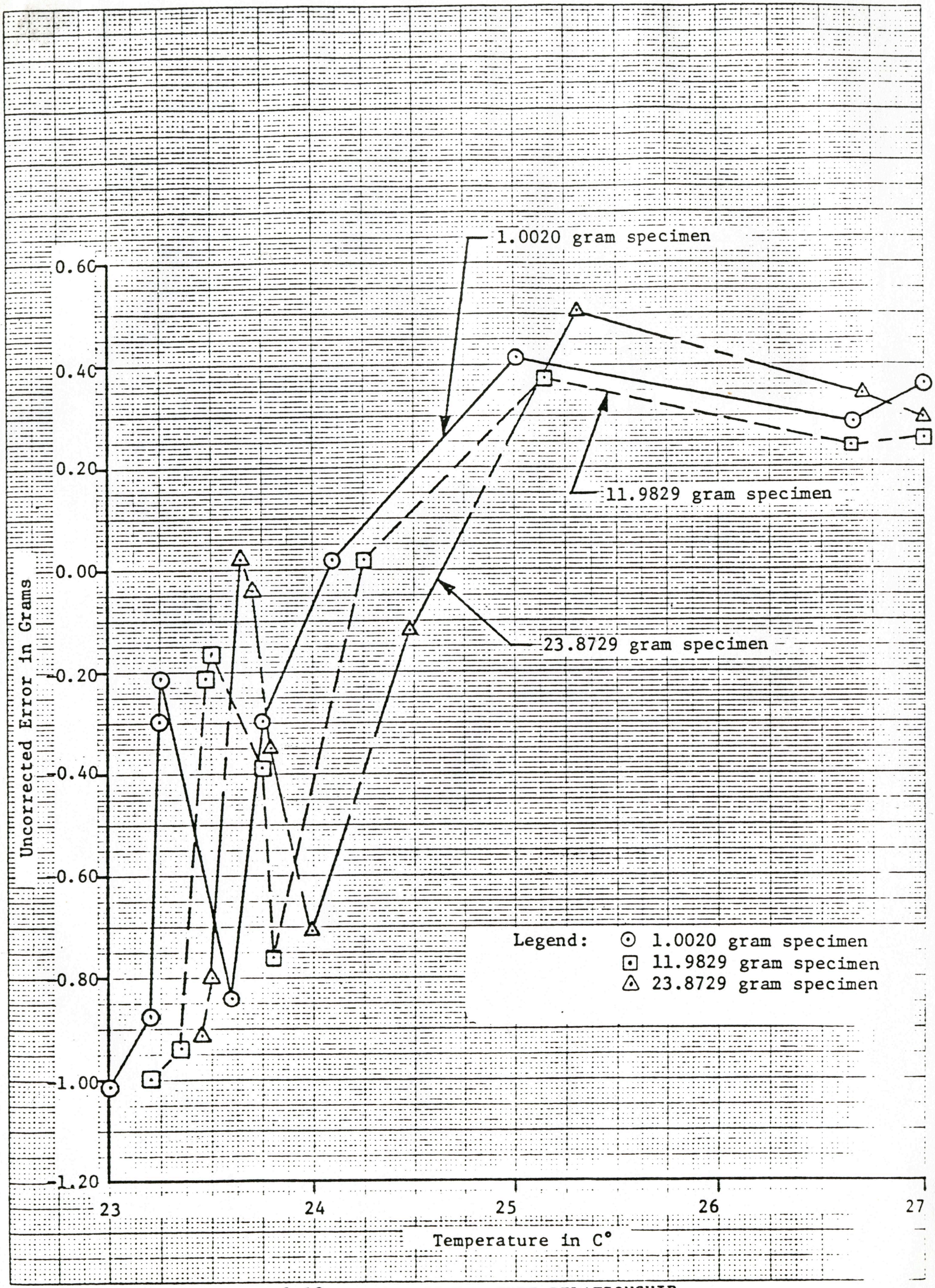


FIGURE 3-19. DRIFT-TEMPERATURE RELATIONSHIP

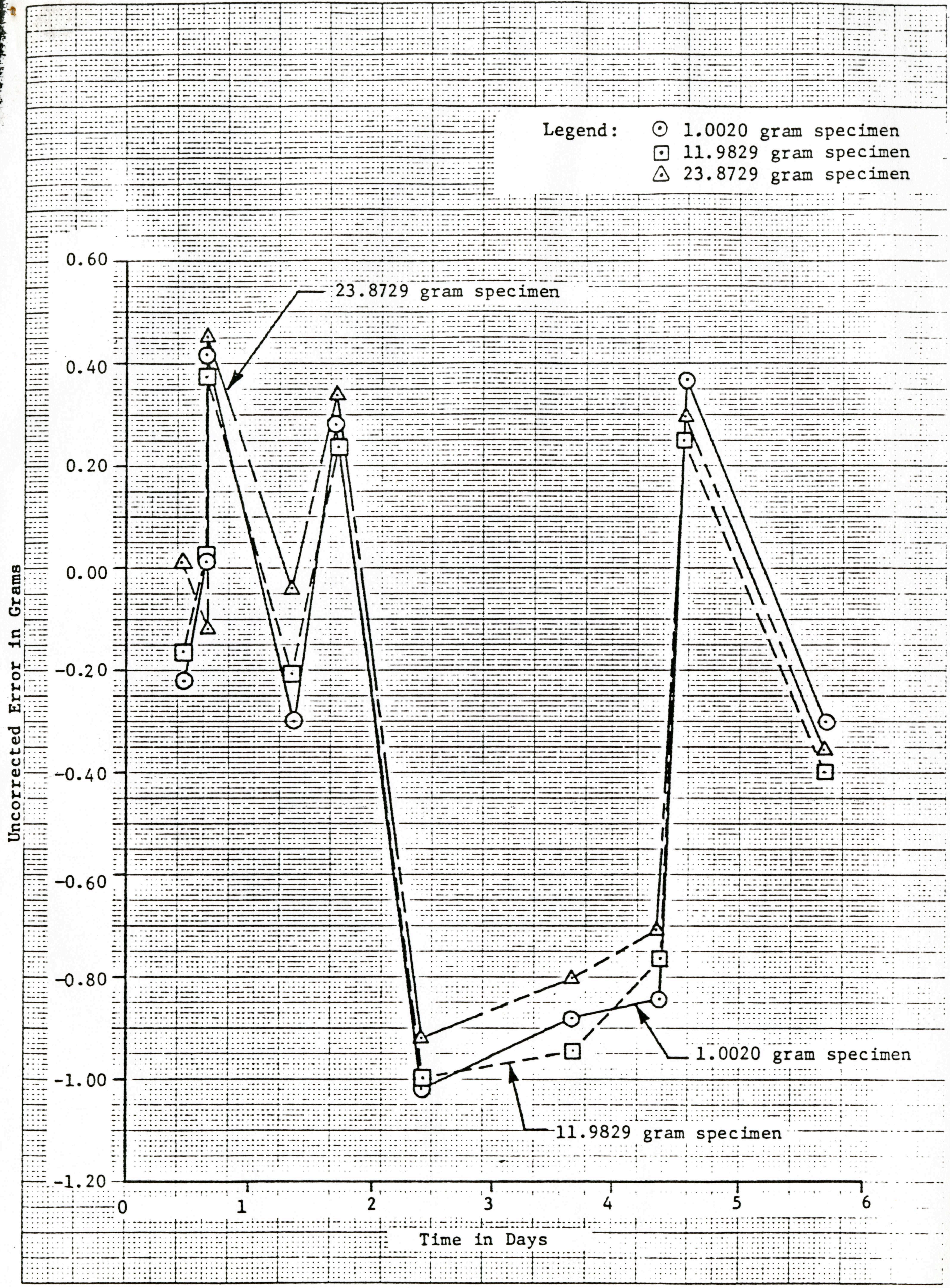


FIGURE 3-20. DRIFT-TIME RELATIONSHIP

Elinvar extra, a material made by Hamilton Technology, Inc., can be supplied with optimum thermoelastic coefficient and mechanical hysteresis properties with the proper chemical constituents, cold working, and heat treatment. The thermoelastic coefficient is the algebraic sum of thermal coefficient of expansion and the thermal coefficient of the modulus of elasticity. Thermoelastic coefficients of zero are theoretically possible. However, these properites can be difficult to measure and interpret accurately for materials with low values. Hamilton probably can supply material for the springs which would have better thermoelastic coefficient than the isoelastic material. Some samples of the material were obtained and some tests were performed during this phase of work. However, the samples did not exactly have the desired properties and were of inadequate size to fabricate springs as desired.

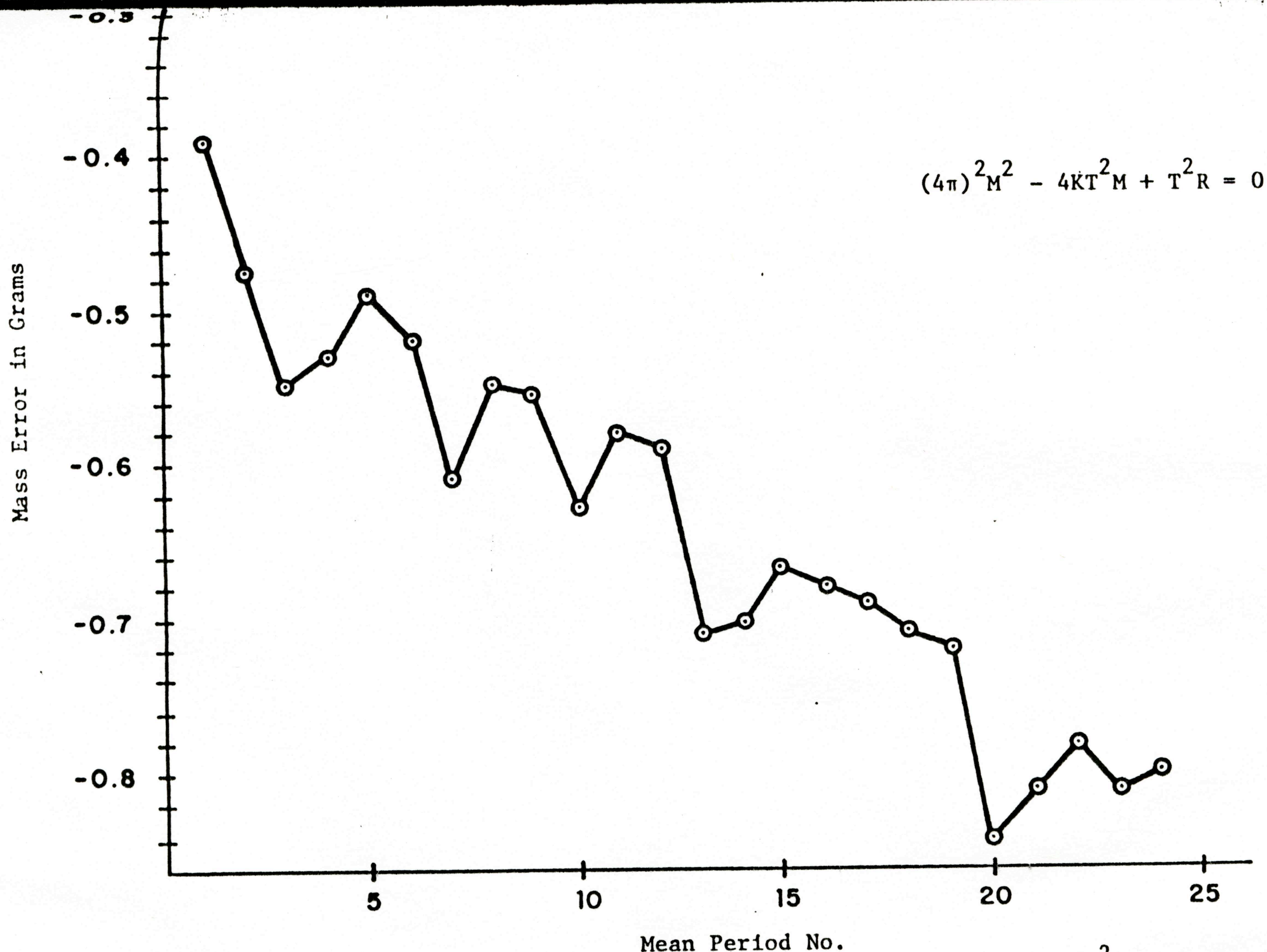
If the drift should not be significantly reduced or elimininated with other materials and for those times when greater precision is required, a technique for correcting for the drift is to measure a known (calibration) mass after the specimen mass has been measured. The constants of the equation can then be adjusted to null out the drift. This technique and its results ~~is~~ are presented in more detail in the section on accuracy. It corrects for drift, whether the cause is from temperature, permanent damage to the instrument, change in tare mass because of spillage on the weighing tray, etc.

An example of the improvement which is possible is shown by Figures 3-21 and 3-22. Twenty-four sets of period means were obtained every 15 minutes during a day for a specimen mass of 100 grams. Figure 3-21 shows the effect of the drift to increase the errors. When the mass equation is partly corrected for the drift, the error is much less, as indicated by Figure 3-22. Note that the mass equation was not completely corrected during the series of measurements, which would have given even smaller errors.

3.3.3 Types of Specimens

Specimens used to evaluate the SMMDs during this phase included solids, semisolids, and liquids. The liquids and semisolids, or nonsolids, included live and dead mice and their organs and limbs. Although a number of different specimens were measured, most of the analyses and results presented in this report were on the basis of some standardized specimens. The nominal weights are presented in Table 3-1. The distribution of these weights in the mass range of 1 to 10,000 grams is presented by Figure 3-23.

Table 3-2 presents a list of the standard types of nonsolid specimens used for most of the analyses and tests. However, again other specimens were sometimes used also. For example, powdered sugar and coffee were used to simulate powdered chemicals. Also, open cell plastic foam was put in containers to check the effect of reducing errors from sloshing of liquids in partially filled containers.



R^2 and K determined from
calibration masses of 0
and 24 g at beginning
Specimen Mass = 100 g
Mean Absolute Mass Error = 0.648 g
Std. Dev. = 0.122 g

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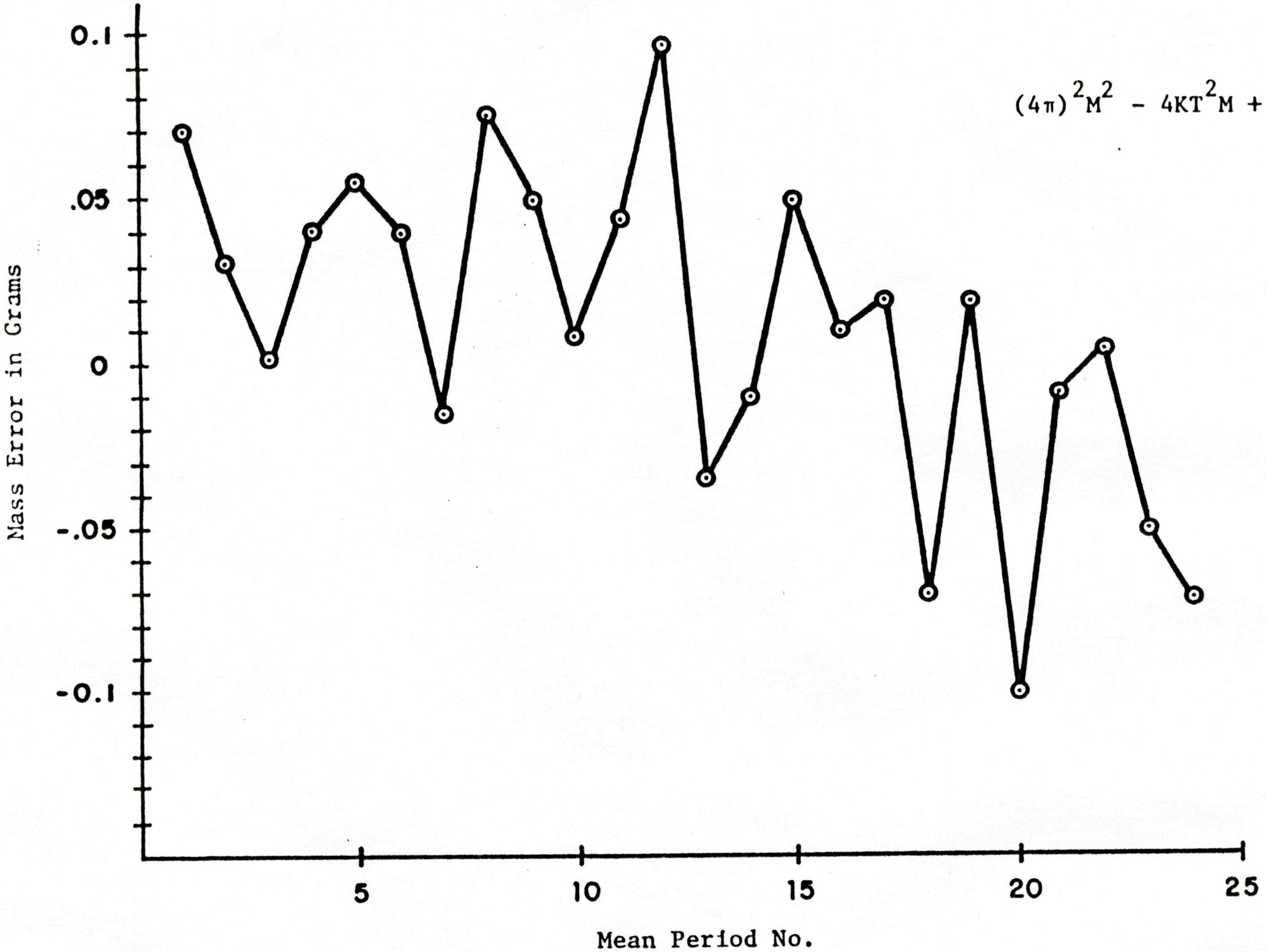
FIGURE 3-21. EFFECT OF DRIFT



$$(4\pi)^2M^2 - 4KT^2M + T^2R = 0$$

R held constant
K calculated from tare at each period measurement
Specimen Mass = 100 g
Mean Absolute Mass Error = 0.0391 g
Note: Probably is absolute V
Std. Dev. = 0.046 g

79A1D6A

FIGURE 3-22. CORRECTION APPLIED TO MASS EQUATION

(2) If repeatable measurements are not obtained with an empty Seat, examine the Device for mechanical interference of moving parts or for possible damage. (See Section 4.3 Contingency Procedures).

4.1.4 Temperature Corrections

A temperature correction may be made to any period measurement if the temperature of the Plate-Fulcra Springs is not at the standard of 72°F. Temperature correction data is given in the ADP for each unit with typical information given in Figure 4.2-1.

The temperature correction is so small for the BMMD that the accuracy is only slightly improved since the operating temperature range is only 65°F to 80°F. Also, if only the first four digits of the periods are recorded for body mass measurements, the temperature corrections will not change the measurements except for large temperature changes. Obviously, temperature correction is not as important during body mass measurements as for calibration with rigid masses.

4.2 Calibration Procedure

The calibration procedure is similar to the body mass measurement procedure, 4.1.3, except that calibration masses and an Adapter to couple the calibration masses to the Seat are used in lieu of a person being in the Seat.

Individual calibration measurements should be made for calibration masses up to about 100 Kilograms in zero and one "g" and recorded as indicated by Table 4.2-1. A typical one "g" calibration curve for the BMMD is shown in Figure 4.2-1.

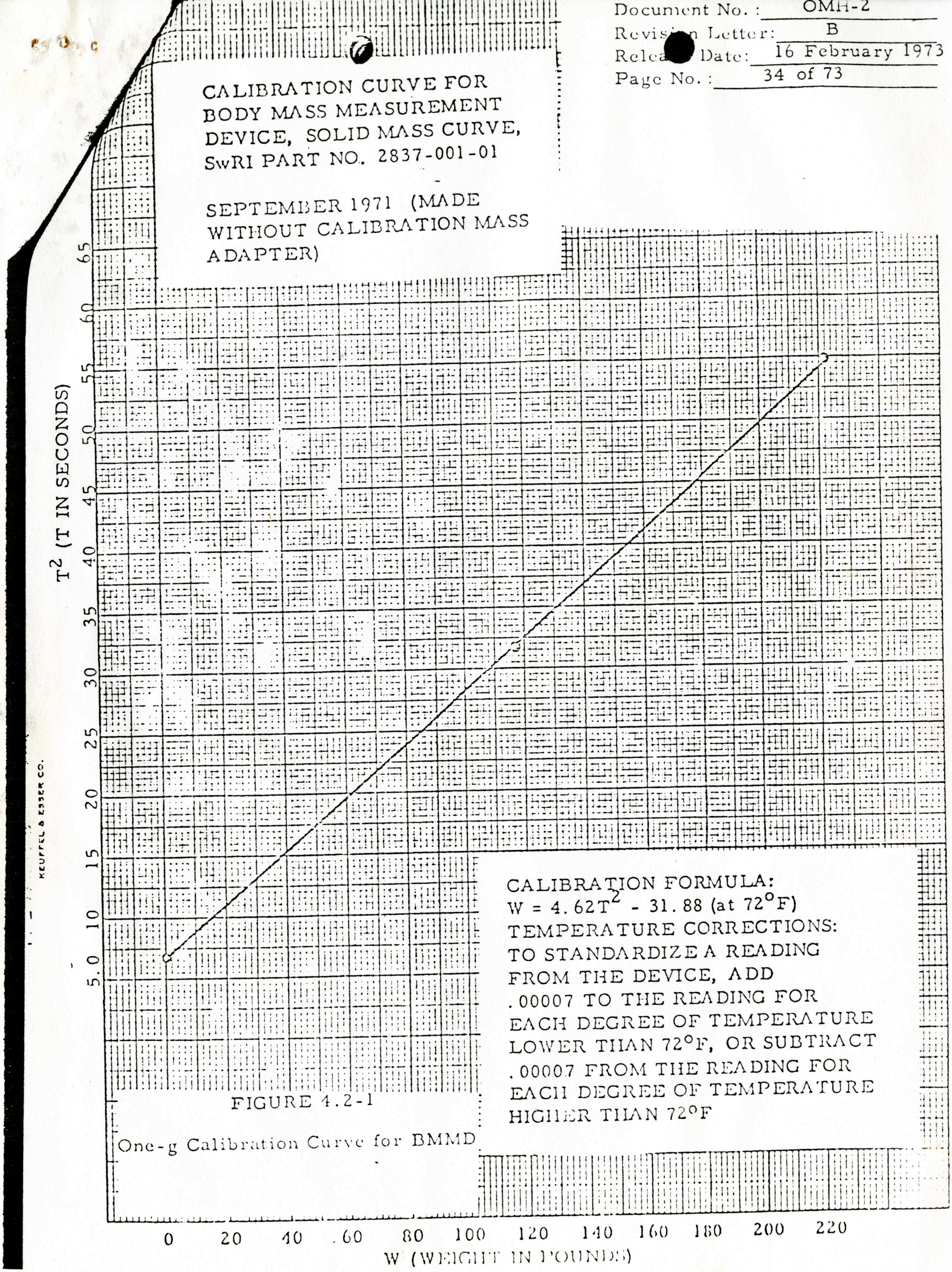


FIGURE 4.2-1

One-g Calibration Curve for BMMD

#1 11.390kg
#2 12.402
#3 13.799
#4 14.008
52.399 kg
X2.2046 = Note

Document No. SwRI 2837-ADP-4.
Note
Release Date: 115.5188 lb. (plus plate???)

Document No.: OMII-2
Revision Letter:
Release Date: 30 October 1970
Page No.: 30 of 56

ATSP-2, Subparagraph 6.4.4.5.5

Xeroxed from ADP, Sec. 9 of BMMD, S/N 001 Qual. Unit. Dec. 1, 1972 RJ

TABLE 4.2-1

Table of Calibration Data; environment: zero "g" ____
one "g" ✓

Masses
27.73 (#2)
30.36 (#3)
30.89 (#4)
26.38 (#1)
115.36

53.194 KG
X 2.2046 = 117.27 lb.

RJB 8/23/71

Calibration No. ________ S/N BMMD S/N 001

Date 8-21-71 Ground Elapsed Time 5 Minutes

Temperature 40°F-100°F Crew Member N Engelhardt

MASS = 115.36 lbs

Mass	Readout	Mass	Readout
115.36 lbs AIR 40, TC 41, BMMD 31 (after) 46, 35	1 5.72495 2 5.72549 3 5.72563 4 5.72577 5 3.81724	AIR 80, TC 81 (4), BMMD 83 (after) 81, 84	1 5.72493 2 5.72488 3 5.72472 4 5.72480 5 5.72482
AIR 50, TC 50, BMMD 48 (after) 53, 50	1 4.77778 2 5.72522 3 3.81706 4 5.72572 5 5.72581	5	1 2 3 4 5
AIR 60, TC 61 (2), BMMD 65 (after) 63, 65	1 5.72624 2 5.72499 3 5.72545 4 5.72520 5 5.72531	6	1 2 3 4 5
AIR 70, TC 71 (3), BMMD 75 (after) 72, 75	1 5.72502 2 5.72543 3 5.72545 4 5.72556 5 5.72525	0	1 2 3 4 5

witness only
L.C. Neely

REMARKS:

M172 BMMD
S/N 001

SwRI 1 RQA

KE 8-21-71 Miscount at 40 & 50 F

Xeroxed from ADP, Sec. 9 of BMMD, S/N 002, Qual. Unit. Dec 1, 1972. R78

Document No. SWRI 2837-ADP- 4
Release Date:

Masses weights # 2, 3, 4, 5, 6, 7, 8, and 1.6 lb. alum. sheet.
221.45 lbs ??
(approximately 100 KG.)
100.500 KG X 2.2046 = 221.5623 lb.
UBP 8/23/71
Note.

TABLE 4.2-1

100.332 kg x 2.2046 = 221.1919 lb.

Table of Calibration Data; environment: zero "g" ____
100.420 kg x 2.2046 = 221.3859 lb one "g" X

Calibration No. ____ S/N BMMD 001

Date 8/22/71 Ground Elapsed Time ____

Temperature 100 to 40° F Crew Member U. B. Page

Mass	Readout	Mass	Readout
AIR 100°, TC 0 100°, BMMD 95°	1 7.55348 2 7.55416 3 7.55378 4 7.55383 5 7.55325	AIR 60°, TC 4 60°, BMMD 63°	1 7.55358 2 7.55371 3 6.29128 4 7.55277 5 7.55350
97° 95°		63° 65°	
AIR 90°, TC 1 91°, BMMD 91°	1 7.55330 2 7.55294 3 7.54742 4 7.55345 5 7.55241	AIR 50°, TC 5 51°, BMMD 50°	1 7.55355 2 7.55313 3 6.29613 4 7.55301 5 7.55316
90° 91°		53° 51°	
AIR 80°, TC 2 80°, BMMD 84°	1 7.55239 2 7.55255 3 7.55254 4 7.55291 5 7.55320	AIR 40°, TC 6 40°, BMMD 30°	1 7.55393 2 7.55460 3 5.03639 4 7.55421 5 7.55494
80° 84°		44° 32°	
AIR 70°, TC 3 71°, BMMD 76°	1 7.55283 2 7.55335 3 7.55268 4 7.55217 5 7.55290	0	1 ____ 2 ____ 3 ____ 4 ____ 5 ____
72° 76°			

REMARKS:

SWRI 3 R&QA

UBP 8/22/71

22 Aug. 71

M172 BMMD
S/N 001