NBSIR 74-601

A Survey of the Temporal Stability of Angle Blocks

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by

Ralph C. Veale and Charles P. Reeve

Introduction

Angle blocks are wedge-shaped specimens made from either steel or chrome carbide with extremely flat faces. The squareness of the angle faces to the top and bottom of the gage are also held to close tolerances. They tend to serve as working standards in angle measurement in much the same way as gage blocks serve the area of length. They come in sets of various sizes that can be wrung together to form almost any angle to the nearest second. The first set developed by Dr. Tomlinson of NPL [1][1] in 1937, consisted of twelve gages of the following sizes:

1, 3, 5, 9, 27, 41	degrees
1, 3, 9, 27	minutes
3, 9, 27	seconds.

Any angle to 81 degrees can be produced from this combination and a square in steps of 3 seconds. The most common set found in the United States consists of 16 blocks of the following sizes:

1, 3, 5, 15, 30, 45	degrees
1, 3, 5, 20, 30	minutes
1, 3, 5, 20, 30	seconds.

Most of the major metrology labs in the U.S. have master sets that are used to calibrate working sets.

Because the standard for angle measurement is the circle which is exactly 360 degrees, NBS possesses no unique capability (as in mass

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[1] Numbers in brackets indicate references given at the end of this paper.

measurement) for angle measurement. Any lab properly staffed and equipped can potentially measure angle blocks as well as the Bureau of Standards.

The Bureau does, however, calibrate a large number of sets and is repeatedly asked how often it is necessary to calibrate the sets which are used as physical standards. A previous report on the stability of optical flats (NBSIR 73-232) indicated the flats had not significantly changed over the period studied. Enough data is now available for a similar study of angle blocks.

In order to determine the stability of the blocks, it is necessary to have a measurement system under statistical control so that an uncertainty in the measurement system cannot be interpreted as a temporal change in the article being measured. This report will therefore be divided into two parts, (1) an analysis of the measuring system and (2) a study of the stability of the angle blocks.

1. Analysis of the Measuring System

For several years prior to 1962, measurements were made by comparing the test blocks to an NBS master set by interferometry. In 1962, the masters were recalibrated and a new system put into effect. It consisted of comparing the test blocks with the NBS master set using two autocollimators with a differential readout which means the master and the test do not have to be identically positioned. Also at this time, an additional set was introduced into the measuring process which served as a check standard. This procedure has been in use for about twelve years so we have now accumulated a ten year history for several sets. Measurements on angle blocks are made twice a year, usually in February and August.

Seven years ago we introduced a second check set made from chrome carbide into the measuring system. The carbide set is scheduled to soon be elevated to our master set. The method of taking data was changed in 1971 to enable us to get more statistical control over the measurement process. An intercomparison design was employed whereby test blocks and check standards were measured against the master block with redundancy. The observed standard deviation of a single measurement was compared with the historical value as a check on the process stability. This new method gave the same precision for each block and required fewer measurements than before. The data taken prior to 1971 has since been examined to determine the standard deviation of the measurement process at that time. In a few cases the measurements were made using a least squares solution and the random component of the measurement uncertainty was available.

The 30 and 45 degree blocks are difficult to measure well using the differential system described, but are easily measured using the "closure technique" which does not require a master. The closure technique simply compares an x degree block to each of the 360/x intervals of x degrees on an indexing table. The measurements are restrained by the fact that the sum of the intervals on the indexing table is exactly 360 degrees. The one second blocks were also measured by a "reversal" technique not requiring a master. The blocks are simply rotated 180 degrees and the difference between the 0 and 180 degree readings is twice the angle of the block.

The 1 second, 20 second, 20 minute, 5 degree and 45 degree blocks have been chosen as representative of the entire set. The one standard deviation random error component of the measuring process for each series of measurements for these five block sizes is given in Table 1. Errors in flatness of the faces and out-of-squareness of the faces to the base and top coupled with individual errors in the autocollimator will usually cause a block to give a different value when supported on its top rather than its base. The difference is usually around 0.1 second but occasionally may be as high as 0.5 second. Our measurement protocol called for measuring the blocks both ways and averaging. In a few of the measurements taken several years ago, it was not possible to tell if this practice had been followed. In other cases, it definitely had not been followed. This partially accounts for the wide range of standard deviations in Table I. Also because these numbers are the standard deviation of the mean and not an individual measurement, they vary depending on the amount of work put into each series. Some of the numbers are the result of only two comparisons with the master and others as many as eight. The numbers were also operator dependent - careful operators tended to get a lower standard deviation than careless ones. Additional factors such as whether the autocollimator with 0.1 second or 0.01 second readout was used caused fluctuations in the standard deviation.

Since 1971 the standard deviation has been constant for each block size because the within-group (or short term) variability of our measurement process has been very stable. Each year thereafter the observed standard deviation of a single measurement has not differed significantly from the 1971 value.

A least squares first order polynomial (a straight line) was fitted to the data from each block from all the sets chosen. Table II gives the standard deviation of the reported values relative to the best fitting straight line for each of the sixteen blocks in twelve sets. Unlike Table I which is a measure of the within group variance, Table II shows the between group variance adjusted so a linear change in the block would not be reflected in the standard deviation. It is not surprising that the between group standard deviation is larger than the within group due to the variations in the measurement process over the past years.

2. Stability Study

If the measured value of a block has changed over a period of time it may be due to (1) the master set has changed (2) the measurement process was out of control or (3) the test block has actually changed.

2.1 Master Values

The original calibration of our master set was a lengthy process involving measuring the individual blocks by interferometry (and other techniques) and then measuring the sums and differences of various wrung combinations. Several of the blocks have been checked by numerous techniques since this original calibration and have shown no detectable change. We have also almost completed an "absolute" calibration on our chrome carbide set of masters. (A paper explaining in detail the method used will be published at a later date.) We have a seven year history of comparison measurements between this set and the master set. The measurements are in good agreement and we are therefore convinced there has been no change in the master set within our ability to measure.

2.2. Measurement Process

The measurement process was analyzed in section 1. Tables 1 and II verify that it has been stable over the twelve year period.

2.3 An Analysis of the Test Blocks

Over one hundred sets have been calibrated during the past twelve years producing a voluminous amount of data to examine. We decided to limit our investigation to our own two check sets and only the test sets which have been calibrated at least five times during the period covered. A cursory examination was made of every set which had been in at least twice which indicated the sets we chose were representative and there were no exceptional cases not covered. Table III lists the slope in arc seconds per year of the least squares line fit to the data. In all cases the slopes were found not to be significantly different from zero. To better illustrate the results of the tables, graphs of the calibrated values have been drawn for the five selected block sizes in the two NBS check sets. The NBS-25 set is made of stainless steel and the NBS-7 set is made of chrome carbide.

At the upper left hand part of each graph is the observed long term slope (m) of the calibrated values. These values are also given in table III. The worst case of slope was for the 5° block of set number 10. Its graph (p. 20) indicates an upward trend, but each of the 3 standard deviation uncertainty bands overlaps which indicates that no significant change has occurred.

Conclusion

Examination of the histories of these sets of angle blocks reveals that there is a significant between-time component of error in the measured values. This error seems to be fairly consistent in all twelve of the sets, and it is not significantly correlated with the block size. None of the blocks exhibited a significant change in value over the ten year period, so it can be concluded that these angle blocks are stable over long periods of time. It should be noted that the 1", 30°, and 45° blocks, which were calibrated "absolutely" most of the time, show roughly the same long term variation as the other sizes.

The large between-time component of error can probably be explained by the inability to duplicate the exact measurement conditions each time a block was calibrated. The out-of-flatness and out-of-squareness of the individual blocks combine with certain alignment errors in the autocollimators and the angle block support to produce an effect which is unique to each calibration. When more is learned about the nature of these errors, it may be possible to compensate for them and reduce the observed between-time component of variation significantly.

References

[1] Knoyle, C. H., Production of Combination Angle Gages, The Engineer, Sept 1, 1950, p237-8 Machy (London)

[2] Farago, Francis T., Handbook of Dimensional Measurement, Industrial Press Inc., New York, 1968.

[3] Parsons, S.A.J., Metrology and Gauging, MacDonald and Evans Ltd., London, 1970.

TABLE I

SHORT TERM STANDARD DEVIATION OF THE MEASUREMENT PROCESS

	One Standard Deviation of the Mean seconds				
Date	1" Block	20" Block	20' Block	5° Block	45° Block
7-62	.102	.089	.065	.055	*.112
8-64	.099	.020	.021	.016	*.023
7-65	.011	.017	.018	.015	*.049
1-66	.035	.050	.053	.016	*.029
7-66	.027	.022	.012	.013	*.022
2-67	.010	.011	.012	.010	*.023
7-67	.056	.020	.014	.013	.056
3-68	.027	.042	.026	.064	.106
8-68	.018	.026	.020	.013	.085
3-69	.029	.029	.046	.052	.067
7-69	.031	.026	.037	.047	.036
2-70	.022	.025	.022	.020	.059
7-70	.042	.034	.035	.039	.104
2-71	.028	.028	.028	.028	.073
8-71	.028	.028	.028	.028	.073
2-72	.028	.028	.028	.028	.073
8-72	.028	.028	.028	.028	.073
3-73	.028	.028	.028	.028	*.025
8-73	.028	.028	.028	.028	*.025
4-74	.028	.028	.028	.028	*.025

*blocks calibrated by closure technique.

TABLE II

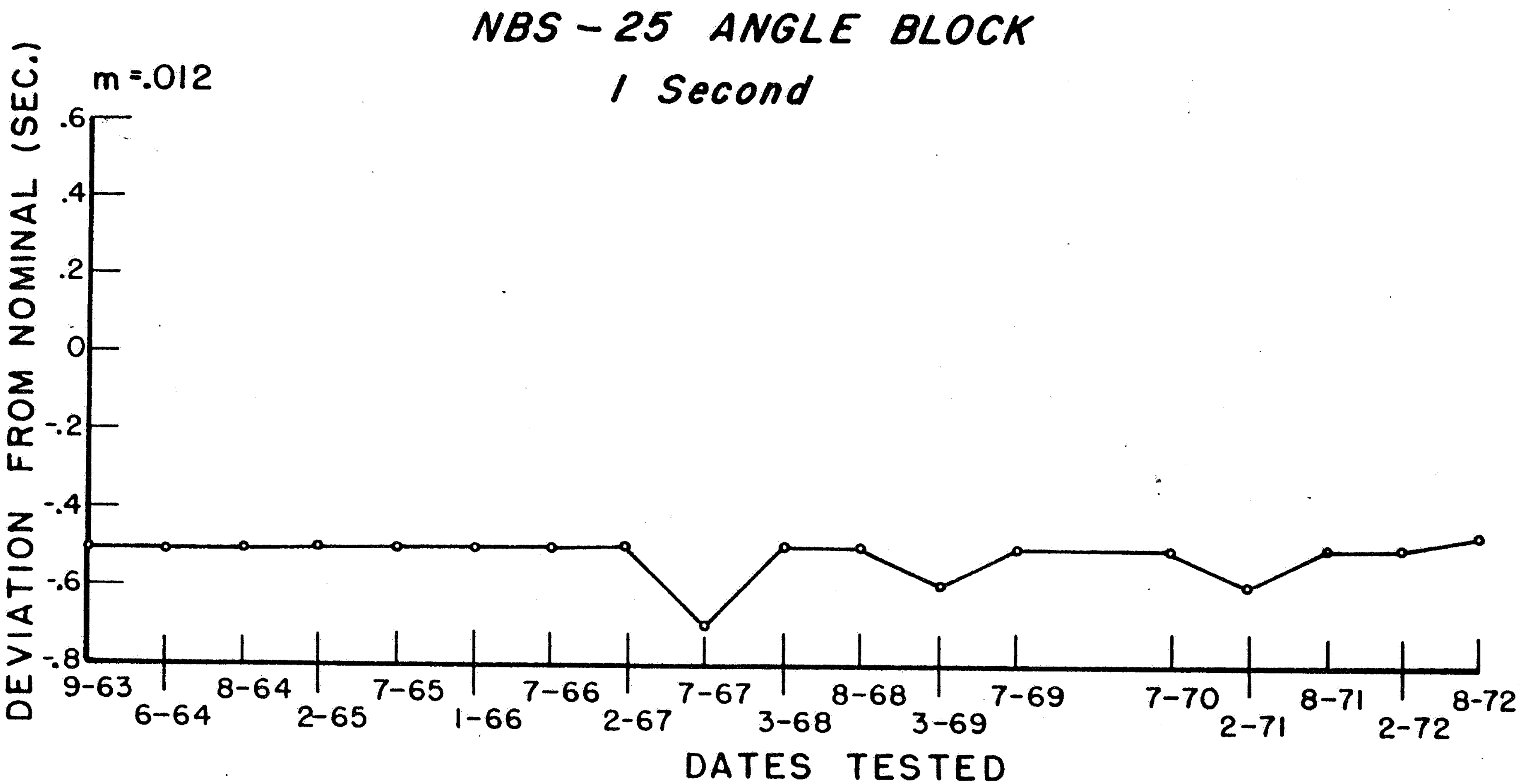
LONG TERM STANDARD DEVIATION OF THE MEASUREMENT PROCESS

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10	NBS-7	NBS-25	MEAN
45°	.000	.175	.096	.110	.102	.103	.093	.055	.096	.098	.033	.100	.098
30°	.147	.095	.095	.051	.079	.071	.163	.056	.136	.077	.057	.085	.099
15°	.063	.151	.038	.048	.080	.058	.070	.094	.187	.150	.081	.110	.104
5°	.038	.127	.113	.048	.109	.100	.061	.019	.062	.180	.059	.056	.092
3°	.097	.052	.072	.105	.073	.090	.037	.047	.096	.113	.052	.126	.085
1°	.092	.053	.000	.046	.101	.115	.046	.060	.062	.161	.078	.096	.085
30'	.038	.055	.080	.066	.074	.025	.059	.066	.000	.076	.043	.063	.058
20'	.131	.059	.058	.040	.085	.115	.069	.043	.114	.113	.050	.064	.084
5'	.095	.112	.083	.057	.071	.046	.025	.053	.094	.088	.083	.063	.076
3'	.078	.043	.095	.041	.077	.070	.051	.060	.047	.074	.101	.085	.071
1'	.030	.153	.067	.049	.086	.038	.036	.063	.087	.061	.048	.056	.072
30"	.047	.088	.050	.043	.110	.115	.126	.074	.000	.070	.054	.063	.078
20"	.092	.062	.000	.061	.067	.148	.154	.070	.094	.067	.086	.071	.090
5"	.079	.050	.063	.012	.079	.102	.091	.025	.115	.067	.074	.073	.075
3"	.086	.054	.042	.063	.047	.057	.046	.009	.126	.021	.050	.079	.064
1"	.080	.036	.141	.083	.076	.039	.093	.003	.062	.054	.029	.060	.072
MEAN	.083	.096	.077	.062	.084	.088	.086	.055	.098	.101	.062	.080	

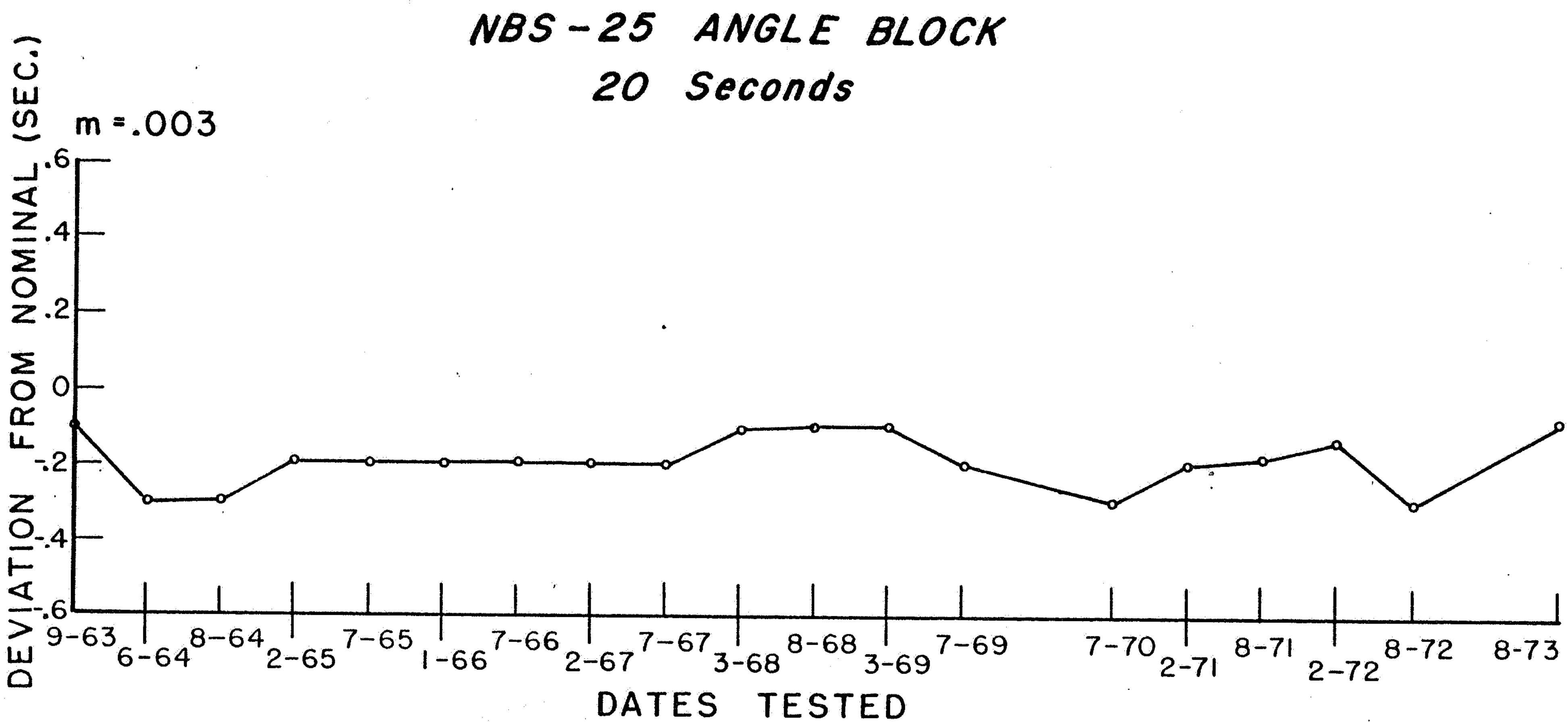
TABLE III

SLOPE (SECONDS/YEAR) VS. ANGLE

	Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10	NBS-7	NBS-25	MEAN
45°	.000	-.016	-.004	.038	-.005	-.040	-.008	-.004	-.037	-.034	-.010	.009	-.009
30°	-.009	-.008	-.013	.006	-.017	-.001	.000	.008	-.023	.009	.031	-.003	-.004
15°	-.001	-.022	.016	.005	-.007	-.002	-.020	-.029	.010	-.018	-.018	.002	-.007
5°	-.010	.006	-.017	-.006	-.002	-.002	.005	.005	-.003	.049	-.011	-.002	.001
3°	.000	.003	.033	.007	.010	-.005	.011	-.004	.003	.015	.011	.007	.008
1°	-.014	-.001	.000	-.005	.009	.002	.007	.000	-.003	-.012	.004	.008	.000
30'	-.010	.004	-.005	-.024	-.005	-.026	.007	-.002	.000	-.015	.004	-.008	-.007
20'	-.004	-.003	-.008	.018	-.006	.000	.034	-.008	-.027	-.023	-.003	.004	-.002
5'	-.012	.001	.032	.043	.022	-.001	.017	-.025	-.007	-.014	-.015	-.008	.003
3'	.007	.010	.005	.010	.008	-.002	-.002	.000	.013	-.011	.027	.026	.008
1'	-.016	-.025	-.022	.009	.001	-.033	.016	-.014	-.013	-.017	.006	.002	-.009
30"	.006	-.009	.012	.007	-.001	-.006	.004	-.019	.000	-.020	-.015	.001	-.003
20"	.014	-.013	.000	-.003	.016	.024	-.005	.009	-.007	-.026	-.005	.003	.001
5"	-.020	-.007	-.002	-.003	-.003	.016	.014	-.014	.000	-.012	-.026	.004	.004
3"	.036	.022	.010	.017	.016	.003	.007	-.003	.003	.005	.009	-.004	.010
• 1"	.019	.011	.000	.027	.005	-.007	.008	.001	.003	.001	-.003	.012	.006
MEAN	-.001	-.003	.002	.009	.003	-.005	.007	-.006	-.006	-.008	-.001	.003	



History of computed values and slope (m) of least squares line fit to values.



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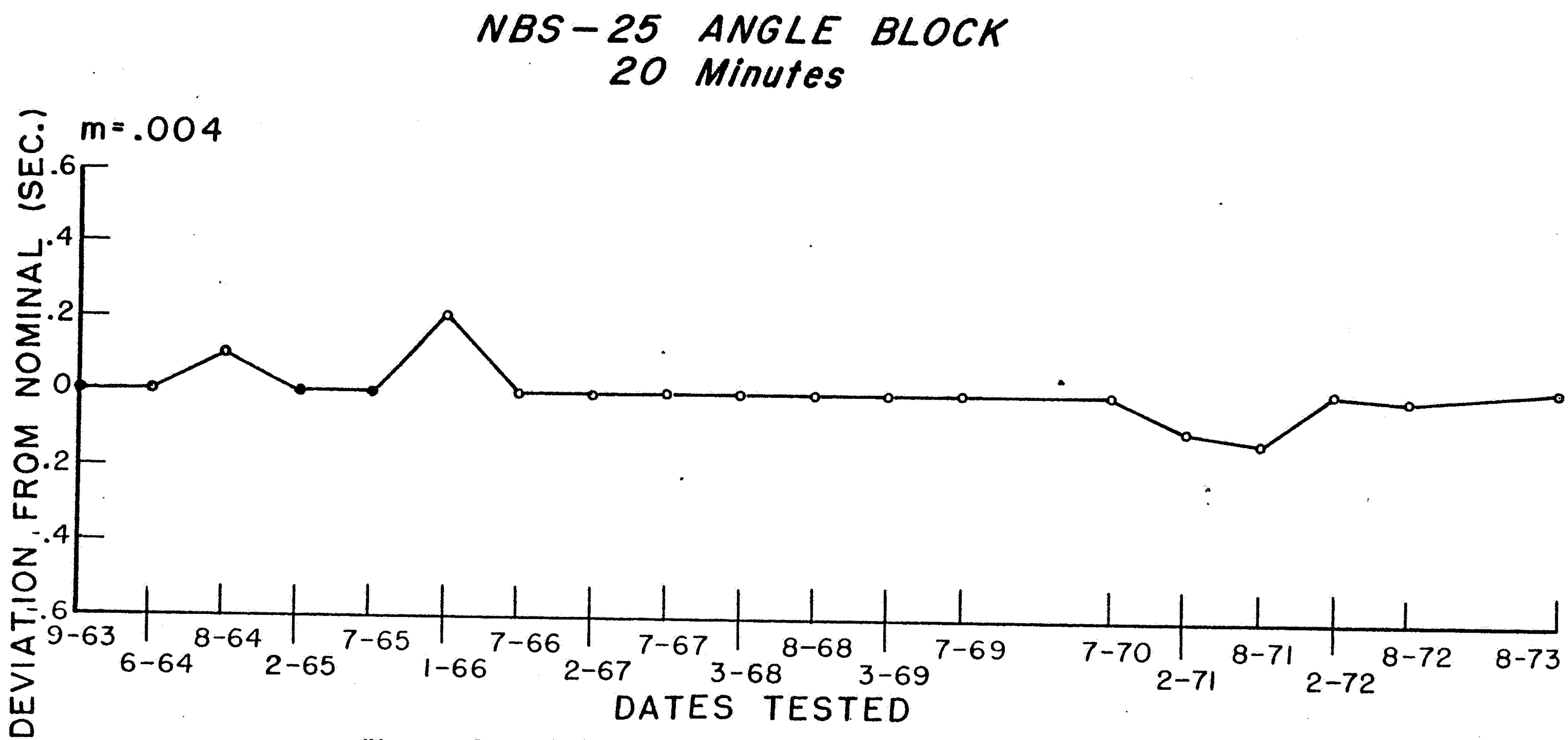

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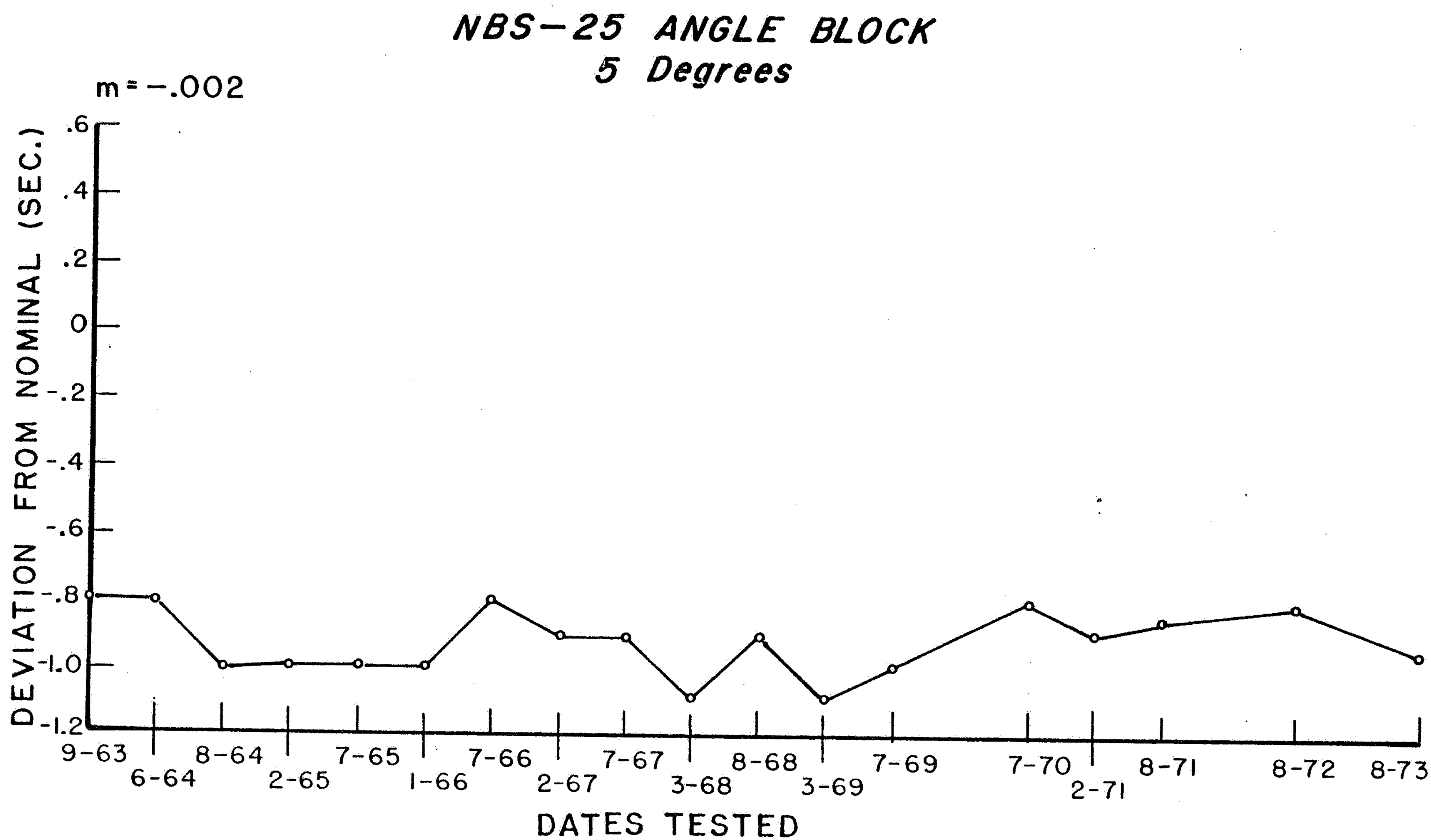

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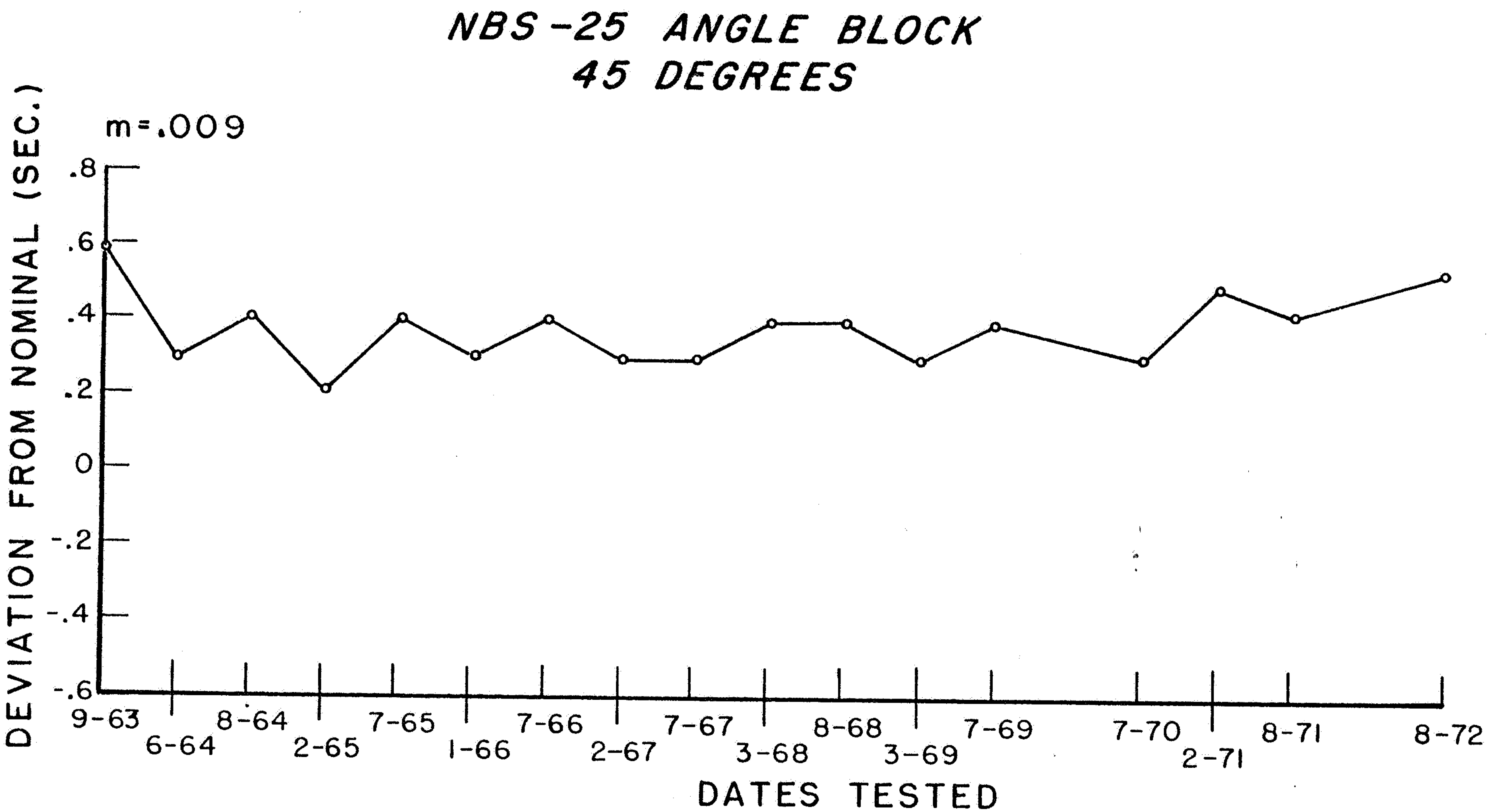

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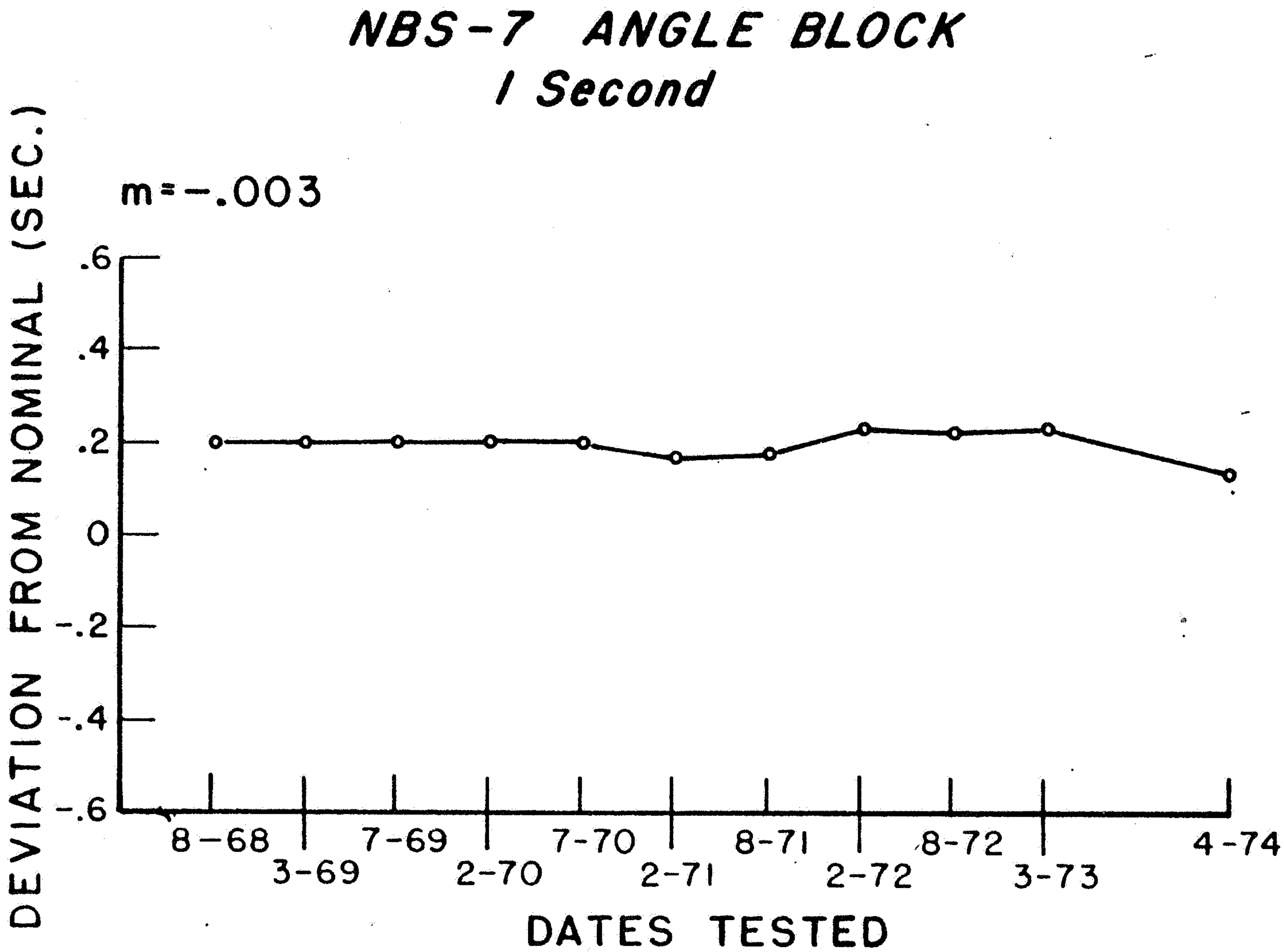

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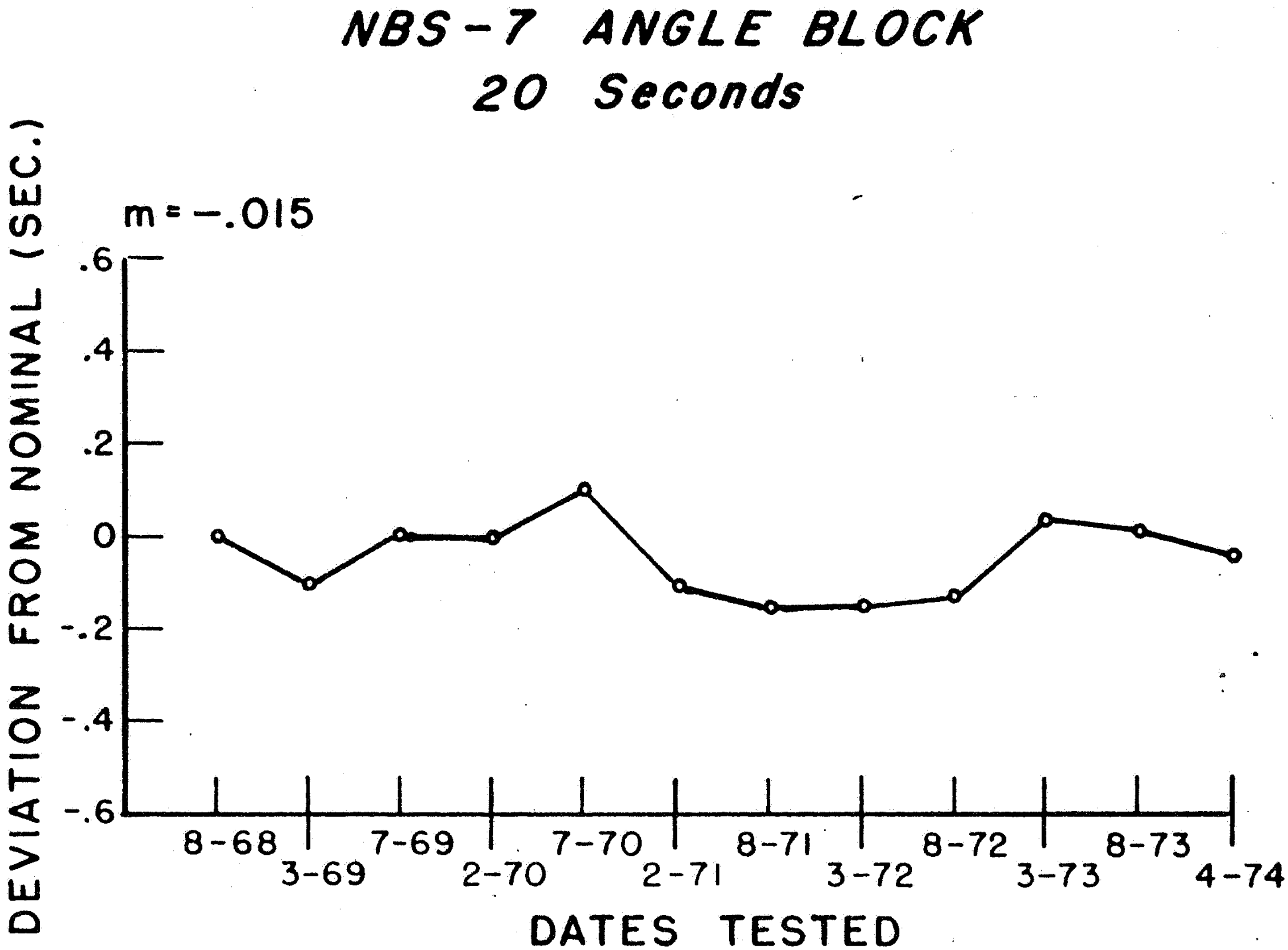

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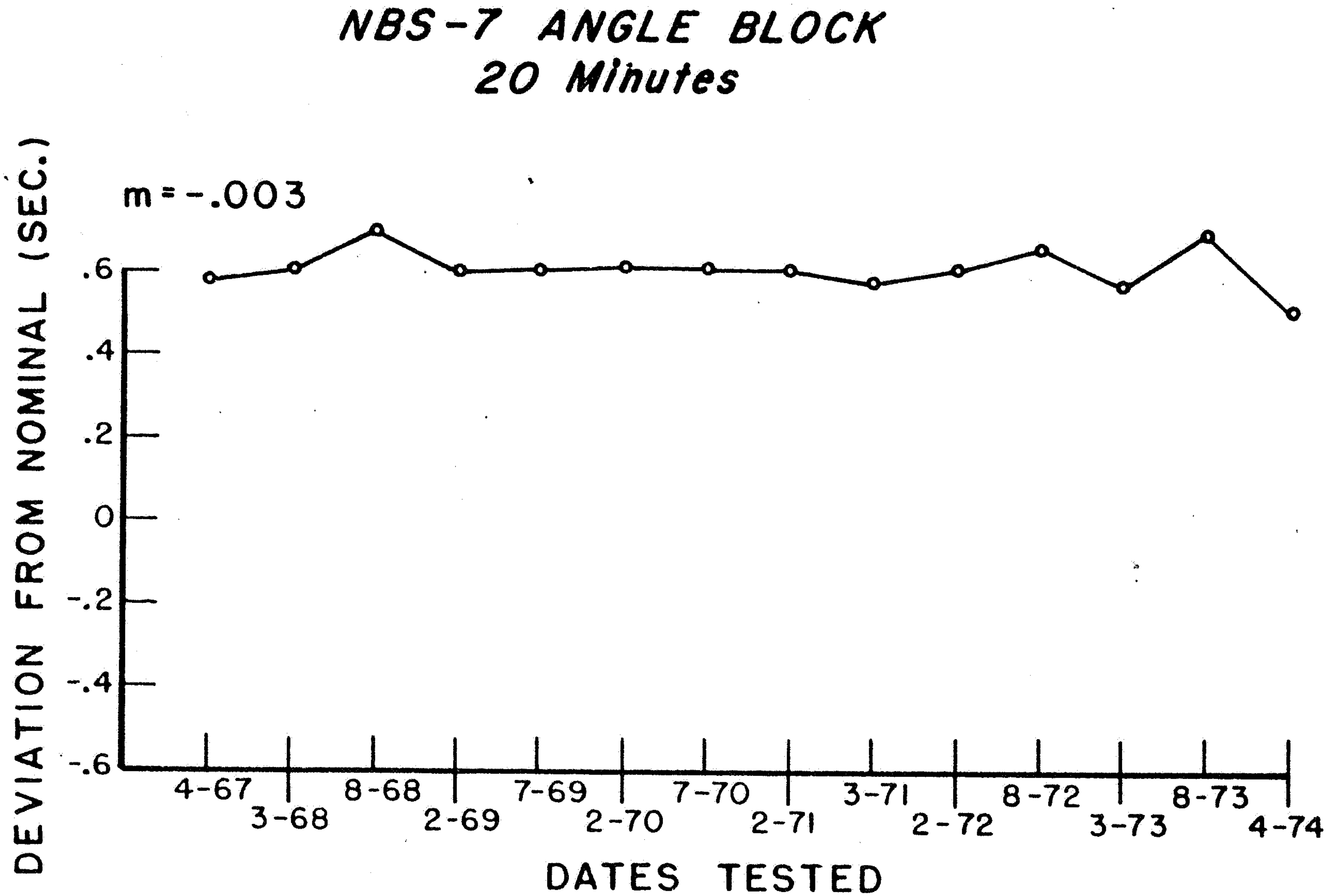

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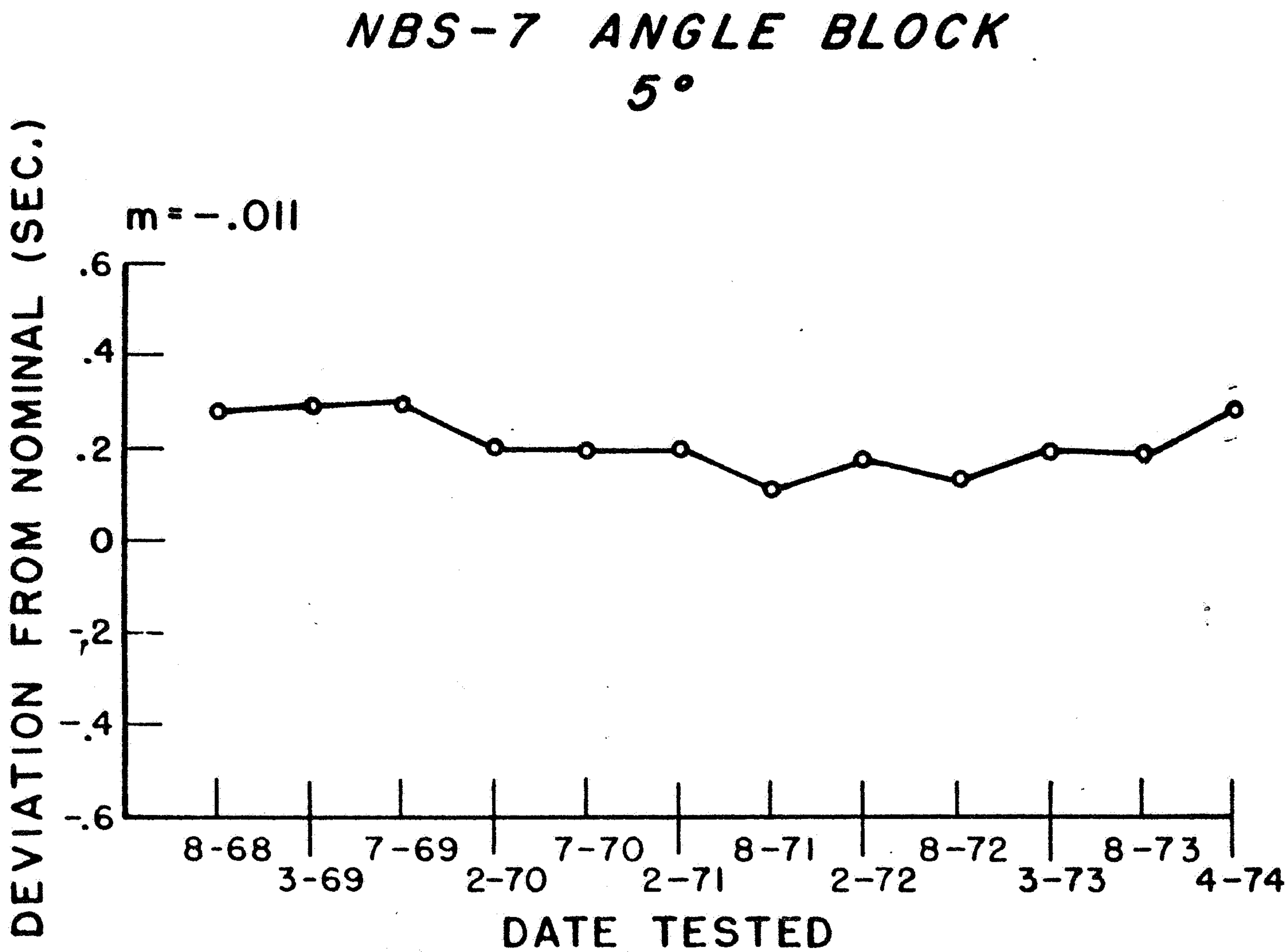
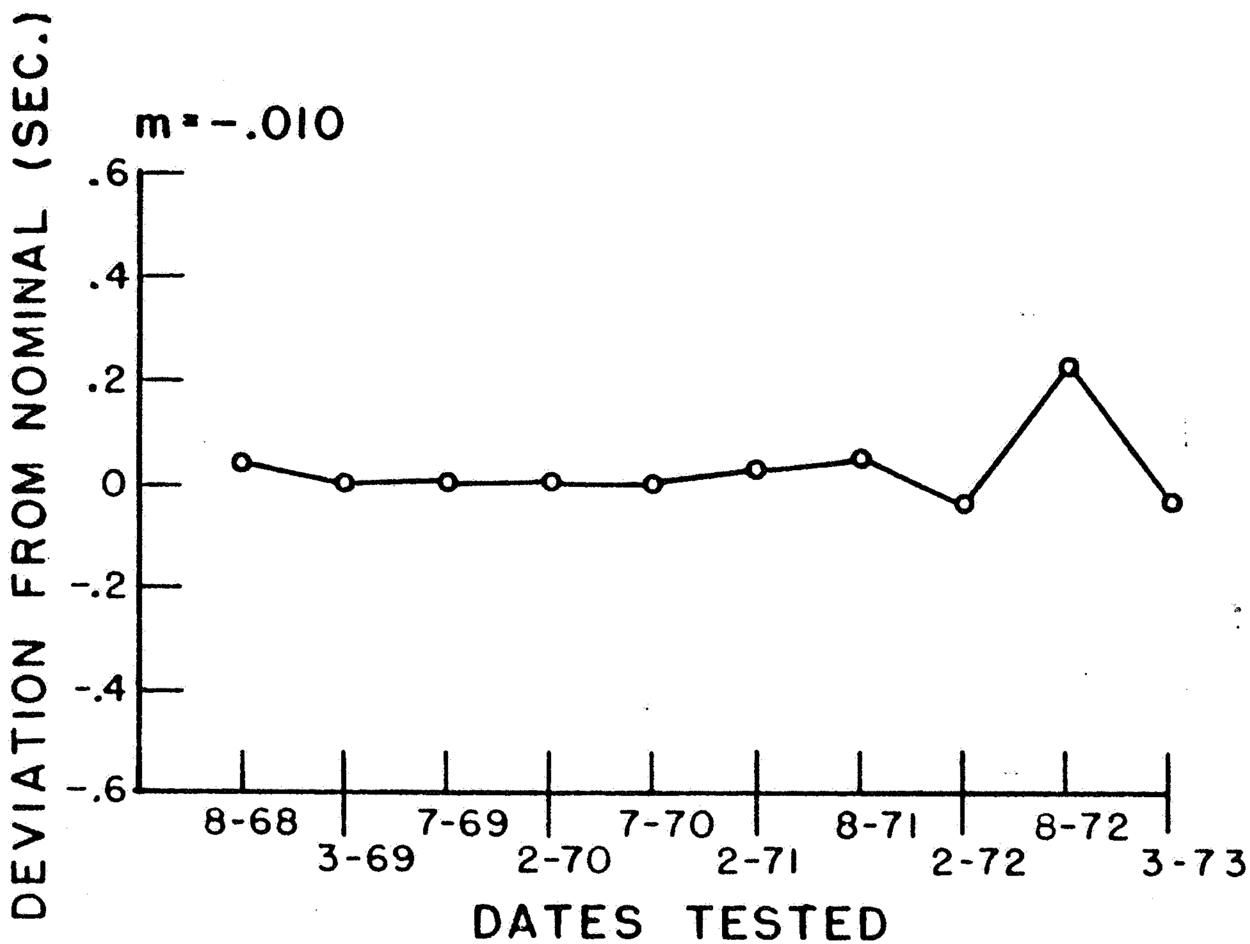


History of computed values and slope (m) of least squares line fit to values.

NBS-7 ANGLE BLOCK
45°



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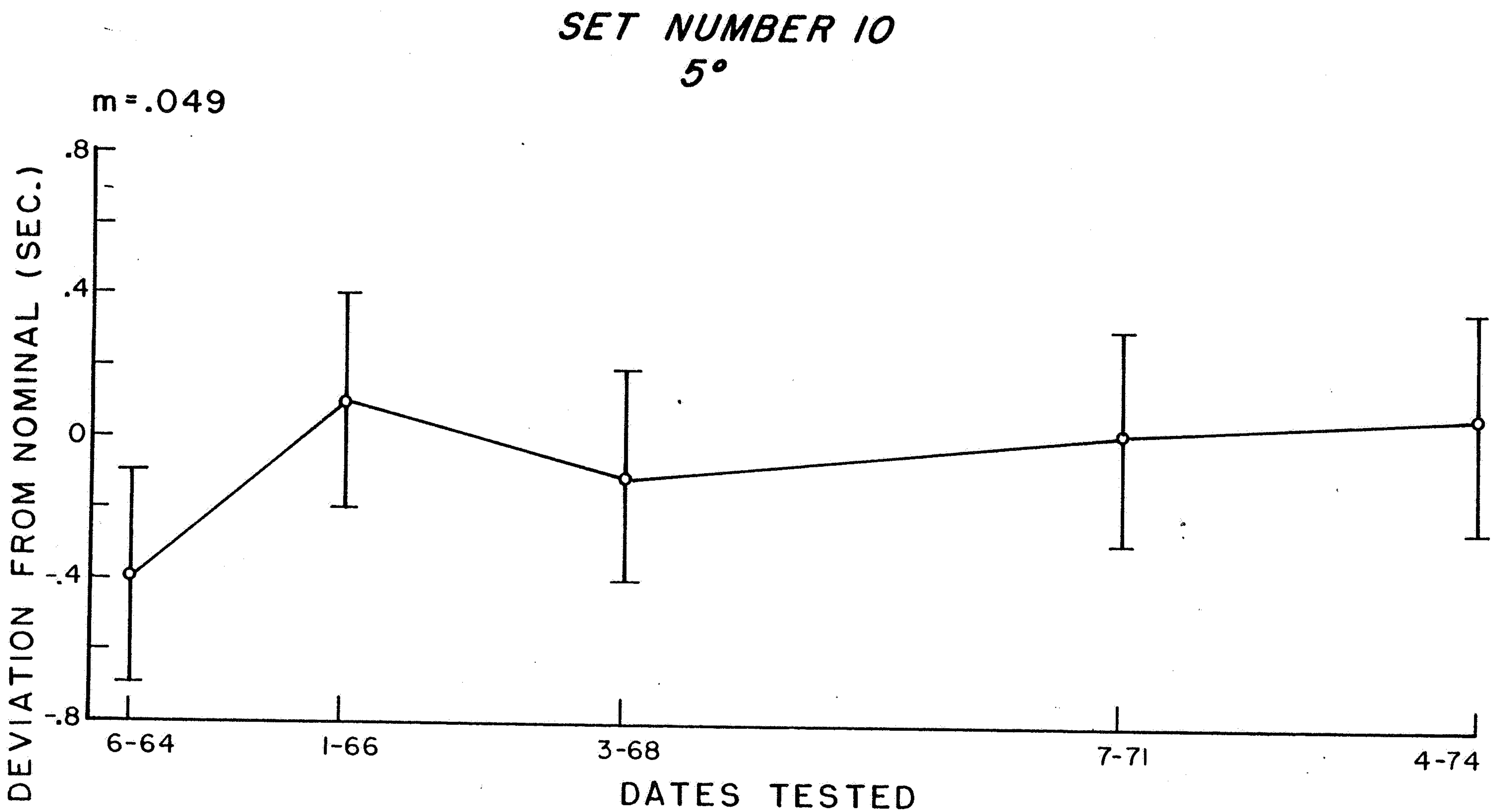

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