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AN/GMD-2 WIND ERRORS

from

Salton Sea Test Series

D. P. Keily and D. J. Beaubien

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CAMBRIDGE SYSTEMS, INC.
Newton Massachusetts

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FINAL REPORT

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PREFACE

In September of 1959, a group of tests known as the Salton-Sea Meteorological Instrumentation Test Series were conducted by the Sandia Corporation, Albuquerque, New Mexico, through the joint cooperation of the U. S. Navy (Bureau of Weapons), U. S. Weather Bureau (Instruments Engineering Division), U. S. Army (USAELRDL) and the Air Force Cambridge Research Laboratories, (at that time Air Force Cambridge Research Center). This test series was conducted to determine the accuracy of meteorological equipment used to gather upper air data. The equipment tested included the AN/GMD-2, SMD-1A, AN/GMD-1B, and the WBRT-57. The standard for comparison was a four-station phototheodolite network operated by the Sandia Corporation.

The reader is encouraged to familiarize himself with Research Report SC-4521(RR), TID 4500 (15th Ed.), Instruments, entitled Salton Sea Meteorological Test Series available from the Office of Technical Services, Department of Commerce, Washington 25, D. C., (Price $2.75). The data presented in this report is an extension of and is based on, the results presented in the reference report.

ABSTRACT

The results of the Salton Sea Meteorological Instrumentation Test Series (MITS) are analyzed and extended to include root mean square errors in the wind speed, range, elevation and azimuth angles, as measured by the AN/GMD-2 Rawin Set, for a series of representative flights. Criteria are presented as guidelines for conducting additional field tests in order that such tests will generate sufficient data to permit the determination of rms wind errors to a higher degree of confidence and accuracy than that which is currently attainable. An effort is made to categorize the wind errors derived, on the basis of established errors in the altitude, slant range, azimuth and elevation angles.

1.0 Introduction

The Salton Sea Meteorological Instrumentation Test Series (Sept. 1959), was a group of eleven (11) carefully conducted field tests designed to compare the relative altitude determining capabilities of the AN/GMD-2, AN/GMD-1B, SMD-1A and WBRT-57 Rawin Sets. The standard for comparison was a four station phototheodolite of the Askania type operated by the Sandia Corporation. The results of this test series (see Reference 1) produced data on the mean errors in altitude, mean and root-mean-square (rms) errors in elevation angle, azimuth angle, and slant range for each set. No effort was made to determine the errors in the wind vector at that time. Although the Salton Sea Test Series included eleven flights, (each fully instrumented with several radiosondes) examination of the flight data showed that only four flights were sufficiently trouble-free to justify a detailed analysis for the GMD-2 wind errors. These four flights were MITS 4, 5, 7, and 8, and are the same flights selected for analysis in the Sandia Report.

1.1 Program Objectives

The data analysis presented in this report is an extension of the analysis given in the Sandia Report. One objective of this analysis is to obtain the value of the rms errors in the wind vector as determined by the GMD-2 Rawin Set. Another objective is to determine the rms errors in the equipment parameters (elevation angle, azimuth angle and slant range) for each of the tests. These errors are derived for range increments of 20,000 feet, in order to permit a more detailed analysis of the errors than is possible if the errors are summated for the entire test. The errors are examined for clues which might reflect a method for classifying the magnitude of an rms error associated with a particular wind vector. Lastly, the requirements for additional tests are examined and guidelines are established which will in-

sure that future tests are designed so as to provide the data required for a better knowledge of the GMD-2 errors.

1.2 Method of Attack

The method of attack requires that the analysis originate with an examination of the raw test data as printed out by the GMD-2, followed by a correlation with the phototheodolite measurements on a minute-to-minute basis. The raw data from the GMD-2 was first checked for obvious transcription errors, and these are presented in an errata sheet in the appendix to this report. The phototheodolite computations which were done by digital computer were not verified since the raw data for this was not available. However, since the entire phototheodolite output was handled by computer, it may be assumed that the number of computational errors in this data are small. The deviations from the phototheodolite data were determined for each one-minute interval for elevation and azimuth angle, and for slant range. The velocity of the balloon was then determined on a one-minute basis for the phototheodolite and GMD-2 by the procedures set forth in Section 2.0 of this report. Mean errors for the angles and range were then computed, as well as the rms deviation from the mean. Finally, the rms wind error was computed. In every case, the computations were carried out for range increments of 20,000 feet, and also for the entire range of the test. Grouping the errors in these 20,000 foot range increments permits the errors for a particular test to be more closely correlated with other variables. The subjective nature of the end points of the test are also isolated, if the errors are grouped. Normally the operator releases the balloon at some arbitrary moment, and the first two to four minutes of operation are utilized to insure that the antenna has "locked-on." During these initial moments the errors are abnormally large and are generally discarded in reducing the data for operational use.

In terminating the tests, an operator deduces that the balloon has burst and ends the test. The last few position values therefore usually reflect very large errors, depending on the acuity of the operator and his ability to end the test. In order that these end point errors, which are generally many times the running error, not influence the results, the initial 3-5 minutes of all tests are discarded. By similar argument, the last 2-3 readings are also discarded.

1.2.1 Review of the Salton Sea Program

As pointed out earlier in this report, the Sandia Report produced comparative data on the altitude-determining capabilities of the various Rawin Sets. To do this, the actual values of elevation angle, azimuth angle, and slant range were tabulated for one-minute intervals for the GMD-2, togetner with the coordinate data for the balloon as determined by the phototheodolite. The phototheodolite data was transformed by digital computer from x, y, z coordinates to slant range, elevation angle and azimuth angle, in order to facilitate the point-to-point comparison. The data obtained in printed form from the GMD-2 was transcribed into a form suitable for analysis. In addition, notations were made on the GMD-2 raw data as it was obtained in the field, to indicate operational difficulaties as they occured. (One such difficulty is the occasional loss of signal, and the tendency for the system to "relock" on the sonde with a 6,000 foot range error. This error is due to an ambiguity in the GMD-2 range determining system, and is readily identified by the operator.)

In order to extend the results of the Sandia Report, it was first necessary to examine the raw data and all sub-

sequent transcriptions, for gross errors. Analysis of the transcribed data for thr four tests used (MITS 4, 5, 7 and 8) did produce several rather significant transcription errors. One large discrepancy in the reduced data was attributed to the failure of the analyist to heed the operators notation of a 6,000 foot shift in the slant range on the raw data. Lastly, a few errors were attributed to simple arithmetic errors. All data errors in the Sandia Report turned up by this analysis are summarized in the Sandia Report Errata in the appendix to this report. This is not to imply that the analysis presented in this report are entirely free from error.

1.2.2 Limitations of the Analysis

The data produced on the GMD-2 wind errors by the analysis in this report is based on a series of four (4) flights in which the actual upper winds seldom exceeded 20 meters/sec. (45 mph.) In addition, slant ranges seldom exceeded 120,000 feet, due to the limitations of the phototheodolite system.. Lastly, the data was obtained on a single GMD-2 Rawin Set, operated by skilled technicians with the objective of obtaining the best possible results. The results obtained, therefore, do not statistically represent the performance capabilities of a GMD-2 under typical "operational" use. Furthermore, the flight conditions were not particularly chosen to test the equipment under extreme conditions, i.e., in strong winds, low elevation angles, or long ranges.

The data does reflect, however, the magnitude of the various errors of a production model GMD-2 when properly adjusted and operated, under typically ideal conditions, as determined from a carefully controlled and properly instrumented field evaluation.

2.0 Technical Discussion.

The computational methods employed for reducing a data are presented in this section.

2.1 Method of computing mean errors and rms deviation from the mean, in slant range, azimuth angles, and elevation angles.

The phototheodolite readings were reduced to "time" readings of slant range, aximuth angle, and elevation angle for each Rawin Set location by means of a digital computer.[1] The error in the theodolite derived points was considered by Sandia to be less than 3 feet per 10,000 feet of average distance to the theodolite. In terms of angular error this corresponds to 0.018° if the error is perpendicular to the line of sight; or .03% of the average slant range if the error lies along the line of sight from the GMD-2 to the AMQ-9.

The error for each of the above mentioned parameters is determined for each data point by subtracting the "true" reading from the reading of the GMD-2. The mean errors are then calculated from the following equation.

$$E = \frac{1}{N - n + 1} \sum_{i=n}^{i=N} (G_i - T_i) \qquad \text{(Eq 1)}$$

Where E = the mean value over the range from n to N including the end point.

G_i = the GMD-2 data point for the i th minute

T_i = the theodolite data point for the i th minute

The rms deviation from the mean is calculated from the following equation:

[1] This work was done at Sandia Corporation and is presented in the Sandia Report.

$$S = \left[\frac{1}{N - n + 1} \sum_{i=n}^{i=N} (G_i - T_i)^2 - E^2 \right]^{1/2} \qquad \text{(Eq. 2)}$$

using the same notation as above in Eq. 1. Although the GMD-2 prints out slant range in yards, this data was converted to feet in the Sandia Report. All of the angle data was calculated in degrees to the nearest hundredth of a degree.

2.2 Method of Computing Wind Errors

The wind velocity is usually computed from Rawin Set data in the form of "X" & "Y" velocity components, where

$$V_{xn} = \frac{1}{T_{n+1} - T_{n-1}} \left[\frac{r \cos E \cos A}{1 + \frac{r}{R} \sin E} \bigg|_{n+1} - \frac{r \cos E \cos A}{1 + \frac{r}{R} \sin E} \bigg|_{n-1} \right] \text{(Eq. 3)}$$

V_{xn} = X component of velocity computed for the n'th data point.

T_{n+1} = The time at the data point after the one in question.

r = Slant range

E = elevation angle

A = azimuth angle

R = radius of the earth

$\big|_{n+1}$ = This notation is used to indicate that the preceding data is evaluated for the data point just after the one in question.

The "Y" component of velocity is computed with a similar equation where the only difference is that the Sin A is used in place of Cos A of Eq. 3.

In evaluation of the wind error the components of the wind velocity were computed for the GMD-2 readings and for the theodolite data. The component wind errors were then obtained from the following equation.

$$\Delta V_x = V_{xg} - V_{xt} \Big|_n \qquad \text{(Eq 4)}$$

where ΔV_x = the wind velocity error in the X direction

V_{xg} = the wind velocity for the n'th data point for the GMD-2 in the X direction

V_{xt} = the wind velocity for the n'th data point for the theodolite in the X direction

Similarly the "Y" component wind errors are computed from Eq. 5.

$$\Delta V_y = V_{yg} - V_{yt} \Big|_n \qquad \text{(Eq. 5)}$$

Finally the vector wind error is defined by Eq. 6.

$$\Delta V = \sqrt{\Delta V_x^2 + \Delta V_y^2} \Big|_n \qquad \text{(Eq. 6)}$$

where ΔV is the vector wind velocity error for the n'th data point.

The rms vector wind velocity error is given by Eq. 7.

$$A_v = \left[\frac{1}{N - n + 1} \sum_{i=n}^{i=N} \Delta V_{xi}^2 + \Delta V_{yi}^2 \right]^{1/2} \qquad \text{(Eq. 7)}$$

Where A_v = the rms wind vector error for the n'th through the N'th data point.

With reference to Eq. 3 for the component wind velocity, this equation includes a correction for the curvature of the earth. The correcting term is $\frac{r}{R}$ Sin E in the denominator. In these tests the maximum value of r is about 10^5 feet, R is about 2×10^7 and in the worst case where E = 90°, Sin E = 1. Thus the effect of the correction is to reduce the numerator term by 5×10^{-3} or 1/2% in the worst case. This correction term is made on both the GMD-2 data and the theodolite data. If the numerator of the GMD-2 is the same as that of the theodolite, the wind velocity error is zero whether or not the correction is used. In fact, if the curvature of the earth term is omitted entirely, the maximum error in the velocity error term is about 1/2% of that term, which is certainly insignificant. This term was therefore omitted and the actual equation used is shown below:

$$V_{xn}^* = 2.54 \ \ 10^{-3} \left[r \text{ Cos E Sin A} \Big|_{n+1} - r \text{ Cos E Sin A} \Big|_{n-1} \right] \qquad \text{(Eq. 8)}$$

Where V_{xn}^{*} = X component of velocity computed for the n'th data point without curvature correction in meters per second

r = slant range in feet

E = elevation angle in degrees

A = azimuth angle in degrees

Data for the n'th minute is taken from the minute before and the minute after the desired point. Thus this is a two minute average.

2.3 General Comments on Methods

It is possible to arrive at an approximation of the wind velocity error without doing a detailed calculation of the individual wind velocity components. The exact form of the approximation depends on the assumptions used. A rather detailed analysis of the wind velocity error as a function of the random errors in elevation angle, aximuth angle, slant range and mean ascent rate, is given in Ref. 2.

An approximation of the wind velocity error can be obtained through differentiation of an equation for the component wind velocity of the form of Eq. 8.

$$dV_x = 2.54\times10^{-3}\,[\mathrm{CosE\ SinA\ dr} - \mathrm{rSinE\ SinA\ dE} + \mathrm{rCosE\ CosA\ dA}) \qquad \text{(Eq. 9)}$$

$$dV_y = 2.54\times10^{-3}\,[\mathrm{CosE\ SinA\ dr} - \mathrm{rSinE\ SinA\ dE} + \mathrm{rCosE\ SinA\ dA}) \qquad \text{(Eq. 10)}$$

where dE and dA are expressed in radians and dr is feet, and, where dV_x and dV_y are the component errors in velocity due to slant range error difference dS, elevation angle error difference dE, and azimuth error difference dA.

From Eq. 6 the vector velocity error is

$$dV = \sqrt{dV_x^{\,2} + dV_y^{\,2}} \qquad \text{(Eq. 11)}$$

If Eq. 9 and Eq. 10 are combined in Eq. 11 the following re-

sult is obtained.

$$dV = 2.54 \times 10^{-3} \left[(dr)^2 \mathrm{Cos}^2 E + (dE)^2 r^2 \mathrm{Sin}^2 E + (dA)^2 r^2 \mathrm{Cos}^2 E + 2 r\, dr\, dE \mathrm{Sin}E\, \mathrm{Cos}E \right]^{1/2} \qquad \text{(Eq. 12)}$$

The wind velocity error as expressed in Eq. 12 is the error for a single computed point in terms of the error differences between the two points used in the calculation.

To determine the rms error these individual errors must be squared and averaged. If we assume that the error differences in slant range, elevation angle, and azimuth angle are independent of the magnitude of range, azimuth angle and elevation angle, i.e., they are truly random. And if we use mean values of elevation angle, azimuth angle and slant range we can use the above expression for the rms error.

One further approximation must be made which concerns the correlation of the errors at a given time to the errors two minutes later. That is, we need to know the relationship between the error differences at two minute intervals to the rms deviation from the mean error for a given run. This relationship is:

$$dr = Sr \sqrt{2} \sqrt{1-C} \qquad \text{(Eq. 13)}$$

where dr = rms error difference between data points taken 2 minutes apart

Sr = rms deviation from the mean error

C = the autocorrelation coefficient for a time delay of 2 minutes.

If the error at a given point is unrelated to the error two minutes later C will be equal to zero and

$$dr = 1.414\ Sr$$

In general $1 < C < 0$ (see Fig. 8). If it is desired to find the maximum error based on Eq. 12 it is wise to use dr = 1.41 Sr, and use the maximum values of the parameters of slant

range and trigonometric functions of the angles. In this connection we note that if the slant range increases linearly with time, the mean value of r^2 is $\frac{V^2_{max}}{3}$ which is the best value to use if this assumption is valid. See Fig. 9 for a comparison of this method with the results obtained by the detailed point-to-point method.

3.0 Results

This section will present graphically the various errors which have been derived. Generally, the errors can be split into two distinct categories:

a) those errors which can be thought of as actual equipment errors, such as the elevation angle, azimuth angle and slant range errors, and

3) those errors which are a result of equipment errors, i.e., the actual wind vector errors.

The equipment errors are presented in terms of both mean errors and the rms deviation from the mean error. The wind errors are presented as rms errors, since a mean wind error is of no significance.

Each test is summarized in tabular form, Tables 1 through 4, from MITS 4, 5, 7 and 8, inclusive. The data from each table is also presented graphically. Where a limit of error can be established from existing equipment specifications, this is entered as a dotted line. In the case of angular errors this limit is entered as .05 degrees. The slant range error limit is set at 20 yards or 0.1% of range.

All errors are presented as a function of slant range, with the number of data points representing a 20,000 foot increment indicated in the respective table for the test.

The data is presented graphically in order to depict the general trend of the errors. It is to be pointed out, however, that each data point represents an average error value for the particular range increment, and there is no geometric basis for connecting the data points.

SUMMARY OF ERRORS

SALTON SEA TEST SERIES

MITS 4

CATEGORY OF ERROR		RANGE SEGMENT (THOUSANDS OF FEET)							
		0 – 20	20 – 40	40 – 60	60 – 80	80 – 100	100 – 120	120 – 140	ENTIRE TEST
AZIMUTH ANGLE (DEGREES)	MEAN E_a	-0.094	-0.0733	-0.0722	-0.0857	-0.064	--	--	-0.0818
	RMS DEV. S_a	0.118	0.014	0.014	0.01	0.01	--	--	0.074
ELEV. ANGLE (DEGREES)	MEAN E_e	0.165	0.122	0.084	0.101	0.102	--	--	0.128
	RMS DEV. S_e	0.045	0.030	0.016	0.028	0.024	--	--	0.047
SLANT RANGE (FEET)	MEAN E_r	54.1	20.8	11.8	-111.4	-186.2	--	--	-4.07
	RMS DEV. S_r	67.8	32.1	107.1	105.9	116.7	--	--	112.3
WIND SPEED M/SEC	RMS ERROR A_v	0.228	0.215	0.304	0.378	0.377	--	--	0.277
NO. OF DATA PTS.		21	12	9	7	5	--	--	54

TABLE I

SUMMARY OF ERRORS

SALTON SEA TEST SERIES

MITS 5

CATEGORY OF ERROR		RANGE SEGMENT (THOUSANDS OF FEET)							
		0 – 20	20 – 40	40 – 60	60 – 80	80 – 100	100 – 120	120 – 140	ENTIRE TEST
AZIMUTH ANGLE (DEGREES)	MEAN Ea	-0.078	-0.169	-0.176	-0.244	-0.050	-0.003	-0.011	-0.076
	RMS DEV. Sa	0.114	0.066	0.073	0.026	0.082	0.068	0.049	0.105
ELEV. ANGLE (DEGREES)	MEAN Ee	0.190	0.256	0.139	0.218	0.193	0.140	-0.182	0.020
	RMS DEV Se	0.077	0.024	0.070	0.066	0.033	0.053	0.119	0.197
SLANT RANGE (FEET)	MEAN Er	67.0	50.6	55.3	47.0	195	35.5	-27.6	25.9
	RMS DEV. Sr	5.40	23.9	71.8	82.5	119	117	174	142
WIND SPEED M/SEC	RMS ERROR Av	0.379	0.151	0.350	0.439	0.562	0.434	0.712	0.541
NO. OF DATA PTS.		5	7	7	5	4	6	26	60

TABLE 2

SUMMARY OF ERRORS

SALTON SEA TEST SERIES

MITS 7

CATEGORY OF ERROR		RANGE SEGMENT (THOUSANDS OF FEET)							
		0 - 20	20 - 40	40 - 60	60 - 80	80 - 100	100 - 120	120 - 140	ENTIRE TEST
AZIMUTH ANGLE (DEGREES)	MEAN E_a	-0.069	-0.064	-0.091	-0.084	-0.060	-0.089	--	-0.076
	RMS DEV. S_a	0.040	0.036	0.028	0.020	0.039	0.027	--	0.035
ELEV. ANGLE (DEGREES)	MEAN E_e	0.099	0.149	0.149	0.143	0.114	0.101	--	0.122
	RMS DEV. S_e	0.047	0.020	0.040	0.020	0.022	0.037	--	0.040
SLANT RANGE (FEET)	MEAN E_r	-50.9	-54.3	-57.9	-75.4	-76.8	-16.8	--	-52.0
	RMS DEV. S_r	29.2	15.4	18.6	32.4	34.7	90	--	53.8
WIND SPEED M/SEC	RMS ERROR A_v	0.081	0.270	0.112	0.158	0.246	0.311	--	0.196
NO. OF DATA PTS.		11	9	7	8	9	13	--	57

TABLE 3

SUMMARY OF ERRORS

SALTON SEA TEST SERIES

MITS 8

CATEGORY OF ERROR		RANGE SEGMENT (THOUSANDS OF FEET)							
		0 – 20	20 – 40	40 – 60	60 – 80	80 – 100	100 – 120	120 – 14C	ENTIRE TEST
AZIMUTH ANGLE (DEGREES)	MEAN Ea	-0.094	-0.15	-0.103	-0.104	-0.118	-0.144	--	-0.127
	RMS DEV. Sa	0.078	0.081	0.058	0.047	0.041	0.047	--	0.062
ELEV. ANGLE (DEGREES)	MEAN Ee	0.102	0.141	0.128	0.139	0.132	0.142	--	0.136
	RMS DEV. Se	0.018	0.032	0.014	0.021	0.022	0.022	--	0.0207
SLANT RANGE (FEET)	MEAN Er	45.4	37.4	141	318	211	29.4	--	75.25
	RMS DEV. Sr	31.6	20.3	119	224	159	45.5	--	124
WIND SPEED M/SEC	RMS ERROR Av	0.158	0.118	0.430	0.789	0.341	0.210	--	0.351
NO. OF DATA PTS.		8	10	8	7	9	27		69

TABLE 4

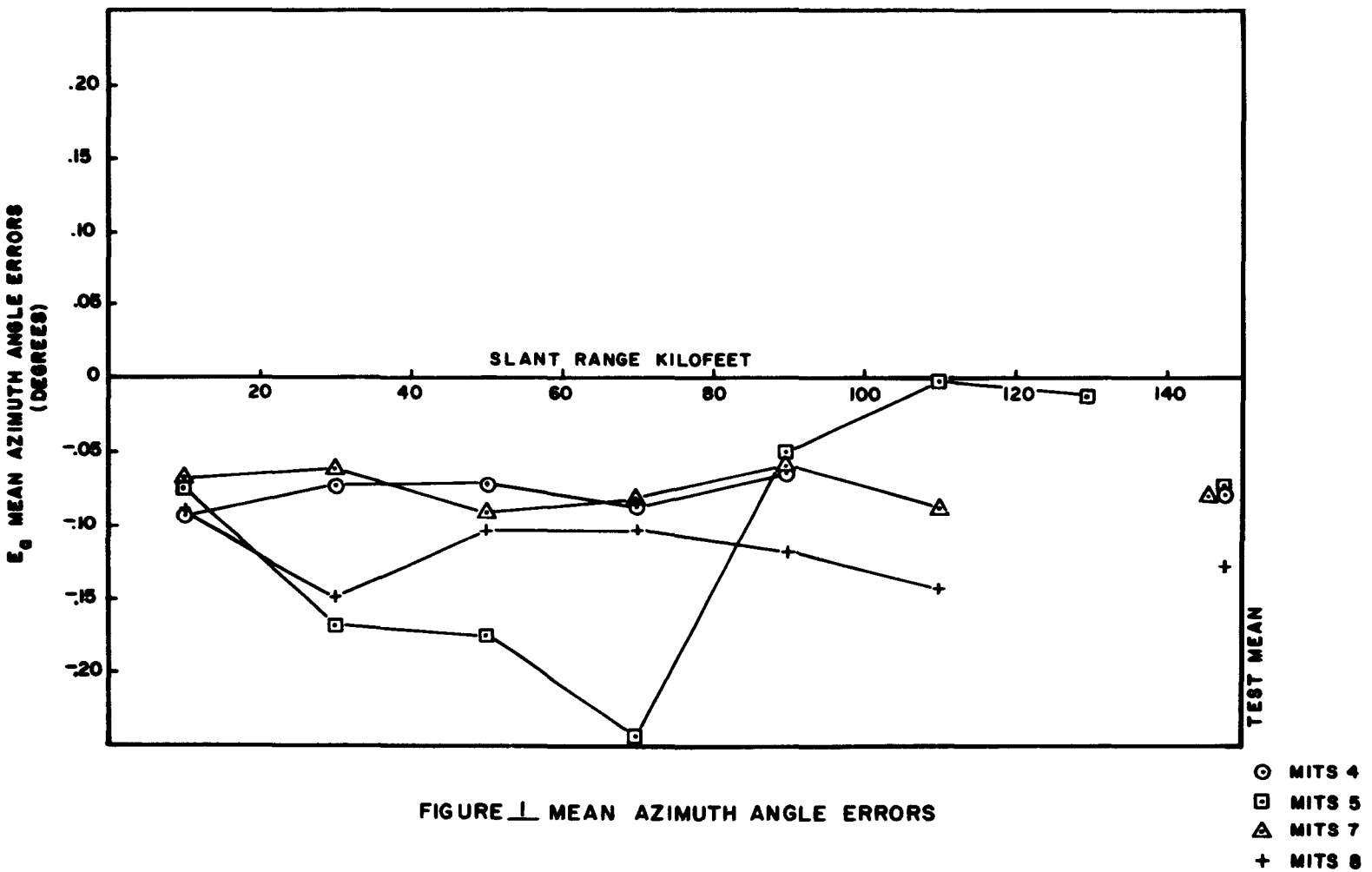

FIGURE 1 MEAN AZIMUTH ANGLE ERRORS

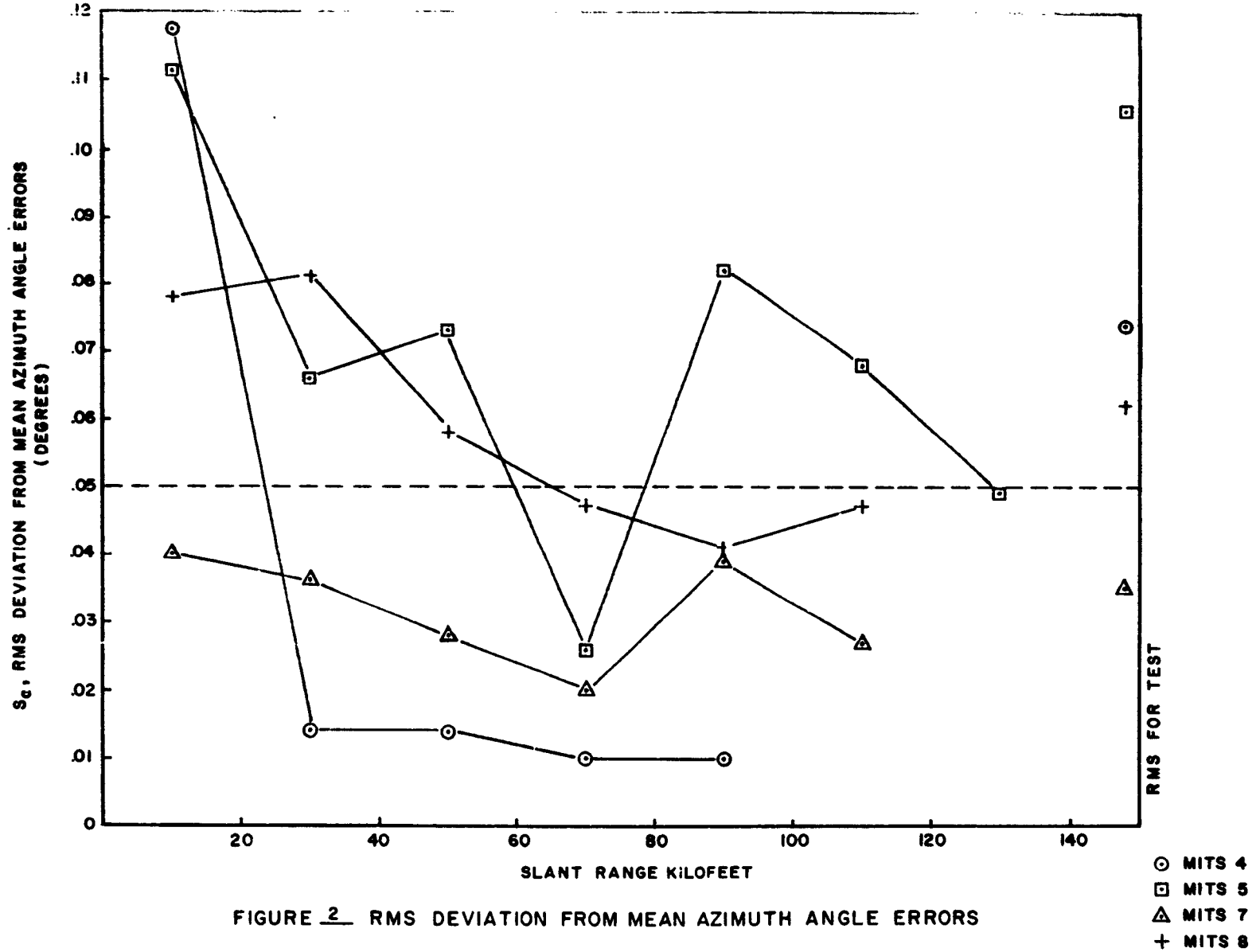

FIGURE 2 RMS DEVIATION FROM MEAN AZIMUTH ANGLE ERRORS

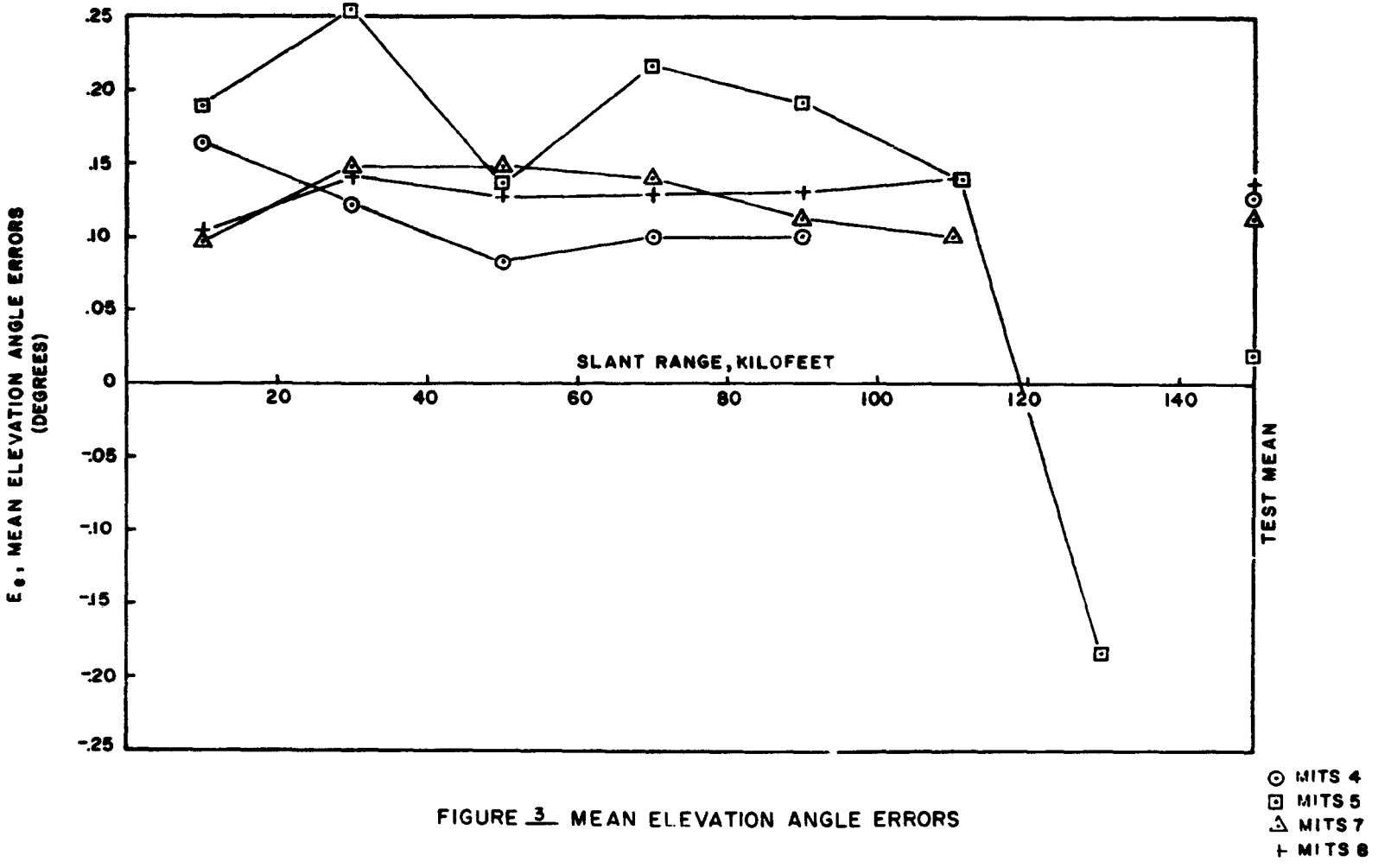

FIGURE 3 MEAN ELEVATION ANGLE ERRORS

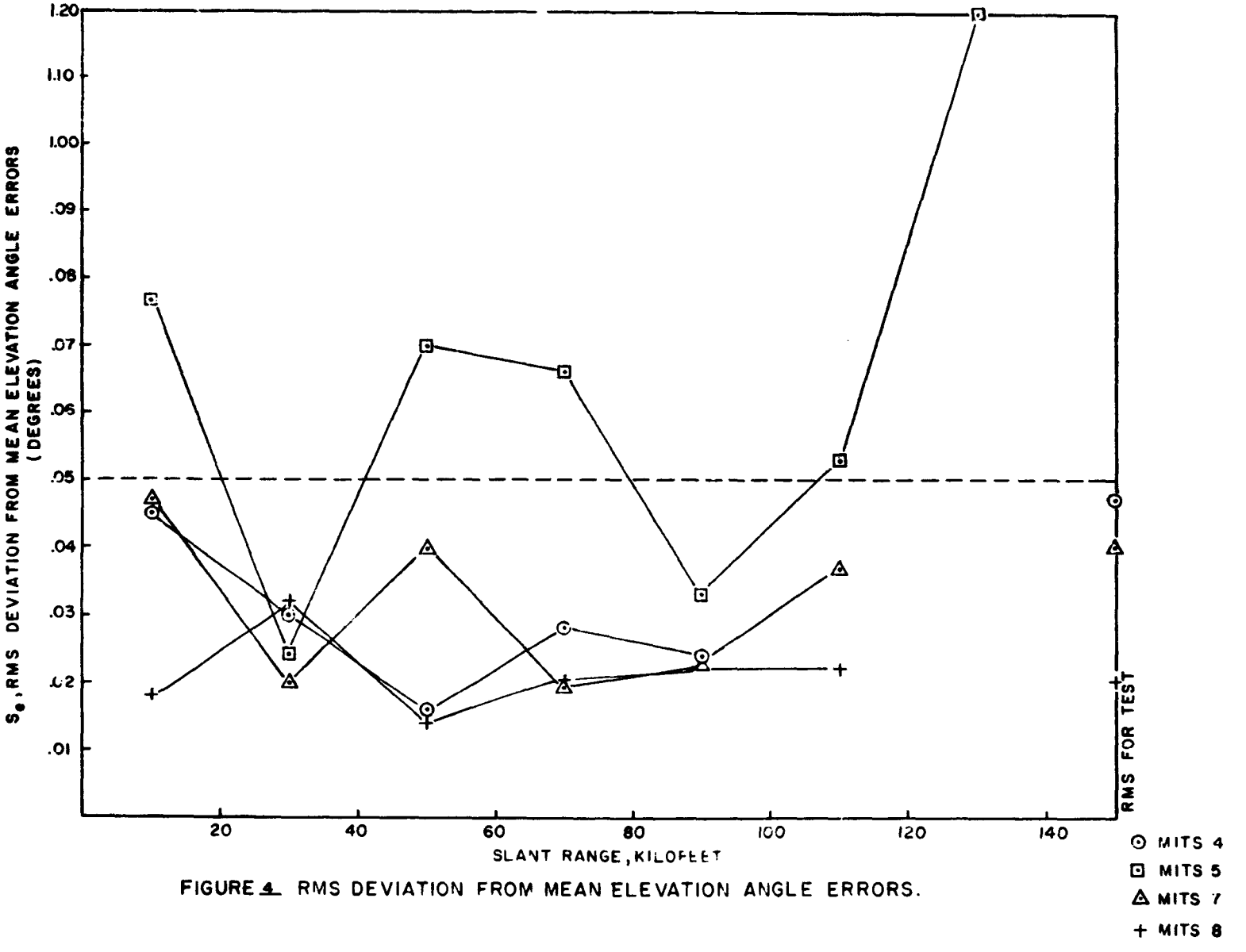

FIGURE 4. RMS DEVIATION FROM MEAN ELEVATION ANGLE ERRORS.

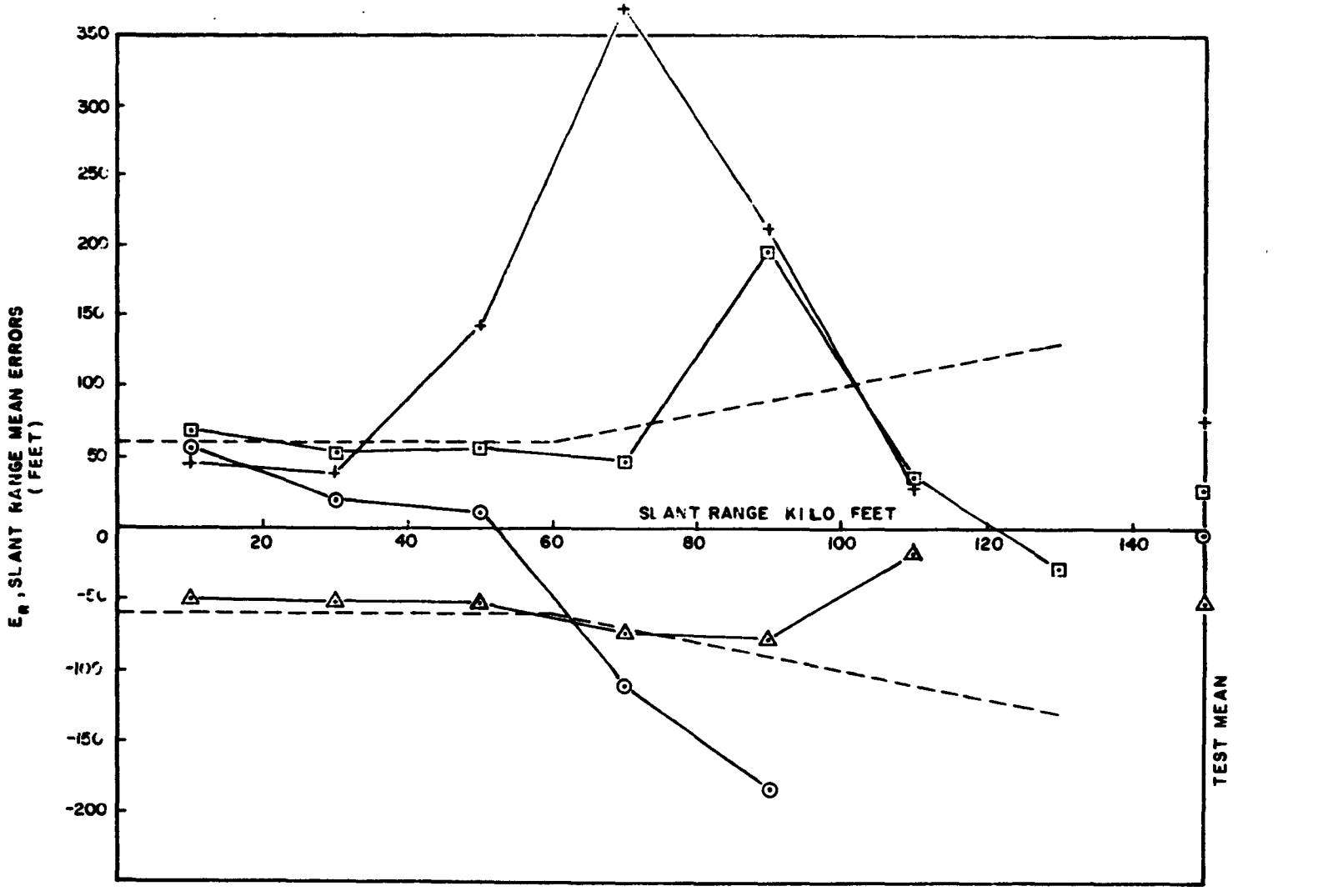

FIGURE 5 MEAN SLANT RANGE ERRORS

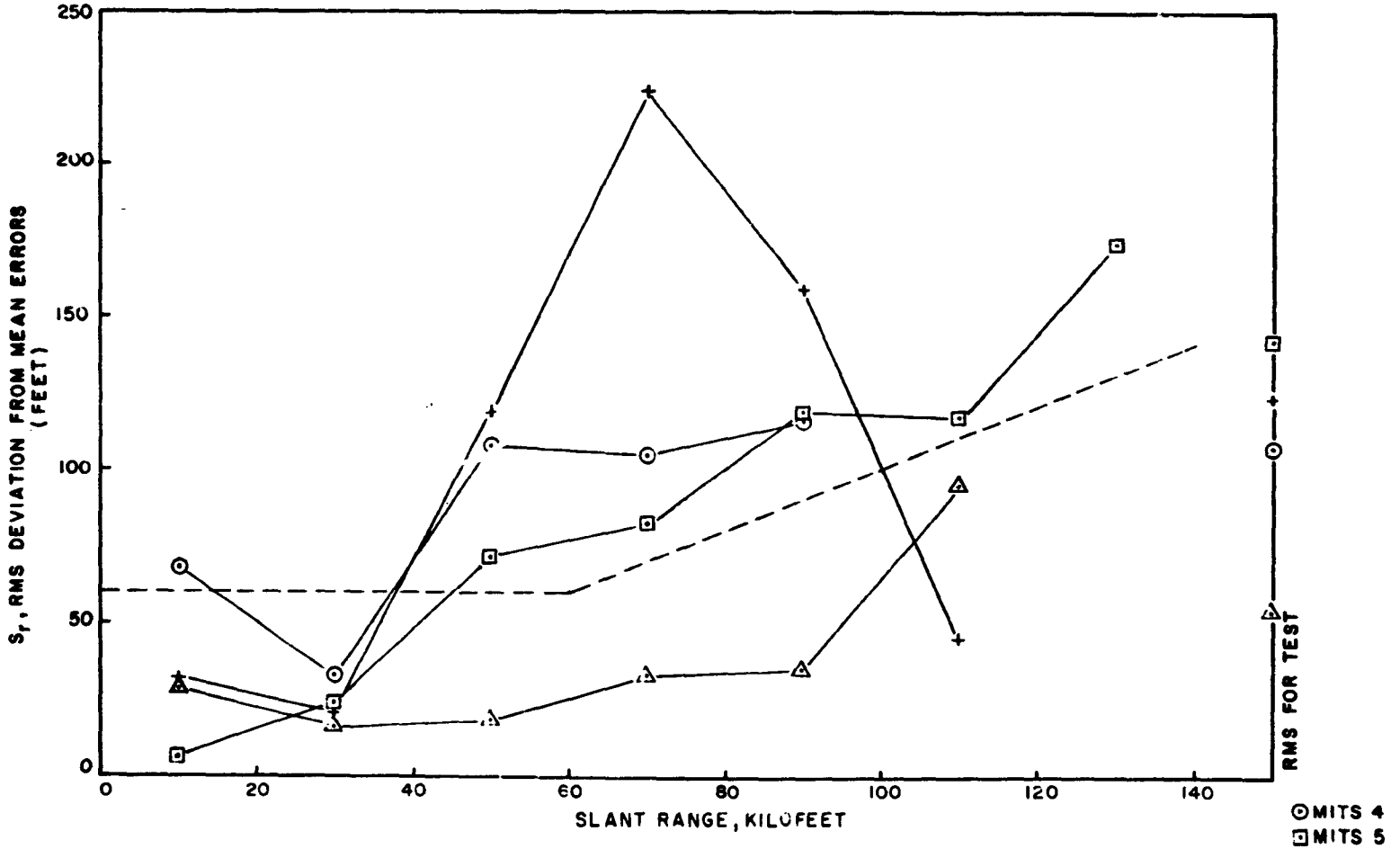

FIGURE 6 .RMS DEVIATION FROM MEAN SLANT RANGE ERRORS

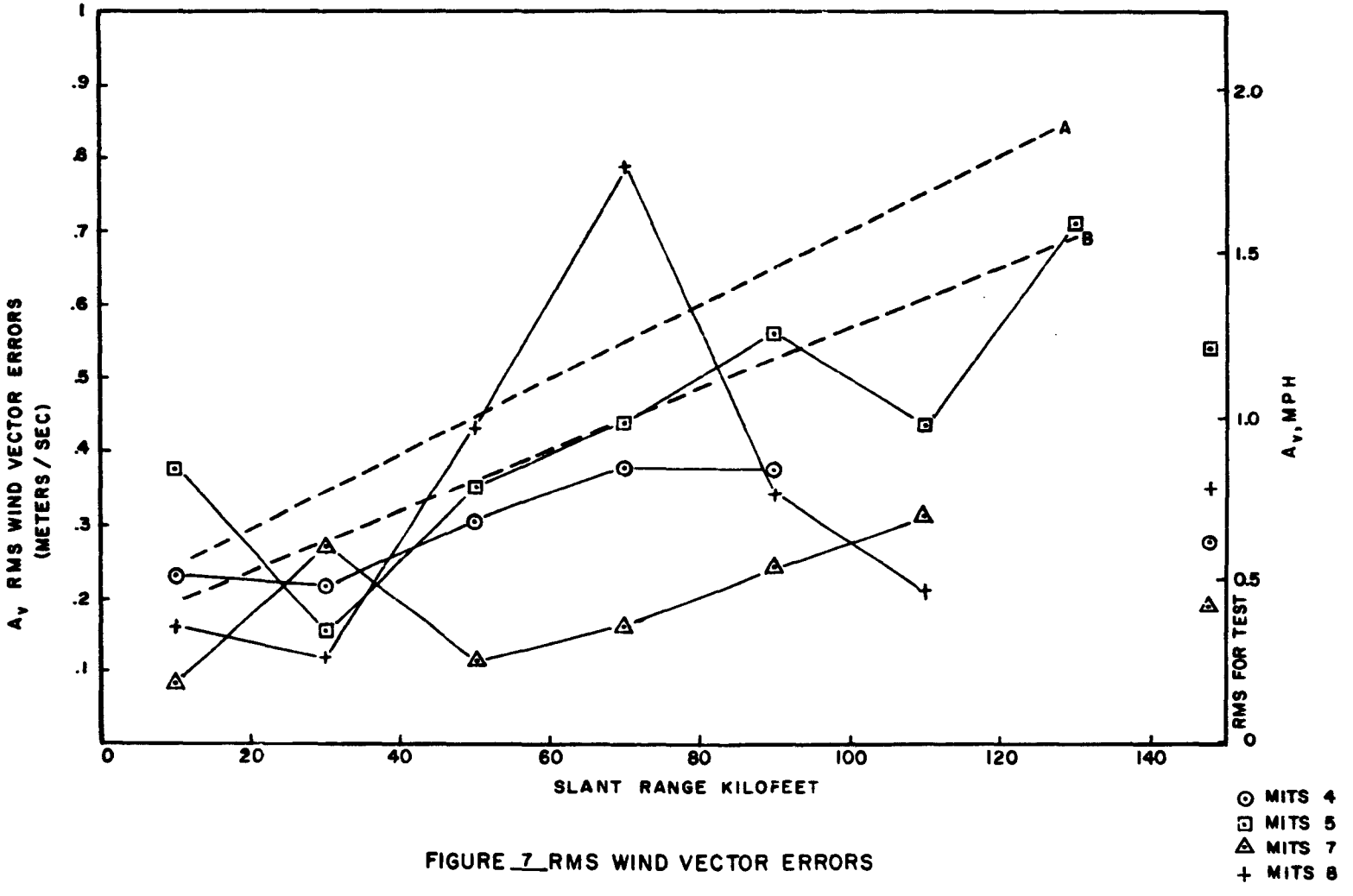

FIGURE 7 RMS WIND VECTOR ERRORS

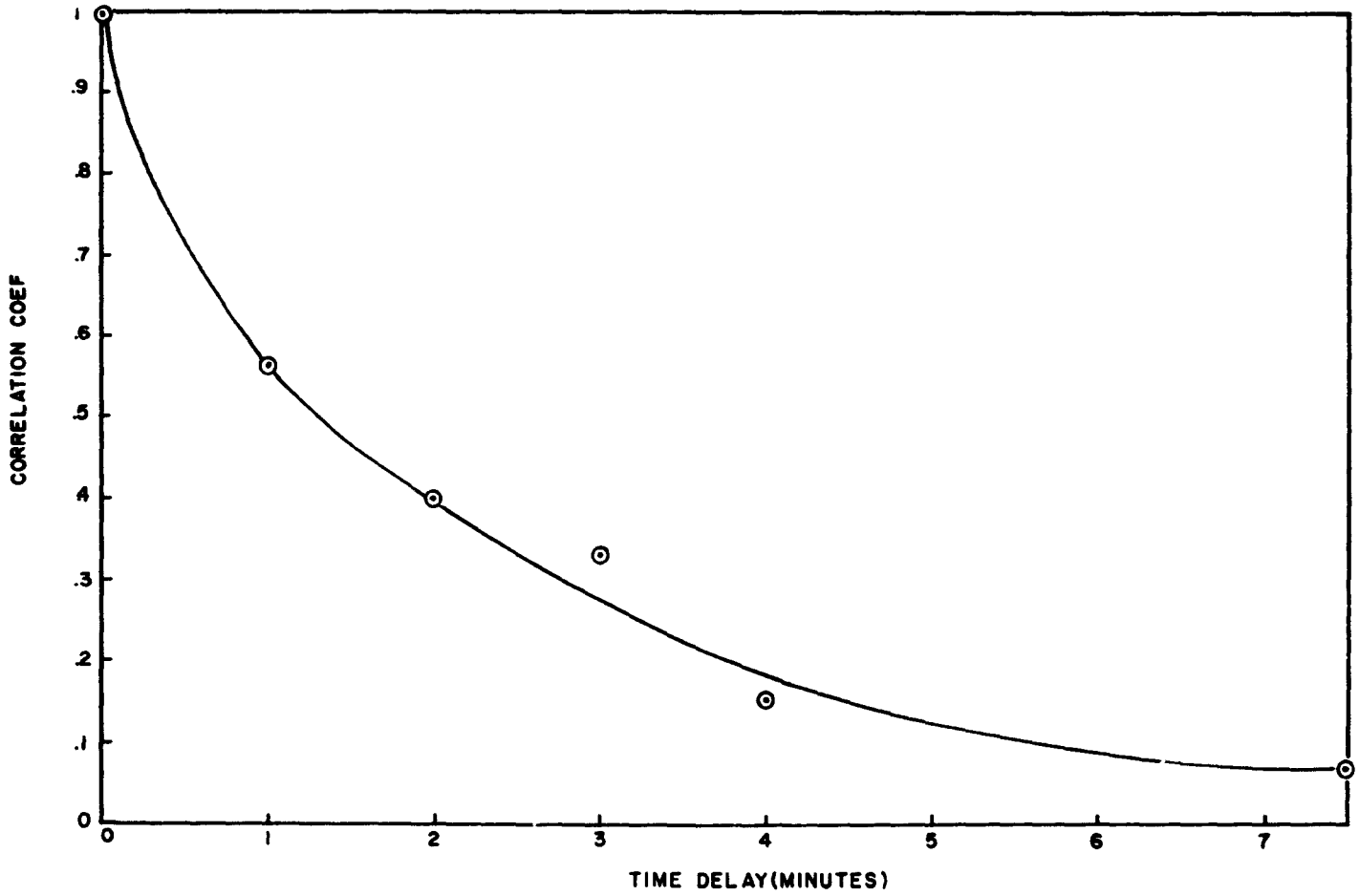

FIGURE 8 AUTOCORRELATION OF SLANT RANGE ERRORS MITS 4

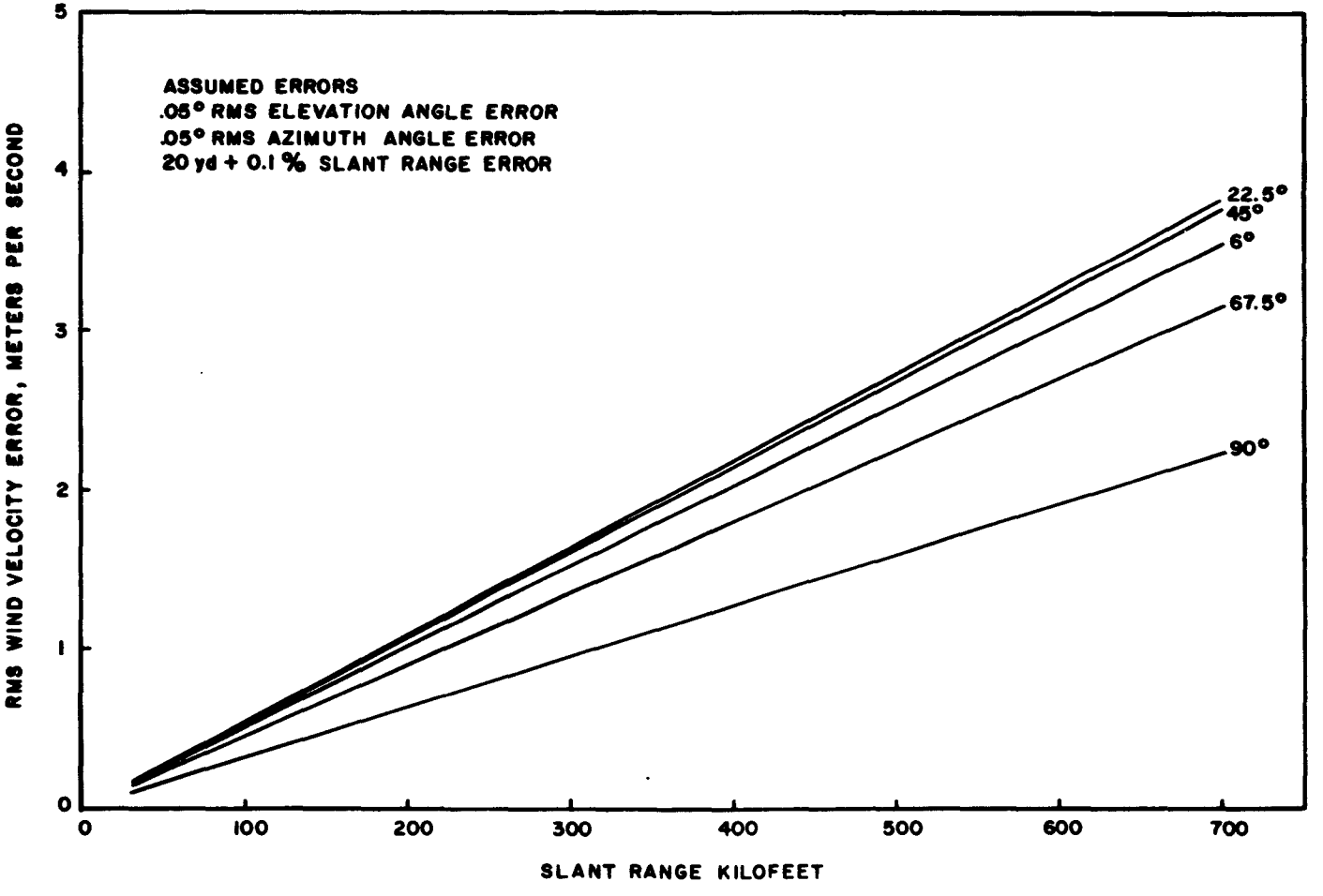

FIGURE 9 RMS WIND ERROR BASED ON EQUATION # 12

4.0 Conclusion

4.1 General Comments.

Some of the general conclusions have been presented previously in Section 1.2.2. Briefly restated, the errors presented in this report reflect the performance of but a single production model, GMD-2, operated by skilled technicians, under very mild wind profiles, at limited slant range and convenient elevation angles. The four tests analyzed do not represent a complete statistical average of the GMD-2 performing under variable, operational conditions. The errors do represent, however, the magnitude of the various errors of the GMD-2, when properly adjusted and operated under typically ideal conditions, as determined from a carefully controlled and properly instrumented field evaluation.

4.1.1 Mean Azimuth Angle Errors. The mean azimuth errors for the four tests indicate rather conclusively that a misalignment error of approximately (-)0.10° existed. This may have been due to an error in setting up the equipment, or, more probably, due to an unnoticed movement of the system after boresighting. In any case, this mean error does not attribute a significant error to the wind determining capabilities of the GMD-2.

4.1.2 RMS Deviation from the Mean Azimuth Angle Errors The rms deviation from the mean azimuth errors generally are greatest at or near the start of the flight, as would be expected. There is no particular correlation in the data presented, however, the trend of the data indicate that the rms S_a for the entire test is slightly beyond the specification limit of .05°.

4.1.3 Mean Elevation Angle Errors. The mean elevation angle errors, E_e, indicate rather conclusively that a system alignment error of approximately +0.13° existed. Although this affects the altitude data, it does not affect the rms wind vector error.

4.1.4 RMS Deviations from Mean Elevation Angle Errors. Except for MITS-5, the rms deviation from the mean elevation angle errors, S_e, are well within the .05° specification limit, with MITS-4, 7, and 8 averaging .036°. The rms data for MITS-5 was outside of the graph, at 0.197°. All phases of the data reduction for MITS-5 were carefully scrutinized in an attempt to account for the large errors existing in the 120,000 to 140,000 feet range increment, however, the error could not be attributed to an analysis error and consequently must be taken as a legitimate, large error. An entry had been made on the raw data to the effect that the AMT-9 sonde used on the test was apparently troublesome after the 25th minute of flight, with the signal-to-noise ratio being poor for the remainder of the test. This accounted for a 6,000 foot shift in the slant range at the 62nd minute, due to complete loss of signal. This error, however, even when corrected, does not account for the large mean error for the test.

4.1.5 Mean Slant Range Errors. For the four tests analyzed, the mean slant range errors taken for each test in its entirety are remarkably low, although there are some wide excursions outside of the specification limits at various points. The low mean error for the entire test is due to the reversal of the error toward

the end of the test. The large error at the 60K to 80K slant range in MITS-8 could not be traced to a source other than the instrument, and must be considered a valid error. The errors start low as to be expected and tend to increase with range.

4.1.6 RMS Deviation from Mean Slant Range Errors. The errors derived indicate that GMD-2 was not meeting the manufacturers specification of 60 feet or 0.1% of range for all tests except MITS-7, which was consistently within these limits. Based on equation 12 and the values of errors for azimuth angle and elevation angle, it can be seen that the slant range errors contribute more to the final wind errors than the other two factors.

4.1.7 RMS Wind Vector Errors. A major objective of this analysis has been to obtain the rms wind vector errors presented in Figure 7. From this data, the average rms wind vector error for the four tests is 0.34 meters/sec., or approximately 0.75 mph. This is acknowledged to be a very low error, and can be attributed to the care with which the equipment was operated, in combination with the mild wind profiles, and the fact that the maximum slant range was in the order of 140 thousand feet. The slant range error increases with the slant range and thus tests with greater ranges would have shown larger wind errors.

4.2 Theoretical RMS Wind Velocity Error. Through the use of Equation 12 a set of wind velocity errors can be plotted as a function of elevation angle and slant range for a given set of as-

sumed rms errors. This computation has been carried out and plotted in Figure 9, for elevation angles from zero through 90°. In this calculation the specification errors were assumed to prevail but the correlation for two minute time delay was assumed to be zero in order to indicate the maximum error for these cases. A sample calculation is shown below.

Assumed Errors:

.05° RMS elevation angle error

.05° RMS azimuth angle error

60 feet +0.1% slant range error

Parameters:

Range: 180,000 feet

Elevation Angle: 22.5°

Correlation Coefficient: 0

Then,

$dr = (60 + 180)\sqrt{2}\sqrt{1-0}$ from Eq. 13

$dr = 240\sqrt{2} = 340$ feet

$de = .05\frac{\pi}{180}\sqrt{2} = 12.35\ 10^{-4}$ radians

$da = de = 12.35\ 10^{-4}$ radians

$$dv = 2.54\times10^{-3}\sqrt{(340)^2 .85 + (12.35\times10^4)^2(1.8\times10^5)^2(\sin^2E+\cos^2E) + 2\times1.8\times10^5\times340\times12.34\times10^{-4}}$$

$$dv = 2.54\times10^{-3}\sqrt{9.82\times10^4 + 4.92\times10^4 + 5.35\times10^4}$$

$dv = 2.54\times10^{-3}\times4.47\times10^2 = 1.13$ meters per sec.

The line representing the maximum errors (elevation of 22.5°) of Figure 9 is plotted on Figure 7 as the dashed line marked A. To show a better approximation line B is also shown. This line is the same as line A but in this case a correlation coefficient of 0.4 was used instead of 0. The correlation coefficient was taken from Figure 8 at a time delay of two minutes.

In as much as the curve B appears to show a fair correlation to the measured velocity errors one can extrapolate that

curve to estimate errors at larger ranges. In this manner we find a maximum rms error 3.15 meters per second at the maximum slant range of 750,000 feet. It must be cautioned that these values are statistical rms values and since these errors appear nearly normally distributed, any individual error can be larger than the rms value. However, the probability is near unity that any individual error will be within three times the rms value.

4.3 Comparison of Results with Previous Studies. The values determined in this analysis for the rms deviation from the mean elevation angle errors, and the rms deviation from the mean slant range errors, have been compared to errors derived from similar tests conducted by the U.S. Weather Bureau for the Upper-Wind Test Project (1958), (Reference 3). In the USWB Project, the GMD-2 data was compared to data obtained from a Decca Windtracking Radar, and a David White Theodolite. Although both the D.W. Theodolite and the Decca Radar are systems of lesser tracking capability than the Askania Phototheodolite employed in the Sandia study, it is interesting to note that the Weather Bureau data and the Sandia data correlate well, for the types of wind profiles measured.

5.0 Recommendations. The recommendations to be offered are based on the assumption that the AN/GMD-2 Rawin Set, since it is an operational instrument, will continue to be field tested and improved. The recommendations therefore, may be considered guidelines for future test programs.

5.1 Data Collection and Processing. A significant number of data analysis errors were uncovered in the Sandia Report, most of these being traceable to transcription errors, and failure to correlate the field notations in the raw data with the data reduction process. It would appear that most of these errors, since they are large and readily noticeable to one familiar with both the field test and the expected results, could be eliminated by employing an individual who could remain associated with the day-to-day details of the test program, for the entire duration of the program. In essence, this individual would serve as a so-called "clerk-of-the-works" whose intimate association with the project would permit him to detect gross errors as they occured, and reorient the data analysis as required. This is not to imply that the individual would attempt to eliminate legitimate errors in the instrumentation system. Unfortunately the chore of scrutinizing large amounts of GMD-2 data is a most tedious and unglamorous one. However, if a true picture of the instrumental errors is to be obtained, gross human errors in the data analysis must be eliminated.

5.2 Design of Tests. The data obtained from closely controlled field tests, such as those conducted by Sandia, are the only means of obtaining the true errors for the various equipment parameters, and for the wind errors in particular. Although plans for additional field tests are underway, in which a high resolution FPS-16 Radar Set will be the standard, care must

be given in designing these tests to produce the most usable amount of data for the least amount of testing. For example, the data obtained in the Sandia MITS Program is of one general type, not reflecting behavior of the GMD-2 at low elevation angles (below 20°) or at slant ranges beyond 140,000 feet. It is recommended that future tests be designed to include elevation angles below 20°, and slant ranges to 750,000 feet, since these conditions are typical and are those in which the performance of the GMD-2 begins to degrade. In addition, it is recommended that additional tests, if they are to reflect any of the variability in the production units of the GMD-2, include data obtained from more than one Rawin Set of the GMD-2 type.

5.3 Data Formats. Many of the errors in the data were attributed to transcription errors, introduced in certain instanced by the transfer of data from one format to another, for reasons of computation and reproduction. As a result, the end data are of a discontinuous format, prone to errors, and in some instances difficult to work with. It is recommended that in future programs, each step in the required analysis procedure be worked out in advance, with an effort toward eliminating needless transcriptions, and providing a uniform format for all results.

6.0 References

1. Salton Sea Meteorological Test Series, Sandia Corporation, Albuquerque, New Mexico, 1961. Available from the Office of Technical Services, Department of Commerce, Washington 25, D.C. (Price $2.75)

2. Handbook of Meteorological Instruments, Part II. Published by Her Majesty's Stationery Office, London.

3. Report on Upper-Wind Test Project, Washington, D.C. 1958. (Prepared by U.S. Weather Bureau.)

APPENDIX

SANDIA REPORT ERRATA

The following transcriptional and arithmetic errors were uncovered in the Sandia Report during the analysis carried out under this contract:

Test Number	Minute	Error and Correction
MITS-8	35	GMD-2 Elevation Angle is recorded in Sandia Report as 31.99°. Correct value is 30.99°.
MITS-5	62 through 67	GMD-2 Slant range values are 6,000 feet too short. Add 6,000 feet to all range data.
MITS-7	47	GMD-2 Azimuth Angle is recorded in Sandia Report as 81.27. Correct value is 80.97°.
MITS-8	32	Slant range is recorded in Sandia Report as 67035 ft. Correct value is 67800 ft.
	34	Same, 73,485 should be corrected to 73,785 feet.

AD Accession No. _____

Cambridge Systems, Incorporated
50 Hunt Street
Newton 58, Mass.
AN GMD-2 WIND ERRORS from Salton-Sea Tests
by D. P. Keily and D. J. Beaubien
FINAL REPORT, April 1963, 32 pages inclusive.
Illustrations and Tables, Contract No. AF 19(628)-1686.

The results of the Salton Sea Meteorological Instrumentation Test Series (MITS) are analyzed and extended to include root mean square errors in the wind speed, range, elevation and azimuth angles, as measured by the AN GMD-2 Rawin Set, for a series of representative flights. Criteria are presented as guidelines for conducting additional field tests in order that such tests will generate sufficient data to permit the determination of rms wind errors to a higher degree of confidence and accuracy than that which is currently attainable. An effort is made to categorize the wind errors derived, on the basis of established errors in the altitude, slant range, azimuth and elevation angles.

UNCLASSIFIED

1. Rawin Set, AN/GMD-2 Wind Errors
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