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RANGE AND GUIDANCE ACCURACY CAPABILITY OF THE ATLAS MISSILE SYSTEM (U)

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FLIGHT PERFORMANCE AND GUIDANCE ANALYSIS

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FOREWORD

An estimate of the accuracy of the two guidance systems used by the Atlas missile system is presented in this report. An approximate indication of the size of the payload that can be delivered to ranges from 4700 n. miles to 8700 n. miles is also given.

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SUMMARY

This report has attempted to answer two questions; first, the range to which various size payloads can be sent and second, the accuracy to which these payloads can be delivered by the guidance systems now available.

A typical D series missile configuration was selected for the purposes of this study. A nominal launch weight of 265,190 lbs. was used and the Rocketdyne MA-2 engines were assumed to produce nominal thrust and specific impulse. The missile that was simulated was launched due north from Vandenberg AFB. The accuracies of two different guidance systems, the G.E. Mod. III radio-inertial and the ARMA Lot IV all-inertial, have been studied and the results included in the text of this report.

Four burnout weights were used to establish the ranges at which the guidance system accuracies were determined. These trajectories were flown with a constant missile inertial attitude of 23.4° during sustainer stage. The following table summarizes these results.

Burnout Weight	Payload	Range (Approx.)	C.E.P.	
			G. E. Mod III System	ARMA System
lbs	lbs	n. miles	n. miles	n. miles
13,642	6000	4750	.61	1.08
12,642	5000	5500	.44	1.25
11,142	3500	6900	1.05	1.57
9,642	2000	8700	2.63	1.97

It was found that the C.E.P.'s could be made smaller by pitching the missile during sustainer stage. The payloads associated with the minimum error trajectories were changed to allow the same range to be reached. These results are listed in the following table. It is obvious from the table that the decrease in error results in lower payload capability.

Range (Approx.)	Payload, lbs		C.E.P., n. miles	
	G.E. Mod III	ARMA	G.E. Mod III	ARMA
4750	5325	5700	.34	1.03
5500	4850	4550	.43	1.20
6900	3600	3000	1.03	1.51
8700	1150	1500	2.23	1.86

It was also found that the maximum payload that can be sent to the 6900 and 8700 n. mile ranges were 3800 and 3000 lbs. As shown in the following table, this is at the expense of an increase in the C.E.P.. The location of the rate antenna would have to be changed if the G.E. System were used. The look angle requirements are not satisfied in the maximum payload trajectories.

Range (Approx.)	Payload	C.E.P., n. miles	
n. miles	lbs	G.E. Mod III	ARMA
6900	3800	0.85	2.55
8700	3000	3.87	3.70

The values of the C.E.P.'s given in this report will be optimistic due to omission of various sources of impact dispersions for which the guidance system cannot predict or correct. The dispersions caused by the effects of geophysical, atmospheric re-entry, and cutoff uncertainties will be of the order of 0.5 n. miles; so the cases which indicate a guidance system C.E.P. of this magnitude will be affected significantly.

INTRODUCTION

This report deals with the range capability of the D series missile for various payloads and the guidance accuracies of both the radio-inertial (RIG) and all-inertial (AIG) guidance systems. The ranges considered were 4750 n. miles, 5500 n. miles, 6900 n. miles, and 8700 n. miles. Although the range capability may change for later series missiles due to changes or design improvements, (i.e., such as the change to MA-3 engines), the guidance error partials at the ranges considered in this study should not be affected greatly.

All of the cases presented herein use the same missile configuration; the only variables are the sustainer and vernier burnout weights and the second stage tilt program. The data for the report was obtained by using a missile trajectory simulation, as described in detail in Reference 1, and radio-inertial and inertial guidance error programs.

Two different guidance systems have been considered, the General Electric Mod. III radio-inertial and the ARMA all-inertial systems. Errors in these systems lead to target misses, the size of the miss being dependent upon the magnitude of the error, the trajectory, and the distance to the target. The errors used to obtain the misses are the 1 σ values as quoted by G.E. and ARMA. The target errors can be minimized by pitching during sustainer stage, as is shown later in the report. Target misses also result from sources other than the guidance system but these errors have not been considered in this report (e.g., re-entry winds, geophysical uncertainties, vernier cutoff errors, and atmospheric density variations).

DISCUSSION

Basic Trajectory Information

The trajectories simulated for this report are those of a nominal D series missile launched due north from Vandenberg AFB. Every trajectory was based on a missile launch weight of 265,190 lbs., a booster jettison weight of 7,197 lbs., nominal thrust and specific impulse (i.e., booster and sustainer engines specific impulses were 251 seconds and 219.3 seconds), and a staging time of 135 seconds. In addition, the D series tilt program was attenuated by a factor of 0.97. The tracker simulated for the radio-inertial guidance (hereafter referred to as RIG) portion of the error study was for the G.E. Mod. III guidance system with the "q" baseline oriented directly downrange and the "p" crossrange.

Four trajectories were flown to establish the ranges at which the error studies were made. These four trajectories were simulated with a constant missile inertial attitude of 23.4° during sustainer stage. The only differences between the trajectories were the sustainer burnout weights, which were taken to be 13,642 lbs., 12,642 lbs., 11,142 lbs., and 9,642 lbs. These burnout weights apply to a D-R&D vehicle and correspond approximately to payloads of 6000 lbs., 5000 lbs., 3500 lbs., and 2000 lbs., respectively. A D-IOC missile is capable of carrying about 1100 lbs. more payload for comparable sustainer burnout weights.

An oblate (Clarke's spheroid of 1866), rotating earth model was assumed in the simulation. The ICAO standard atmosphere was used during both powered flight and nose cone re-entry. To conserve computer time, a spherical earth and vacuum re-entry were assumed in finding the error partials. These approximations will cause little change in the partials since the errors are relative quantities.

Varying Attitude Trajectories

In addition to the four constant attitude cases, trajectories were simulated which included pitch rates during sustainer stage. This was done in an effort to minimize the target miss due to errors in the guidance systems. Trajectories that were flown to minimize the misses for the RIG system had a constant tilt rate throughout sustainer stage. Runs for the all-inertial guidance (hereafter referred to as AIG) system had a rapid tilt at the start of sustainer stage with a constant attitude thereafter. A rapid tilt rate was used in order to simulate the ARMA system. The missile is pitched in accordance with the function:

$$\omega_\eta = 0.2\,(\epsilon - \epsilon_o)$$

The tilt rate in deg./sec. is denoted by ω_η; ϵ is the missile attitude (i.e., angle between missile roll axis and launch horizontal) at the initiation of guidance; and ϵ_o is the desired missile attitude. ϵ and ϵ_o have the units of degrees in this equation.

Powered flight for all of these runs was terminated when the missile had attained the velocity necessary to hit the previously established impact point. This enabled the error study to be made at the same four ranges. The tilt rates in sustainer stage will cause the size of the payload that can be delivered to a given range to be different than that for the constant attitude case. The amount of change is discussed in the results.

The RIG System Errors

The RIG System can be considered to be composed of two subsystems, one ground-based and the other airborne. Included in the ground-based equipment is a tracker which measures the position and velocity of the missile in terms of six quantities: slant range (R), elevation angle (γ), azimuth angle (A), slant range rate ($\dot{R}$), and two lateral rate quantities ($\dot{P}$ and $\dot{Q}$). For this study, the system error is considered to be due solely to bias errors in the tracking quantities. The tracker bias errors used in this report were obtained from Reference 3 and are listed in Table IV. They were the latest available 1σ values for the G.E. Mod. III System when the computations of the target miss presented herein were made.* These errors were assumed to be the same for the various trajectories simulated. The slant range error given in the table is in kilofeet rather than feet. This was done to prevent the values of the partials from becoming too unwieldy.

The RIG System imposes a constraint on the trajectory that is not present for vehicles that are flown with no guidance or with the AIG System. The tracker must receive good rate data during the latter part of sustainer stage if sustainer shutdown is to occur at the proper instant. To insure that good data are being obtained, the radar cone angle θ_L (i.e., the angle between the line of sight from the tracker to the missile and the longitudinal axis of the vehicle) must be greater than 2° for the last 30 seconds of sustainer stage. In addition, the tracking antenna must view the top of the missile during this period since the rate antenna is located on the top.

Because of the look angle constraint, the missile cannot be pitched down at too fast a rate if lock is to be maintained. For the configuration in this study the maximum rate was approximately +.02°/sec. The data pertaining to the larger rates would be applicable if the antenna were moved to a location on the bottom of the missile.

The AIG System Errors

The AIG System is composed of an airborne computer and an inertially stabilized platform upon which three accelerometers are placed. The accelerometers are

* The latest G.E. estimates of the tracking errors are given in Reference 5 and indicate the R.M.S. of the bias and residual noise errors to be of the same order of magnitude as the bias errors used in this report.

mounted so as to form an orthogonal coordinate system, the axes being designated by x, y, and z. The platform and accelerometers are oriented prior to launch by ground-based alignment equipment. The x-axis is oriented downrange toward the target and the y-axis is directed in a crossrange direction. The z-axis is aligned along the plumb bob vertical to form a right-handed system. The accelerometers are used to sense the thrust and aerodynamic accelerations in the three orthogonal directions. The measured accelerations are fed to the airborne computer which computes the gravity accelerations, sums the measured and computed accelerations, and then integrates to obtain position and velocity. The position and velocity are used to determine the time of sustainer and vernier cutoff and to generate the yaw steering signals.

According to Reference 4, there are five general sources of error in the AIG system; the gyros, accelerometers, platform, computer, and ground support equipment. In this study, none of the sources of error in the computer were considered but their omission should not affect the system C.E.P. to any sizable degree. It can be seen in Reference 4 that the computer errors are the least significant of any of the five.

Most of the major contributors to the error in the remaining four parts of the system have been considered. Since all effects could not be considered, the results of the study will give an optimistic value of accuracy and should not be expected to give the best possible estimate for the entire system. It does indicate the manner in which the major errors change with sustainer attitude and with trajectory range and is valuable in this respect.

There are a number of causes of error in each of the above sources that are considered. The following paragraphs give a brief description of the causes. For a more complete discussion, see Reference 4.

If the gyros which align the platform drift for any reason, the orientation of the platform and accelerometers will be changed and errors will result in the measurement of acceleration. There are, in general, three types of drifts that could occur: constant drifts, drifts that are proportional to the acceleration, and drifts that are proportional to the square of acceleration. A fixed drift of 0.1°/hr. (which represents the drift remaining after compensation) was assumed for each gyro.

The spin axis of the pitch gyro lies in the plane of the x and z platform axes and was offset from the x axis by 54° in this study. The offset minimizes the downrange errors resulting from the behavior of the thrust acceleration. On Page 16 of Reference 4 there is a brief discussion of the offset and the error involved in the offset.

A mass unbalance drift of .36°/hr/g due to an unbalance along the outer wire axis of the pitch gyro was considered for the pitch gyro mass unbalance error. If the compromise offset angle for the trajectories were optimum, little or no miss would result from this unbalance so the error is actually a combination of the two effects. The mass unbalance error for the roll-azimuth gyro was attributed to an unbalance along the spin axis of the ball. The characteristics of two, single degree of freedom gyros, one for roll and the other for yaw, were used to obtain the partials and the results are given in that form. When these results are applied to the two degree of freedom gyro used in the ARMA system, only one change has to be made. The crossrange errors for the two gyros is such that the roll gyro error partially cancels that of the yaw gyro. In the results this effect has been taken into account and the errors have been combined. The effect of a gimbal mass unbalance along the spin axis of the gyro has also been studied. It was assumed to have an effect equivalent to that for a roll gyro spin axis mass unbalance drift. No temperature sensitive mass unbalance drifts have been included.

An error of 0.15°/hr/g was used in calculating the miss distance due to the mass unbalance along the spin axis of the roll-azimuth gyro. This value represents two errors listed in Reference 4. The value given in the gyro data in Reference 4 (Table 3) has been combined with the roll-azimuth gyro drift compensation uncertainty that is quoted among other ground support equipment errors in Table 10 of that report. A figure of 0.15°/hr/g has also been used for the gimbal mass unbalance and corresponds to the value given in Table 3. Note that all values used in the target miss computations are based on the ARMA Lot IV system.

Accelerometer errors consist of a bias or zero error, a g sensitive or scale factor error, and g^2 and g^3 sensitive errors. The value of uncertainty in the setting of the accelerometer zero that was used is the R.S.S. sum of three terms; the linearity, the measurement uncertainty, and the x and z offset resolutions. The latter two are included in the GSE section (Table 10) of Reference 4.

Two errors have been combined to give the value used for the scale factor effect, the uncertainty due to linearity and the measurement uncertainty (a GSE error). Inclusion of the latter is not entirely correct since the miss partial for it should be slightly different. With present capability no differentiation could be made between the two; so, rather than omit it completely, it has been added in this manner.

The values used for the K_2 and K_3 effects are the same as given in Reference 4 for the K_2 acceleration and the K_3 uncertainty errors.

Accelerometer misalignment errors are the only platform errors considered. Two types of misalignments are possible; a perfectly aligned pair of accelerometers (i.e., exactly at right angles to each other) may not be perfectly aligned with the pendulum, or a pair of axes may not be orthogonal to one another. The non orthogonal alignments considered are the z-axis in pitch, the y-axis in azimuth and roll, and the x-axis in pitch. The x-axis could be misaligned in azimuth and the z-axis in roll but this would only result in a cosine effect and is negligible.

Misalignments of a pair of axes in pitch, yaw, and roll have been studied. Values of errors in this section are the R.S.S. values of similar errors in both Tables 7 and 10 of Reference 4. No servo errors were included in the study.

It has been mentioned in preceding paragraphs that the system accuracy quoted in the results will be somewhat optimistic due to omission of certain errors. The C.E.P. quoted in Reference 4 for the Lot IV system was 1.46 n. miles. When calculated using the values given in that report for all the effects that have been considered for this study, the C.E.P. was found to be 1.21 n. miles. This comparison gives some indication of the amount the results of this study could be in error.

Guidance Error Programs

Two digital computer programs, which were developed specifically to simulate the errors that can appear in the two types of guidance systems, were used to find the error partials. The program used to obtain the RIG errors alters the position or velocity vector at vernier cutoff in such a manner as to duplicate the amount by which the particular tracker quantity under study is supposed to be in error. The impact point obtained using the altered vector is then compared with the reference impact location to obtain the target miss and error partial.

The AIG error program uses as input the powered flight time history of acceleration and inertial attitude of the missile as obtained from the reference trajectory, and alters these quantities in the way the various error sources would be expected to affect them. The altered position and velocity at vernier cutoff are then used to obtain an impact location, which, when compared with the reference impact, yields the target miss and error partial.

RESULTS

Range and Payload Capabilities

The maximum range of a missile carrying a payload of 6000 lbs., 5000 lbs., 3500 lbs., or 2000 lbs. was found to be 4766 n. miles, 5478 n. miles, 6889 n. miles, or 8724 n. miles respectively for missile trajectories in which a constant missile inertial attitude of 23.4^{o} was maintained during sustainer stage. The RIG and AIG error studies were made at these ranges although, for the sake of brevity, the ranges are referred to as 4750 n. miles, 5500 n. miles, 6900 n. miles, and 8700 n. miles.

In Figure 1(a) the payload of the missile is plotted against range for various sustainer stage tilt rates. The role of range and tilt rate is reversed in Figure 1(b). The negative tilt rates that are shown refer to a pitch up maneuver, whereas the positive tilt rates indicate a pitch down. Similar plots of payload, range, and missile inertial attitude can be found in Figure 2(a) and 2(b). It can be seen from these plots that the lower trajectories increase the payload capability at the longer ranges.

RIG Error Study

A summary of the C.E.P.'s obtained for each of the trajectories in the RIG portion of the study can be found in Table I. A plot of these data is given in Figure 3. The C.E.P.'s were computed in the manner described in Reference 4. A plot from the reference has been reproduced and is included as Figure 14.

Reference to Figures 5 and 6, which are plots of downrange and crossrange miss, shows that the shape of the C.E.P. curves is due primarily to the behavior of the downrange misses. The dominant effect in the downrange miss is the Q tracking error, as can be seen by looking at Table IV or Figure 7, and is directly responsible for the manner in which the system C.E.P. and downrange miss behaves at the different ranges.

Table IV and Figures 7 and 8 contain the values of downrange and crossrange miss that result from the assumed tracking errors for each of the ranges included in the study. The numbers in the tables and graphs represent the absolute value of the miss. The downrange miss due to the Q errors can be seen to reach a sharp minimum at the two shorter ranges. This minimum represents the point where the miss becomes zero and indicates a change in sign of the miss.

Tracking errors in Q are reflected as errors in the flight path angle γ and missile velocity V_m. For some trajectories the misses due to changes in these two quantities are additive, for others they are subtractive. This is the reason the misses go through zero and the slope of the plots varies from range to range. Figure 15 has been included to give a pictorial idea of the manner in which the miss due to Q errors varies with range and tilt rate.

Tracking errors in P are the major source of crossrange miss at the 4750 n. mile and 5500 n. mile ranges. At the two longer ranges the Q errors become very important contributors to this miss. The crossrange miss due to Q errors can be attributed to earth rotation effects. The situation has been exaggerated somewhat due to the fact the trajectory impact locations vary from 65° N latitude for the 4750 n. mile case to 3° S latitude for the 8700 n. mile case.

AIG Error Study

The C.E.P.'s obtained for each of the trajectories in the AIG portion of the study are summarized in Table II and plotted in Figure 4. It is interesting to note that the case with an inertial attitude of 23.-° and range of 5500 n. miles (i.e., the case that corresponds most closely to the one in Reference 4) yields a C.E.P. of 1.25 n. miles. It was pointed out in the discussion earlier in this report that a C.E.P. of 1.21 n. miles was obtained from the ARMA data when only the errors included in this study were considered. The results indicate the system C.E.P. to be relatively insensitive to the inertial attitude in the region from $\epsilon = 20°$ to $\epsilon = 30°$. The optimum attitude for missiles using the AIG system would appear to be dependent on the payload or range capability of the missile for the various attitudes in this range of magnitude.

Table V lists the total R.S.S. value of downrange and crossrange miss for the AIG trajectories. These values have been plotted and are included as Figures 9 and 10. The graphs show the results to be consistent except for the crossrange miss for the 8700 n. mile case. The increase in the miss at the low attitude angles for this case can be seen to be due to errors in the accelerometer. Section 4(b) of Table VI or Figure 12(d) verifies this. As was true with the Q error in the RIG portion of the study, the increase is the result of earth rotation effects.

Figures 11 and 12 are plots of target miss against missile inertial attitude for each error source and each range. It can be seen that the largest source of downrange error can be attributed to the accelerometers. Gyro errors yield the smallest misses at 4750 and 5500 n. miles but become a more important contributor with increasing range.

The system target miss was found to increase as the trajectories became lower. Therefore, the size of the payload that can be delivered to a target, particularly those at ranges of over 6000 n. miles, will be limited by the guidance accuracy that is required.

The results obtained from examination of a number of errors have been omitted from this report. This was done because the miss from these errors was insignificant and could be neglected. Such items as gyro anisoelastic effects, y-accelerometer scale factor, g^2, and g^3 effects, and x and z accelerometer misalignment in roll are examples of errors that have been omitted.

Among the figures found in the latter part of the report are plots relating tilt rate and inertial attitude to the flight path angle at power cutoff. These plots are denoted as Figures 13(a) and 13(b).

Comparison of RIG and AIG Systems

The constant attitude trajectories that were used for the RIG error study correspond exactly to the AIG trajectories in which a missile attitude of 23.4° was maintained. Comparison of the C.E.P.'s for these cases shows that the RIG system gives the smallest values, except at the extreme range of 8700 n. miles. The following table gives a concise summary of these results.

Range	C.E.P.	
	RIG System	AIG System
4750	.61	1.08
5500	.44	1.25
6900	1.05	1.57
8700	2.63	1.97

When the RIG system errors were minimized, it was found that little improvement could be obtained for the 4750 and 5500 n. mile cases. A tilt rate of +.1°/sec. was found to decrease the error at 6900 n. miles to .89 n. miles, an improvement of .16 n. miles. Unfortunately, the look angle requirements were not met for any trajectory that was pitched at a rate greater than .02°/sec.; so the location of the rate antenna would have to be changed from the top to the bottom of the missile if this trajectory were to be flown. The C.E.P. can be reduced to 1.03 n. miles by pitching the missile at the rate of +0.02°/sec., but this represents a negligible improvement. The smallest error that can be achieved at the 8700 n. mile range is heavily dependent upon the size of the payload that could be flown. If a 1100 lb. payload were available for use with the Atlas, the error could be reduced to 2.23 n. miles by pitching at -0.05°/sec. The lightest nose cone now being used weighs approximately 2100 lbs.

The AIG system errors could not be improved very much at the shorter ranges either. They could be decreased slightly at the longer ranges by flying at an attitude of $\epsilon_0 \approx 28°$. This would result in a loss of 500 lbs. in the payload that could be delivered to a target 8700 n. miles from the launch site and would only improve the guidance accuracy by .1 n. mile. By decreasing the accuracy to that obtained for the constant attitude trajectory in the RIG study, the payload could be increased to approximately 2375 lbs. from 2000 lbs.

[redacted]

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[redacted]

TABLE I

C.E.P. FOR RADIO-INERTIAL GUIDANCE SYSTEM

RANGE NAUTICAL MILES	TILT RATE DEG/SEC	C.E.P. NAUTICAL MILES
4750	-0.10	0.34
4750	-0.05	0.43
4750	0.00	0.61
4750	+0.05	0.91
4750	+0.10	1.45
5500	-0.10	0.55
5500	-0.05	0.43
5500	0.00	0.44
5500	+0.05	0.64
5500	+0.10	1.10
6900	-0.10	1.11
6900	-0.05	1.09
6900	0.00	1.05
6900	-0.05	0.98
6900	+0.10	0.39
8700	-0.10	1.91
8700	-0.05	2.23
8700	0.00	2.63
8700	+0.05	3.08
8700	+0.10	3.89

TABLE II

C.E.P. FOR ALL-INERTIAL GUIDANCE SYSTEM

RANGE NAUTICAL MILES	ATTITUDE DEGREES	C.E.P. NAUTICAL MILES
4750	31.1	1.03
4750	23.4	1.08
4750	15.8	1.19
5500	31.1	1.20
5500	23.4	1.25
5500	15.8	1.41
6900	31.1	1.51
6900	23.4	1.57
6900	15.8	1.83
6900	9.9	2.27
8700	31.1	1.91
8700	23.4	1.97
8700	15.8	2.37
8700	8.0	3.23

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TABLE III

TOTAL R.S.S. MISS FOR 1σ ERRORS

IN RADIO-INERTIAL GUIDANCE SYSTEM

RANGE	TILT RATE	TARGET MISS	
		DOWNRANGE	CROSSRANGE
N. MILES	DEG/SEC	N.MILES	N.MILES
4750	-0.10	0.16	0.44
4750	-0.05	0.31	0.42
4750	0.00	0.64	0.41
4750	+0.05	1.17	0.40
4750	+0.10	2.03	0.40
5500	-0.10	0.46	0.47
5500	-0.05	0.29	0.45
5500	0.00	0.31	0.44
5500	+0.05	0.67	0.43
5500	+0.10	1.47	0.42
6900	-0.10	1.40	0.53
6900	-0.05	1.39	0.49
6900	0.00	1.35	0.47
6900	+0.05	1.23	0.46
6900	+0.10	1.09	0.45
8700	-0.10	2.60	0.74
8700	-0.05	3.11	0.65
8700	0.00	3.76	0.56
8700	+0.05	4.47	0.51
8700	+0.10	5.66	0.48

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TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 1 - RANGE OF 4750 NAUTICAL MILES

PART A - MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR					CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR				
	SUSTAINER TILT RATE , DEG/SEC					SUSTAINER TILT RATE , DEG/SEC				
	-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.436	0.505	0.570	0.632	0.706	0.008	0.005	0.003	0.000	[illegible]
ELEVATION ANGLE (γ)	1.765	3.450	5.993	8.879	14.007	0.393	0.403	0.431	0.440	0.475
AZIMUTH ANGLE (A)	0.959	1.009	1.056	1.160	1.291	3.350	3.312	3.278	3.265	3.254
RANGE RATE ($\dot{R}$)	0.713	0.783	0.855	0.980	1.150	0.000	0.001	0.001	0.001	0.001
LATERAL RATES ($\dot{P}$)	69.31	72.95	84.71	85.25	97.37	266.9	255.9	246.1	239.7	234.7
($\dot{Q}$)	14.7	151.8	373.3	719.3	1287.	66.65	65.87	67.34	68.32	73.00

TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 1 - RANGE OF 4750 NAUTICAL MILES

PART B - TARGET MISSES

ERROR SOURCE	1 SIGMA ERRORS	DOWNRANGE TARGET MISSES NAUTICAL MILES					CROSSRANGE TARGET MISSES NAUTICAL MILES				
		SUST. TILT RATE, DEG/SEC					SUST. TILT RATE, DEG/SEC				
		-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.020 KILOFEET	.01	.01	.01	.01	.01	.00	.00	.00	.00	.00
ELEVATION ANGLE (γ)	4.37×10^{-2} M.RAD.	.08	.15	.26	.39	.61	.02	.02	.02	.02	.02
AZIMUTH ANGLE (A)	4.37×10^{-2} M.RAD.	.04	.04	.05	.05	.06	.15	.15	.14	.14	.14
RANGE RATE ($\dot{R}$)	0.1 FT/SEC	.07	.08	.09	.10	.12	.00	.00	.00	.00	.00
LATERAL RATES ($\dot{P}$)	0.0015 FT/SEC	.10	.11	.13	.13	.15	.40	.38	.37	.36	.35
($\dot{Q}$)	0.0015 FT/SEC	.02	.23	.56	1.08	1.93	.10	.10	.10	.10	.11

TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 2 – RANGE OF 5500 NAUTICAL MILES

PART A – MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR — SUSTAINER TILT RATE, DEG/SEC					CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR — SUSTAINER TILT RATE, DEG/SEC				
	-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.410	0.511	0.611	0.711	0.832	0.016	0.010	0.005	0.002	0.002
ELEVATION ANGLE (Ψ)	0.653	2.362	4.981	7.968	13.388	0.555	0.554	0.581	0.590	0.622
AZIMUTH ANGLE (A)	1.193	1.262	1.348	1.499	1.703	3.406	3.363	3.328	3.310	3.298
RANGE RATE ($\dot{R}$)	0.809	0.903	1.009	1.179	1.410	0.000	0.001	0.001	0.001	0.002
LATERAL RATES ($\dot{P}$)	86.0	90.1	106.7	108.6	125.0	277.9	265.9	258.1	250.9	244.3
($\dot{Q}$)	285.5	140.4	62.2	355.0	883.7	101.7	96.2	97.7	96.3	99.2

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SAN DIEGO, CALIFORNIA

TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 2 - RANGE OF 5500 NAUTICAL MILES

PART B - TARGET MISSES

ERROR SOURCE	1 SIGMA ERRORS	DOWNRANGE TARGET MISSES NAUTICAL MILES					CROSSRANGE TARGET MISSES NAUTICAL MILES				
		SUST. TILT RATE,DEG/SEC					SUST. TILT RATE,DEG/SEC				
		-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.020 KILOFEET	.01	.01	.01	.01	.02	.00	.00	.00	.00	.00
ELEVATION ANGLE (Ψ)	4.37×10^{-2} M.RAD.	.03	.10	.22	.35	.59	.02	.02	.03	.03	.03
AZIMUTH ANGLE (A)	4.37×10^{-2} M.RAD.	.05	.06	.06	.07	.07	.15	.15	.15	.15	.14
RANGE RATE ($\dot{R}$)	0.1 FT/SEC	.08	.09	.10	.12	.14	.00	.00	.00	.00	.00
LATERAL RATE ($\dot{P}$)	0.0015 FT/SEC	.13	.14	.16	.16	.19	.42	.40	.39	.38	.37
($\dot{Q}$)	0.0015 FT/SEC	.43	.21	.09	.53	1.33	.15	.14	.14	.14	.15

TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 3 - RANGE OF 6900 NAUTICAL MILES

PART A - MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR					CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR				
	SUSTAINER TILT RATE , DEG/SEC					SUSTAINER TILT RATE , DEG/SEC				
	-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.301	0.469	0.648	0.834	1.089	0.040	0.023	0.012	0.005	0.000
ELEVATION ANGLE (Y)	1.964	0.623	1.574	4.036	8.613	1.034	0.977	0.974	0.955	0.990
AZIMUTH ANGLE (A)	1.589	1.696	1.874	2.129	2.557	3.058	3.008	2.978	2.959	2.936
RANGE RATE $(\dot{R})$	0.948	1.096	1.271	1.530	1.918	0.000	0.001	0.002	0.003	0.003
LATERAL RATES $(\dot{P})$	113.9	120.0	145.2	148.7	179.4	263.1	252.6	247.4	237.1	231.8
$(\dot{Q})$	918.3	913.5	881.3	791.3	641.3	213.9	188.5	174.0	166.6	167.6

SECRET

TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 3 - RANGE OF 6900 NAUTICAL MILES

PART B - TARGET MISSES

ERROR SOURCE	1 SIGMA ERRORS	DOWNRANGE TARGET MISSES NAUTICAL MILES					CROSSRANGE TARGET MISSES NAUTICAL MILES				
		SUST. TILT RATE,DEG/SEC					SUST. TILT RATE,DEG/SEC				
		-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.020 KILOFEET	.01	.01	.01	.02	.02	.00	.00	.00	.00	.00
ELEVATION ANGLE (Ψ)	4.37×10^{-2} M.RAD.	.09	.03	.07	.18	.38	.05	.04	.04	.04	.04
AZIMUTH ANGLE (A)	4.37×10^{-2} M.RAD.	.07	.07	.08	.09	.11	.13	.13	.13	.13	.13
RANGE RATE ($\dot{R}$)	0.1 FT/SEC	.10	.11	.13	.15	.19	.00	.00	.00	.00	.00
LATERAL RATE ($\dot{P}$)	0.0015 FT/SEC	.17	.18	.22	.22	.27	.40	.38	.37	.36	.35
($\dot{Q}$)	0.0015 FT/SEC	1.38	1.37	1.32	1.19	.96	.32	.28	.26	.25	.25

SECRET

TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 4 – RANGE OF 8700 NAUTICAL MILES

PART A – MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR					CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR				
	SUSTAINER TILT RATE , DEG/SEC					SUSTAINER TILT RATE , DEG/SEC				
	-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.076	0.314	0.600	0.907	1.363	0.140	0.056	0.050	0.010	0.000
ELEVATION ANGLE (Ψ)	5.448	5.314	4.874	4.669	3.973	2.136	1.843	1.670	1.549	1.523
AZIMUTH ANGLE (A)	1.961	2.073	2.243	2.685	3.445	1.548	1.673	1.693	1.667	1.647
RANGE RATE ($\dot{R}$)	1.001	1.203	1.466	1.835	2.410	0.006	0.004	0.004	0.005	0.005
LATERAL RATE ($\dot{R}$)	148.3	145.9	163.7	180.7	229.3	159.4	164.7	167.3	156.8	152.3
($\dot{Q}$)	1715.	2061.	2497.	2936.	3770.	461.7	396.5	332.6	291.5	273.0

TABLE IV

SUMMARY OF RADIO INERTIAL ERROR STUDY

SECTION 4 - RANGE OF 8700 NAUTICAL MILES

PART B - TARGET MISSES

ERROR SOURCE	1 SIGMA ERRORS	DOWNRANGE TARGET MISSES NAUTICAL MILES					CROSSRANGE TARGET MISSES NAUTICAL MILES				
		SUST. TILT RATE,DEG/SEC					SUST. TILT RATE,DEG/SEC				
		-.10	-.05	0.00	+.05	+.10	-.10	-.05	0.00	+.05	+.10
SLANT RANGE (R)	0.020 KILOFEET	.00	.00	.01	.02	.03	.00	.00	.00	.00	.00
ELEVATION ANGLE (ψ)	4.37×10^{-2} M.RAD.	.24	.23	.21	.20	.17	.09	.08	.07	.07	.07
AZIMUTH ANGLE (A)	4.37×10^{-2} M.RAD.	.09	.09	.10	.12	.15	.07	.07	.07	.07	.07
RANGE RATE ($\dot{R}$)	0.1 FT/SEC	.10	.12	.15	.18	.24	.00	.00	.00	.00	.00
LATERAL RATE ($\dot{P}$)	0.0015 FT/SEC	.22	.22	.25	.27	.34	.24	.25	.25	.24	.23
($\dot{Q}$)	0.0015 FT/SEC	2.57	3.09	3.75	4.45	5.66	.69	.60	.50	.44	.41

TABLE V

TOTAL R.S.S. MISS FOR 1σ ERRORS
IN ALL-INERTIAL GUIDANCE SYSTEM

RANGE	ATTITUDE	TARGET MISS	
		DOWNRANGE	CROSSRANGE
N. MILES	DEGREES	N. MILES	N. MILES
4750	31.1	1.03	0.73
4750	23.4	1.20	0.68
4750	15.8	1.45	0.63
5500	31.1	1.32	0.75
5500	23.4	1.48	0.70
5500	15.8	1.80	0.66
6900	31.1	1.90	0.73
6900	23.4	2.07	0.64
6900	15.8	2.52	0.60
6900	9.9	3.21	0.58
8700	31.1	2.72	0.45
8700	23.4	2.83	0.40
8700	15.8	3.43	0.39
8700	8.0	4.70	0.48

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 1 - RANGE OF 4750 N. MILES

PART A - MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR			CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR		
	SUSTAINER ATTITUDE , DEG.			SUSTAINER ATTITUDE , DEG.		
	31.1	23.4	15.8	31.1	23.4	15.8
GYRO=						
PITCH DRIFT						
A) CONSTANT	2.220	0.600	2.680	0.050	0.040	0.030
B) MASS UNBAL.	0.654	0.511	0.729	0.014	0.011	0.008
YAW DRIFT						
A) CONSTANT	0.770	1.010	1.050	2.990	3.070	3.030
B) MASS UNBAL.	1.200	1.500	1.517	1.789	1.972	2.350
ROLL DRIFT						
A) CONSTANT	0.470	0.500	0.420	1.890	1.520	1.130
B) MASS UNBAL						
BALL	0.778	0.844	0.639		SEE NOTE	
GIMBAL	0.778	0.844	0.639	3.200	2.578	1.856

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

ACCELEROMETER=

ZERO

A) X-AXIS	218.0	268.3	303.7	2.3	3.3	1.7
B) Y-AXIS	10.3	15.0	17.0	49.0	51.3	45.7
C) Z-AXIS	114.7	148.7	176.3	0.7	1.0	0.0

SCALE FACTOR

A) X-AXIS	456.4	582.1	678.6	5.0	6.4	3.6
B) Z-AXIS	183.6	202.1	230.0	1.1	1.4	0.0

SECOND DEGREE

A) X AXIS	1437.5	1765.0	2262.5	15.0	20.0	17.5
B) Z AXIS	437.7	470.2	522.0	5.1	4.9	2.7

THIRD DEGREE

A) X AXIS	5178.0	6777.1	8532.0	156.2	178.0	66.8
B) Z AXIS	760.1	819.9	910.2	0.0	0.0	0.0

PLATFORM=

NONORTHOGONAL

A) Z AXIS-PITCH	.0352	.0448	.0578	.0002	.0003	.0001
B) Y AXIS-ROLL	.0025	.0032	.0032	.0121	.0104	.0086
C) Y AXIS-YAW	.0033	.0047	.0059	.0160	.0164	.0161
D) X AXIS-PITCH	.0537	.0588	.0584	.0005	.0006	.0003

MISALIGNMENT

A) IN PITCH	.0185	.0138	.0007	.0004	.0003	.0003
B) IN YAW	.0044	.0054	.0063	.0162	.0164	.0162
C) IN ROLL	.0030	.0033	.0038	.0121	.0103	.0097

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 1 – RANGE OF 4750 N. MILES

PART B – TARGET MISSES

ERROR SOURCE	1σ ERROR	DOWNRANGE MISS NAUTICAL MILES			CROSSRANGE MISS NAUTICAL MILES		
		SUST. ATTITUDE, DEG.			SUST. ATTITUDE, DEG.		
		31.1	23.4	15.8	31.1	23.4	15.8
GYRO=							
PITCH DRIFT							
A) CONSTANT	.10 DEG/HR	0.22	0.06	0.27	0.00	0.00	0.00
B) MASS UNBAL.	.36 DEG/HR/G	0.24	0.18	0.26	0.00	0.00	0.00
YAW DRIFT							
A) CONSTANT	.10 DEG/HR	0.08	0.10	0.11	0.30	0.31	0.30
B) MASS UNBAL.	.15 DEG/HR/G	0.18	0.23	0.23	0.27	0.30	0.35
ROLL DRIFT							
A) CONSTANT	.10 DEG/HR	0.05	0.05	0.04	0.19	0.15	0.11
B) MASS UNBAL							
BALL	.15 DEG/HR/G	0.12	0.13	0.10	SEE NOTE		
GIMBAL	.15 DEG/HR/G	0.12	0.13	0.10	0.48	0.39	0.28

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

ERROR SOURCE	1σ ERROR	DOWNRANGE 31.1	DOWNRANGE 23.4	DOWNRANGE 15.8	CROSSRANGE 31.1	CROSSRANGE 23.4	CROSSRANGE 15.8
ACCELEROMETER=							
ZERO							
A) X AXIS	11×10^{-4} F/S^2	0.24	0.32	0.33	0.00	0.00	0.00
B) Y AXIS	6×10^{-4} F/S^2	0.01	0.01	0.01	0.03	0.03	0.03
C) Z AXIS	12×10^{-4} F/S^2	0.14	0.18	0.21	0.00	0.00	0.00

SCALE FACTOR							
A) X AXIS	7×10^{-4} F/S^2/G	0.32	0.41	0.48	0.00	0.00	0.00
B) Z AXIS	7×10^{-4} F/S^2/G	0.13	0.14	0.16	0.00	0.00	0.00
SECOND DEGREE							
A) X AXIS	4×10^{-4} F/S^2/G^2	0.58	0.71	0.91	0.01	0.01	0.01
B) Z AXIS	4×10^{-4} F/S^2/G^2	0.18	0.19	0.21	0.00	0.00	0.00
THIRD DEGREE							
A) X AXIS	45×10^{-6} F/S^2/G^3	0.23	0.31	0.38	0.01	0.01	0.00
B) Z AXIS	45×10^{-5} F/S^2/G^3	0.03	0.04	0.04	0.00	0.00	0.00
PLATFORM=							
NONORTHOGONAL							
A) Z AXIS-PITCH	8 SEC.	0.28	0.36	0.46	0.00	0.00	0.00
B) Y AXIS-ROLL	10 SEC.	0.02	0.03	0.03	0.12	0.10	0.09
C) Y AXIS-YAW	10 SEC.	0.03	0.05	0.06	0.16	0.16	0.16
D) X AXIS-PITCH	8 SEC.	0.43	0.47	0.47	0.00	0.00	0.00
MISALIGNMENT							
A) IN PITCH	6.1 SEC.	0.11	0.09	0.00	0.00	0.00	0.00
B) IN YAW	14.4 SEC.	0.06	0.08	0.09	0.23	0.24	0.23
C) IN ROLL	6.6 SEC.	0.02	0.02	0.02	0.08	0.07	0.06

TOTAL R.S.S. MISS=

ERROR SOURCE	DOWNRANGE MISS NAUTICAL MILES SUSTAINER ATTITUDE , DEG.			CROSSRANGE MISS NAUTICAL MILES SUSTAINER ATTITUDE , DEG.		
	31.1	23.4	15.8	31.1	23.4	15.8
GYRO	0.42	0.37	0.47	0.65	0.60	0.55
ACCELEROMETER	0.78	0.97	1.19	0.03	0.04	0.03
PLATFORM	0.53	0.61	0.67	0.32	0.31	0.30

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 2 - RANGE OF 5500 N. MILES

PART A - MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR			CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR		
	SUSTAINER ATTITUDE , DEG.			SUSTAINER ATTITUDE , DEG.		
	31.1	23.4	15.8	31.1	23.4	15.8
GYRO=						
PITCH DRIFT						
A) CONSTANT	4.291	2.361	0.980	0.080	0.060	0.020
B) MASS UNBAL.	1.095	0.789	1.049	0.022	0.019	0.022
YAW DRIFT						
A) CONSTANT	0.990	1.230	1.370	3.180	3.190	3.200
B) MASS UNBAL.	1.528	1.822	1.950	1.333	2.005	2.439
ROLL DRIFT						
A) CONSTANT	0.572	0.590	0.540	2.010	1.558	1.159
B) MASS UNBAL						
BALL	0.956	1.006	0.839	SEE NOTE		
GIMBAL	0.956	1.006	0.839	3.478	2.706	1.967

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

ACCELEROMETER=						
ZERO						
A) X AXIS	277.7	344.3	384.3	5.0	6.7	6.3
B) Y AXIS	11.3	17.0	21.7	51.0	50.7	45.3
C) Z AXIS	122.0	150.0	184.7	2.0	2.7	2.3
SCALE FACTOR						
A) X AXIS	570.0	711.4	881.5	10.7	14.3	15.7
B) Z AXIS	188.6	205.0	245.7	2.9	3.6	2.9
SECOND DEGREE						
A) X AXIS	1800.0	2205.0	2890.5	40.0	42.5	52.5
B) Z AXIS	480.2	508.4	582.8	9.8	10.0	10.3
THIRD DEGREE						
A) X AXIS	7178	8910	11762	356.0	399.7	200.4
B) Z AXIS	43	89	102	2.2	2.2	2.2
PLATFORM=						
NONORTHOGCNAL						
A) Z AXIS-PITCH	.0363	.0457	.0609	.0006	.0008	.0009
B) Y AXIS-ROLL	.0024	.0035	.0042	.0110	.0103	.0103
C) Y AXIS-YAW	.0033	.0055	.0077	.0149	.0166	.0166
D) X AXIS-PITCH	.0597	.0707	.0744	.0011	.0014	.0013
MISALIGNMENT						
A) IN PITCH	.0299	.0246	.0135	.0006	.0006	.0004
B) IN YAW	.0052	.0064	.0078	.0166	.0166	.0166
C) IN ROLL	.0034	.0038	.0043	.0122	.0103	.0086

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 2 - RANGE OF 5500 N. MILES

PART B - TARGET MISSES

ERROR SOURCE	1σ ERROR	DOWNRANGE MISS NAUTICAL MILES			CROSSRANGE MISS NAUTICAL MILES		
		SUST.	ATTITUDE, DEG.		SUST.	ATTITUDE, DEG.	
		31.1	23.4	15.8	31.1	23.4	15.8
GYRO=							
PITCH DRIFT							
A) CONSTANT	.10 DEG/HR	0.43	0.24	0.10	0.01	0.01	0.00
B) MASS UNBAL.	.36 DEG/HR/G	0.39	0.28	0.38	0.01	0.01	0.01
YAW DRIFT							
A) CONSTANT	.10 DEG/HR	0.10	0.12	0.14	0.32	0.32	0.32
B) MASS UNBAL.	.15 DEG/HR/G	0.23	0.27	0.29	0.20	0.30	0.37
ROLL DRIFT							
A) CONSTANT	.10 DEG/HR	0.06	0.06	0.05	0.20	0.16	0.12
B) MASS UNBAL							
BALL	.15 DEG/HR/G	0.14	0.15	0.13	SEE NOTE		
GIMBAL	.15 DEG/HR/G	0.14	0.15	0.13	0.52	0.41	0.29

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

ERROR SOURCE	1σ ERROR	DOWNRANGE SUST. 31.1	DOWNRANGE 23.4	DOWNRANGE 15.8	CROSSRANGE SUST. 31.1	CROSSRANGE 23.4	CROSSRANGE 15.8
ACCELEROMETER=							
ZERO							
A) X AXIS	11×10^{-4} F/S^2	0.31	0.38	0.42	0.00	0.01	0.01
B) Y AXIS	6×10^{-4} F/S^2	0.01	0.01	0.01	0.03	0.03	0.03
C) Z AXIS	12×10^{-4} F/S^2	0.13	0.18	0.22	0.00	0.00	0.00

SCALE FACTOR							
A) X AXIS	7×10^{-4} F/S^2/G	0.40	0.50	0.62	0.01	0.01	0.01
B) Z AXIS	7×10^{-4} F/S^2/G	0.13	0.14	0.17	0.00	0.00	0.00
SECOND DEGREE							
A) X AXIS	4×10^{-4} F/S^2/G^2	0.72	0.88	1.16	0.02	0.02	0.02
B) Z AXIS	4×10^{-4} F/S^2/G^2	0.19	0.20	0.23	0.00	0.00	0.00
THIRD DEGREE							
A) X AXIS	45×10^{-6} F/S^2/G^3	0.32	0.40	0.53	0.02	0.02	0.01
B) Z AXIS	45×10^{-6} F/S^2/G^3	0.00	0.00	0.00	0.00	0.00	0.00
PLATFORM=							
NONORTHOGONAL							
A) Z AXIS-PITCH	8 SEC.	0.29	0.37	0.49	0.00	0.01	0.01
B) Y AXIS-ROLL	10 SEC.	0.02	0.04	0.04	0.11	0.10	0.10
C) Y AXIS-YAW	10 SEC.	0.03	0.05	0.08	0.15	0.17	0.17
D) X AXIS-PITCH	8 SEC.	0.48	0.57	0.60	0.01	0.01	0.01
MISALIGNMENT							
A) IN PITCH	6.1 SEC.	0.18	0.15	0.08	0.00	0.00	0.00
B) IN YAW	14.4 SEC.	0.07	0.09	0.11	0.24	0.24	0.24
C) IN ROLL	6.6 SEC.	0.02	0.02	0.03	0.08	0.07	0.06

TOTAL R.S.S. MISS=

ERROR SOURCE	DOWNRANGE MISS NAUTICAL MILES			CROSSRANGE MISS NAUTICAL MILES		
	SUSTAINER ATTITUDE , DEG.			SUSTAINER ATTITUDE , DEG.		
	31.1	23.4	15.8	31.1	23.4	15.8
GYRO	0.67	0.52	0.54	0.67	0.62	0.58
ACCELEROMETER	0.98	1.19	1.52	0.04	0.04	0.03
PLATFORM	0.60	0.70	0.79	0.31	0.32	0.31

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 3 – RANGE OF 6900 N. MILES

PART A – MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR				CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR			
	SUSTAINER ATTITUDE , DEG.				SUSTAINER ATTITUDE , DEG.			
	31.1	23.4	15.8	9.9	31.1	23.4	15.8	9.9
GYRO=								
PITCH DRIFT								
A) CONSTANT	8.670	6.941	4.250	0.852	0.161	0.219	0.180	0.058
B) MASS UNBAL.	1.903	1.265	1.403	2.035	0.035	0.043	0.057	0.116
YAW DRIFT								
A) CONSTANT	1.398	1.601	1.909	2.310	3.052	2.970	2.927	2.911
B) MASS UNBAL.	2.144	2.361	2.650	3.211	1.378	1.789	2.172	2.416
ROLL DRIFT								
A) CONSTANT	0.511	0.710	0.782	0.738	1.916	1.441	1.042	0.761
B) MASS UNBAL								
BALL	0.956	1.250	1.261	0.989	SEE NOTE			
GIMBAL	0.956	1.250	1.261	0.989	3.444	2.578	1.822	1.278

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

ACCELEROMETER=								
ZERO								
A) X AXIS	347.0	440.7	553.3	724.7	7.3	14.3	21.7	31.3
B) Y AXIS	8.0	20.3	35.0	53.3	44.0	42.7	39.7	38.0
C) Z AXIS	110.0	135.7	177.0	232.3	2.7	4.3	6.7	9.7
SCALE FACTOR								
A) X AXIS	743.6	945.7	1247.8	1652.1	15.7	30.7	49.3	72.1
B) Z AXIS	175.0	194.3	224.3	275.0	4.3	6.4	8.6	11.4
SECOND DEGREE								
A) X AXIS	2295	3078	4104	5438	85.0	97.5	140.0	185.0
B) Z AXIS	480	533	633	780	17.4	17.6	19.6	24.8
THIRD DEGPEE								
A) X AXIS	10692	12958	18558	23692	578.1	600.2	710.7	822.0
B) Z AXIS	93	96	109	132	2.2	3.2	4.1	4.7
PLATFORM=								
NONORTHOGONAL								
A) Z AXIS-PITCH	.0333	.0414	.0557	.0750	.0008	.0013	.0021	.0031
B) Y AXIS-ROLL	.0019	.0042	.0064	.0086	.0108	.0087	.0071	.0058
C) Y AXIS-YAW	.0027	.0068	.0122	.0189	.0151	.0147	.0144	.0141
D) X AXIS-PITCH	.0851	.0920	.1019	.1165	.0018	.0030	.0040	.0051
MISALIGNMENT								
A) IN PITCH	.0521	.0502	.0458	.0411	.0010	.0016	.0018	.0019
B) IN YAW	.0064	.0080	.0103	.0137	.0151	.0146	.0145	.0143
C) IN ROLL	.0027	.0045	.0060	.0075	.0108	.0087	.0071	.0059

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 3 - RANGE OF 6900 N. MILES

PART B - TARGET MISSES

ERROR SOURCE	1σ ERROR	DOWNRANGE MISS NAUTICAL MILES				CROSSRANGE MISS NAUTICAL MILES			
		SUST. ATTITUDE,DEG.				SUST. ATTITUDE,DEG.			
		31.1	23.4	15.8	9.9	31.1	23.4	15.8	9.9
GYRO=									
PITCH DRIFT									
A) CONSTANT	.10 DEG/HR	0.87	0.69	0.43	0.09	0.02	0.02	0.02	0.01
B) MASS UNBAL	.36 DEG/HR/G	0.69	0.46	0.51	0.73	0.01	0.02	0.02	0.04
YAW DRIFT									
A) CONSTANT	.10 DEG/HR	0.14	0.16	0.19	0.23	0.31	0.30	0.29	0.29
B) MASS UNBAL	.15 DEG/HR/G	0.32	0.35	0.40	0.48	0.21	0.27	0.33	0.36
ROLL DRIFT									
A) CONSTANT	.10 DEG/HR	0.05	0.07	0.08	0.07	0.19	0.14	0.10	0.08
B) MASS UNBAL									
BALL	.15 DEG/HR/G	0.14	0.19	0.19	0.15	SEE NOTE			
GIMBAL	.15 DEG/HR/G	0.14	0.19	0.19	0.15	0.52	0.39	0.27	0.19

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

ERROR SOURCE	1σ ERROR	31.1	23.4	15.8	9.9	31.1	23.4	15.8	9.9
ACCELEROMETER=									
ZERO									
A) X AXIS	11×10^{-4} F/S^2	0.38	0.48	0.61	0.80	0.01	0.02	0.02	0.03
B) Y AXIS	6×10^{-4} F/S^2	0.00	0.01	0.02	0.03	0.03	0.03	0.02	0.02
C) Z AXIS	12×10^{-4} F/S^2	0.13	0.16	0.21	0.28	0.00	0.00	0.01	0.01

SCALE FACTOR									
A) X AXIS	$7X10^{-4}$ F/S/G^{2}	0.52	0.66	0.87	1.16	0.01	0.02	0.03	0.05
B) Z AXIS	$7X10^{-4}$ F/S/G^{2}	0.12	0.14	0.16	0.19	0.00	0.00	0.01	0.01
SECOND DEGREE									
A) X AXIS	$4X10^{-4}$ F/S/G^{2} ^{2}	0.92	1.23	1.64	2.18	0.03	0.04	0.06	0.07
B) Z AXIS	$4X10^{-4}$ F/S/G^{2} ^{2}	0.19	0.21	0.25	0.31	0.01	0.01	0.01	0.01
THIRD DEGREE									
A) X AXIS	$45X10^{-6}$ F/S/G^{2} ^{3}	0.48	0.58	0.84	1.07	0.03	0.03	0.03	0.04
B) Z AXIS	$45X10^{-6}$ F/S/G^{2} ^{3}	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
PLATFORM=									
NONORTHOGONAL									
A) Z AXIS-PITCH	8 SEC.	0.27	0.33	0.45	0.60	0.01	0.01	0.02	0.03
B) Y AXIS-ROLL	10 SEC.	0.02	0.04	0.06	0.09	0.11	0.09	0.07	0.06
C) Y AXIS-YAW	10 SEC.	0.03	0.07	0.12	0.19	0.15	0.15	0.14	0.14
D) X AXIS-PITCH	8 SEC.	0.68	0.74	0.82	0.93	0.01	0.02	0.03	0.04
MISALIGNMENT									
A) IN PITCH	6.1 SEC.	0.32	0.30	0.28	0.25	0.01	0.01	0.01	0.01
B) IN YAW	14.4 SEC.	0.09	0.11	0.15	0.20	0.22	0.21	0.21	0.21
C) IN ROLL	6.6 SEC.	0.02	0.03	0.04	0.05	0.07	0.06	0.05	0.04

TOTAL R.S.S. MISS=

ERROR SOURCE	DOWNRANGE MISS NAUTICAL MILES				CROSSRANGE MISS NAUTICAL MILES			
	SUSTAINER ATTITUDE , DEG.				SUSTAINER ATTITUDE , DEG.			
	31.1	23.4	15.8	9.9	31.1	23.4	15.8	9.9
GYRO	1.18	0.96	0.84	0.94	0.66	0.58	0.53	0.51
ACCELEROMETER	1.25	1.62	2.16	2.84	0.05	0.06	0.08	0.11
PLATFORM	0.80	0.88	0.99	1.17	0.30	0.28	0.27	0.26

SECRET

[redacted]

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 4 - RANGE OF 8700 N. MILES

PART A - MISS PARTIALS

ERROR SOURCE	DOWNRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR				CROSSRANGE MISS PARTIALS NAUT. MILES/UNIT ERROR			
	SUSTAINER ATTITUDE , DEG.				SUSTAINER ATTITUDE , DEG.			
	31.1	23.4	15.8	8.0	31.1	23.4	15.8	8.0
GYRO=								
PITCH DRIFT								
A) CONSTANT	15.39	14.10	12.81	10.54	0.109	0.531	1.138	1.320
B) MASS UNBAL.	2.988	1.592	1.208	2.645	0.019	0.059	0.108	0.327
YAW DRIFT								
A) CONSTANT	1.702	1.820	1.890	2.101	1.901	1.788	1.671	1.550
B) MASS UNBAL.	2.622	2.683	2.878	3.489	0.784	1.007	1.272	1.448
ROLL DRIFT								
A) CONSTANT	0.071	0.731	1.470	1.902	1.179	0.848	0.491	0.161
B) MASS UNBAL								
BALL	0.159	1.318	2.571	2.830		SEE NOTE		
GIMBAL	0.159	1.318	2.571	2.830	2.244	1.617	0.922	0.322

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

SECRET

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[redacted]

ACCELEROMETER=

ZERO								
A) X AXIS	395.3	515.0	670.7	1009.7	2.0	20.0	59.7	125.3
B) Y AXIS	4.7	20.3	66.0	14.1	22.0	21.7	15.7	3.7
C) Z AXIS	66.3	83.3	108.3	169.7	0.0	3.3	9.3	20.7
SCALE FACTOR								
A) X AXIS	902.9	1155.7	1562.9	2357.9	4.3	45.0	139.3	292.9
B) Z AXIS	106.4	122.1	149.3	220.7	0.0	5.0	12.9	27.1
SECOND DEGREE								
A) X AXIS	3255	4030	5438	7950	120.0	155.0	220.0	262.5
B) Z AXIS	355	460	605	758	15.0	17.5	22.5	25.0
THIRD DEGREE								
A) X AXIS	15510	18490	25778	36004	578.0	7 1.0	1022.1	1489.2
B) Z AXIS	620	800	980	1160	2.2	3.2	4.1	4.7

PLATFORM=

NONORTHOGONAL								
A) Z AXIS-PITCH	.0186	.0238	.0319	.0495	.0001	.0010	.0030	.0028
B) Y AXIS-ROLL	.0012	.0043	.0122	.0215	.0057	.0045	.0026	.0017
C) Y AXIS-YAW	.0017	.0070	.0239	.0514	.0084	.0082	.0063	.0020
D) X AXIS-PITCH	.1012	.1098	.1241	.1534	.0005	.0042	.0110	.0190
MISALIGNMENT								
A) IN PITCH	.0827	.0857	.0914	.1047	.0006	.0032	.0081	.0130
B) IN YAW	.0063	.0087	.0123	.0190	.0085	.0081	.0073	.0060
C) IN ROLL	.0004	.0044	.0111	.0184	.0057	.0045	.0027	.0006

SECRET

TABLE VI

SUMMARY OF ALL INERTIAL ERROR STUDY

SECTION 4 - RANGE OF 8700 N. MILES [redacted]

PART B - TARGET MISSES

ERROR SOURCE	1σ ERROR	DOWNRANGE MISS NAUTICAL MILES SUST. ATTITUDE, DEG. 31.1	23.4	15.8	8.0	CROSSRANGE MISS NAUTICAL MILES SUST. ATTITUDE, DEG. 31.1	23.4	15.8	8.0
GYRO=									
PITCH DRIFT									
A) CONSTANT	.10 DEG/HR	1.54	1.41	1.28	1.05	0.01	0.05	0.11	0.13
B) MASS UNBAL	.36 DEG/HR/G	1.04	0.57	0.44	0.95	0.01	0.02	0.04	0.12
YAW DRIFT									
A) CONSTANT	.10 DEG/HR	0.17	0.18	0.19	0.21	0.19	0.18	0.17	0.16
B) MASS UNBAL	.15 DEG/HR	0.39	0.40	0.43	0.52	0.12	0.15	0.19	0.22
ROLL DRIFT									
A) CONSTANT	.10 DEG/HR	0.01	0.07	0.15	0.19	0.12	0.09	0.05	0.02
B) MASS UNBAL									
BALL	.15 DEG/HR/G	0.02	0.20	0.39	0.42	SEE NOTE			
GIMBAL	.15 DEG/HR/G	0.02	0.20	0.39	0.42	0.34	0.24	0.14	0.05

NOTE= ROLL AND YAW CROSSRANGE ERRORS DUE TO MASS UNBALANCE ALONG SPIN AXIS OF BALL CANCEL AND HAVE BEEN COMBINED IN THE YAW DRIFT PORTION OF THESE TABLES.

ERROR SOURCE	1σ ERROR	31.1	23.4	15.8	8.0	31.1	23.4	15.8	8.0
ACCELEROMETER=									
ZERO									
A) X AXIS	11X10^{-4} F/S^{2}	0.44	0.57	0.74	1.11	0.00	0.02	0.07	0.14
B) Y AXIS	6X10^{-4} F/S^{2}	0.00	0.01	0.04	0.01	0.01	0.01	0.01	0.00
C) Z AXIS	12X10^{-4} F/S^{2}	0.08	0.10	0.13	0.20	0.00	0.00	0.01	0.02

SECRET [redacted]

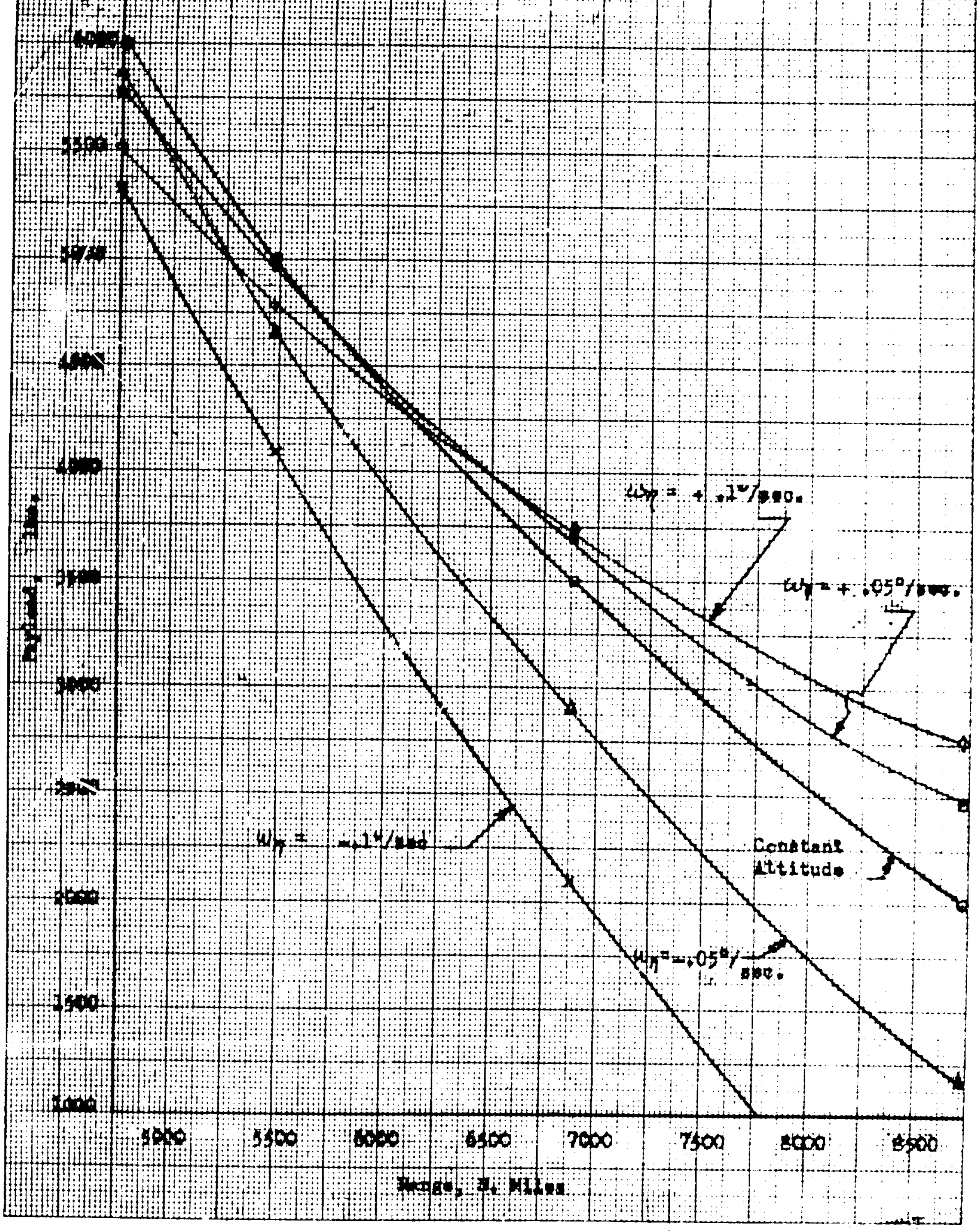
SCALE FACTOR									
A) X AXIS	$7X10^{-4}$ $F/S/G^{2}$	0.63	0.81	1.09	1.65	0.00	0.03	0.10	0.20
B) Z AXIS	$7X10^{-4}$ $F/S/G^{2}$	0.07	0.09	0.10	0.15	0.00	0.00	0.01	0.02
SECOND DEGREE									
A) X AXIS	$4X10^{-4}$ $F/S/G^{2\ 2}$	1.30	1.61	2.18	3.18	0.05	0.06	0.09	0.11
B) Z AXIS	$4X10^{-4}$ $F/S/G^{2\ 2}$	0.14	0.18	0.24	0.30	0.01	0.01	0.01	0.01
THIRD DEGREE									
A) X AXIS	$45X10^{-6}$ $F/S/G^{2\ 3}$	0.70	0.83	1.16	1.62	0.03	0.03	0.05	0.07
B) Z AXIS	$45X10^{-6}$ $F/S/G^{2\ 3}$	0.03	0.04	0.04	0.05	0.00	0.00	0.00	0.00
PLATFORM=									
NONORTHOGONAL									
A) Z AXIS-PITCH	8 SEC.	0.15	0.19	0.26	0.40	0.00	0.01	0.02	0.02
B) Y AXIS-ROLL	10 SEC.	0.01	0.04	0.12	0.22	0.06	0.05	0.03	0.02
C) Y AXIS-YAW	10 SEC.	0.02	0.07	0.24	0.51	0.08	0.08	0.06	0.02
D) X AXIS-PITCH	8 SEC.	0.81	0.88	0.99	1.23	0.00	0.03	0.09	0.15
MISALIGNMENT									
A) IN PITCH	6.1 SEC.	0.50	0.52	0.56	0.64	0.00	0.02	0.05	0.08
B) IN YAW	14.4 SEC.	0.09	0.13	0.18	0.27	0.12	0.12	0.11	0.09
C) IN ROLL	6.6 SEC.	0.00	0.03	0.07	0.12	0.04	0.03	0.02	0.00

TOTAL R.S.S. MISS=

ERROR SOURCE	DOWNRANGE MISS NAUTICAL MILES SUSTAINER ATTITUDE , DEG.				CROSSRANGE MISS NAUTICAL MILES SUSTAINER ATTITUDE , DEG.			
	31.1	23.4	15.8	8.0	31.1	23.4	15.8	8.0
GYRO	1.91	1.61	1.54	1.65	0.42	0.35	0.32	0.32
ACCELEROMETER	1.67	2.08	2.81	4.11	0.08	0.08	0.16	0.29
PLATFORM	0.97	1.05	[illegible].21	1.57	0.16	0.16	0.16	0.20

FIGURE 1(m)

PAYLOAD VS. RANGE FOR VARIOUS CONSTANT TILT RATES



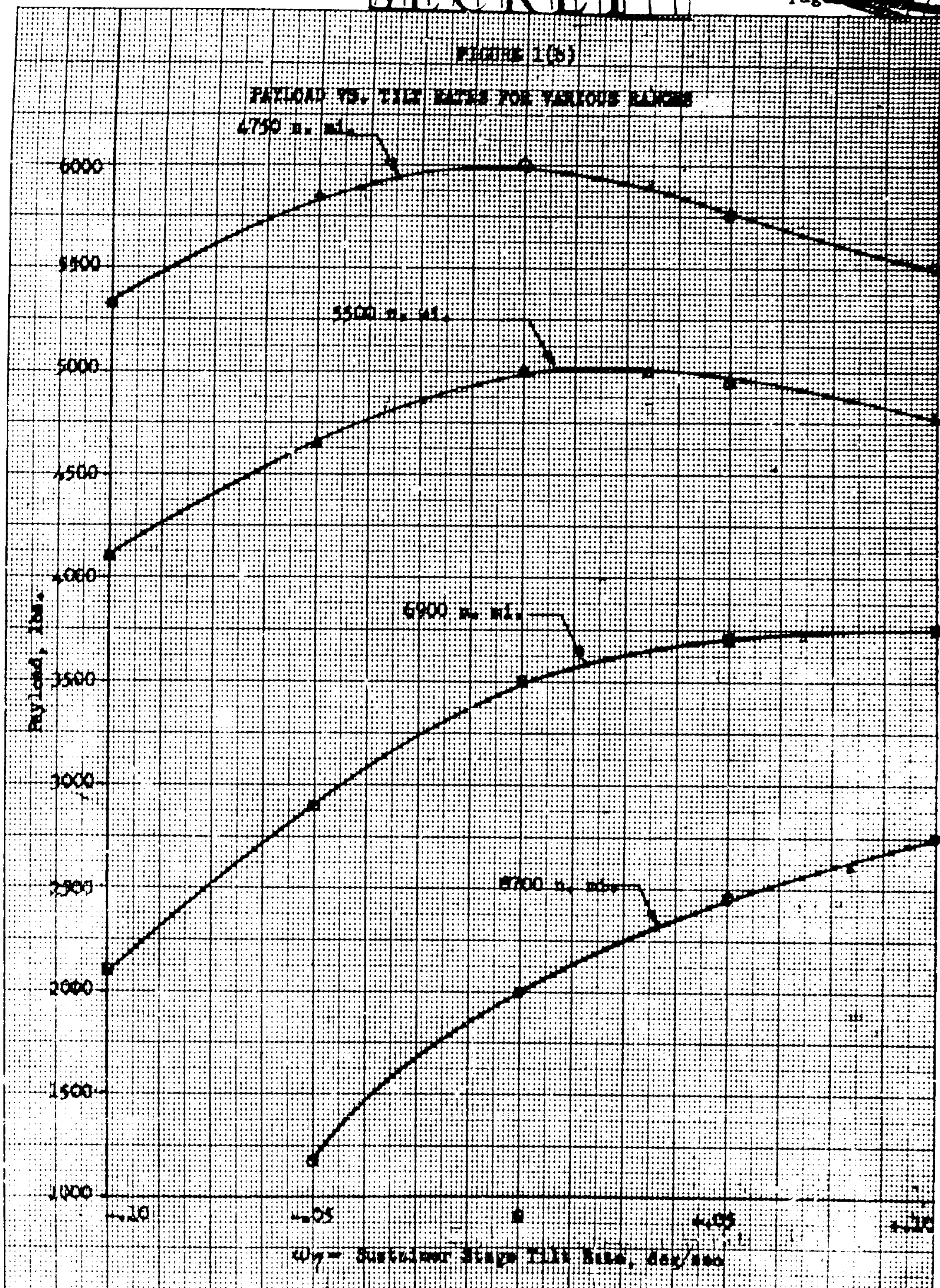


FIGURE 1(b)
PAYLOAD VS. TILT RATES FOR VARIOUS RANGES
4750 n. mi.
5500 n. mi.
6900 n. mi.
8700 n. mi.
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
Payload, lbs.
-.10
-.05
0
+.05
+.10
ωT = Sustainer Stage Tilt Rate, deg/sec

FIGURE 2(a)

PAYLOAD VS. RANGE FOR VARIOUS INERTIAL ATTITUDES

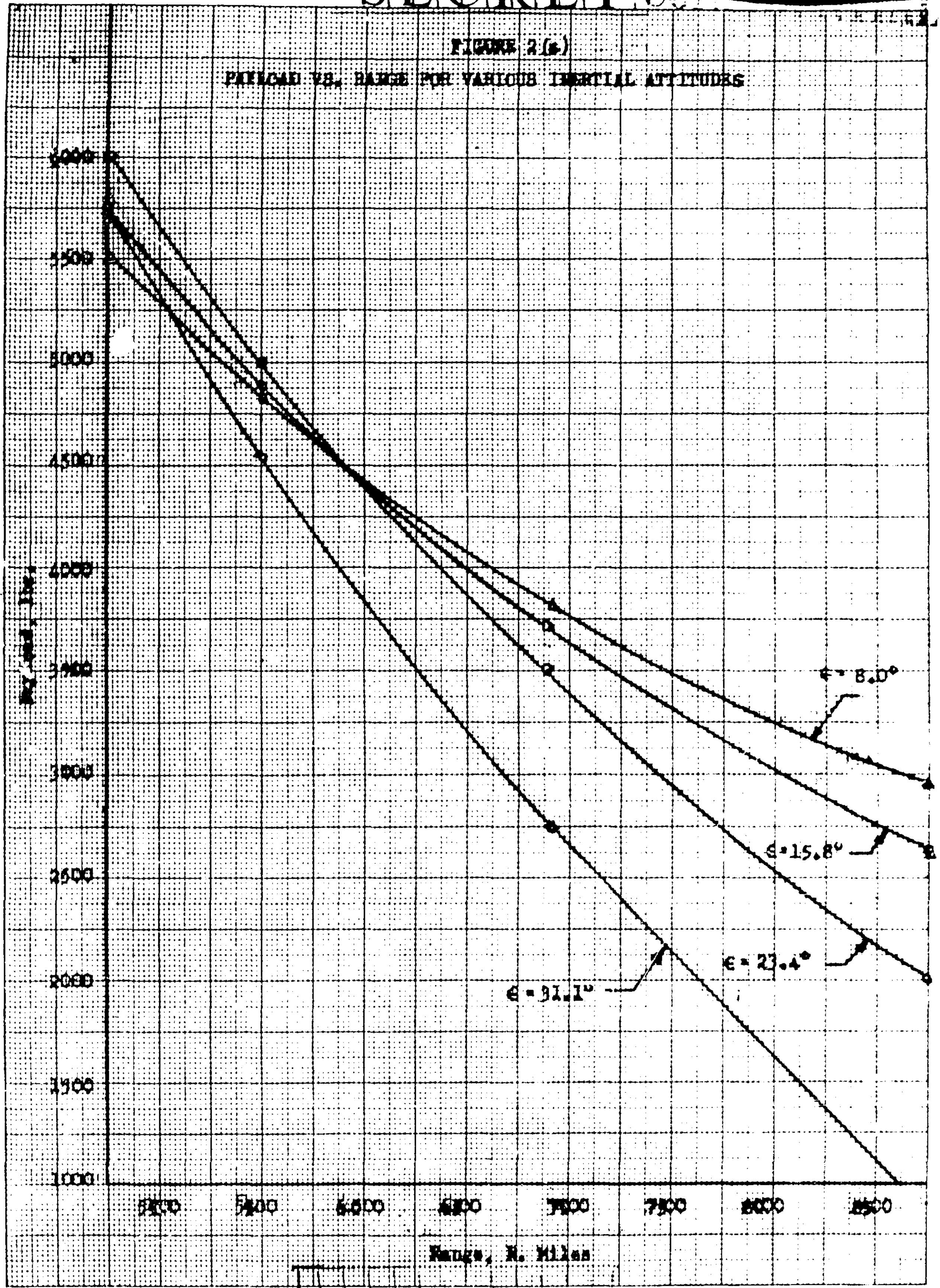


FIGURE 2(m)

PAYLOAD VS. RANGE FOR VARIOUS RANGES

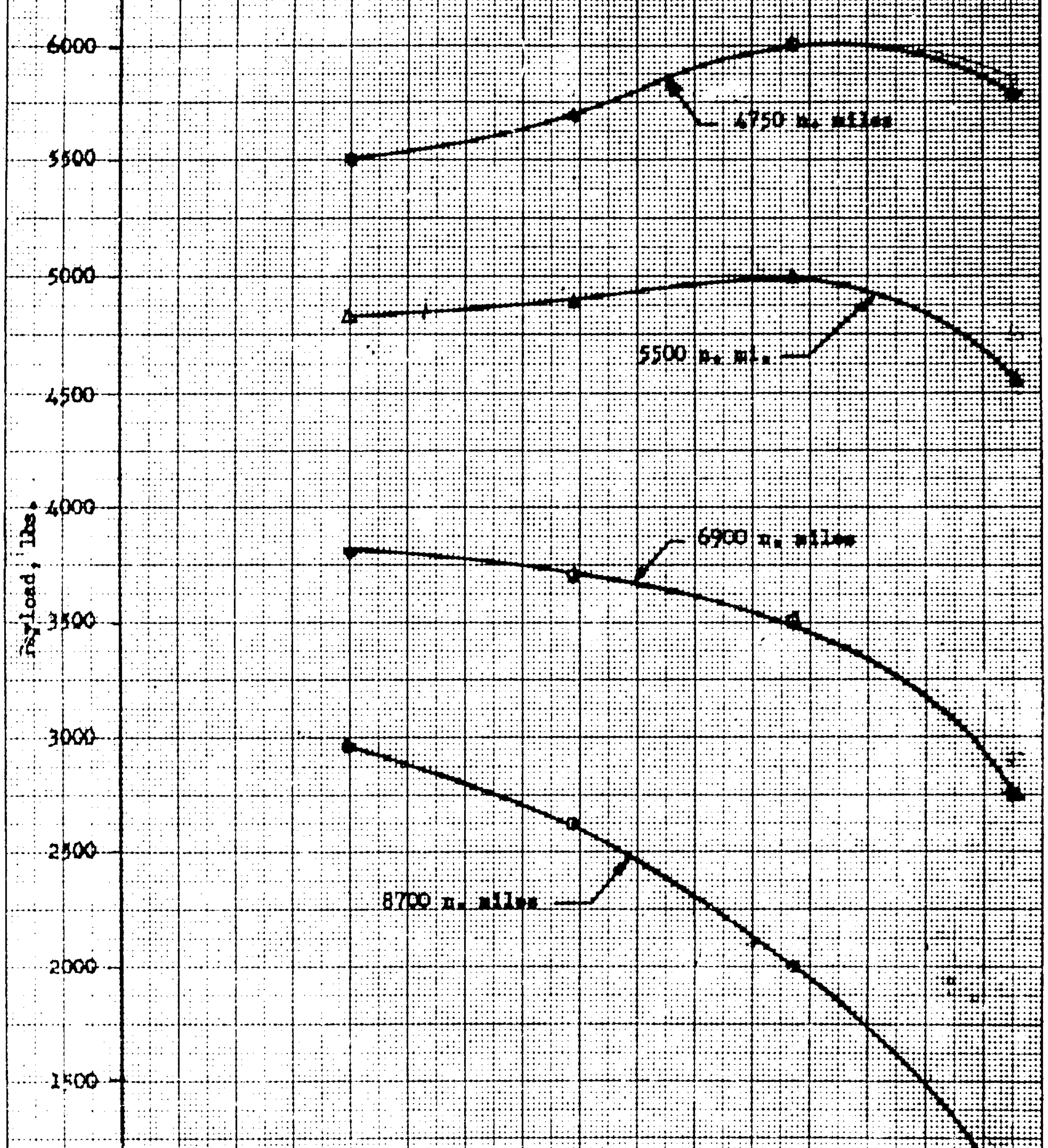
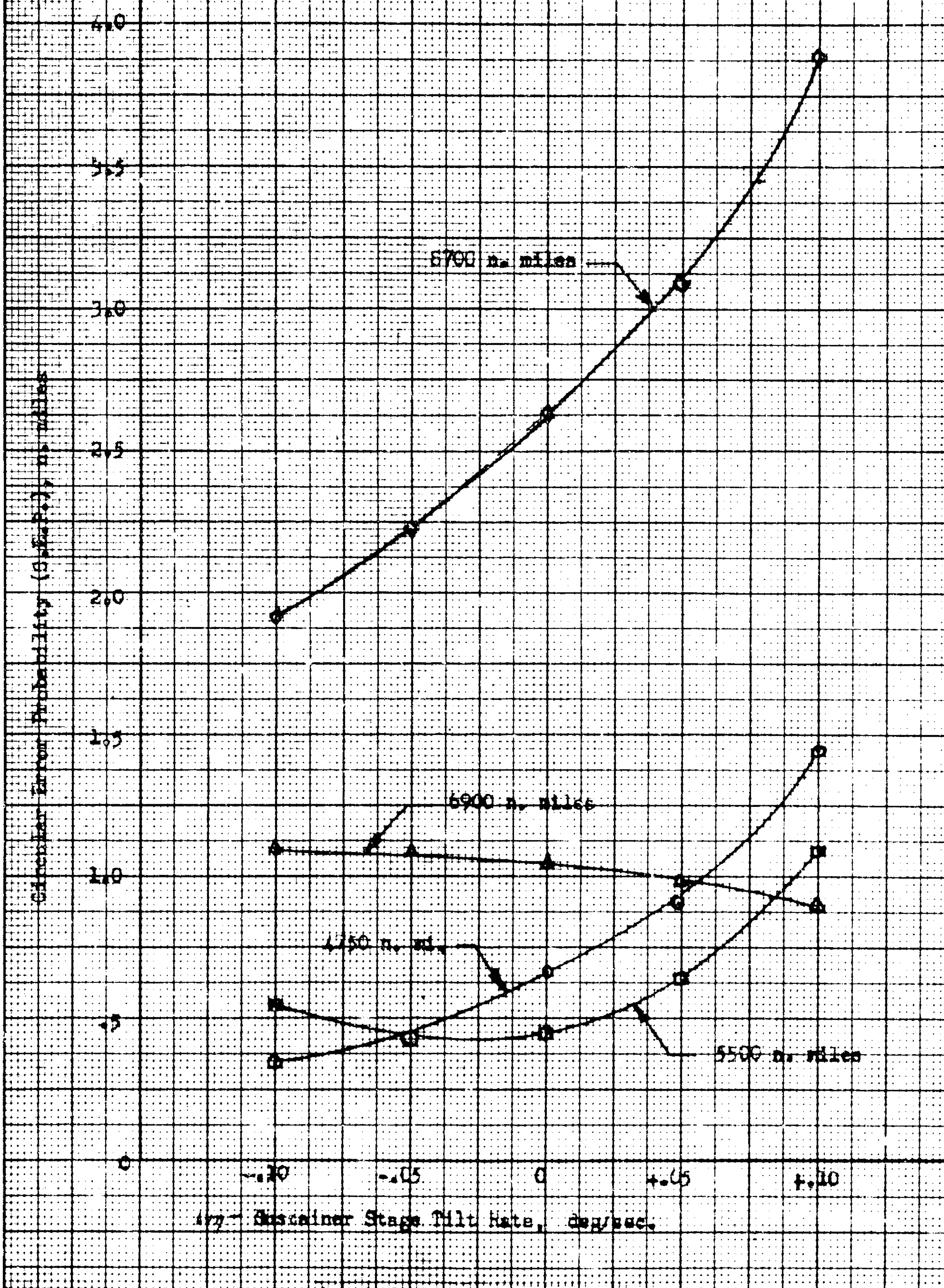


FIGURE 3

C. E. P. FOR RIG SYSTEM



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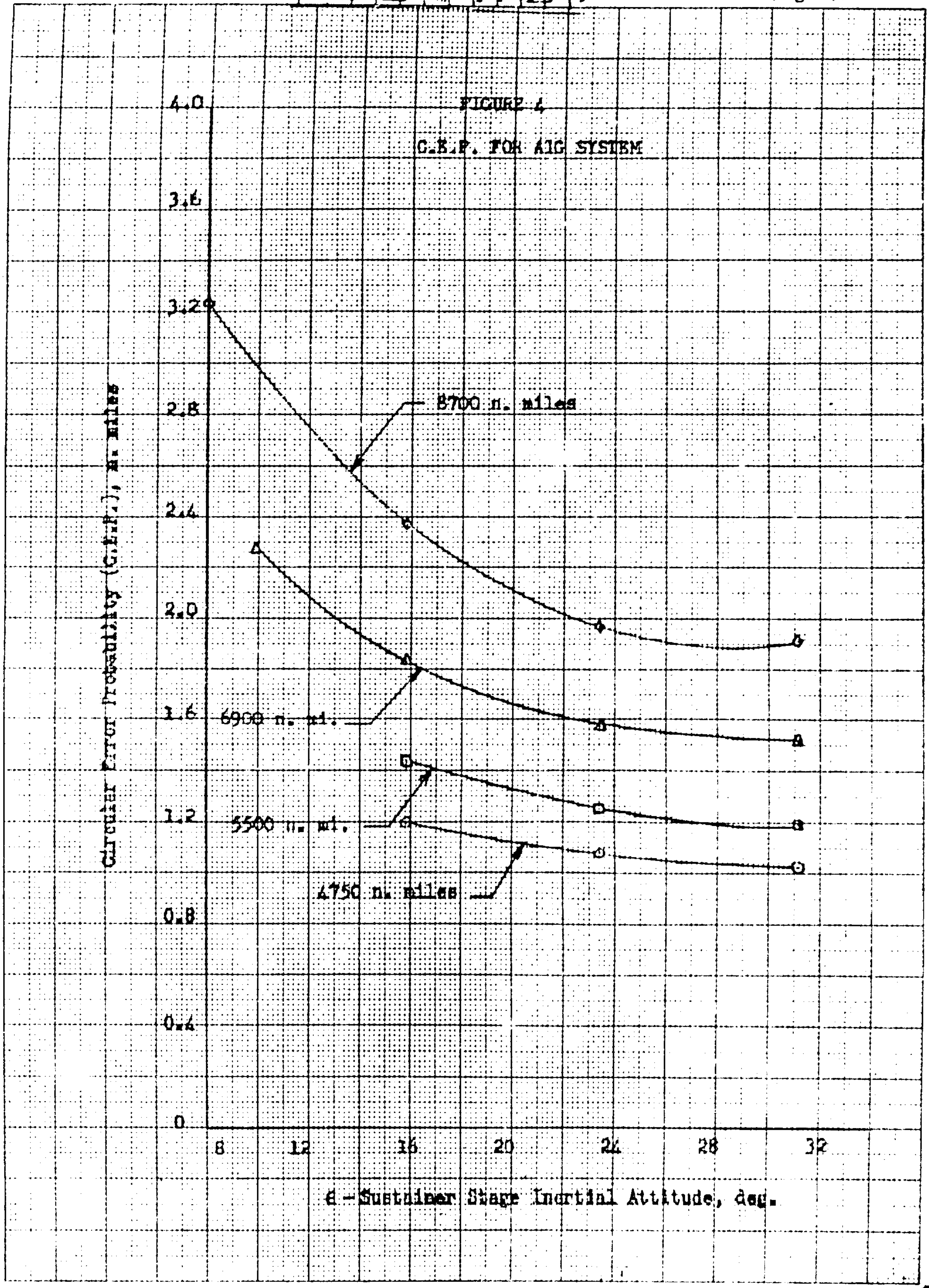
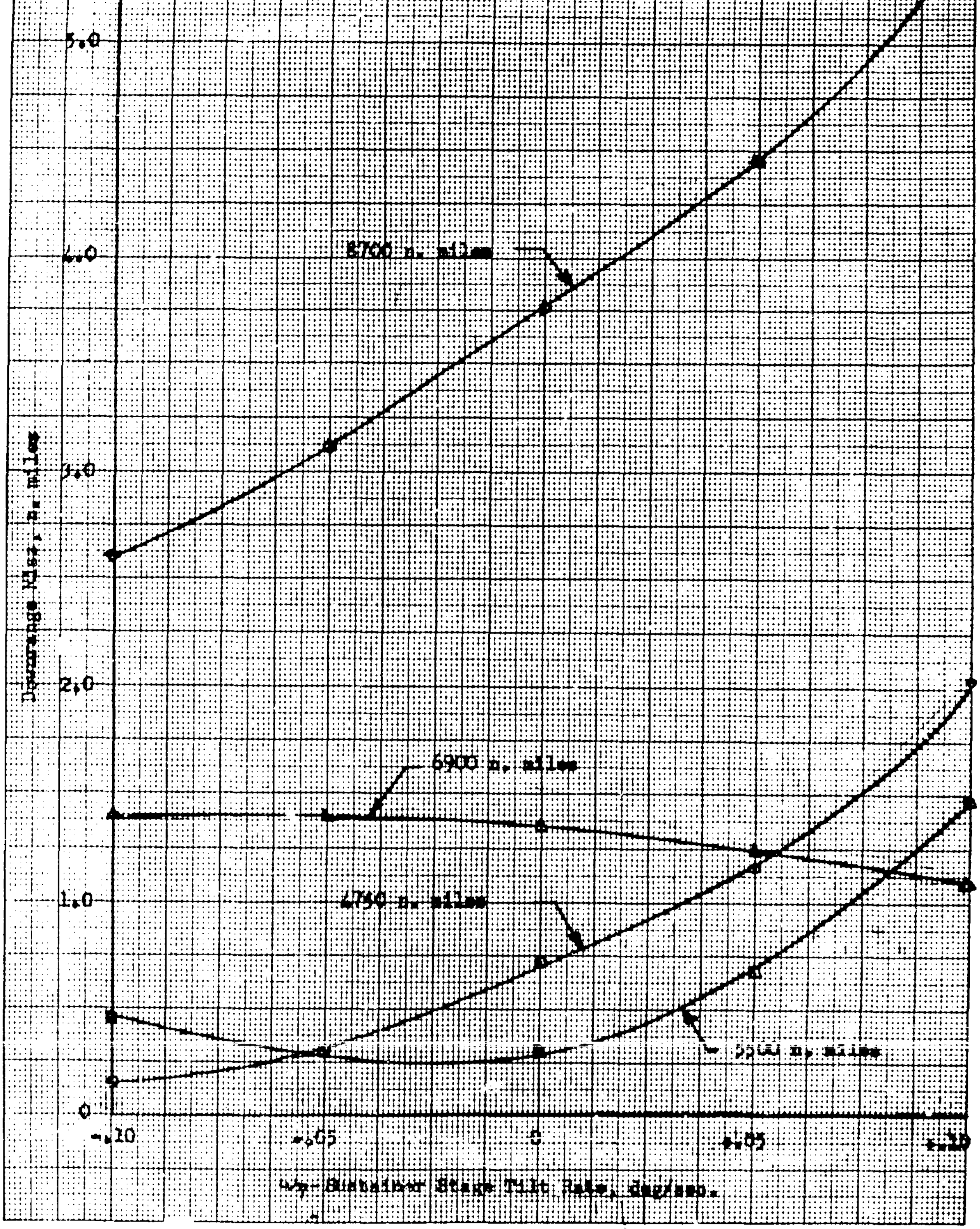


FIGURE 4
C.E.P. FOR A1G SYSTEM
8700 n. miles
6900 n. mi.
5500 n. mi.
4750 n. miles
Circular Error Probability (C.E.P.), n. miles
θ - Sustainer Stage Inertial Attitude, deg.
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
0.8
0.4
0
8
12
16
20
24
28
32

FIGURE 5

TOTAL DOWNRANGE MISS FOR RIG SYSTEM



 [redacted]

FIGURE 6

TOTAL CROSSRANGE MISS FOR RIG SYSTEM

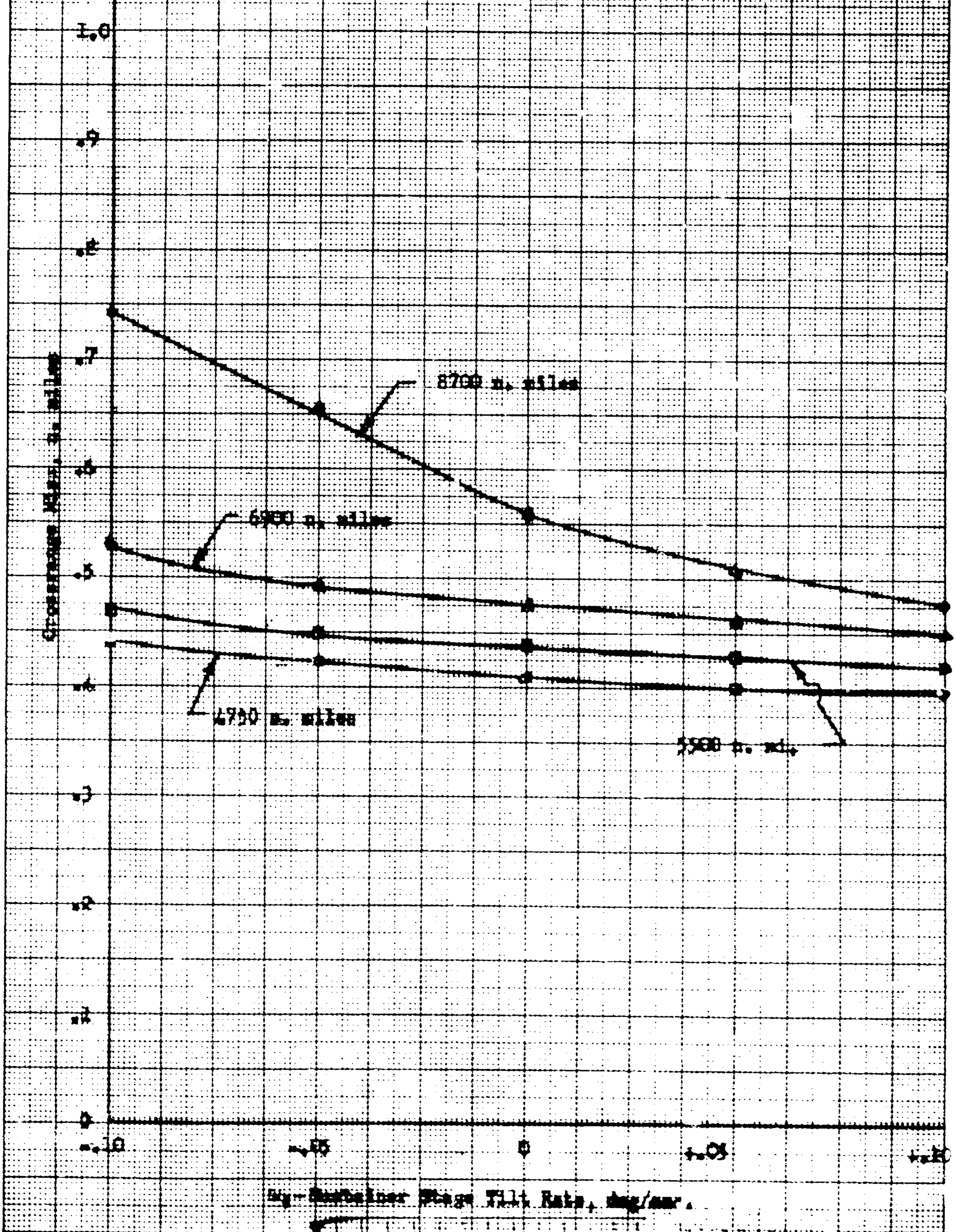
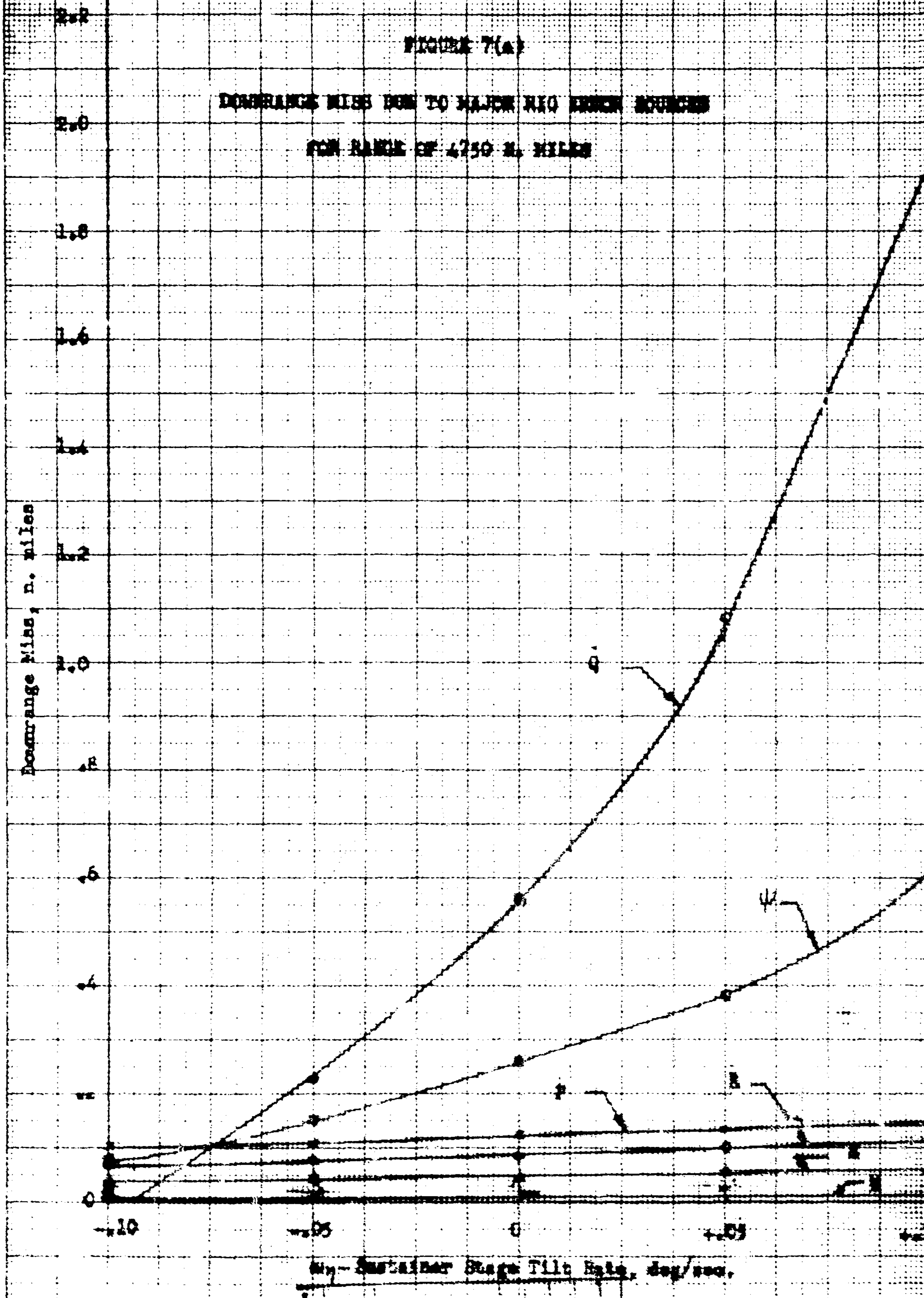


FIGURE 7(a)

DOWNRANGE MISS DUE TO MAJOR RIG ERROR SOURCES

FOR RANGE OF 4750 N. MILES



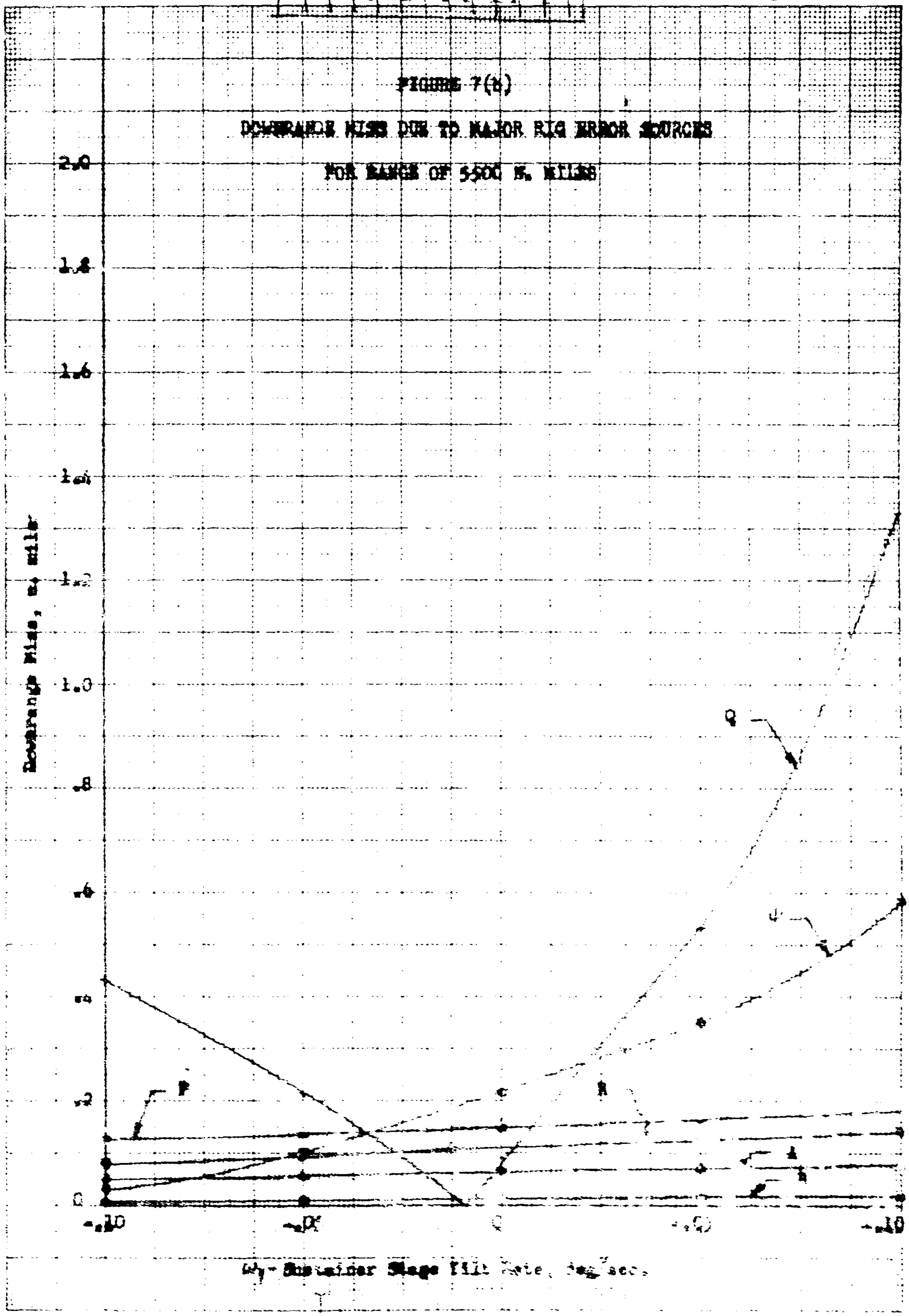


FIGURE 7(b)

DOWNRANGE MISS DUE TO MAJOR RIG ERROR SOURCES

FOR RANGE OF 5500 N. MILES

FIGURE 7(c)

DOWNRANGE MISS DUE TO MAJOR RIG ERROR SOURCES

FOR RANGE OF 6900 N. MILES

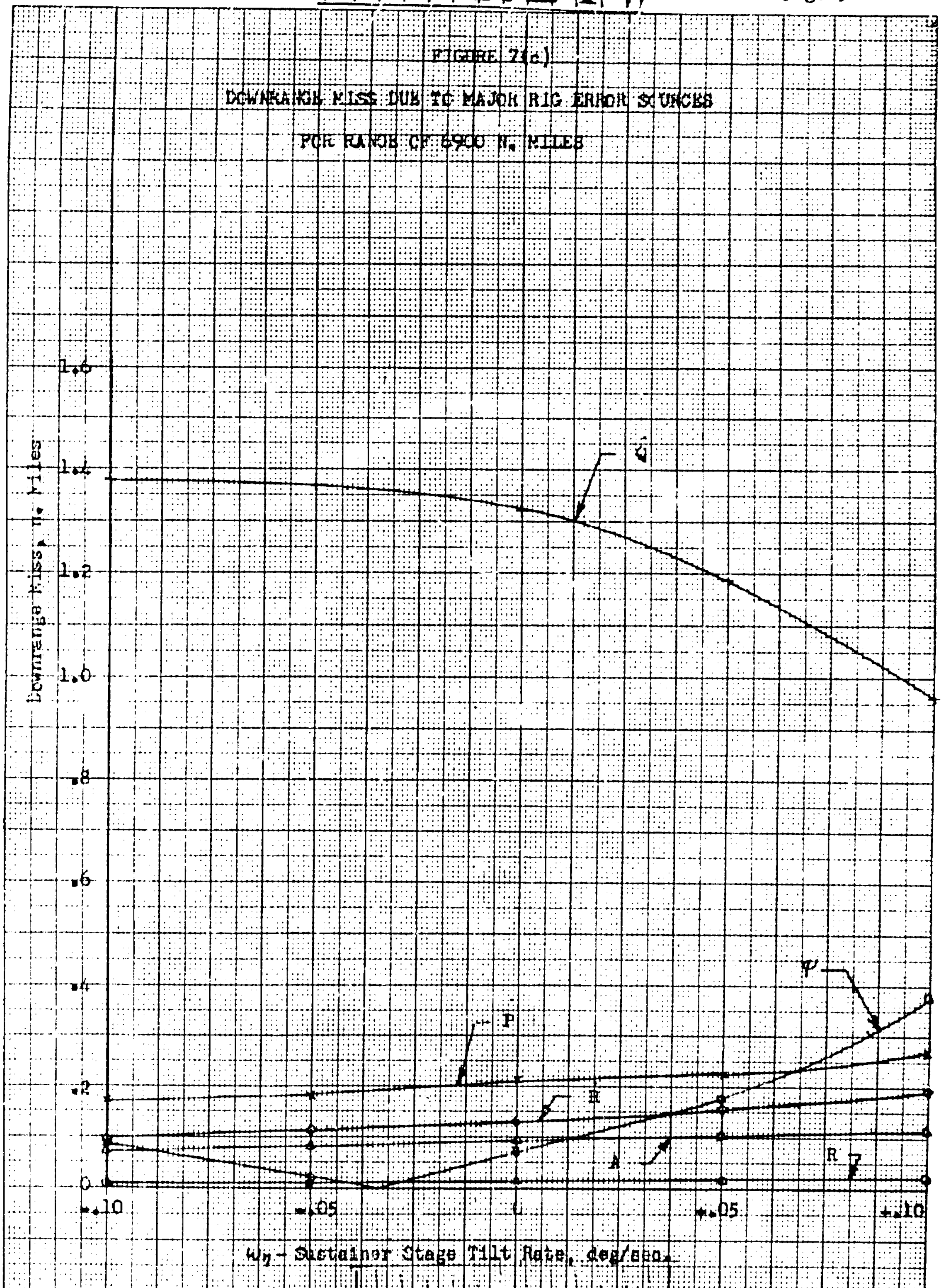


FIGURE 7(d)

DOWNRANGE MISS DUE TO MAJOR RIG ERROR SOURCES

FOR RANGE OF 8700 N. MILES

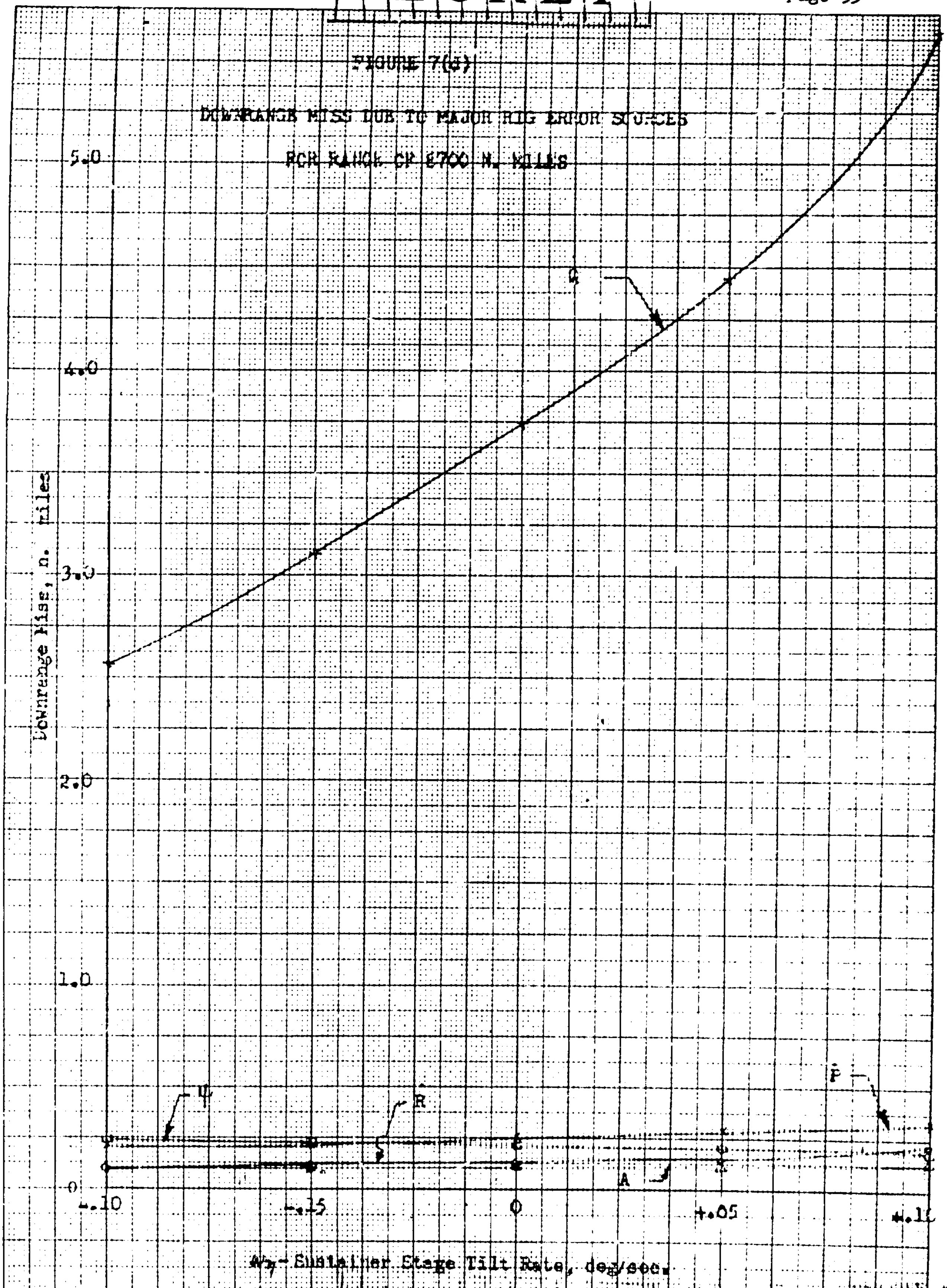
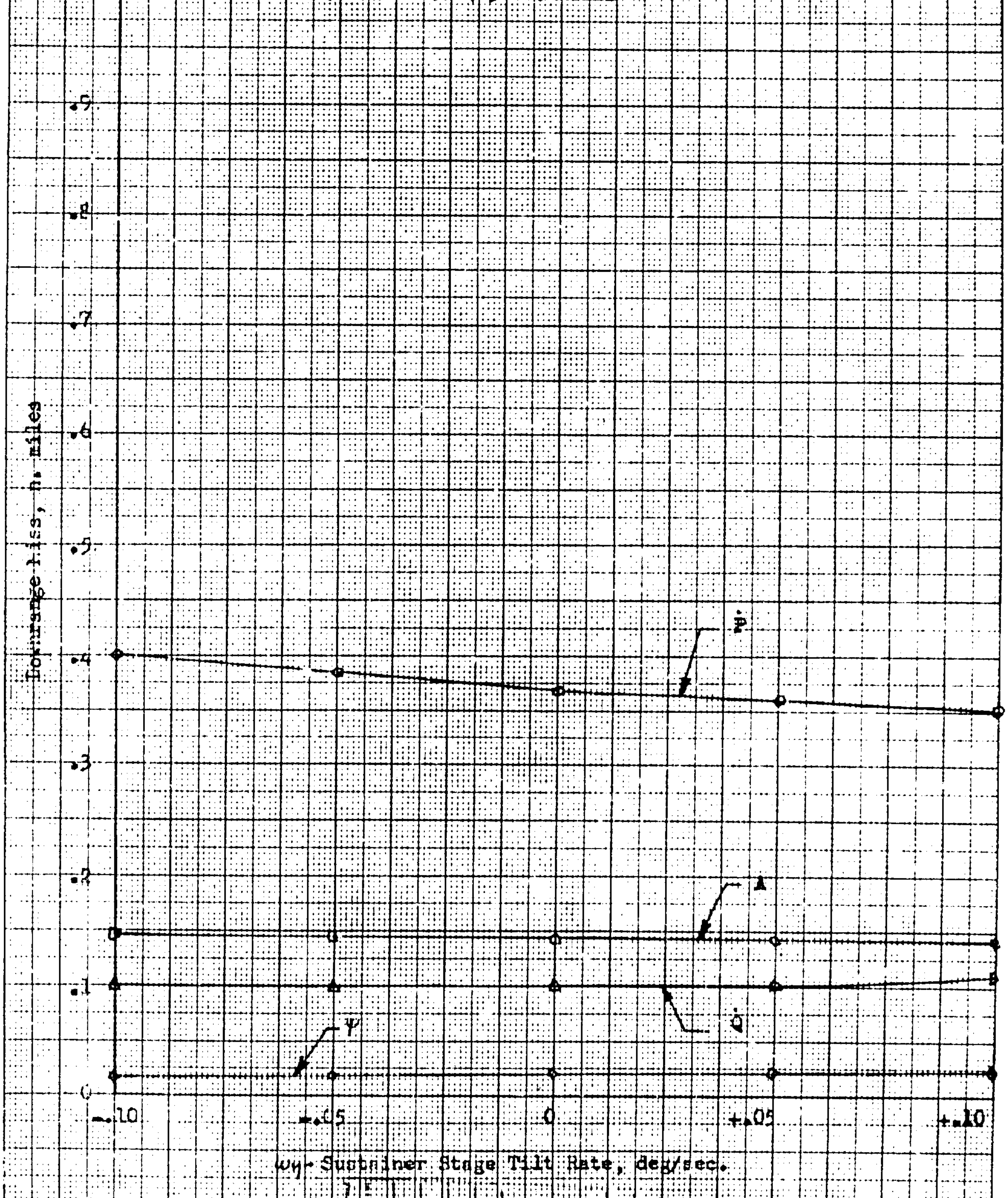


FIGURE 8(a)

CROSSRANGE MISS DUE TO MAJOR RIG ERROR SOURCES

FOR RANGE OF 4750 N. MILES



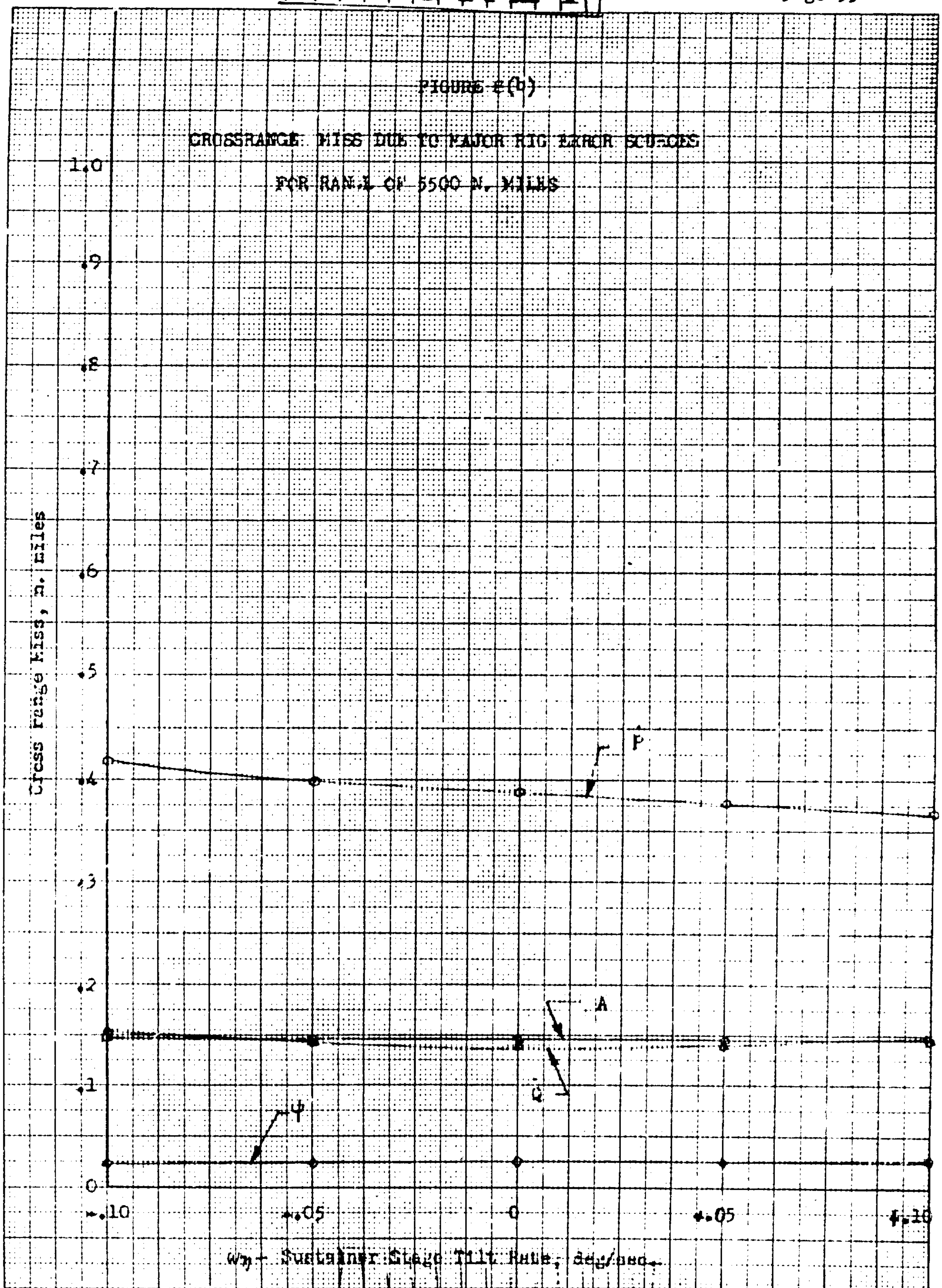


FIGURE 8(b)
CROSSRANGE MISS DUE TO MAJOR RIG ERROR SOURCES
FOR RANGE OF 5500 N. MILES
Cross Range Miss, n. miles
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
-.10
-.05
0
+.05
+.10
P
A
Q
ψ
ω_η - Sustainer Stage Tilt Rate, deg/sec.

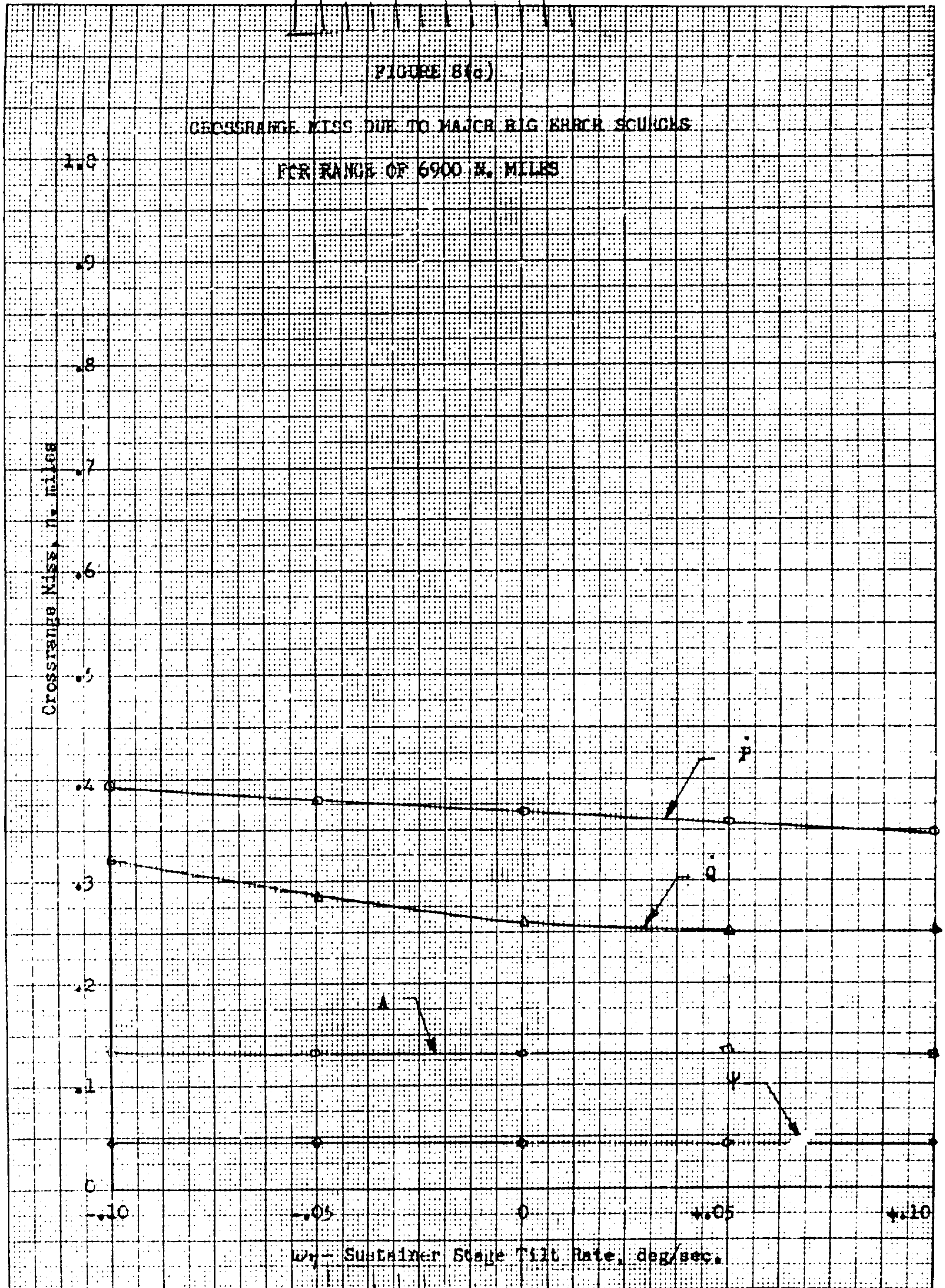


FIGURE 8(c)

CROSSRANGE MISS DUE TO MAJOR BIG ERROR SOURCES

FOR RANGE OF 6900 N. MILES

FIGURE 8(d)

CROSSRANGE MISS DUE TO MATCH RIG ERROR SOURCES FOR RANGE OF 5700 N. MILES

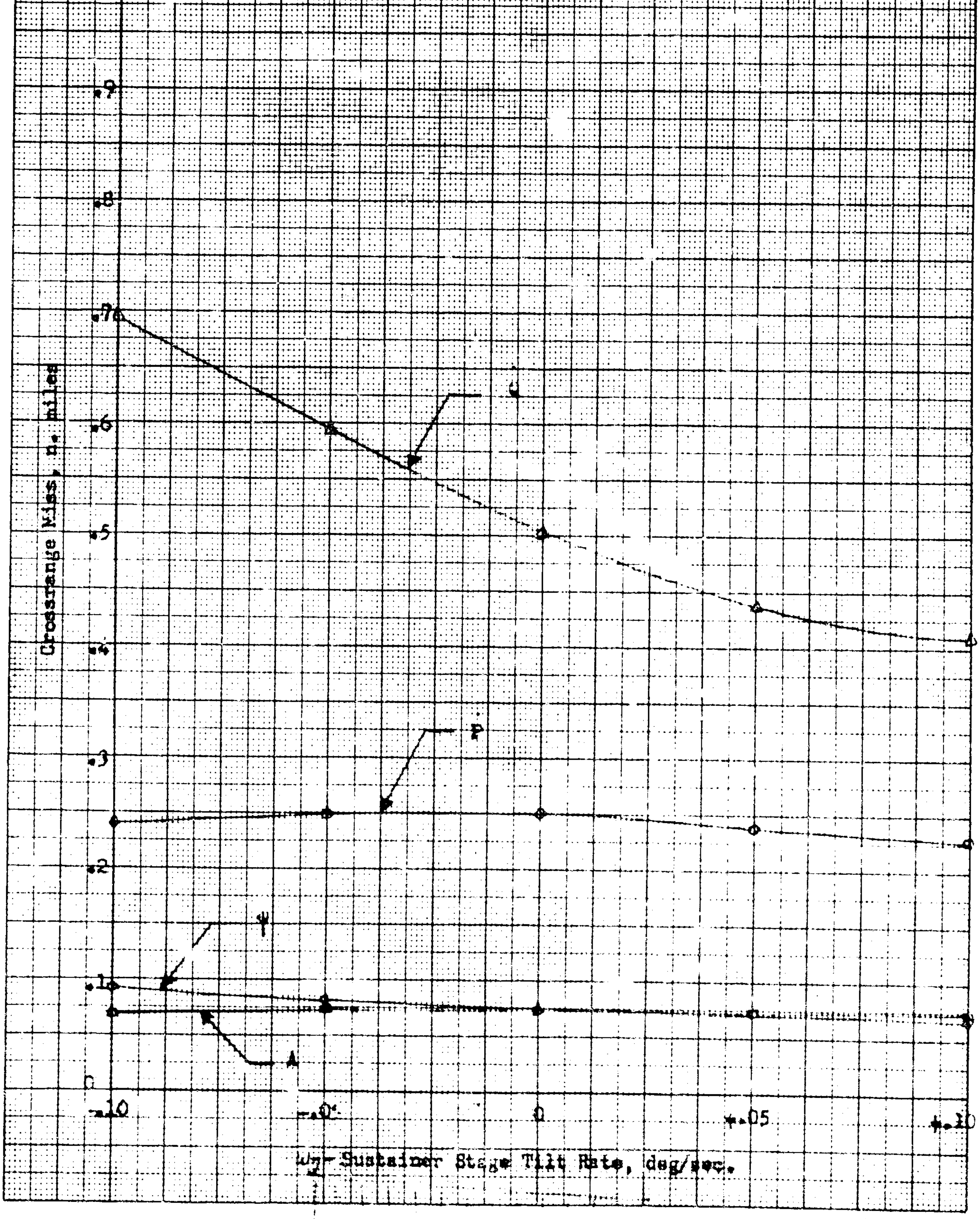


FIGURE 9

TOTAL AIG SYSTEM DOWNRANGE MISS

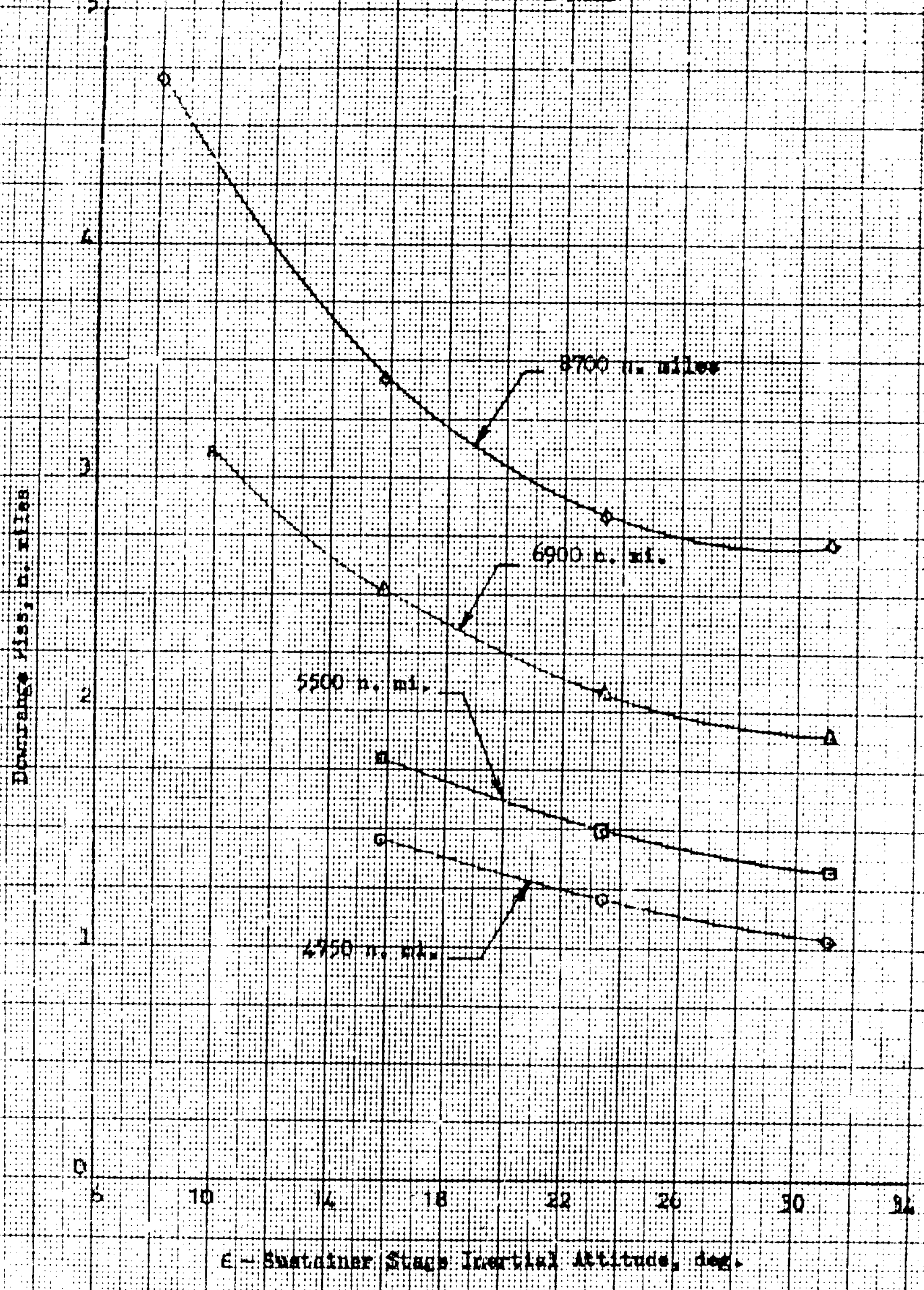


FIGURE 10

TOTAL AIG SYSTEM CROSSRANGE MISS

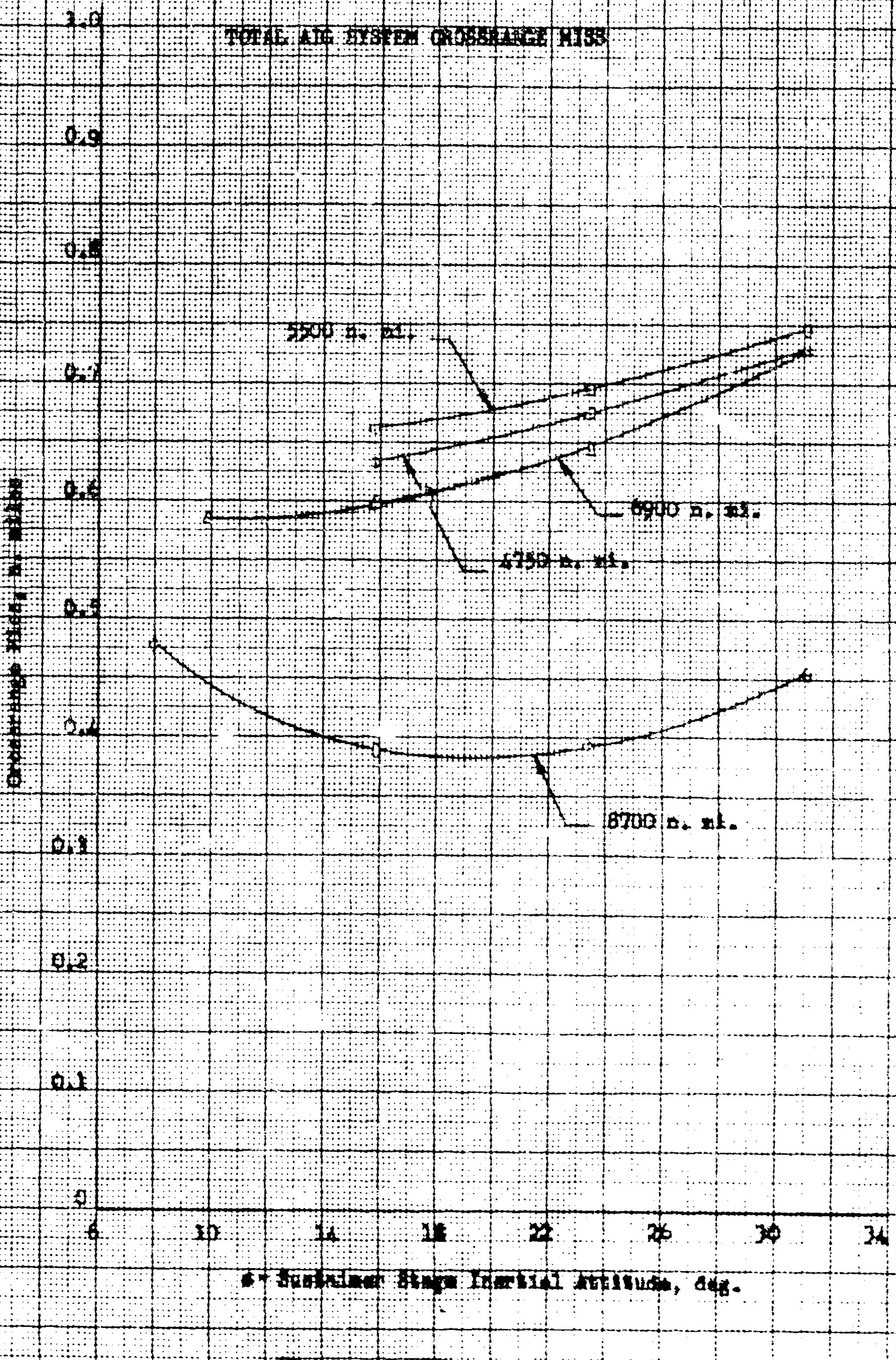


FIGURE 11(a)

DOWNRANGE MISS DUE TO MAJOR AIG ERROR SOURCES

FOR RANGE OF 4750 N. MILES

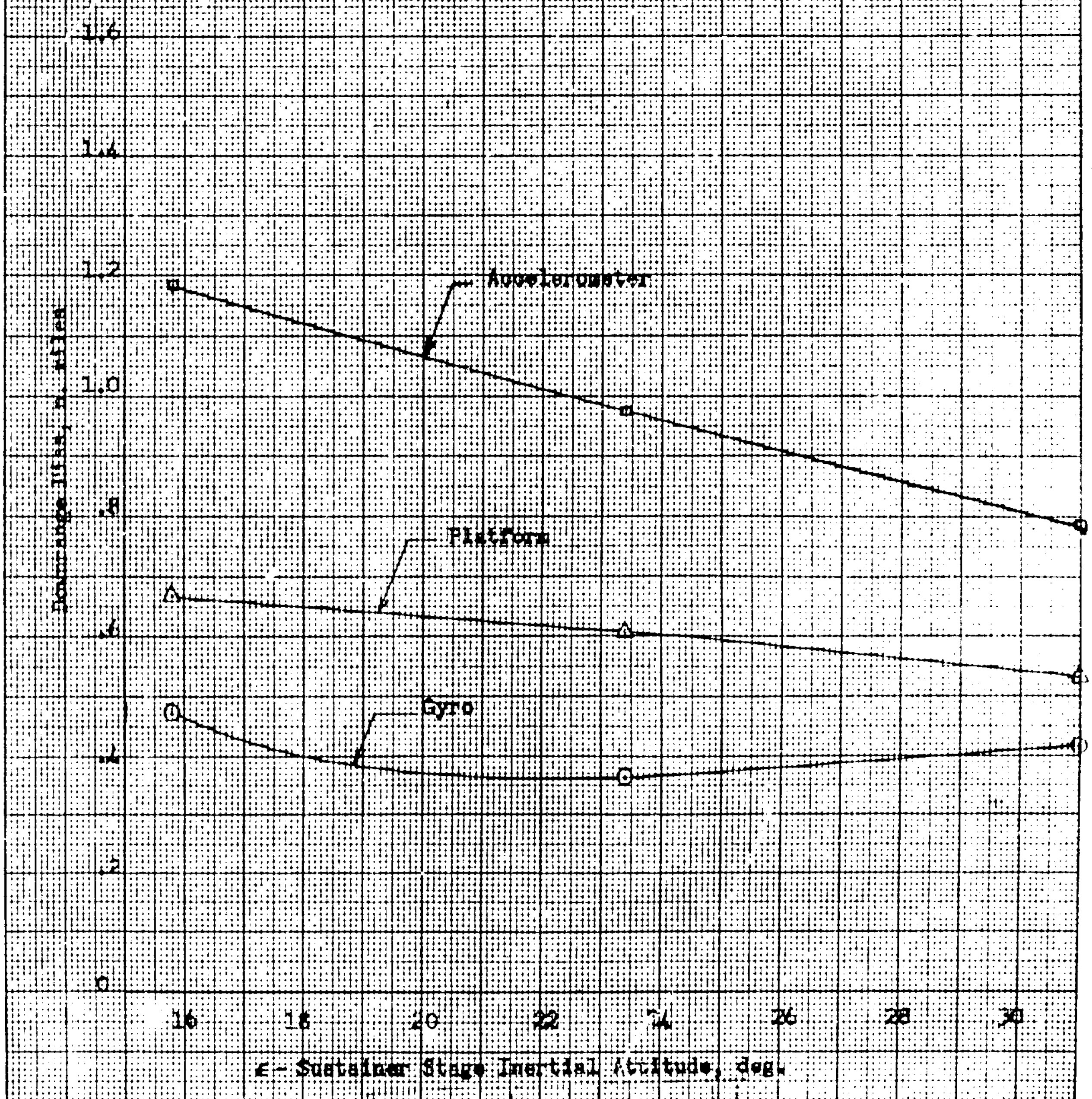


FIGURE 11(b)

DOWNRANGE MISS DUE TO MAJOR AIG ERROR SOURCES

FOR RANGE OF 5500 N. MILES

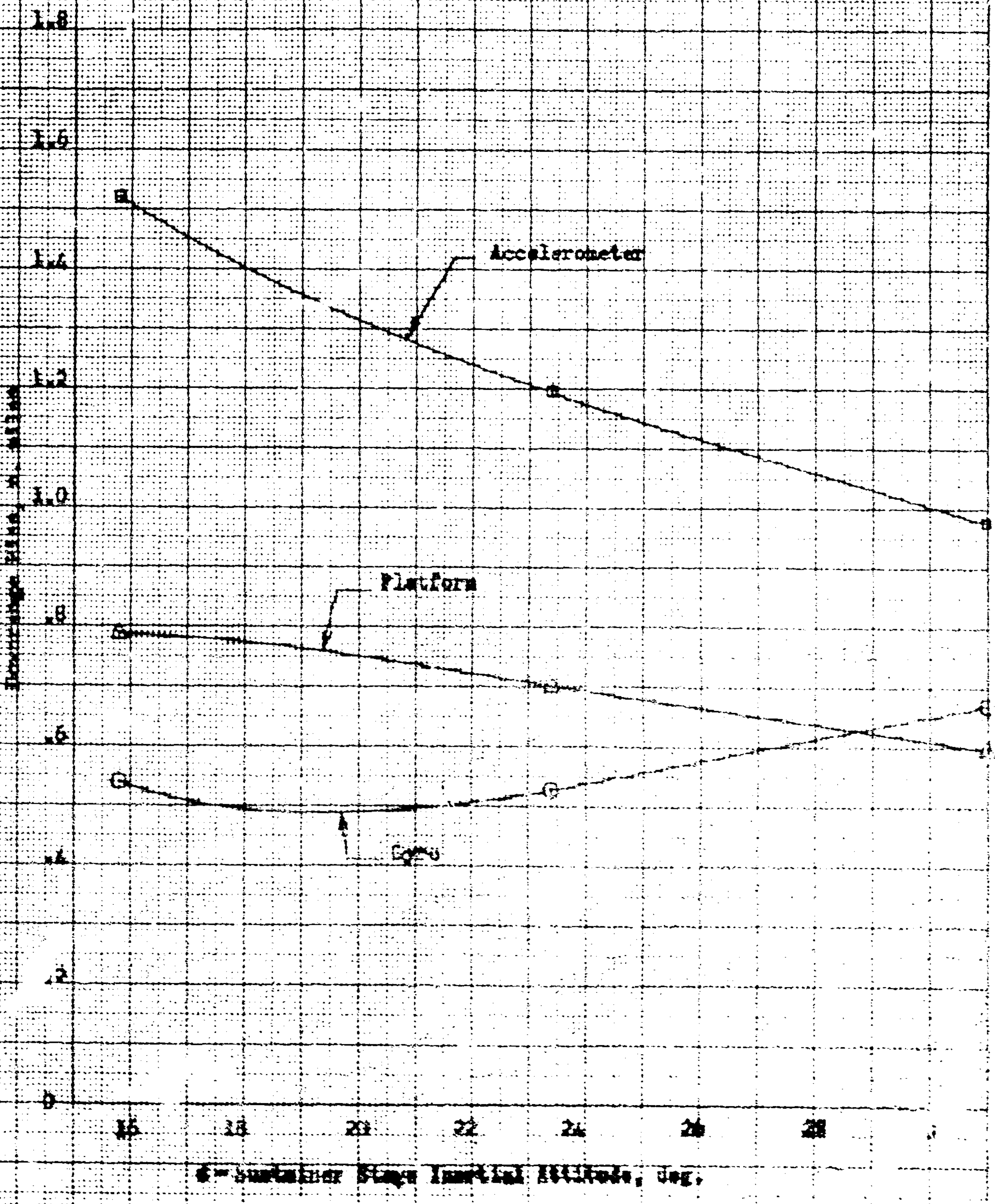


FIGURE 11(c)

DOWNRANGE MISS DUE TO MAJOR AIC ERROR SOURCES
FOR RANGE OF 6900 N. MILES

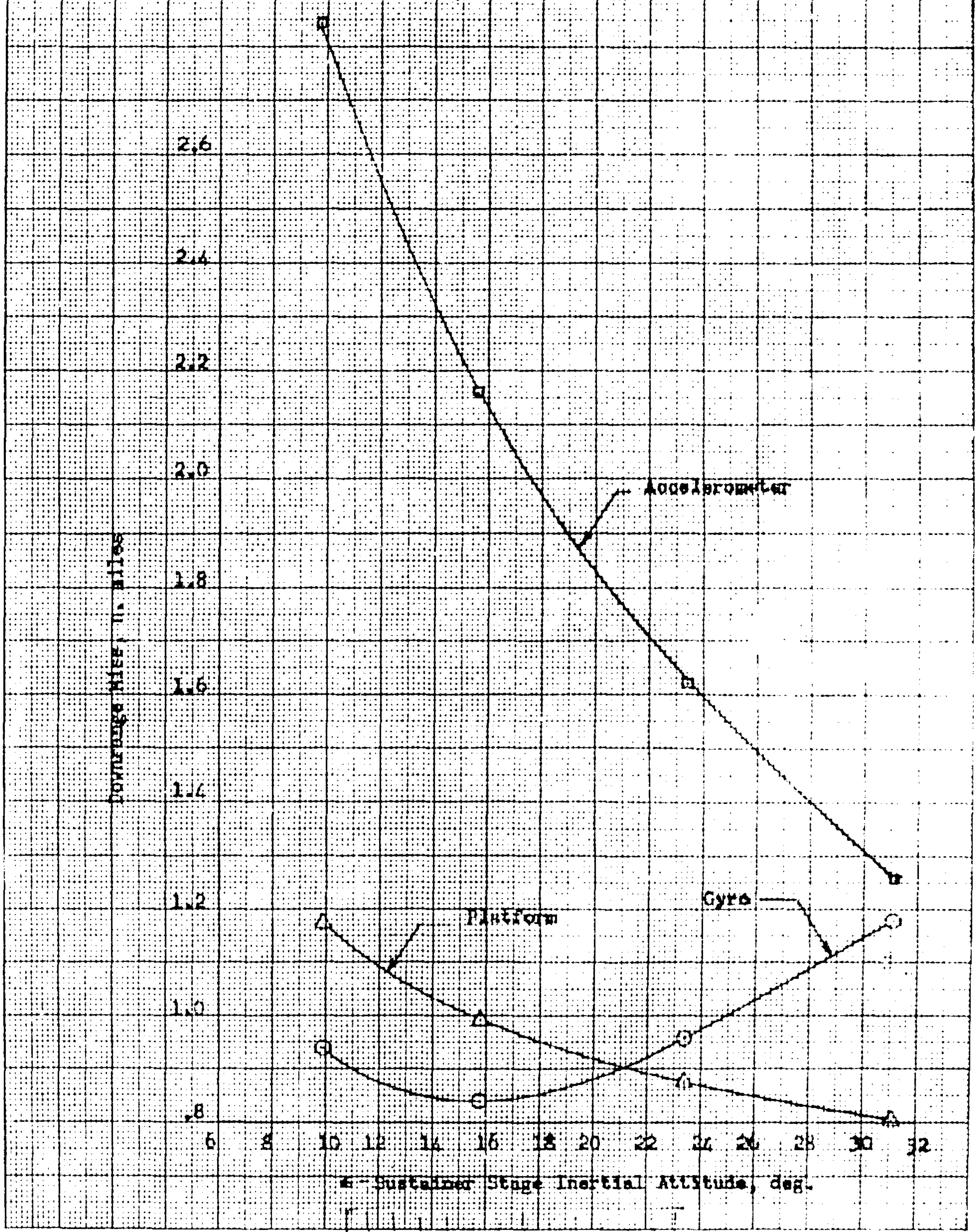


FIGURE 11(d)

DOWNRANGE MISS DUE TO MAJOR A&G ERROR SOURCES

FOR RANGE OF 8700 N. MILES

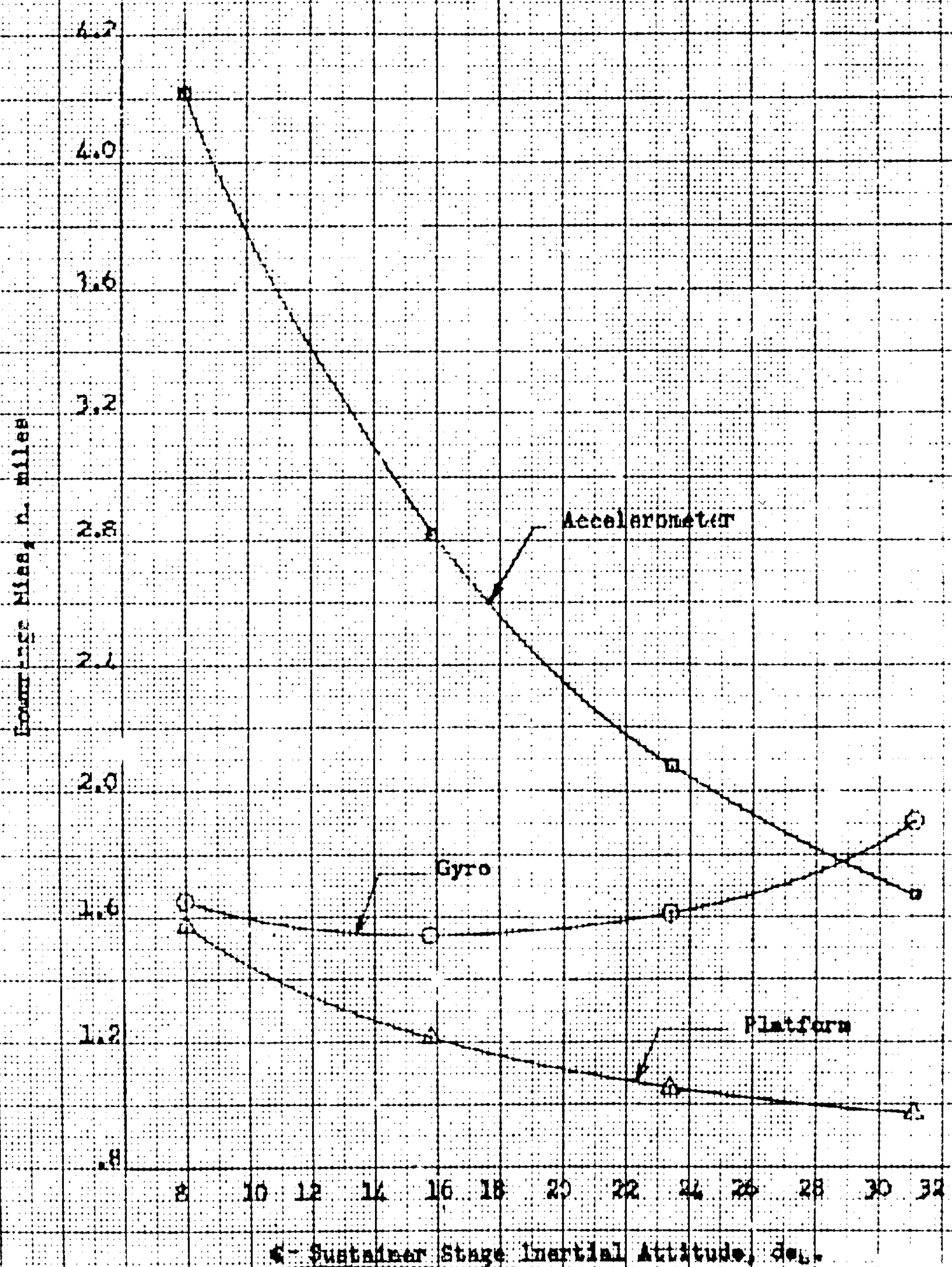
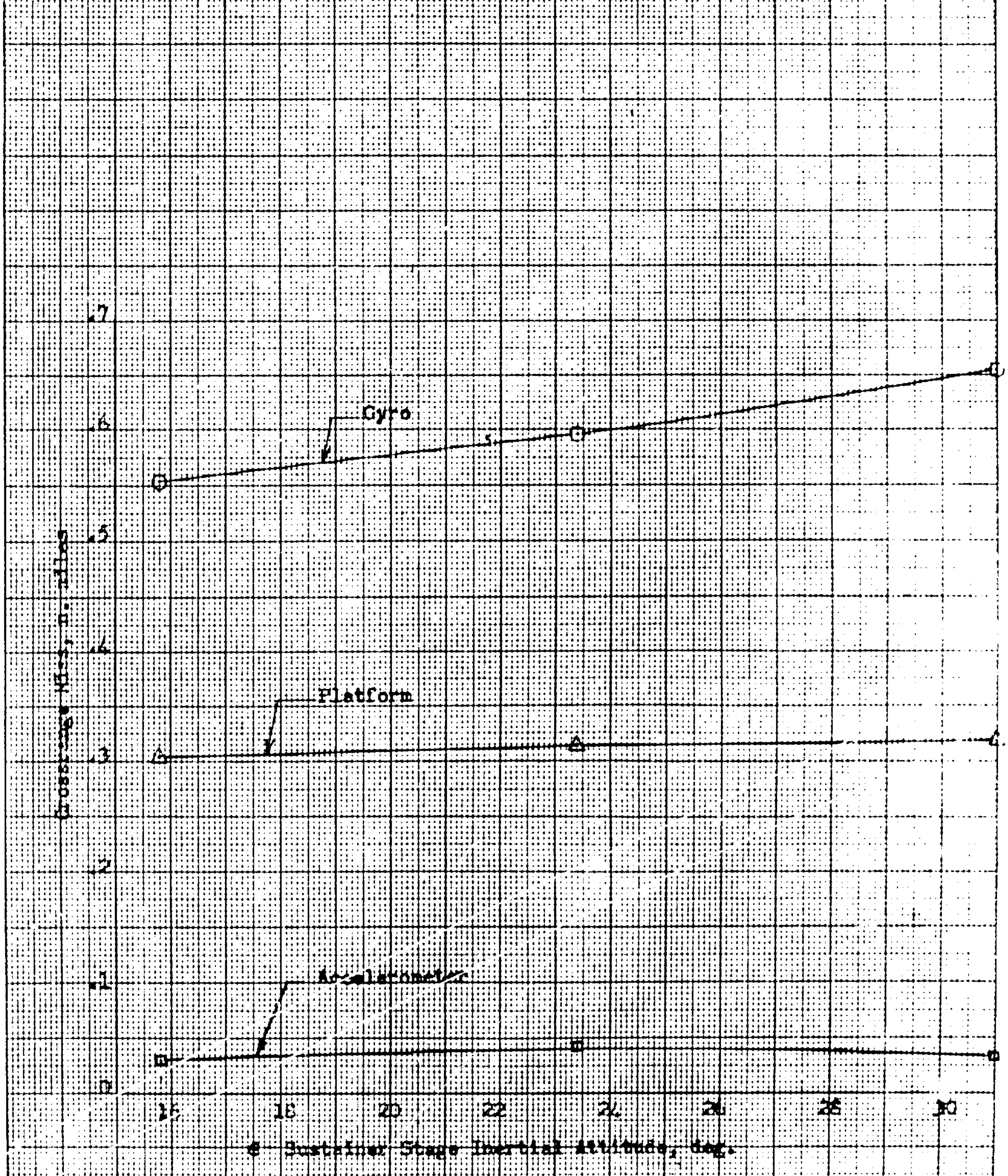


FIGURE 12(a)

CROSSRANGE MISS DUE TO MAJOR AIG ERROR SOURCES

FOR RANGE OF 4250 N. MILES



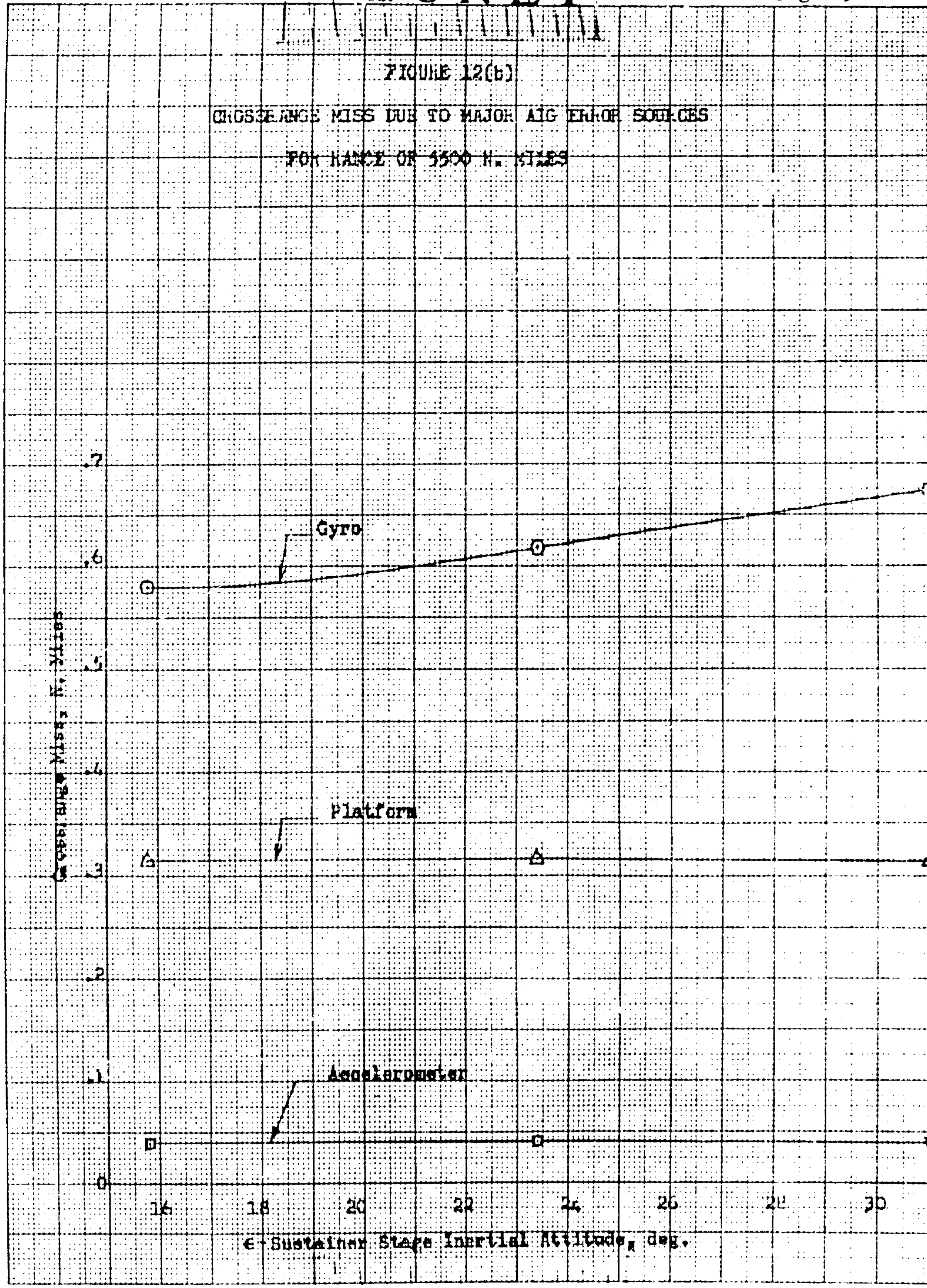


FIGURE 12(b)

CROSSRANGE MISS DUE TO MAJOR AIG ERROR SOURCES

FOR RANGE OF 5500 N. MILES

FIGURE 12(c)

CROSSRANGE MISS DUE TO MAJOR AND ERROR SOURCES

FOR RANGE OF 6900 N. MILES

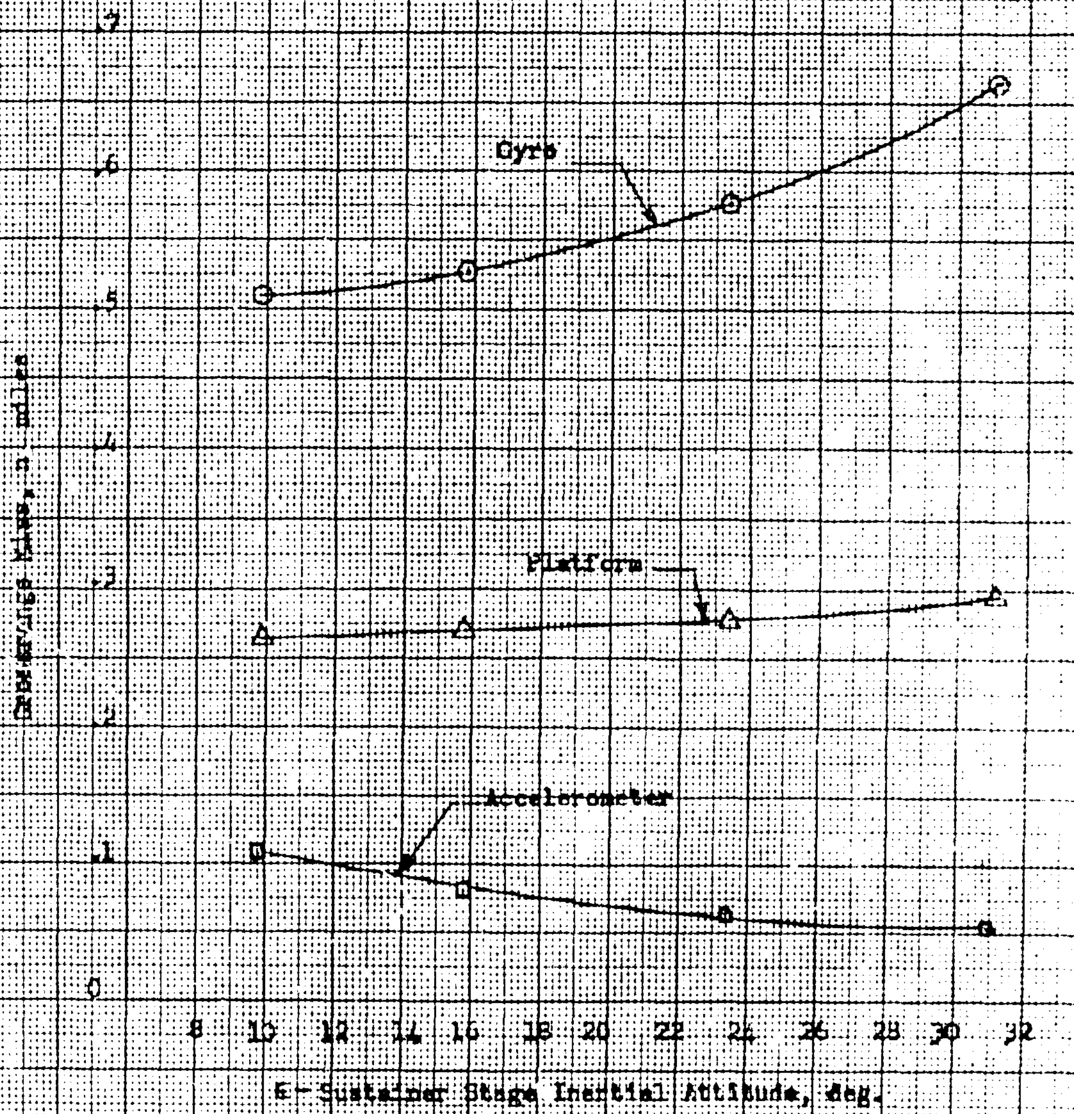
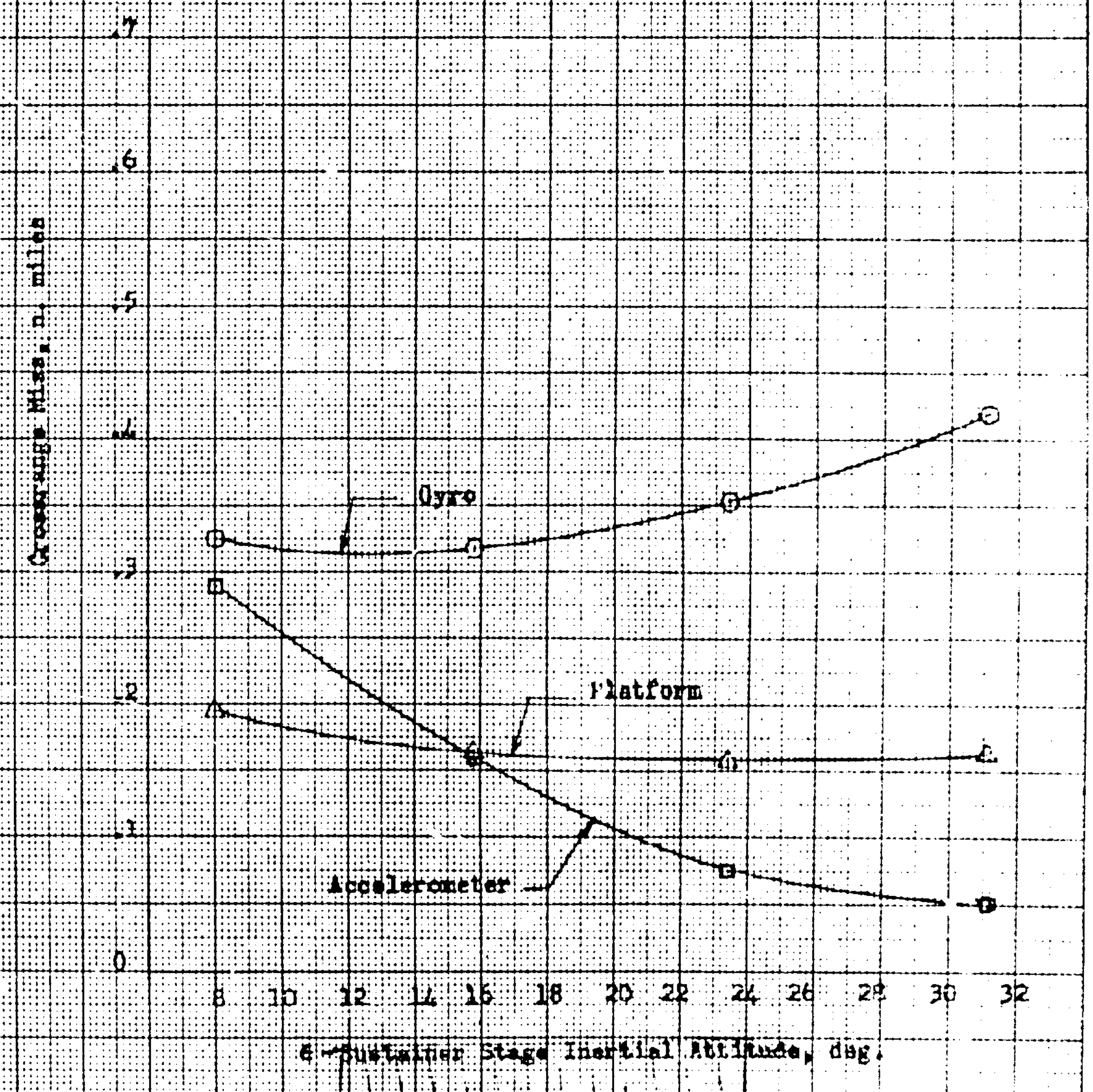


FIGURE 12(d)

CROSSRANGE MISS DUE TO MAJOR AIG ERROR SOURCES

FOR RANGE OF 5700 N. MILES



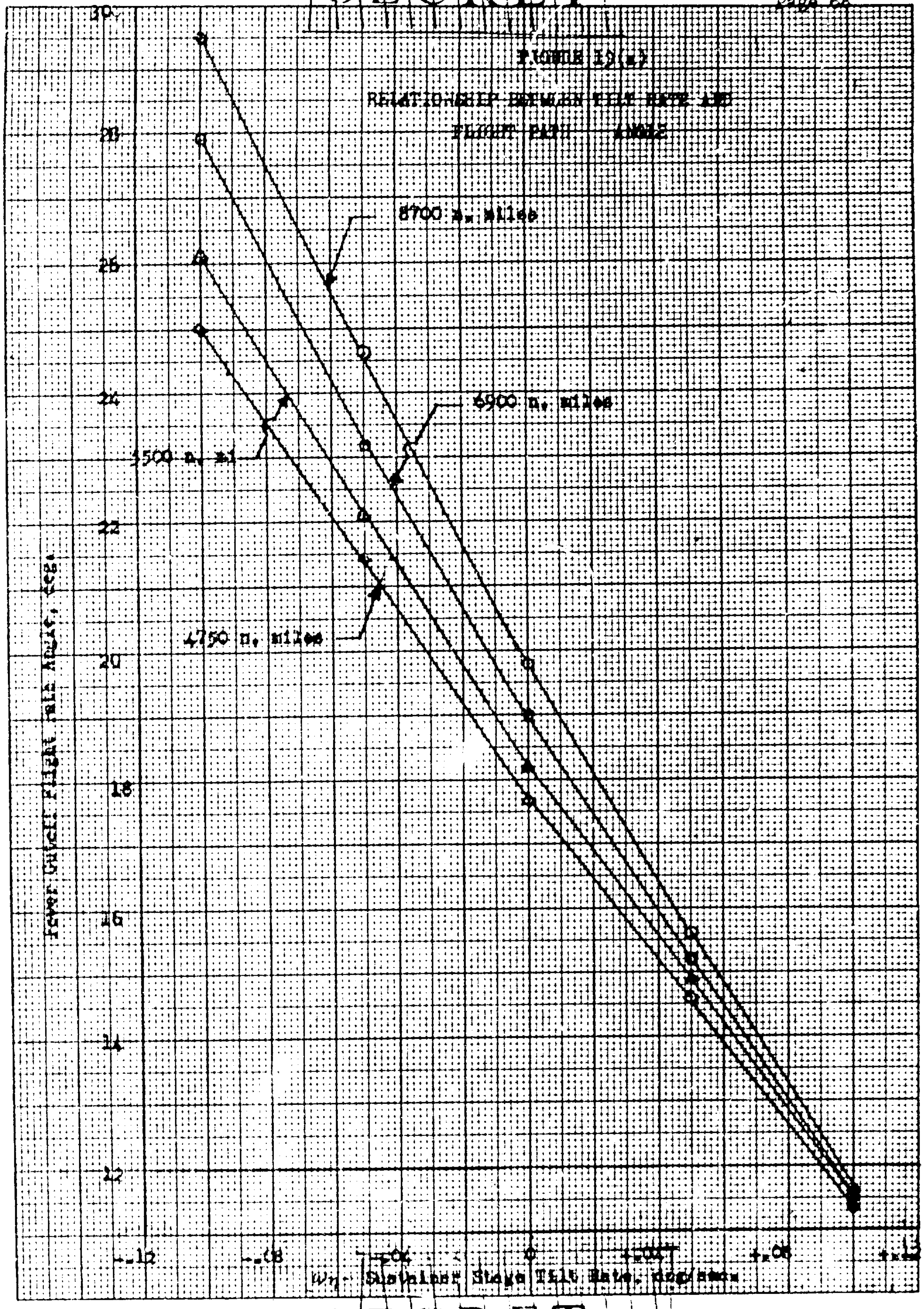
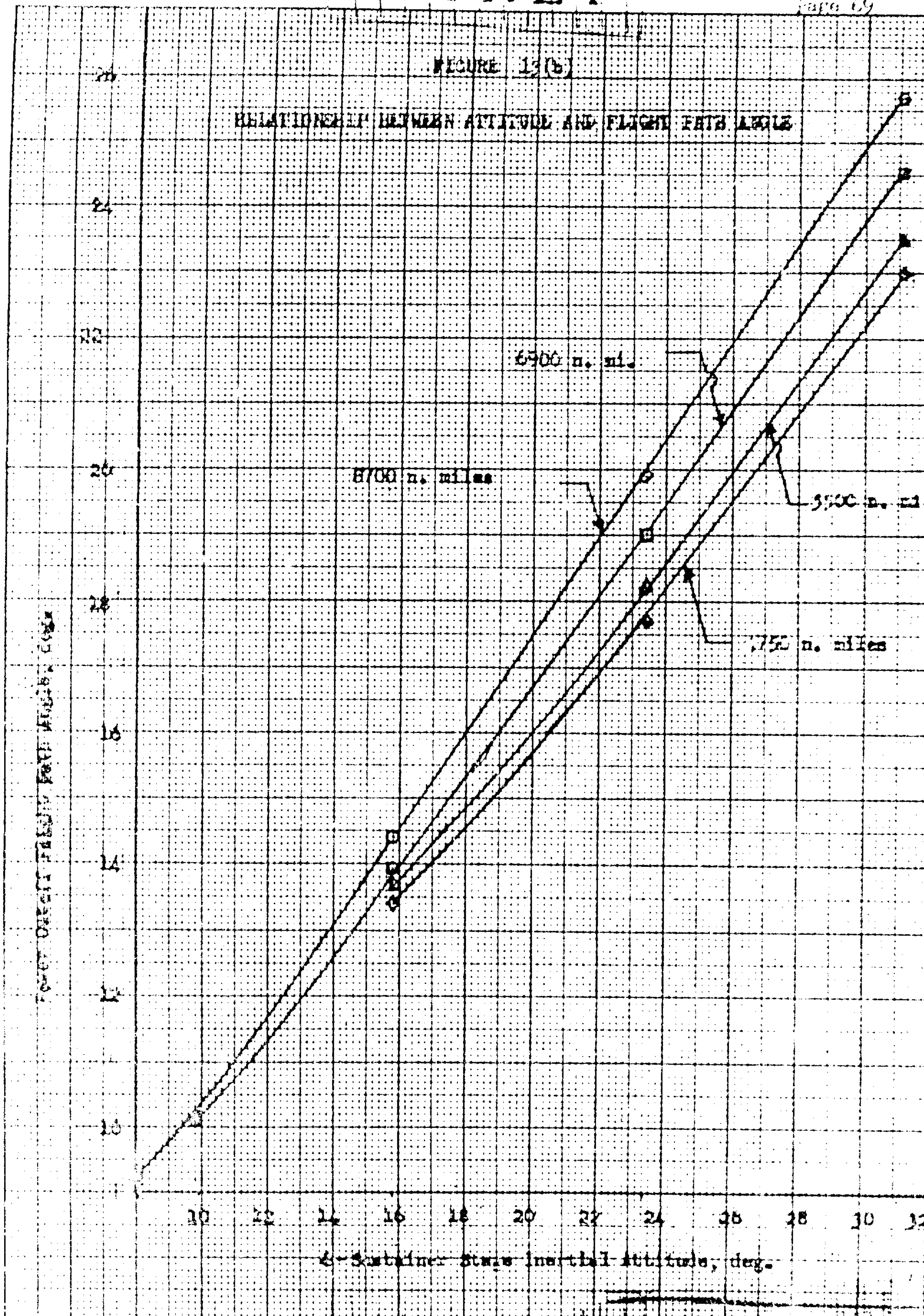

8700 n. miles
6900 n. miles
5500 n. mi
4750 n. miles
30
28
26
24
22
20
18
16
14
12
-.12
-.08
-.04
0
+.04
+.08
+.12

FIGURE 13(b)

RELATIONSHIP BETWEEN ATTITUDE AND FLIGHT PATH ANGLE



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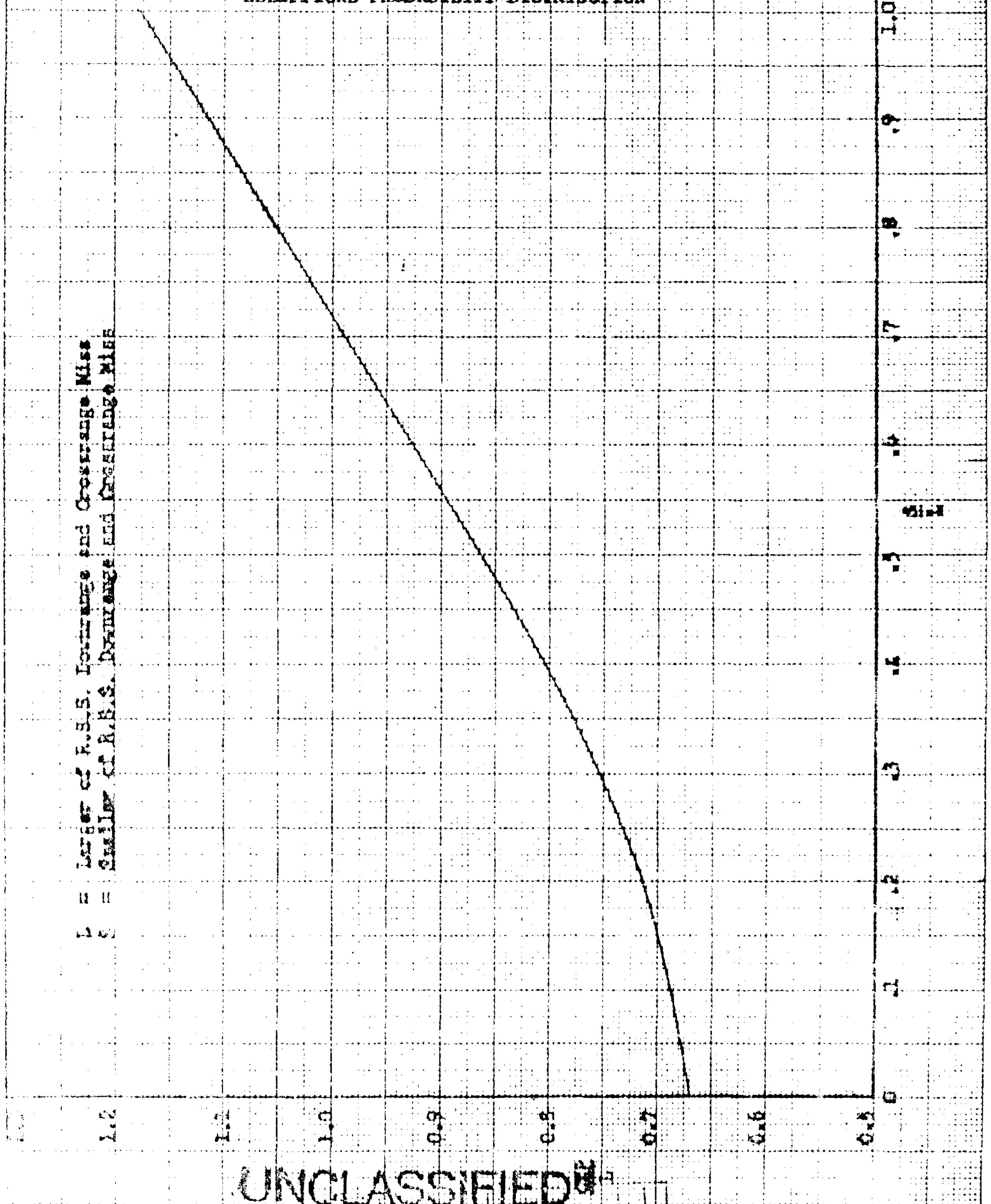
UNCLASSIFIED

FIGURE 14

CIRCULAR ERROR PROBABILITY
FROM
ELLIPTICAL PROBABILITY DISTRIBUTION



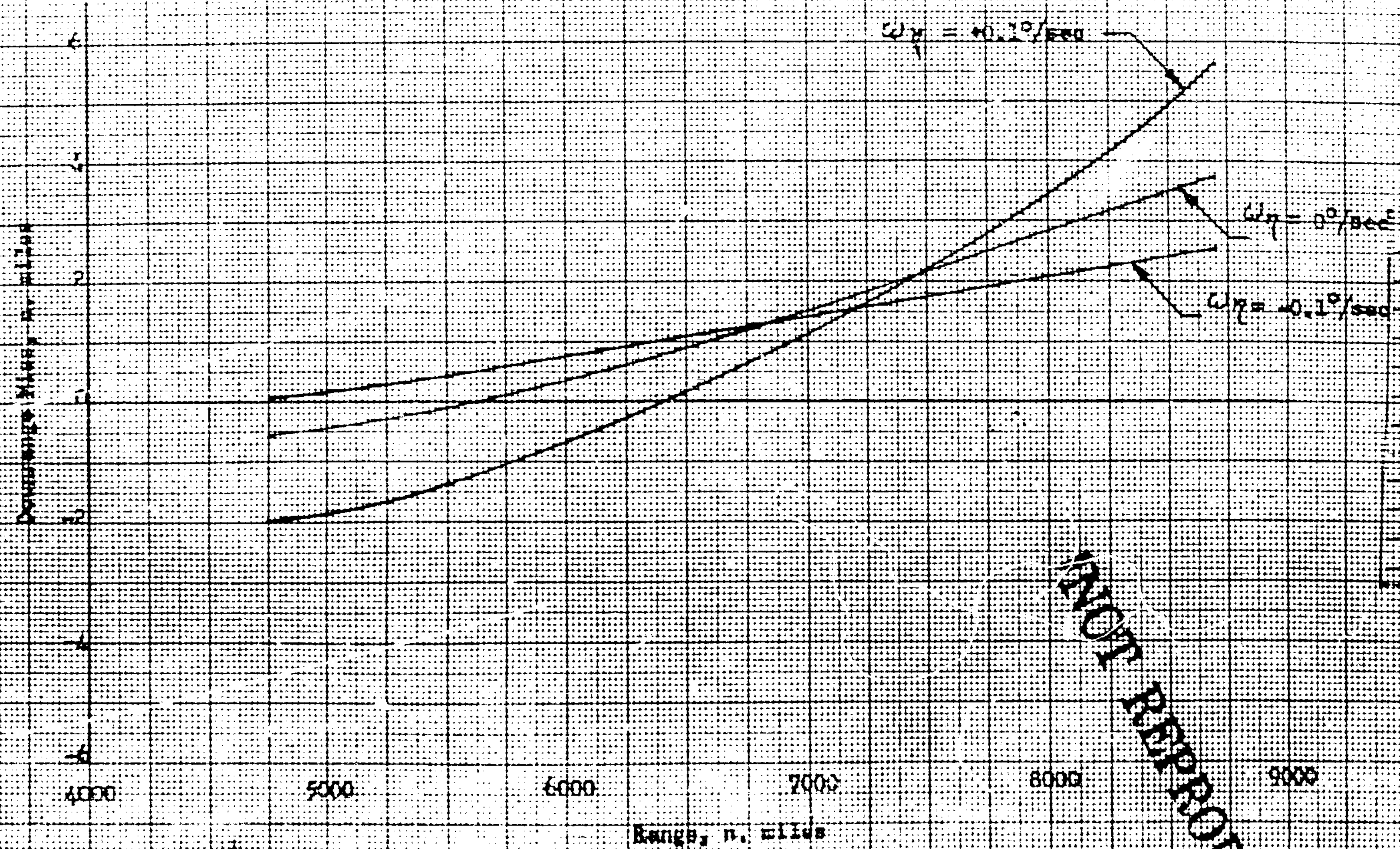
UNCLASSIFIED

SECRET

SECRET

FIGURE 15

DOWNRANGE MISS DUE TO $\dot{\eta}$ TRACKING ERROR



SECRET