RM A54K16

NACA

RESEARCH MEMORANDUM

TRACKING PERFORMANCE OF A SWEPT-WING FIGHTER WITH A DISTURBED RETICLE LEAD-COMPUTING SIGHT

By Burnett L. Gadeberg and George A. Rathert, Jr.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON
February 15, 1955
Declassified December 1, 1959

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SUMMARY

Standardized gunnery runs against a target airplane have been conducted with an F-86A airplane equipped with a disturbed-reticle gun sight (A-1). The tests were conducted to determine the effect of adding a disturbed-reticle computing sight of varying dynamic response to the pilot-airplane tracking loop which was previously tested with a fixed sight.

It was found that the tracking aim wander was not affected and remained nearly equal to the fixed-sight values. In his effort to track, however, the pilot induced control-line or gun-line motions which under some conditions were approximately twice as large as the tracking aim wanders. This increase was found to be consistent with the increase in the amplitude response of the sight computing mechanism resulting from operation at longer ranges.

INTRODUCTION

The Ames Aeronautical Laboratory has been investigating the influence of airplane flying qualities on gun-platform suitability for various combinations of airplanes, pilots, and fire-control systems. References 1 and 2 reported the results of initial tests in which only two dynamic elements, the pilot and the airplane, were involved in the closed tracking loop. The results of these tests determined the tracking effectiveness of several pilots using World War II fighters and high-performance swept-wing fighters with simple fixed-reticle optical sights. It was found that the pilots successfully adapted themselves to a surprisingly wide range of real and simulated stability and control characteristics and flight conditions.

The next stage of this investigation, reported herein, was to assess the effects of adding another dynamic element (a typical disturbed-reticle lead-computing gun sight) to the closed tracking loop. Figure 1 illustrates the position of this element in the loop and defines the angles pertinent to the tracking problem. When using the lead-computing sight, the pilot must track with a reticle loosely coupled to the airplane through the dynamic elements of the sight computer mechanism rather than with a fixed reticle which identically follows the airplane motion. With the computing sight the tracking-line wander (root mean square deviation from the mean of the reticle pip relative to the target) differs from the control-line wander (root mean square deviation from the mean of the airframe or gun-bore reference line relative to the target). With the fixed sight these variables were identical.

The present tests were designed to scrutinize three general problems:

1. Does introducing a loosely coupled reticle increase the pilot's tracking-line aim wander as compared to his aim wander with a fixed sight?

2. Are the control-line wanders or airplane motions produced by the pilot in his effort to track significantly larger than his fixed-sight aim wanders?

3. Can the control-line wanders be predicted from the results of fixed-sight tests using the known dynamic characteristics of the sight computer and considering that the input disturbances are a function of the pilot's varying frequence response?

The investigation was conducted at two altitudes, three Mach numbers, five values of normal acceleration, two ranges, and four values of sight damping.

TEST EQUIPMENT

Airplane

The airplane used for these tests was a standard North American Aviation, Inc., F-86A. Pertinent specifications are listed in table I. Photographs, drawings, and descriptions may be found in references 1 and 3.

Computing Gun Sight

An A-1 disturbed-reticle lead-computing-type gun sight was installed in the airplane. The operation of the sight may be understood by reference to the block diagram of figure 2 and the notation of the Appendix. Basically the sight consists of a gyroscopically actuated computer shaft which is restrained by an electro-magnetic spring and a viscous damper. The inputs to the sight, when operated in conjunction with fixed guns, are: (1) angular turning velocity of the airplane, (2) range, (3) altitude, and (4) normal acceleration. The output is the computed lead angle which is presented to the pilot by the position of an illuminated pip (2-mils[1] diameter) and concentric range circle. The computed lead angle is apparent to the pilot only indirectly as a displacement of the pip or tracking line from a fixed but invisible control line. The control line is fixed with respect to the airplane and may be considered as the bore line of the armament equipment. Tracking (continuous coincidence of the pip with the target) results in continuous correct lead-angle solutions within the accuracy of the computer. The correct computation of lead angle, for a given angular velocity input, is controlled by the electro-magnetic spring which is, in turn, a function of the range and altitude. A complete description and analysis of the sight may be found in reference 4 and a simplified description may be found in reference 5.

Radar range information is normally used as an input to the sight. For these tests, however, since it was desired to obtain data at constant sensitivities, the range information was set manually on the pilot's control and was held constant during any given run.

Instrumentation

A 16-millimeter, electrically driven, motion-picture camera (GSAP) was mounted on the sight head in the cockpit in the manner shown in figure 3. By the use of a right-angle prism the body of the camera was placed outside the pilot's line of vision but the scene recorded was that which the pilot saw. The camera was loaded with Kodachrome film and was set at f/11 and 16 frames per second. Color film was used because it was found to be easier to read than black-and-white film under the widely different exposure conditions encountered in flight. Although standard NACA recording instruments were installed in the airplane, only the pilot's reported Mach number, altitude, and normal-acceleration factor were utilized, since these were considered to be sufficiently accurate for the purposes of this report.

Pilot

It was found from the results of fixed-sight tests reported in reference 1 that little difference could be detected in the tracking performance of the pilots available. As a consequence one pilot was utilized for the complete series of tests reported herein. A description of this pilot's flying experience is presented in reference 1 under the heading of "Pilot A."

[1]A mil is defined as 0.001 radian.

TESTS

Test Maneuver

The same standardized repeatable maneuver was used for these tests as that described in reference 1. The maneuver (fig. 4) consisted of an initial entry ending in straight-and-level flight; a straight-and-level portion; then a transition to steady-turning flight; and finally a steady-turn portion. Each of the two steady-state portions was held for approximately 35 to 40 seconds. This standardized maneuver was utilized so that (1) as many flight conditions as possible, such as Mach number, altitude, and normal acceleration, could be kept reasonably constant, and (2) statistically significant amounts of data could be obtained in a single run at the selected flight condition (for a discussion of what constitutes a statistically significant amount of data see ref. 6, pp. 16-20).

Altitude was maintained during the 1g portion of the run. During the turns, only enough altitude was lost so that constant Mach number could be maintained with constant throttle setting. (No more than 3,000 feet of altitude was lost during any one run.) The range between the airplanes varied somewhat during any given test maneuver due to the requirement of constant throttle setting. The variation did not exceed 50 percent of the initial range and was not considered significant for these tests. The aiming point on the target was the tailpipe exit at all times.

Flight Conditions

The tests were conducted at the various combinations of the conditions of stability number (a parameter, representing the internal damping of the sight, to be discussed later), range, altitude, Mach number, and normal-acceleration factor listed in table II. The test conditions were chosen from the normal operating ranges of the airplane below the pitch-up and buffet boundaries, hence the different ranges of Mach number and normal acceleration at the two different altitudes. All of the test data were obtained in smooth air conditions typical of the test altitudes.

DATA REDUCTION METHODS

The gun-sight camera records were assessed on an automatically recording projection-type film reader. The resultant readings were automatically recorded on paper tape by an electric typewriter and were simultaneously punched on IBM calculating cards. Both the elevation and deflection components were recorded simultaneously, and each component of both the tracking line and the control line was determined with respect to the target as origin. The control line was defined by a set of four reference marks recorded on each frame of the film.

After the film data had been assessed, time histories were plotted automatically from the IBM cards. The steady-straight and steady-turn portions of each run were then determined visually by inspection of the time histories. The mean or bias errors and the standard deviation or aim wanders were then determined by IBM electronic computing machines for the two steady portions of the runs. The bias errors are defined by the equations

$$\bar{x} = \frac{\Sigma x}{n}, \quad \bar{y} = \frac{\Sigma y}{n}$$

and the aim wanders by

$$\sigma_x = \left[\frac{\Sigma(x - \bar{x})^2}{n}\right]^{1/2}, \quad \sigma_y = \left[\frac{\Sigma(y - \bar{y})^2}{n}\right]^{1/2}$$

The errors were expressed in rectangular coordinates of elevation and deflection instead of polar coordinates in order to associate them with their respective computer function within the gun sight.

The mean and standard deviations have been used since aim errors follow a random process and show a Gaussian or normal distribution (ref. 1). Thus, it can be assumed that the aim error will be within plus or minus one standard deviation from the mean value for 68 percent of the time.

The accuracy of the aim-wander measurements was investigated during the fixed-sight tests and was reported in reference 1. It was found that since the pip was 1-1/2 to 2 mils in diameter and the aiming point (the tailpipe exit) as much as 2 mils in diameter, there was a definite limit to the size of an aiming error which was apparent to the pilot and resulted in corrective action. Repeated experiments at different ranges indicated that the pilot allowed the center of the pip to drift a maximum of 1 mil from the center of the aiming point without considering a tracking error to exist. The aim errors on individual frames of the gun-camera film were read with a similar accuracy of ±1 mil. In order to check the accuracy of the aim-wander calculation, one 45-second length of film record was completely analyzed twice. The difference between the two resulting aim wanders was only 0.3 mil. Since it was considered that the above checks applied equally well to the A-1 sight tests they were not re-evaluated.

RESULTS AND DISCUSSION

The discussion is organized in accordance with three general problems outlined in the Introduction. The bias-error and aim-wander data for the tracking line and control line are presented first as functions of the flight conditions and the sight parameters for comparison with the basic fixed-sight test results from reference 1. The frequency-response characteristics of the sight mechanism are considered next, both to explain the control-line behavior and to explore the possibility of predicting control-line behavior from fixed-sight data and the sight frequency response.

For one run, typical time histories of the control-line and tracking-line wanders for both the elevation and deflection components are presented in figure 5. The figure has been marked to show the entry, steady-state 1g, transition, and steady-state-turn regions. The effect of lead computation by the sight may be observed in the control-line time histories by the differences in the levels of the means between the steady 1g and steady-turn portions of the record.

Tracking-Line Performance

Bias errors.- The bias errors for the tracking line are similar to those reported in reference 1 for the fixed sight. The values were low and showed no significant trends with any of the flight conditions or sight parameters. The data are summarized and compared with the fixed-sight results from reference 1 for the F-86A airplane in the following table:

Sight	$\bar{x}_{average}$	$\bar{y}_{average}$
A-1 (128 runs)	0.0(-2.4 to 2.1)[a]	-0.1(-2.2 to 1.3)
Fixed (96 runs)	0.6(-1.3 to 2.2)	2.6(0.6 to 4.7)

[a]Wherever averaged data are compared, the amount of scatter present has been indicated by placing in parentheses the range of values which include 90 percent of the observed data; thus, $\bar{x}_{average} = 0.0$ with 90 percent of the test points falling between -2.4 and 2.1.

As with the fixed-sight results, the errors are probably within the limit of the pilot's ability to perceive when an error is large enough to require correction. For this reason the tracking-line bias-error data are considered not to reveal anything significant about the effects of the computing sight on tracking performance.

Tracking-line wander.- Plots showing the variation of tracking-line wander with normal-acceleration factor at noted Mach numbers and altitudes are presented in figures 6(a) through 6(h) for each of the combinations of stability number and range. All of the data presented were obtained below the pitch-up boundary of the F-86A and outside the wake of the target airplane, since reference 1 indicated these conditions make it prohibitively difficult for the pilot to track a target even with a fixed sight.

The aim wanders of the tracking line appear to be practically unaffected either by changes in flight conditions, as was the case for the fixed-sight data in reference 1, or by changes in range and stability number. The over-all averages are compared with the data from the fixed-sight tests in the following table:

Tracking-line wander		
Sight	$\sigma_{x_{average}}$	$\sigma_{y_{average}}$
A-1 (128 runs)	2.4(1.2 to 4.7)	2.3(0.8 to 4.6)
Fixed (96 runs)	2.6(1.1 to 5.2)	2.7(1.0 to 4.2)

The tracking-line aim-wander averages are almost identical to those found with the fixed sight, and even the spread including 90 percent of the data points is within 0.5 mil of the fixed sight results in each case. Thus, it may be concluded that introducing a disturbed-reticle sight mechanism with a wide range of dynamic response characteristics did not significantly change the pilot's ability to track.

Control-Line Performance

Bias errors.- The bias errors of the control line reflect the computed prediction angles or lead and were used only as a static check on the operation of the sight; therefore, no data are presented.

Control-line wander.- The control-line wanders, figures 6(a) through 6(h), do not vary systematically with Mach number or normal acceleration. However, the effects of range, altitude, and stability number are not so readily apparent. To clarify these effects, the values for the various Mach numbers and accelerations have been averaged for each of the combinations of range, altitude, and stability number and are compared with the over-all averages of the fixed-sight and the computing-sight tracking-line wanders in table III.

From this table it may be seen that the control-line wanders increase with increasing range for each condition of stability number and altitude. The effects of stability number and altitude are not so readily apparent and will be discussed later. In comparison with the fixed-sight and computing-sight tracking-line values (first two lines of table III), it appears that the pilot under some conditions induces about twice as much motion of the control line in order to track successfully as he used with the fixed sight. Since airborne weapons are generally rigidly attached to the control line, this increased motion is considered to be quite significant for guns and some types of rockets.

Dynamic Response Characteristics

The amplitude of the motions of the tracking line or sight reticle can be expressed as the movements of the control line multiplied by the proper dynamic-response amplitude ratio of the sight computer mechanism. Since the preceding tracking-line wanders show that the amplitude of this product was small and nearly constant under all test conditions, the control-line wanders should be a function of the sight dynamic characteristics. The parameters used in the existing literature to express these characteristics are the characteristic time CT, sensitivity S_p, and stability number SN. The significance of these three parameters may be appreciated by considering the differential equations of the sight mechanism.

The sum of the moments acting on the deflection-channel computer shaft (see fig. 2) is

$$F_x - kP - c\dot{P} = 0$$

We define $S_1 = \frac{F_x}{\dot{\theta}}$, then

$$c\dot{P} + kP = S_1\dot{\theta}$$

provided that the mass of the moving parts and their accelerations combine to produce a negligibly small inertia term and that the uncertainty torque components and velocity components other than the one about the deflection axis can be neglected. If the equation is divided by the spring constant k and we define $CT = \frac{c}{k}$ and $S_p = \frac{S_1}{k}$, then the mechanism equation becomes

$$CT\,\dot{P} + P = S_p\dot{\theta}$$

or

$$\frac{P}{\dot{\theta}} = \frac{S_p}{1 + CT\ D}$$

The characteristic time CT now defines the exponential decay curve followed by the computer shaft after the shaft is released from an initial deflection corresponding to an initial value of $\dot{\theta}$. This type of test may be readily made on the ground. The sensitivity S_p determines the static lead angle P generated per unit input. If we now consider that the mechanism is being operated as a sight and an attempt is being made to track the target with the pip, it may be seen from figure 1(c) that

$$\theta = P + TL + LS$$

and

$$\dot{\theta} = \dot{P} + \dot{TL} + \dot{LS}$$

For the case of perfect tracking,

$$\dot{TL} = 0$$

and

$$\dot{\theta} = \dot{P} + \dot{LS}$$

Substituting for $\dot{\theta}$ in the mechanism equation, the equation of the sight while tracking then becomes

$$CT\,\dot{P} + P = S_p\dot{P} + S_p\dot{LS}$$

and

$$S_p\left(\frac{CT}{S_p} - 1\right)\dot{P} + P = S_p\dot{LS}$$

When the stability number is defined as

$$SN = \frac{CT}{S_p} - 1$$

the equation becomes

$$S_pSN\,\dot{P} + P = S_p\dot{LS}$$

or

$$\frac{P}{\dot{LS}} = \frac{S_p}{1 + S_pSN\ D}$$

The product S_p SN now represents the characteristic time when the input to the sight is $L\dot{S}$. The stability number has the interesting property, which may be verified by considering the definitions of CT and S_p, of being a function only of the damping coefficient c, and this is invariant in flight. Moreover, it controls the initial movement of the pip relative to the target when the input to the sight mechanism $\dot{\theta}$ is altered. It can be shown that if the stability number is positive, the pip (relative to the target) will move in the same direction as the initial angular acceleration applied to the tracking airplane and will thus facilitate the tracking process. On the other hand, if the stability number is negative, the pip will initially move away when an attempt is made to realine it with the target and, consequently, will tend to confuse the pilot. Variations of the stability number during the tests were obtained by altering the temperature of the damping oil.

It is intended first to examine these parameters separately and then to consider the response of the complete system in the more familiar form of the amplitude and phase-angle response to a sinusoidal input.

Characteristic time.- In figure 7 the wanders of both the control line and the tracking line are presented as a function of the characteristic time for both the deflection and elevation components. Values of the characteristic time were determined by both damping and sensitivity. The fixed-sight aim wanders for reference 1 have been plotted at zero characteristic time which corresponds to an instantaneous solution of the lead-angle computation. The tracking-line wander remains almost constant at a value equal to the fixed-sight results but the control-line wander increases linearly with characteristic time to about double the fixed-sight values at the longest time tested of about 1.8 seconds. At short characteristic times the control-line wanders are about equal to the fixed-sight and tracking-line wanders. Of the various flight conditions tested, a short characteristic time primarily corresponds to the shorter target range where the required lead to be computed is small.

Sensitivity.- Since the sensitivity (S_p) is a function of both range and altitude, four sensitivities were tested as indicated in the following table:

Sensitivities, S_p, sec		
Range, ft \ Altitude, ft	10,000	35,000
1,000	0.27	0.19
3,000	1.18	0.93

The effect of sight sensitivity on the wander may be assessed from figure 8. Here the wanders of the elevation and deflection components of both the control line and the tracking line have been plotted as a function of the sight sensitivity. The results here are similar to those observed in figure 7 where aim wander was considered as a function of the characteristic time. The greater the sensitivity (the looser the coupling between the control line and the tracking line), the greater the wander of the control line was found to be, whereas the aim wander for the tracking line remained almost constant.

Stability number.- In figure 9 the wanders have been plotted as a function of the stability number for the various combinations of range and altitude. For both the control line and the tracking line, it appears that the stability number is not a significant parameter in determining the magnitude of the wanders within the present range of test conditions.

Amplitude response.- Characteristic time and sensitivity have been identified as significant variables; however, to understand their effects it is easier to work directly with the amplitude response of the sight mechanism. Figure 10 presents the theoretical amplitude and phase-angle response to a sinusoidal input as a function of the sensitivity and frequency for constant values of stability number. These curves were derived from the sight mechanism equation discussed previously. The stability number has been used to ease the nondimensional presentation.

A direct flight check of the numerical accuracy of these curves was made for one flight condition. The control line was operated at a single frequency and amplitude for several cycles and the resulting ratio of control-line to tracking-line motion was shown to correspond closely to that predicted by the theoretical curves.

A consistent qualitative explanation for the increase in control-line wander with increasing characteristic time or sensitivity (at constant tracking-line wander) can be seen in figure 10. The increase in amplitude response with increasing values of the sensitivity-frequency product implies that the pilot must increase the amplitude of his control-line motions proportionally in order to return the reticle to the target when making aim corrections.

However, in addition to the amplitude, the pilot is also free to vary the frequency of his control motions. Both factors must be known before a quantitative relationship between tracking-line wander and control-line wander can be deduced; however, to date attempts at obtaining a quantitative relationship have failed, possibly because of the varying frequency content of the disturbance imposed by the pilot.

The extent to which the pilot varies the frequency of his control input in response to varying sight stimuli can be assessed by looking at power spectral densities of the control-line wander corresponding to representative test points from the characteristic-time study of figure 7. These data, figure 11, show quite clearly that even for conditions where the sight characteristics are identical, the frequency content of disturbances imposed by the pilot varies considerably.

CONCLUSIONS

A study of the tracking performance in straight level flight and steady turns in smooth air of a pilot using a disturbed-reticle computing gun sight over the normal operating range of altitude, Mach number, and normal acceleration of the airplane with variations of sight sensitivity and damping has indicated that:

1. The tracking aim wanders were equal to those obtained with a fixed sight under the test conditions and were not significantly affected by changing the dynamic response of the sight.

2. The control-line or gun-line motions induced by the pilot in order to track were as much as twice as large as the tracking wander at test conditions where the dynamic response of the sight mechanism was increased (long range).

3. The increased control-line wanders were qualitatively consistent with an increased amplitude response of the sight; however, to date attempts to obtain a quantitative relationship between the control-line and tracking-line motions have failed, possibly because of the varying frequency content of the disturbance imposed by the pilot even for conditions where the sight characteristics are identical.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Nov. 16, 1954

APPENDIX

NOTATION

A_z normal-acceleration factor, ratio of the net aerodynamic force along the z axis (positive when directed upward as in normal level flight) to the weight of the airplane

c sight damping coefficient, lb-ft/radian/sec

CL control-line angle, the angle between the longitudinal reference line of the sight (fixed with respect to the airplane) and the target, radians

CT characteristic time, $\frac{c}{k}$, sec

f frequency, cps

F moment applied to sight computer shaft, lb-ft

k sight spring constant, lb-ft/radian

LS line of sight angle, the angle between the line of sight (from tracker to target) and a fixed-space reference, radians

M free-stream Mach number

n number of observations

p atmospheric pressure, lb/sq ft

P sight computed lead angle, radians

R present range to target, ft

SN sight stability number, a measure of the tracking stability, $\frac{CT}{S_p} - 1$

S_1 sight gyro physical constant, lb-ft/radian/sec

S_p sight sensitivity, the ratio of the steady-state computed lead angle to the angular velocity input when the sight mechanism is unaccelerated, $\frac{S_1}{k}$, sec

t time, sec

TL tracking-line angle, the angle between the illuminated pip and the target, radians

x tracking error in deflection, lateral component of the angular separation, between the target and either the control line or tracking line, mils

y tracking error in elevation, normal component of the angular separation, between the target and either the control line or tracking line, mils

$\bar{x}$ bias error in deflection, the mean of the tracking errors in deflection, $\Sigma x/n$, mils

$\bar{y}$ bias error in elevation, the mean of the tracking errors in elevation, $\Sigma y/n$, mils

σ_x aim wander in deflection, the standard deviation of the x component, $\left[\frac{\Sigma(x - \bar{x})^2}{n}\right]^{1/2}$, mils

σ_y aim wander in elevation, the standard deviation of the y component, $\left[\frac{\Sigma(y - \bar{y})^2}{n}\right]^{1/2}$, mils

θ angle between the longitudinal reference line of the sight and a fixed-space reference, radians

Subscripts

x of the deflection component

y of the elevation component

A dot over a symbol represents $\frac{d}{dt}$.

REFERENCES

1. Rathert, George A., Jr., Gadeberg, Burnett L., and Ziff, Howard L.: An Analysis of the Tracking Performances of Two Straight-Wing and Two Swept-Wing Fighter Airplanes with Fixed Sights in a Standardized Test Maneuver. NACA RM A53H12, 1953.

2. McNeill, Walter E., Drinkwater, Fred J., III, and Van Dyke, Rudolph D., Jr.: A Flight Study of the Effects on Tracking Performance of Changes in the Lateral Oscillatory Characteristics of a Fighter Airplane. NACA RM A53H10, 1953.

3. Anderson, Seth B., and Bray, Richard S.: A Flight Evaluation of the Longitudinal Stability Characteristics Associated with the Pitch-Up of a Swept-Wing Airplane in Maneuvering Flight at Transonic Speeds. NACA RM A51I12, 1951.

4. Draper, Charles S.: A-1 Sight for the Control of Gunfire from Fixed Guns, Rocket Fire and Bombing from Aircraft. Volumes I and II, M.I.T. Instrumentation Laboratory, Apr. 1946.

5. Ehrenfried, A. D.: General Operating Principles of the A-1 Gun-Bomb-Rocket Sight. M.I.T. Inst. Lab. Rep. R-10.

6. Press, Harry, and Houbolt, John C.: Some Applications of Generalized Harmonic Analysis to Gust Loads on Airplanes. I.A.S. Preprint No. 449.

TABLE I.- SPECIFICATIONS OF TEST AIRPLANE

Gross weight, lb	14,000
Airfoil section (root) (Normal to 1/4-chord line)	NACA 0012-64 (Modified)
Airfoil section (tip)	NACA 0011-64 (Modified)
Total wing area, sq ft	287.9
Span, ft	37.1
Aspect ratio	4.79
Sweepback of 1/4-chord line, deg	35.2
Sweepback of leading edge, deg	37.7
Dihedral, deg	3.0
Twist, deg	2.0
Incidence, deg	1.0
Taper ratio	0.51

TABLE II.- COMBINATIONS OF FACTORS AT WHICH FLIGHT TESTS WERE CONDUCTED

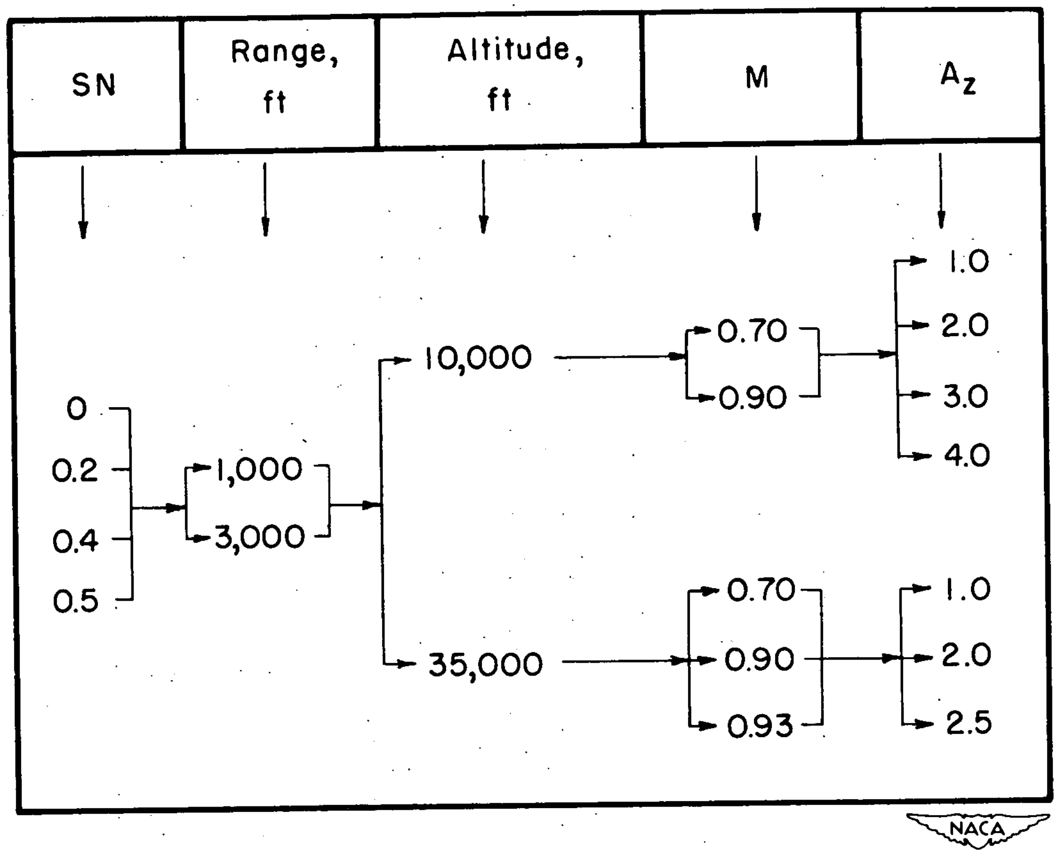
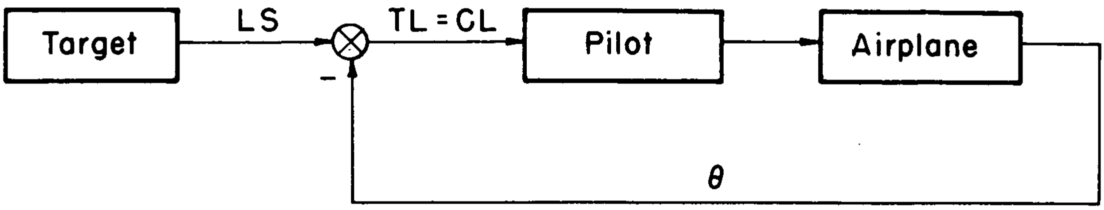
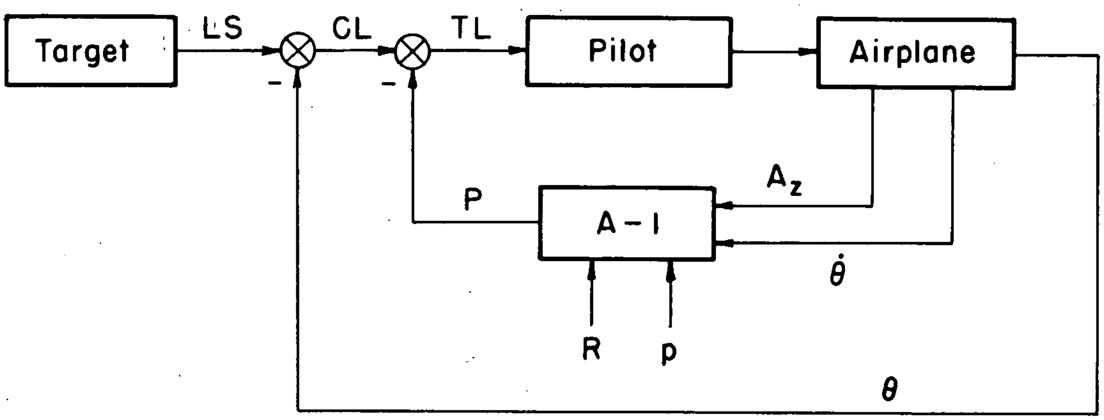


TABLE III.- AVERAGES OF CONTROL-LINE AND TRACKING-LINE WANDERS

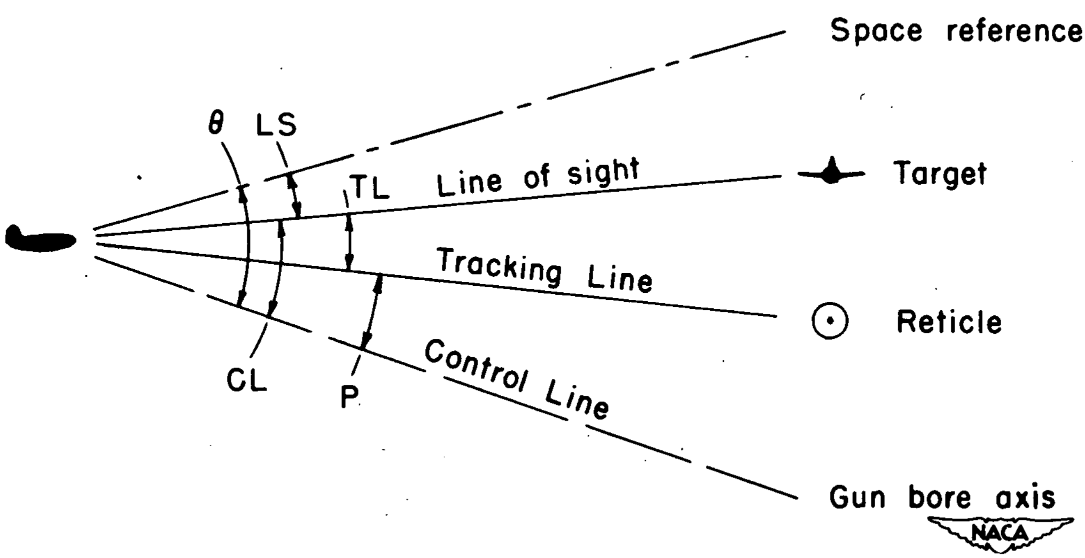
Sight	SN	R, ft	Altitude, ft	$\sigma_{x_{average}}$	$\sigma_{y_{average}}$
Fixed	∞	1,000	35,000 and 10,000 (96 runs)	2.6(1.1 to 5.2)	2.7(1.0 to 4.2)
A-1 (tracking line)	All	1,000 and 3,000	35,000 and 10,000 (128 runs)	2.4(1.2 to 4.7)	2.3(0.8 to 4.6)
A-1 (control line)	0	1,000	35,000 (9 runs)	3.2(1.5 to 4.4)	3.8(1.4 to 6.2)
			10,000 (6 runs)	2.9(1.7 to 3.1)	2.6(1.3 to 3.1)
		3,000	35,000 (8 runs)	4.0(2.3 to 5.2)	4.4(0.4 to 7.0)
			10,000 (6 runs)	5.6(2.9 to 9.8)	5.0(2.5 to 5.4)
	0.2	1,000	35,000 (9 runs)	2.4(1.4 to 3.2)	2.8(0.3 to 3.9)
			10,000 (8 runs)	2.7(2.0 to 2.7)	2.8(1.6 to 3.4)
		3,000	35,000 (9 runs)	4.4(2.5 to 7.0)	4.1(1.0 to 8.2)
			10,000 (6 runs)	6.4(3.6 to 7.4)	5.9(4.9 to 6.4)
	0.4	1,000	35,000 (10 runs)	3.1(1.4 to 4.4)	3.4(1.5 to 5.6)
			10,000 (8 runs)	2.8(1.6 to 3.3)	3.2(1.5 to 4.3)
		3,000	35,000 (9 runs)	5.5(2.2 to 8.1)	4.3(1.0 to 6.8)
			10,000 (5 runs)	6.9(3.6 to 7.6)	4.0(2.6 to 4.9)
	0.5	1,000	35,000 (10 runs)	3.3(1.6 to 5.3)	3.3(1.0 to 4.0)
			10,000 (10 runs)	2.8(1.6 to 3.5)	2.6(1.7 to 3.1)
		3,000	35,000 (11 runs)	5.3(3.1 to 7.7)	6.4(2.0 to 7.5)
			10,000 (4 runs)	6.3(3.3 to 6.2)	6.3(2.5 to 6.5)



(a) Fixed sight.



(b) Computing sight.



(c) Angular relationships for a tracking problem.

Figure 1.- Block diagram of tracking loops for fixed and computing sights and angular relationships for a tracking problem.

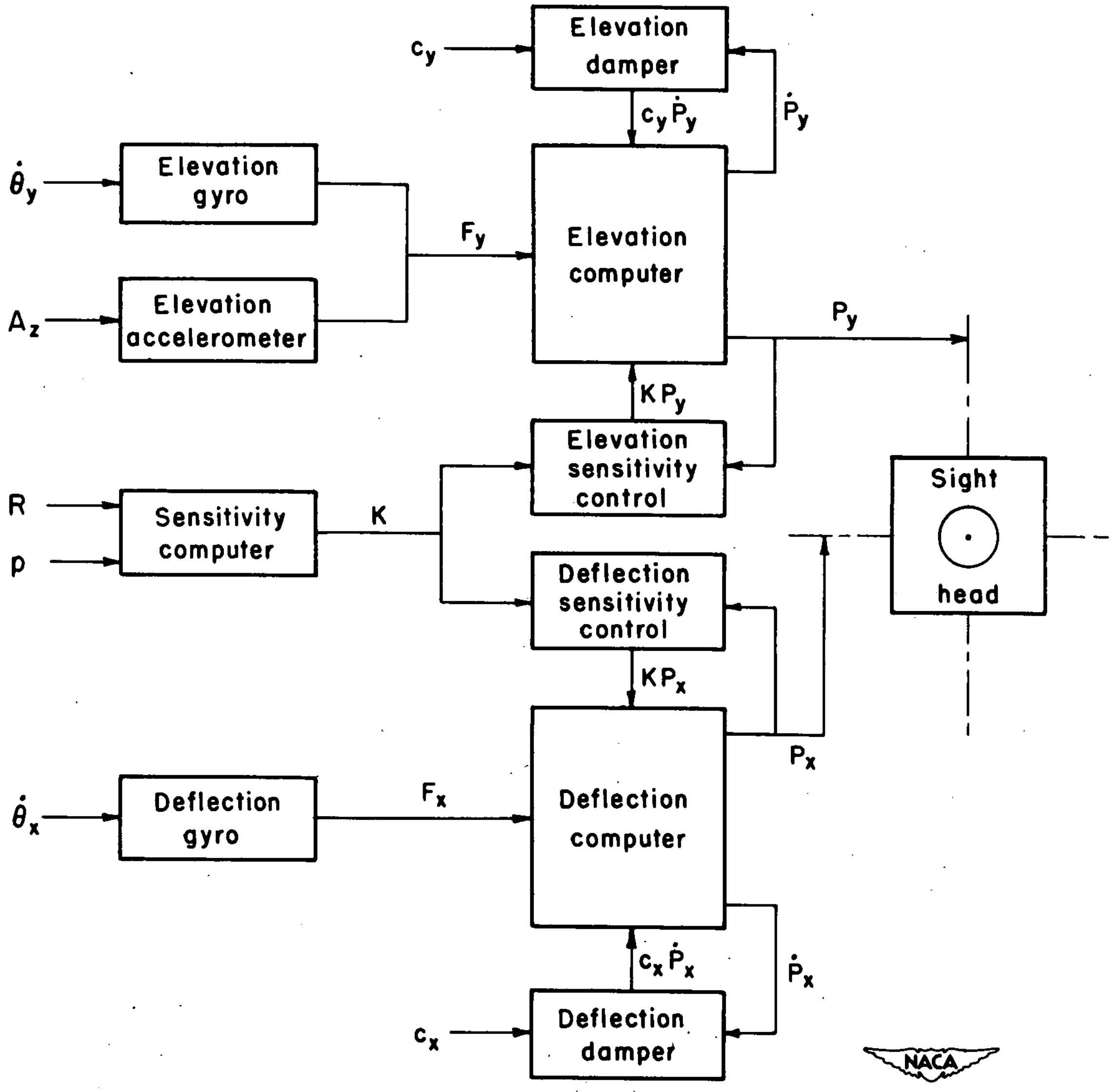


Figure 2.- Block diagram of the computing mechanism of the A-1 sight.

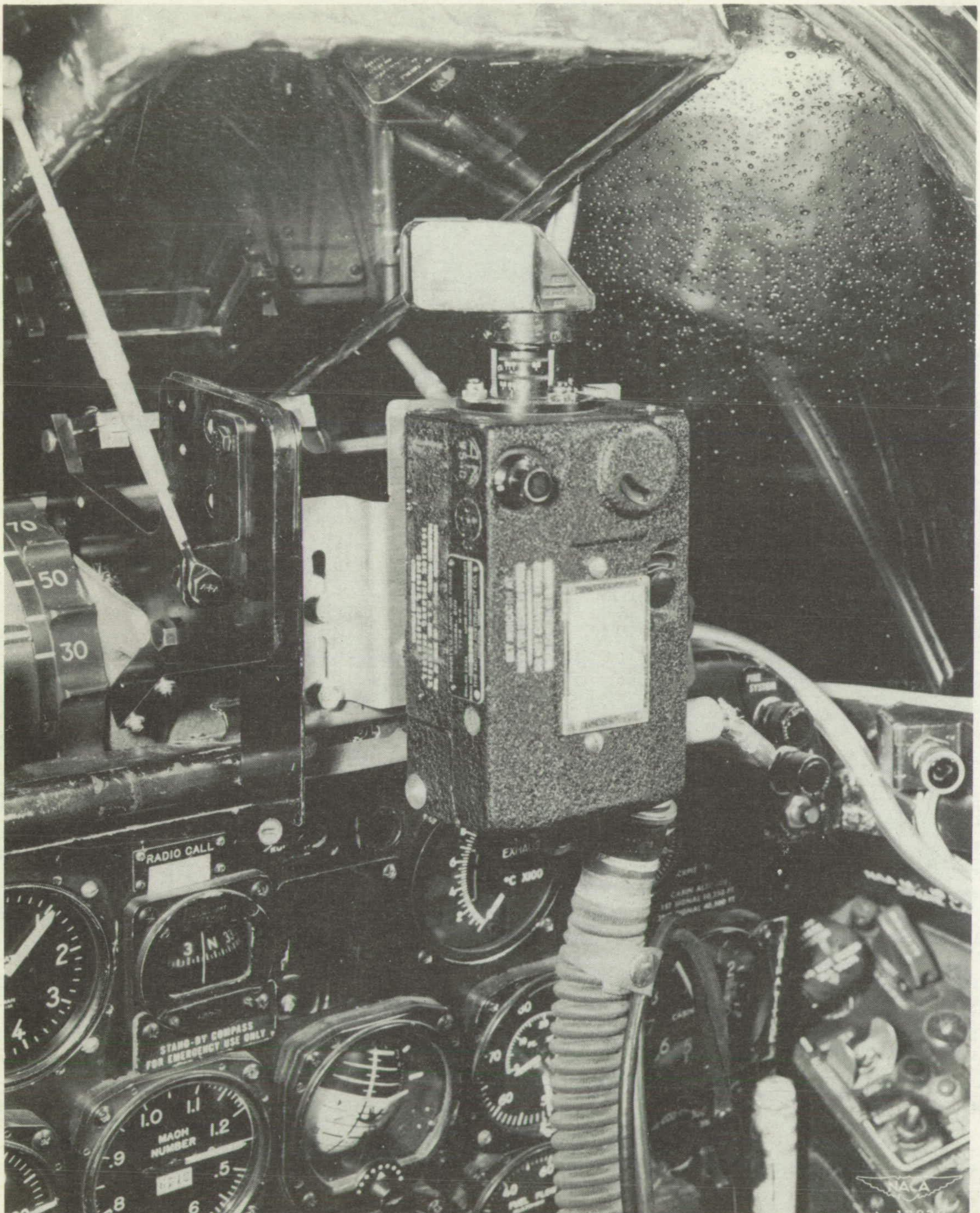


Figure 3.- Photograph of GSAP camera mounted in cockpit of test airplane.

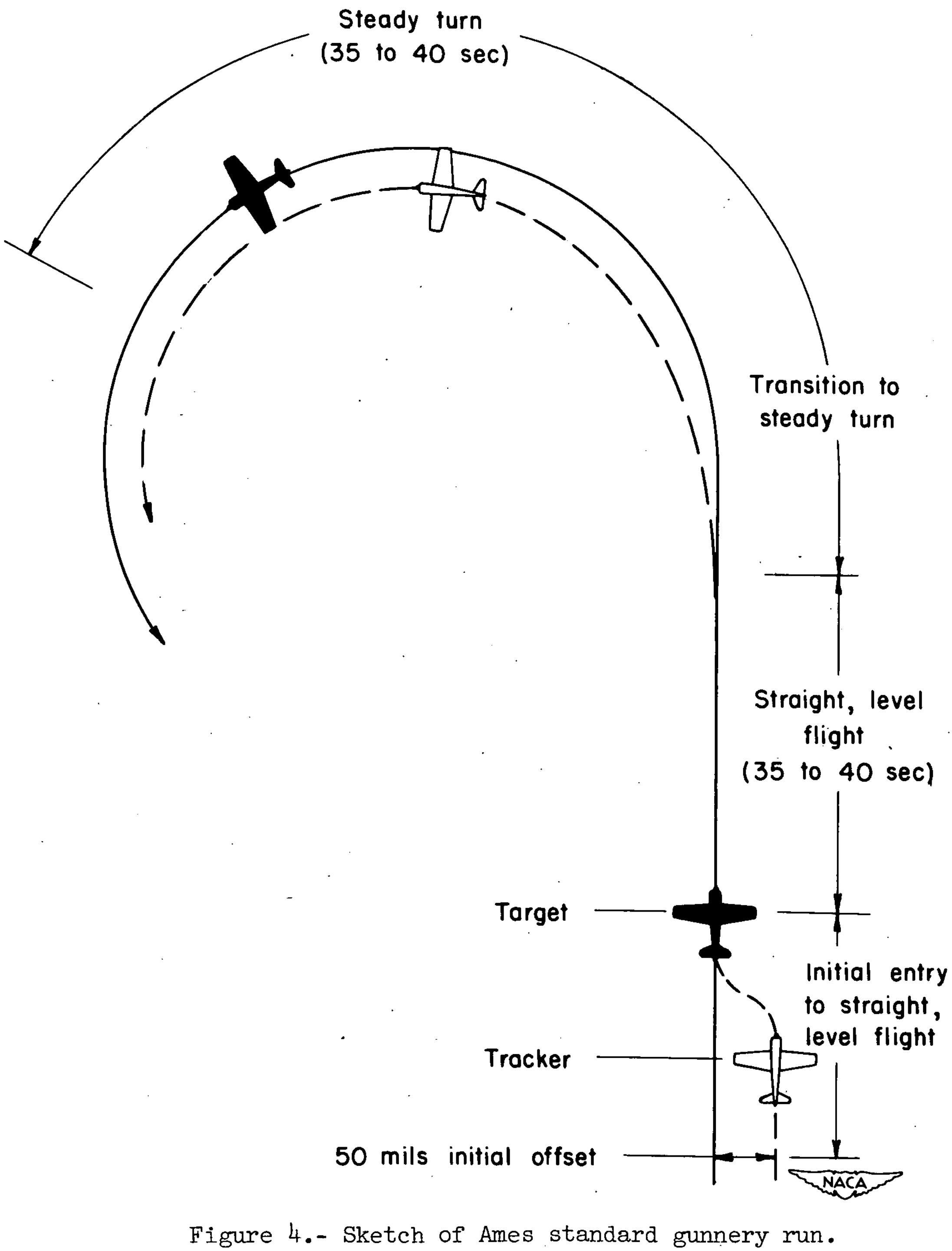


Figure 4.- Sketch of Ames standard gunnery run.

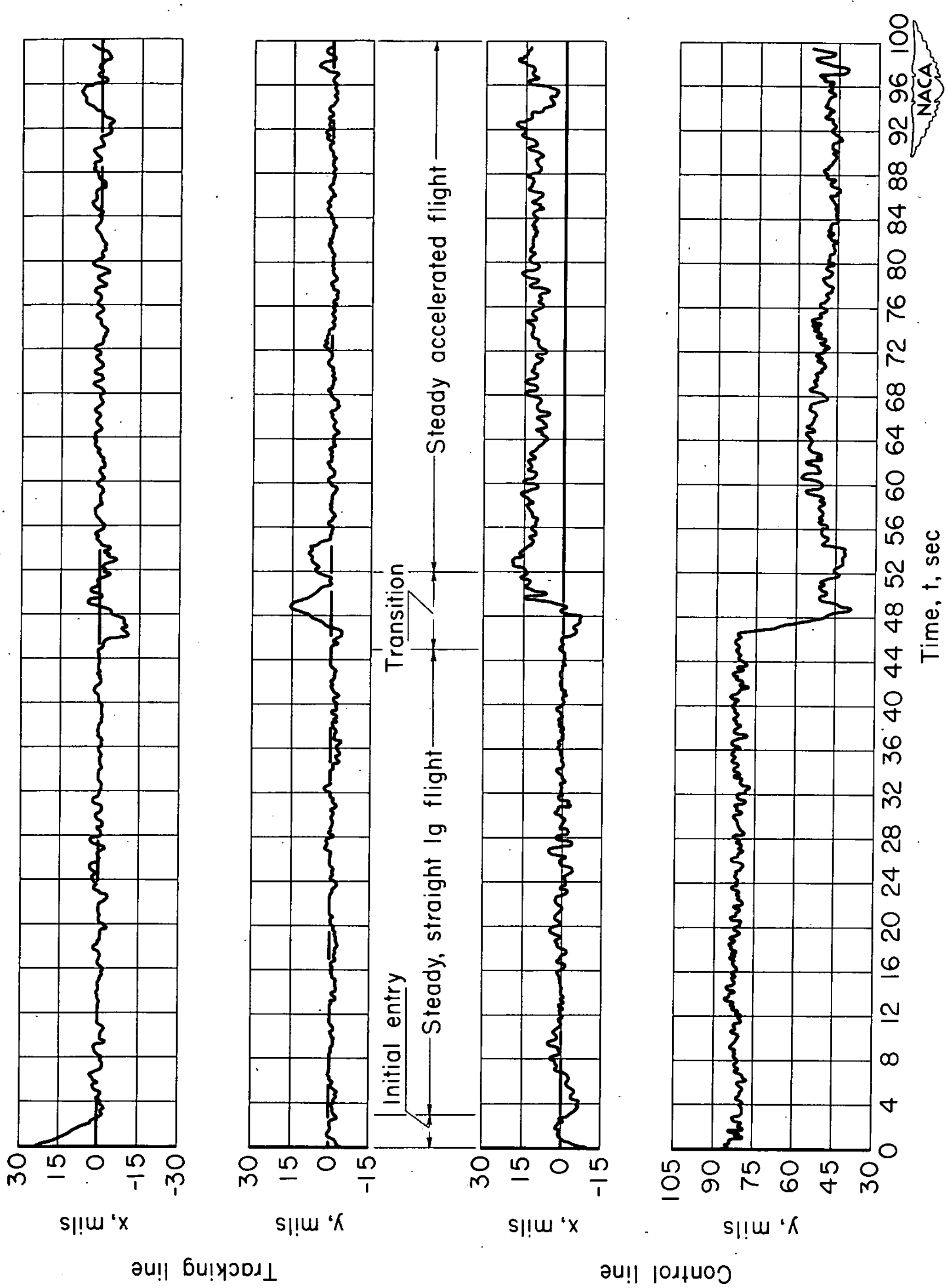
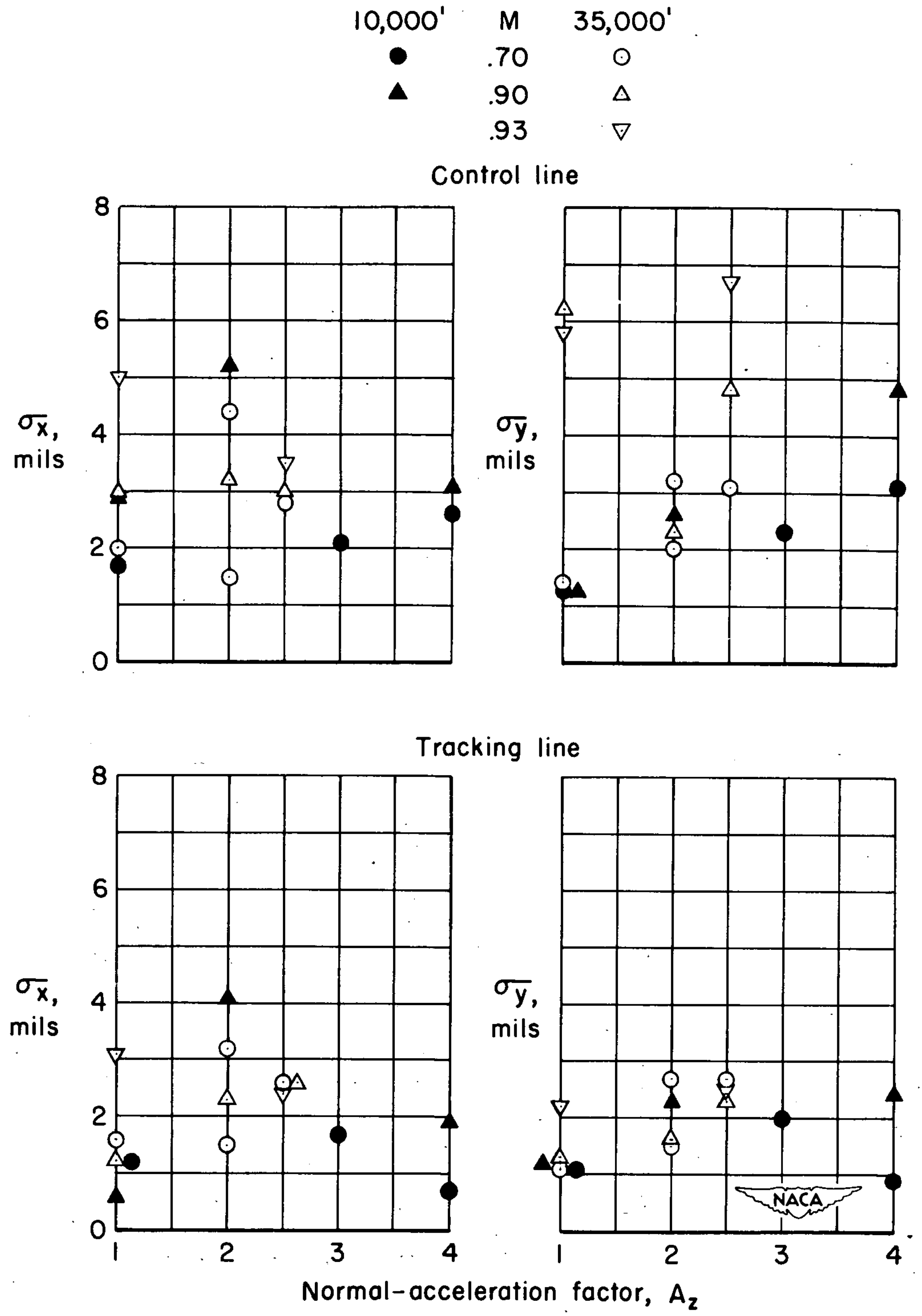
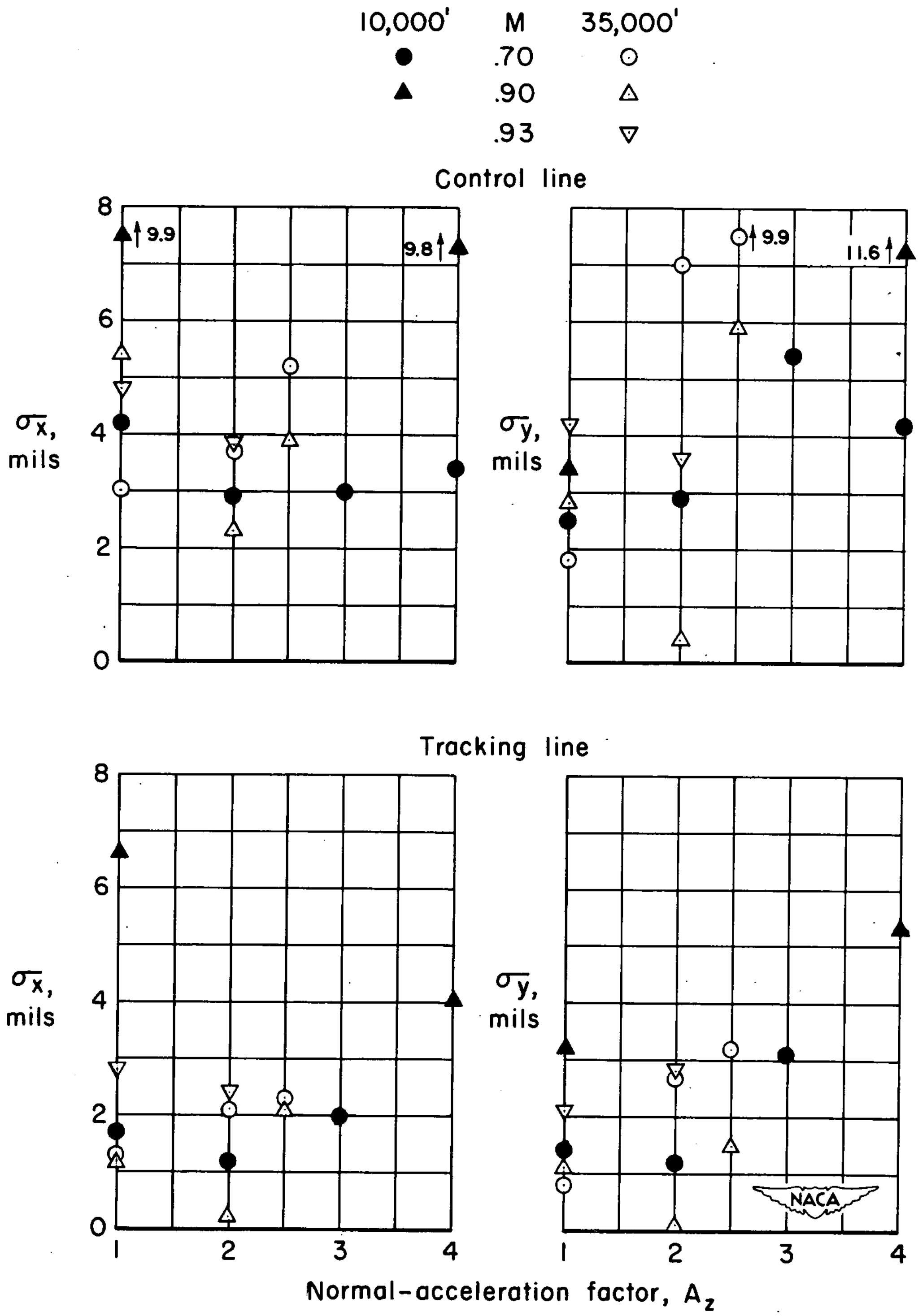


Figure 5.- Typical time histories of control-line and tracking-line wanders.



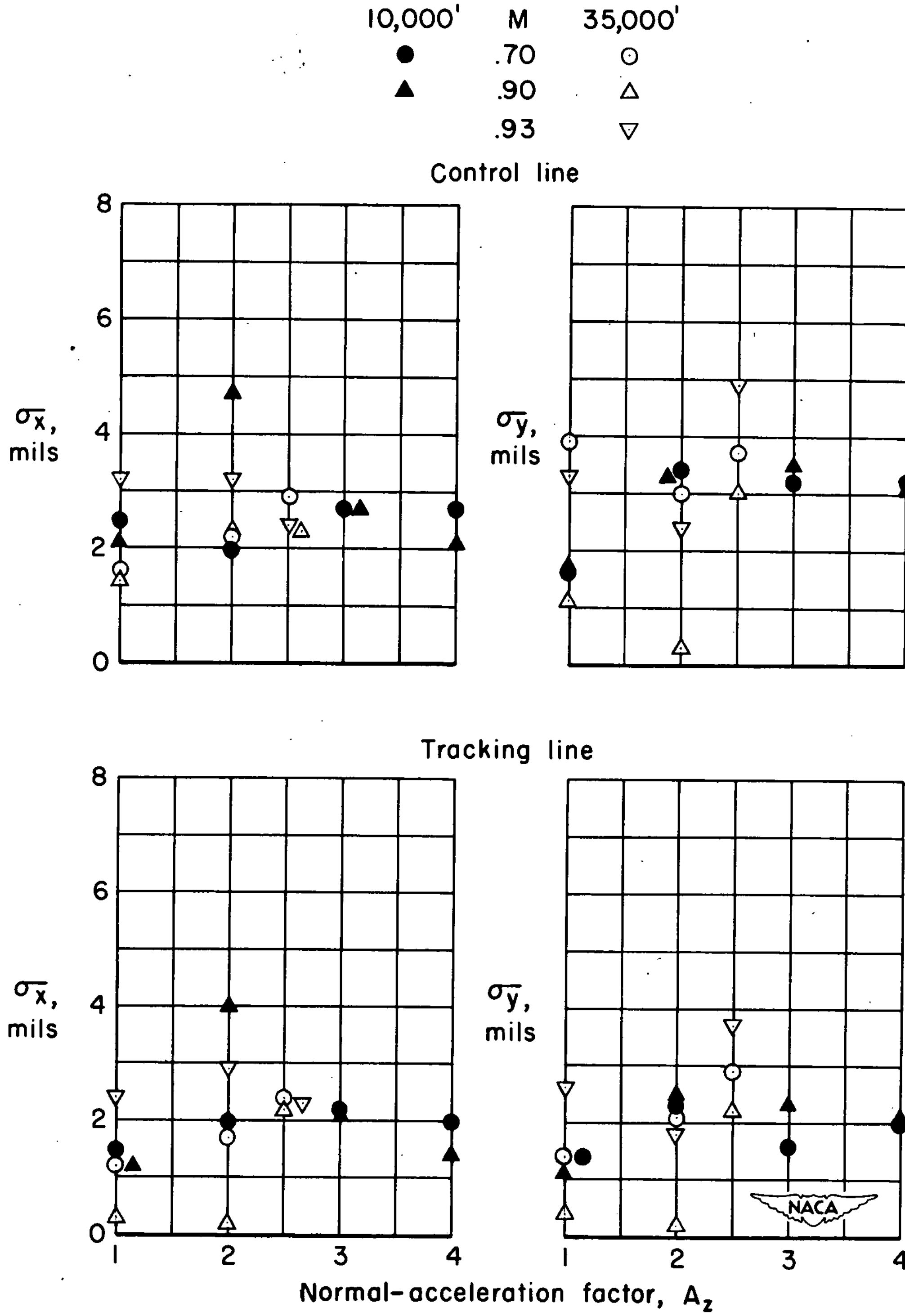
(a) SN = 0; range = 1,000 ft

Figure 6.- Aim wander as a function at airplane normal-acceleration factor.



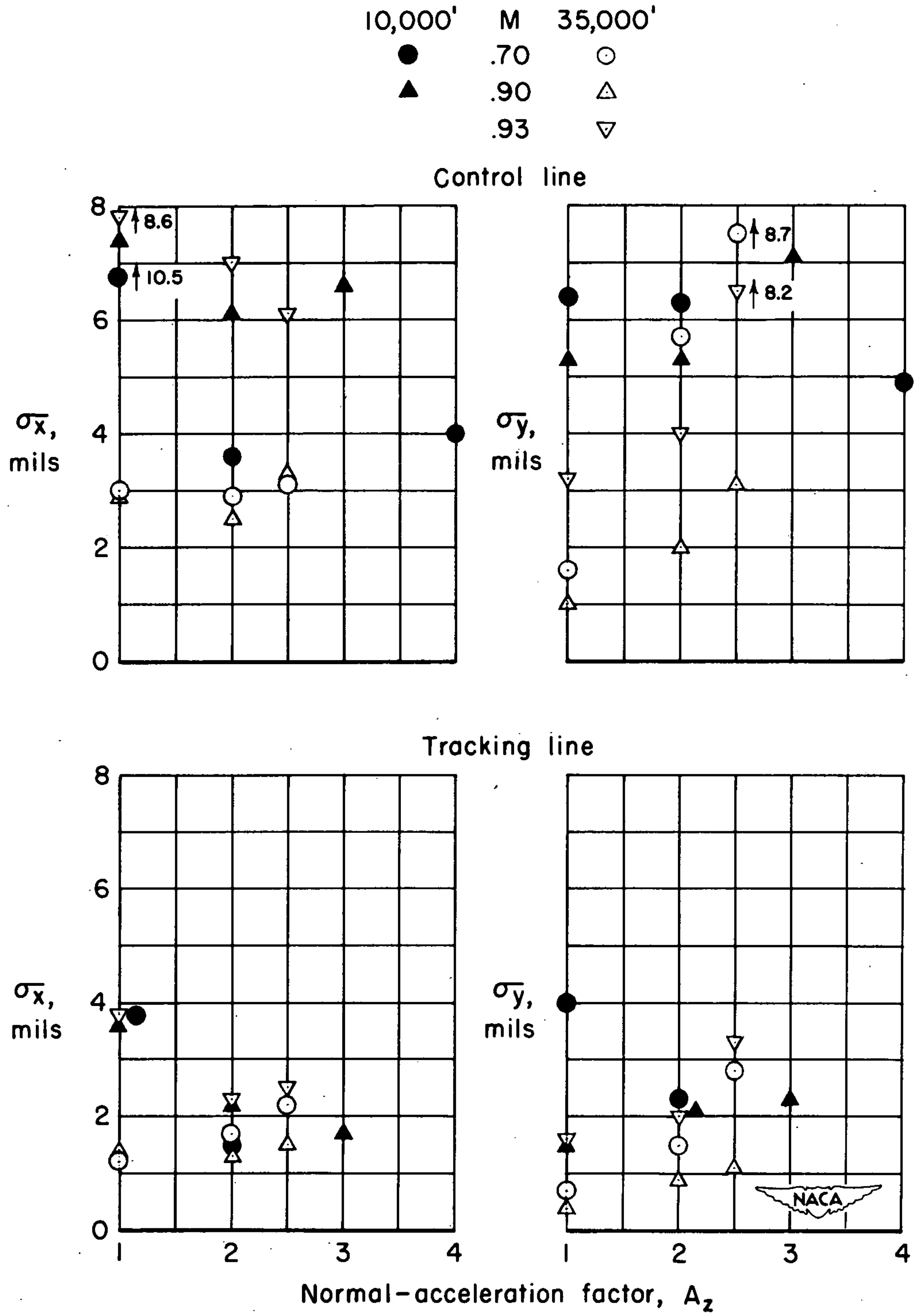
(b) SN = 0; range = 3,000 ft

Figure 6.- Continued.



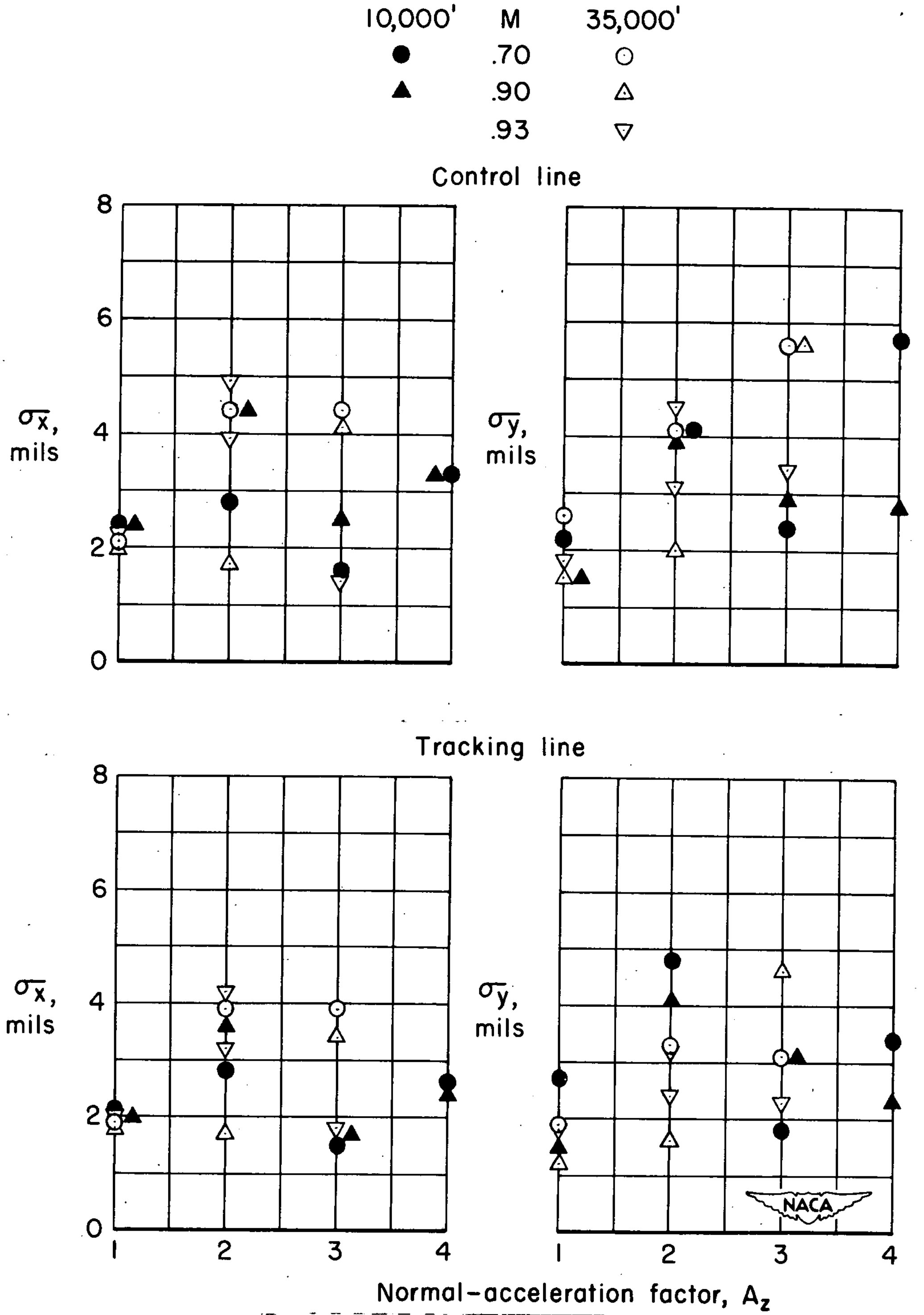
(c) SN = 0.2; range = 1,000 ft

Figure 6.- Continued.



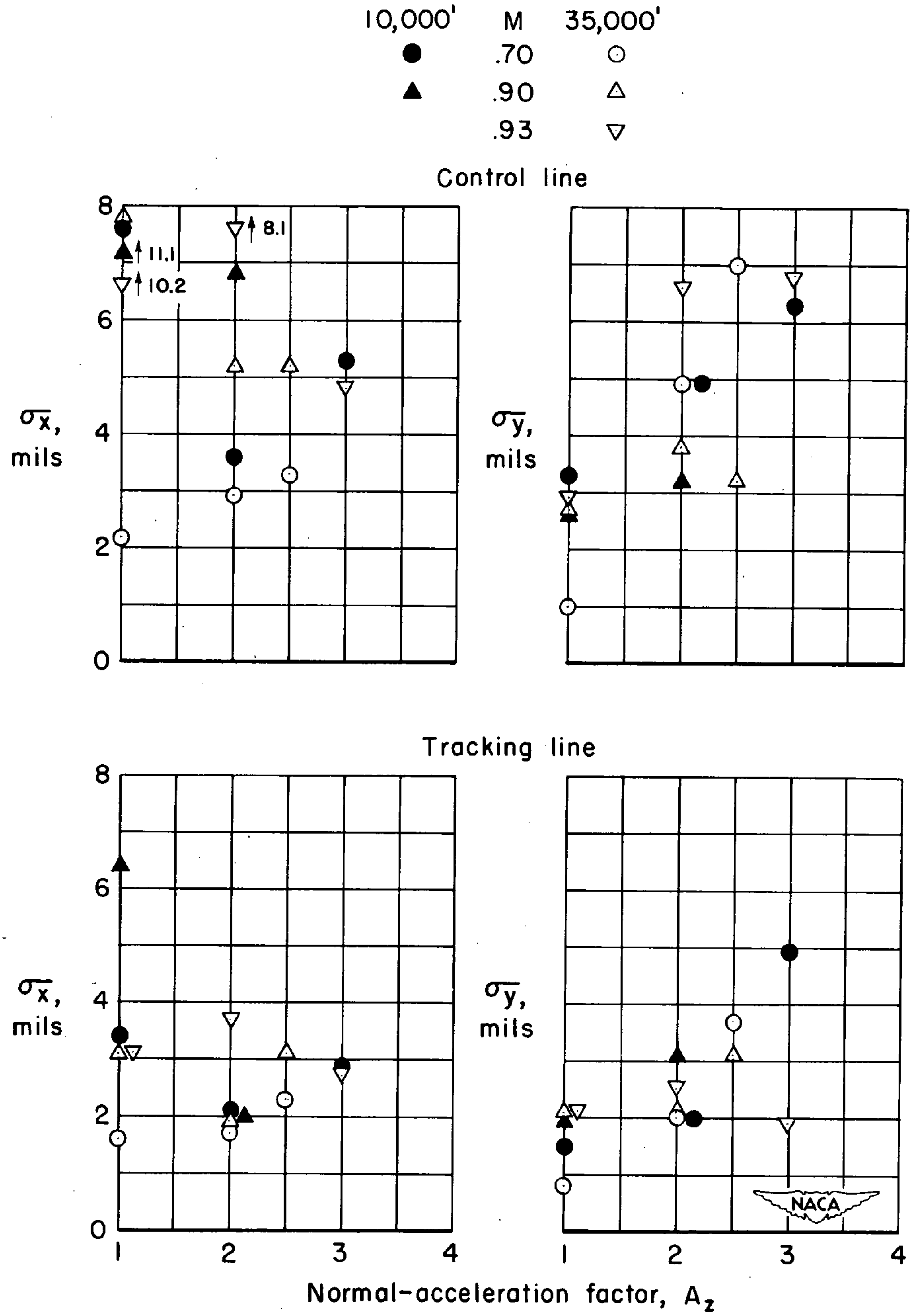
(d) SN = 0.2; range = 3,000 ft

Figure 6.- Continued.



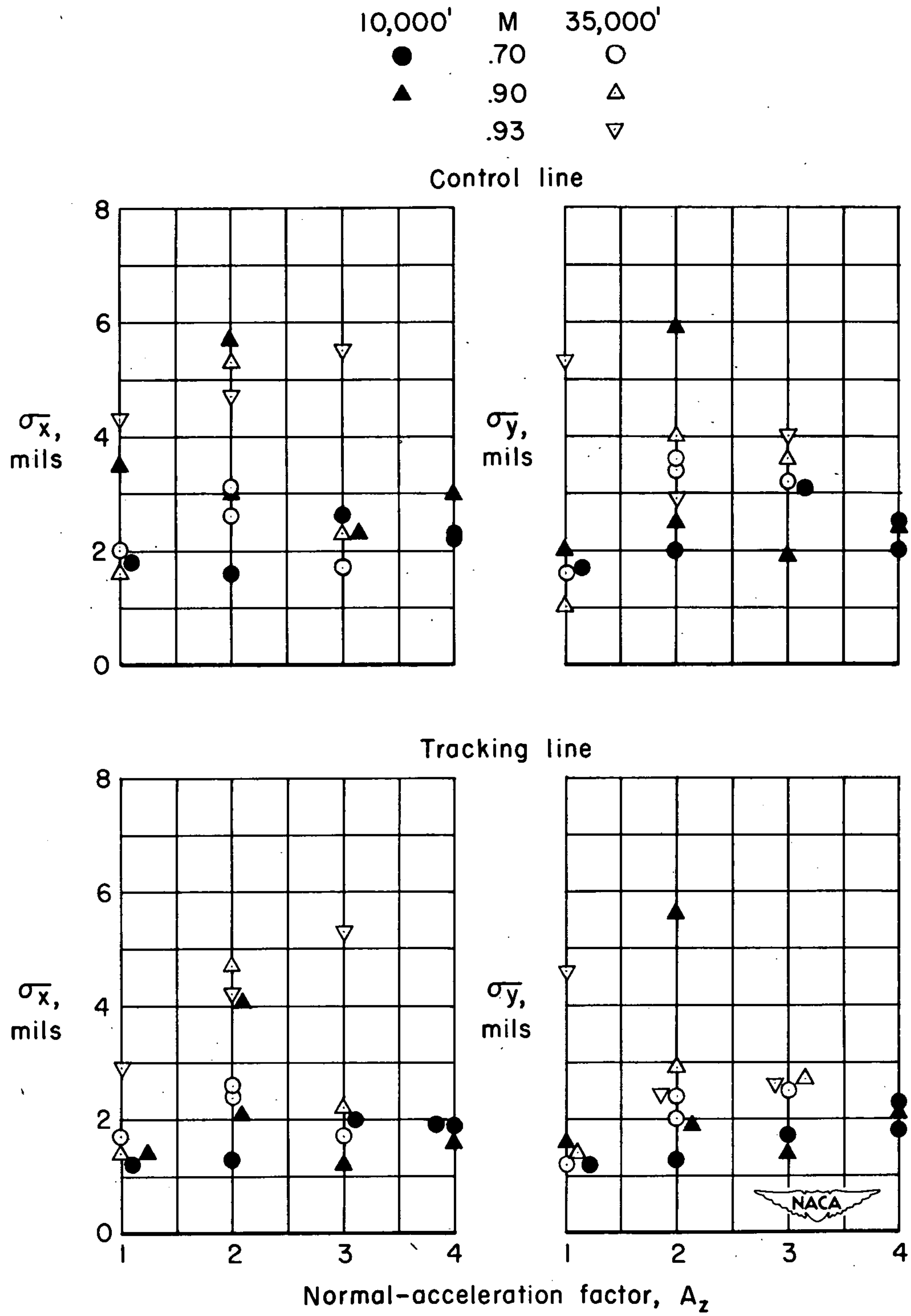
(e) SN = 0.4; range = 1,000 ft

Figure 6.- Continued



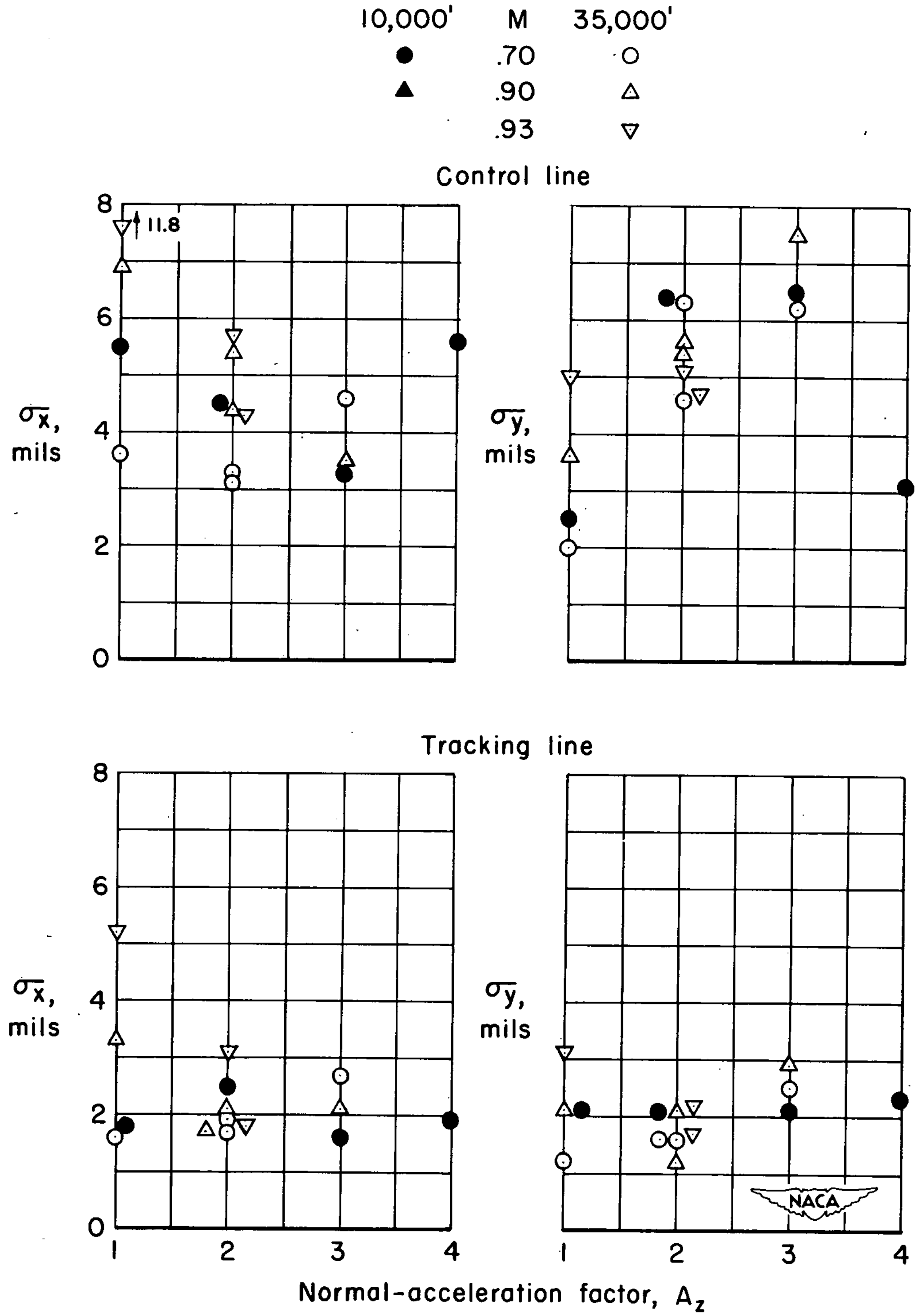
(f) SN = 0.4; range = 3,000 ft

Figure 6.- Continued.



(g) SN = 0.5; range = 1,000 ft

Figure 6.- Continued.



(h) SN = 0.5; range = 3,000 ft

Figure 6.- Concluded.

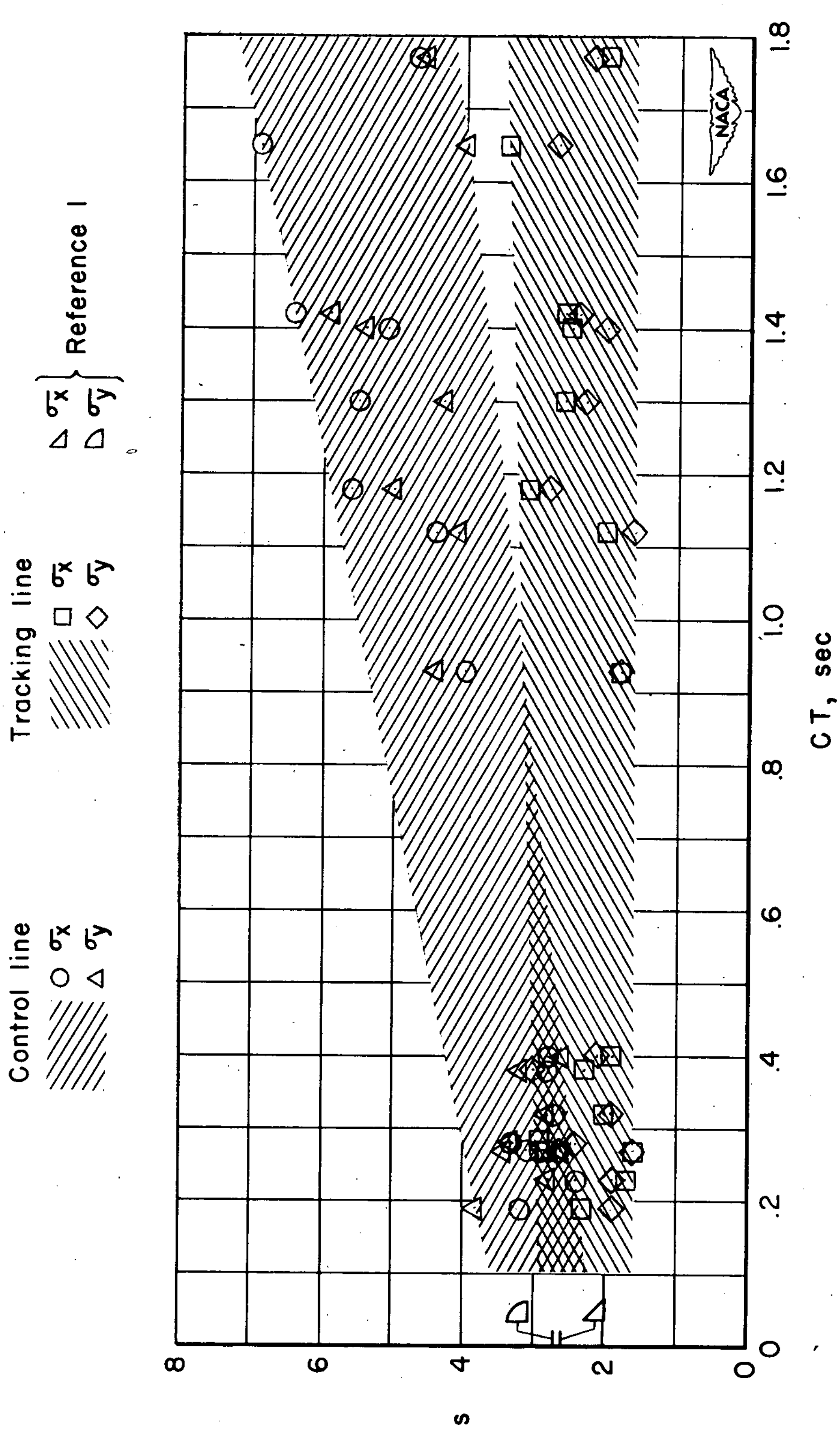


Figure 7.- Control-line and tracking-line wander as a function of sight-mechanism characteristic time.

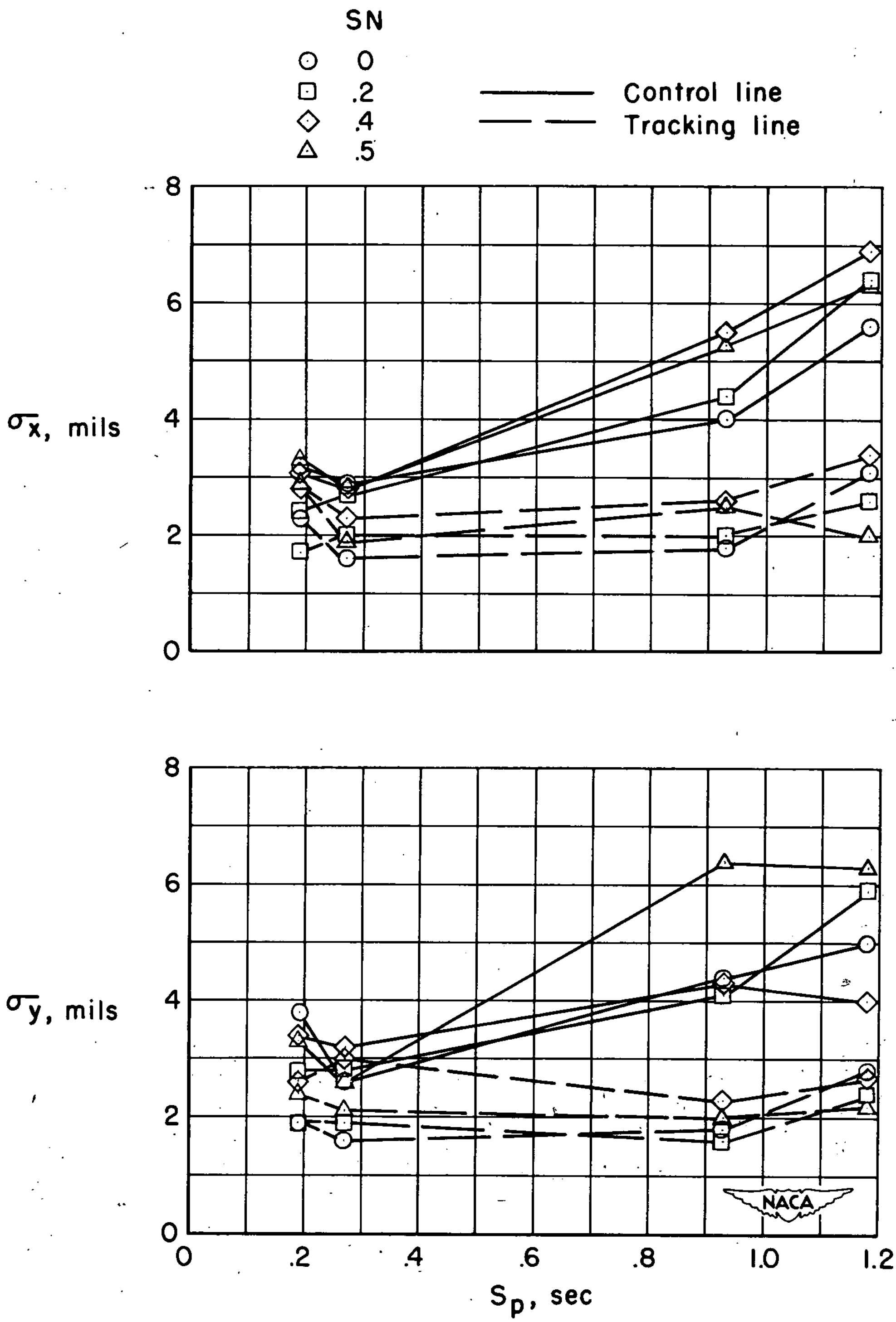


Figure 8.- Control-line and tracking-line wander as a function of sensitivity.

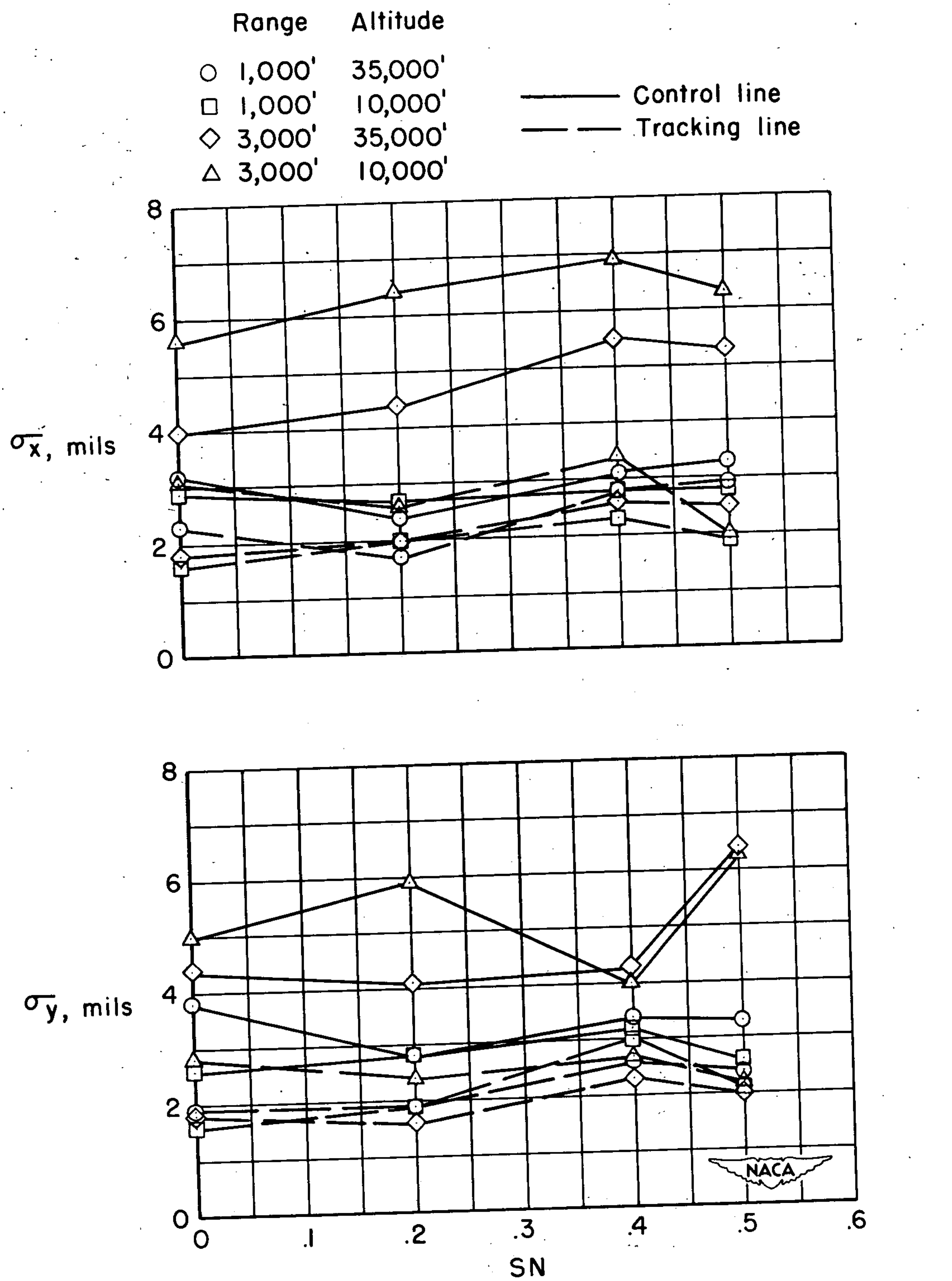


Figure 9.- Control-line and tracking-line wander as a function of stability number.

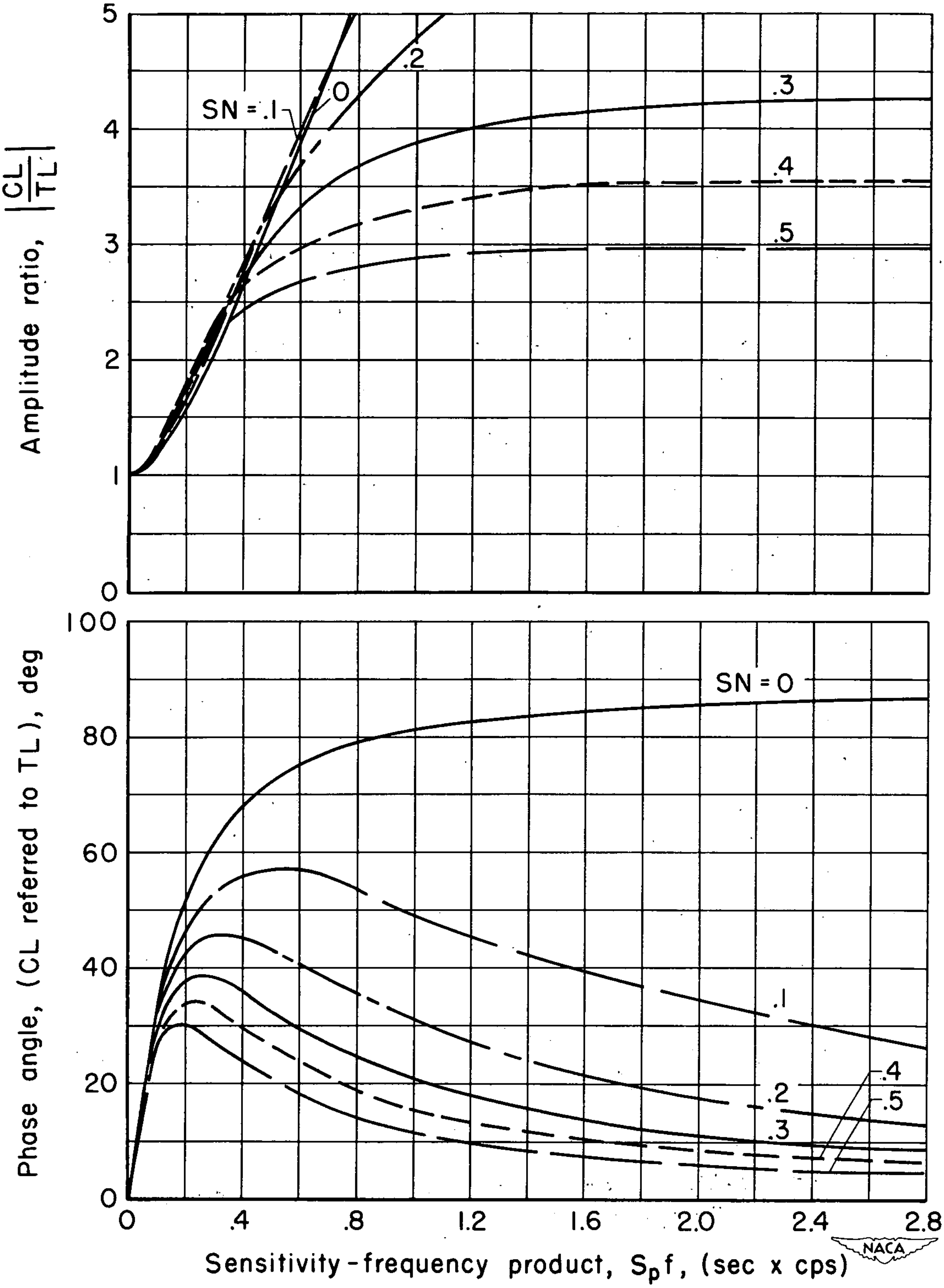


Figure 10.- Theoretical frequency response of the A-1 sight.

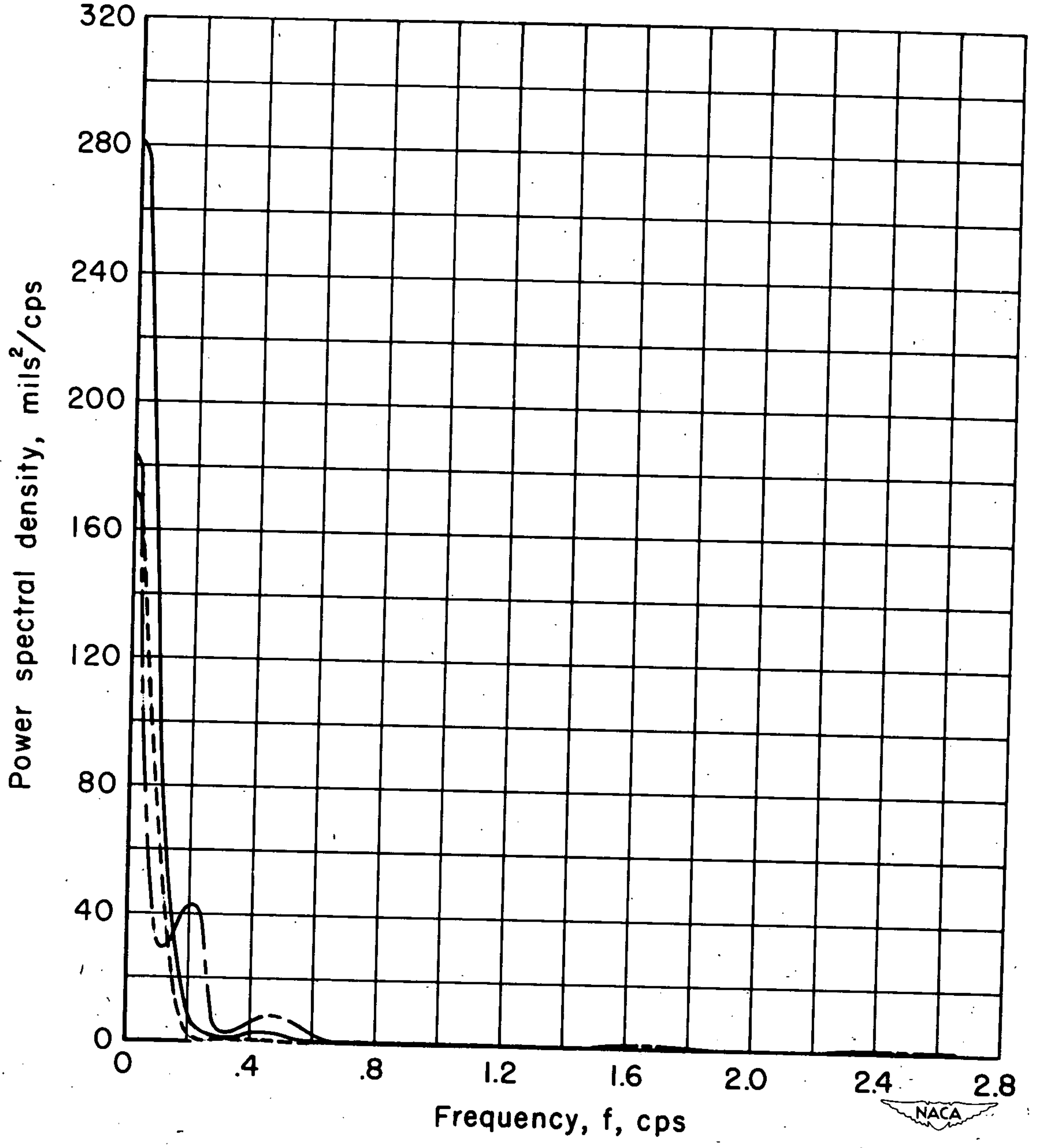


Figure 11.- Control-line power spectral densities for three typical runs at large characteristic times.