324

CONFIDENTIAL

Copy
RM L55I06

NACA RM L55I06

NACA

CASE FILE
COPY

RESEARCH MEMORANDUM

COMPARATIVE DISPERSION DATA FROM GROUND-LAUNCHED 2.25-INCH ROCKETS EQUIPPED WITH CRUCIFORM AND MONOPLANE FINS

By Paul E. Purser

Langley Aeronautical Laboratory
Langley Field, Va.

CLASSIFICATION CHANGED TO UNCLASSIFIED
AUTHORITY: NASA PUBLICATION ANNOUNCEMENT NO. 4
EFFECTIVE DATE: FEBRUARY 10, 1959
WHL

CLASSIFIED DOCUMENT

This material contains information affecting the National Defense of the United States within the meaning of the espionage laws, Title 18, U.S.C., Secs. 793 and 794, the transmission or revelation of which in any manner to an unauthorized person is prohibited by law.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

November 1, 1955

CONFIDENTIAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

COMPARATIVE DISPERSION DATA FROM GROUND-LAUNCHED 2.25-INCH ROCKETS EQUIPPED WITH CRUCIFORM AND MONOPLANE FINS

By Paul E. Purser

SUMMARY

About 150 rounds of 2.25-inch subcaliber aircraft rockets, equipped with standard cruciform fins and with twisted monoplane fins, were ground-launched at the Langley Pilotless Aircraft Research Station at Wallops Island, Va. These tests provided dispersion data for use in evaluating the effectiveness of twisted monoplane fins for rocket stabilization.

The data indicated no significant difference in dispersion for rockets equipped with cruciform fins, with monoplane fins having 4° of twist at the fin tip, and with monoplane fins having 8° of twist.

The monoplane-fin rockets showed a small increase in range to impact over the cruciform-fin rockets. Mean deflections in crosswind firings were slightly smaller for the monoplane-fin rockets than for the cruciform-fin rockets but the differences may not be statistically significant in view of the relatively small number of rounds fired.

INTRODUCTION

An analysis and a brief flight investigation by the National Advisory Committee for Aeronautics has shown that bodies may be stabilized in flight by the use of twisted monoplane fins rather than the usual cruciform or triform fin arrangements. These studies, reported in references 1 and 2, did not provide any quantitative data on such items as the effect of fixing the monoplane fins to the body and thus including the body inertia in the rolling system, the dispersion of monoplane fin bodies such as rockets or bombs, the actual static and dynamic stability of such bodies, or the problems involved in launching or releasing monoplane-fin bodies from aircraft. The present tests were undertaken to provide data

on the effects of fixing the monoplane fins to the body and on the dispersion of monoplane-fin rockets. The tests consisted of measurements of the dispersion of ground-launched 2.25-inch subcaliber aircraft rockets equipped with cruciform fins and with twisted monoplane fins. The dispersion data obtained in these tests are presented and discussed herein.

SYMBOLS

ω_θ^2 pitch-frequency parameter, $\left(\frac{\omega_y}{p}\right)^2$

ω_ψ^2 yaw-frequency parameter, $\left(\frac{\omega_z}{p}\right)^2$

p rate of roll, rps

ω_y pitch frequency, $\frac{1}{2\pi}\sqrt{\frac{-C_{m_\alpha}57.3qSd}{I_y}}$, cps

ω_z yaw frequency, $\frac{1}{2\pi}\sqrt{\frac{C_{n_\beta}57.3qSd}{I_z}}$, cps

C_{m_α} variation of pitching-moment coefficient with angle of attack per deg

C_{n_β} variation of yawing-moment coefficient with angle of sideslip per deg

I_y moment of inertia in pitch, 0.195 slug-ft^2

I_z moment of inertia in yaw, 0.195 slug-ft^2

I_x moment of inertia in roll, 0.0036 slug-ft^2

d maximum body diameter, ft

S maximum body cross-sectional area, sq ft

q dynamic pressure, lb/sq ft

ROCKETS, TESTS, AND EQUIPMENT

Rockets

The rockets used were standard 2.25-inch subcaliber aircraft rockets, designated 2.25TA001 or 2.25TA002 in reference 3. Approximately 50 rounds were fired with standard cruciform fins of the type shown in figure 1(a). Approximately 100 rounds were fired with twisted monoplane fins, also shown in figure 1(a). Half of the monoplane-fin rounds had a fin twist of 4° at the tip and half had a twist of 8° at the tip. The direction of twist was such as to produce a clockwise roll as viewed from the rear. The fins were twisted in a simple jig that allowed the application of a pure torque at the tip. The fact that the fins were thin plates, however, resulted in a twist configuration, as shown in figure 1(b), that produced effectively leading-edge and trailing-edge flaps as well as a twisted center portion of the chord plane. Figure 1(b) illustrates the final twist mode and average values of twist angles measured on each fin panel of 14 of the monoplane-fin rockets.

Tests

As shown in table I, the test program was divided into 5 lots of 30 rounds each. Each lot was equally divided among standard cruciform-fin rockets, 4° monoplane-fin rockets, and 8° monoplane-fin rockets.

Lots 1 to 5 were intended to provide angular deflection measurements up to a slant range of about 1,000 feet for several values of crosswind velocity and for two launching elevation angles. The data obtained and presented were lateral and vertical deflection in mils and slant range in feet. A few rounds of lots 1 to 5 were tracked by CW Doppler velocimeter and NACA modified SCR 584 position radar sets. Records were not taken on the position radar for these rounds, the operator simply noted the general appearance of the flight path and the range at impact.

Launcher

The launcher used was a rail type as shown in figure 2. The launcher length measured from the center of the rear launching lug to the end of the rails was $48\frac{7}{8}$ inches.

Cameras

Deflection data.- The deflection data were obtained with a 70-millimeter rapid-sequence Hulcher camera mounted in a protective

frame beneath the launcher rail. (See fig. 2.) The camera was operated at approximately 15 frames per second. The lens used was a 305-millimeter focal length K-24 aerial camera lens adapted to the 70-millimeter camera. The camera was alined parallel to and directly below the center line of the rail launcher. The vertical separation of the center lines of the camera and of a rocket resting on the launcher rail was 0.95 foot. The camera field of view was approximately ±114 mils in the vertical plane and ±93 mils in the lateral plane.

Rolling-velocity data.- Some rolling-velocity data were obtained with a 16-millimeter Mitchell camera hand-tracked from a position directly behind the launcher. The camera was operated at approximately 125 frames per second. The rocket fins were painted bright yellow and color film was used to provide better definition of fin position in space.

Axis System

The lateral and vertical deflections are referenced to the line of sight which is an extension of the rocket center line when the rocket is on the launcher. The range used was the slant range to points along the rocket flight path except for some data which are presented as true horizontal range to impact.

DATA REDUCTION AND ACCURACY

Deflection Data

The angular deflection data for round 1 of lot 1 are plotted in figure 3, to illustrate the general quality and amount of data obtained from each round. The following paragraphs discuss the data reduction procedures used and the estimated accuracy of various portions of the data.

The lateral and vertical deflection data were obtained from the 70-millimeter film by use of a transparent overlay gridded in mil measure. The smallest division on the grid was 2 mils. Considerations of grid size and repeatability of alining the overlay and the film indicate that the basic deflection measurements are probably accurate to ±2 mils. No parallax corrections were required for lateral deflection, but, because the camera was located 0.95 foot below the line of sight, the vertical deflection data did require parallax corrections. The accuracy of the parallax corrections depends directly on the accuracy of the range data to be discussed later; however, by the time the rocket has reached burnout a range error of 35 feet would produce a change of only about 1/4 mil in the parallax correction.

Range Data

Slant range for the first 1,000 feet along the trajectory or until the rocket image on the film was too faint to identify or until the rocket was no longer in the camera field of view was evaluated by integrating velocity data obtained from a CW Doppler velocimeter for several rounds. Comparison of these data indicated that a common range-against-time curve could be used for all rounds with a slant range of 385 feet at burnout. The time of burnout could be established within one camera frame (or 1/15 second), thus, from near burnout to 1,000-foot range, the slant range is probably correct within ±35 feet $\left(\text{determined from } \pm\frac{1}{2} \times \frac{1}{15} \times \text{maximum velocity}\right)$. It was possible to determine the slant range between 10 and 100 feet at from 1 to 4 points for most of the rockets based on measurements of the span of the fin image on the camera film. This procedure is believed to have provided slant-range data accurate to ±10 feet or less in the early part of the flight.

Roll Data

The rolling velocity data were obtained by differentiation of roll-position time histories obtained from frame-by-frame analysis of the 16-millimeter film taken at 125 frames per second. The film was projected on white paper and the roll position marked for each frame; the accuracy of the roll position determination varied from $\pm\frac{1}{6}$ revolution to $\pm\frac{1}{3}$ revolution depending on the clarity of the fin image on the film. The scatter of the data indicated that the rolling velocity could be determined to $\pm 1\frac{1}{2}$ revolutions per second when evaluated over intervals of 10 to 20 frames.

Crosswind Data

Wind velocity and direction measurements used in determining the crosswind velocity for each round were obtained from a recording Bendix-Friez Aerovane. The measuring instrument was located at an altitude of 27 feet about 50 feet from the launcher. No measurements were made of the variation of wind velocity and direction with altitude.

The data as presented are believed correct within the following limits:

Wind velocity, fps	±1.5
Wind direction, deg	±2

Overall Accuracy

Considering the various accuracy values noted in the preceding paragraphs and the shapes of the curves presented in figure 3, the short-range data presented are believed to be correct within the following limits:

Indicated slant range, ft	Slant range, ft	Accuracy of -	
		Lateral deflection, mils	Vertical deflection, mils
25	±10	±4	+10, -25
50	±10	±4	+4, -6
100	±10	±4	±4
200	±25	±3	±3
385 (burnout)	±35	±2	±2
770 (twice range at burnout)	±35	±2	±2
1,000	±35	±2	±2

RESULTS AND DISCUSSION

Stability of Monoplane-Fin Rockets

Theory and background.- An analytical study of the possibility of using rolling to stabilize a body, such as a monoplane-fin rocket, that would normally be stable in either the pitch or yaw plane but unstable in the other plane appears in reference 1, an analysis of the effects of rolling on the longitudinal stability of aircraft. Reference 2 presents the results of a brief experimental verification of the effects of rolling in stabilizing bodies that would normally be stable in only one plane. The data of reference 2 were only qualitative in nature and thus did not provide information on the degree of stability actually achieved or on the possible difference in dispersion between cruciform-fin and monoplane-fin rockets. The analysis of reference 1 shows that if a body is stable in one plane and unstable in the other, stability may be achieved by forcing the body to roll at a rate (in revolutions per second) that is equal to or greater than the natural frequency (in cycles per second) in the stable plane. There are additional requirements that tend to limit the roll rate if the ratio of stability in the unstable plane to the stability in the stable plane is large. The study of reference 2, however,

indicated that configurations similar to those used in reference 2 and in the present tests could be modified over rather wide ranges without exceeding the stability limits.

Data for present tests.- Some stability data for the rockets used in the present tests are presented in figures 4 and 5. The roll and pitch frequencies of the 4° monoplane-fin rockets are presented in figure 4 along with velocity and time data for the early stages of the flight. The velocity time history was calculated from knowm mass and thrust characteristics of the rocket and was checked by measurements of time and distance made with a 35-millimeter Fastax camera during the first 8 feet of travel for a few rounds and by Doppler radar measurements of maximum velocity. The rockets had a velocity of about 120 fps on leaving the launcher and reached a maximum velocity of 1,170 fps at 0.65 second after firing. The pitch frequency was calculated from estimates of the stability and checked against the value of oscillation distance of 126 feet given in reference 3. The yaw period (imaginary) was calculated from the body-alone portion of the stability estimates. The roll frequency, as previously noted, was obtained from the film records. The steady-state values of the measured roll frequency are considerably higher than values calculated from strip theory for rigid fins. The difference is believed attributable to aeroelastic effects on the thin metal fins of the rocket. The plots of figure 4 show that the roll frequency exceeded the pitch frequency (which is the requirement for stability) very early in the flight, the cross-over point was at about 0.17 second which corresponds to velocity of about 325 feet per second and a range of about 30 feet. Figure 5 is a stability chart as presented in reference 1 and has superimposed on it a time-trace of the stability characteristics of the 4° monoplane-fin rocket. Figure 5 shows that the monoplane-fin rockets are well within the stable region after less than 0.2 second of flight.

Presentation of Results

Angular-deflection data and wind data for all lots are presented in figures 6 to 20. Table I, which presents the test program, may be used as an index to those figures. The data on lateral dispersion and cross-wind effects on lateral deflection are summarized in figures 21 and 22 and in table II. Data on the dispersion at impact are summarized in table III.

General Characteristics of Rocket Flight Paths

Although the primary purpose of this paper is the presentation of comparative dispersion data for cruciform-fin and monoplane-fin rockets, a review of the general characteristics of the flight paths of ground-launched rockets may be worthwhile to many readers. Such a review may

be based to a large degree on the data of figure 3. In considering these data one must remember that the deflections presented are angular values and that the actual distance between the flight path and line of sight is the product of range and angular deflection. Consider first the lateral deflection at a 12-foot range - this value of 4 mils corresponds to a distance of 0.048 foot or about 1/2 inch, this deflection is probably a result of thrust malalinement although irregularities in the launcher rails may be a contributing factor. Later in the flight, at 70-foot range, the 20-mil deflection corresponds to a distance of 1.4 feet and probably results from a combination of crosswind effects and fin malalinement. During burning, a stable rocket tends to weathercock into the wind and the thrust then drives the rocket up wind. The angle through which the rocket tends to turn in a given crosswind may be increased or decreased by fin malalinement but the rate of turning decreases as the rocket forward velocity increases so the crosswind effect tends to diminish as the rocket continues to accelerate. After burnout the rocket would tend to drift down wind, fin malalinement, depending on its direction, might increase or decrease this drift. The oscillation that occurs near burnout is probably due primarily to a sudden change in the direction of the crosswind effect but may also be due, to some extent, to momentary thrust malalinement resulting from nozzle separation at low pressure during burnout or from propellant slivers being caught in the nozzle during the burning-out process.

Considering the vertical deflection, any crosswind would have effects similar to those noted for the lateral deflection. For this particular round, however, the actual wind direction and the low launching angle combined to result in only a small vertical crosswind component and the major effects on the vertical deflection are the gravity effects noted in figure 3. As the rocket leaves the launcher, the forward support becomes free before the rear support; thus gravity forces acting at the rocket center of gravity induce a nose-down pitch and pitching rate; the thrust then drives the rocket down and the resulting deflection is called gravity tip-off. For stable rockets the gravity tip-off effect decreases as the rocket accelerates since the increased aerodynamic forces tend to reduce both the pitch angle and pitching rate. The burnout oscillation in the vertical plane is similar to that noted previously in the lateral plane. After burnout, the rocket continues under the influence of gravity, thus undergoing an increasing downward vertical deflection known as gravity drop. The apparent gravity tip-off and gravity drop may both be either increased or decreased by fin or thrust malalinement. The effects of fin and thrust malalinement may be decreased by imparting spin to the rocket provided the spin rate is sufficiently higher than the pitch and yaw natural frequencies to avoid resonance and instability.

The following table summarizes the major items affecting rocket deflection and dispersion, and it indicates possible means of reducing the effects of these items:

Item	Means of reducing effects
Thrust malalinement and launcher irregularities	Increase static stability or increase velocity at launch by increasing length of ground launchers. For high-speed air-launching, zero-length launchers may reduce disturbances.
Crosswind effects	Increase velocity at launch, reduce static stability to near neutral.
Fin malalinement	Increase stability, impart spin at rate higher than natural pitch and yaw frequencies.
Gravity tip-off	Increase velocity at launch, release front and rear of rocket from launcher simultaneously.
Gravity drop	Increase velocity of rocket during complete flight.

Deflection and Dispersion Data

In general the deflection and dispersion data presented in figures 6 to 20 show the various effects noted in the preceding discussion of figure 3. There appear to be no major differences in the deflection data for the three rocket configurations used.

Figures 21 and 22 present statistical summaries of the lateral deflection data as plots of mean lateral deflection in mils against mean crosswind in feet per second for each lot at burnout range and at twice burnout range. Also shown is the lateral dispersion expressed as the standard deviation of the deflection from its mean value for each lot. The procedures used in determining the mean and standard deviation are given in the appendix. The slopes at 2 mils/fps faired through the data represent an average value for the effect of crosswind on the deflection of ground-launched rockets according to some British sources. The data in figures 21 and 22 appear to fit this average value of crosswind effect fairly well. The data appear to show slightly smaller crosswind effects for the monoplane-fin rounds than for the cruciform-fin rounds. Although

statistical reliability checks listed in the appendix indicate the data to be relatively reliable, the small number of samples in each lot probably does not justify any conclusion other than that the crosswind effects are approximately equal for the three rocket configurations.

The deflection and dispersion values shown in figures 21 and 22 are summarized in table II. The root-mean-square values of standard deviation shown in table II indicate no significant difference among the three types of rocket whether or not one includes the values for lot 4 which the statistical checks in the appendix indicated to be the least reliable lot. Ignoring lot 4 gives mil dispersion values of 25.7 and 27.75 for the cruciform-fin rockets - these values are slightly larger than the value of 23 listed in reference 3. The present tests, however, used a 4-foot launcher rather than the 7-foot launcher listed in reference 3 and would be expected to show slightly higher dispersion values.

Impact-Range Dispersion

As noted in the section entitled "Tests" a few rounds were tracked with the NACA modified SCR 584 radar and although no records were taken the operator's notes provide some data on range to impact. The impact-range data are summarized in table III. These data, although few in number, show slightly greater mean range for the monoplane-fin rockets than for the cruciform-fin ones. The range dispersions for the cruciform-fin and 4° monoplane-fin round are about equal. The greater dispersion shown for the 8° monoplane rounds may or may not be significant in view of the small sample size considered (4 rounds).

CONCLUDING REMARK

The data from the present tests indicate that fixing the monoplane fins to the body had no drastic effects on stability and that there were no significant differences in the dispersion and crosswind effects of cruciform-fin and monoplane-fin rockets.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., September 6, 1955.

APPENDIX

STATISTICAL PROCEDURES

The mean values of deflection, crosswind velocity, and range and the dispersion or standard deviations of these values were calculated by the following procedures:

Mean values were determined by

$$\bar{x} = \frac{\sum(x)}{n}$$

where x is individual values of deflection, crosswind velocity, and range; n is number of samples; and $\bar{x}$ is mean value

$$d = \frac{\sum\left|x - \bar{x}\right|}{n}$$

where d is mean deviation or average scatter of values about mean

$$s.d. = \sqrt{\frac{\sum(x - \bar{x})^2}{n - 1}}$$

where s.d. is standard deviation of values about mean and is the usual statistical measure of dispersion. The value $(n - 1)$ rather than n was used because of the relatively small sample size in each lot.

Checks on Statistical Reliability

Various checks were made on the statistical reliability of the data.

The first test was a comparison of the ratio $\frac{d}{s.d.}$ for each lot with the standard value of $\frac{d}{s.d.} = 0.798$ for "normal" or "Gaussian" distribution. Values of $\frac{d}{s.d.}$ for the lateral dispersion of the various lots of rockets ranged from 0.608 to 0.884. (See table II.) This range of values for $\frac{d}{s.d.}$ indicates fairly normal distribution.

The reliability of the samples was also checked by performing the following steps (based on refs. 4 and 5) on the data:

(1) From the range between extreme values in each sample w find the mean range $\overline{w}$ and the standard deviation σ_w of the ranges using $n - 1$ instead of n for small samples.

(2) Calculate the following:

$$\alpha = \frac{\pi}{\sigma_w\sqrt{3}}$$

$$u = \frac{\pi\overline{w} - 2\gamma\sigma_w\sqrt{3}}{2\pi}$$

where $\pi = 3.14$ and $\gamma = 0.57722$

(3) Find R for each w, where $R = \alpha(w - 2u)$

(4) The range for each R which falls outside the limits $-1.75 \leqq R \leqq 5.35$ is then from a poor sample (for a 95 percent confidence level.) Shown in table IV are values of R obtained by performing this test on the samples.

In general the test indicated the data to be fairly reliable. Lot 4 for the cruciform fins, lot 2 for the 4° monoplane fins, and lot 4 for the 8° monoplane fins appeared to be possibly somewhat less reliable than the other lots.

REFERENCES

1. Phillips, William H.: Effect of Steady Rolling on Longitudinal and Directional Stability. NACA TN 1627, 1948.

2. Purser, Paul E., and Stevens, Joseph E.: Exploratory Rocket Flight Tests To Investigate the Use of a Freely Spinning Monoplane Tail for Stabilizing a Body. NACA RM L52I05a, 1952.

3. Anon.: Internal and External Ballistic Data - Fin-Stabilized Rockets. OSRD Rep. No. 2409, C.I.T. UBC 28, NDRC, Div. 3, Sec. L, Mar. 15, 1945.

4. Gumbel, E. J.: Probability Tables for the Analysis of Extreme-Value Data, Appl. Math. Series 22, National Bur. Standards, July 6, 1953.

5. Gumbel, E. J.: The Distribution of the Range. Annals Mathematical Statistics, vol. XVIII, no. 3, Sept. 1947, pp. 384-412.

TABLE I.- INDEX TO 2.25-INCH ROCKET DISPERSION TESTS

Round	Fins (a)	Fin angle, deg	Launcher		Wind		Crosswind, fps (b)	Figure	Remarks
			Elevation, deg	Azimuth, deg	Azimuth, deg	V, fps			
Lot 1 on April 17, 1953									
1	+	0	30	171	240	23.5	21.9	6	
2	-	4	30	171	252	23.5	23.2	7	
3	-	8	30	171	249	22.1	21.5	8	
4	+	0	30	171	234	20.6	18.3	6	
5	-	4	30	171	227	22.1	18.2	7	
6	-	8	30	171	243	22.1	20.9	8	
7	+	0	30	171	262	23.5	23.5	6	
8	-	4	30	171	261	25.0	24.9	7	
9	-	8	30	171	256	22.1	21.9	8	
10	+	0	30	171	228	26.5	22.1	6	
11	-	4	30	171	226	39.8	32.4	7	
12	-	8	30	171	203	29.4	15.5	8	
13	+	0	30	171	224	22.1	17.6	6	
14	-	4	30	171	226	30.9	24.9	7	
15	-	8	30	171	224	20.6	----	-	Camera did not operate
16	+	0	30	171	225	22.1	17.8	6	
17	-	4	30	171	225	28.0	22.5	7	
18	-	8	30	171	204	29.4	16.0	-	Tumbled on leaving launcher
19	+	0	30	171	202	32.4	16.6	6	
20	-	4	30	171	208	25.0	15.0	7	
21	-	8	30	171	187	20.6	5.7	8	
22	+	0	30	171	191	22.1	7.5	6	
23	-	4	30	171	197	29.4	12.9	7	
24	-	8	30	171	195	29.4	11.9	8	
25	+	0	30	171	199	30.9	14.5	6	Fired after round 30 because of faulty igniter
26	-	4	30	171	190	30.9	----	-	Mk 13 motor, data not reduced
27	-	8	30	171	195	32.4	----	-	Mk 13 motor, data not reduced
28	+	0	30	171	198	32.4	14.7	6	
29	-	4	30	171	194	25.0	----	-	Mk 13 motor, data not reduced
30	-	8	30	171	195	30.9	12.5	8	
Lot 2 on April 22, 1953									
1	+	0	60	99	196	22.1	21.8	9	
2	-	4	60	99	203	23.5	22.8	10	
3	-	8	60	99	207	19.1	----	--	Camera jammed
4	+	0	60	99	198	27.9	----	--	Camera jammed
5	-	4	60	99	195	22.1	21.9	10	
6	-	8	60	99	199	26.4	26.0	11	
7	+	0	60	99	193	20.6	20.5	9	
8	-	4	60	99	188	27.9	27.9	10	
9	-	8	60	99	198	27.9	27.5	11	
10	+	0	60	99	203	27.9	27.0	9	
11	-	4	60	99	195	26.4	26.3	10	
12	-	8	60	99	203	23.5	22.8	11	
13	+	0	60	99	203	20.6	19.9	9	
14	-	4	60	99	195	29.4	29.2	10	
15	-	8	60	99	201	20.6	20.1	11	
16	+	0	60	99	196	30.9	30.6	9	
17	-	4	60	99	192	29.4	29.3	10	
18	-	8	60	99	189	29.4	29.3	11	
19	+	0	60	99	192	27.9	27.8	9	
20	-	4	60	99	189	32.5	32.3	10	
21	-	8	60	99	185	29.4	29.3	11	
22	+	0	60	99	184	26.4	26.3	9	
23	-	4	60	99	188	34.0	33.7	10	
24	-	8	60	99	192	26.4	26.4	11	
25	+	0	60	99	190	27.9	27.9	9	
26	-	4	60	99	195	27.9	27.7	10	
27	-	8	60	99	187	30.9	30.8	11	
28	+	0	60	99	180	23.5	23.2	9	
29	-	4	60	99	180	30.9	30.4	10	
30	-	8	60	99	180	30.9	30.4	11	
31	-	8	60	99	180	32.5	31.9	11	
32	+	0	60	99	176	29.4	28.6	9	
33	-	4	60	99	180	25.0	24.6	10	

[a]+ denotes cruciform, - denotes monoplane.

[b]Positive values denote wind from right.

TABLE I.- INDEX TO 2.25-INCH ROCKET DISPERSION TESTS - Continued

Round	Fins (a)	Fin angle, deg	Launcher		Wind		Crosswind, fps (b)	Figure	Remarks
			Elevation, deg	Azimuth, deg	Azimuth, deg	V, fps			
Lot 3 on August 31, 1953									
1	+	0	60	130	206	14.5	14.2	12	
2	-	4	60	130	206	17.5	----	--	Mk 13 motor, data not reduced
3	-	8	60	130	195	20.5	----	--	Mk 13 motor, data not reduced
4	+	0	60	130	195	12.0	10.6	12	
5	-	4	60	130	200	10.5	9.7	13	
6	-	8	60	130	205	14.5	14.2	14	
7	+	0	60	130	200	12.0	11.0	12	
8	-	4	60	130	210	14.5	14.4	13	
9	-	8	60	130	200	13.0	12.4	14	
10	+	0	60	130	215	12.0	11.7	12	
11	-	4	60	130	200	13.0	12.4	13	
12	-	8	60	130	215	14.5	----	--	Mk 13 motor, data not reduced
13	+	0	60	130	210	12.0	11.6	12	
14	-	4	60	130	215	13.0	----	--	Mk 13 motor, data not reduced
15	-	8	60	130	205	16.0	----	--	Mk 13 motor, data not reduced
16	+	0	60	130	220	16.0	16.1	12	
17	-	4	60	130	210	12.0	11.6	13	
18	-	8	60	130	215	12.0	----	--	Mk 13 motor, data not reduced
19	+	0	60	130	220	13.0	13.2	12	
20	-	4	60	130	215	9.0	8.8	13	
21	-	8	60	130	220	7.5	7.3	14	
22	+	0	60	130	210	9.0	8.7	12	
23	-	4	60	130	215	12.0	11.7	13	
24	-	8	60	130	215	12.0	11.7	14	Observers believe fins broke off
25	+	0	60	130	215	10.5	10.2	12	
26	-	4	60	130	210	12.0	11.6	13	
27	-	8	60	130	210	10.5	----	--	Mk 13 motor, data not reduced
28	+	0	60	130	205	12.0	11.3	12	
29	-	4	60	130	200	10.5	9.7	13	
30	-	8	60	130	200	14.5	----	--	Mk 13 motor, data not reduced
Lot 4 on July 9, 1954									
1	+	0	60	130	83	16.0	-11.8	15	
2	-	4	60	130	91	14.5	-9.2	16	
3	-	8	60	130	81	17.5	-13.3	17	
4	+	0	60	130	82	17.5	-----	--	Fins broke off at launching
5	-	4	60	130	98	14.5	-7.8	16	
6	-	8	60	130	83	16.0	-11.8	17	
7	+	0	60	130	73	17.5	-14.8	15	
8	-	4	60	130	76	17.5	-14.2	16	
9	-	8	60	130	78	19.0	-15.0	17	
10	+	0	60	130	75	16.0	-13.2	15	
11	-	4	60	130	78	22.0	-17.3	16	
12	-	8	60	130	76	15.0	-12.5	17	
13	+	0	60	130	72	22.0	-18.7	15	
14	-	4	60	130	76	17.5	-14.2	16	
15	-	8	60	130	79	19.0	-14.8	17	
16	+	0	60	130	83	20.0	-14.8	15	
17	-	4	60	130	75	19.0	-15.6	16	
18	-	8	60	130	75	17.5	-14.4	17	
19	+	0	60	130	76	23.5	-19.0	15	
20	-	4	60	130	75	23.0	-18.6	16	
21	-	8	60	130	93	19.0	-11.5	17	
22	+	0	60	130	88	21.0	-14.2	15	
23	-	4	60	130	80	22.0	-16.9	16	
24	-	8	60	130	81	22.0	-16.6	17	
25	+	0	60	130	87	14.5	-10.0	15	
26	-	4	60	130	94	22.0	-12.9	16	
27	-	8	60	130	89	21.0	-14.0	17	
28	+	0	60	130	90	17.0	-10.8	15	
29	-	4	60	130	91	16.0	-10.2	16	
30	-	8	60	130	84	15.0	-11.1	17	

[a]+ denotes cruciform, - denotes monoplane.

[b]Positive values denote wind from right.

TABLE I.- INDEX TO 2.25-INCH ROCKET DISPERSION TESTS - Concluded

Round	Fins (a)	Fin angle, deg	Launcher		Wind		Crosswind, fps (b)	Figure	Remarks
			Elevation, deg	Azimuth, deg	Azimuth, deg	V, fps			
Lot 5 on October 28, 1954									
1	+	0	60	116	120	11.7	0.8	18	
2	-	4	60	116	120	11.7	.8	19	
3	-	8	60	116	150	8.8	4.9	20	
4	+	0	60	116	130	11.7	2.8	18	
5	-	4	60	116	125	11.7	1.8	19	
6	-	8	60	116	120	11.7	.8	20	
7	+	0	60	116	120	11.7	.8	18	
8	-	4	60	116	120	11.7	.8	19	
9	-	8	60	116	120	11.7	.8	20	
10	+	0	60	116	120	8.8	.6	18	
11	-	4	60	116	120	8.8	.6	19	
12	-	8	60	116	130	8.8	2.1	20	
13	+	0	60	116	130	8.8	2.1	18	Camera jammed shortly after burnout
14	-	4	60	116	130	5.9	---	--	Camera jammed
15	-	8	60	116	130	5.9	---	--	Camera jammed
16	+	0	60	116	130	5.9	1.4	18	
17	-	4	60	116	130	5.9	---	--	Misfire
18	-	8	60	116	130	5.9	1.4	20	
19	+	0	60	116	150	5.9	3.3	18	
20	-	4	60	116	150	5.9	3.3	19	
21	-	8	60	116	150	5.9	3.3	20	
22	+	0	60	116	150	5.9	3.3	18	
23	-	4	60	116	150	5.9	3.3	19	
24	-	8	60	116	150	5.9	3.3	20	
25	+	0	60	116	150	5.9	3.3	18	
26	-	4	60	116	150	5.9	3.3	19	
27	-	8	60	116	150	5.9	3.3	20	
28	+	0	60	116	150	5.9	3.3	18	
29	-	4	60	116	150	5.9	3.3	19	
30	-	8	60	116	150	5.9	3.3	20	

[a] + denotes cruciform, - denotes monoplane.

[b] Positive values denote wind from right.

CONFIDENTIAL

TABLE II.- SUMMARY OF 2.25-INCH ROCKET LATERAL DISPERSION DATA

Fins	Lot	Mean crosswind velocity, fps	At burnout range (385 ft)			At twice burnout range (770 ft)			Remarks
			Mean deflection, mils	Standard deviation, mils	Mean deviation / Standard deviation (a)	Mean deflection, mils	Standard deviation, mils	Mean deviation / Standard deviation (a)	
Cruciform	1	17.41	28.67	15.77	0.845	37.20	23.41	0.813	Root-mean-square standard deviation of all lots = 31.63 at burnout, = 42.40 at twice burnout range. Ignoring lot 4, values are 25.70 and 27.75
	2	25.36	64.30	22.12	.798	67.57	20.81	.806	
	3	11.96	43.00	26.73	.798	42.00	22.53	.843	
	4	-14.62	-26.50	48.56	.676	-19.00	76.86	.859	
	5	2.17	1.90	34.50	.884	-3.62	39.9	.793	
4° Monoplane	1	22.10	15.83	21.11	.608	30.50	15.11	.711	Root-mean-square standard deviation of all lots = 29.10 at burnout, = 30.08 at twice burnout range. Ignoring lot 2, values are 25.05 and 26.20
	2	27.82	41.10	41.53	.867	26.25	39.51	.702	
	3	11.46	31.43	22.55	.758	35.67	25.57	.787	
	4	-11.74	-17.20	25.01	.633	(b)	(b)	(b)	
	5	2.22	13.67	30.50	.823	13.80	34.3	.858	
8° Monoplane	1	15.70	-2.07	29.13	.768	4.30	31.96	.667	Root-mean-square standard deviation of all lots = 43.69 at burnout, = 39.41 at twice burnout range. Ignoring lot 4, values are 27.21 and 23.91
	2	27.24	61.94	29.50	.732	57.43	15.22	.748	
	3	(b)		(b)	(b)	(b)	(b)	(b)	
	4	-13.88	-31.12	73.58	.846	-26.17	67.06	.781	
	5	2.64	-15.43	22.40	.800	-19.17	21.50	.783	

[a]Ratio of 0.798 indicates data have "normal" or "Gaussian" distribution.

[b]Insufficient data to justify statistical analysis.

CONFIDENTIAL

TABLE III.- 2.25-INCH ROCKET IMPACT DISPERSION DATA

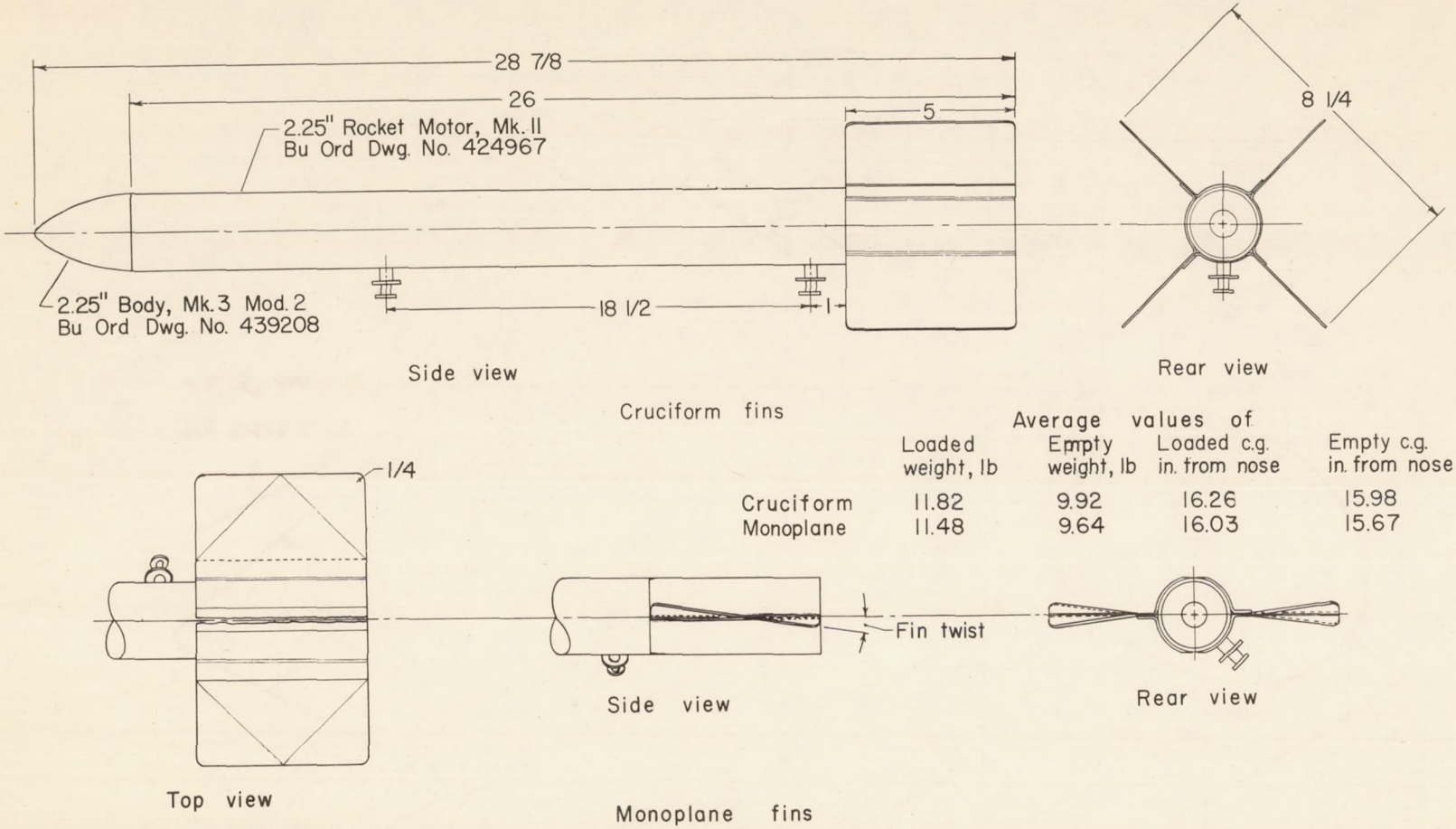
Fins	Lot	Round	Range at impact, yd (a)	Mean range at impact, yd	Standard deviation of range at impact, yd	Mean deviation / Standard deviation
Cruciform	2	1	4,960	5,073	235	0.842
	2	4	5,370			
	2	22	4,960			
	2	25	5,370			
	5	10	4,950			
	5	16	4,830			
4° Monoplane	2	5	5,880	5,735	238	.797
	2	8	5,970			
	5	2	5,440			
	5	11	5,650			
8° Monoplane	2	12	5,970	5,683	292	.831
	2	27	5,880			
	5	6	5,530			
	5	15	5,350			

[a]Data from radar operator's notes.

TABLE IV.- STATISTICAL CHECK OF DATA

Fins	Lot	R (a)	
		At burnout range	At twice burnout range
Cruciform	1	-1.46	-0.19
	2	.72	-.13
	3	1.07	-.19
	4	3.22	3.20
	5	2.38	3.08
4° Monoplane	1	.38	-1.24
	2	4.36	3.04
	3	.51	1.39
	4	-.08	-----
	5	.60	1.54
8° Monoplane	1	.94	2.07
	2	2.68	-.73
	3	-----	-----
	4	2.28	3.22
	5	-1.34	.06

[a]Value of R should be between -1.75 and 5.35 for 95% confidence level (see appendix).

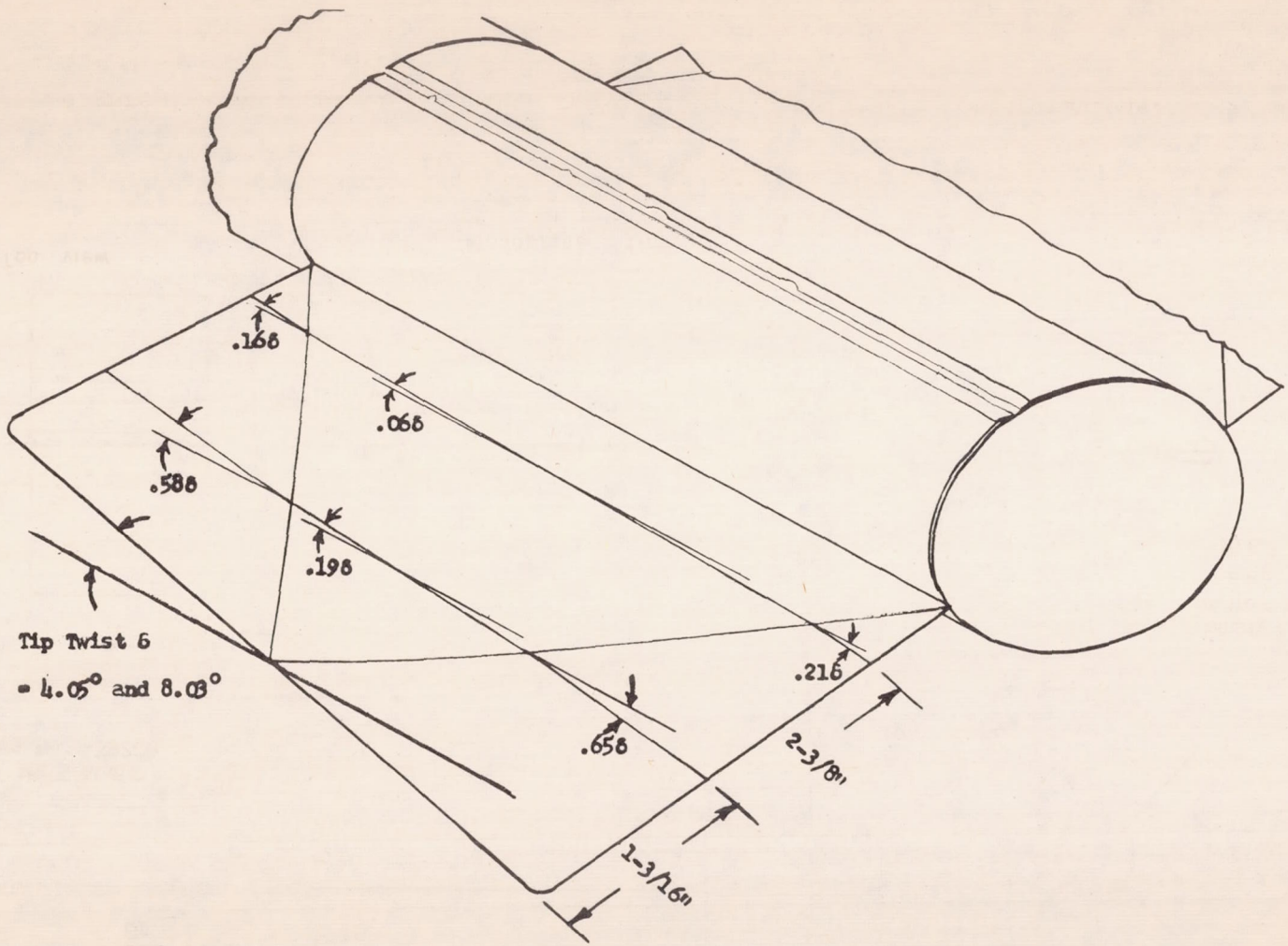


Average values of

	Loaded weight, lb	Empty weight, lb	Loaded c.g. in. from nose	Empty c.g. in. from nose
Cruciform	11.82	9.92	16.26	15.98
Monoplane	11.48	9.64	16.03	15.67

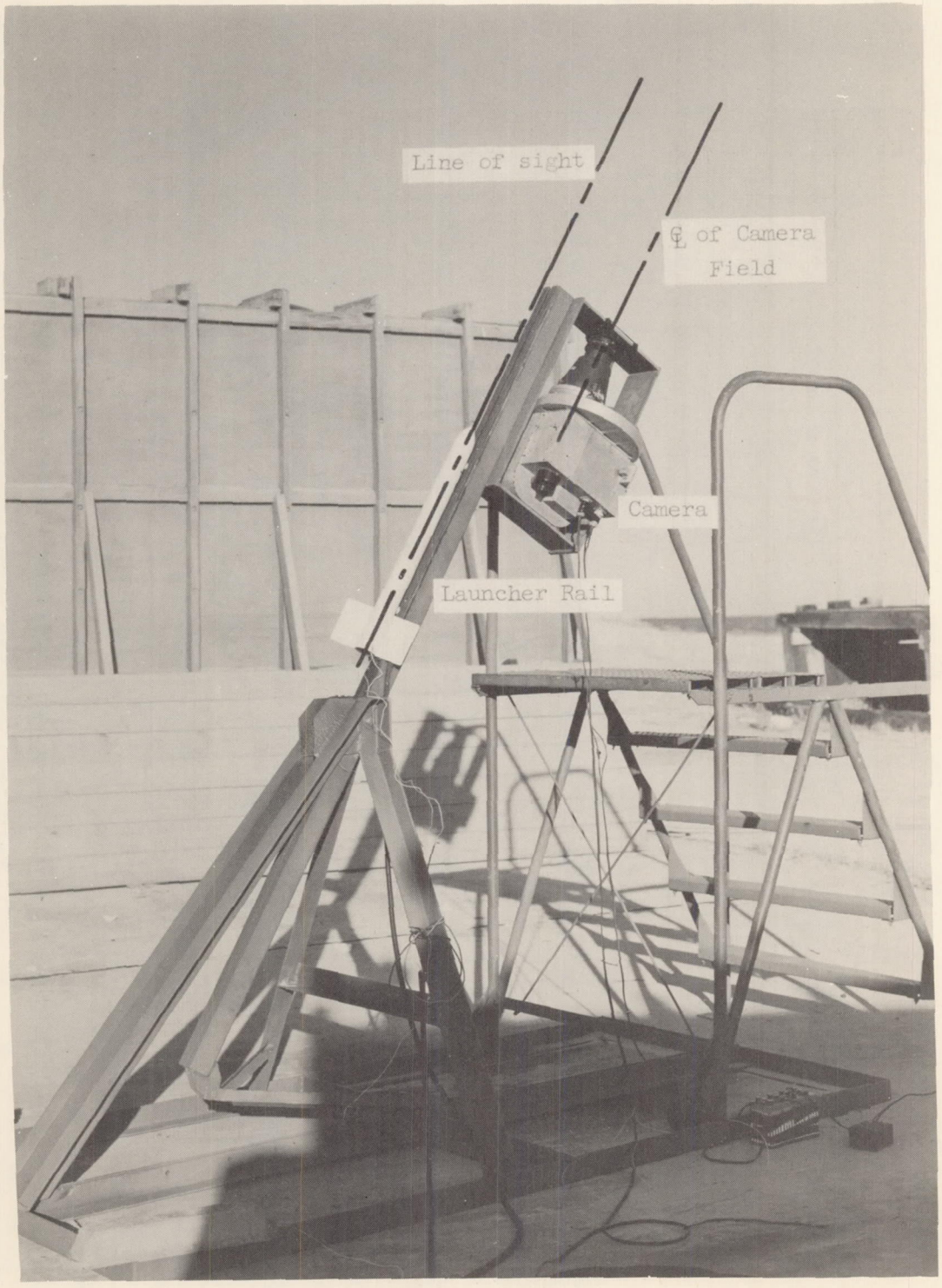
(a) General arrangement.

Figure 1.- Sketches of 2.25-inch rocket motor, showing fin configurations. All dimensions are in inches.



(b) Mode and average values of fin twist, average of 14 rounds.

Figure 1.- Concluded.



L-87285.1

Figure 2.- Photograph of typical monoplane-fin rocket on launcher.

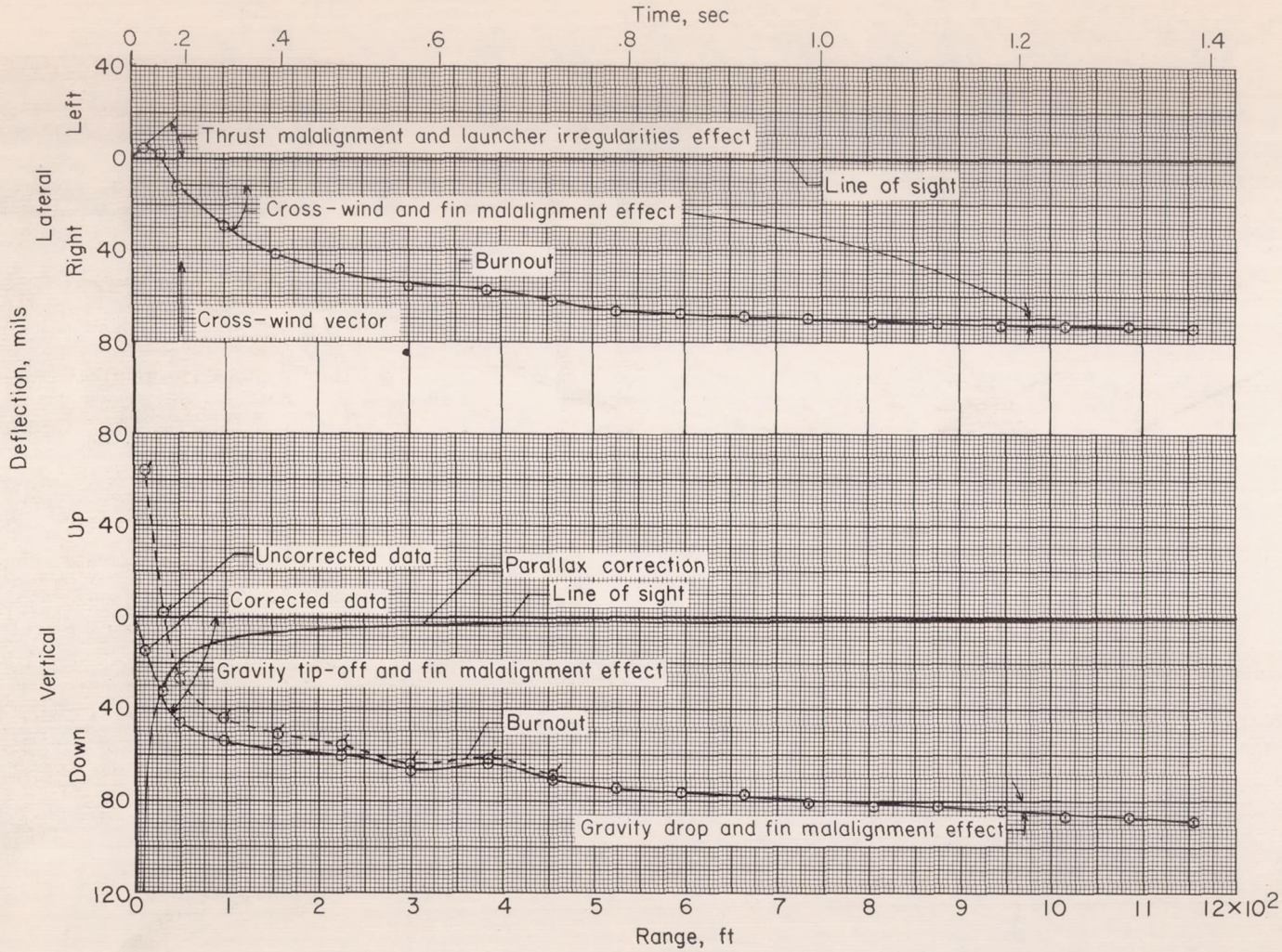


Figure 3.- Sample deflection data; lot 1; round 1; cruciform-fin rocket; crosswind 21.9 fps from right.

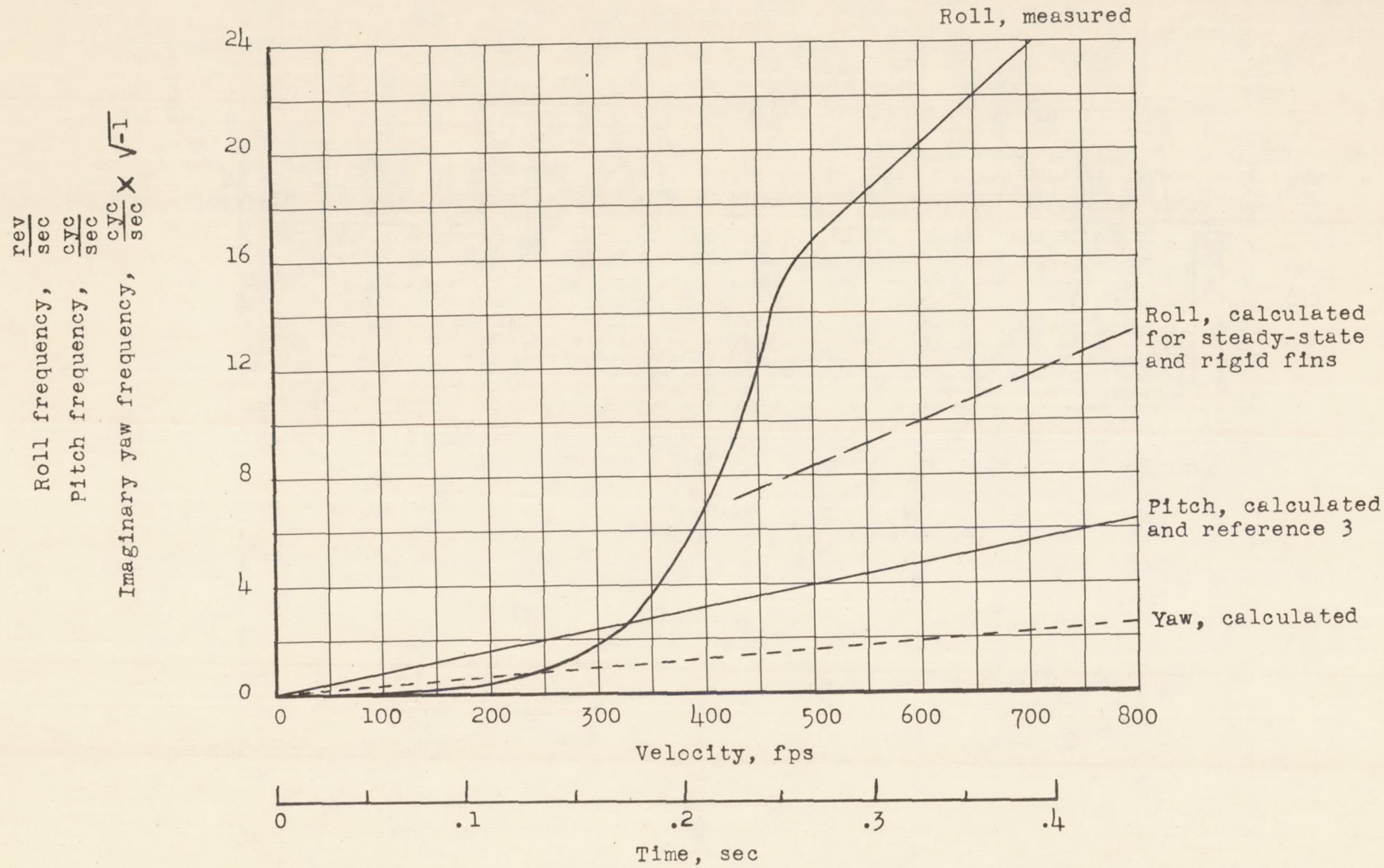


Figure 4.- Stability parameters for 4° monoplane-fin rockets.

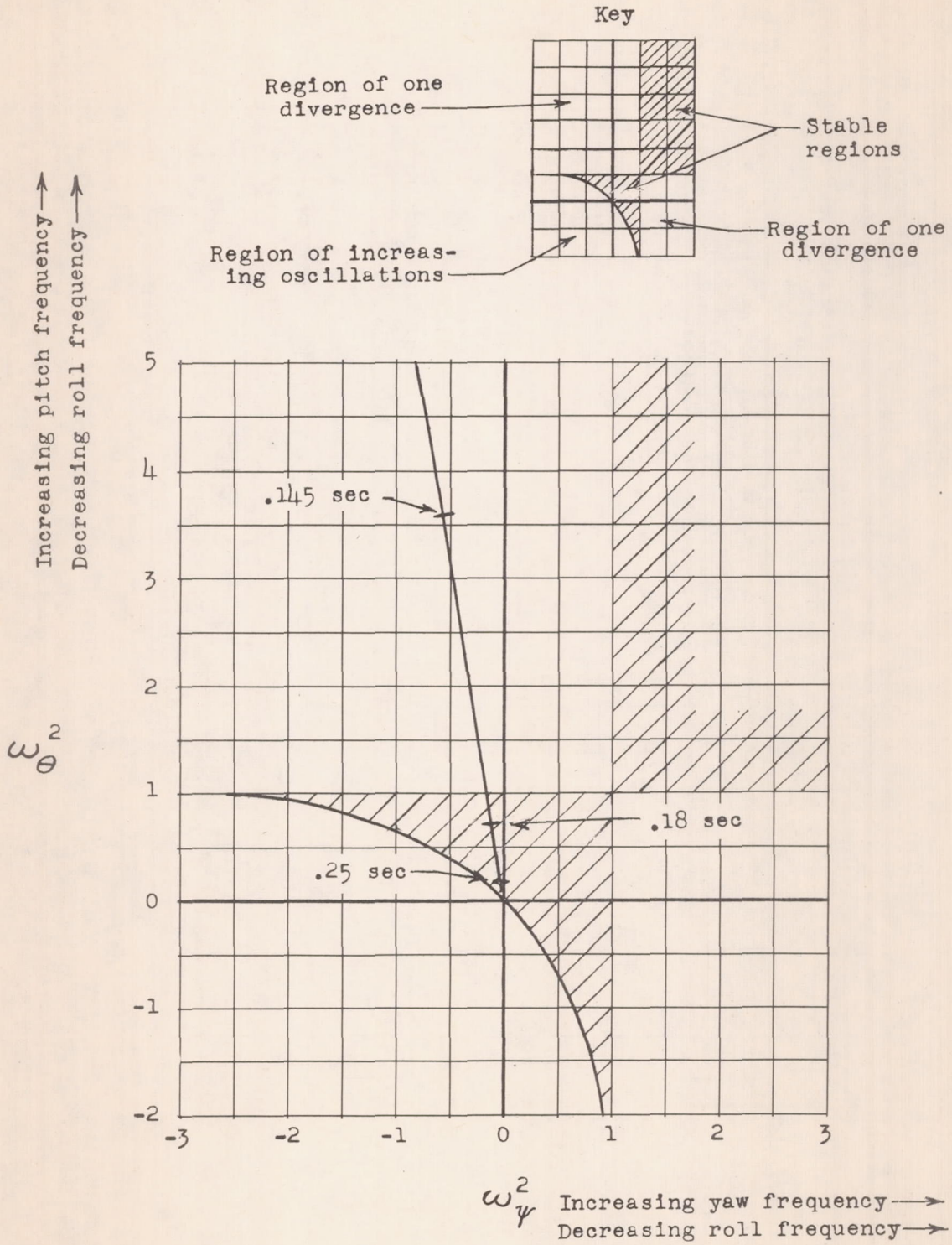


Figure 5.- Stability chart for 4° monoplane-fin rockets.

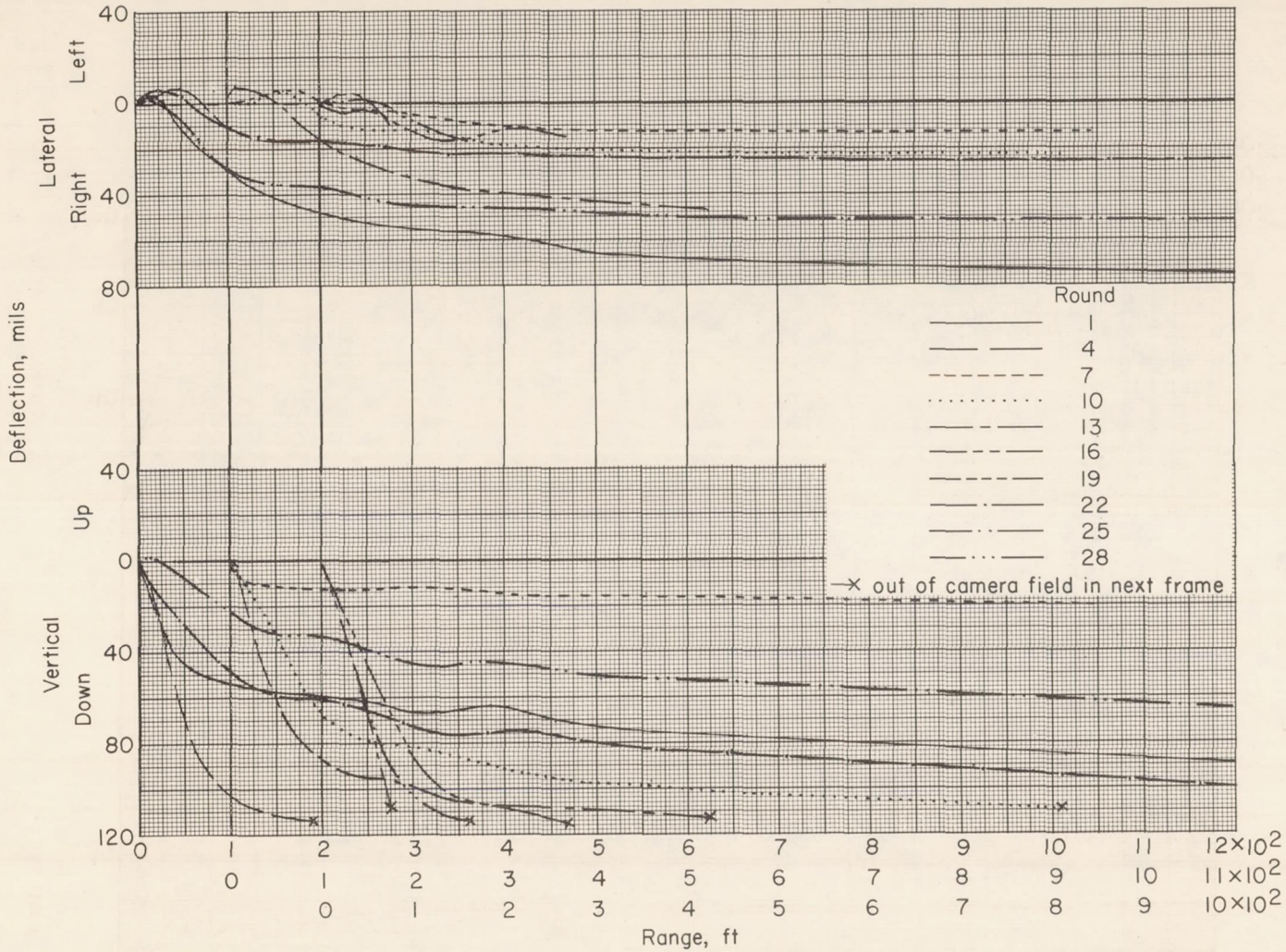


Figure 6.- Deflection data; lot 1; cruciform-fin rockets; mean crosswind 17.41 fps from right.

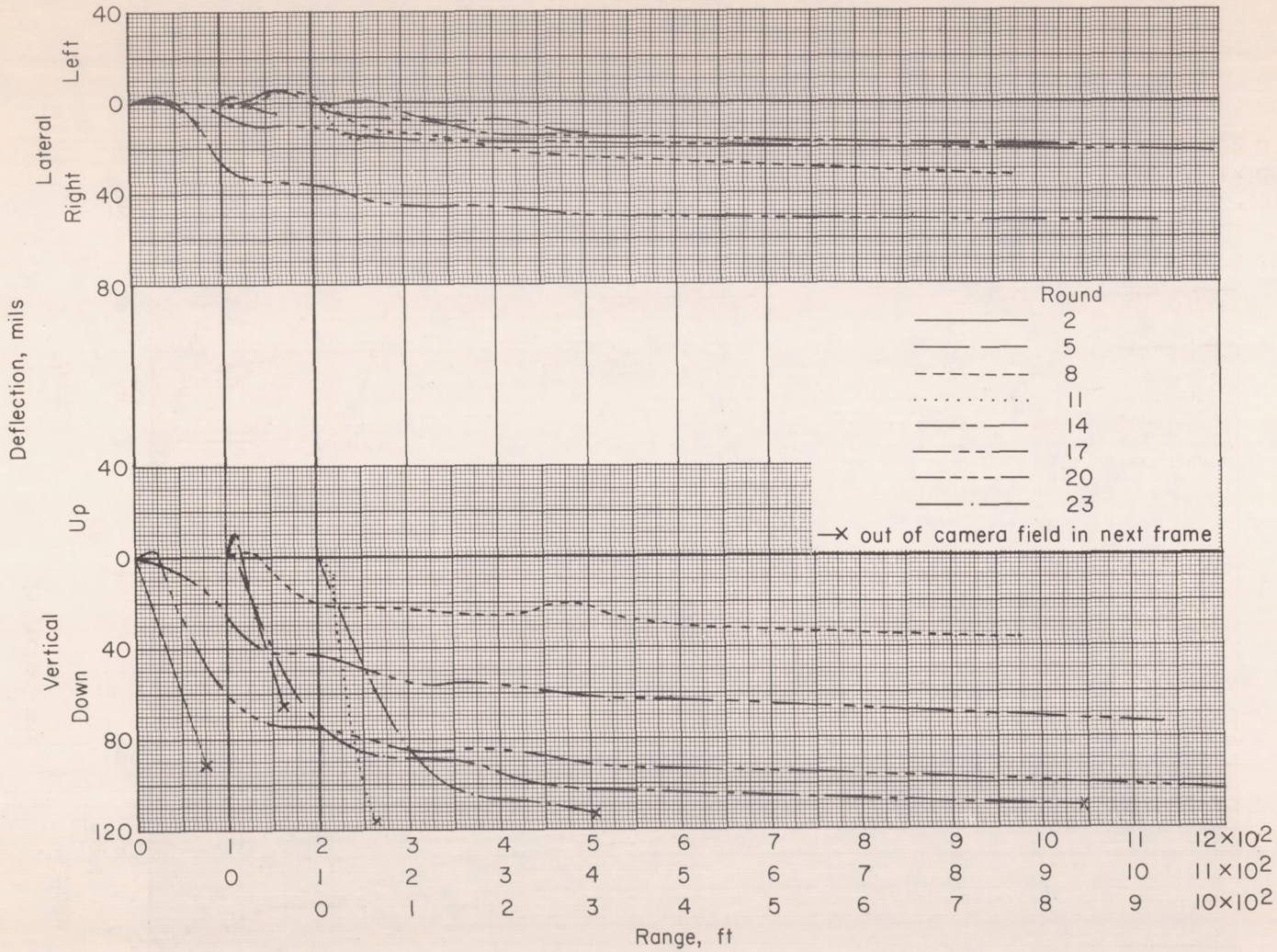


Figure 7.- Deflection data; lot 1; 4° monoplane-fin rockets; mean crosswind 22.1 fps from right.

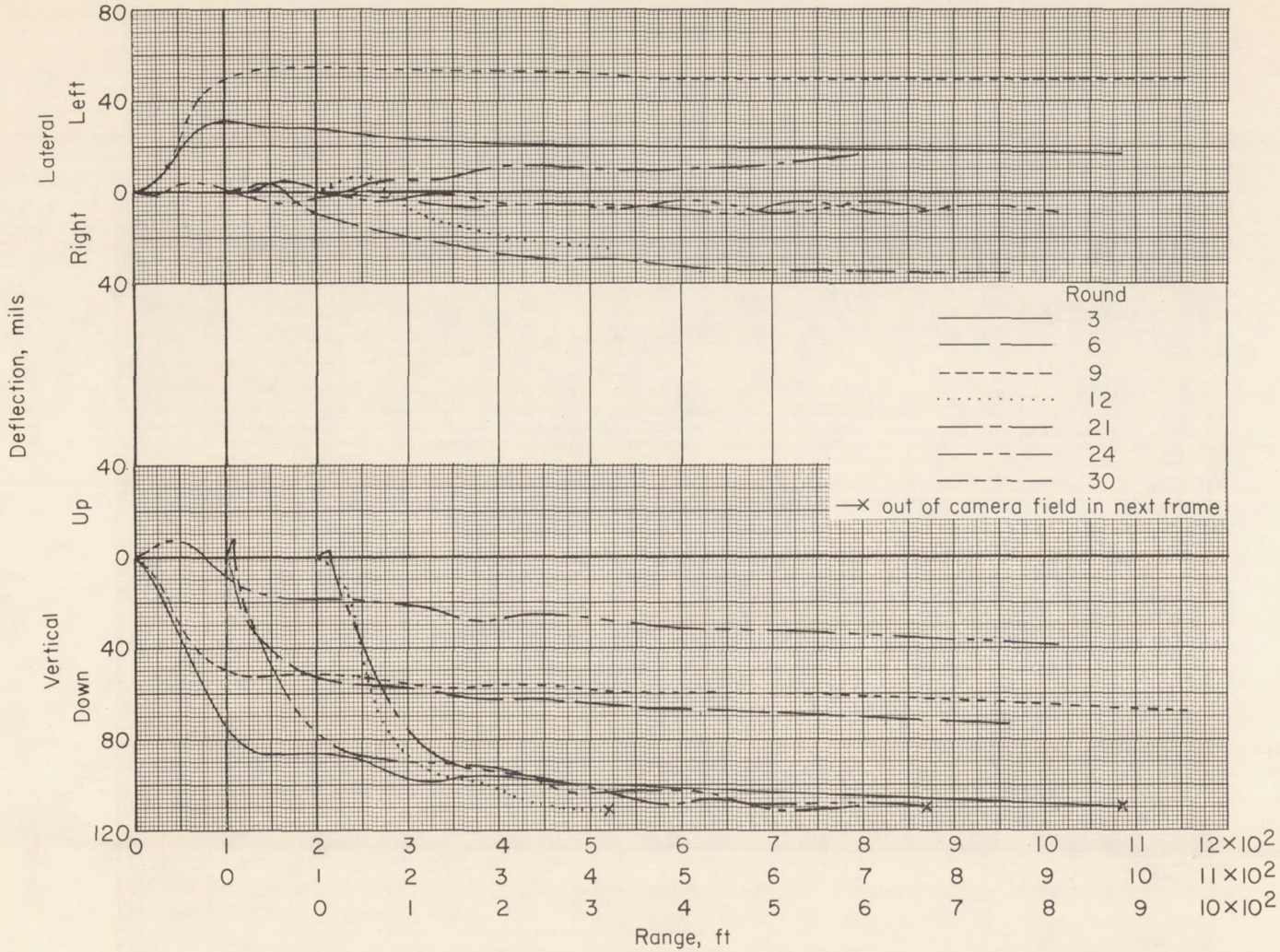


Figure 8.- Deflection data; lot 1; 8° monoplane-fin rockets; mean crosswind 15.7 fps from right.

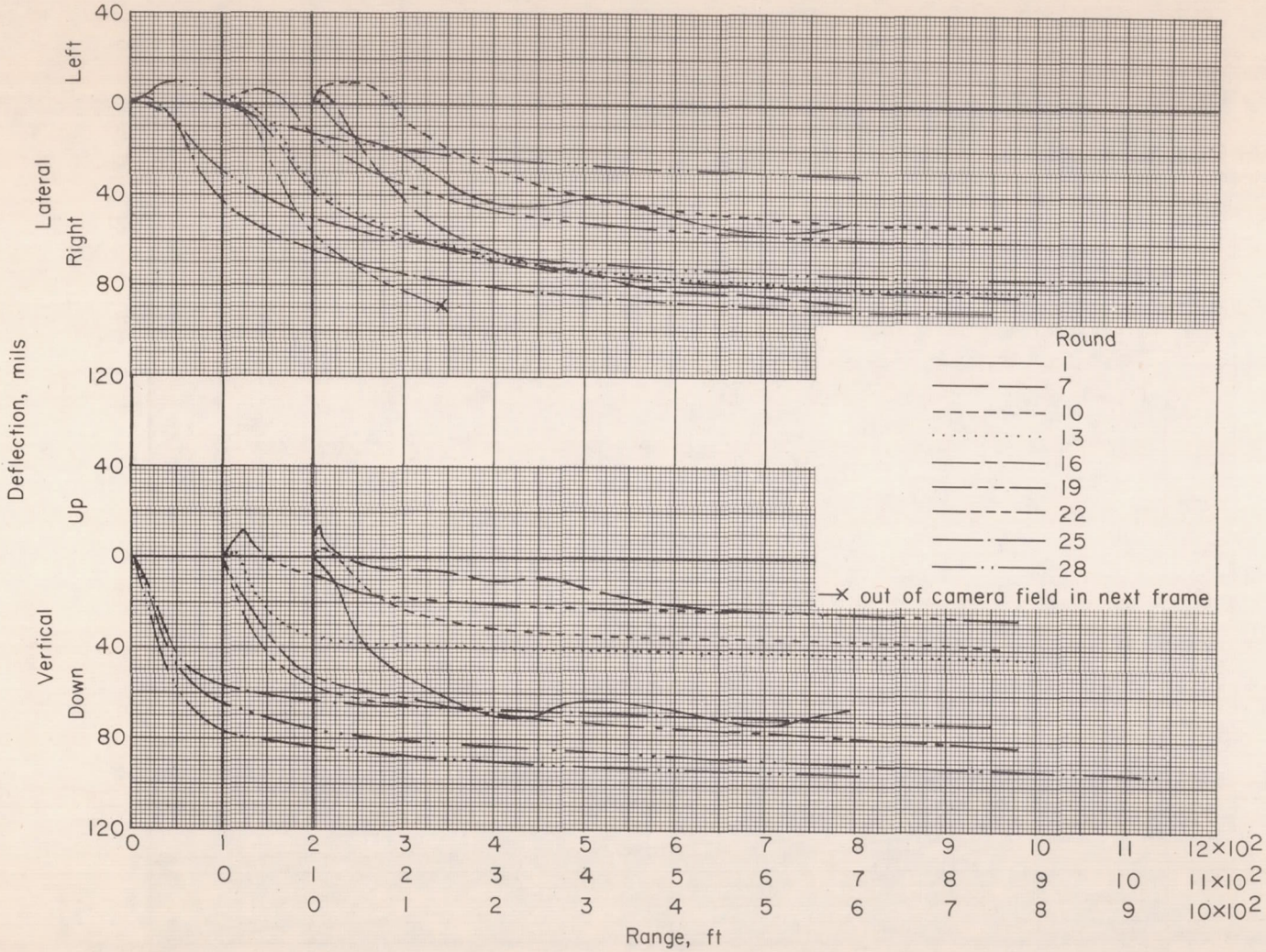


Figure 9.- Deflection data; lot 2; cruciform-fin rockets; mean crosswind 25.63 fps from right.

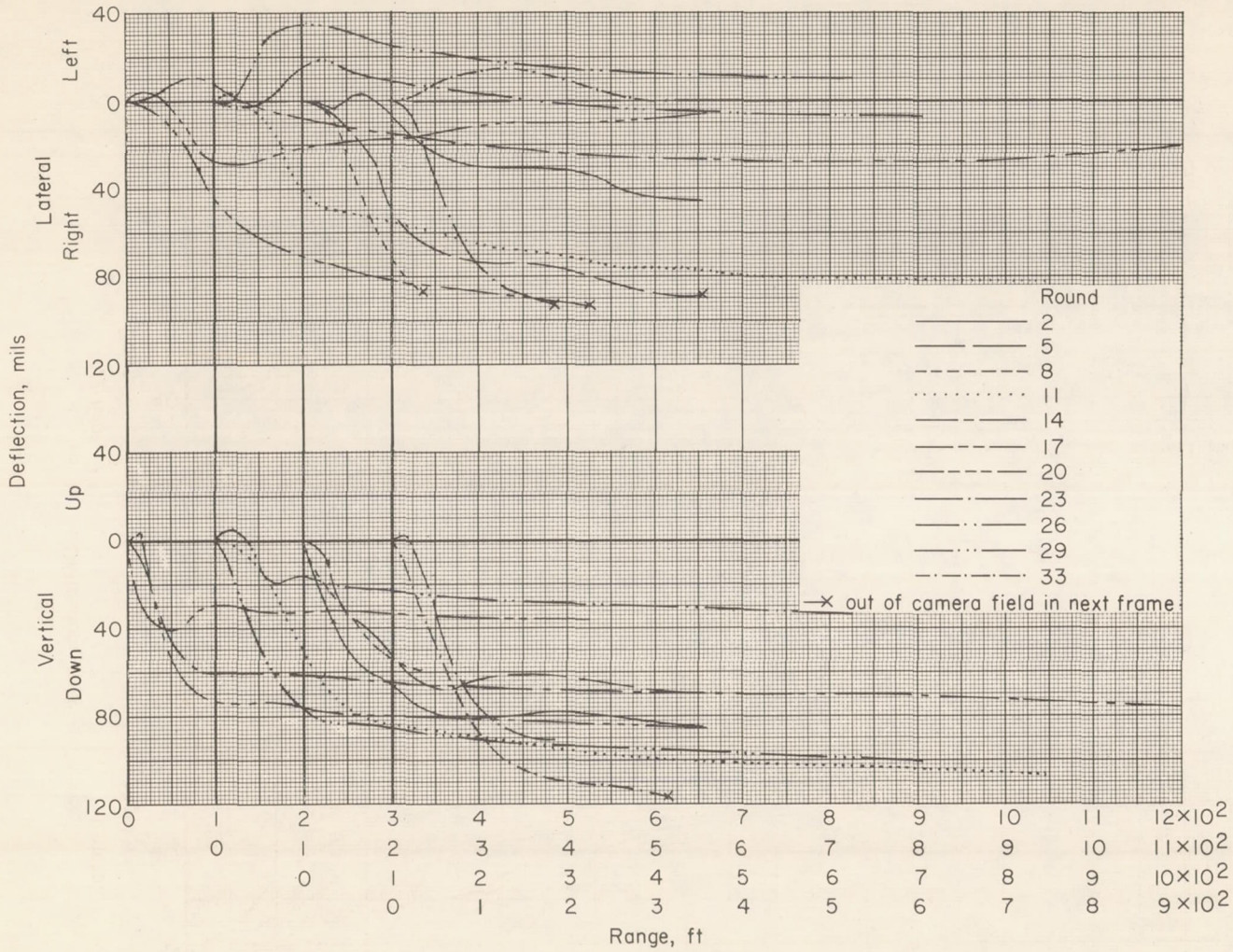


Figure 10.- Deflection data; lot 2; 4° monoplane-fin rockets; mean crosswind 27.82 fps from right.

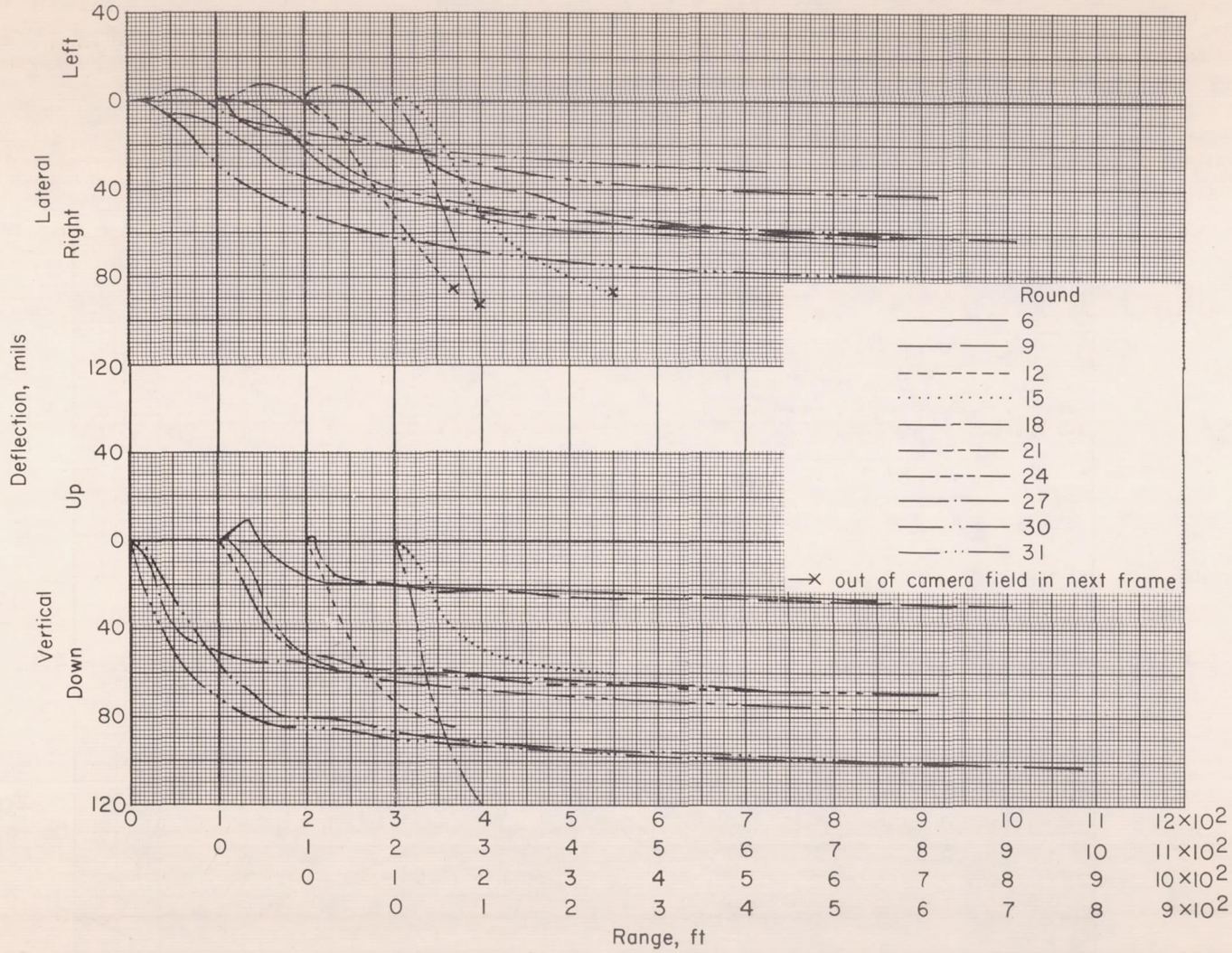


Figure 11.- Deflection data; lot 2; 8° monoplane-fin rockets; mean crosswind 27.24 fps from right.

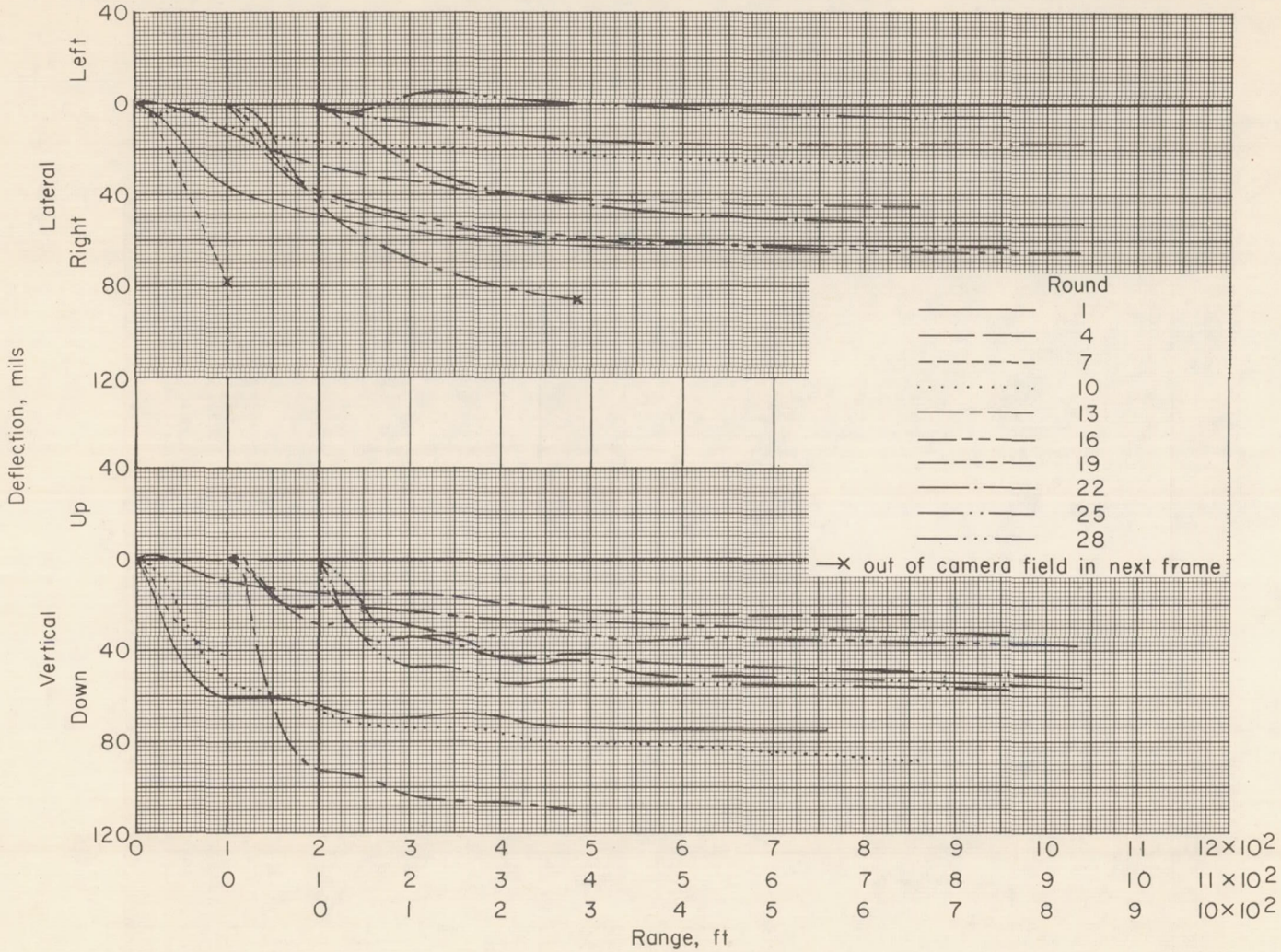


Figure 12.- Deflection data; lot 3; cruciform-fin rockets; mean crosswind 11.96 fps from right.

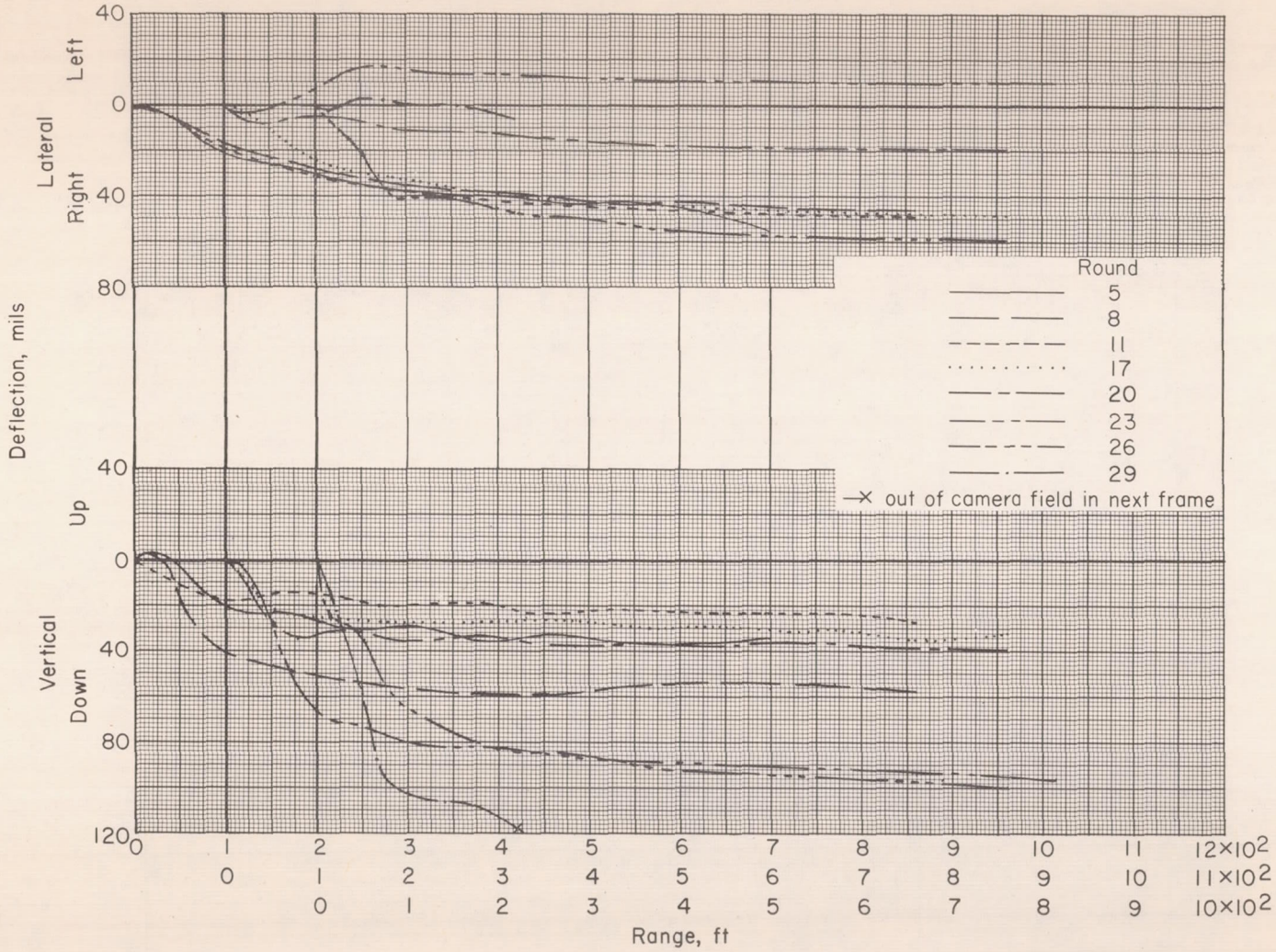


Figure 13.- Deflection data; lot 3; 4° monoplane-fin rockets; mean crosswind 11.46 fps from right.

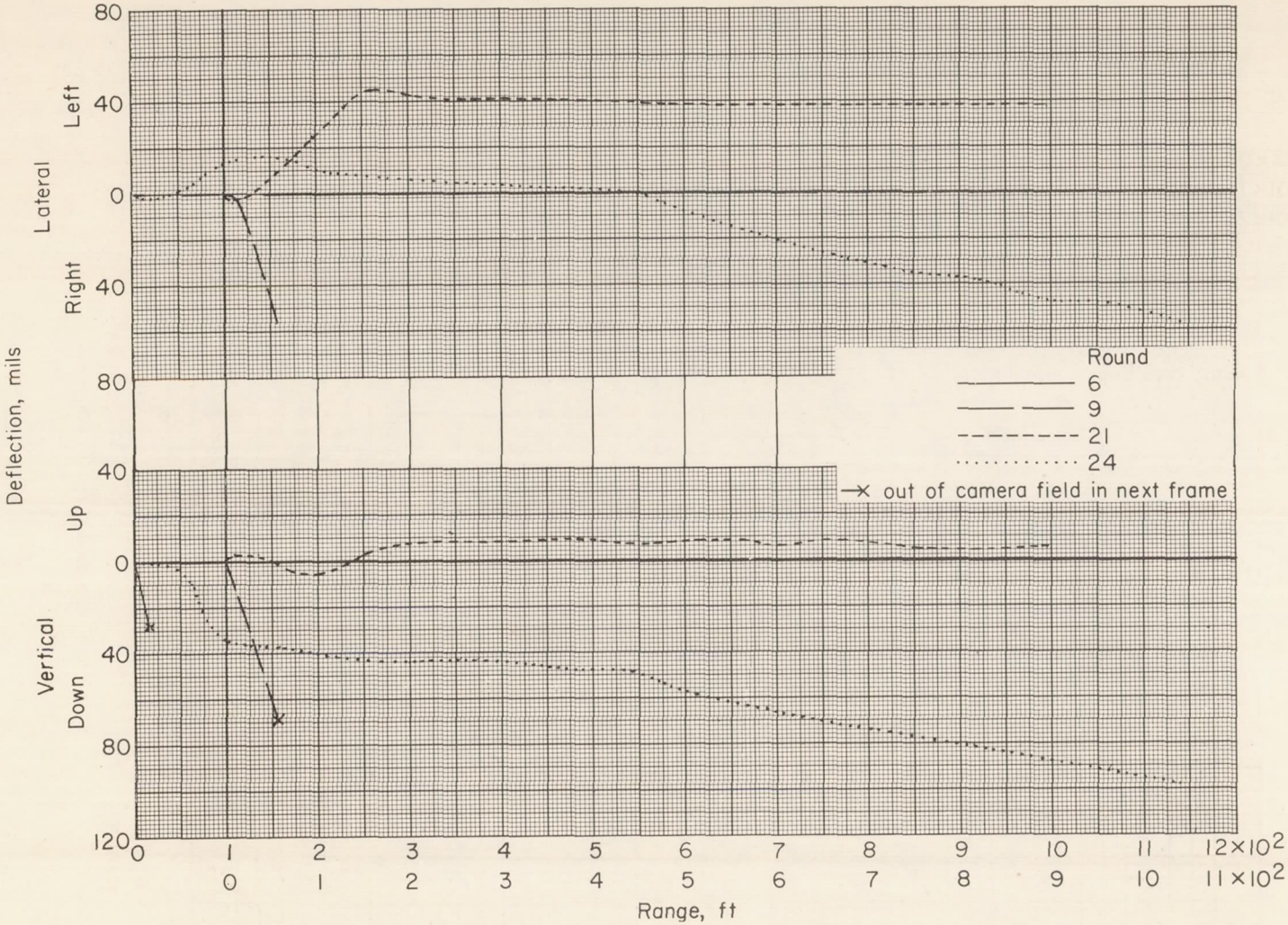


Figure 14.- Deflection data; lot 3; 8° monoplane-fin rockets; mean crosswind 11.40 fps from right.

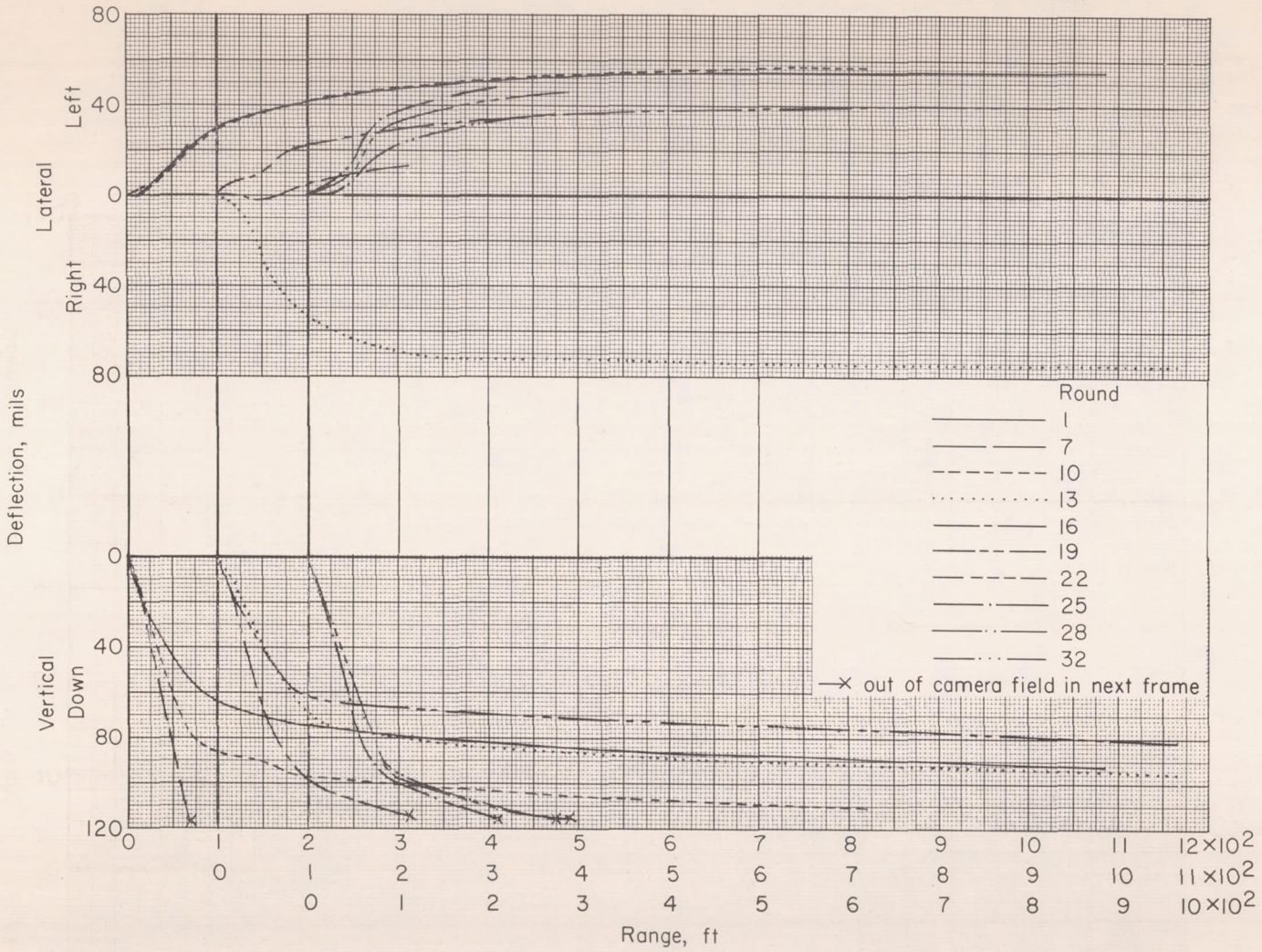


Figure 15.- Deflection data; lot 4; cruciform-fin rockets; mean crosswind 14.62 fps from left.

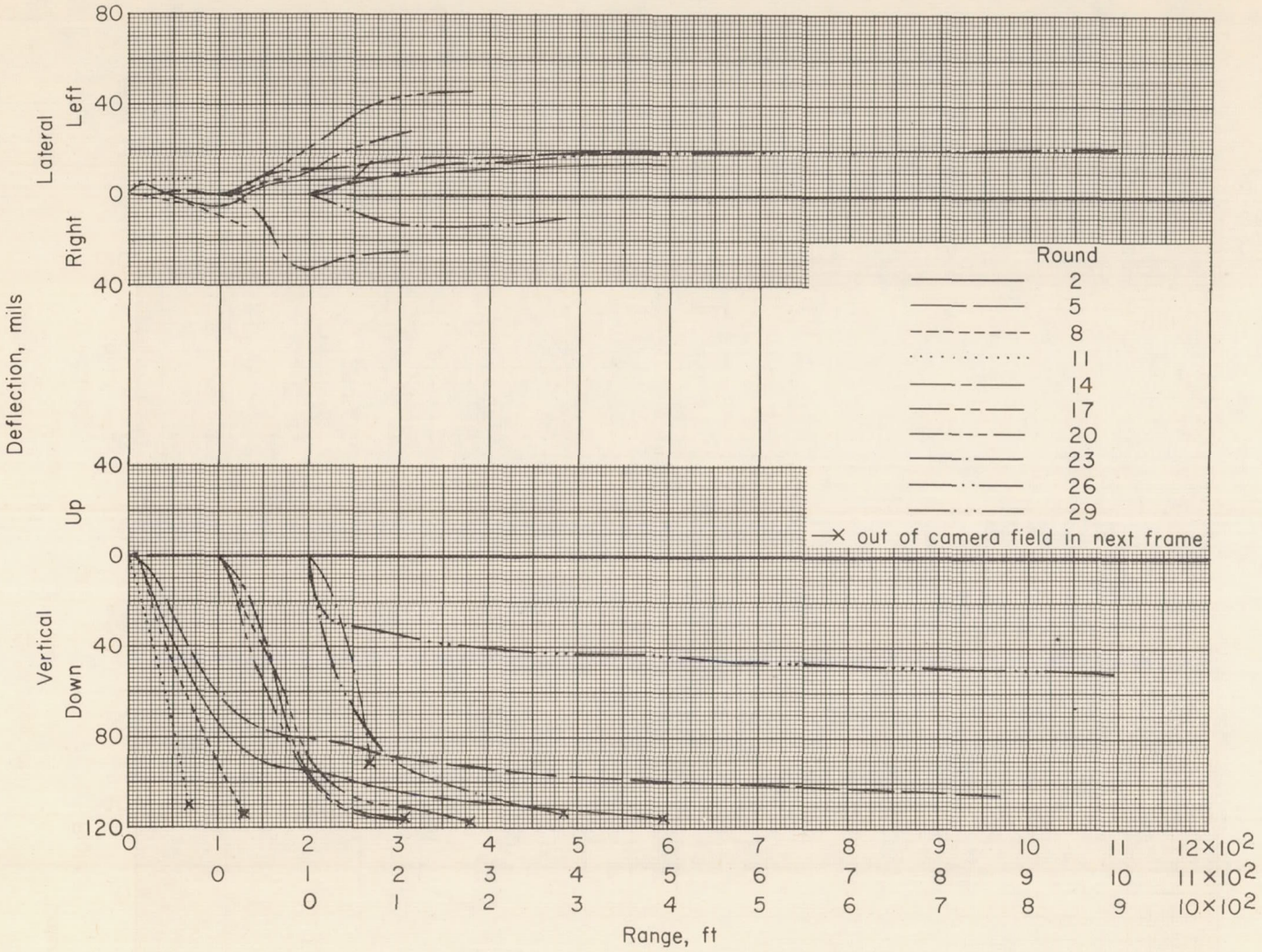


Figure 16.- Deflection data; lot 4; 4° monoplane-fin rockets; mean crosswind 11.74 fps from left.

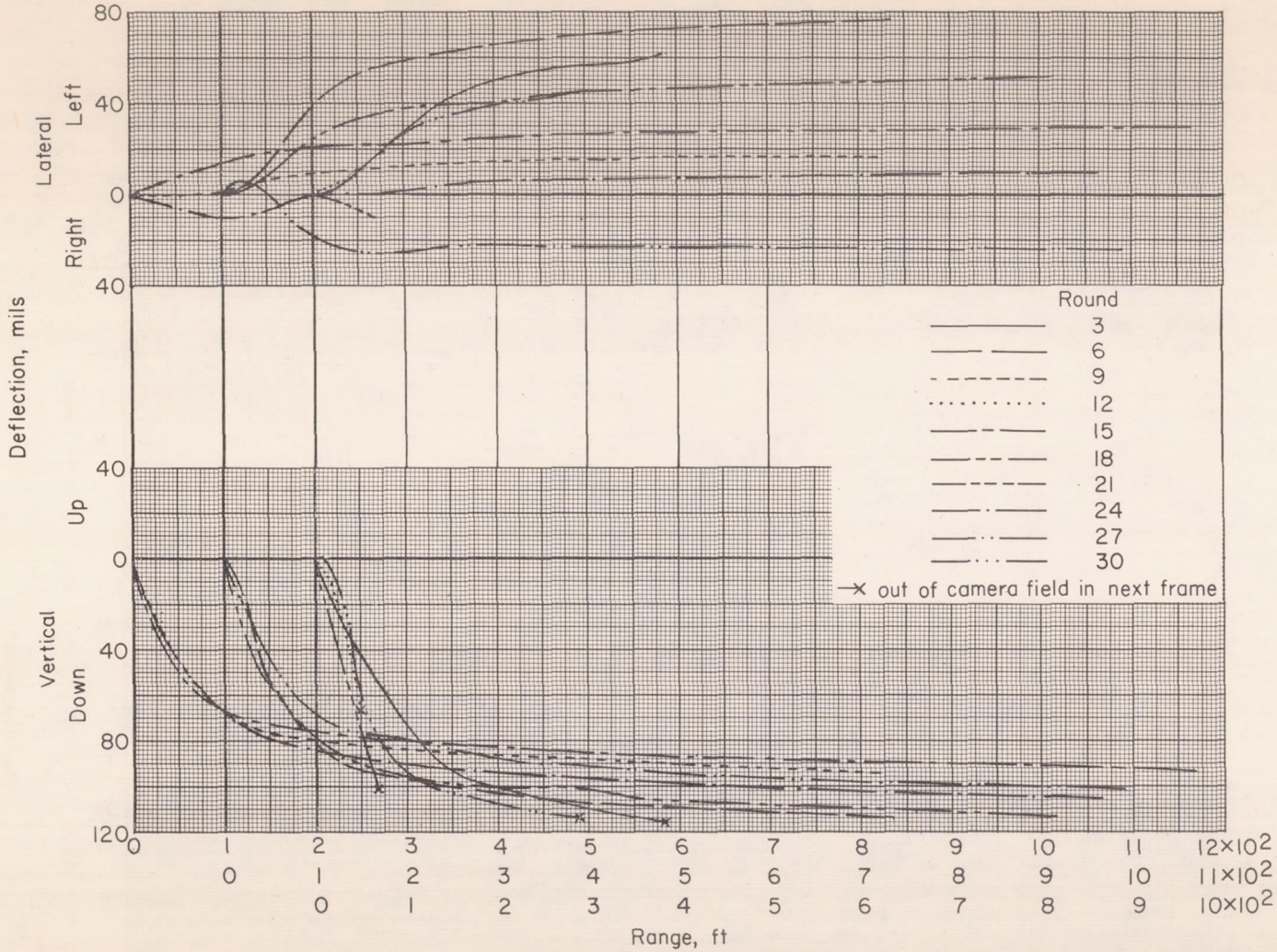


Figure 17.- Deflection data; lot 4; 8° monoplane-fin rockets; mean cross-wind 13.88 fps from left.

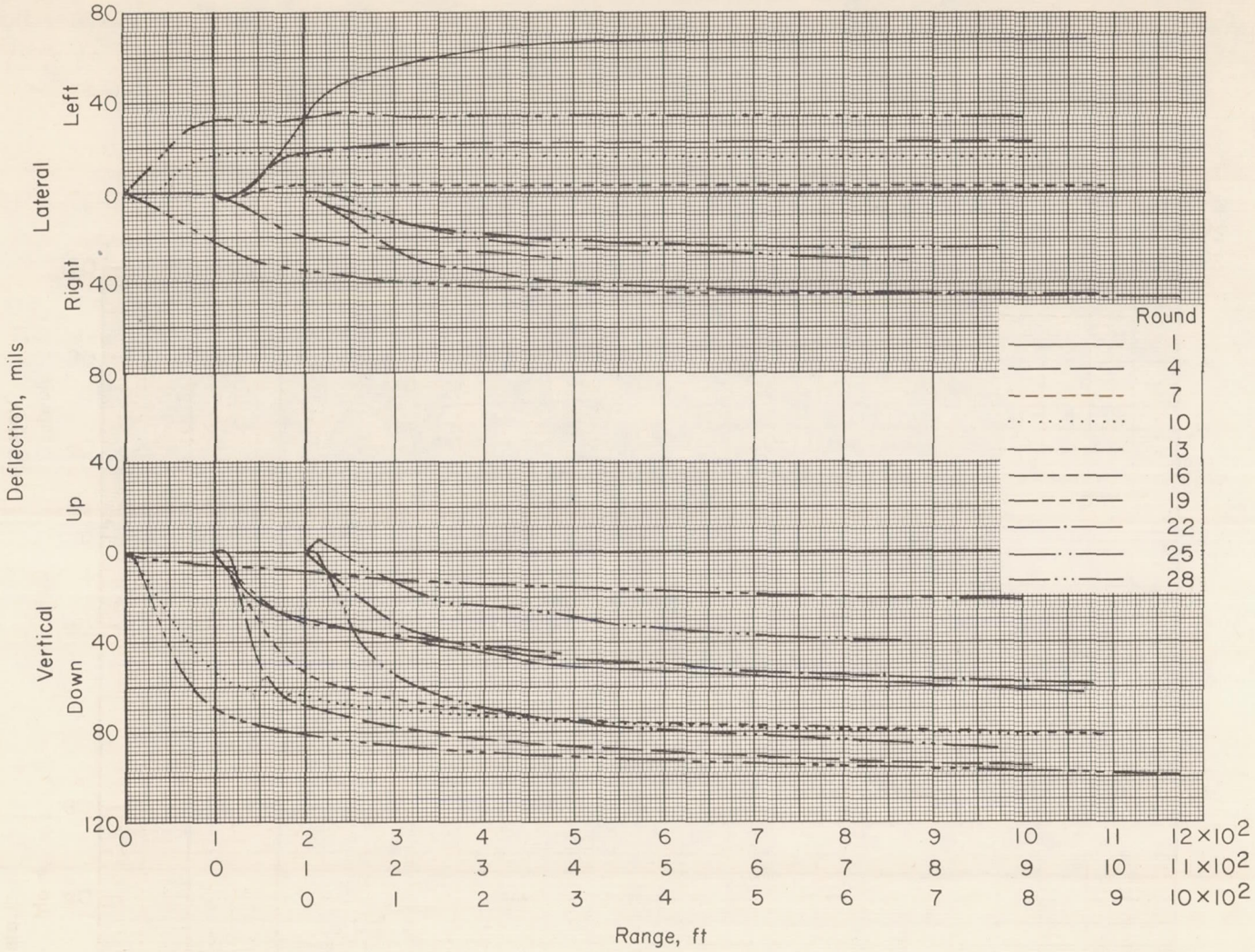


Figure 18.- Deflection data; lot 5; cruciform-fin rockets; mean cross-wind 2.17 fps from right.

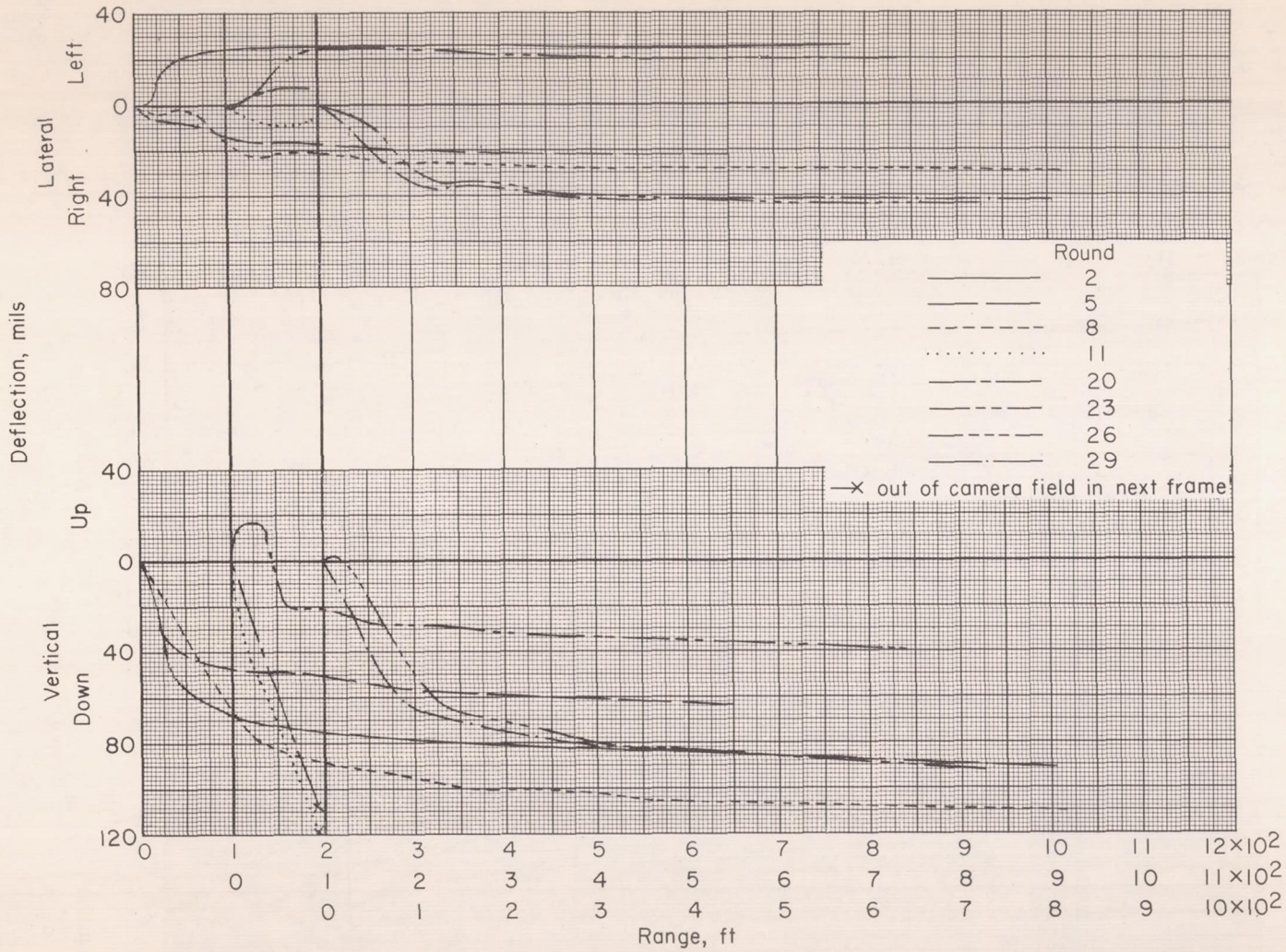


Figure 19.- Deflection data; lot 5; 4° monoplane-fin rockets; mean cross-wind 2.22 fps from right.

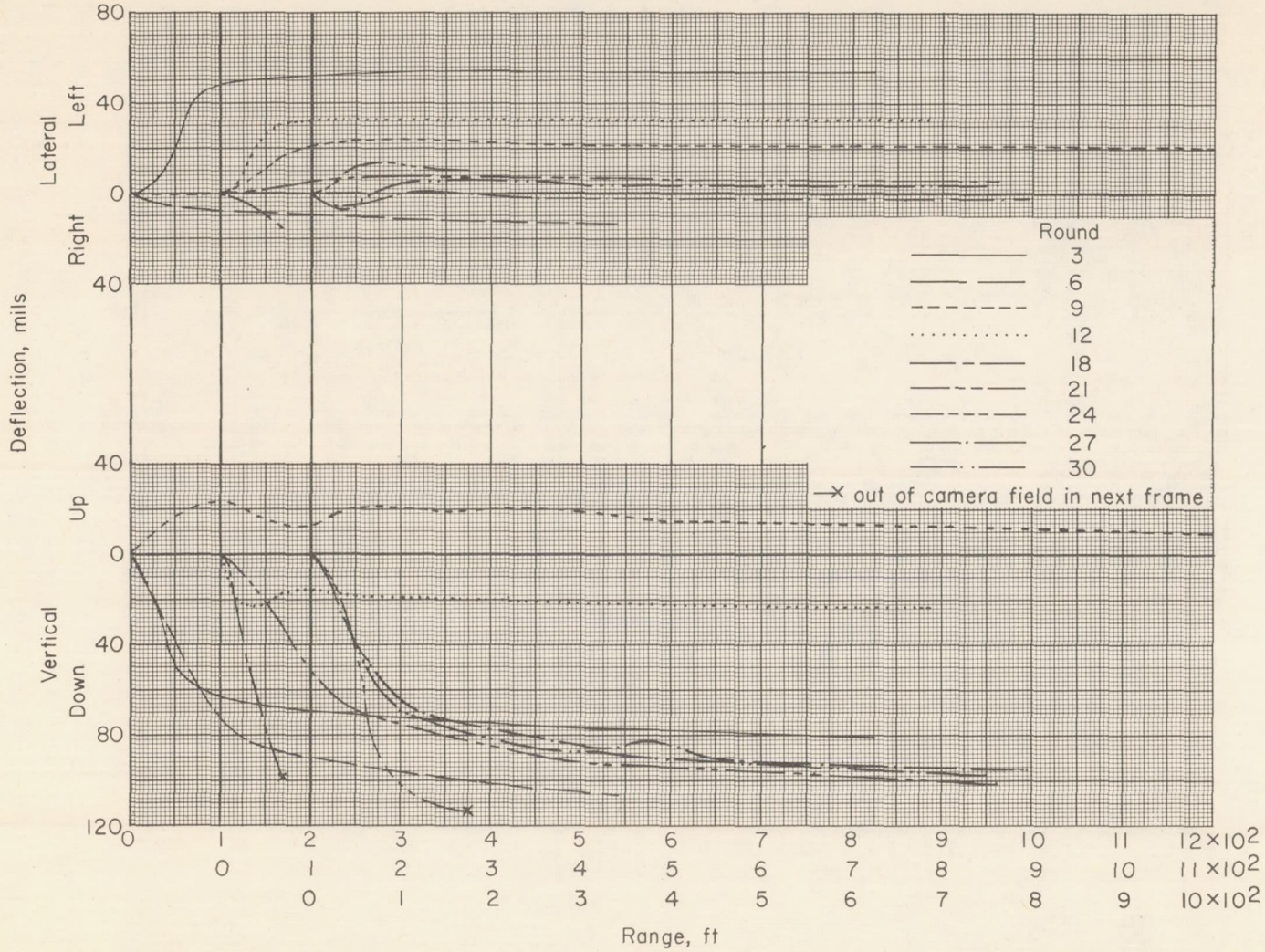
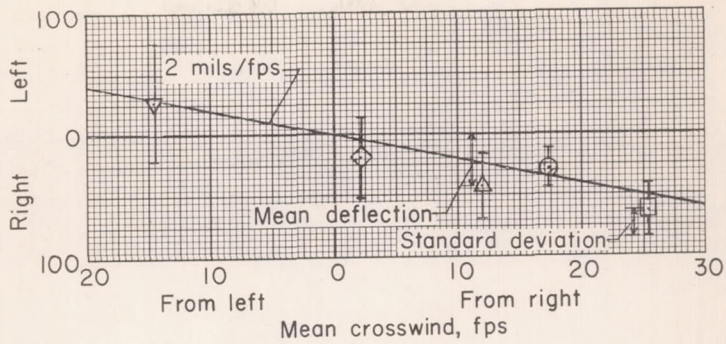
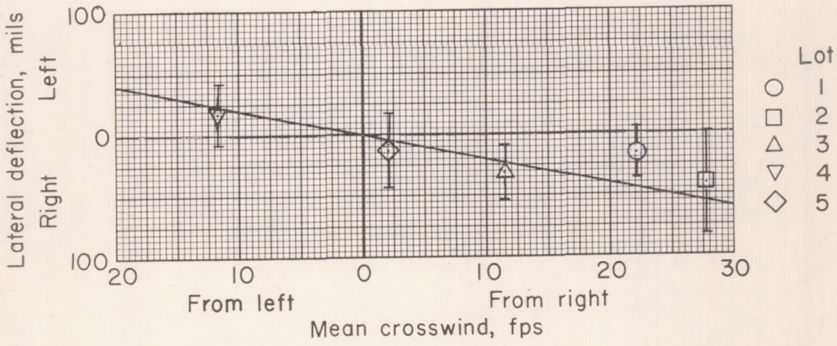


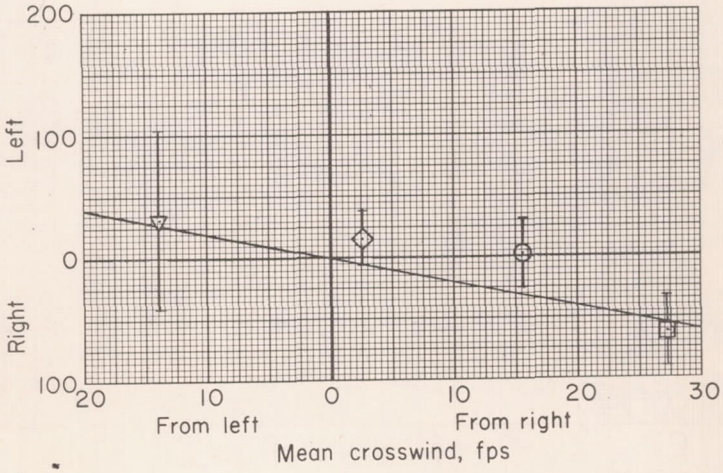
Figure 20.- Deflection data; lot 5; 8° monoplane-fin rockets; mean cross-wind 2.64 fps from right.



(a) Cruciform-fin rockets.

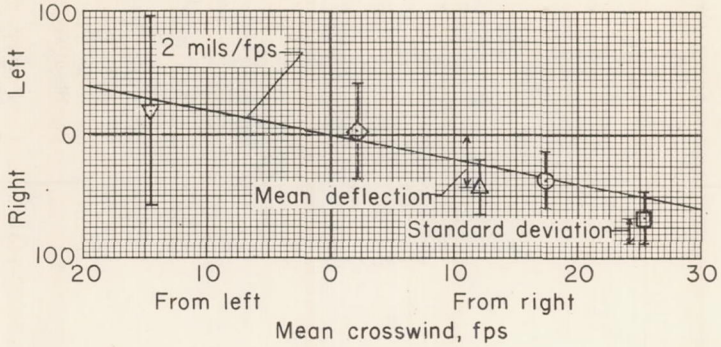


(b) 4° monoplane-fin rockets.

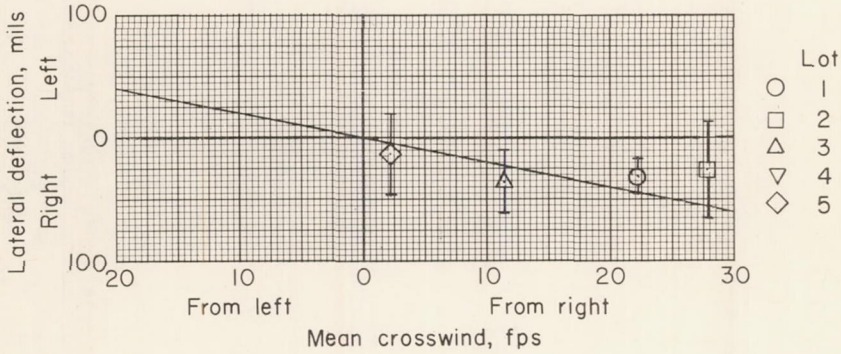


(c) 8° monoplane-fin rockets.

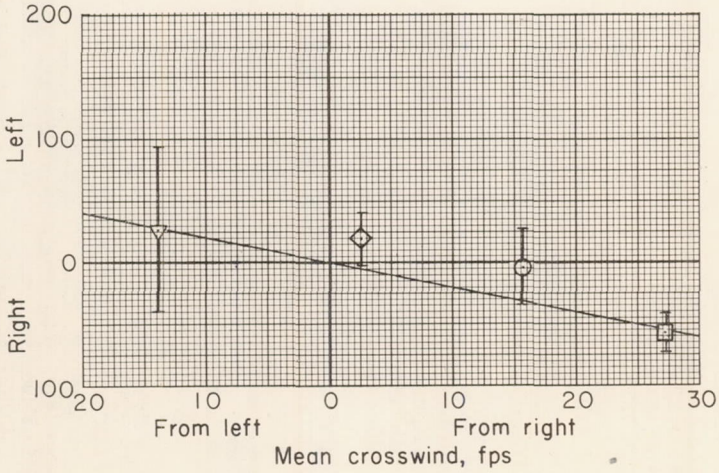
Figure 21.- Crosswind effects on deflection at burnout range (385 ft); lot 1 fired at 30° elevation; lots 2 to 5 fired at 60° elevation.



(a) Cruciform-fin rockets.



(b) 4° monoplane-fin rockets.



(c) 8° monoplane-fin rockets.

Figure 22.- Crosswind effects on lateral deflection at twice burnout range (770 ft); lot 1 fired at 30° elevation; lots 2 to 5 fired at 60° elevation.

NACA - Langley Field, Va.