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ACCURACY OF TRACKING AIRBORNE TARGETS

by

Edgar A. Murray

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BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

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Ballistic Measurements Laboratory

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ABSTRACT

Tracking tests of an airborne target have been made with a tracking telescope to determine accuracy that could be expected under optimum conditions. The desired accuracy is 0.15 milliradians or better for at least ten per cent of a critical period lasting approximately 15 seconds. Considerable difficulty was experienced in alignment of the relatively low power guiding scope with the main tracking telescope. This problem was solved by inserting a beam splitter, used for fine tracking, in the main optical system. The results show that the target was tracked from 6 per cent to 12 per cent of the critical period.

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INTRODUCTION

As part of the laser beam-spread experiment currently being conducted at the Ballistic Research Laboratories (BRL), tracking tests have been conducted to determine the feasibility of using an existing tracking telescope as a device to position the laser beam on an airborne target. In the tests described, photographic methods were used to determine target position and target tracking accuracy.

PROCEDURE

A tracking telescope with a camera was used to photograph a target aircraft. At the same time, another camera, attached to the tracking telescope was used to record telescope azimuth and elevation information. Data from the processed film from the two cameras were used to determine the target position and the percentage of time that the tracker was on the target.

Tracking Instrument

The tracking telescope used has an alt-azimuth mount and an 18-inch reflector-corrector optical system. The normal focal length of the optical system is 84 inches, but during this experiment the focal length was increased to 248 inches by the addition of an amplifying lens in the optical path.

The driving mechanism for the main telescope is a hydraulic-servo system. An aided tracking "joy stick" is controlled by the operator for rate and direction in both azimuth and elevation. The telescope operator uses a 20 power guiding scope to point the main telescope.

A Mitchell 35mm motion picture camera is used as an event camera which photographs the target as it appears in the telescope field of view. Azimuth and elevation positions of the main optical axis are recorded by another Mitchell 35mm camera from which the intermittent movement has been removed. This camera photographs precision etched glass dials which are periodically illuminated by a stroboscopic flash. The signal pulse, used to fire the stroboscope is derived from a magnetic pick-up on the event camera. This signal is generated at the center of exposure of each frame of the event camera. A coded time signal is imposed on the film record of each camera. Synchronous motors are used to drive each camera. Figure No. 1 shows the tracking instrument.

Reticles and Collimation

Four reticles were used alternately in the guiding scope; these included:

1. The original crosshair reticle. The crosshairs obscured the centers of the collimation target and the airborne target.

2. A reticle obtained from a BC scope, M-65. A center circle, .040" in diameter, permitted an unobscured view of the target, but the circle was too large for good tracking.

3. A reticle obtained from a Height Finder, designation unknown. The center circle is .020", with 4 lines extending toward center for .005". The open space between line ends is .010". This was an improvement, but still required careful alignment (and judgment) in collimating.

4. A specially designed and cut reticle, patterned after the Height Finder reticle above. This reticle also has a .020" center circle, and lines extending in toward the center. The open space between line ends is .003". This corresponds, roughly, with the 18 x 18 inch target size at 17,500 ft, therefore this reticle is near optimum for this size target.

Collimation, using an open center reticle, relies on the judgement of the tracker to decide when the guiding scope is centered on the target. It was found that the settings varied with the individual tracker, and each tracker had variations within his own series of settings. A group of test collimations were made, and the orientation film measured. The results are shown in Figure No. 2. This plot shows that varying reading errors are present. These errors are averaged, and the mean is indicated by the symbols Δ and O in the Target Displacement plots.

The following procedure was used in collimating: The camera operator, riding on top of the mount, adjusted the event camera to the viewing position, and directed the tracker as he brought the viewfinder crosshairs

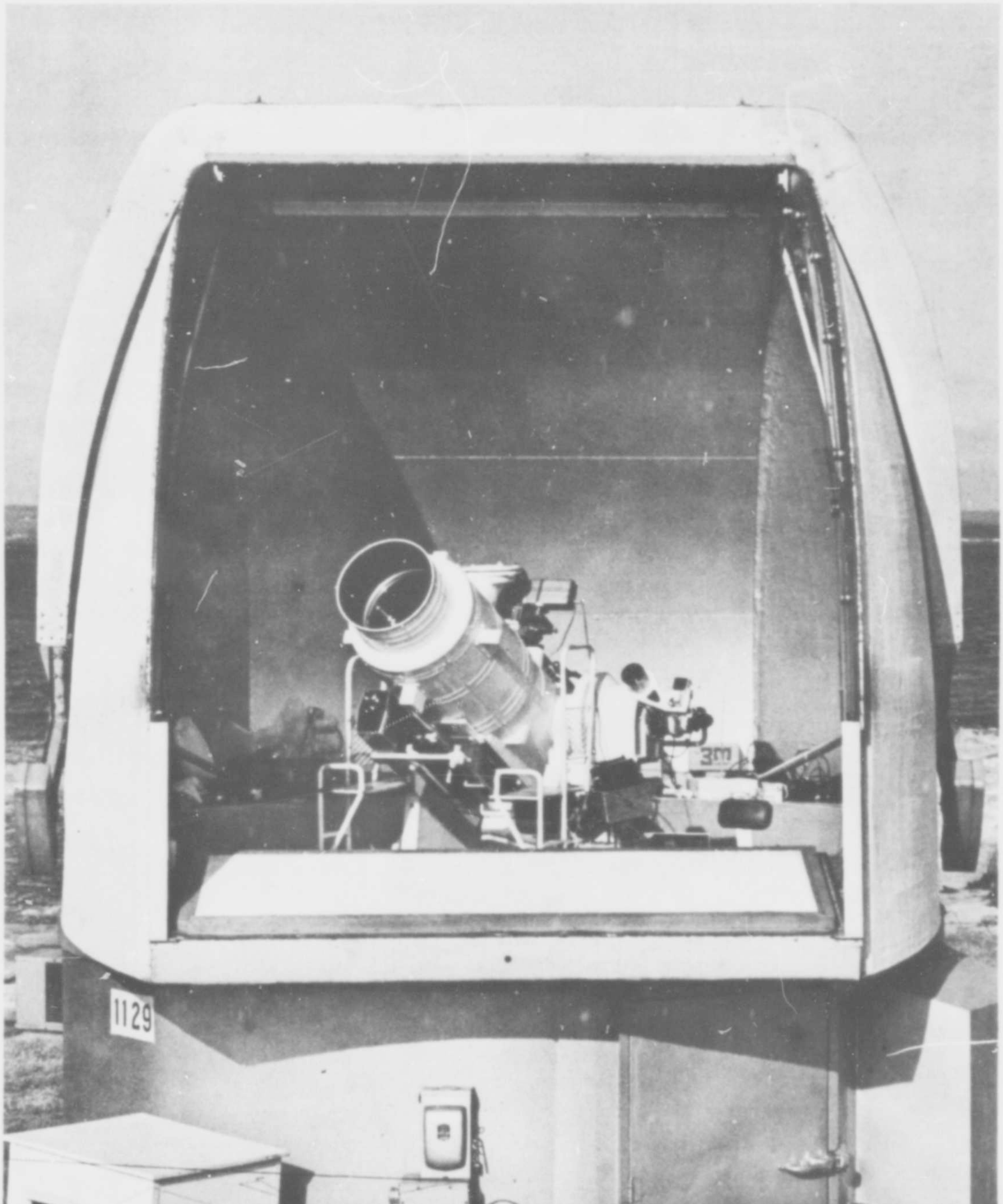


FIGURE 1. TRACKING TELESCOPE

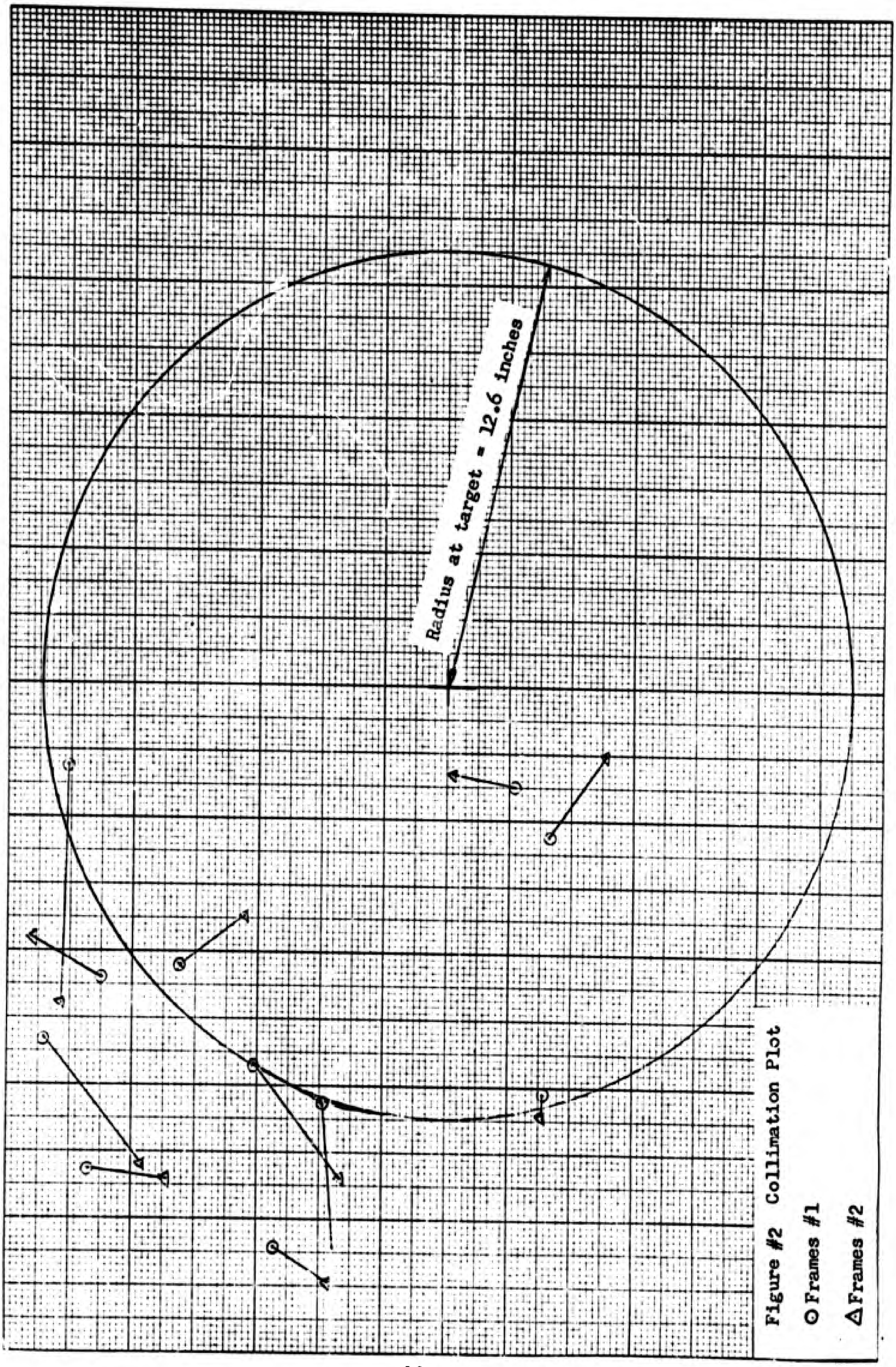


Figure #2 Collimation Plot

to the collimation target. When this position was reached, the mount was stopped and the guiding scope crosshairs were brought to the center of the collimation target. This was done by push-pull adjustment screws on the guiding scope. The camera operator continued to view the target through the camera viewfinder until the guiding scope was aligned. The camera operator then adjusted the camera to the photographic position, and an orientation shot was made of the collimation target. The weight of the camera operator rested either on the telescope tube or the elevation trunnion bearing while he was viewing the target. In either case, the shifting of weight after the camera was adjusted into photographic position, caused a shift in both azimuth and elevation. The amount of this change was not discernible to the tracker, nor could the camera operator check, without again shifting his weight. The misalignment error cannot be detected until the collimation film is measured. The use of a scaffold to support the camera operator during collimation was considered, but such a procedure would entail tedious assembly and disassembly of the scaffold. The collimation target is mounted on a building, located near Swan Creek, at an approximate distance of 17,000 ft. The optical path is entirely over water; therefore, air turbulence effects contribute to the already difficult task of collimation.

Television Guidance

Because of the collimation difficulties, a half-silvered mirror was installed in the optical system and a TV camera was mounted on the telescope to supplement the guiding scope. The optical path of the main system was intercepted by a half-silvered mirror, half of the light was reflected to the television camera, and half passed through to the event camera. Once the tracker had acquired the target through the guiding scope, he switched to the television monitor, and maneuvered the telescope until the image of the target appeared in the center of the television monitor screen. Preliminary tests have shown considerable improvement in tracking performance when the television monitor was used. The tedious alignment procedures detailed above are eliminated, and collimation errors are reduced to a minimum.

Target Aircraft and Course

The basic experiment, measurements of laser beam spread, to which this experiment is related, calls for the target to be at 8000 ft altitude, and for the slant range to be 17,500 ft. For this experiment, the target, which was tracked, was carried on an aircraft flown on an East to West course over the Chesapeake Bay. The physical construction of the aircraft prevented the pilot from aligning the aircraft by sighting on ground markers while in level flight, after the "on course" portion of the flight was started. Several of the early flights produced large course deviations. The course was shifted about 45 degrees to the East. This enabled the pilot to use the Kenton omni-range signal. Some improvement was noted, but course errors were still present. These errors were attributed to beam spread of the omni-range signal, to crosswinds, and to some signal interference. Many of the earlier runs were made at aircraft speeds varying between 75 mph and 150 mph. Since a low angular rate was desired, the slowest aircraft speed that would produce minimum vertical motion was requested. The stable range on most days was between 100 - 120 mph. At the desired slant range, this produced azimuth rates between .480 and .570 degrees per second.

For the data runs, a target was mounted on each side of the fuselage. Target No. 1 was a white X on blue background, and target No. 2 was a blue X on white background. The targets were 18 inches square, and the lines of the X were 3 inches in width. By using a No. 29 red filter and Shellburst Linograph film in the event camera, the cross (X) was resolved sufficiently well to provide a measurable image. Figure No. 3 is a sample frame from the event camera.

Test Flights

In the period January 6, 1965, to July 1, 1965, 37 flights, yielding 72 recorded runs were made. In the same flights, 108 practice runs were made. The practice runs were made to help the tracker reach a satisfactory efficiency plateau, and to make sure that the equipment was performing properly. Aircraft course, stability, and photographic feasibility were also checked on these runs. Several practice runs were usually required

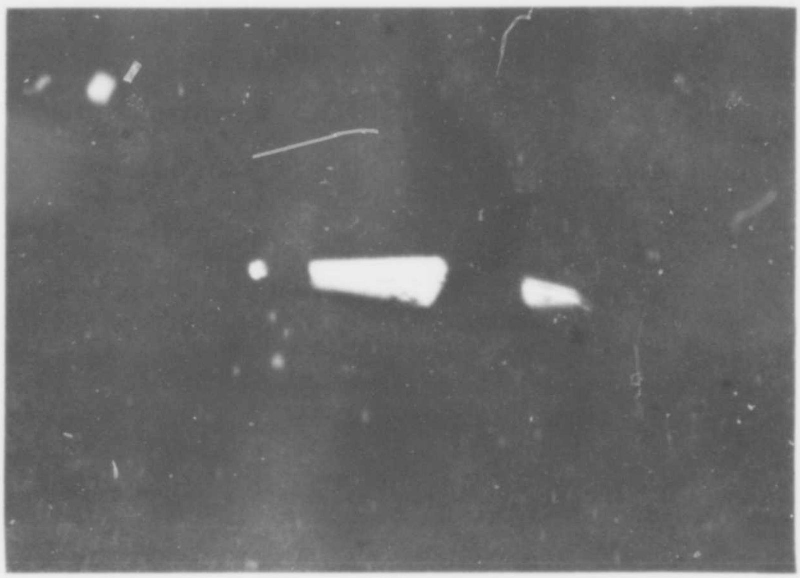


FIGURE 3. SAMPLE FRAME FROM EVENT CAMERA FILM

before the first record run was made. Some runs that started as record runs were changed to practice runs because of malfunctions (poor course, camera jams, etc). In these runs, the tracker continued to follow the target.

It may be seen in Table I that wide variations in temperature and wind conditions were encountered. The environmental conditions affected the instrumentation only when optical seeing was impaired, or when the winds made the target aircraft too unstable to follow.

Beginning with the June 4 flight, the television system was used as a tracking aid. On three flights (7, 11, 22 June) no records were made because of atmospheric haze. This hazy condition persisted throughout most of May and June. Table I is a summary of flights and conditions under which the flights were made. Several of the record runs were not measured because of poor photographic quality.

TABLE I

SUMMARY OF FLIGHTS, TEMPERATURE RANGES AND WIND VELOCITIES

Month	Number of flights	Record runs	Practice runs	Temperature range, deg F	Wind velocity * knots
Jan	5	12	18	18 to 62	0 to 60
Feb	13	30	39	22 to 55	10 to 60
Mar	8	12	8	20 to 54	10 to 40
Apr	4	8	14	42 to 74	10 to 40
May	1	0	8	70	10
June	4	4	15	68 to 82	0 to 30
July	2	6	6	84	25
total	37	72	108		

*Measured at 8000 feet altitude.

RESULTS

When the desired conditions of the flight plan were met, the target aircraft was at 8000 ft. altitude, the slant range was 17,500 ft, and the azimuth tracking rate was approximately .500 degrees per second. As seen from the tracking telescope position, the target was at an elevation of 27.2 degrees when it passed through the center of the run.

From the processed data film, azimuth rate differences, and elevations were determined and plotted. This information was used to identify the pertinent portion of the run, mark off the center, and to determine the quality of the run. The event film was then measured on an X-Y coordinate film reader. The projection lens used in this reader is 27X, and the scale of the projected image is 10 counts per millimeter. The term count refers to a unit measured by the read-out head of the film reader. The projected image of the airborne target, photographed at 17,500 ft slant range, is 150 counts x 150 counts.

The curves plotted from the film reader data show target displacement. This is the sum of the errors of tracking, measurement, collimation, and in azimuth only, parallax displacement. For the television camera runs, parallax is not involved.

On runs No. 62 through No. 64, inclusive, during which the television system was used, the postflight collimation check disclosed an azimuth error of approximately 2 feet, about 200 counts. On runs No. 66 through No. 70, the postflight check indicated a 2 foot vertical error. In each case, the preflight orientation shot was made without allowing sufficient time for stabilization of the electronic components of the television system.

Tables II and III contain summaries of the percentage of film frames during which the telescope was centered on some portion of the target. The data used in compiling Tables II and III were derived from the measurement of each frame of the event film record. When the measurement indicated that the axis of the tracking instrument was on the target, that frame was recorded as a target hit. While many of the hits were on consecutive frames, the curves indicate a hunting tendency of the tracker as he attempted to improve target position. Thus, the tracker was on the target periodically.

Table II contains data as acquired and as corrected for the 200 count azimuth error. Table III contains data as acquired and as corrected for the vertical error.

TABLE II

PERCENTAGE OF FILM FRAMES DURING WHICH TELESCOPE WAS CENTERED ON SOME PORTION OF TARGET, RUNS NO. 62, 63 AND 64

Run	Target frames no correction	Per cent	Target frames corrected	Per cent	Total frames
No. 62	28	4.3%	81	12.6%	640
No. 63	5	.86%	12	2.0%	580
No. 64	27	4.3%	53	8.5%	618

In Table III, the data are presented as compiled, and with the 200 count vertical correction applied.

TABLE III

PERCENTAGE OF FILM FRAMES DURING WHICH TELESCOPE WAS CENTERED ON SOME PORTION OF TARGET, RUNS NO. 66 THROUGH 70

Run	Target frames no correction	Per cent	Target frames corrected	Per cent	Total frames
No. 66	34	5.5%	50	8.1%	610
No. 67	73	11.3%	80	12.4%	643
No. 68	40	6.0%	122	18.5%	658
No. 69	55	7.9%	124	17.8%	695
No. 70	31	4.9%	71	11.2%	631

Generally, the runs made at the slower azimuth rates yielded the highest percentage of frames on target. However, runs No. 62, No. 63, and No. 64 were made under similar conditions, including tracker, slant range, and azimuth rate. Runs No. 62 and No. 64 produced similar results, but No. 63 produced fewer frames on target than normally would be expected.

Table IV shows the mean deviation (A) and the standard deviation with respect to this mean (σ) in azimuth and elevation.

TABLE IV

MEAN AND STANDARD DEVIATIONS IN ELEVATION AND AZIMUTH READINGS (COUNTS)

Run	Azimuth		Elevation	
	A	σ	A	σ
No. 28	505	240	-396	218
No. 63	-355	450	-146	267
No. 64	-314	294	-74	198
No. 67	44	123	-277	250

CONCLUSIONS

The data from which Tables II and III were derived are the minimum number of samples required to determine feasibility of this method. The analysis of the results shown in these tables indicates that a sufficient number of target hits can be recorded on an airborne target to furnish a measurement of laser beam spread.

Further data runs do not appear to be essential to prove feasibility. However, more runs will be made in an effort to minimize collimation errors, and additional practice runs are expected to improve the technique of television tracking.

EDGAR A. MURRAY

APPENDIX

Figure 4 shows the parallax displacement error for various slant ranges. Figure 5 shows slant ranges versus elevation. The azimuth rate difference and elevation plots that follow were taken from the data camera films. Four runs were selected as examples. Run No. 28 is above average for tracking stability when the guiding scope is used as the main sight. Run No. 63 was poorest of the television aided runs, No. 64 was about average, and No. 67 was one of the better runs. Target displacement plots are included for these runs and for all other television runs that were measured. The term "counts" was used as the displacement unit, rather than seconds of arc. On the measurement scale used, 8.7 counts = 1 second of arc.

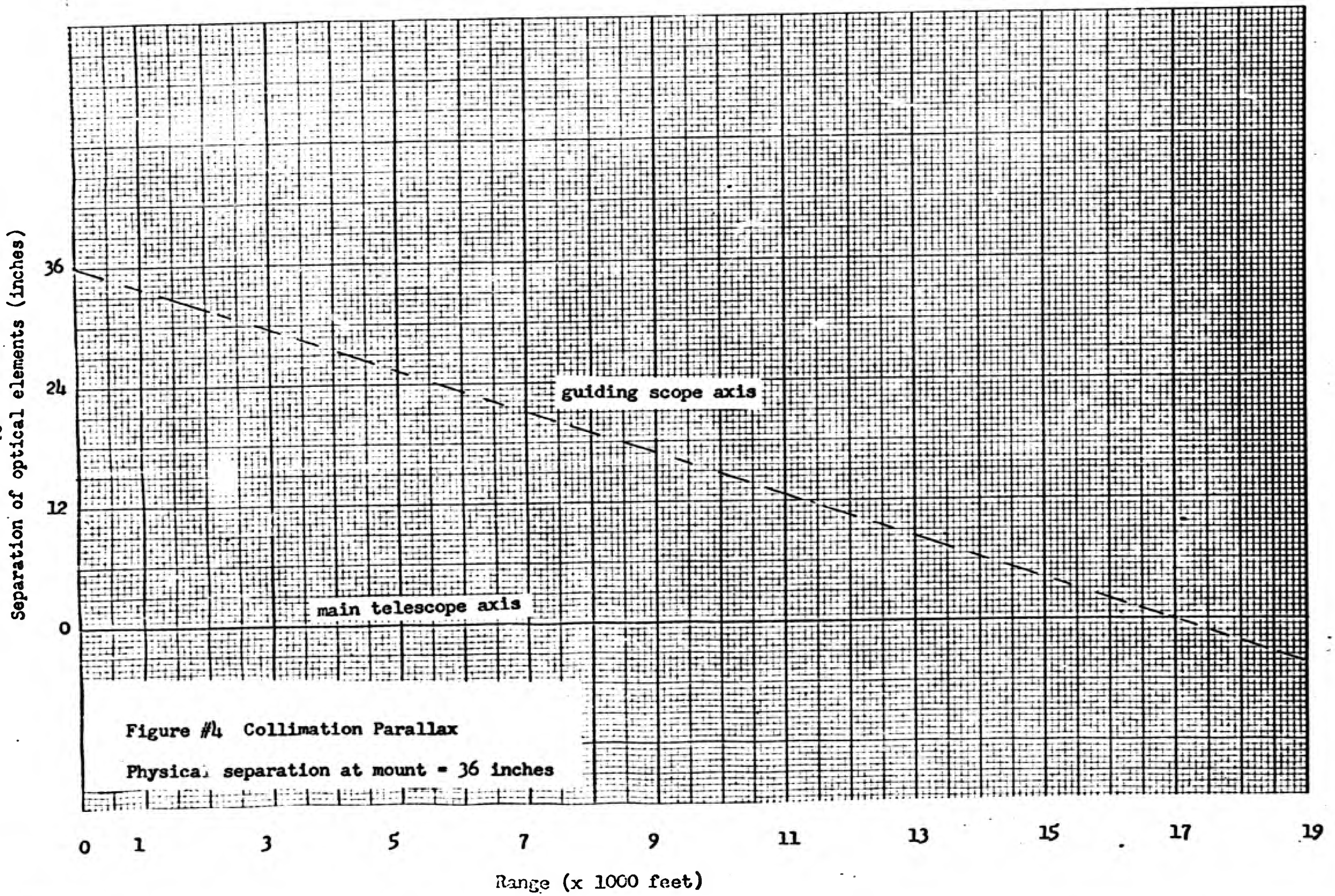


Figure #4 Collimation Parallax

Physical separation at mount = 36 inches

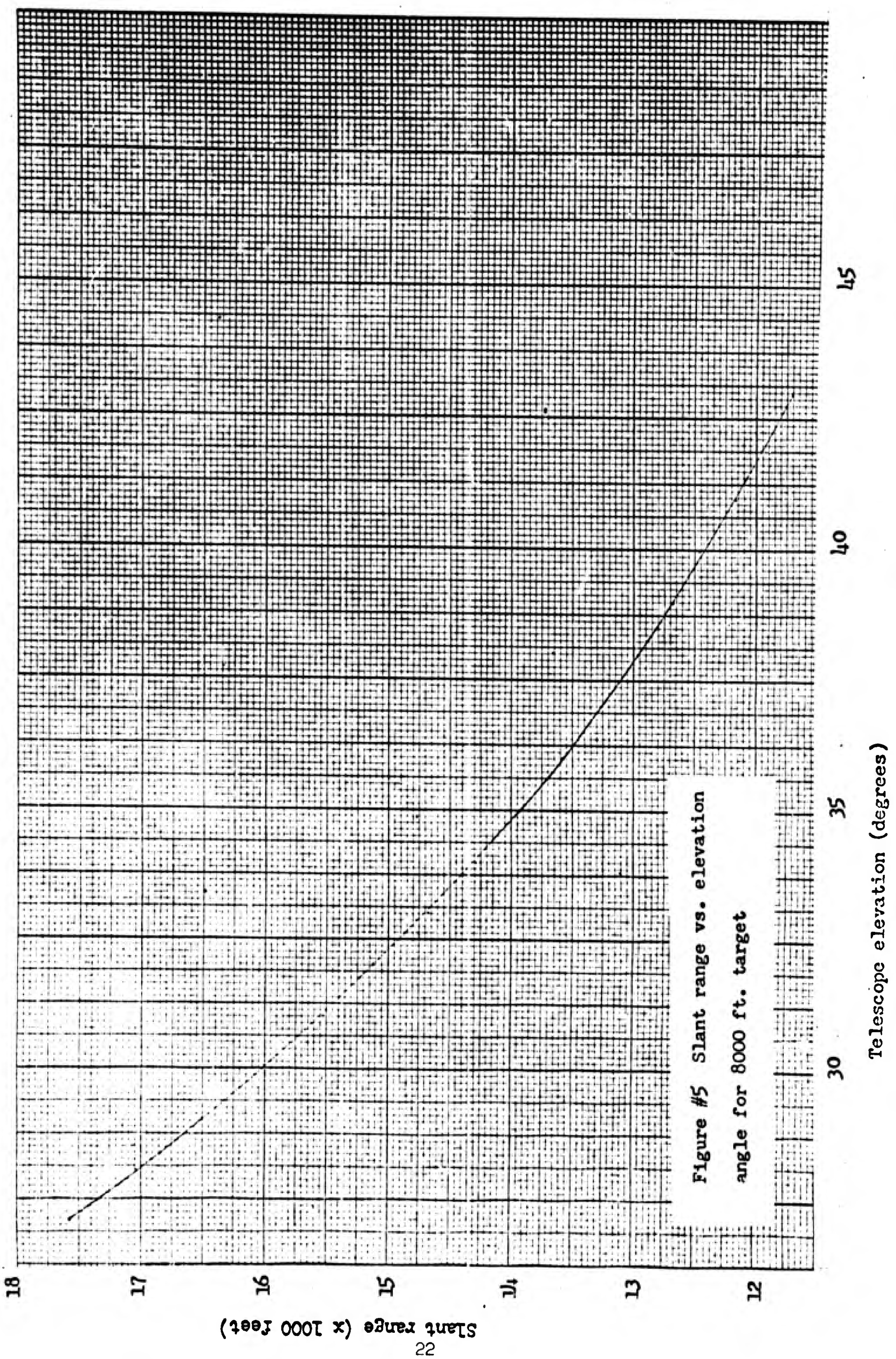


Figure #5 Slant range vs. elevation angle for 8000 ft. target

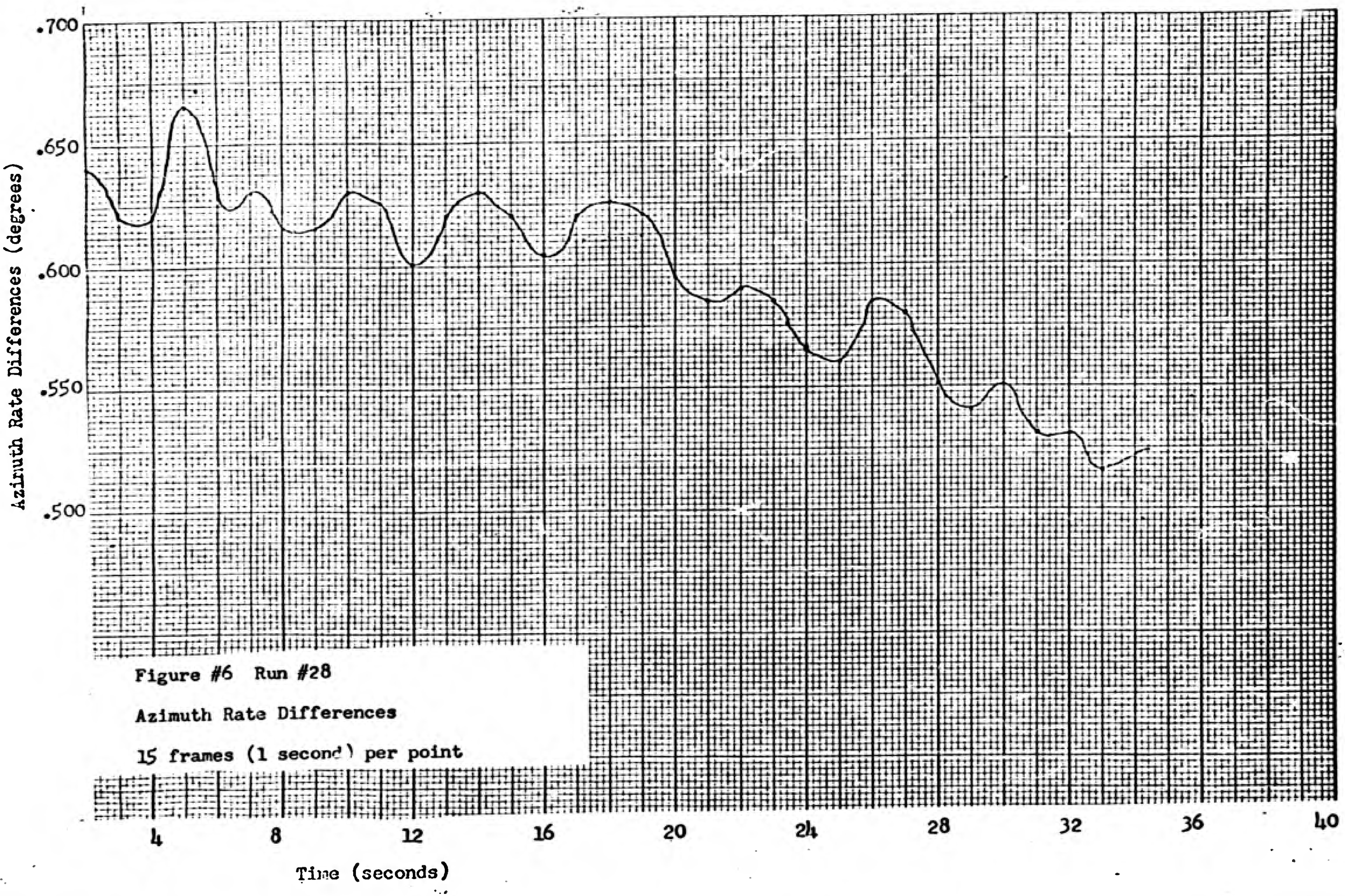


Figure #6 Run #28

Azimuth Rate Differences

15 frames (1 second) per point

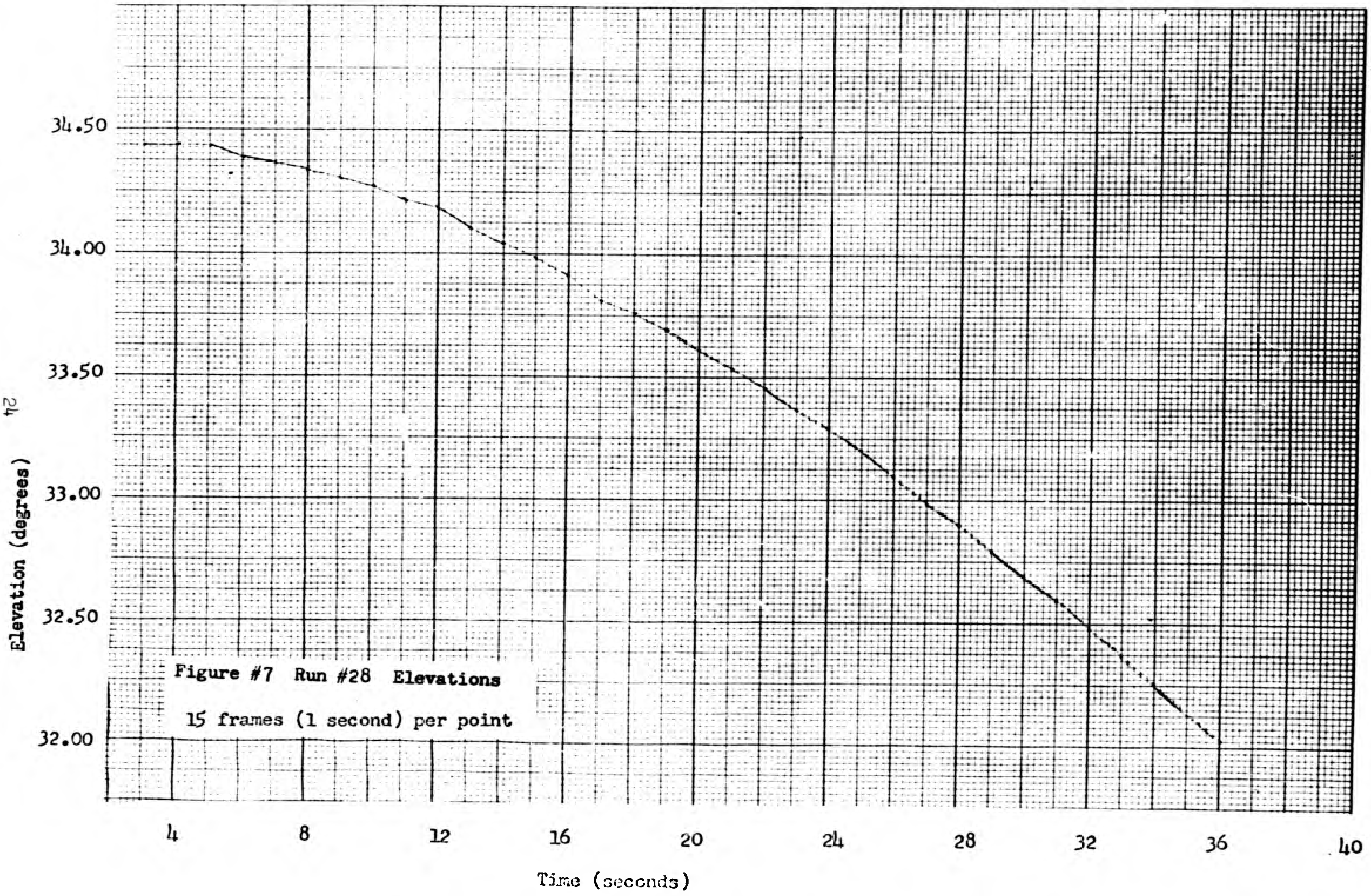


Figure #7 Run #28 Elevations

15 frames (1 second) per point

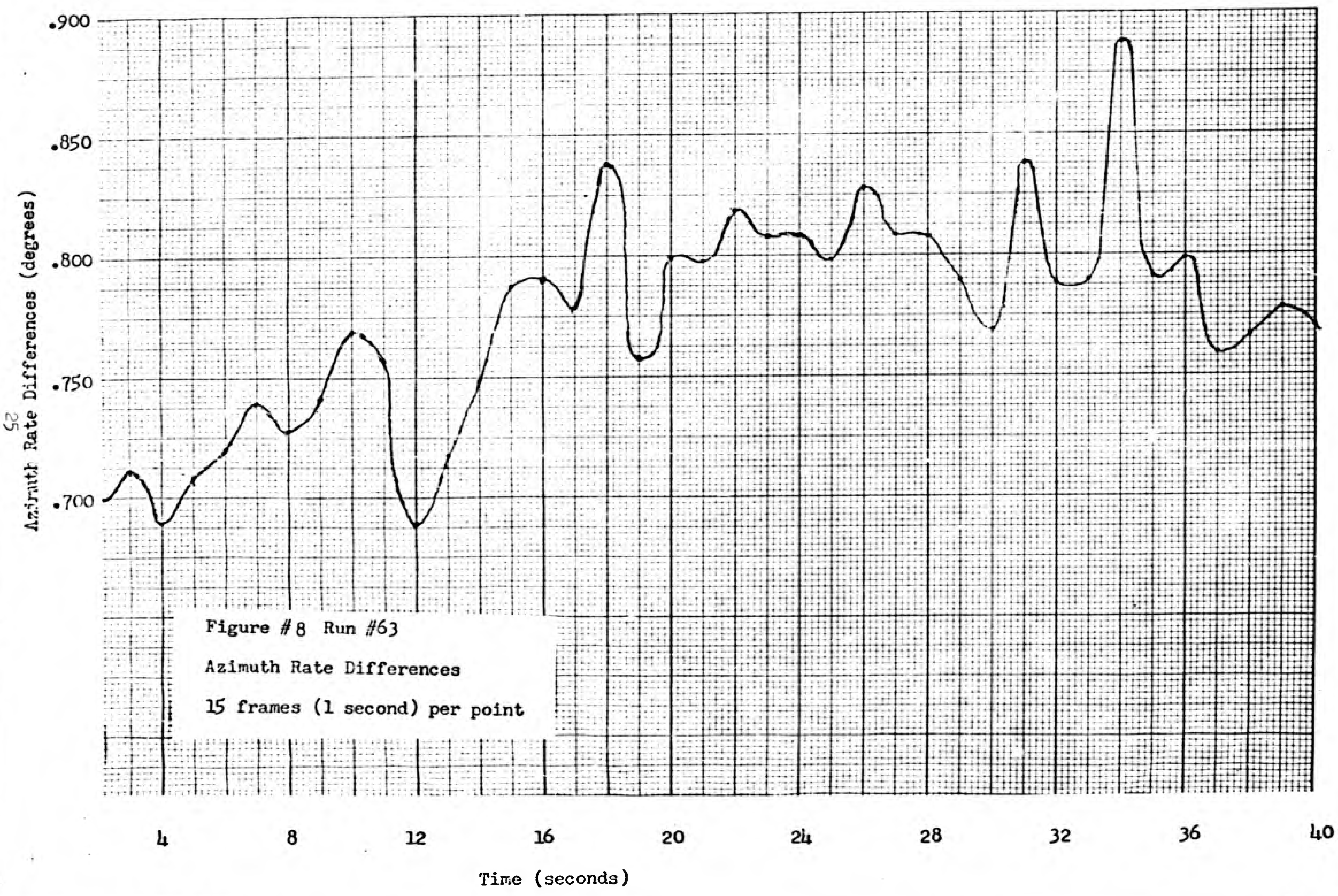


Figure #8 Run #63
Azimuth Rate Differences
15 frames (1 second) per point
.900
.850
.800
.750
.700
Azimuth Rate Differences (degrees)
4
8
12
16
20
24
28
32
36
40
Time (seconds)

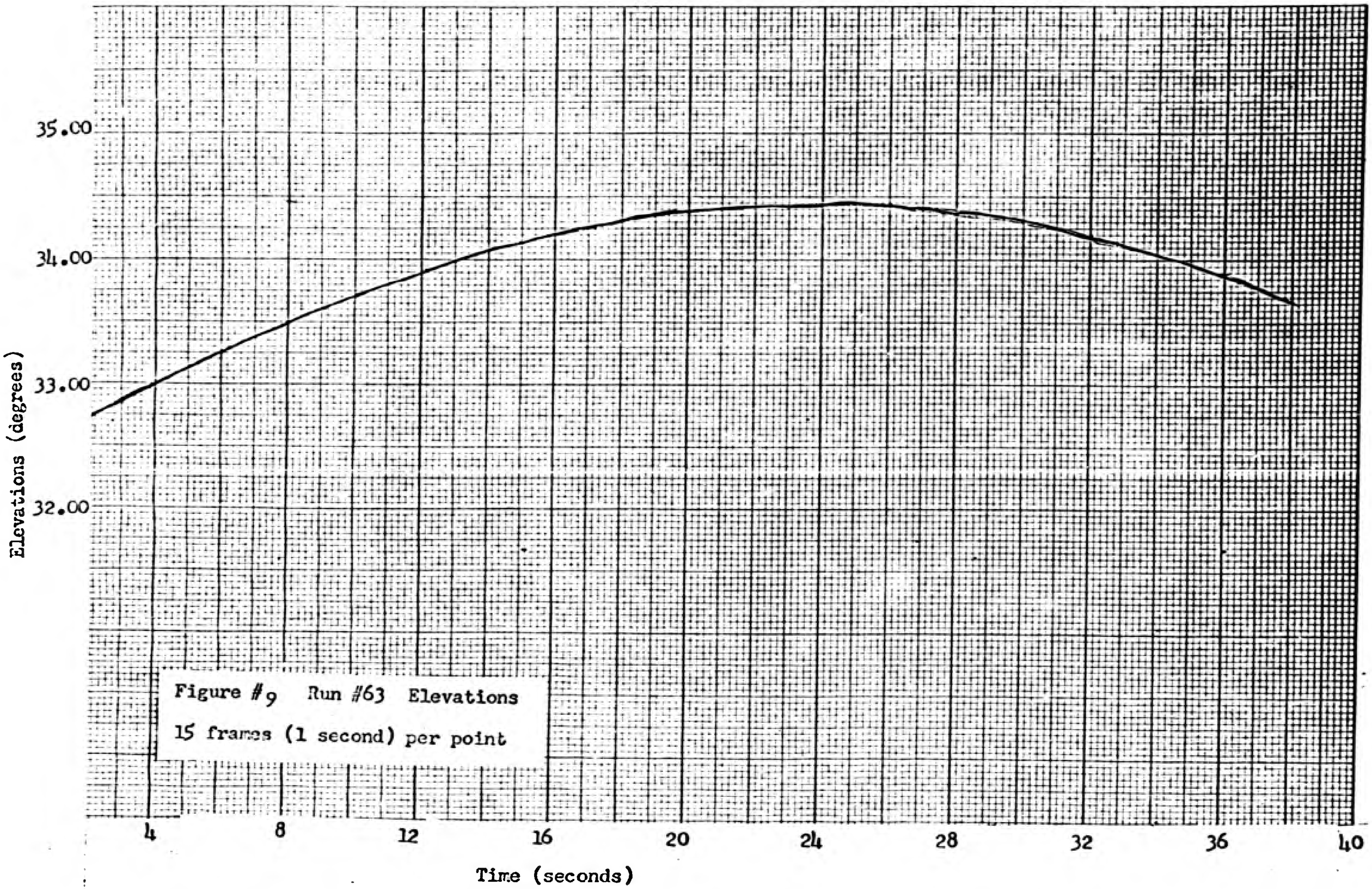


Figure #9 Run #63 Elevations
15 frames (1 second) per point

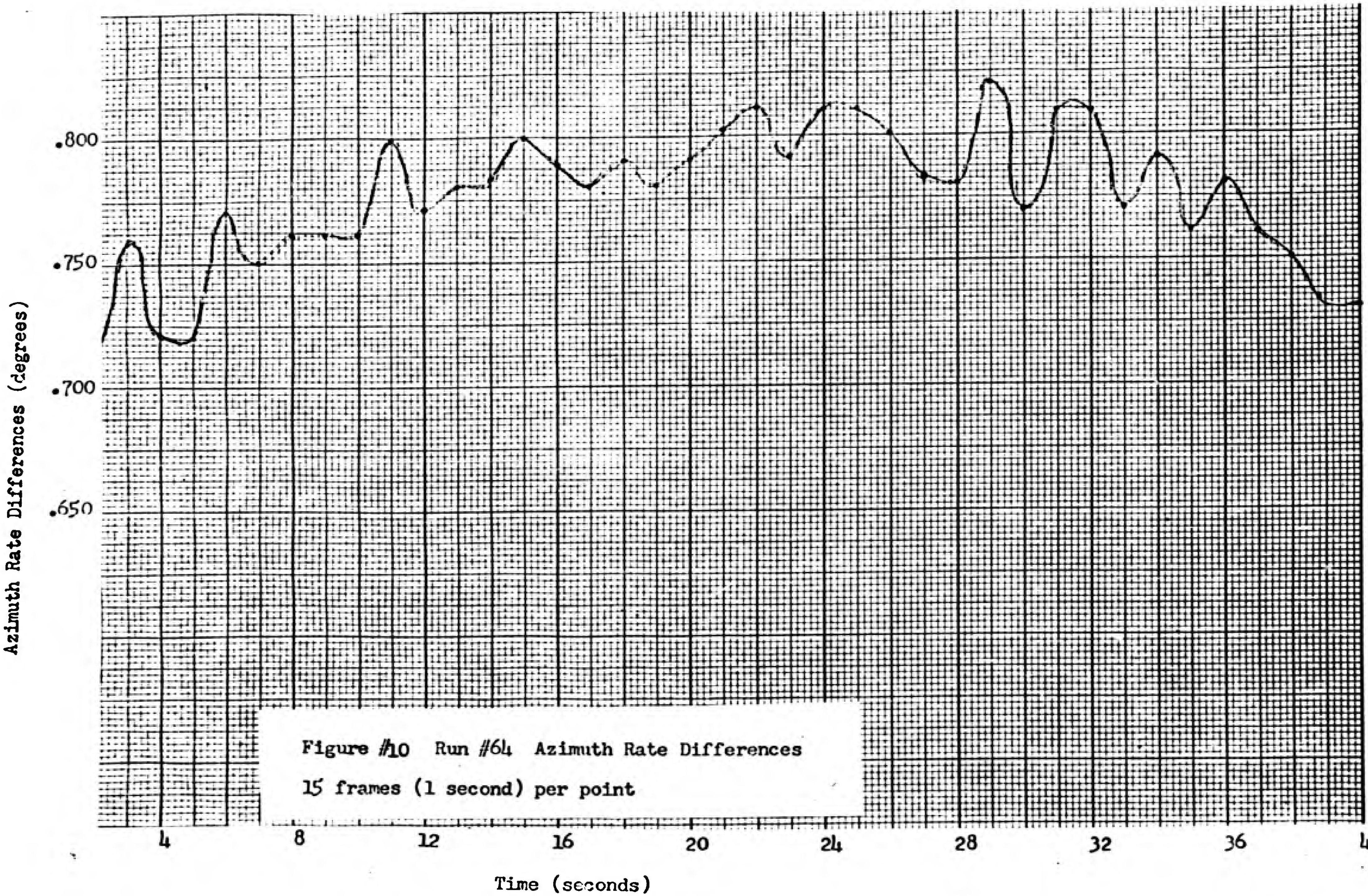


Figure #10 Run #64 Azimuth Rate Differences
15 frames (1 second) per point

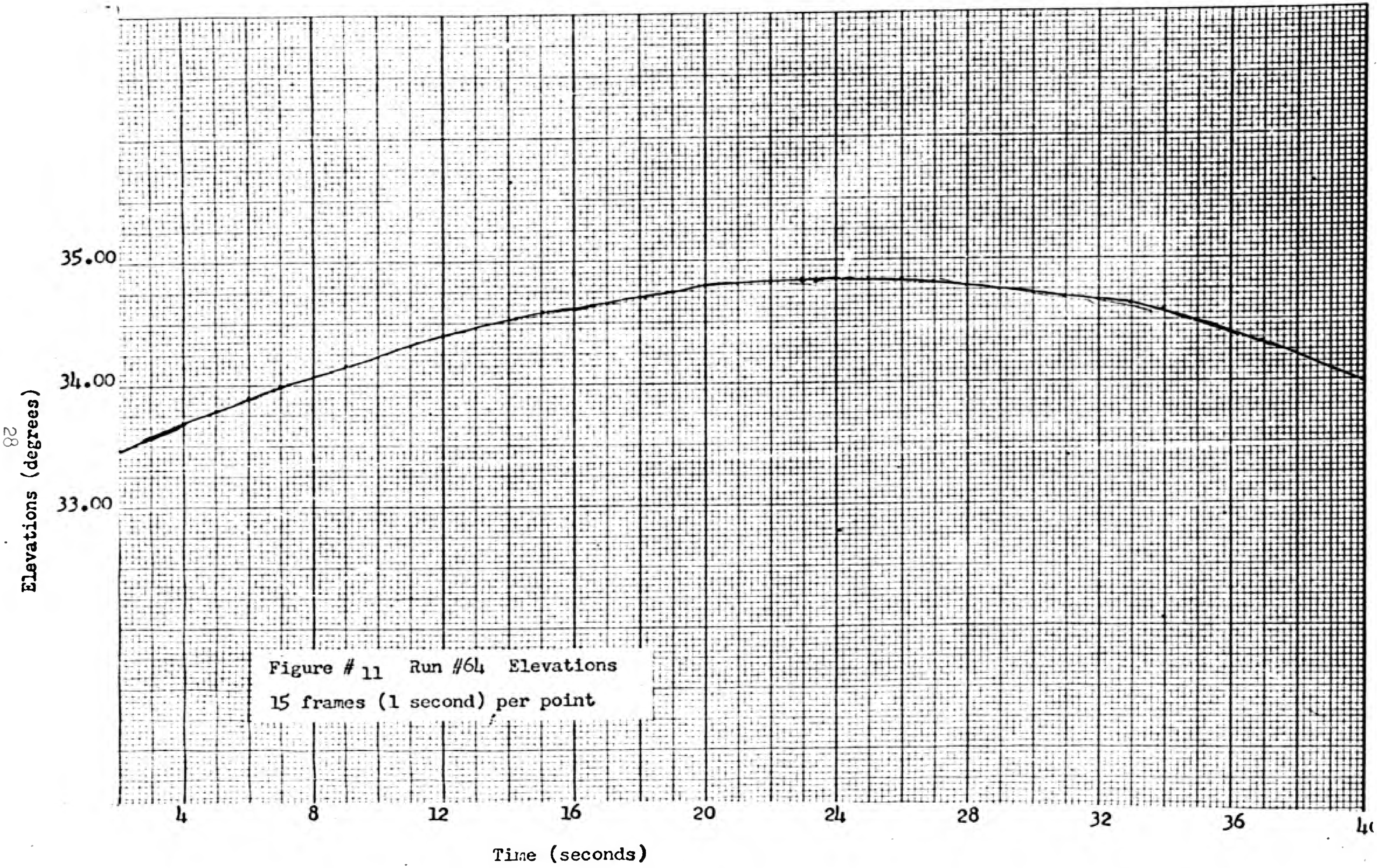
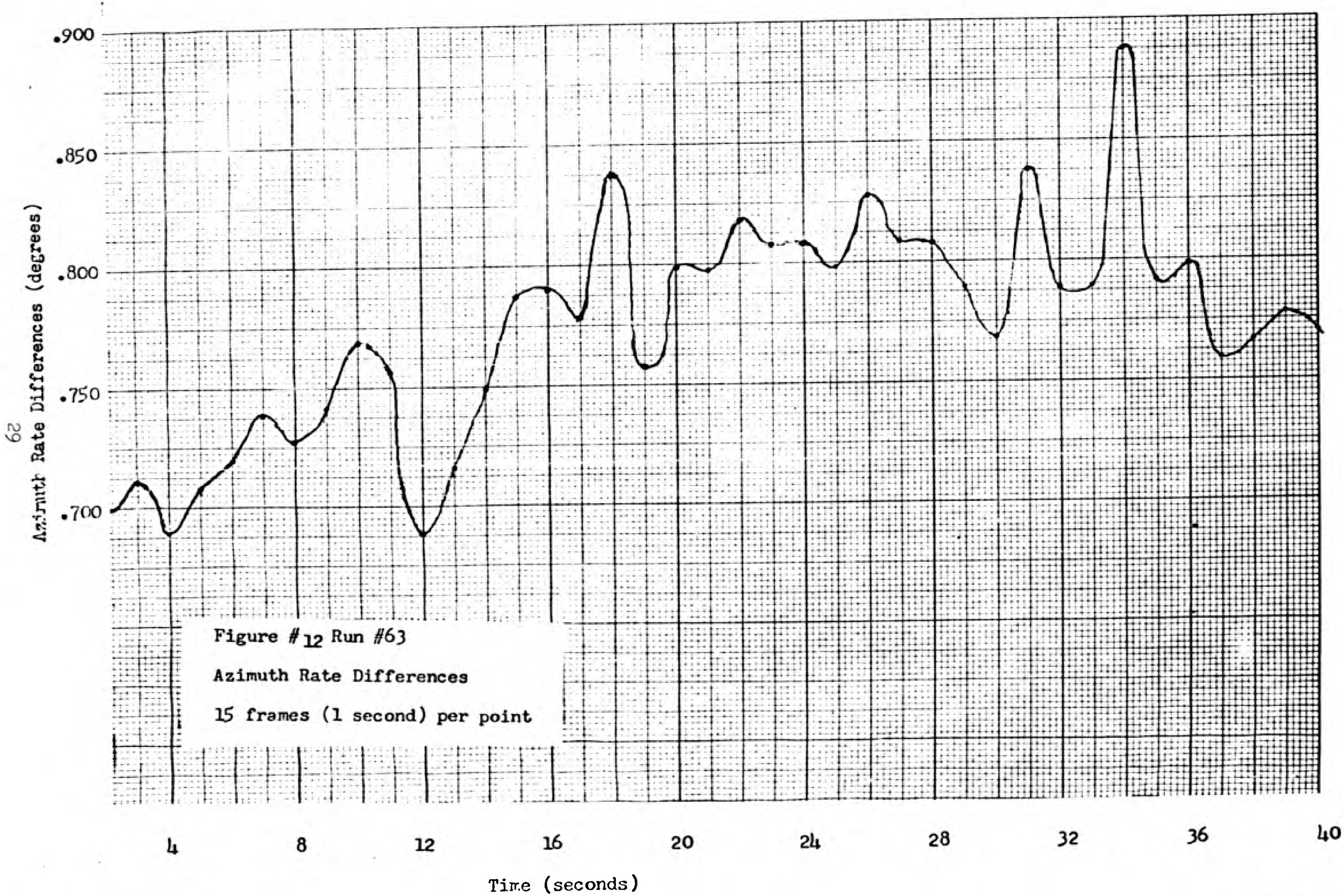


Figure # 11 Run #64 Elevations
15 frames (1 second) per point


.900
.850
.800
.750
.700
Azimuth Rate Differences (degrees)
Figure # 12 Run #63
Azimuth Rate Differences
15 frames (1 second) per point
4
8
12
16
20
24
28
32
36
40
Time (seconds)

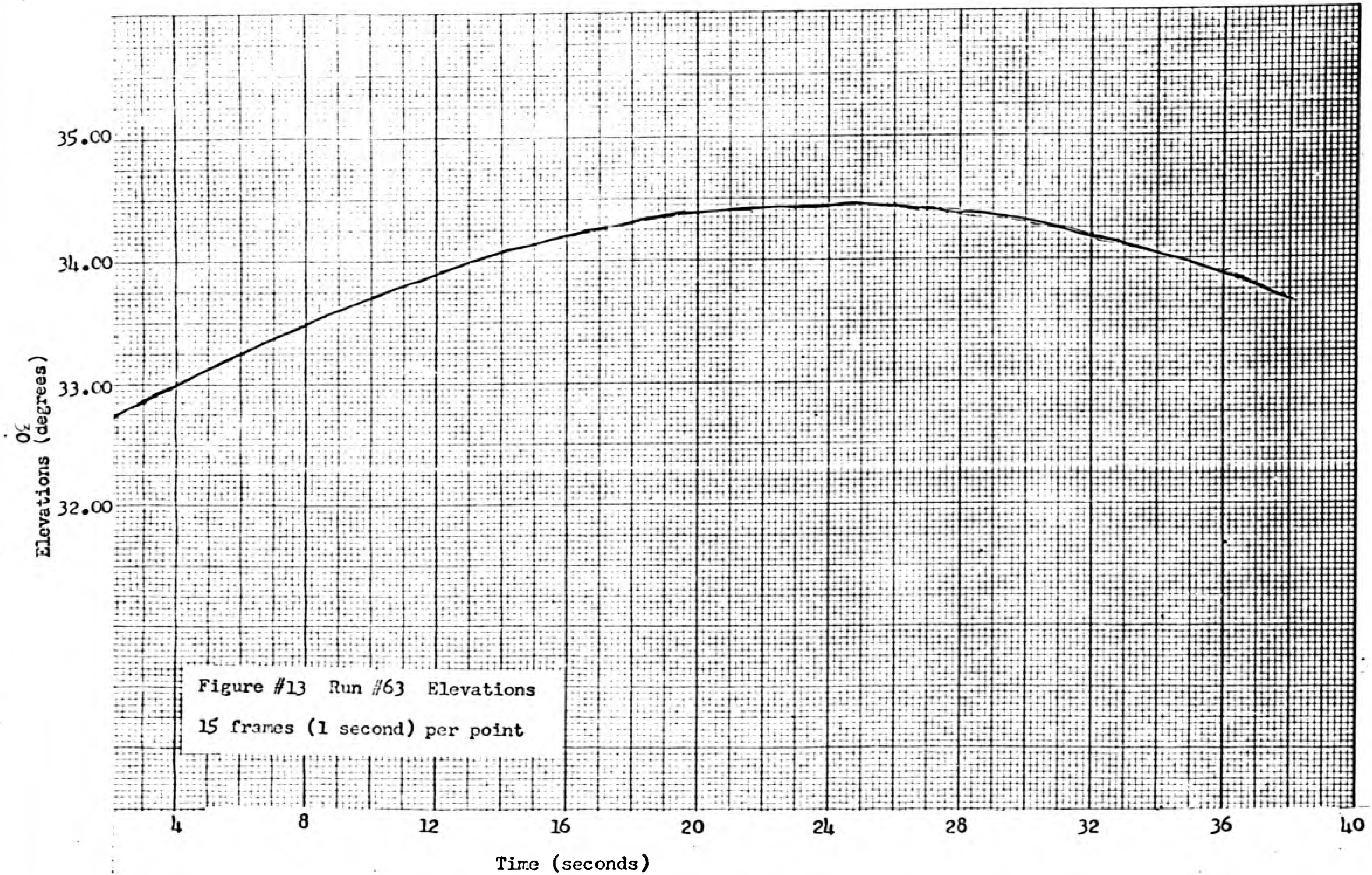


Figure #13 Run #63 Elevations
15 frames (1 second) per point
35.00
34.00
33.00
32.00
Elevations (degrees)
4
8
12
16
20
24
28
32
36
40
Time (seconds)

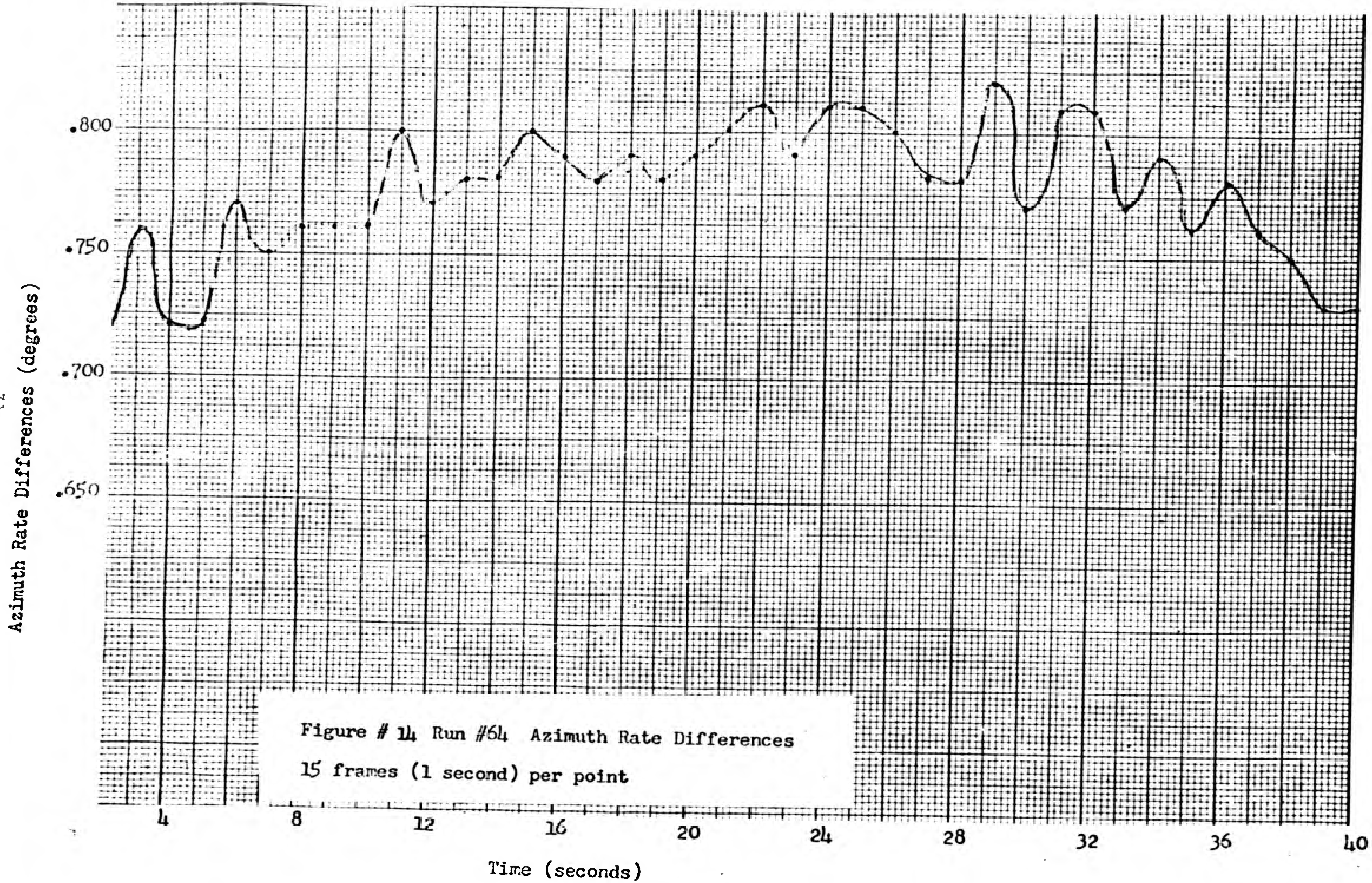


Figure # 14 Run #64 Azimuth Rate Differences

15 frames (1 second) per point

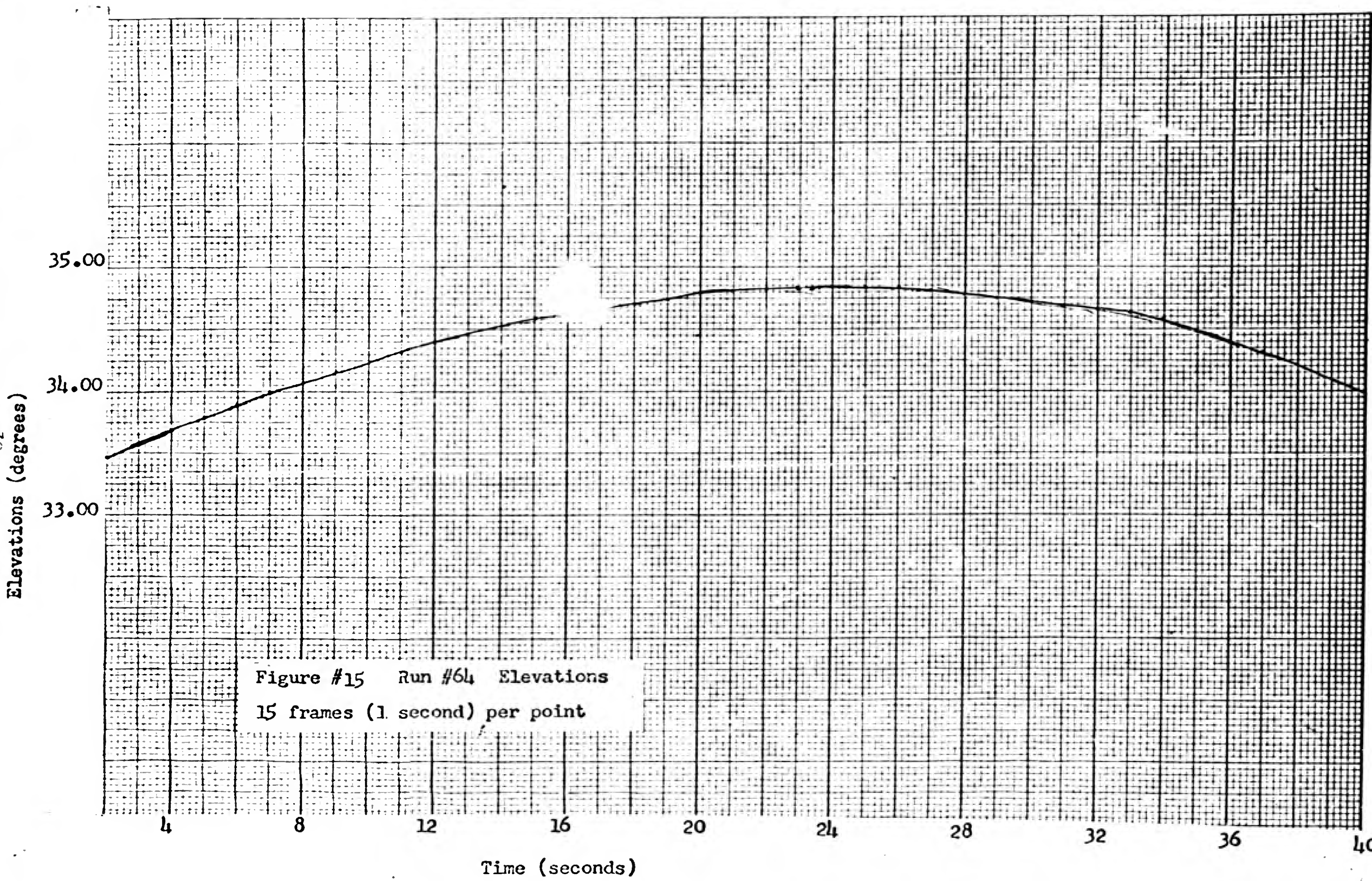


Figure #15 Run #64 Elevations
15 frames (1 second) per point

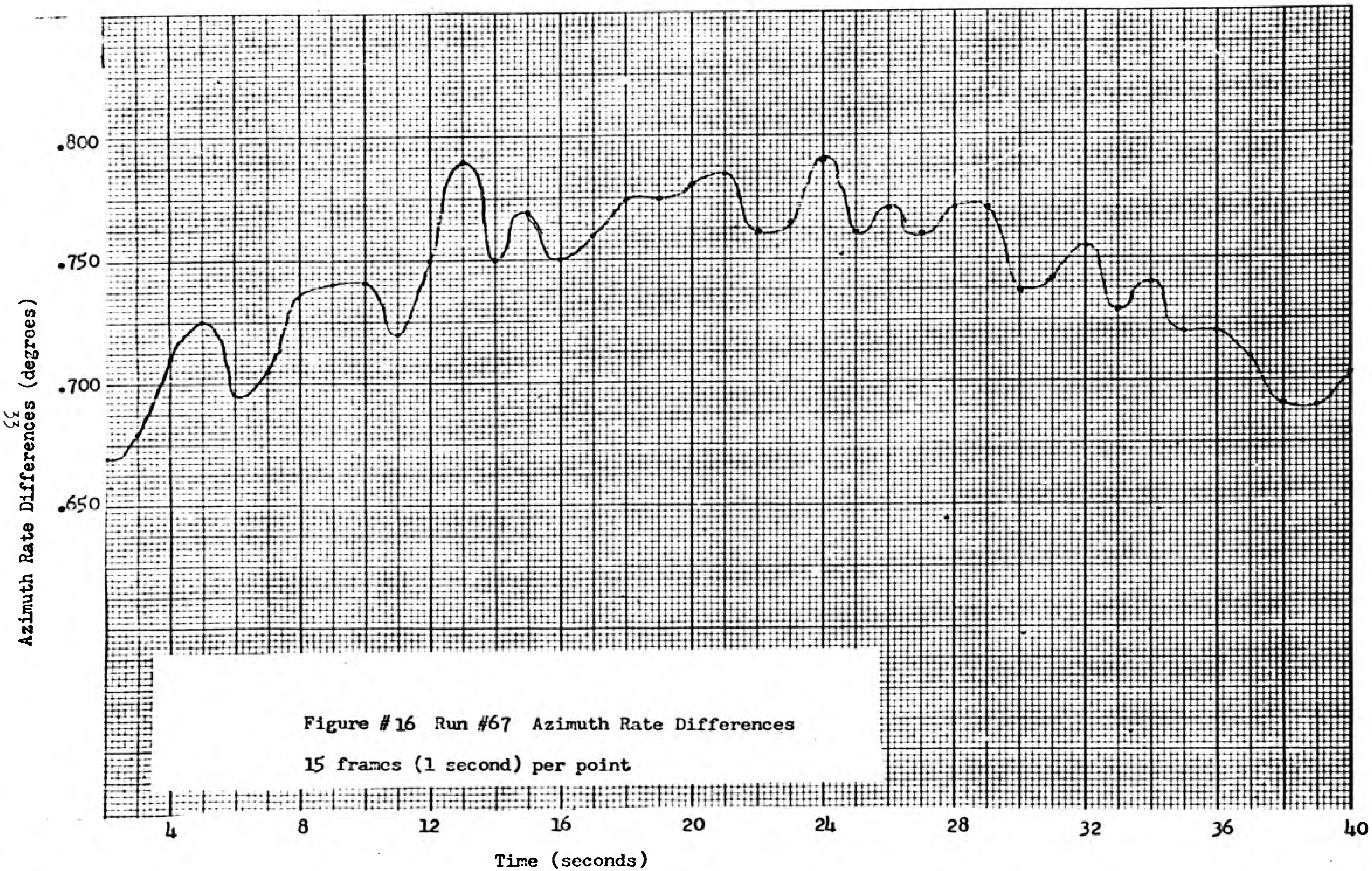


Figure #16 Run #67 Azimuth Rate Differences
15 frames (1 second) per point
Azimuth Rate Differences (degrees)
.800
.750
.700
.650
4
8
12
16
20
24
28
32
36
40
Time (seconds)

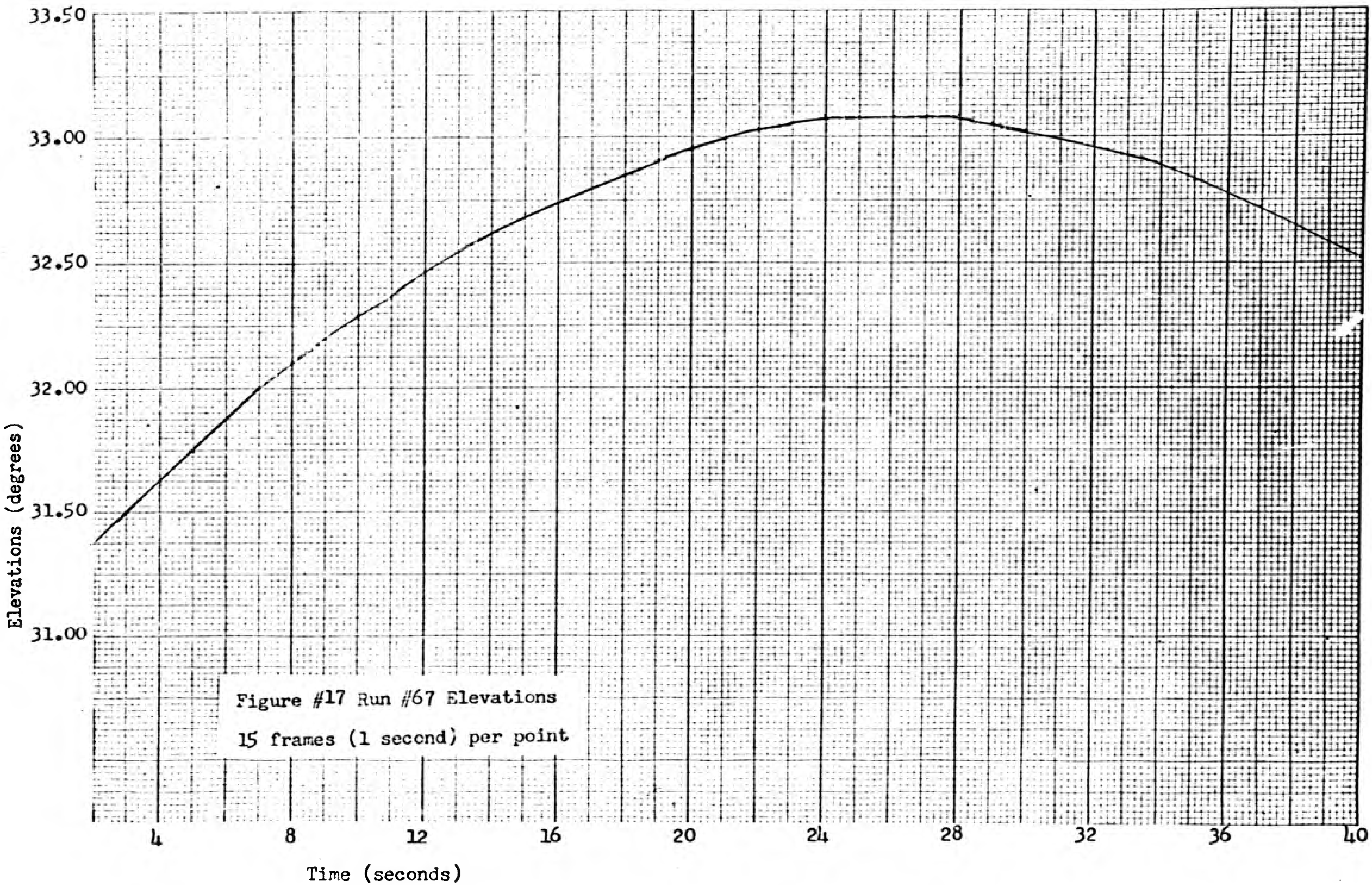


Figure #17 Run #67 Elevations

15 frames (1 second) per point

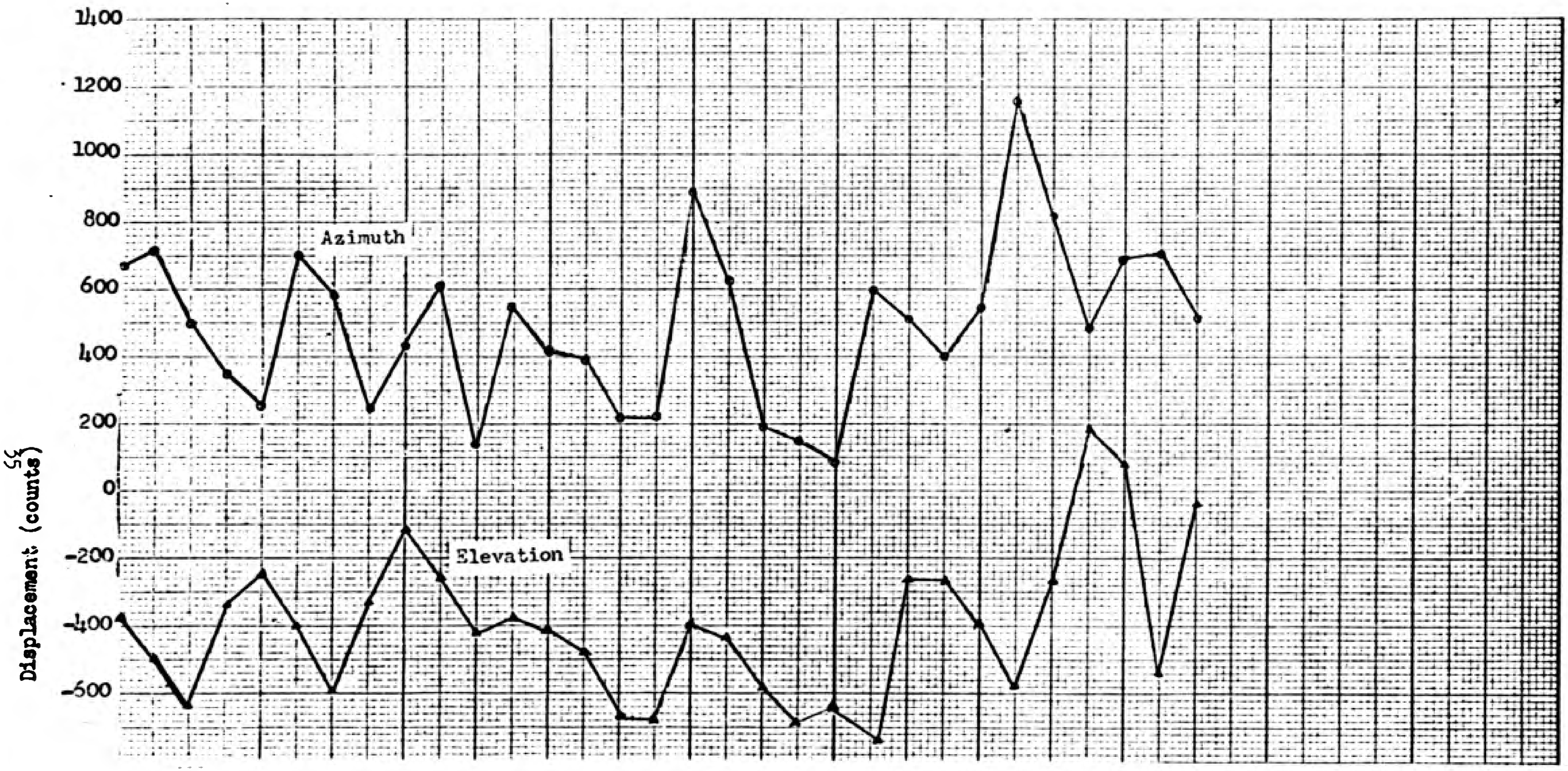


Figure # 18

Run #28 Target Displacement
Center of orientation target = 0,0
15 frames per point
Elevation at center = 34.440 degrees
o = mean reading error, azimuth

Slant range = 14150 feet
Target size = 184 counts
Parallax displacement =+.55 feet
Azimuth tracking rate = .640 degrees per second
▲ = mean reading error, elevation

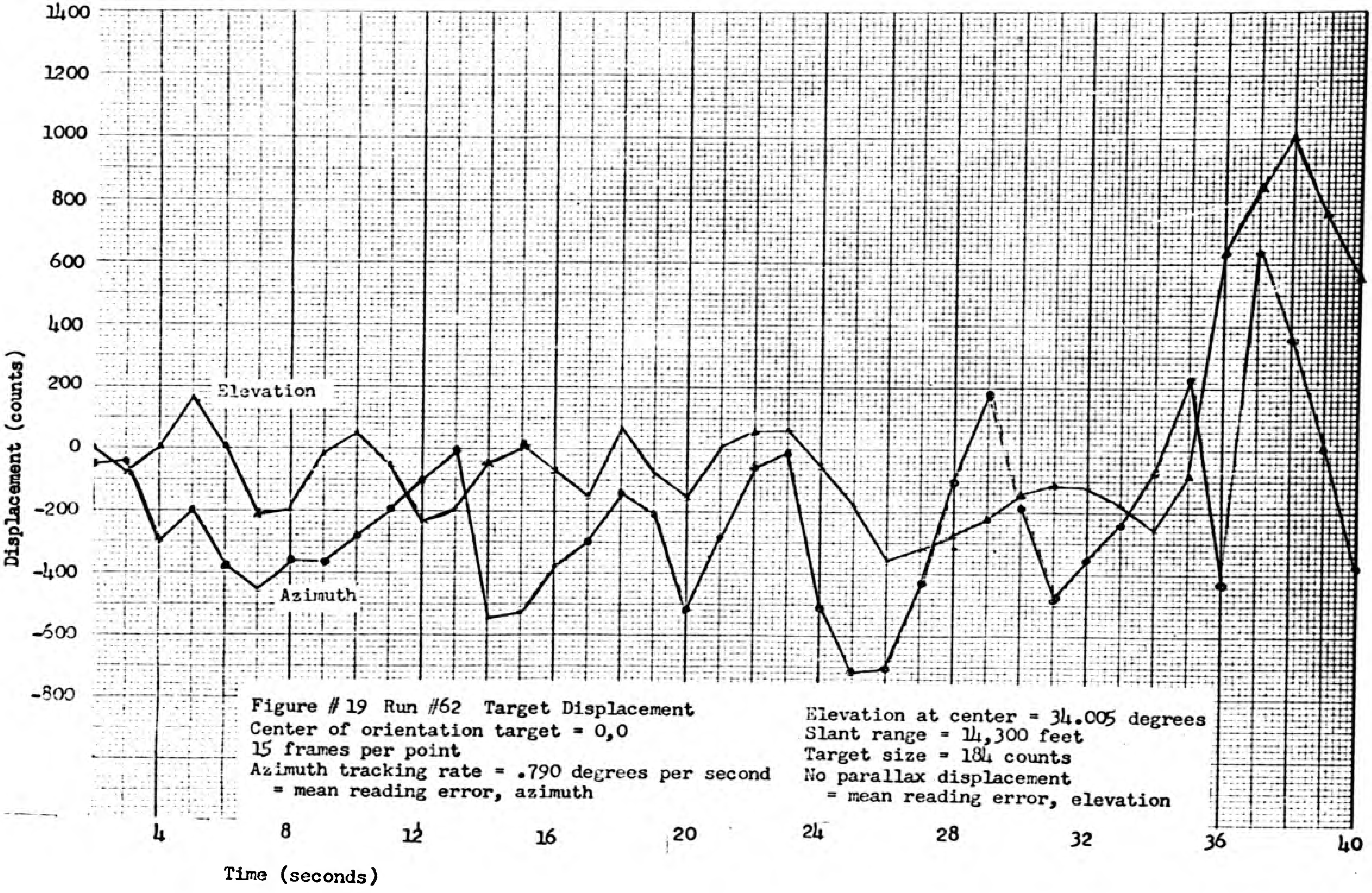


Figure # 19 Run #62 Target Displacement
Center of orientation target = 0,0
15 frames per point
Azimuth tracking rate = .790 degrees per second
= mean reading error, azimuth

Elevation at center = 34.005 degrees
Slant range = 14,300 feet
Target size = 184 counts
No parallax displacement
= mean reading error, elevation

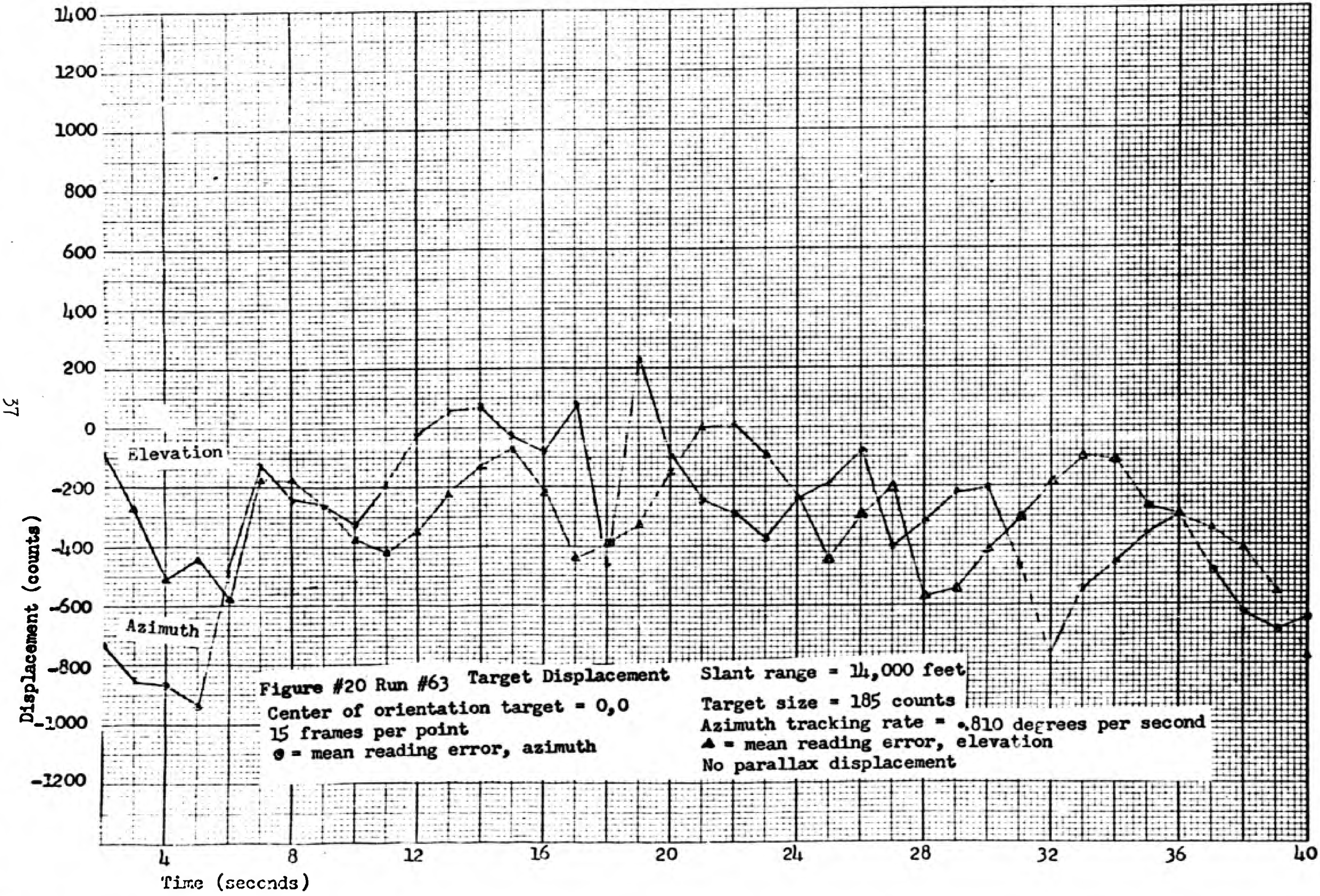


Figure #20 Run #63 Target Displacement

Center of orientation target = 0,0
15 frames per point
● = mean reading error, azimuth

Slant range = 14,000 feet
Target size = 185 counts
Azimuth tracking rate = .810 degrees per second
▲ = mean reading error, elevation
No parallax displacement

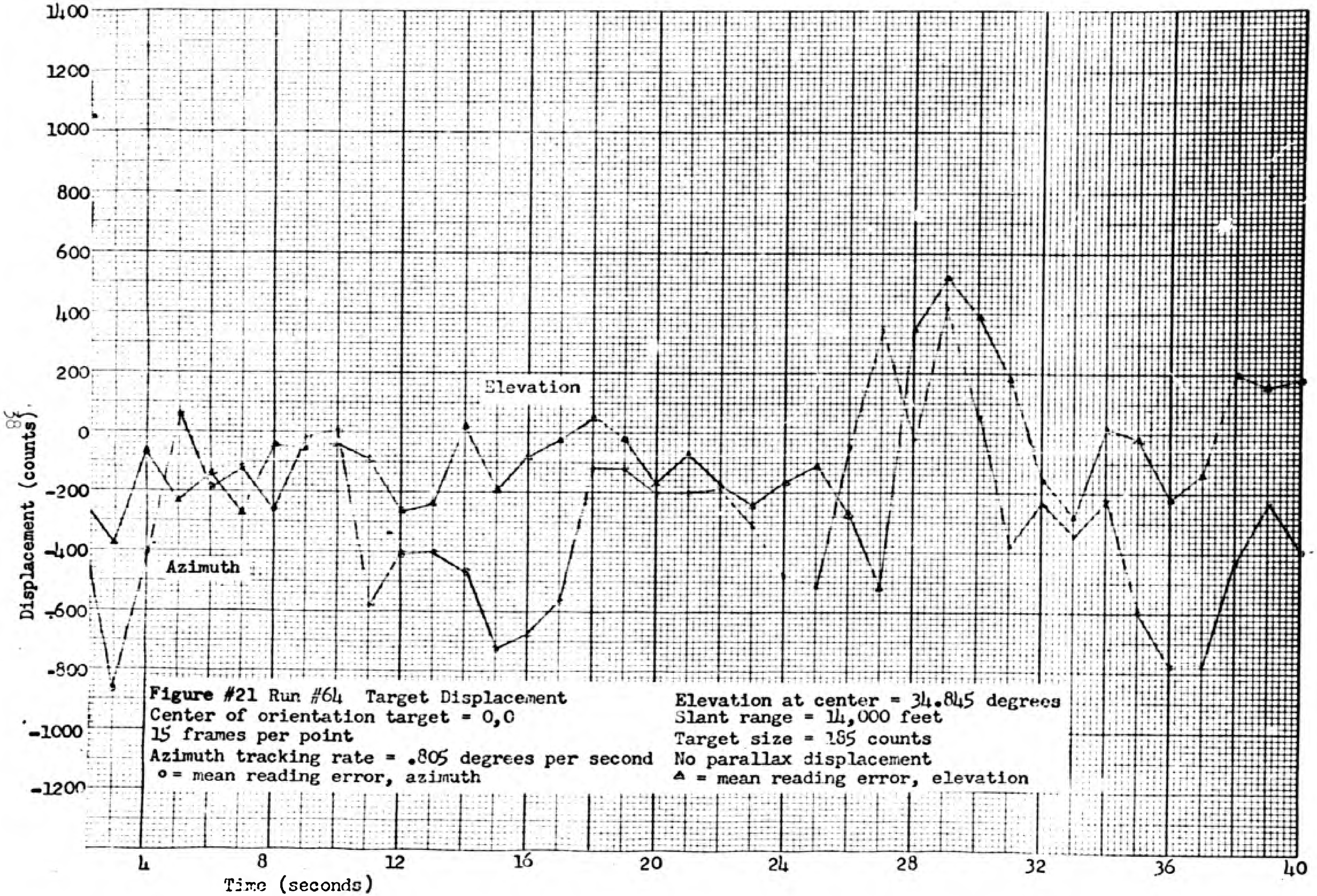


Figure #21 Run #64 Target Displacement
Center of orientation target = 0,0
15 frames per point
Azimuth tracking rate = .805 degrees per second
o = mean reading error, azimuth

Elevation at center = 34.845 degrees
Slant range = 14,000 feet
Target size = 185 counts
No parallax displacement
▲ = mean reading error, elevation

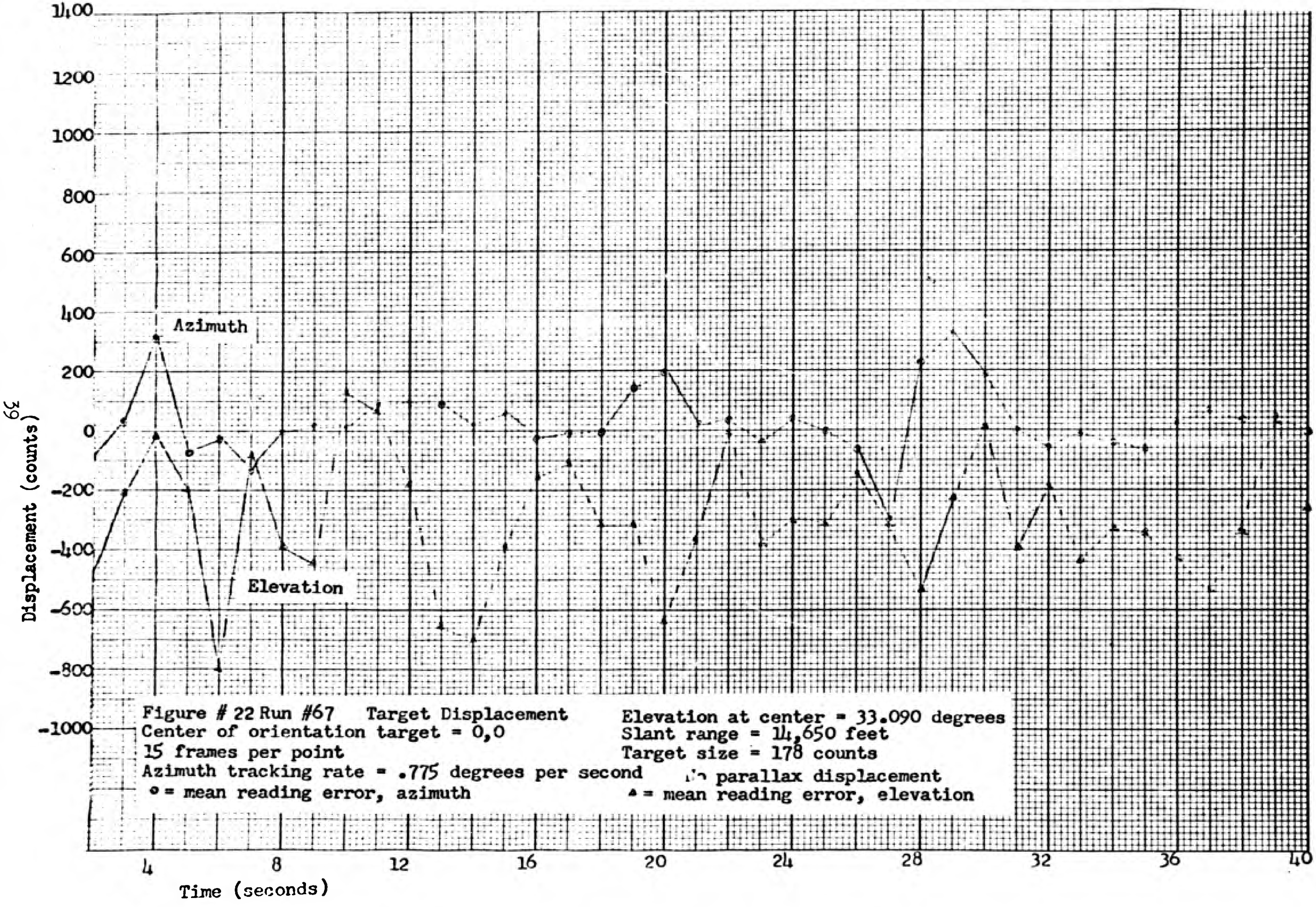


Figure # 22 Run #67 Target Displacement
Center of orientation target = 0,0
15 frames per point
Azimuth tracking rate = .775 degrees per second
o = mean reading error, azimuth

Elevation at center = 33.090 degrees
Slant range = 14,650 feet
Target size = 178 counts
No parallax displacement
▲ = mean reading error, elevation

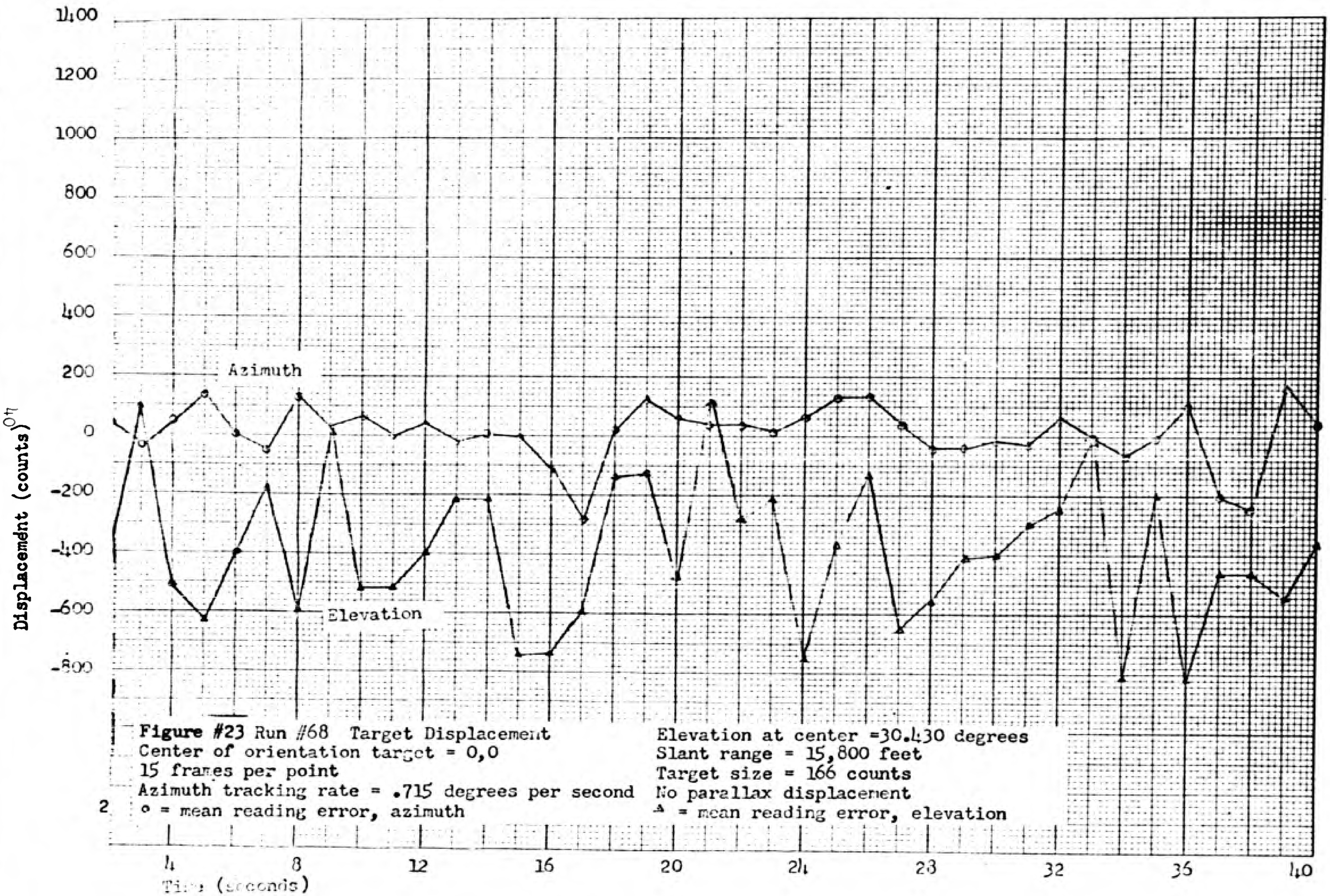
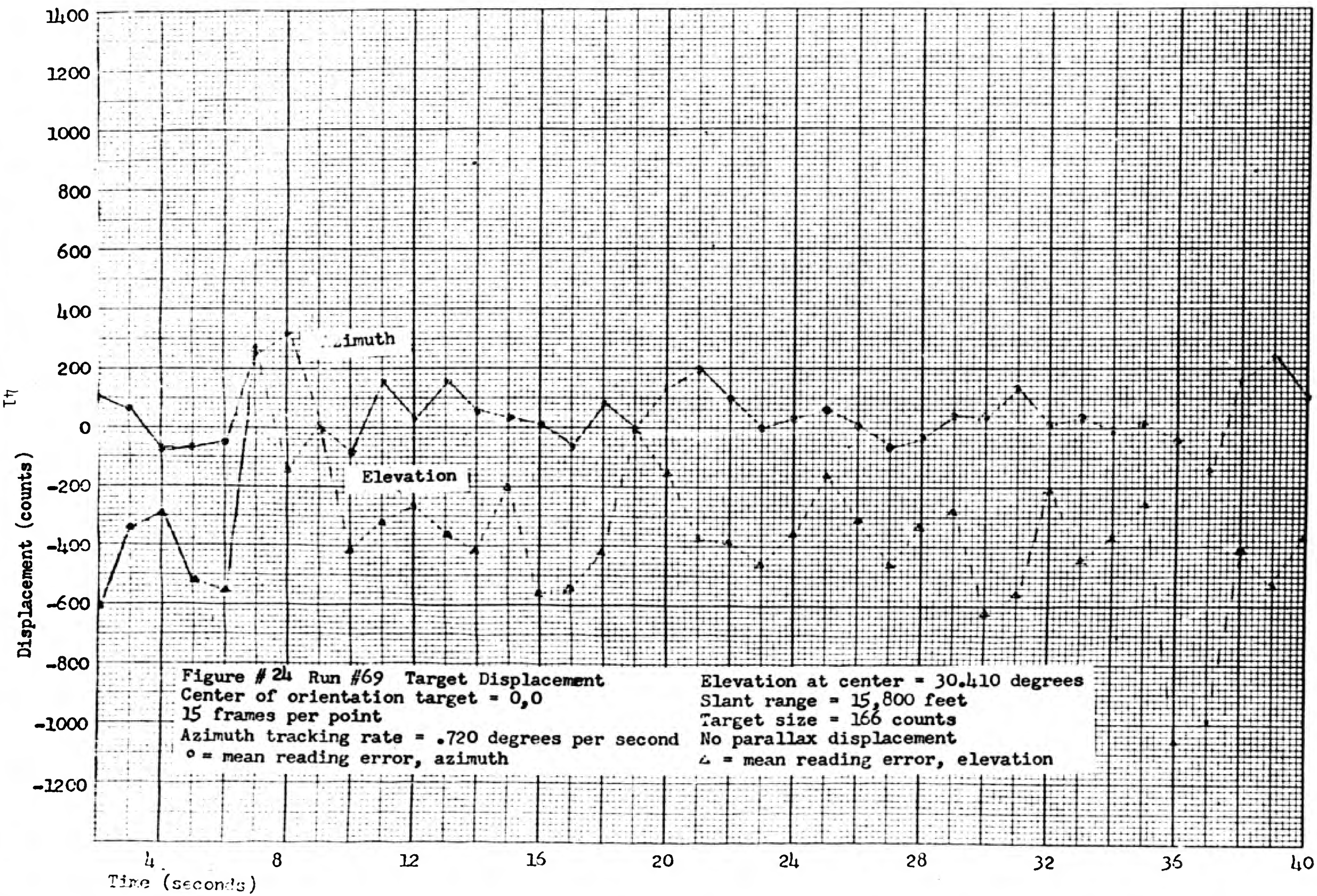


Figure #23 Run #68 Target Displacement
Center of orientation target = 0,0
15 frames per point
Azimuth tracking rate = .715 degrees per second
o = mean reading error, azimuth

Elevation at center =30.430 degrees
Slant range = 15,800 feet
Target size = 166 counts
No parallax displacement
Δ = mean reading error, elevation


Azimuth
Elevation
Displacement (counts)
1400
1200
1000
800
600
400
200
0
-200
-400
-600
-800
-1000
-1200
Time (seconds)
4
8
12
16
20
24
28
32
36
40
Figure # 24 Run #69 Target Displacement
Center of orientation target = 0,0
15 frames per point
Azimuth tracking rate = .720 degrees per second
o = mean reading error, azimuth
Elevation at center = 30.410 degrees
Slant range = 15,800 feet
Target size = 166 counts
No parallax displacement
△ = mean reading error, elevation

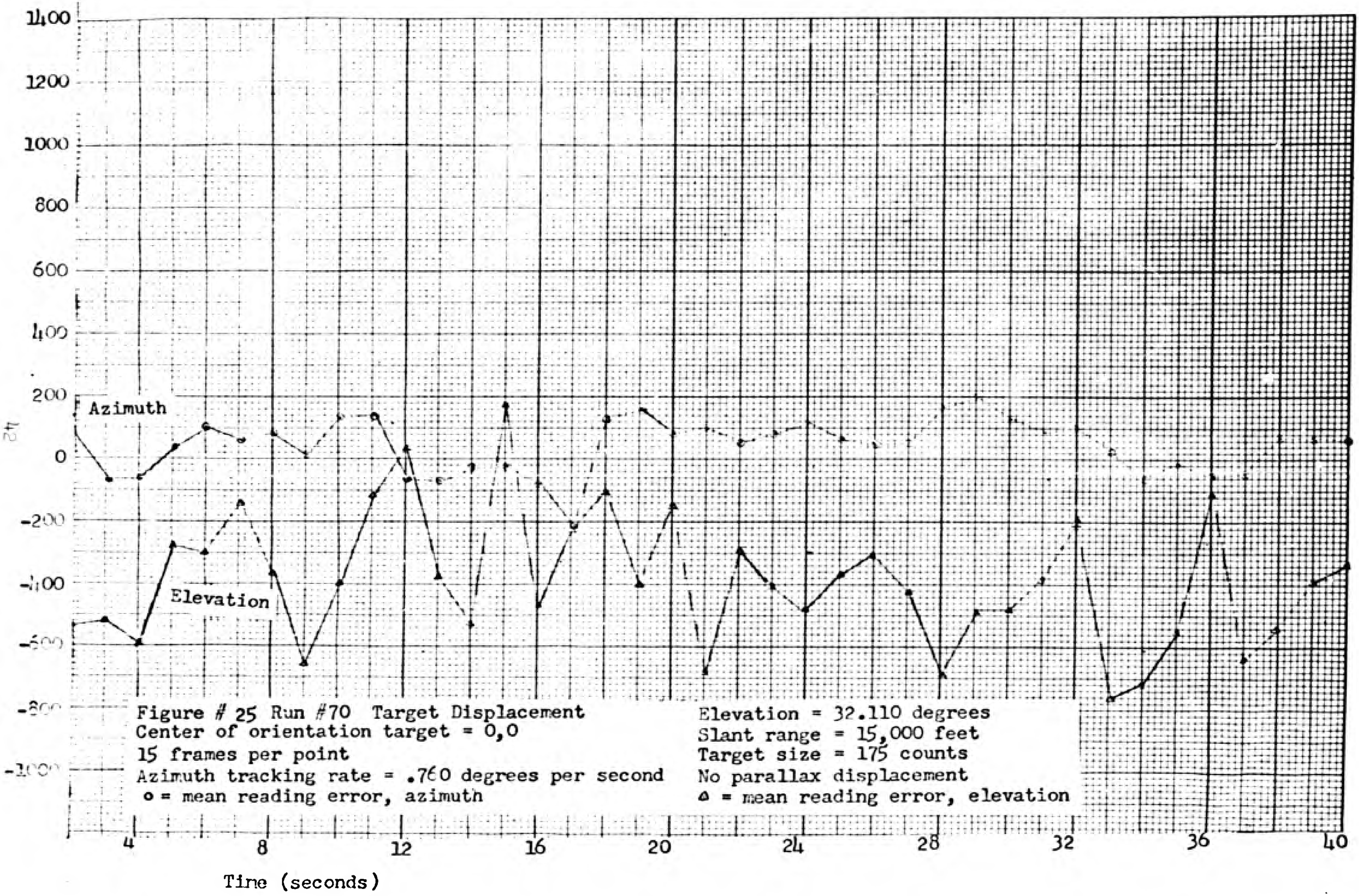


Figure # 25 Run #70 Target Displacement
Center of orientation target = 0,0
15 frames per point
Azimuth tracking rate = .760 degrees per second
o = mean reading error, azimuth

Elevation = 32.110 degrees
Slant range = 15,000 feet
Target size = 175 counts
No parallax displacement
Δ = mean reading error, elevation

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY U.S. Army Materiel Command Washington, D. C.

13. ABSTRACT

Tracking tests of an airborne target have been made with a tracking telescope to determine accuracy that could be expected under optimum conditions. The desired accuracy is 0.15 milliradians or better for at least ten percent of a critical period lasting approximately 15 seconds. Considerable difficulty was experienced in alignment of the relatively low power guiding scope with the main tracking telescope. This problem was solved by inserting a beam splitter, used for fine tracking, in the main optical system. The results show that the target was tracked from 6 percent to 12 percent of the critical period.

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Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Laser Beam Spread						
Airborne Target						
Tracking Instrument						
Critical Period						

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