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COMPARATIVE TESTS OF RADAR TRACKERS T-5 AND T-6

J. Leeder

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

8 September 1947

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J. LEEDER

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BALLISTIC RESEARCH LABORATORIES

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Details of illustrations in this document may be better studied on microfiche.

J. LEEDER

8 SEPTEMBER 1947

ABERDEEN PROVING GROUND, MARYLAND

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J. Leeder
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ABSTRACT

This report is of a series concerned with the general program of acceptance tests of the major caliber AA director systems T-38 and the T-6 tracker of the director T-39 on authority of O.O. 413.68/51 dated 22 April, 1946. BRLM Reports Nos. 432, 450 and 454 contain data of previous tests.

This report contains the results of all the remaining tests on the comparative tracking characteristics of the T-5 and the T-6. Specifically, the following portions of the test program are covered:

A. Automatic tracking accuracy in each of the positional coordinates of azimuth, elevation, and slant range at short and medium ranges, and at high azimuth rates.

B. Manual radar tracking accuracy in reference to tests in which operators position the radar tracker by observing radar signals.

C. Minimum or critical angle of tracking defined as that minimum angle of elevation for which the tracking errors become twice as great as normal.

The results of the test program as carried out on a B-25 target plane with a speed of approximately 100 yd./sec. are summarized in the following section:

SUMMARY OF RESULTS

At the medium ranges (minimum slant range 5300 yd.) the angular tracking accuracy as measured by the probable errors of tracking (excluding bias) was about .7 mil for the T-5 and .4 mil for the T-6. At shorter ranges (less than 2750 yds.) the angular tracking accuracy of both units decreased with that of the T-6 remaining within the specified 1.5 mils while the errors of the T-5 tended to exceed this limit. The explanation for this decrease in performance is to be found in the higher azimuth rate of travel of the target with respect to the radar sets at the shorter ranges.

The tests at high azimuth rates were conclusive in demonstrating the superiority of the T-6 tracker but were not sufficiently extensive to establish the precise relationship between tracking accuracy and angular rate of travel of target. It was found that with azimuth rates in the neighborhood of 125 mils per sec. the performance of the T-6 as well as that of the T-5 was well below that prevailing in the tests at medium ranges.

Under manual radar tracking the accuracy of both units depended upon the skill of the operators employed, but in general the angular tracking errors of the T-6 were only about one-third those for the T-5. With the better team of operators, average probable errors in angular tracking of 4 mils for the T-5 and 1.3 mils for the T-6 were obtained. Smaller errors could be expected with operating personnel having more experience with this form of tracking.

With respect to the foregoing results, the superiority in the angular tracking performance of the T-5 as compared with that of the T-6 is attributable mainly to the narrower beam of the T-6 and the resulting increase in angular sensitivity.

The results of minimum angle tests carried out over a body of water showed that the critical or minimum angle of elevation for accurate tracking was 75 mils for the T-5 and 23 mils for the T-6.

With respect to the accuracy in range tracking, no significant differences between the T-5 and T-6 could be established. For both sets the probable errors in range — excluding bias — were small, on the order of 5 yds. However, the range biases were frequently very large — as much as 50 to 60 yds. — due in good part to the difficulty in correctly aligning the range dials. Undoubtedly the Sperry Gyroscope Corp. has now evolved procedures for reducing the biases found in the reported tests as such work was in progress throughout the tests, but the results are not within the scope of this report.

INTRODUCTION

The following lists the series of Ballistic Research Laboratory Memorandum Reports already published on the general test program for the T-38 and the T-39 director systems.

Report No. 432: "Tests of Antiaircraft Gun Director T-38"

Report No. 450: "Comparative Tests Radar Trackers T-5 and T-6"

Report No. 454: "Tests of Antiaircraft Gun Director T-38"

In the interest of continuity a resumé is presented of the subject matter covered in the previous reports.

In B. R. L. Memorandum Report No. 432 results for these phases of the test program were discussed:

A. Search Tests, or the determination of the characteristics of the radar tracker (T-5) in locating a distant target plane as a function of range and tracking conditions.

B. Tracking tests performed with the radar tracker, T-5 and with the tracker-computer combination, T-38; the computer being utilized to furnish the regenerative tracking feature. In addition, tests on the comparative tracking accuracy of the T-5 and the SCR 584 Radar Units were included.

C. Static tests of the tracker (T-5) to determine the accuracy of the azimuth and elevation gearing, and the data dials.

D. Barber Coleman dynamic tests; in reference to tests conducted with a cam controlled device that supplied artificial data to the computer simulating the course of an actual plane.

In B. R. L. Memorandum Report No. 450 the comparative performance of the T-5 and the T-6 Radar Trackers was evaluted with respect to the following points:

A. Maximum range at which targets are first detected.

B. Time required for operator to change from PPI pick-up to automatic tracking.

C. Time required for operator to change from target selector pick-up to automatic tracking.

D. Minimum angle of resolution of the trackers as determined by having two planes fly at a constant wing to wing distance over the tracker site and on the outgoing leg ascertaining that minimum angle subtended by the planes at which the tracker ceased to resolve the targets and started to jump from one target plane to the other.

B. R. L. Memorandum Report No. 454 was concerned with the performance of the T-38 Director System as a whole, with particular emphasis upon the accuracy characteristics of the system under actual flight conditions as a function of the different methods of operating the director and variations in the type of test course.

The scope of the present report is summarized in the Abstract section.

Information concerning the radar trackers and their operation is presented in some detail in B. R. L. Reports No. 432 and 450. In order, however, that this report may be sufficiently coherent and intelligible without the necessity of constant reference to the earlier reports of the series, a brief listing of the salient technical characteristics of both radar trackers is repeated in this report, and, in addition, summaries of pertinent sections from previous reports are given wherever necessary.

The detailed description of the flight courses for the target plane; the conduct of the test program with the layout of the equipment; and the instrumentation employed were all discussed in Report No. 432. A less extensive treatment of these subjects is offered in this report and recourse should be had to the previous reports for omitted matter.

It should be mentioned that the results discussed in this report were obtained with equipment which was maintained by a competent engineer of the Sperry Corp.; under less skilled maintenance the equipment would not have performed in the manner to be discussed. This is indeed a weakness of both radar trackers but is similarly the case with complex radar equipment.

DESCRIPTION OF APPARATUS, REVIEW

The principal technical characteristics of the T-5 and T-6 Radar Trackers as listed in the Notes on Materiel (Sperry Publication No. 14-8090) are as follows:

	T-5	T-6
Power Supply	115 volts, 60 cycle, 3 phase A.C.	
Wave Length	10.7 cm.	3. cm
Frequency	3000 megacycles	9300 megacycles
Pulse Width	0.2 or 0.8 micro-seconds	As T-5
Pulse Repetition Rate	1100 per sec.	As T-5
Peak Power Output	250 KW	40 KW
Conical Scan of Beam:		
Antenna stationary	5 deg.	1.3 deg.
Antenna spinning	8 deg.	2.1 deg.
Angle Between Axis of Beam and Axis of Reflector	1.5 deg.	0.39 deg.
Speed of Antenna Spinner	3600 RPM	
Range		
Searching-Maximum	50,000 yd.	
Automatic Tracking		
-Maximum	35,000 yd.	
-Minimum	500 yd.	
Range Accuracy (Averaged)	25 yds., probable error	
Azimuth or Elevation Accuracy (Averaged)	1.5 mils probable error	
TRACKING RATES:		
Automatic		
Elevation Angle	250 mils per sec.	
Azimuth Angle	350 mils per sec.	
Slant Range	300 yds. per sec.	
Manual		
Elevation	250 mils per sec.	
Azimuth	500 mils per sec.	

TEST PROCEDURE

All tests were carried out by having the radar units track a target plane (a B-25 for the most part) on certain courses and determining the errors of the radar units with respect to each of the elements of present position: namely, azimuth, elevation and slant range. The flight courses followed and the location of the tracker sites are shown on a small overlay of the Proving Ground, Plate I. The location for all except the minimum angle tests was either "Old Phillips Airfield" or the "Balloon Hangar". In the case of the minimum angle tests, it was found that the flight courses over land led to results which could not be analyzed and correlated in view of the interference with the radar beam by irregular terrain features and sundry objects on the ground. For this type of test, therefore, it was advantageous to have the test course wholly over water and thus eliminate all factors except the influence of level "ground" reflections upon the tracking of the radar units. Sandy Point upon Spesutie Island was chosen as the radar site with the flight course (labelled E in Plate I) over Chesapeake Bay.

The angular tracking errors of each radar unit were obtained by means of a tracking camera which was mounted near the reflector of the tracker and photographed the area directly forward of the reflector. The reduction of the photographic data and the alignment of the camera are discussed in the section under instrumentation.

To obtain the errors in slant range a somewhat more elaborate test procedure was necessary. For this, the target plane was tracked on course and photographed every second on the second by each of three photo-theodolites, approximately 4000 yds. apart and located at the apices of a triangle through which the horizontal projection of the plane's course passed. The true path of the plane could be determined from the photo-theodolite data in terms of the rectangular coordinates, X, Y and H in the Aberdeen Proving Ground Grid System. (Actually every fourth second of theodolite data was reduced in most cases; each pair of stations provided one "fix" and the spread in three determinations provided a measure of the validity and accuracy of the data). The X, Y and H rectangular coordinate data were transformed to the spherical polar coordinates, A (Aximuth), E (Elevation Angle), and D (Slant Range) with origin of coordinates at the tracker location----as illustrated in Plate II. For the tests covered by this report, only true range, D was necessary. Slant range errors of the radar units were determined by subtracting the correct ranges, as calculated from the photo-theodolite data, from the radar ranges which were obtained by photographing the radar range dials every second on the second.

MANUAL RADAR TRACKING TESTS

Manual radar tracking tests were carried out with flight courses for which the minimum slant range varied from 2000 to 6400 yds.

In such tests the target plane is followed by two operators, the azimuth and elevation trackers who are seated in chairs at their respective ends of the radar mount. Each operator views an oscilloscope, and by manually positioning the tracker so as to match two video signals or pips on his oscilloscope, the radar tracker is caused to follow the target plane in both azimuth and elevation. For best results, it is clear that operators with the necessary aptitude and training should be employed. Inasmuch as the tests reported were carried out with trackers who could be given only a limited amount of training, the results can not be considered the optimum obtainable with either of the two radar sets.

In order, therefore, to arrive at a fair comparison of the T-5 and T-6 which would be independent of the skill of the operators, the crews were interchanged so that operating team differences could be evaluated and a true comparative analysis determined.

For all manual radar tracking tests, automatic range tracking was used.

INSTRUMENTATION

GENERAL

A review of the main instruments used and their functions are summarized in the accompanying table. While some of the units are described more fully in succeeding section, for a more detailed exposition recourse should be had to Report No. 432.

SUMMARY OF INSTRUMENTATION EMPLOYED IN TESTS OF T-5 AND T-6 TRACKERS

1. Mitchell photo-theodolites to determine the true course of the target plane; test procedure has been described previously.

2. Dial recording cameras and stroboscopic lights (for illumination of dials) to record slant range information from range dials on radar trackers.

3. Tracking cameras, one per tracker, to record target position information every second on the second. Two sets of lenses were available: a 15" lens with a 20 mil field of view; and a 6" lens with about a 50 mil field of view. Where the angular errors of the tracker became very large, as was the case with the T-5 on some of the tests, recourse was had to the 6" lens with the greater field.

4. Central timing mechanism to send out triggering pulses every second over a common line system to Edgerton units with pulse amplifers for simultaneous operation of tracking and dial recording cameras and stroboscopic dial lights.

5. Radio and telephone communication nets; and remaining miscellaneous equipment as described in Report No. 432.

DESCRIPTION OF TRACKING CAMERA

The tracking camera was a modified 16 mm cine' Kodak, motor driven and equipped with an electromagnetic clutch and control mechanism in such manner as to take a single frame picture upon receipt of a timing pulse.

For proper adjustment the optic axis of the camera was aligned parallel to the geometric axis of the reflector (or the radar beam) in accordance with the following procedure: The line of sight of the optical tracking scopes on the radar tracker was aligned with the radar beam while the radar unit was locked on a target plane; and in turn the tracking camera was collimated with the radar tracker's optical scopes by orientation upon a distant fixed target. Photographs of the orientation point were taken at the beginning and end of each day's run.

During the tests the target plane was photographed every second on the second on its course; and since the position of the orientation point in the frame of film represented the actual position of the radar beam in the field of view, the angular tracking errors of the radar sets in Azimuth, A_o and Elevation, E_o could be obtained by taking the difference: orientation point position in film (or actual radar beam position) minus target plane position and converting the film reading differences, horizontal and vertical, to corresponding angular displacements in mils.

DIAL RECORDING CAMERAS

The dial recording cameras were similar to the tracking cameras except that the shutters were removed; the exposure taking place upon the illumination of the output dials of the trackers by Edgerton lights.

FURTHER COMMENTS

While on the whole the instrumentation proved satisfactory in meeting the requirements of the test program, the tracking and dial recording cameras can not be considered as satisfactory. The all too frequent jamming of the 16mm film magazines and the general unreliability of the clutch mechanism employed dictate that such equipment should be replaced on all similar type tests with more reliable cameras.

PRESENTATION OF RESULTS

The results of the test program are presented in the extensive series of graphs, Figs. 1 to 54 inclusive, and in Tables I and II appended to the report. Each graph shows the errors of the trackers in azimuth, elevation, and slant range for one particular test run, along with the test conditions and the calculated probable errors for the run in each of the positional coordinates.

The target size delineated on the graphs by two dotted lines was determined by measurement of the maximum horizontal and vertical dimensions of the target plane on the tracking camera film.

Table I essentially serves as an index to the graphs; listing the nature of the test, the test conditions, and summarizing the results for each run in the form of the probable errors, with and without bias.

In Table II the results obtained for the different types of tests; namely, those at short and medium ranges, and manual radar tracking, have been summarized for each type test to indicate the average overall performance of the radar units for the given type test conditions.

As the criterion for judging the accuracy of the radar units, the probable errors in azimuth, elevation and slant range were calculated for each test run using the data for the individual points. (According to Field Manual, FM-4-10, the probable error "is the error which is as likely as not to be exceeded".) Probable error with bias included is computed by taking the median of the absolute errors for all points.

The bias for each run is the algebraic average of all individual errors, and therefore represents the level about which the individual errors fluctuate. Essentially, bias is a measure of the adjustment of the radar system, and with proper alignment should vanish.

The probable error without bias is calculated by subtracting the bias figure from each individual value and computing the probable error in accordance with the method outlined previously. Technically, the radar trackers should be evaluated on the basis of the probable errors with bias included inasmuch as this is the measure of the actual performance of the system; it determines the errors which would be fed to the computing mechanisms of the directors. However, due to various causes, some of which were practically beyond control at the time of test, correct alignment was not always achieved and large enough biases resulted which, incorporated in the probable errors, do not give a valid representation of the tracking merits of the two radar systems.

The foregoing discussion is intended to apply mainly to the angular tracking errors; in the case of the range errors a somewhat different situation prevails, and this is considered in a latter section.

As an example of the alignment difficulties encountered, the elevation telescope on the T-6 tracker had been displaced at least several times from its correct orientation with the radar beam, and some of the test results were affected before the condition became apparent. This misalignment was due to the fact that both azimuth and elevation telescope assemblies were attached to the elevating shaft by means of soft steel taper pins — the taper pins shearing upon application of excess torque to the shaft; thus preventing more serious mechanical damage. The telescopes were moved in elevation along with the radar dish through a lever coupling system from the dish to the shaft to which the telescopes were attached. Particularly in the case of the elevation telescope, improper handling of the dish and, or the telescope tube frequently caused a partial shearing of the taper pin with a resulting misalignment of the elevation telescope with the radar beam.

DISCUSSION OF RESULTS

SHORT RANGES, ANGULAR TRACKING ACCURACY

At the shorter ranges, (750 to 2750 yds. slant range), the tracking errors of both the T-5 and the T-6 trackers were considerably greater — by about a factor of two — than those prevailing for the tests at the greater ranges. While in the case of the T-6 the probable errors without bias for azimuth and elevation fall within the specified limit of 1.5 mils, the values for the T-5 are on the border line. The graphs, Figs. 1 to 3, illustrate clearly the rather erratic tracking of both units, particularly when compared with the results in the graphs, Figs. 10 to 17 for the medium and long range tests.

Fundamentally, the cause for the lowered tracking accuracy of the T-5 and T-6 at the short ranges is not to be found in the factor of range as such, but rather in the high azimuth rate of the target plane with respect to the trackers; a consequence of the short range with a constant speed target. In the subsequent section the effect of high azimuth rate upon tracking accuracy is considered.

EFFECT OF HIGH AZIMUTH RATES UPON ANGULAR TRACKING ACCURACY

The results of the tests at high azimuth rates (45 to 524 mils per sec.), Figs. 4 to 9 inclusive, were conclusive for demonstrating the superiority of the T-6 tracker, but were not sufficiently extensive to establish the limits of performance of both trackers as a function of angular rate of travel of the target plane.

In some of the runs, as that shown in Fig. 9, the data for the T-5 were not available near the cross-over region since the errors exceeded the field of view of the tracking camera. As in the computation of the probable errors these missed points were not included, the calculated probable errors are less than the true values.

The tabulated probable errors on the graphs and in Table I do not adequately reveal the degree of superiority of the T-6 tracker; this, apparently, is indicated more realistically in the pictorial representation of the errors in the graphs.

At the highest azimuth rate of 524 mils per second (Fig. 7), which is over twice the specified maximum rate of 250 mils per second, both the T-5 and the T-6 lost the target. However, at the lower azimuth rates of 122 and 162 mils per second (Figs. 8 and 9 respectively) the performance of both radar units was below the standard found in medium range tests; the angular errors of the T-6 attaining values as high as 7 to 8 mils. The performance of the T-5 was erratic with high tracking errors at azimuth tracking rates as low as 64 mils per second. (Fig. 4). For a fair evaluation, however, it would seem that the number of tests were inadequate to determine with a reasonable degree of statistical certainty the tracking characteristics of the T-5 and the T-6 at high azimuth rates.

ANGULAR ERRORS FOR AUTOMATIC TRACKING TESTS AT MEDIUM RANGES

At medium and long ranges (minimum slant range greater than 5300 yds.), Figs. 10 to 17 inclusive, the average probable error without bias for either azimuth or elevation is about .7 mil for the T-5 and .4 mil for the T-6. The variations in the probable errors without bias as well as the averages determined from all the tests in the given category are given in the following table:

Summary of Tracking Errors of T-5 and T-6 at Medium and Long Ranges (Minimum Slant Range 5300 Yds.)

	Azimuth in mils	Elevation in mils	Slant Range in yds
Variations in Probable Error Without Bias			
T-5	.4 to .9	.4 to 1.3	2.4 to 7.0
T-6	.3 to .5	.2 to .3	2.0 to 5.0
Average Probable Error Without Bias from All Tests			
T-5	.65	.75	4.5
T-6	.37	.22	3.5

And in the following table the results for the probable error with bias are presented:

Summary of Tracking Errors of T-5 and T-6 at Medium and Long Ranges (Minimum Slant Range 5300 yds.)

	Azimuth in mils	Elevation in mils	Slant Range in yds
Variation in Probable Error With Bias			
T-5	.4 to 1.0	.8 to 1.9	3.5 to 24
T-6	.3 to .5	2.8 to 3.2	11 to 18
Average Probable Error with Bias From All Tests			
T-5	.71	1.3	15
T-6	.33	3.0	14

The explanation for the relatively large biases, particularly in the case of the elevation results for the T-6 has been advanced in a previous section. And as has been mentioned, as the valid criterion for evaluating the performance of the trackers— at least insofar as the angular tracking errors are concerned— the probable errors without bias should be employed.

Insofar as range tracking was concerned, there was no significant difference between the T-5 and the T-6. In all cases the probable errors were within the specification limit of 25 yds. A more detailed analysis of range data is presented in a subsequent section.

The tabulated probable errors on the graphs and in Table I do not adequately reveal the degree of superiority of the two radar sets; as clearly indicated by visual observation through the tracking scopes on the radar mounts, the T-6 tracks far more smoothly than the T-5. In general, the oscillations of the T-6 about the target center are sufficiently limited in amplitude so that the cross hairs of the telescope are on part of the target most of the time; whereas the T-5 tracks in a more jerky fashion and swings off target quite frequently.

The smoother tracking of the T-6 is primarily due to the narrower beam width of the T-6 as compared with that of the T-5 and the resulting increased angular sensitivity of the T-6. Hence, a smaller angular movement of the T-6 off target is sufficient to give rise to an error signal of sufficient magnitude to actuate the automatic tracking mechanism to bring the tracker back on target.

ANGULAR ERRORS IN MANUAL RADAR TRACKING TESTS

Comparison of the detailed test results in Figs. 18 to 36, inclusive, and Table I shows that the T-6 was decidedly superior to the T-5 in manual radar tracking tests for medium range courses. The relative performance of the radar units with operating team differences considered is made clearer in the summary given in Table II where the results from the tests carried out on the same day under similar conditions have been averaged. The values used as a basis of evaluation are the probable errrors without bias as this is a true measure of the smoothness of tracking. Presumably, the bias characteristics of a given crew could be determined and eliminated from the output data of the trackers.

The decided superiority of the T-6 is evidenced by the fact that, disregarding differences in operational skill of crews, the errors of the T-6— in both azimuth and elevation— were almost in all cases less than half those for the T-5.

If the test results are further summarized for each tracker and set of operators the overall averages at the end of Table II are obtained. It is seen that, on the whole, the Team 1 pair of operators was at least twice as skilled as Team 2; and the angular errors of the T-6 with either crew were about 1/3 those for the T-5.

Again the superior tracking characteristics of the T-6 under the stated conditions is directly attributable to the narrower beam width of the T-6 and the resulting increase in angular sensitivity. Under manual radar tracking conditions, an angular error in the tracker position with respect to the target plane must first occur before an operator can discern a mismatch in the radar pips and correct the error. With the T-5, errors may become as large as 20 mils before an operator can detect a significant difference in the size of the radar signals. Due to the narrower beam of the T-6, however, a smaller angular error in the radar tracker is necessary for a noticeable variation in the size of the radar pips on either oscilloscope. As a consequence, a relatively unskilled crew can track with the T-6 with an average probable angular error (without bias) of less than 3 mils; whereas in the case of the T-5, the average probable errors may become excessive, exceeding 10 mils.

RANGE ACCURACY

It should be mentioned that many of the views embodied in the following discussion were originally obtained from the reports of Mr. Dale Jahn to his organization, the Sperry Gyroscope Corp. Of those present at the test, this engineer was clearly the best informed concerning the details of the operation and idiosyncracies of the electronic circuits embodied in both radar units.

An analysis of the range data obtained in the tests of Aug. 8, Oct. 14, and Sept. 20 (Figs. 4 to 9; 10 to 17; and 18 to 36) indicates that the probable errors in range, if bias is disregarded, run to less than 8 yds. However, when the probable errors in range with bias included are considered, only the values for the medium range tests (data of Oct. 14) consistently fell within the specified limit of 25 yds. An analysis of the data reveals in general large biases, which constitute the major portion of the errors found, and the explanation of which can not always be satisfactorily given.

Part of the biases encountered can, in many instances, be attributed to the difficulty in correctly aligning the range dials. In the method employed for the most part, the range dials of both trackers were aligned on a land target (water tower) of known range. The indication from the results, however, was that such procedure would not invariable result in correct ranges being measured to the target plane; the strength of the returned radar signal from the target apparently influencing the setting of the ranging circuits; with other variables as receiver tuning, temperature and humidity of air possibly playing a role, the nature of which is not understood. For example, a change in the video level from 80% of the saturation value to 50% due to a decrease in the received signal results in a 15 yd. change in measured range.

As a matter of interest, an analysis of the biases found in the tests has been attempted on the basis of the known factors entering into the make-up thereof.

In most of the tests the range dials of the T-5 and T-6 trackers were adjusted to read the known range to the Service Club water tower, the settings being:

T-5 Range: 3515 yds. T-6 Range: 3525 yds.

However, a reexamination of the survey showed that the correct values should have been:

T-5 Range: 3500 yds. T-6 Range: 3520 yds.

so that as a consequence the following adjustment corrections should be applied to the measured ranges:

Adjustment Corrections in Range

T-5: -15 yds. T-6: -5 yds.

As another component of bias, drift of the range system was determined by ranging in on the water tower at the beginning and end of each series of runs; the difference in range values establishing the total drift during the series of tests. And on the assumption that drift was a continuous process proceeding proportional to time, the drift in range for each particular run could be approximated.

Analysis of Aug. 8 Data

High Azimuth Rates. Figs. 4 to 9

Drift was determined from the following values:

	T-5	T-6
Range of Tower at Start:	3515	3525
Range of Tower at Finish:	3525	3555
Total Drift, in yds	+10	+25

The large drift of the T-6 is ascribed to the failure of the ventilating system.

With these values, the biases which would have resulted had the adjustment error and the drift been removed are as follows:

Figure No. Report	4	5	6	7	8	9
Run	2	4	6	8	9	10
T-5 Results						
BIAS*	31	45	32	27	15	34
Adjust. Error.	-15	-15	-15	-15	-15	-15
True Bias is Bias Minus Adj. Error	16	30	17	12	0	19
Drift	2	3	5	7	8	10
Corrected Bias is True Bias minus Drift	14	27	12	5	-8	9

*Note. All values in yds.

T-6 Results

BIAS*	44	54	52	58	61	58
Adjust. Error	-5	-5	-5	-5	-5	-5
True Bias is Bias minus Adj. Error	39	49	47	53	56	53
Drift	5	10	15	20	25	25
Corrected Bias is True Bias minus Drift	34	39	32	33	31	28

*Note. All values in yds.

After drift is removed from the T-6 data, there still remains a 30 yd. bias that can not be accounted for. Since the reference target saturated the receiver, it is possible that a large part of the bias may be ascribed to this influence on alignment. The wide variation in the T-5 biases (with all corrections) may be due to a shift in receiver tuning during the tests.

It should be mentioned that the data just discussed was obtained during the high azimuth rate tests in which the angular tracking errors in general were greater than normal.

Analysis of Sept. 20 Tests.

Manual Radar Tracking Tests. Figs. 18 to 36.

As stated previously, automatic range tracking was employed in the manual radar tests.

The range dials of both trackers were read while locked on the Service Club water tower with no attempt made to set the range dials correctly. The observed range values, then, should be adjusted in accordance with the following corrections:

	T-5	T-6
True Range:	3500 yd.	3520 yd.
Range Dial Reading:	3560 yd.	3525 yd.
Correction to Dial Reading:	-60 yd.	-5 yd.

The drift for both radar systems proved to be zero.

The corrected values of bais are then calculated as in the preceding table to be:

Figure No. Report	23	24	25	26
Run No.	3	4	5	6
	T-5			
BIAS*	82	74	101	26
Adjust. Error	-60	-60	-60	-60
True Bias in Bias minus Adjust. Error	22	14	41	-34
Drift	0	0	0	0
Corrected Bias is True Bias minus Drift	22	14	41	-34

*Note. All values in yds.

	T-6			
BIAS*	2.3	.9	-1.3	- .5
Adjust. Error	-5	-5	-5	-5
True Bias in [is] Bias minus Adjust. Error	-2.7	-4.1	-5.5	-5.5
Drift	0	0	0	0
Corrected Bias is True Bias minus Drift	-2.7	-4.1	-5.5	-5.5

*Note. All values in yds.

In the opinion of the Sperry engineer, the very small biases observed in the T-6 data were due to the similarity of the signal (with respect to strength) received from the local water tower used for ranging with the signals received from the target plane during this series of tests. The large biases for the T-5 in runs 5 and 6 may be due to a change in receiver tuning; the change in tuning having started in Run 5 as the start of this run is similar to Runs 3 and 4.

An instance of the difficulty in correctly adjusting the range dials is here presented, in that on Aug. 8 the T-6 was adjusted to read 3525 yds to the Service Club water tower and all readings to the plane were about 30 yds. (corrected bias) too high; while on Sept. 20 the T-6 was again adjusted to read 3525 yds to the water tower and all range data were correct.

Analysis of Oct. 17 Data

Automatic Tracking Tests at Medium Ranges. Figs. 10 to 17

In the tests of Oct. 17 the T-5 was adjusted to read correct range to water towers with relatively weak signal strengths; and in addition ranging on the transmitter current pulse was carried out to check the latter method of alignment.

Alignment Tests for T-5

	Tower No. 1	Tower No. 2
True Range*	6245	5150
Radar Measured Range	6255	5155
Current Pulse at Start of Run:	-85	
Current Pulse at End of Run:	-75	
Drift	10	

*All values in yds.

As suitable ranging points could not be seen from the T-6 station, the range dials were set to read

-65 yds. for the transmitter pulse, a figure determined from previous tests to give zero bias for ranges to the target plane.

The biases found in the medium range tracking tests of Oct. 17 then are as follows:

Figure No Report	10	11	12	13	14	15	16	17
Run No:	3	4	5	6	7	8	9	10
T-5 Bias*	-5.	-21.	-7.	-22.	-11.	-19.	-14.	-24.
T-6 Bias	-17.	-18.	-12.	-15.	-14.	-12.	-10.	12

*All values in yds.

According to the current pulse measurements, the bias for the T-5 should not have exceeded 10 yds.

MINIMUM OR CRITICAL ANGLE OF ELEVATION TESTS

Detailed results for the minimum angle tests are presented in Fig. 37 to 49 inc. In the tests at the lower altitudes the T-5 oscillated with very large amplitudes about the target position, and the tracking errors were so great that on the graphs they extend over a large portion of the ordinate scale. A different scale factor should probably have been used in plotting those large errors.

In the test procedure, the target plane flew a constant altitude course, but the angle of elevation to the plane from the tracker site constantly changed, the exact variation in both angle of elevation and slant range being given for each run in the corresponding graph. At crossover, of course, the angle of elevation attained its maximum value for a run, and the slant range its minimum. Inasmuch as the factor determining the tracking accuracy of the radar sets at minimum elevations is clearly the angle of elevation, rather than the altitude of the plane, the test data has also been evaluated in terms of tracking errors as a function of angle of elevation. The probable errors of tracking in elevation as a function of the angle of elevation were computed from the tracking errors—taken from all runs— found at each given angle of elevation; to insure sufficient test data at each angle, a range of plus or minus 5 mils was taken for each angle from 0 to 200 mils, and plus or minus 25 mils from 359 to 925 mils angle of elevation. The resulting functions are portrayed in Fig. 50 for the probable errors with and without bias. The number of individual test points included in the calculations of each probable error value is also indicated on the Fig. as a sort of weighting factor.

As an additional and more inclusive picture of the elevation tracking errors as a function of the angle of elevation, the test points for each run were grouped along the run for every 10 mil increment in angle of elevation, and the probable error determined for the points within each group. These values of probable errors, with and without bias included, as a function of the angle of elevation for all the minimum angle runs have been plotted in Figs. 52 and 53. Evidently on each graph a zone may be delineated within which most of the tracking errors lie. In Fig. 54 the zones marked out in Figs. 52 and 53 for the probable errors with and without bias, have been plotted on the same graph for ease in comparison.

If the critical or minimum angle of tracking be defined as that minimum angle at which the probable error in tracking (elevation) becomes twice that for normal operation—where ground reflections do not play a part, then the minimum angles of elevation tracking for the T-5 and the T-6, as determined from the results in Figs. 50 and 52 (taking the probable errors without bias as the criterion) are:

T-5: 75 mils T-6: 23 mils

The T-6 can track to a much lower angle of elevation than the T-5 since with its narrower beam, interfering ground reflections occur at a lower angle of elevation.

That the azimuth tracking accuracy is little affected at the minimum angles of elevation can readily be shown. Plotting the average probable error in azimuth as a function of the altitude of test run, the graph in Fig. 51 results. Comparison of this function with the variation of errors in elevation tracking indicates fairly well that at the lower altitudes (or angles of elevation) the azimuth tracking accuracy of the T-6 is little affected, while the errors of the T-5 become, at worst, about twice as great as normal.

BREAKDOWNS OF EQUIPMENT

In addition to the usual complement of tubes that became defective, the following lists the major breakdowns that occurred with the equipment during the conduct of the tests discussed in this report:

1. Brushes on the T-6 400 volt generator failed several times; the positive brush seemed to wear much faster than the other.

2. Transformers T-201 and T-204 in the T-6 remote station power supply unit failed; a possible voltage breakdown occurring at the terminal insulating beads.

3. There were an excessive number of failures in the 6Y6 G regulator tubes in the T-5 IF strip voltage regulator.

4. The telescopes on the radar trackers, particularly the elevation scope on both the T-5 and the T-6, frequently did not retain their adjustment; the partial shearing of the taper pin coupling the telescope to the shaft being responsible, as has been discussed in a previous section.

5. An excessive number of failures of the magnetron in the T-6 indicated that the fault lay with the T-6 rather than with the magnetrons.

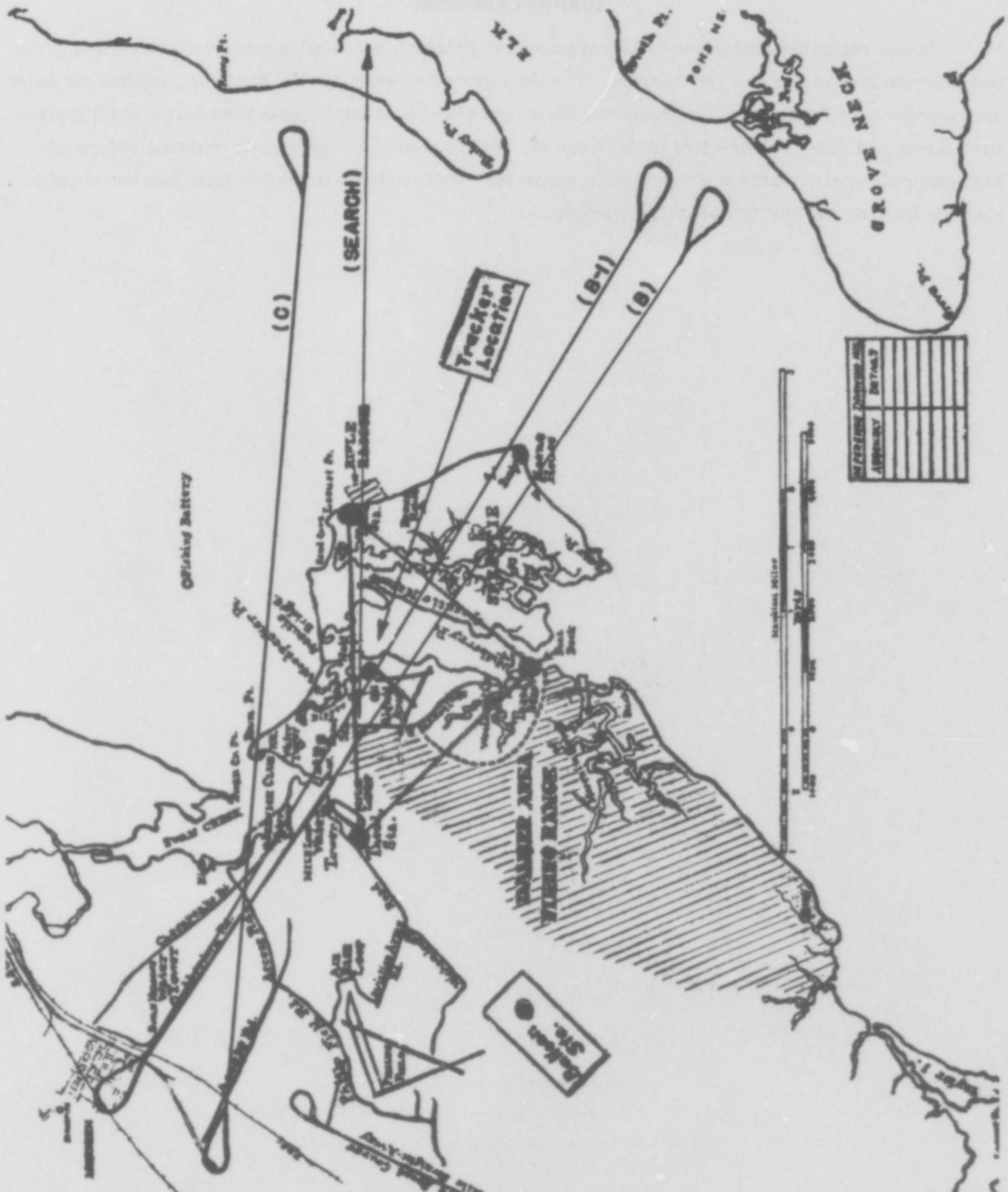
CONCLUSIONS AND RECOMMENDATIONS

The essential results of the test program have been presented in the abstract section.

The indications from the results are that additional tests should be performed for the determination of the tracking characteristics of both the T-5 and the T-6 radar units at high azimuth rates. Also, further investigation and possibly, development work are warranted for the ranging mechanisms of both trackers to achieve a correct alignment procedure and eliminate the rather large range biases which sometimes occur.

ACKNOWLEDGMENT

In this report the author has mainly attempted to present a coordinated picture of the results of the test program for the T-5 and T-6 trackers. The tests described were, for the most part, carried out under the supervision of Capt. Oscar Laudenslayer; while the reduction of data and the preparation of all graphs were performed under the direction of Mr. Bernier. As has been stated previously, frequent reference has been made—particularly in the section on range data—to the reports which Mr. Dale Jahn submitted to his organization, The Sperry Gyroscope Corporation.


(SEARCH)
(C)
(B-1)
(B)
Tracker Location
GROVE NECK

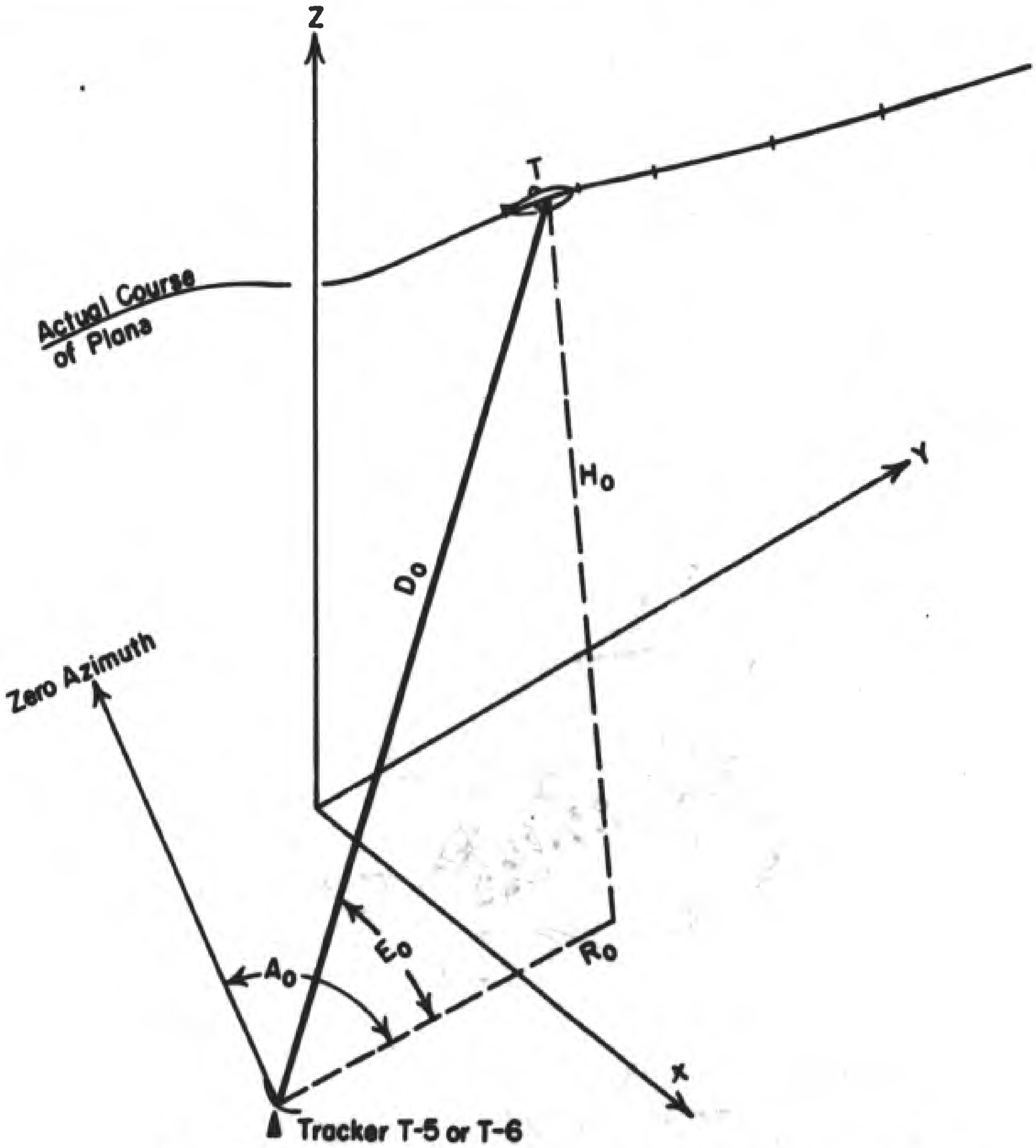


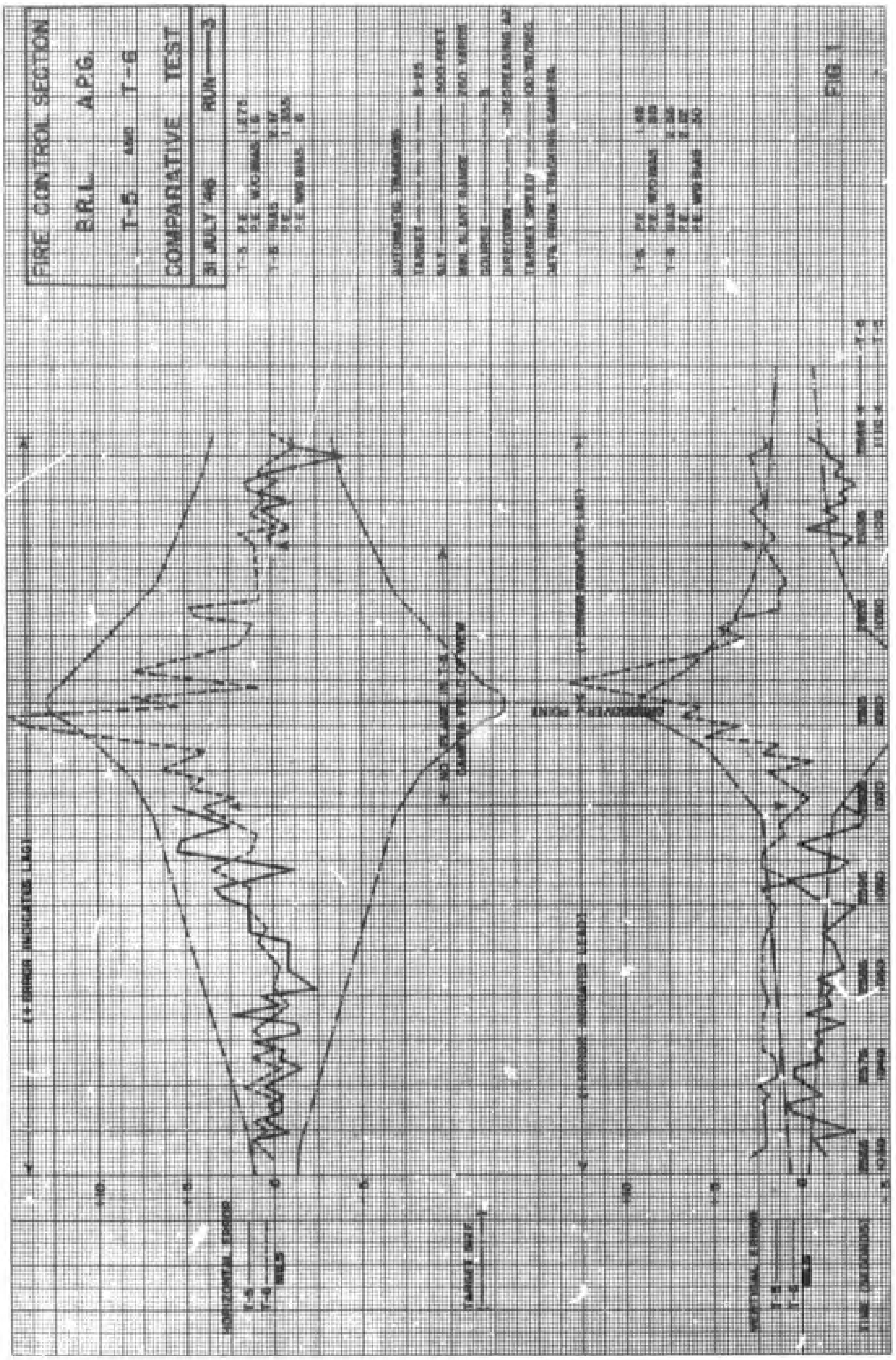
PLATE II - ILLUSTRATION OF LINEAR FLIGHT COURSE

EXPLANATION OF SYMBOLS, PLATE II

X, Y, Z **Aberdeen Proving Ground Rectangular Coordinate System**

The following are present position data of the target plane in a spherical coordinate system.

A_0	**Azimuth, mils**	H_0	**Altitude, yds.**
E_0	**Elevation, mils**	R_0	**Horizontal Range, yds.**
D_0	**Slant Range, yds.**		



FIRE CONTROL SECTION
B.R.L. A.P.G.
T-5 AND T-6
COMPARATIVE TEST
31 JULY '46
RUN — 3

FIG. 1

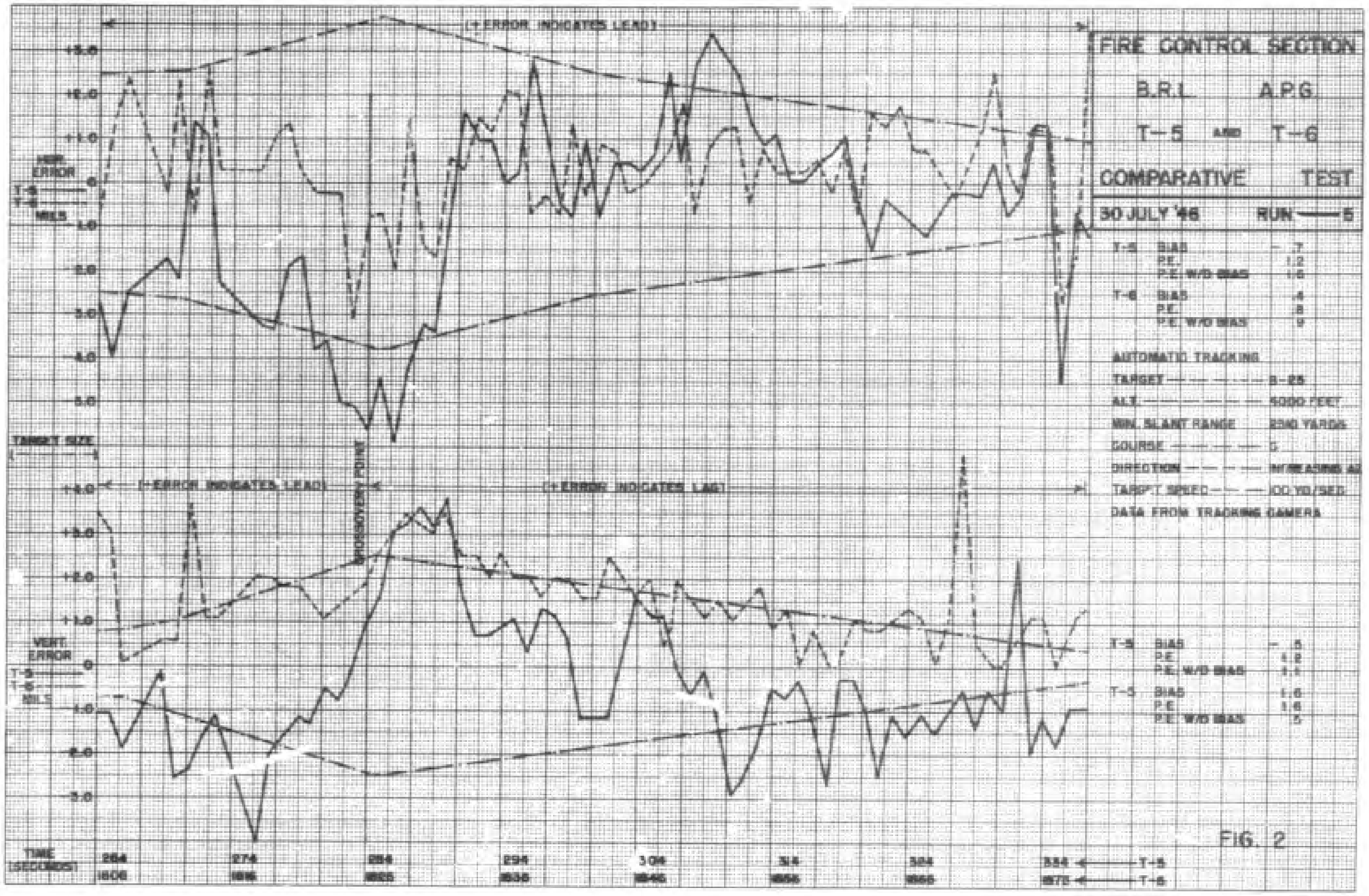

FIRE CONTROL SECTION
B.R.L. A.P.G.
T-5 AND T-6
COMPARATIVE TEST
30 JULY '46 RUN — 5
T-5 BIAS -.7
P.E. 1.2
P.E. W/O BIAS 1.0
T-6 BIAS .4
P.E. .8
P.E. W/O BIAS .9
AUTOMATIC TRACKING
TARGET B-25
ALT. 5000 FEET
MIN. SLANT RANGE 2510 YARDS
COURSE 5
DIRECTION INCREASING
TARG'T SPEED 100 YD/SEC
DATA FROM TRACKING CAMERA
T-5 BIAS -.5
P.E. 1.2
P.E. W/O BIAS 1.1
T-5 BIAS 1.6
P.E. 1.6
P.E. W/O BIAS .5
(+ ERROR INDICATES LEAD)
(+ ERROR INDICATES LAG)
CROSSOVER POINT
HOR. ERROR
VERT. ERROR
T-5
T-6
MILS
TARGET SIZE
+3.0
+2.0
+1.0
0
-1.0
-2.0
-3.0
-4.0
-5.0
TIME (SECONDS)
264
1806
274
1816
284
1825
294
1836
304
1846
314
1856
324
1866
334 T-5
1876 T-6

FIG. 2

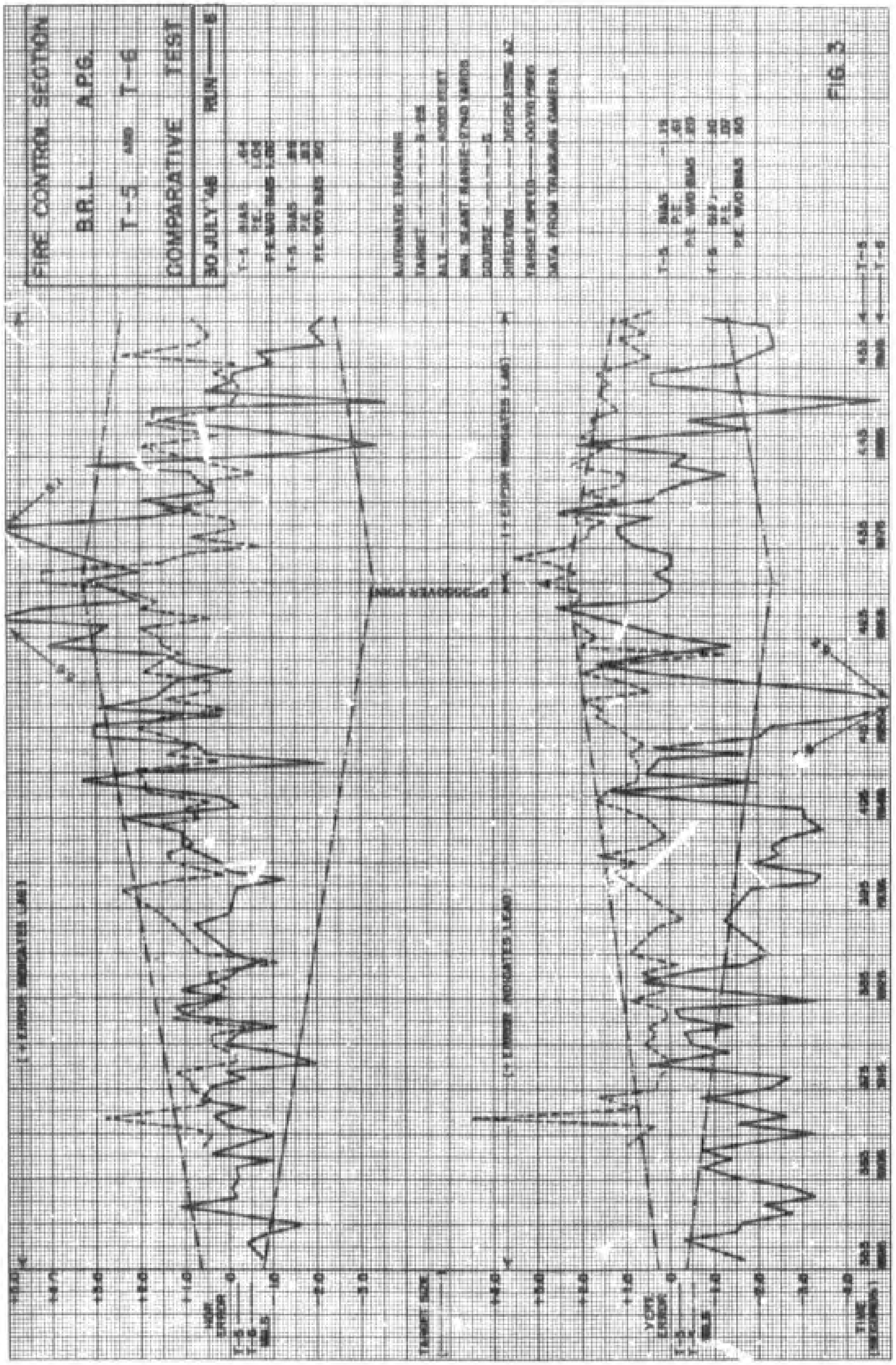
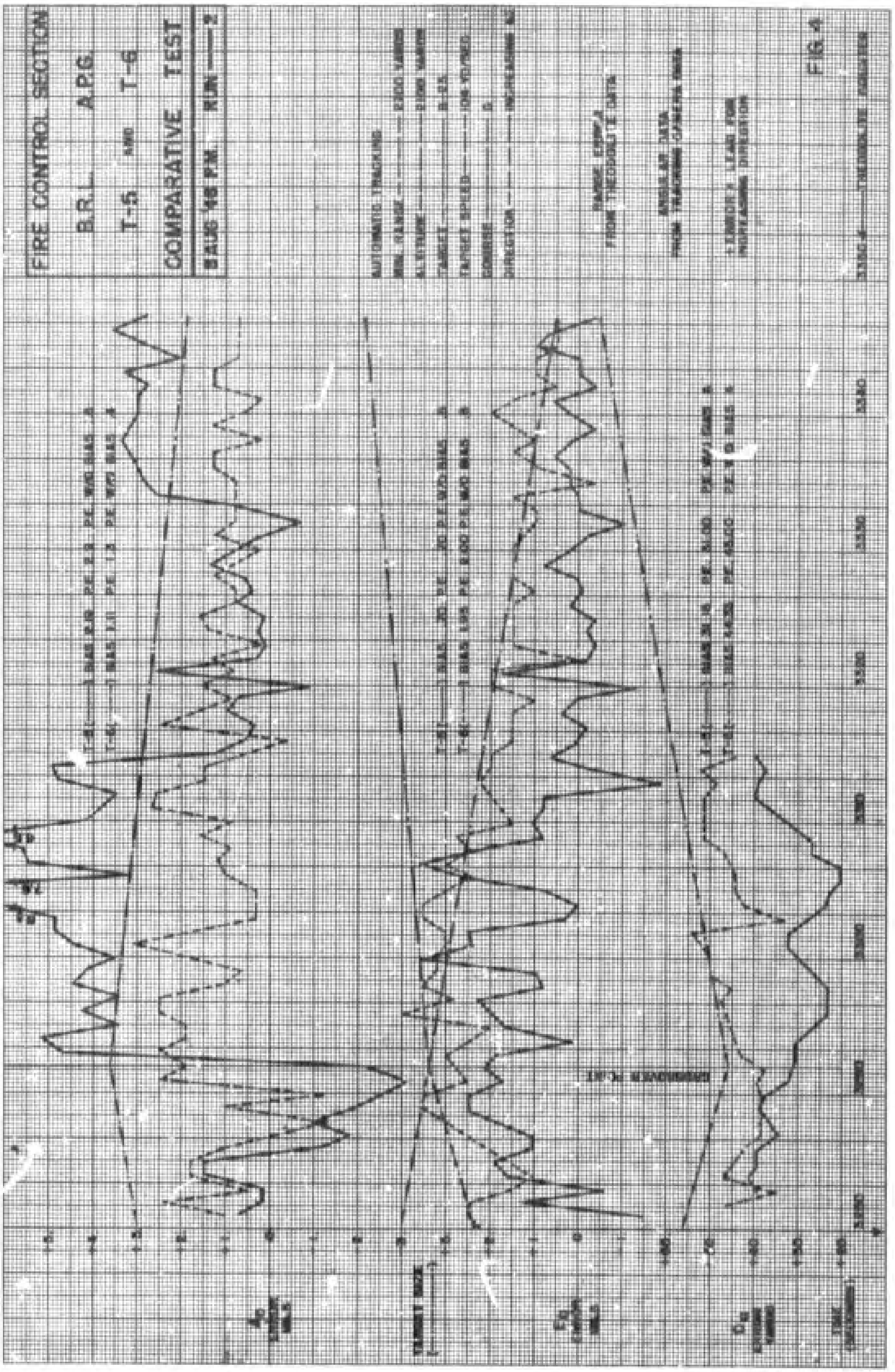

FIRE CONTROL SECTION
B.R.L. A.P.G.
T-5 AND T-6
COMPARATIVE TEST
30 JULY '46 RUN — 6

FIG. 3


FIRE CONTROL SECTION
B.R.L. A.P.G.
T-5 AND T-6
COMPARATIVE TEST
5 AUG '46 P.M. RUN — 2
AUTOMATIC TRACKING
RANGE ERROR FROM THEODOLITE DATA
ANGULAR DATA FROM TRACKING CAMERA DATA
TARGET SIZE
FIG. 4

[redacted]

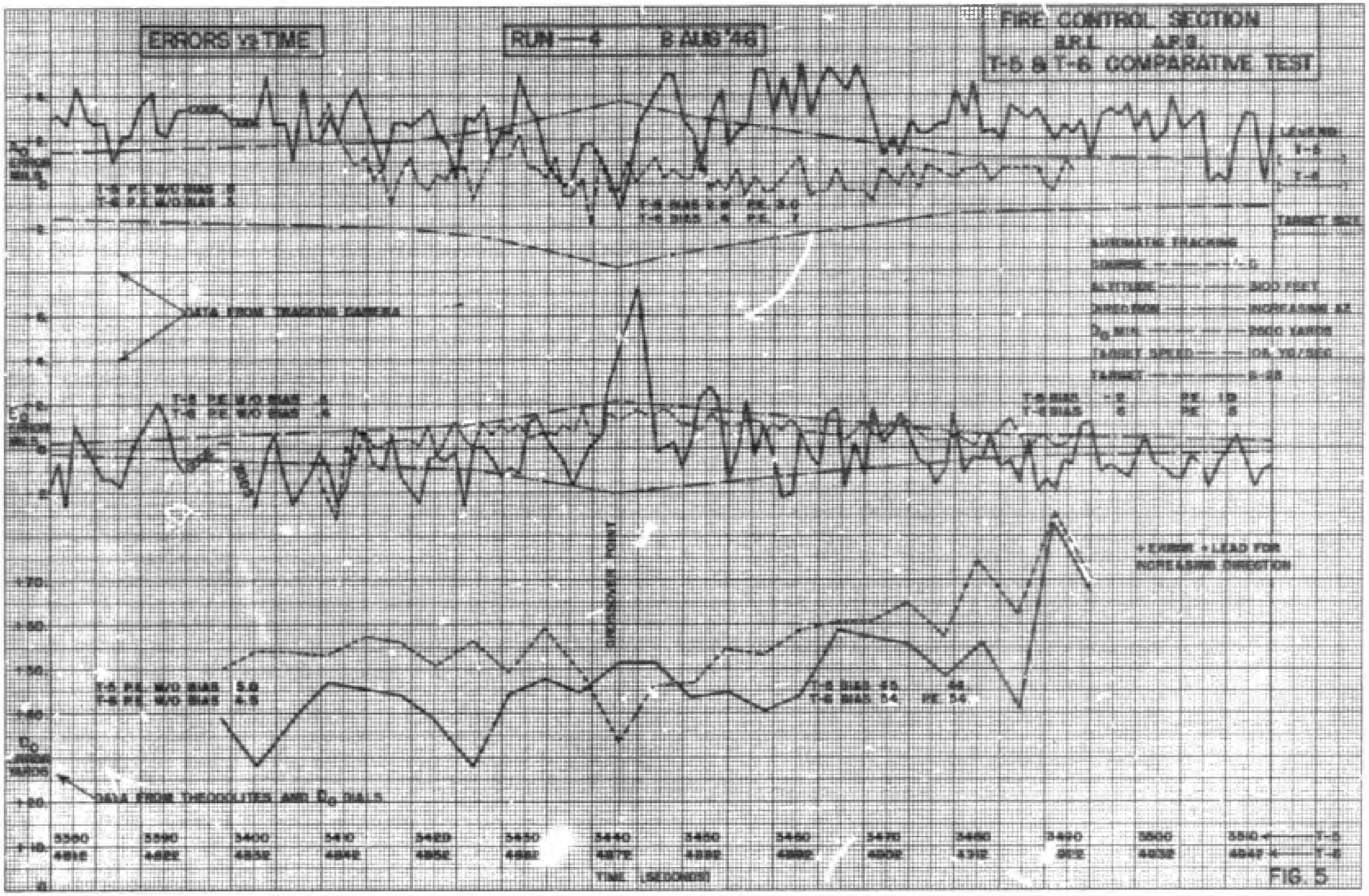


FIG. 5

[redacted]

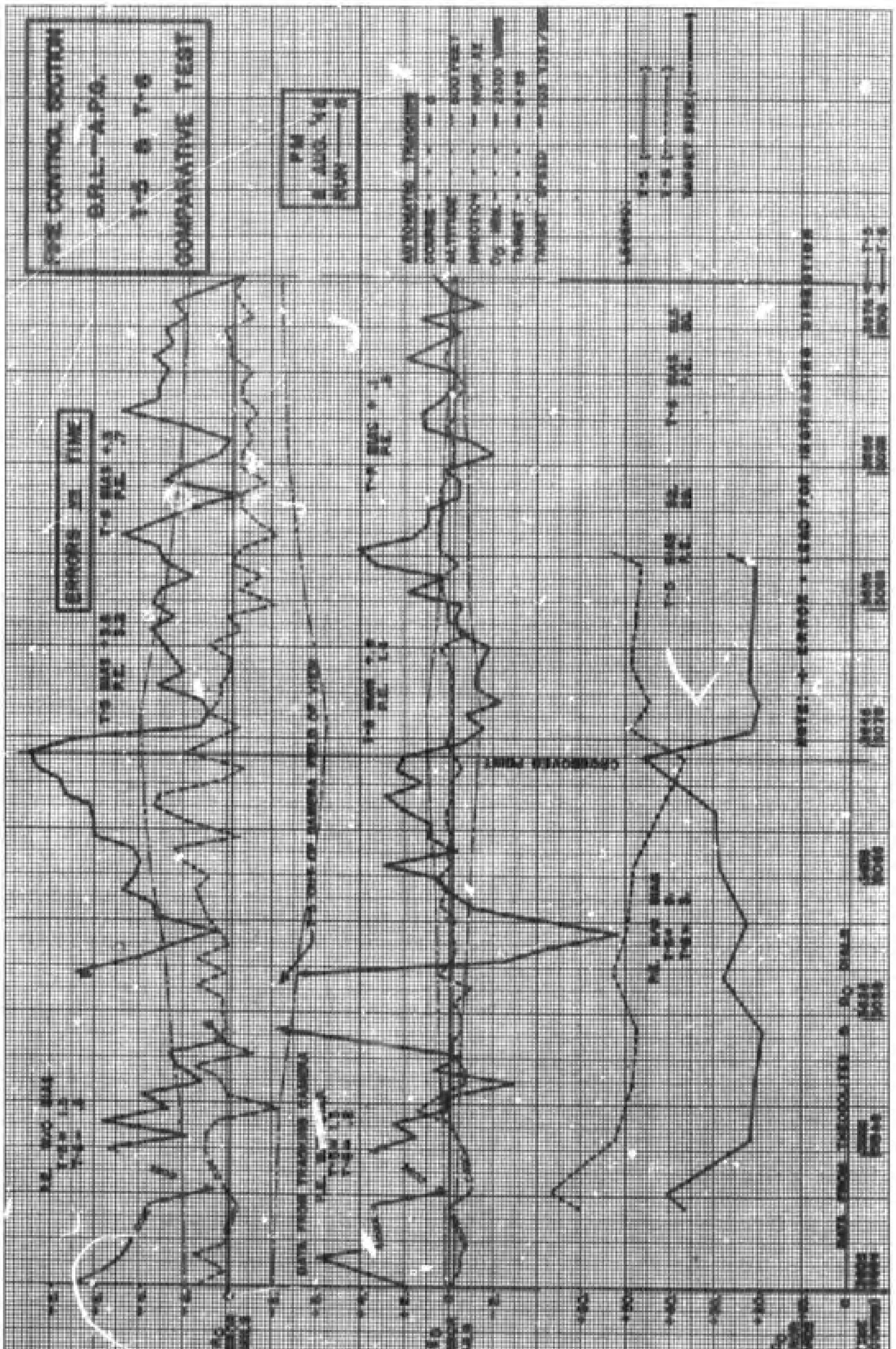

FIRE CONTROL SECTION
B.R.L.—A.P.G.
T-5 & T-6
COMPARATIVE TEST
ERRORS VS TIME
CROSSOVER POINT

FIG 6

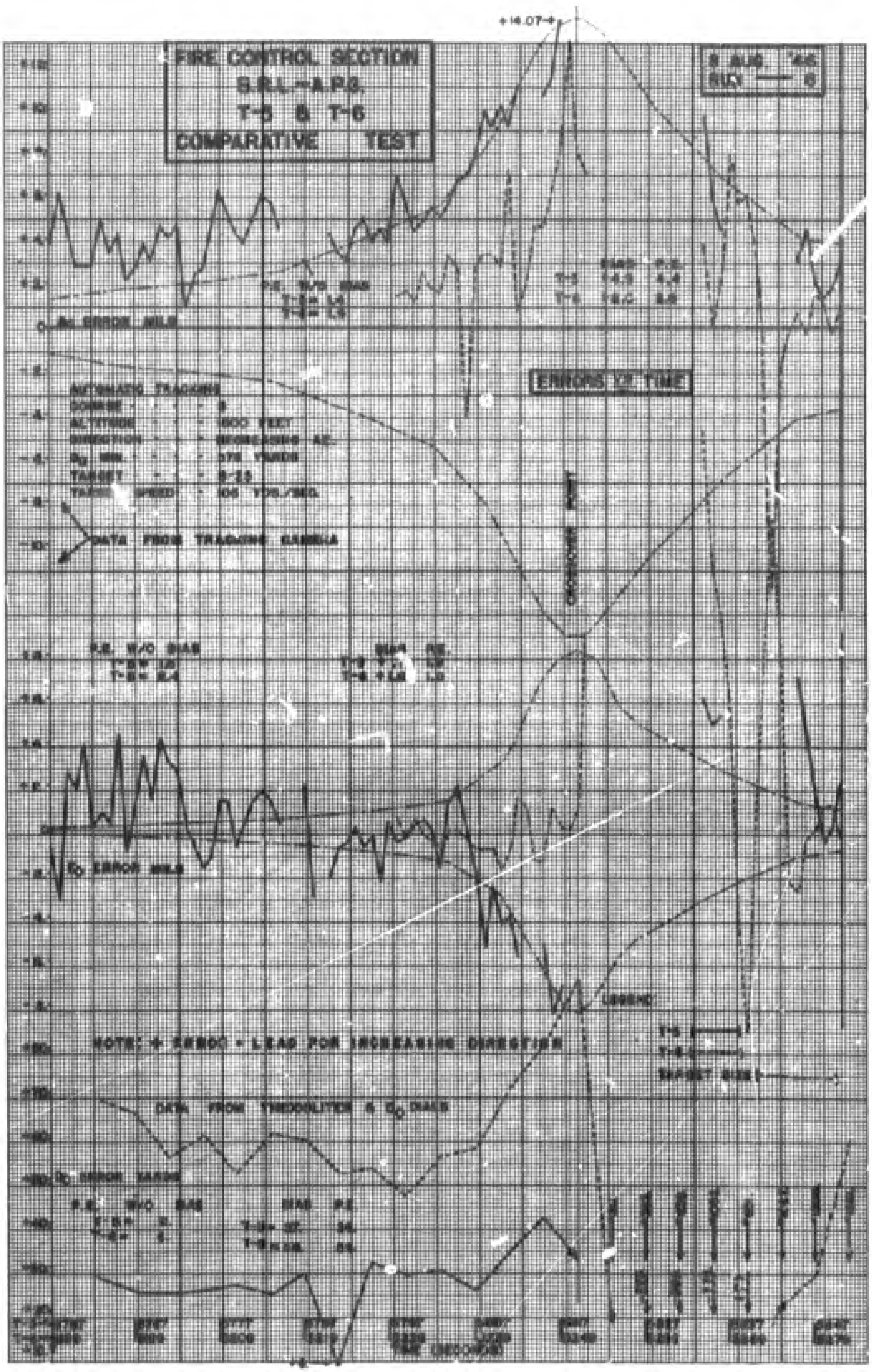

FIRE CONTROL SECTION
S.R.L.—A.P.G.
T-5 & T-6
COMPARATIVE TEST
+14.07
ERRORS VS TIME
DATA FROM TRACKING CAMERA
NOTE: + ERROR = LEAD FOR INCREASING DIRECTION

FIG 7

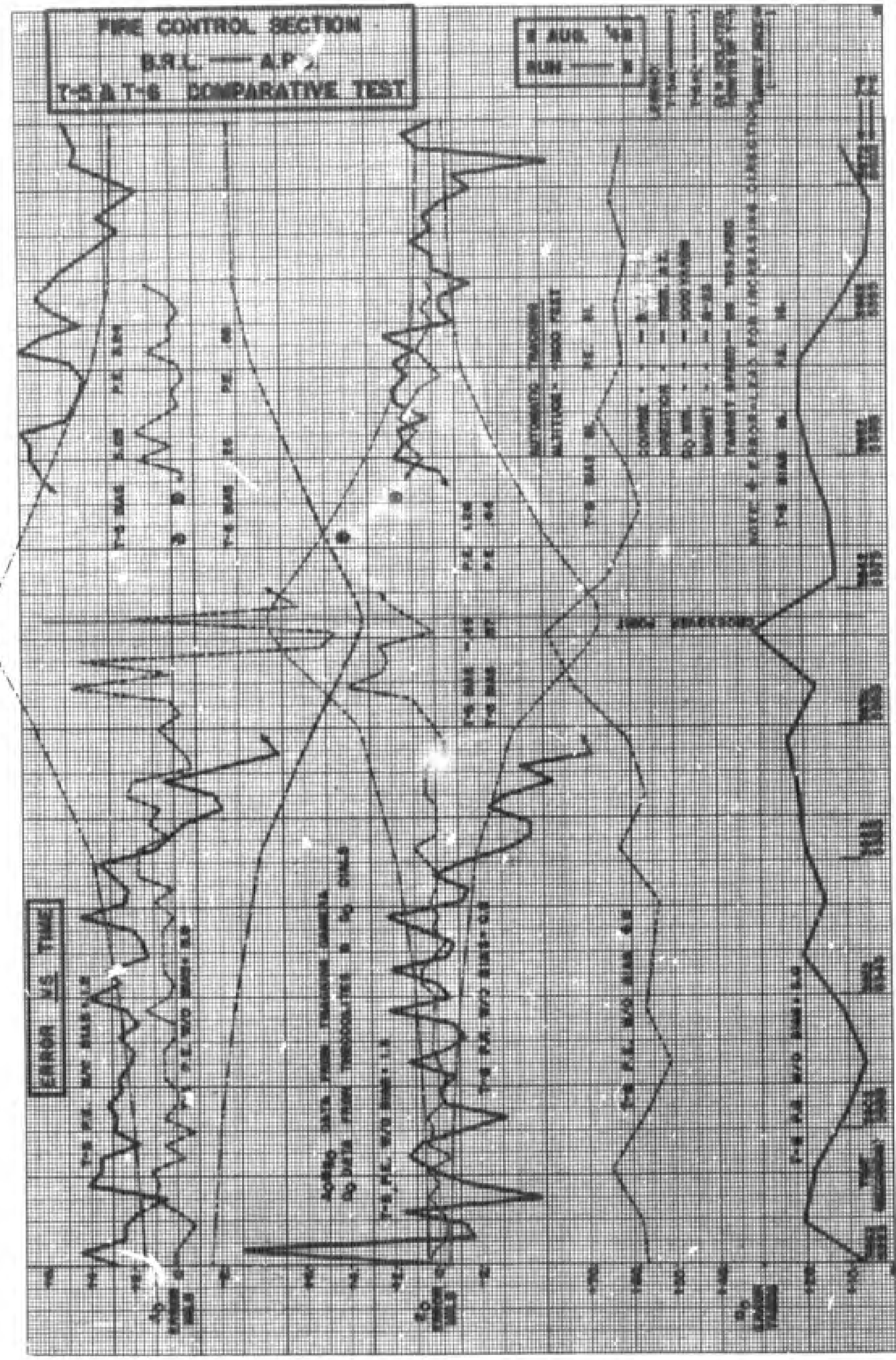

FIRE CONTROL SECTION
B.R.L. — A.P.G.
T-5 & T-6 COMPARATIVE TEST
ERROR VS TIME

FIG 8

[redacted]

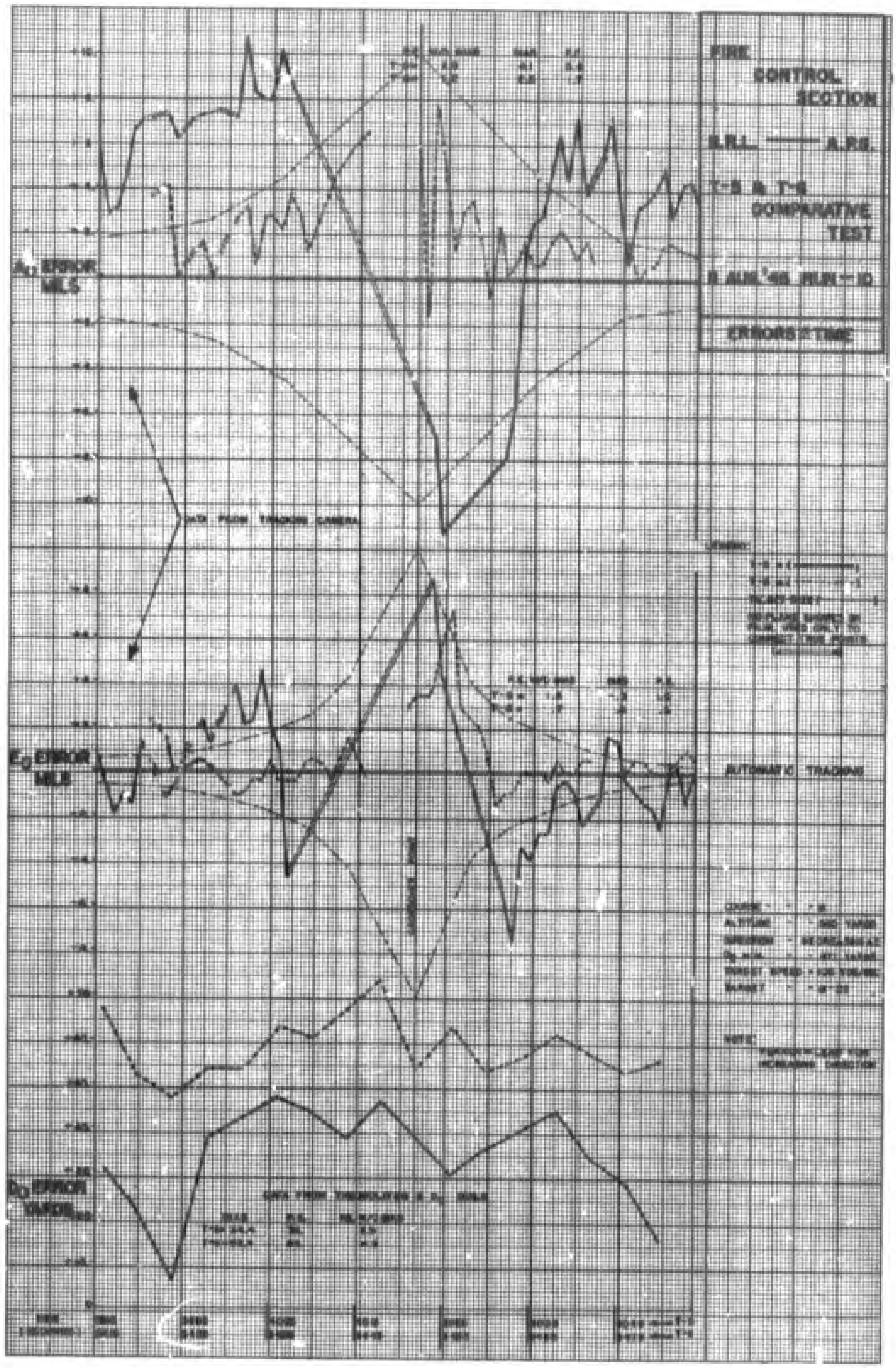


FIG 9

[redacted]

[redacted]

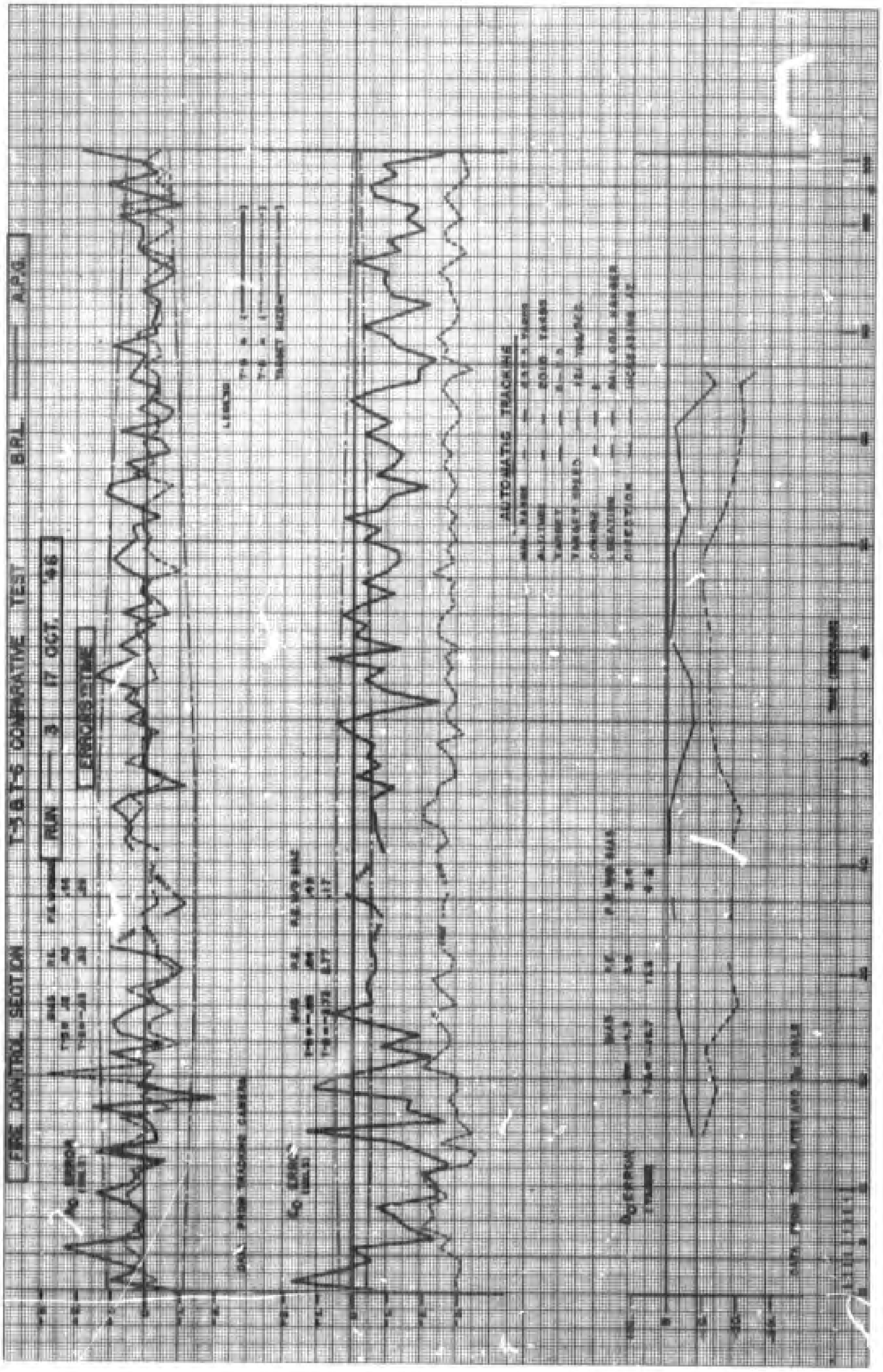


FIG. 10

[redacted]

[redacted]

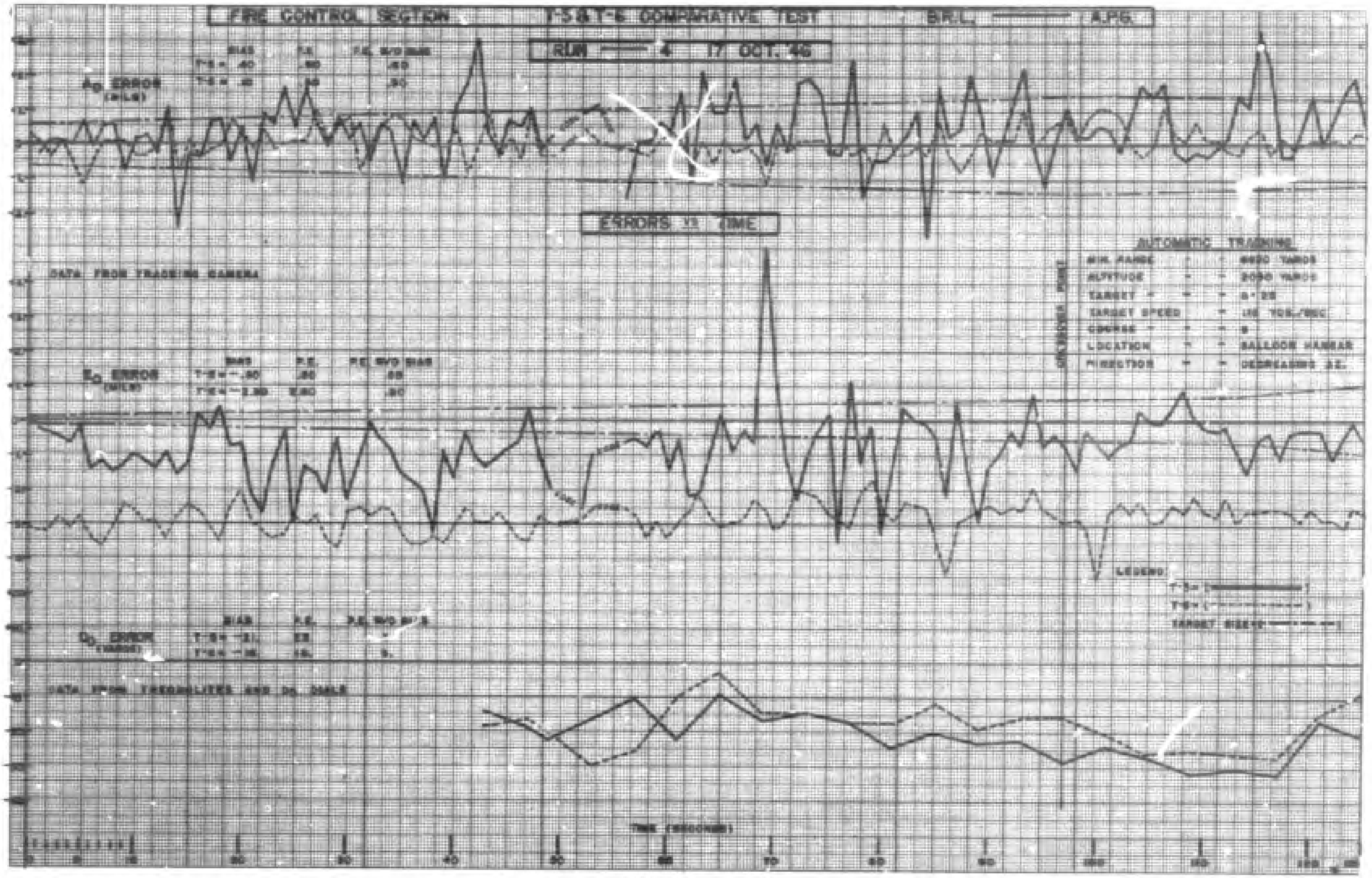


FIG. 11

[redacted]

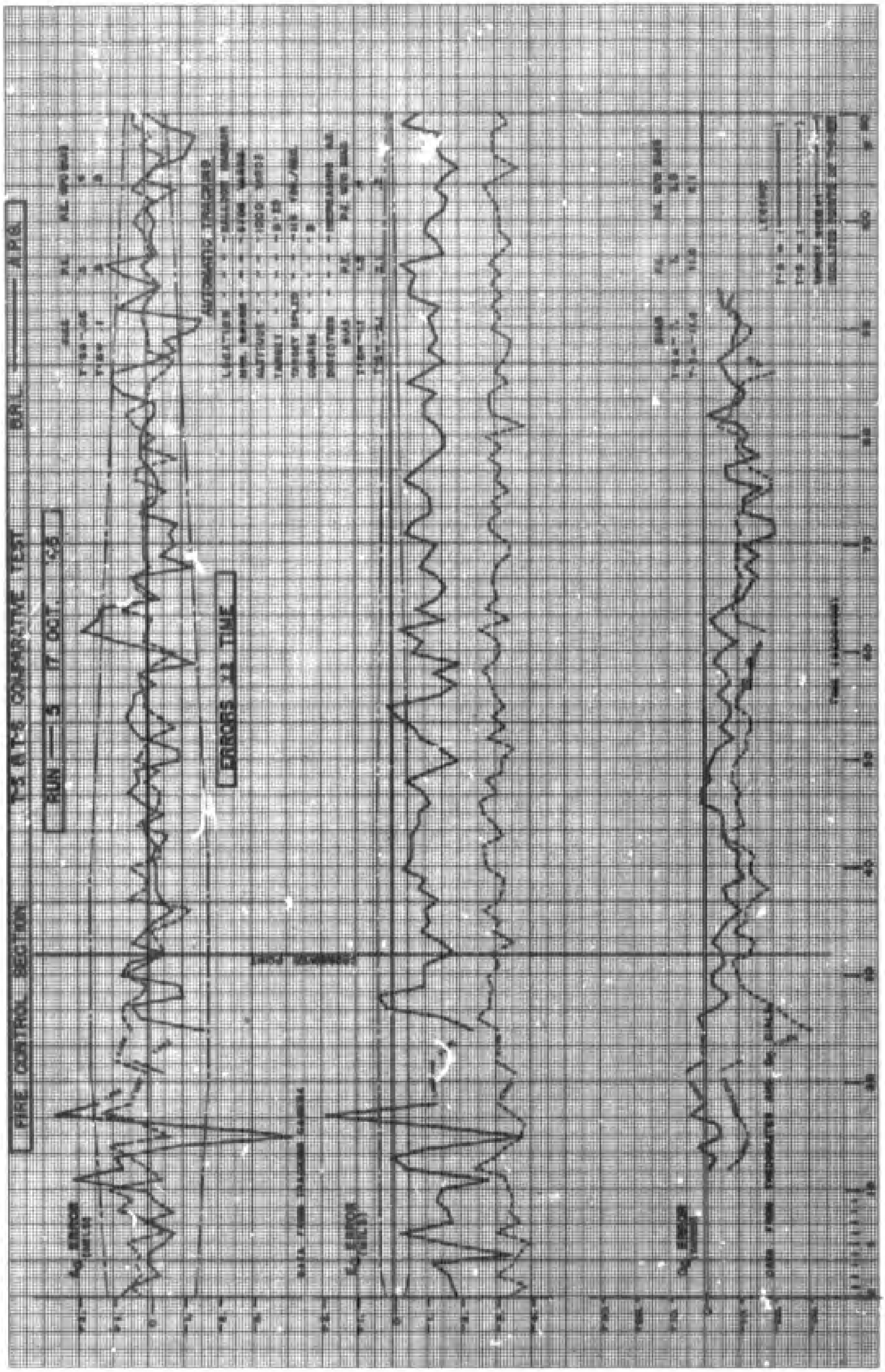


FIG 12

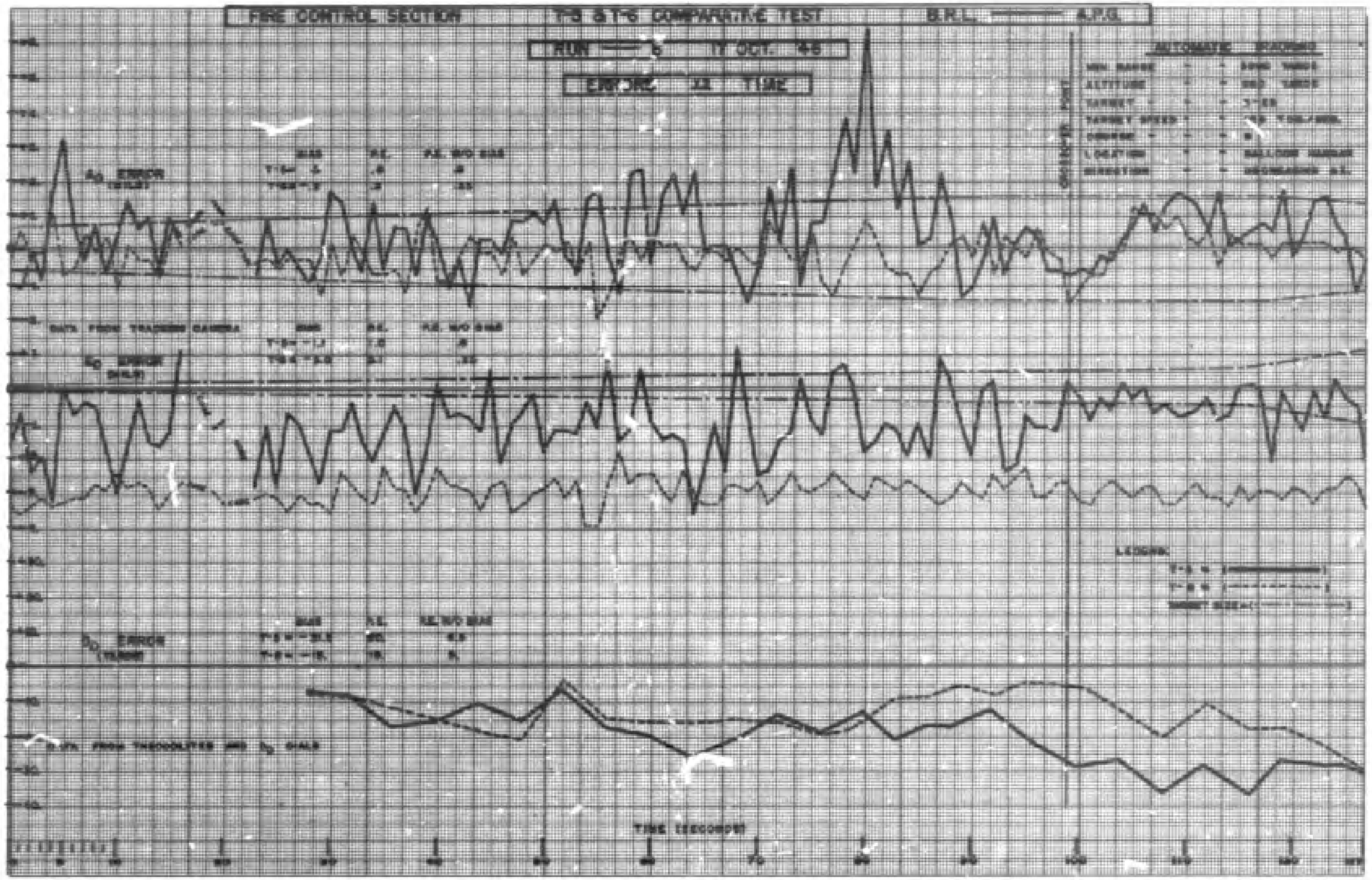

FIRE CONTROL SECTION
COMPARATIVE TEST
B.R.L.
A.P.G.
TIME (SECONDS)

FIG 13

[redacted]

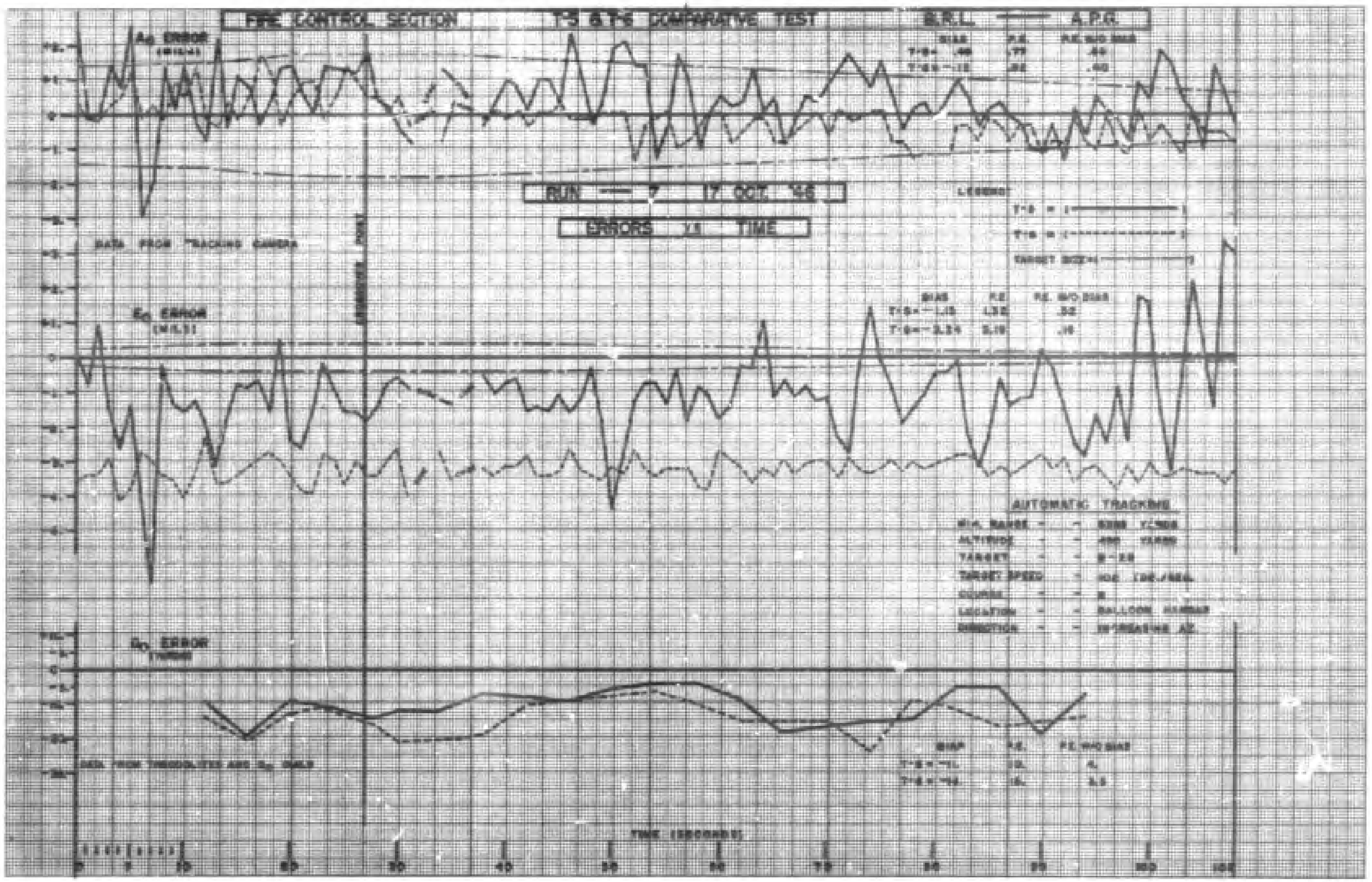


FIG 14

[redacted]

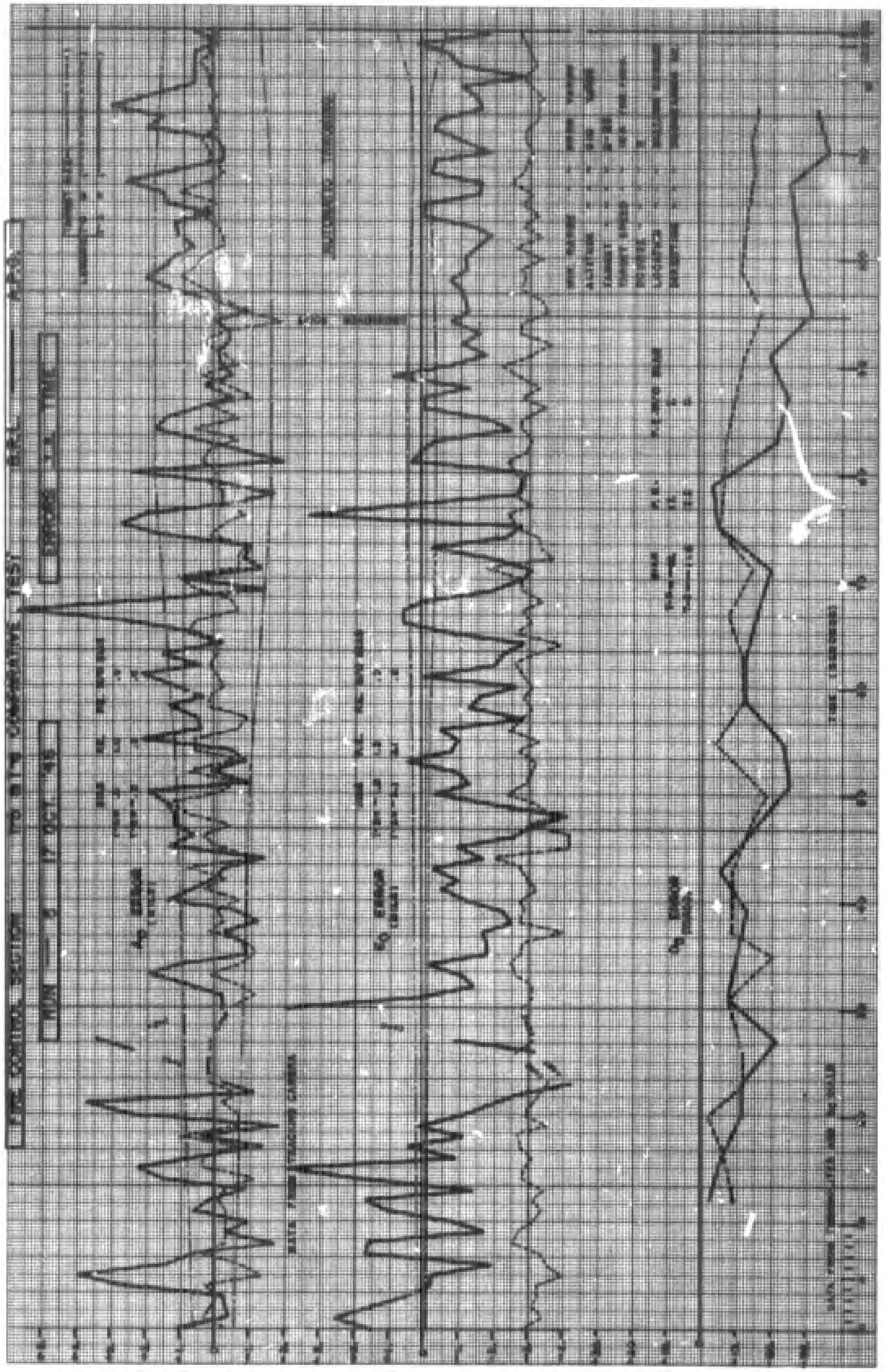


FIG 15

[redacted]

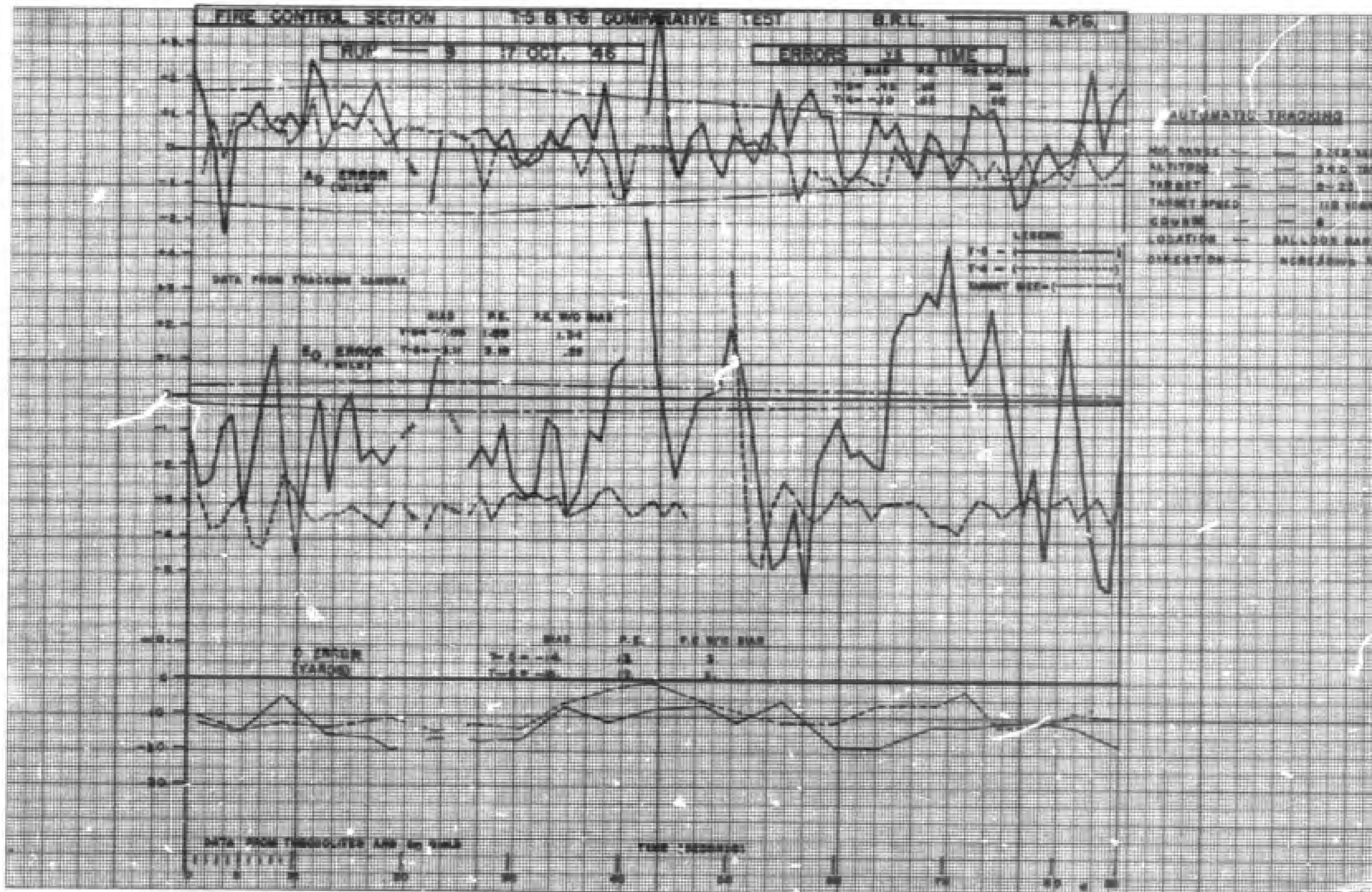


FIG 16

[redacted]

[redacted]

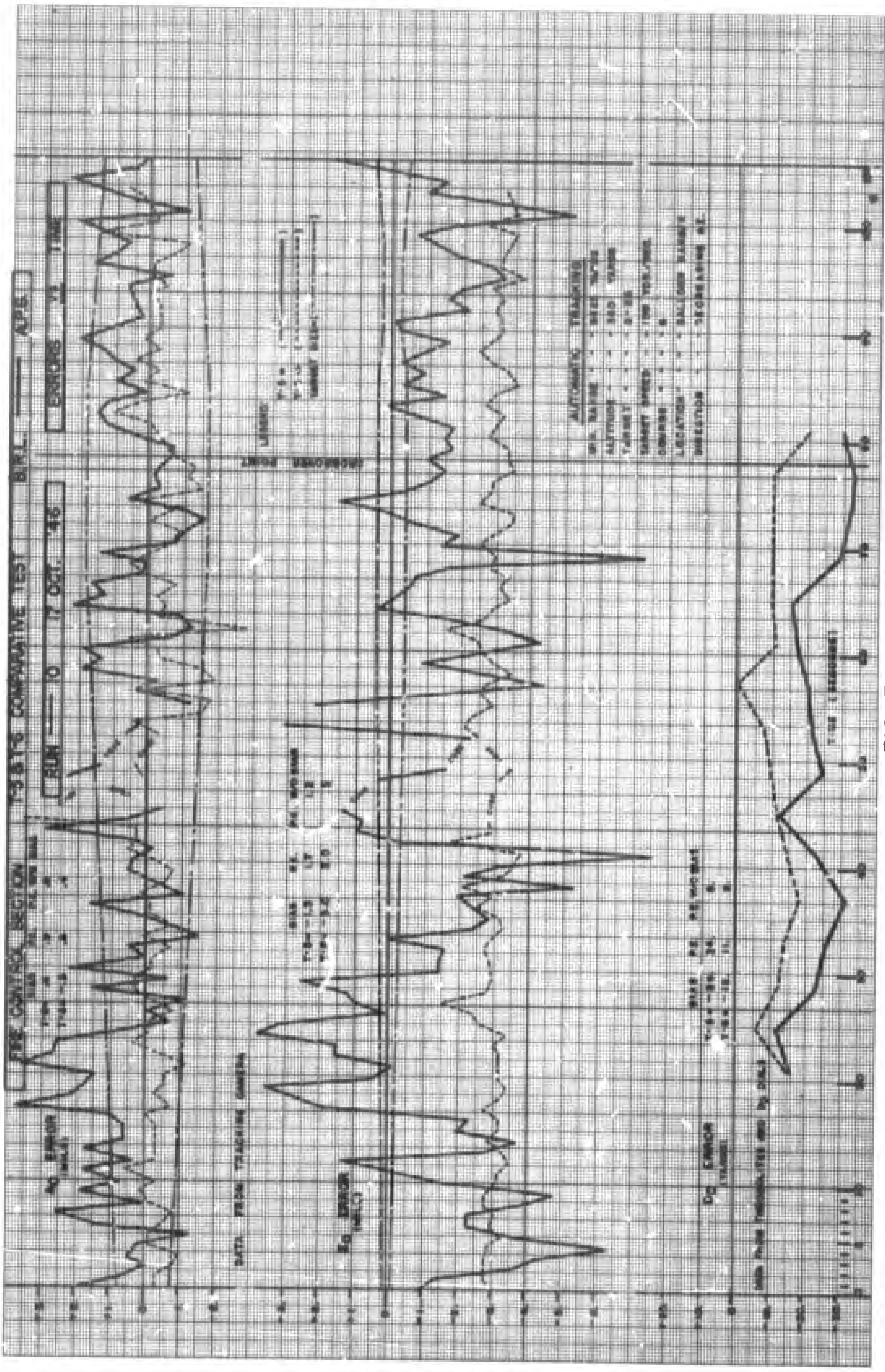


FIG 17

[redacted]

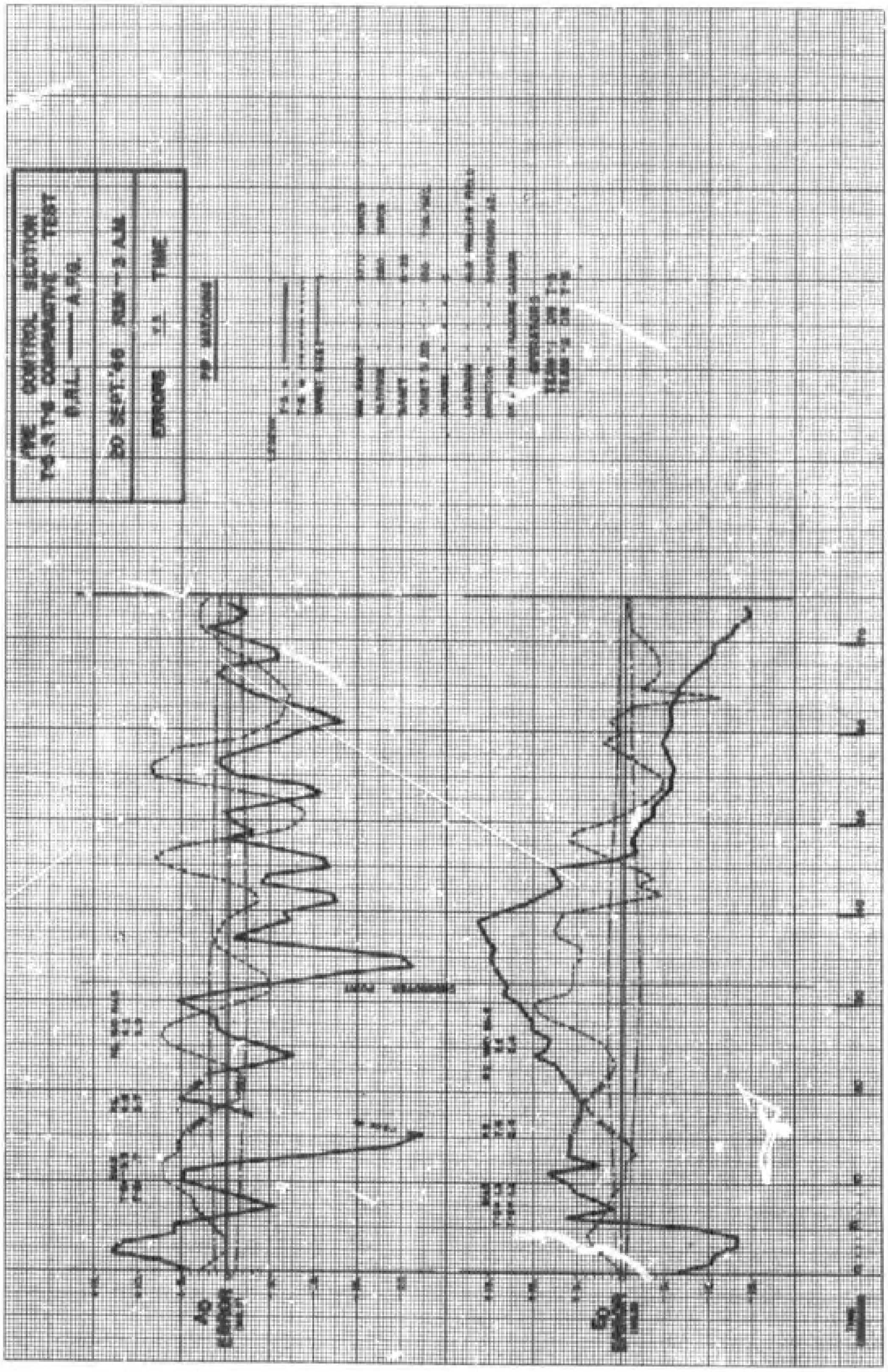


FIG 18

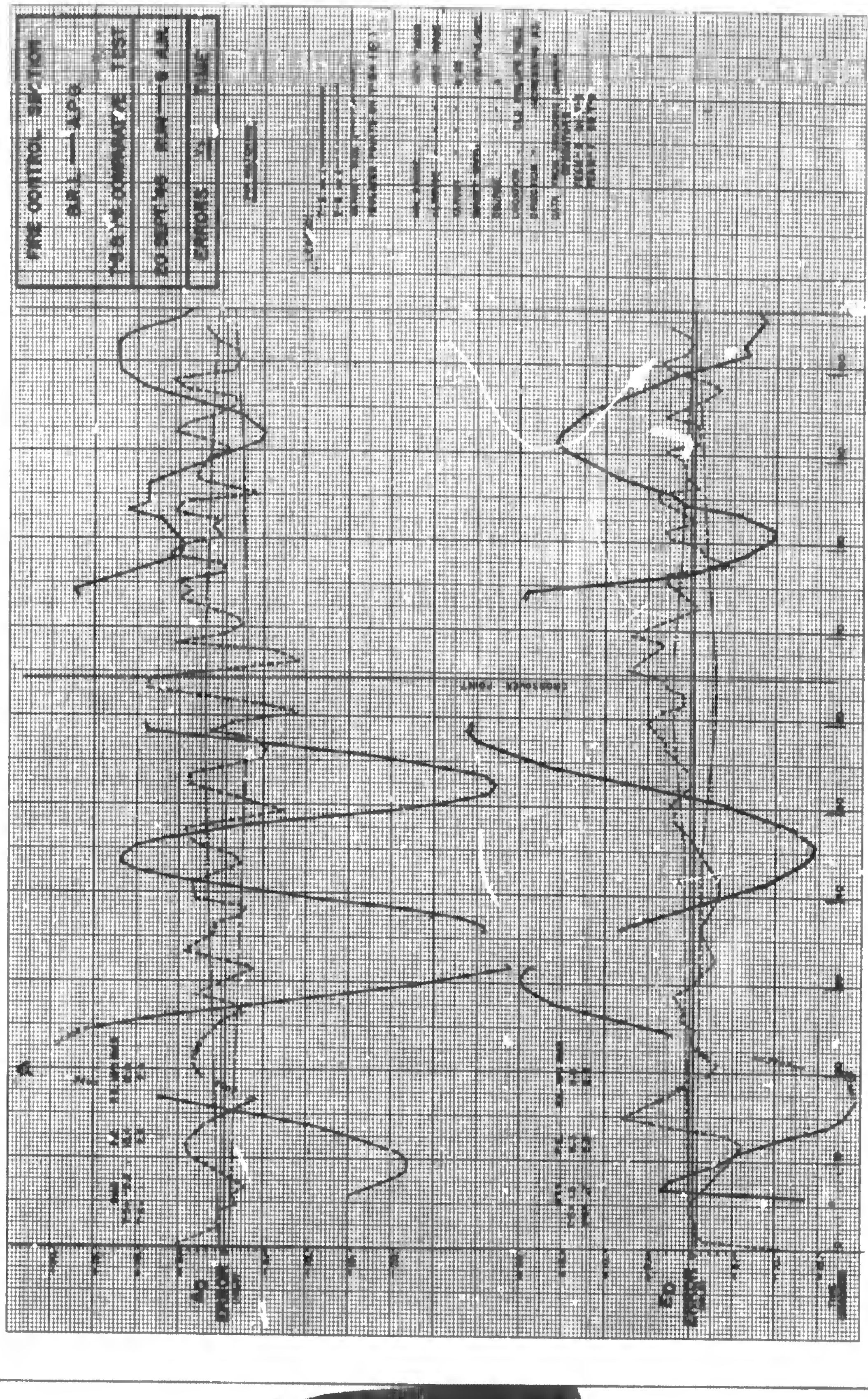


FIG 19

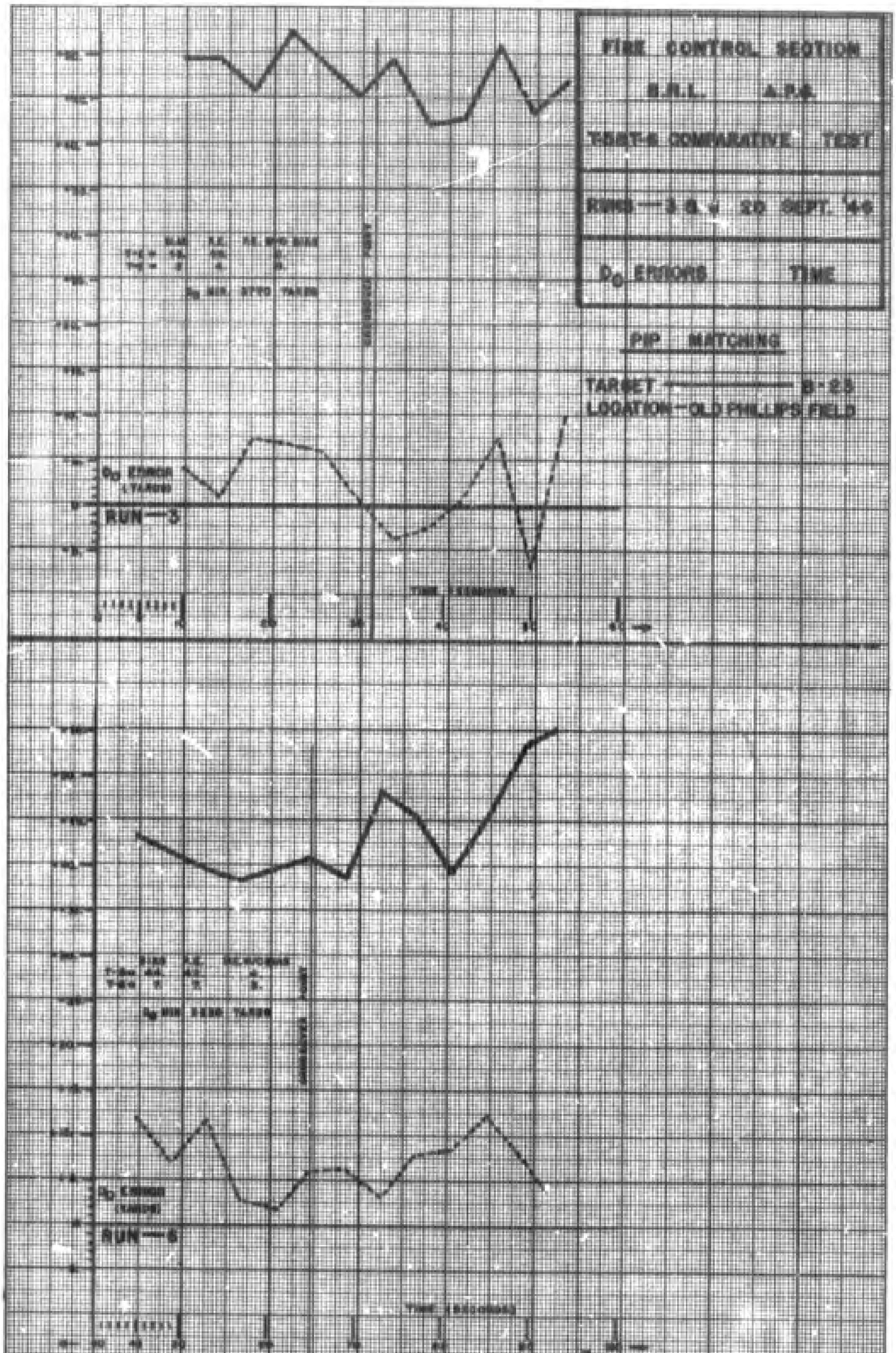

FIRE CONTROL SECTION
D_0 ERRORS TIME
PIP MATCHING
TARGET
LOCATION—OLD PHILLIPS FIELD
RUN—3

FIG 20

[redacted]

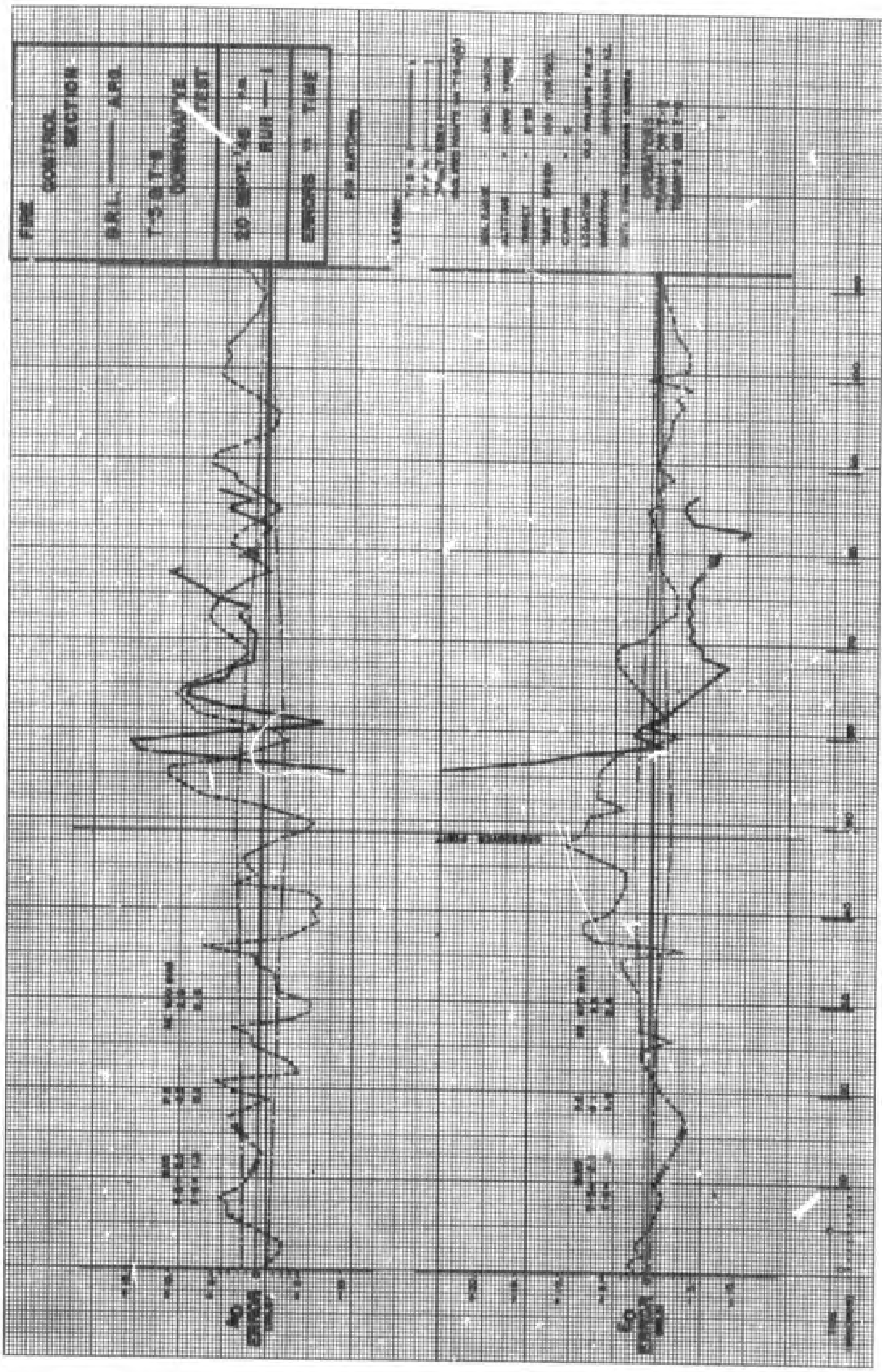


FIG 21

[redacted]

[redacted]

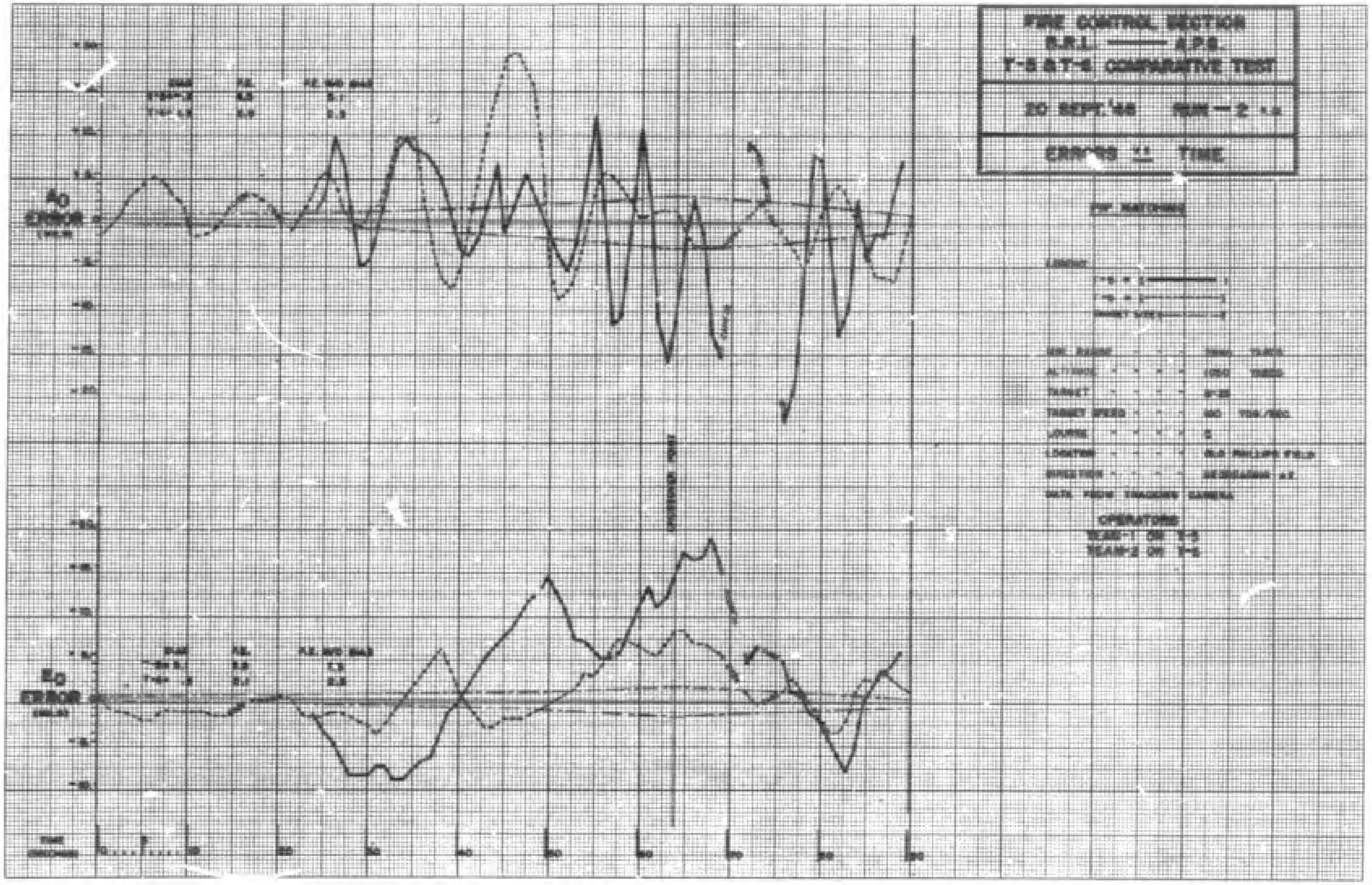


FIG 22

[redacted]

[redacted]

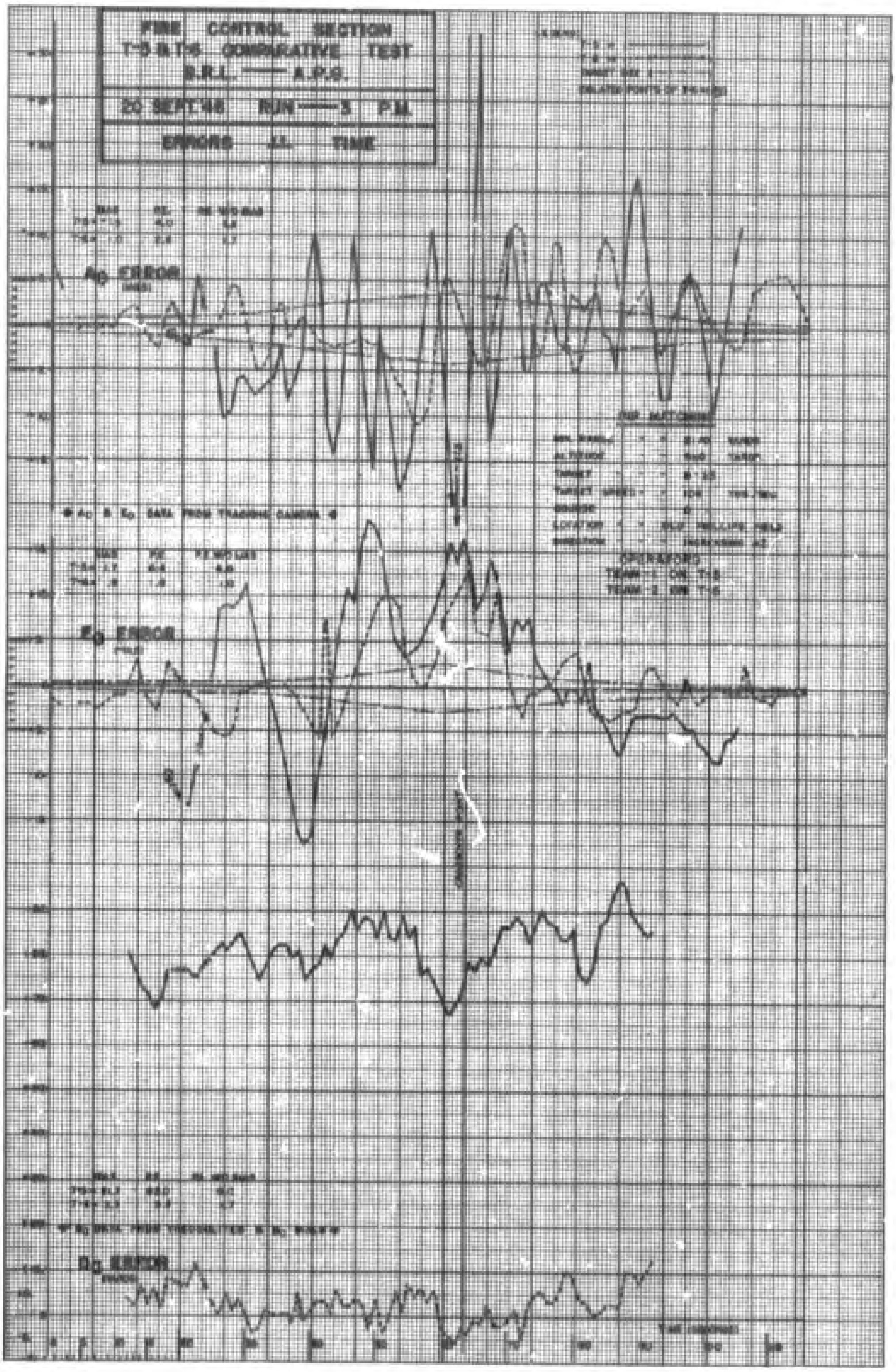


FIG 23

[redacted]

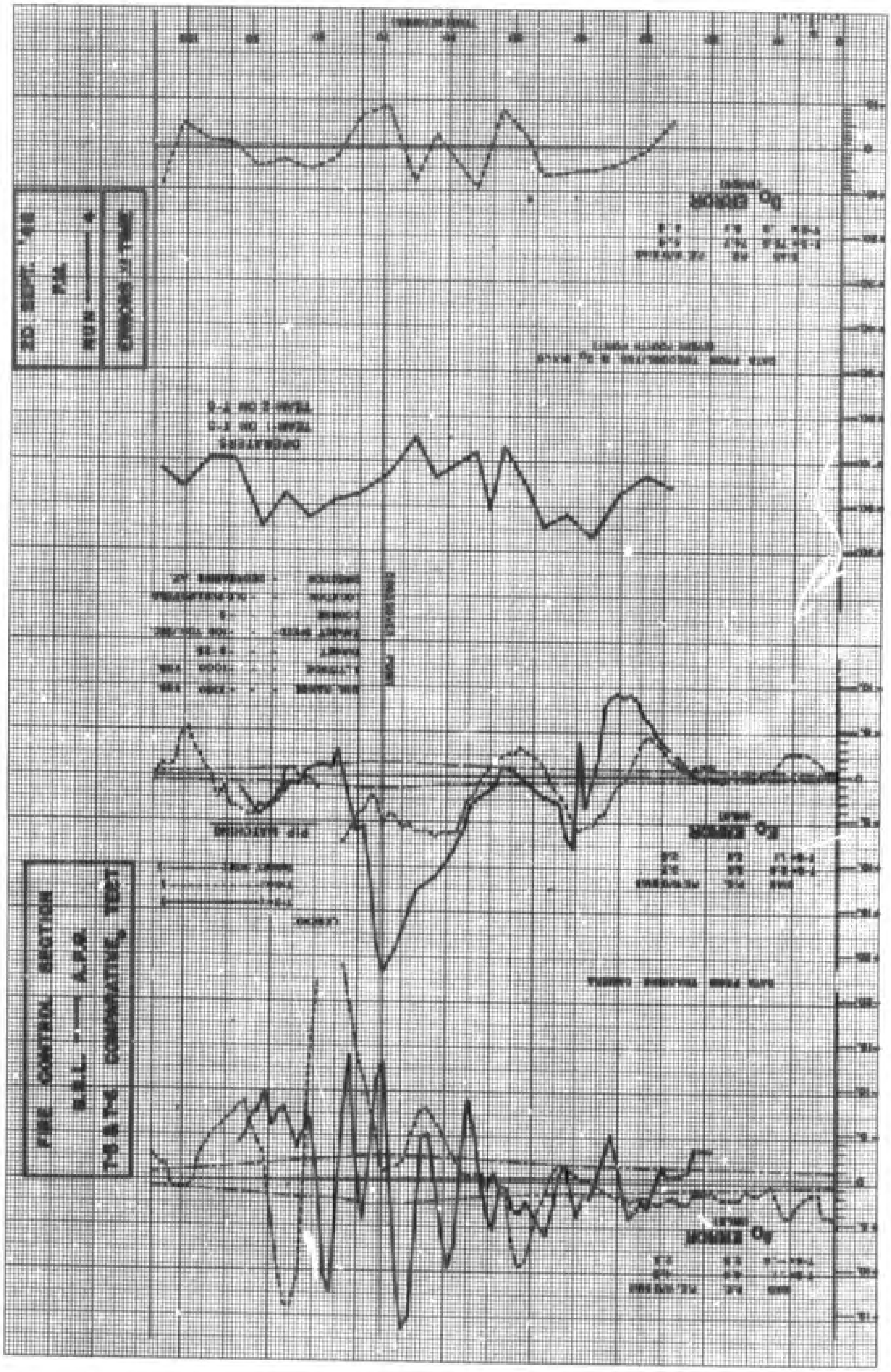


FIG 24

[redacted]

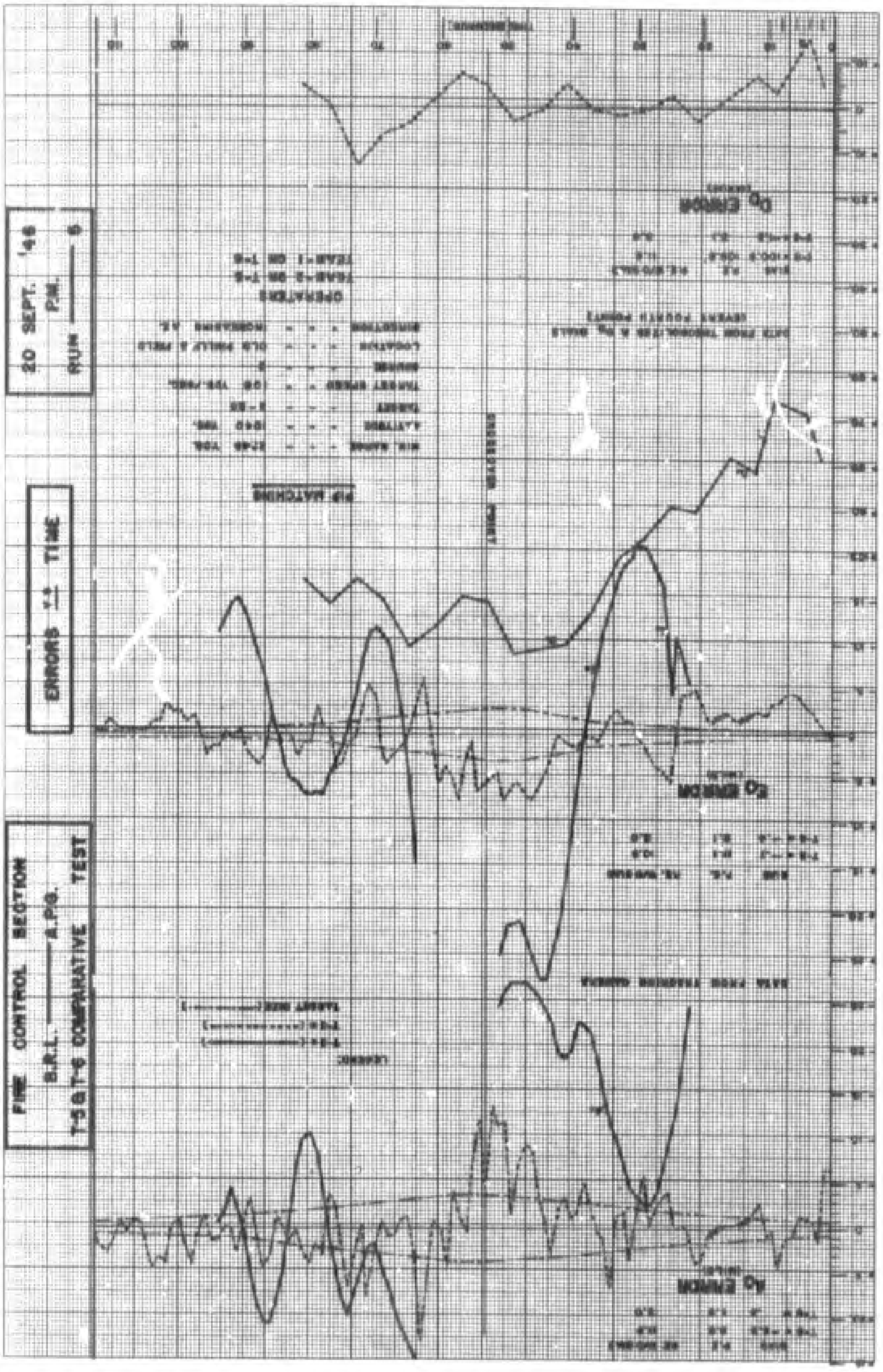


FIG 25

[redacted]

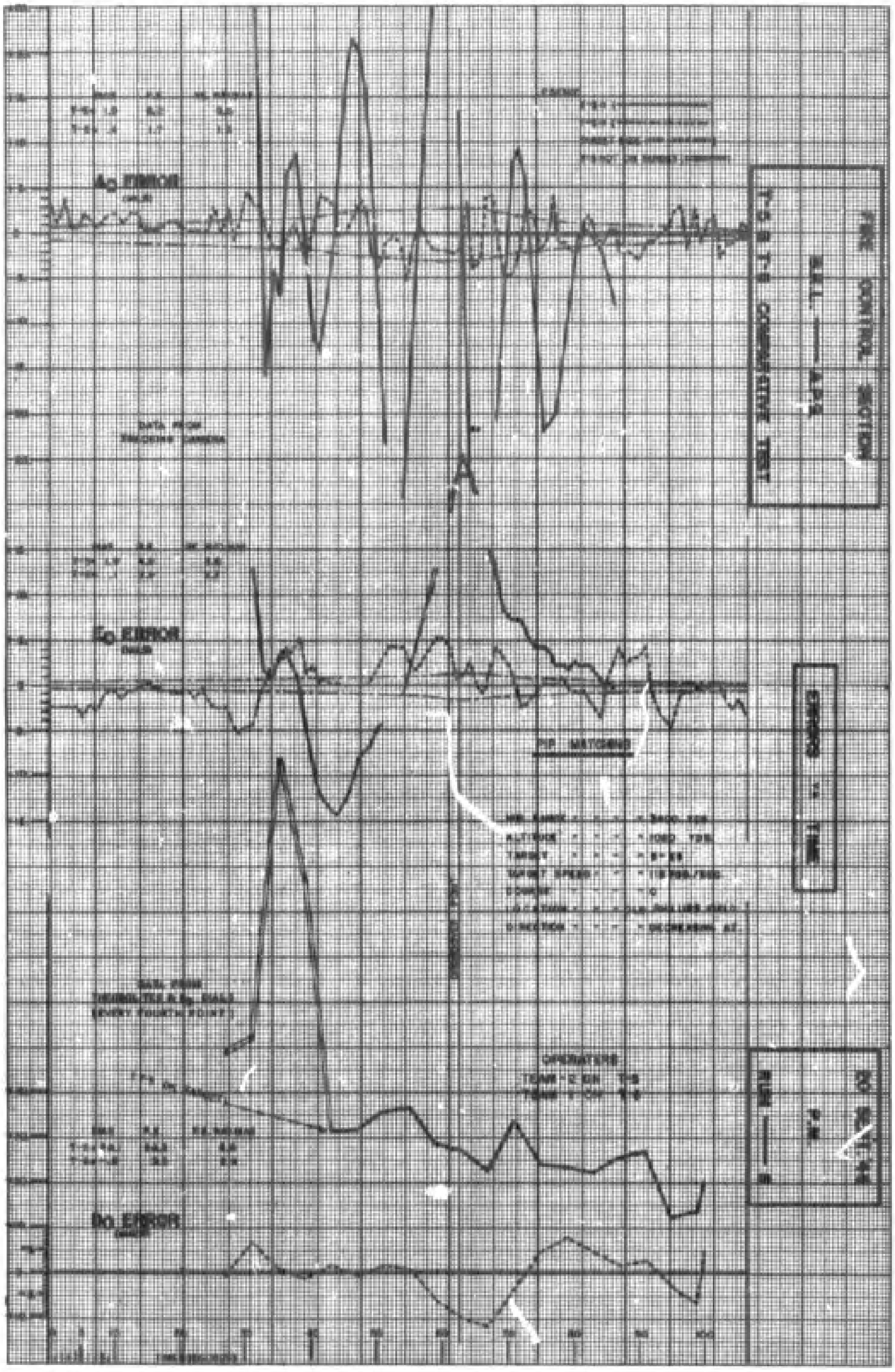

FIRE CONTROL SECTION
T-5 & T-6 COMPARATIVE TEST
ERRORS VS TIME
PIP MATCHING
OPERATORS
DATA FROM TRACKING CAMERA

FIG 26

[redacted]

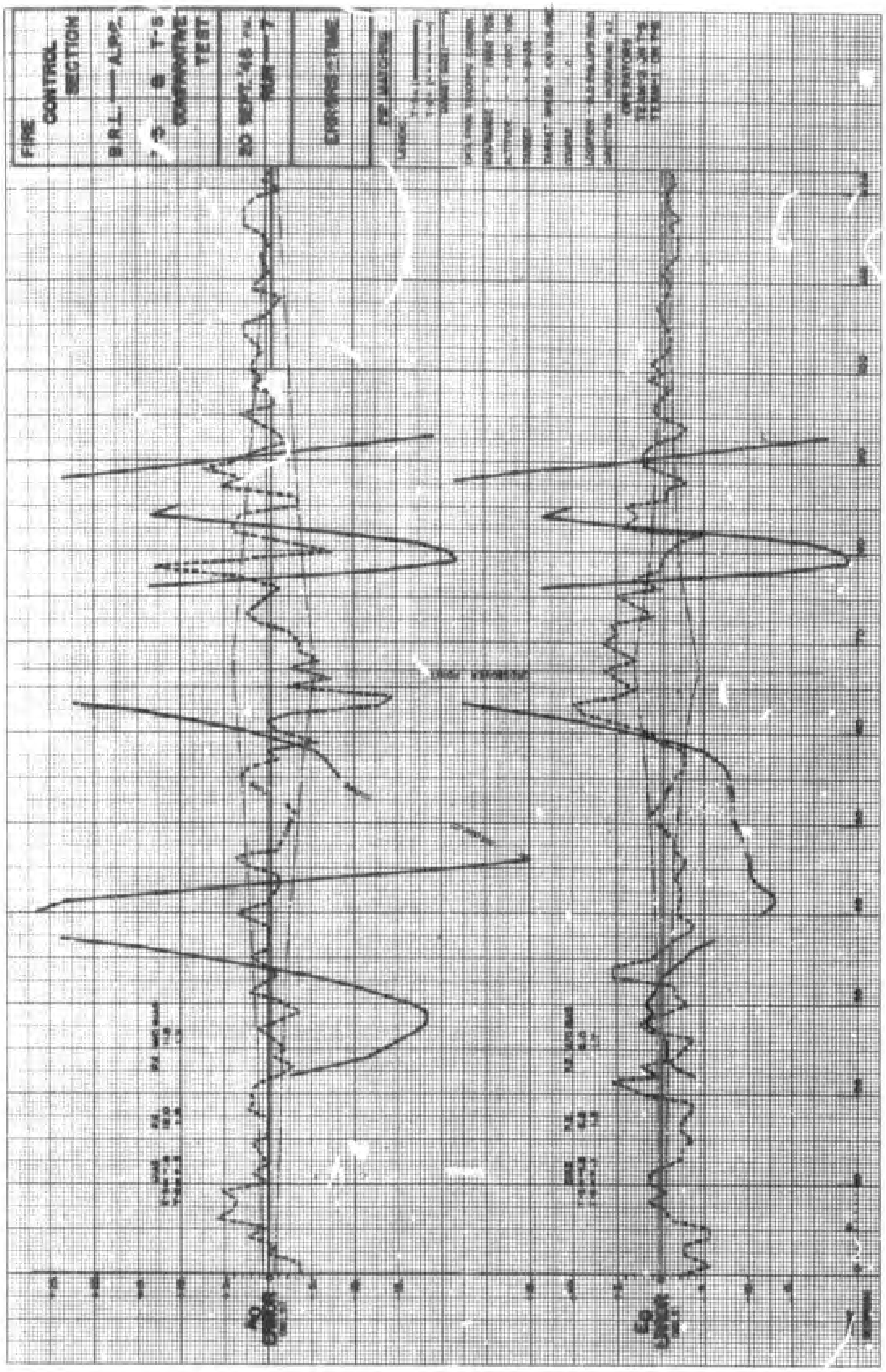


FIG 27

[redacted]

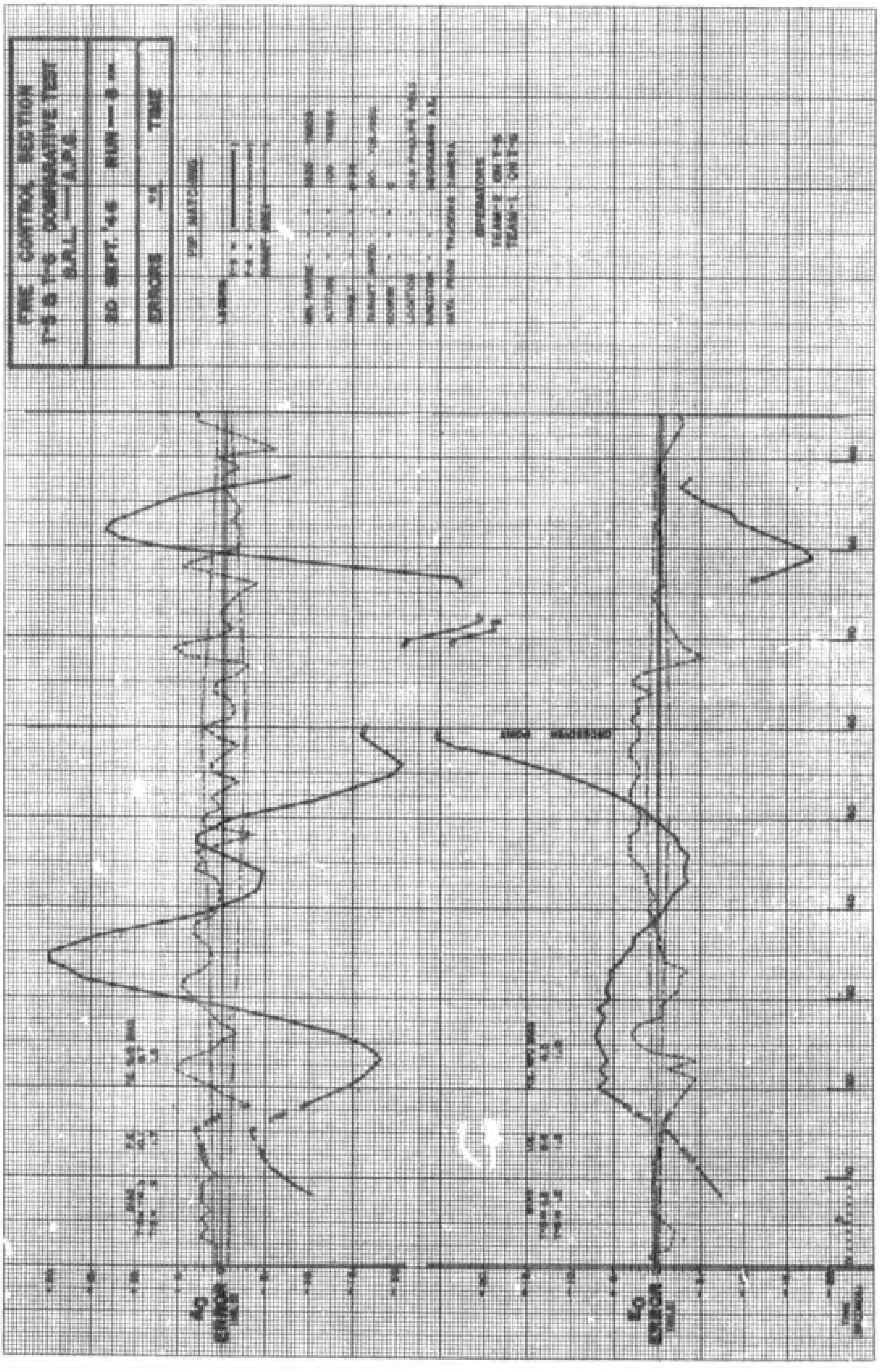


FIG 28

[redacted]

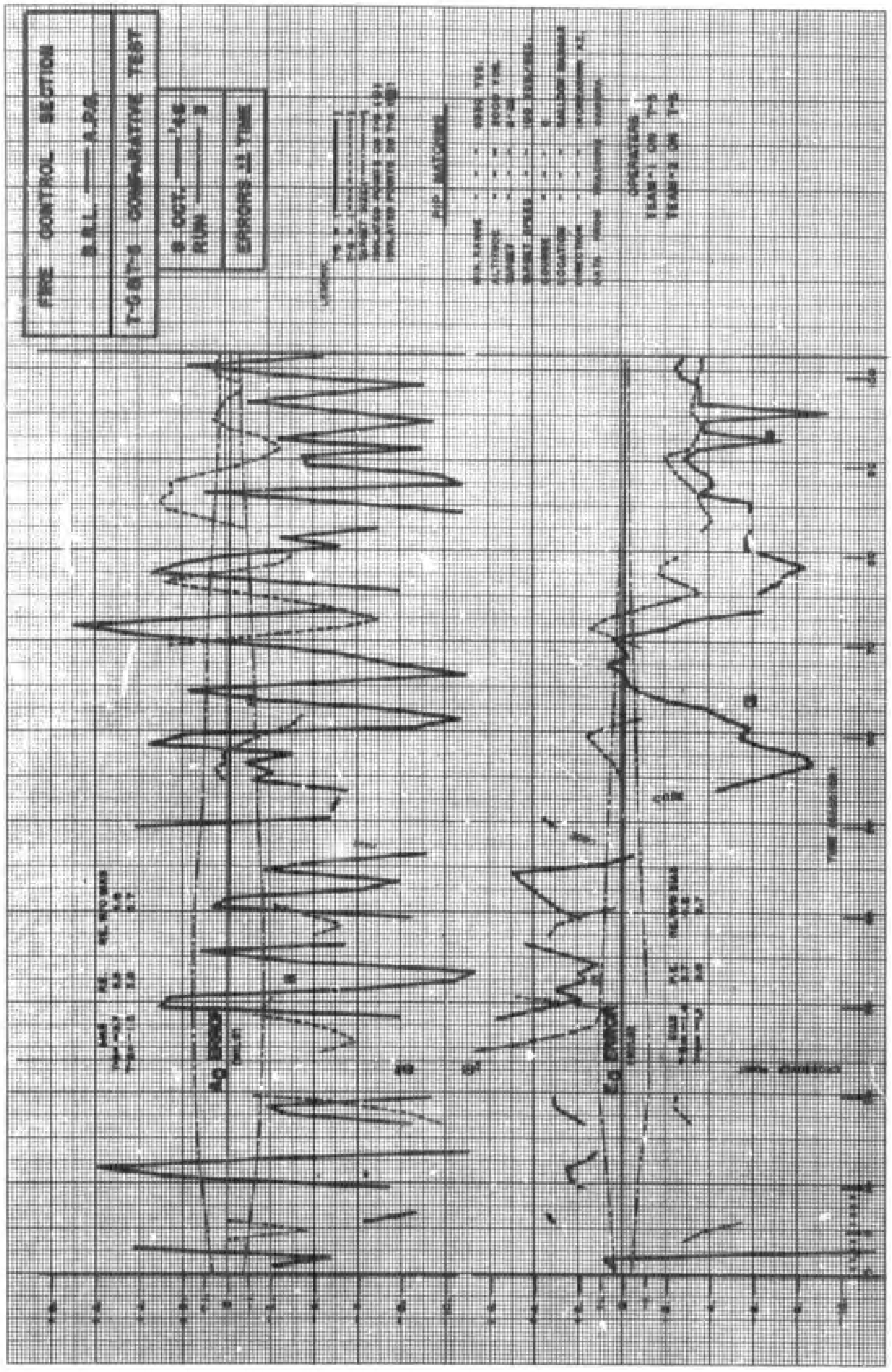


FIG 29

[redacted]

[redacted]

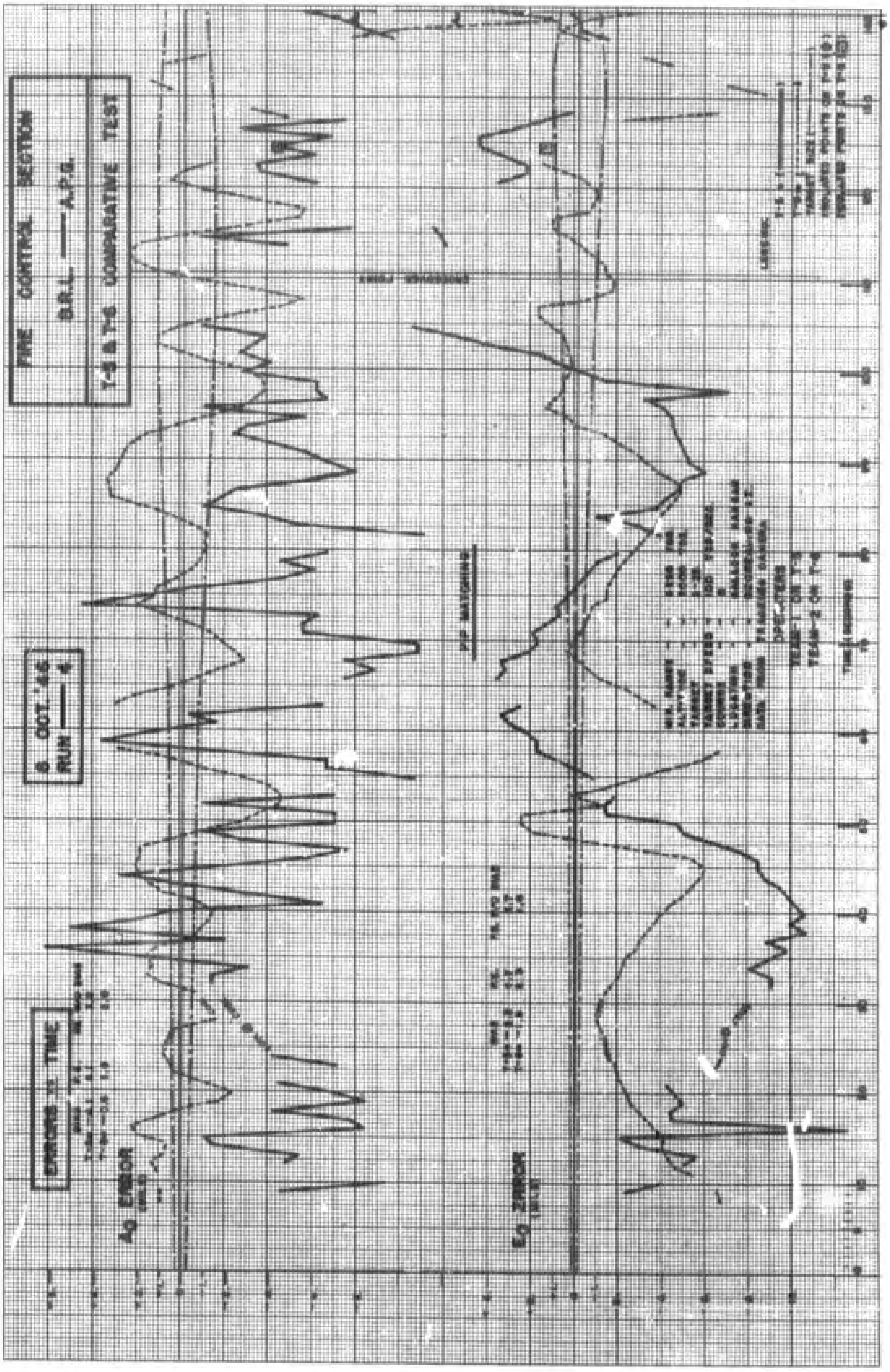


FIG 30

[redacted]

[redacted]

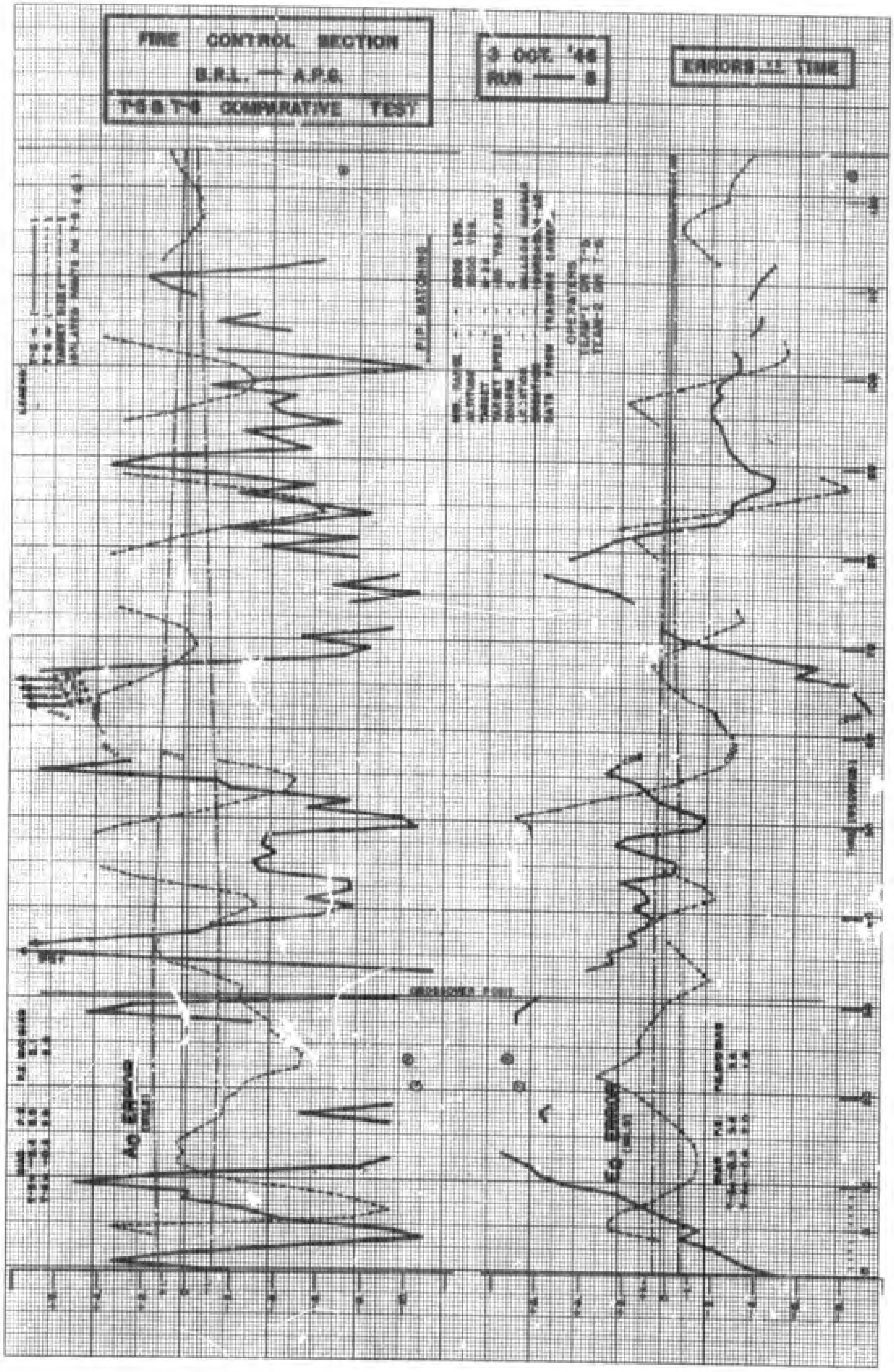


FIG 31

[redacted]

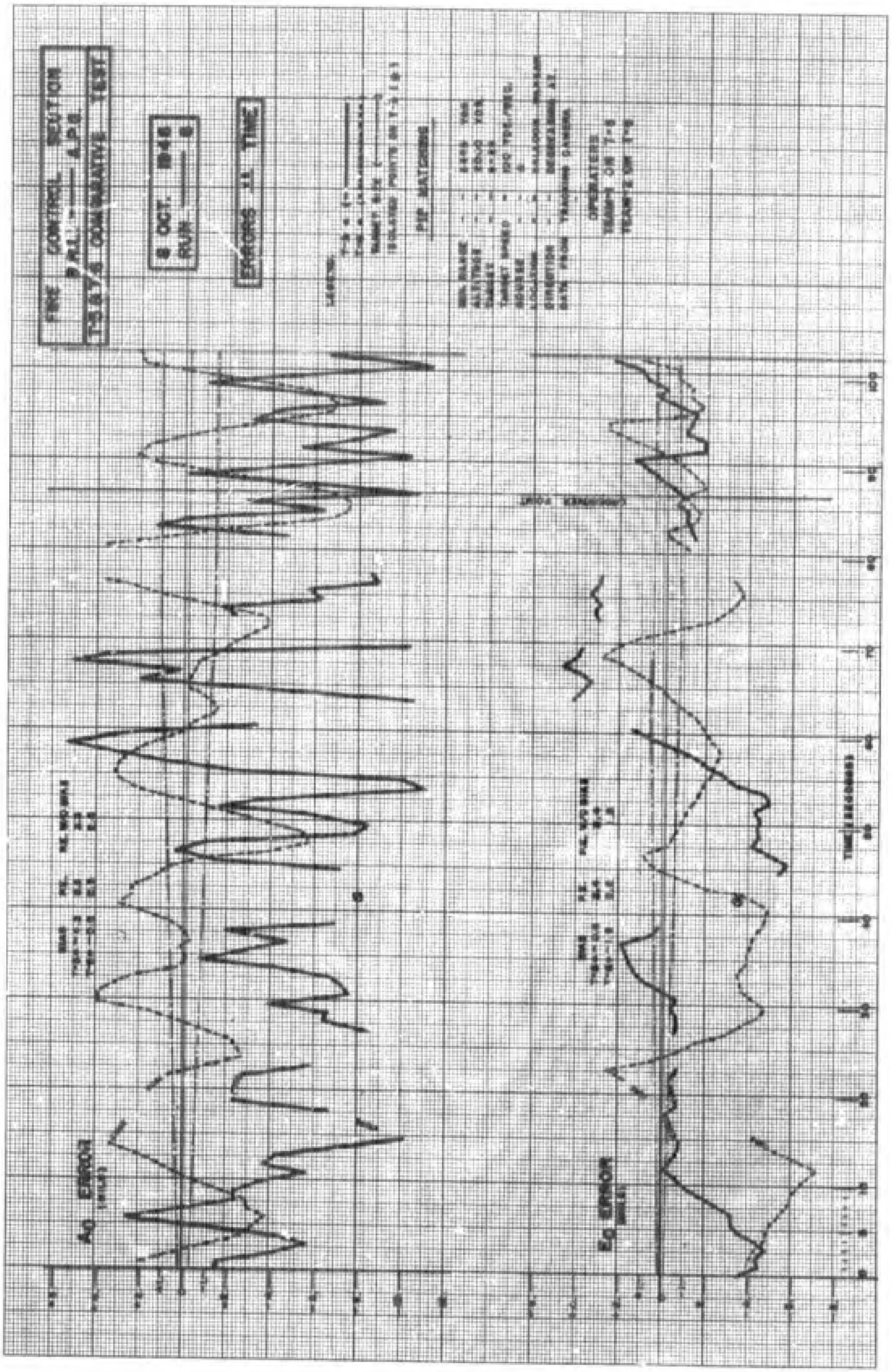

FIRE CONTROL SECTION
TS-8 T/S COMPARATIVE TEST
8 OCT. 1948
ERRORS VS TIME
PIP MATCHING
OPERATORS
Ao ERROR
Eo ERROR
TIME (SECONDS)

FIG 32

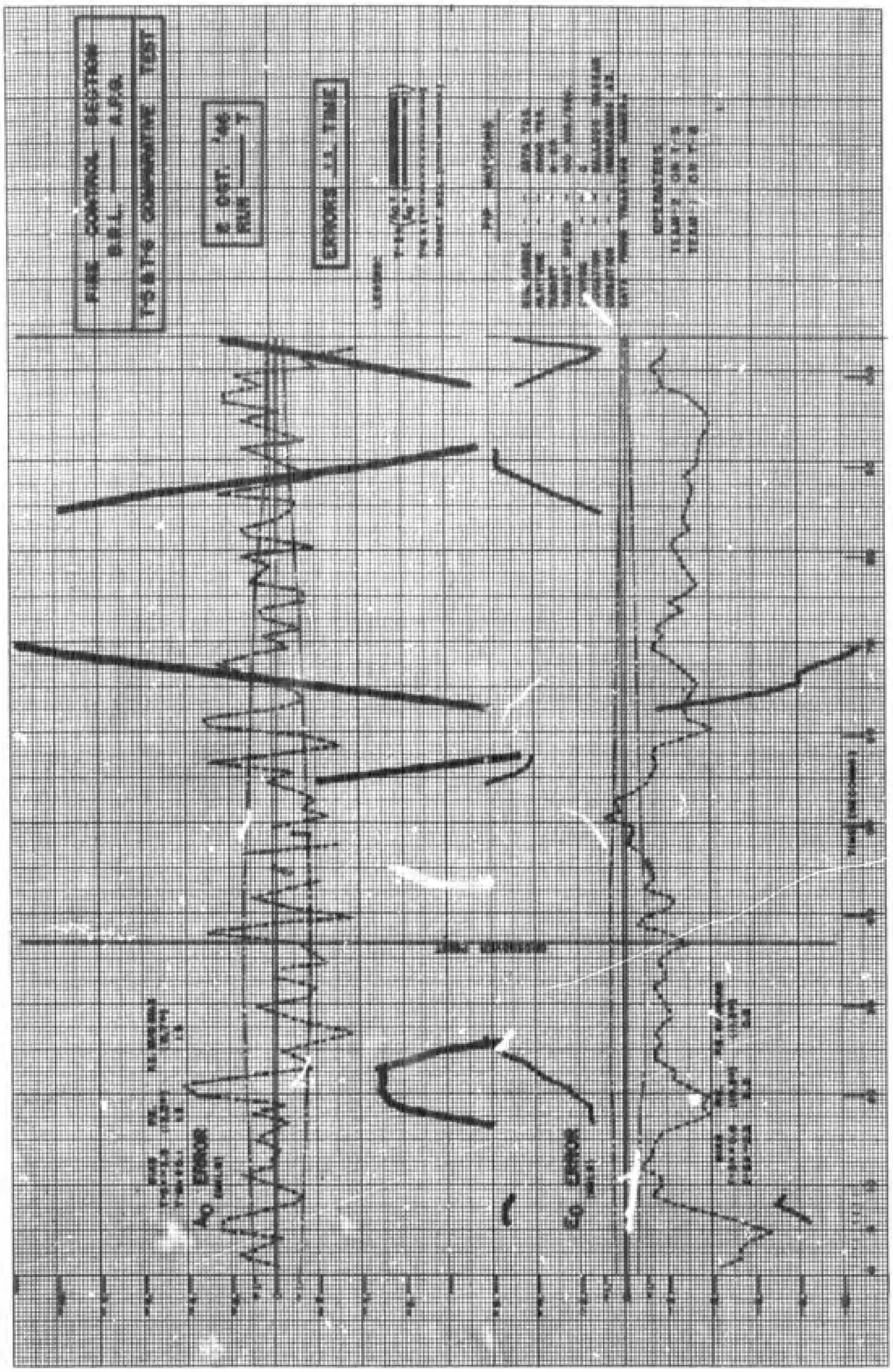

FIRE CONTROL SECTION
B.R.L. —— A.P.G.
T-15 & T-16 COMPARATIVE TEST
ERRORS vs TIME

FIG 33

[redacted]

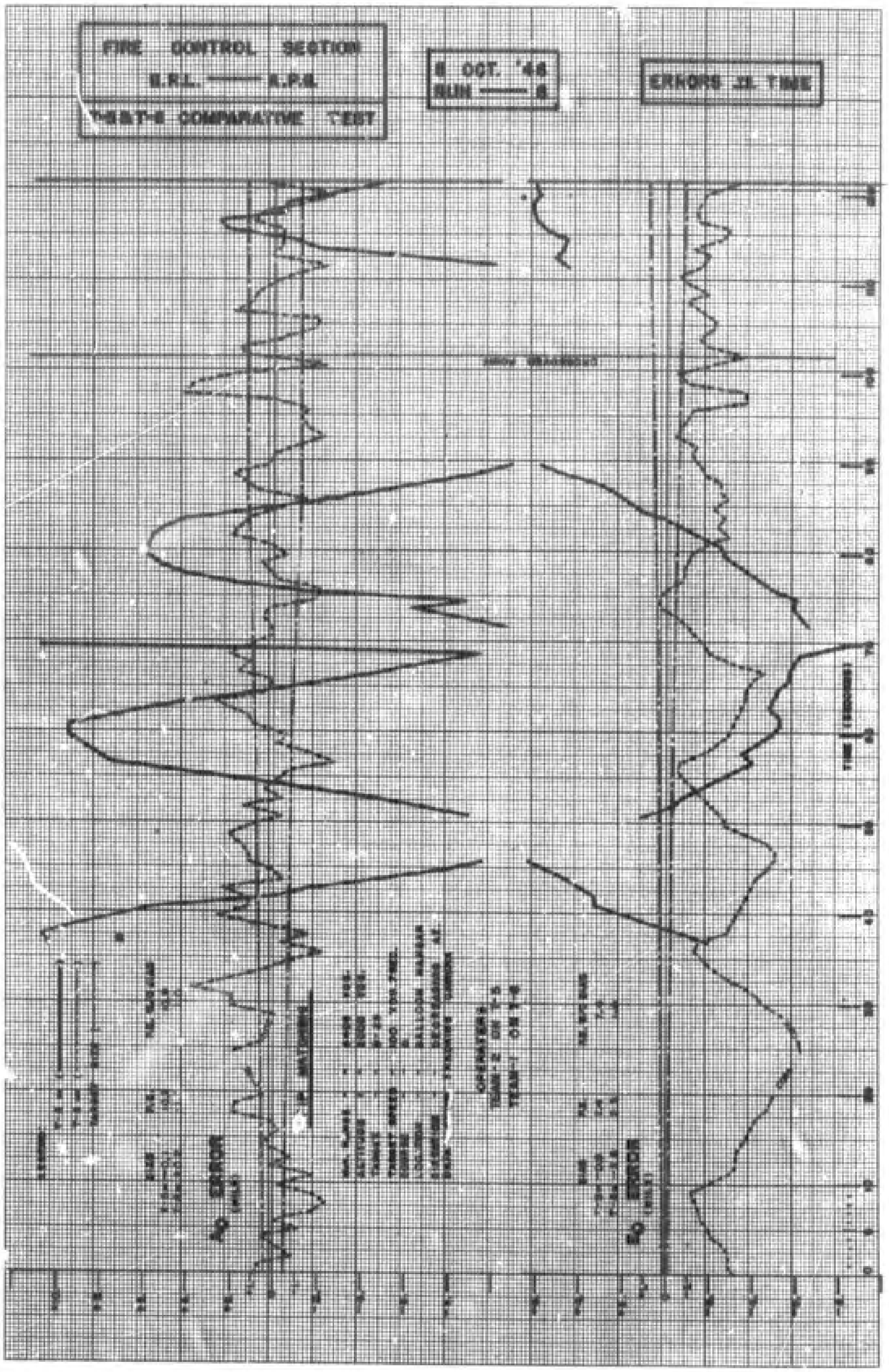


FIG 34

[redacted]

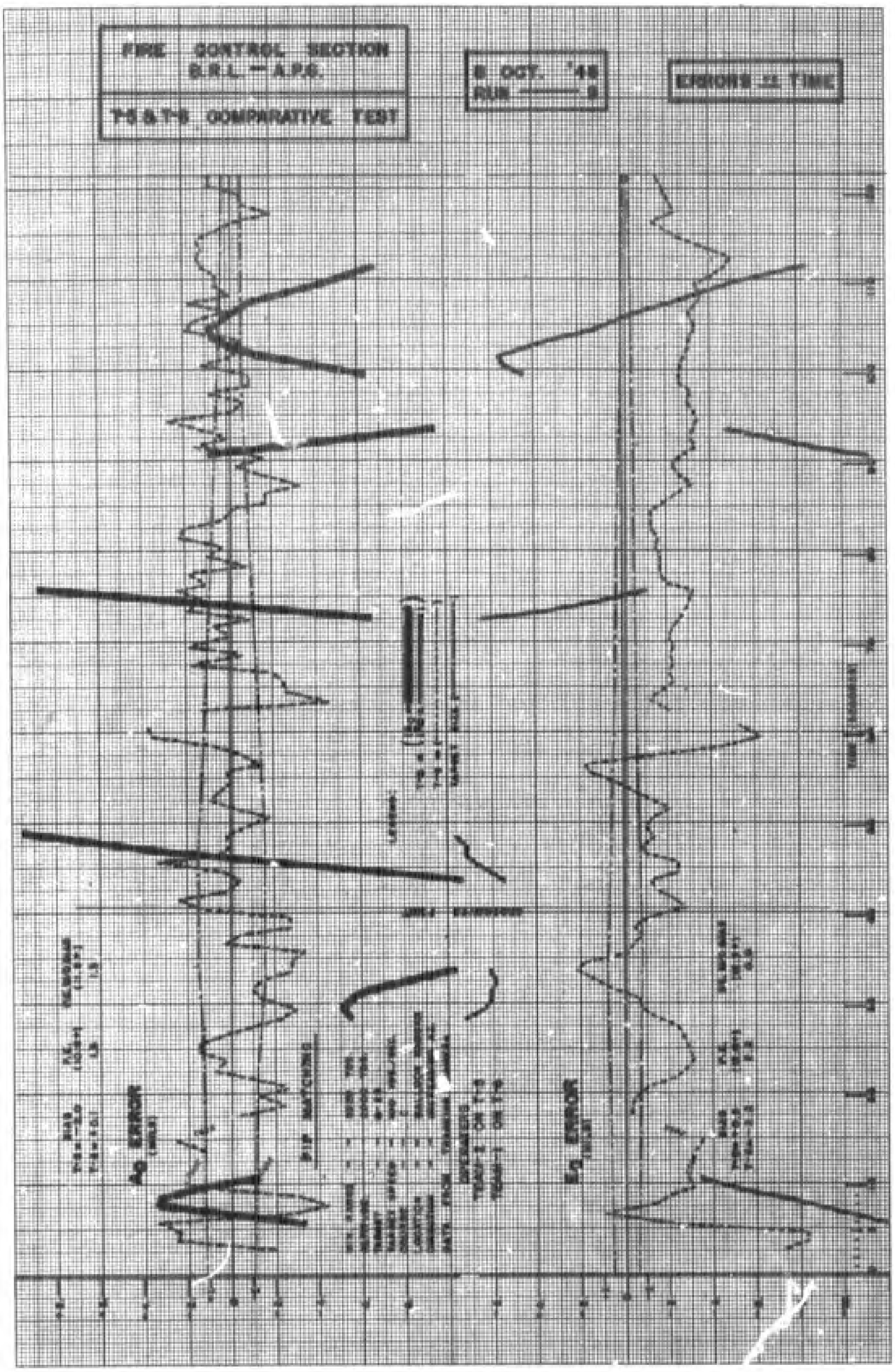

FIRE CONTROL SECTION
B.R.L. — A.P.G.
T-5 & T-6 COMPARATIVE TEST
ERRORS vs TIME

FIG 35

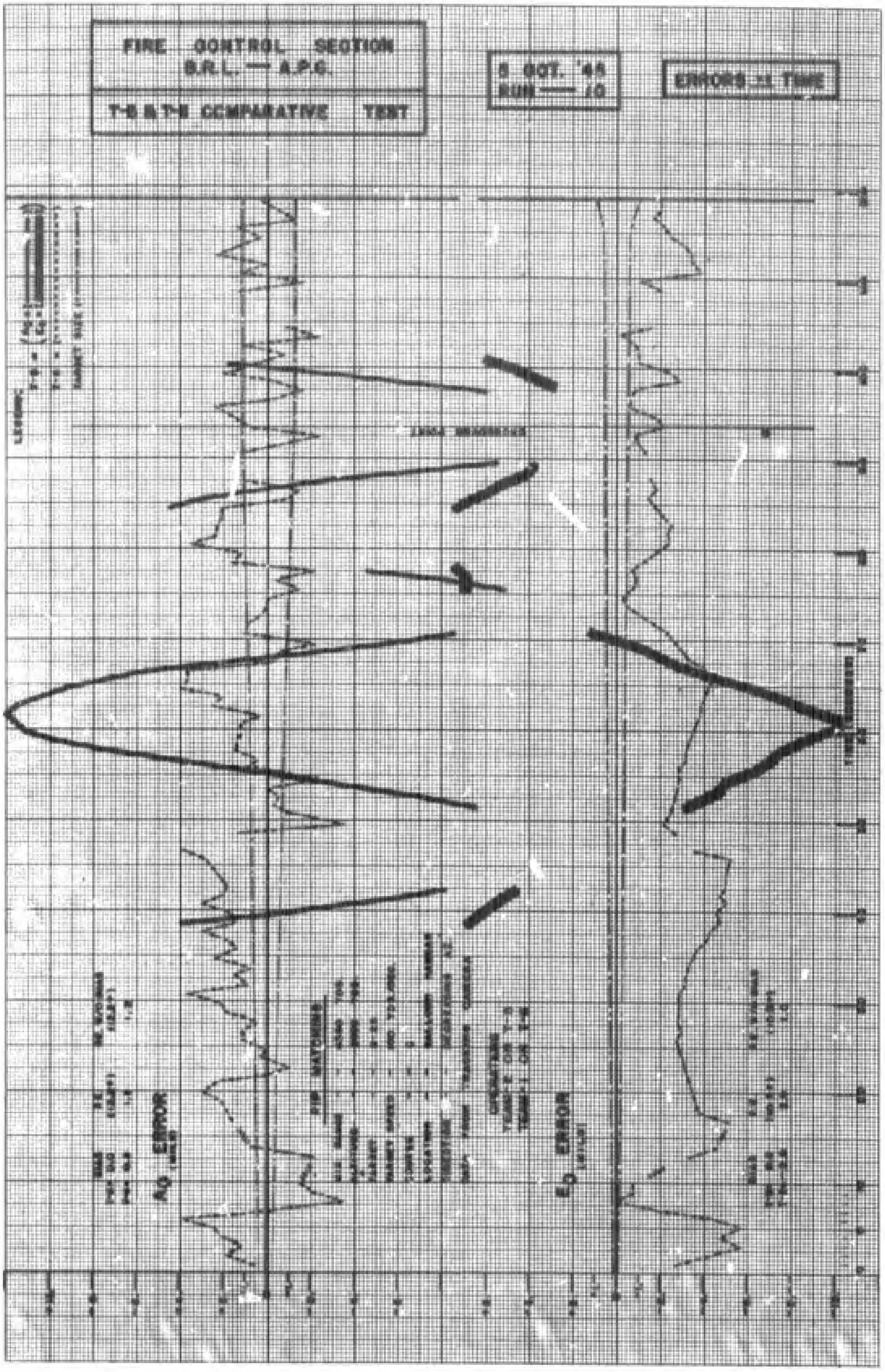

FIRE CONTROL SECTION
B.R.L. — A.P.G.
T-6 & T-8 COMPARATIVE TEST
5 OCT. '45
RUN — 10
ERRORS vs TIME

FIG 36

[redacted]

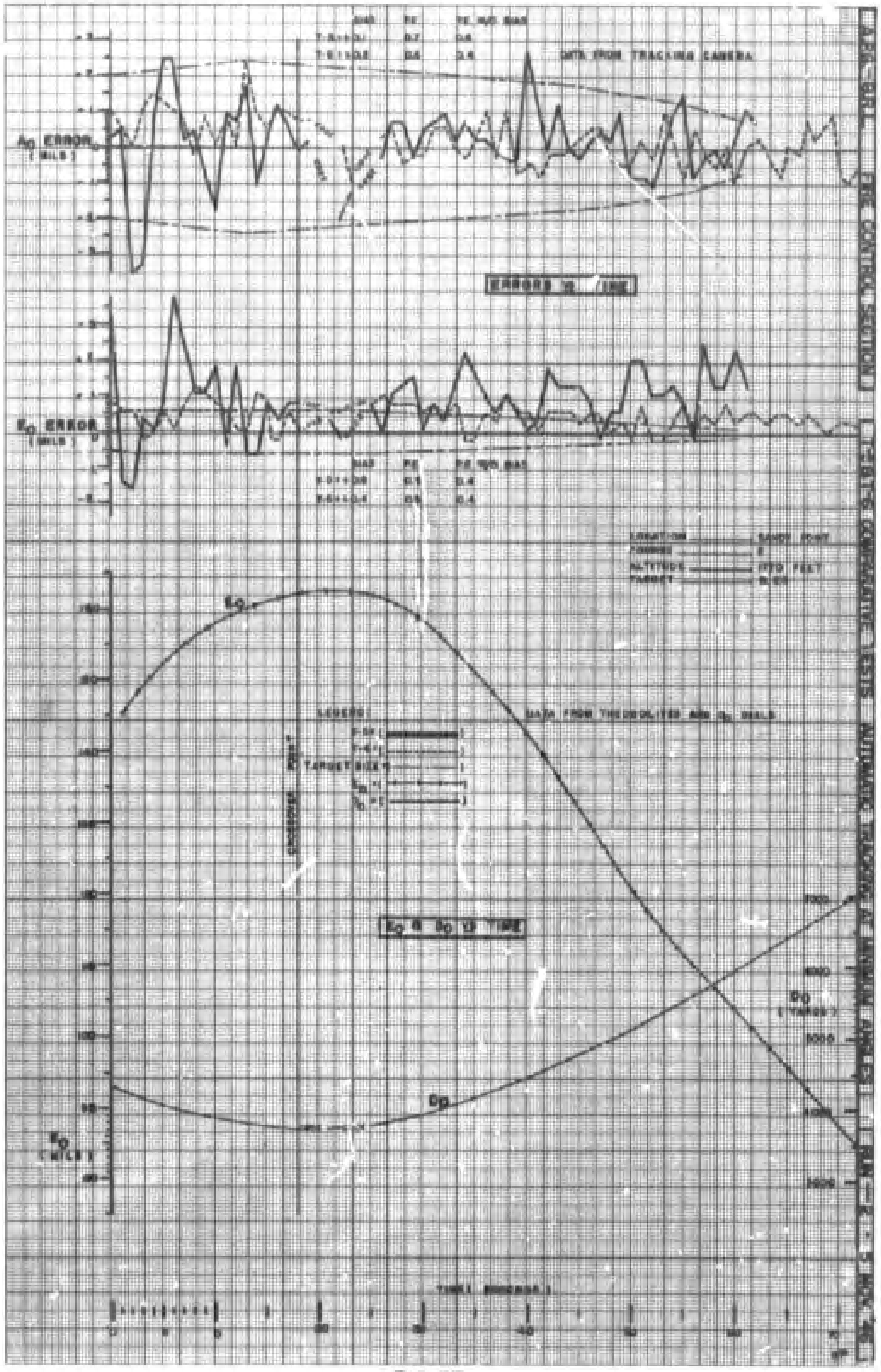


FIG 37

[redacted]

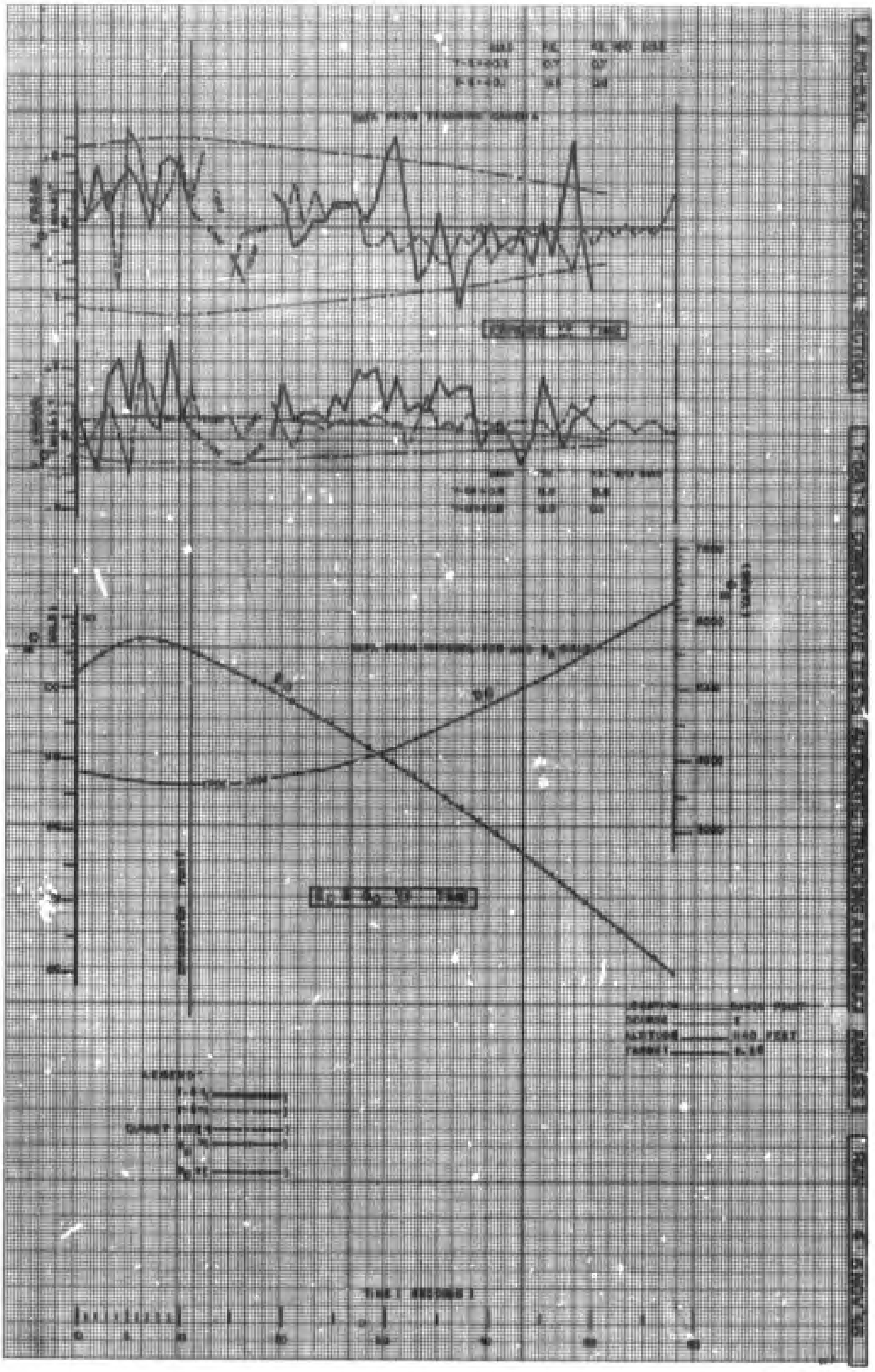


FIG 38

[redacted]

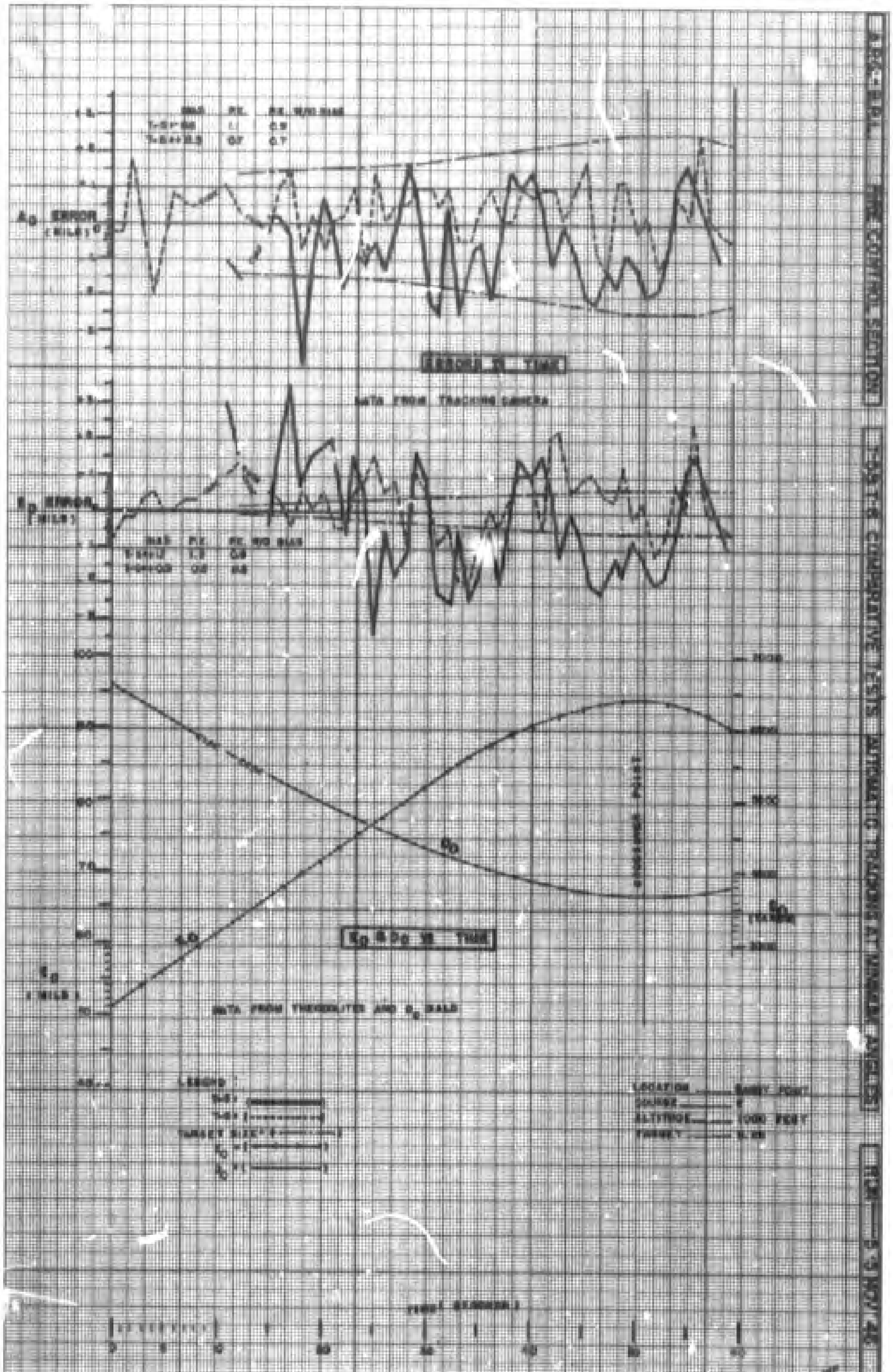


FIG 39

[redacted]

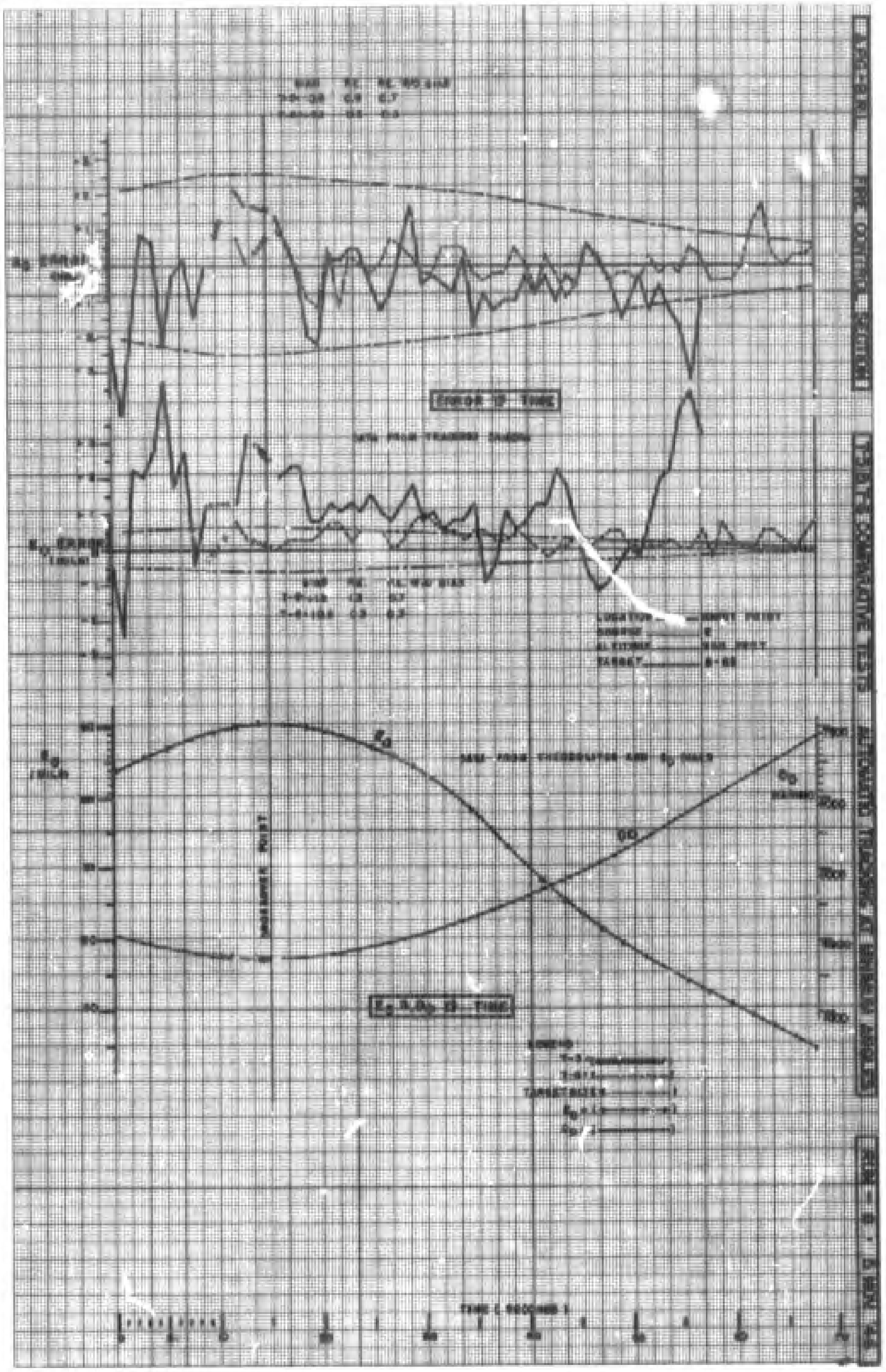


FIG 40

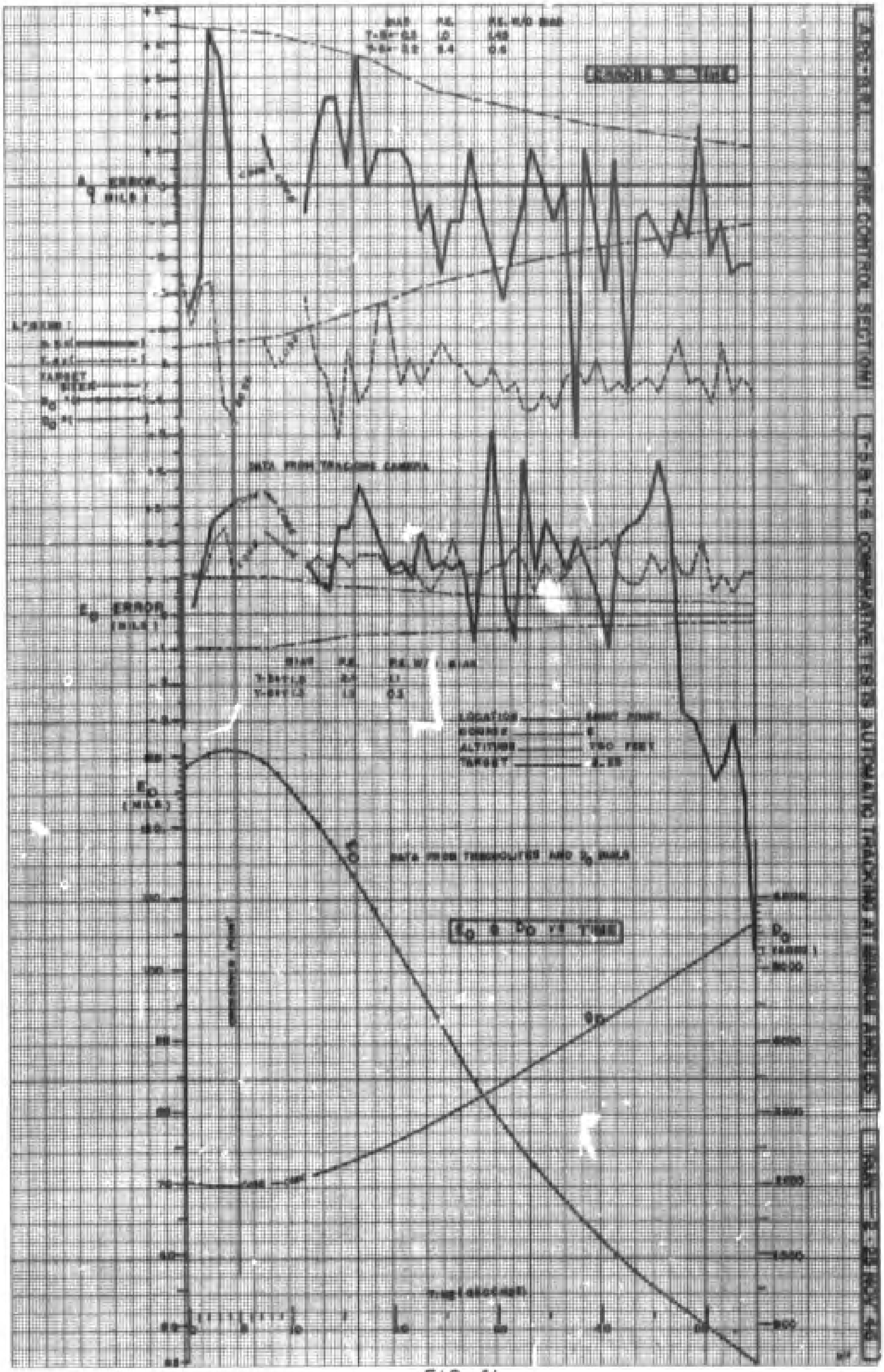


FIG 41

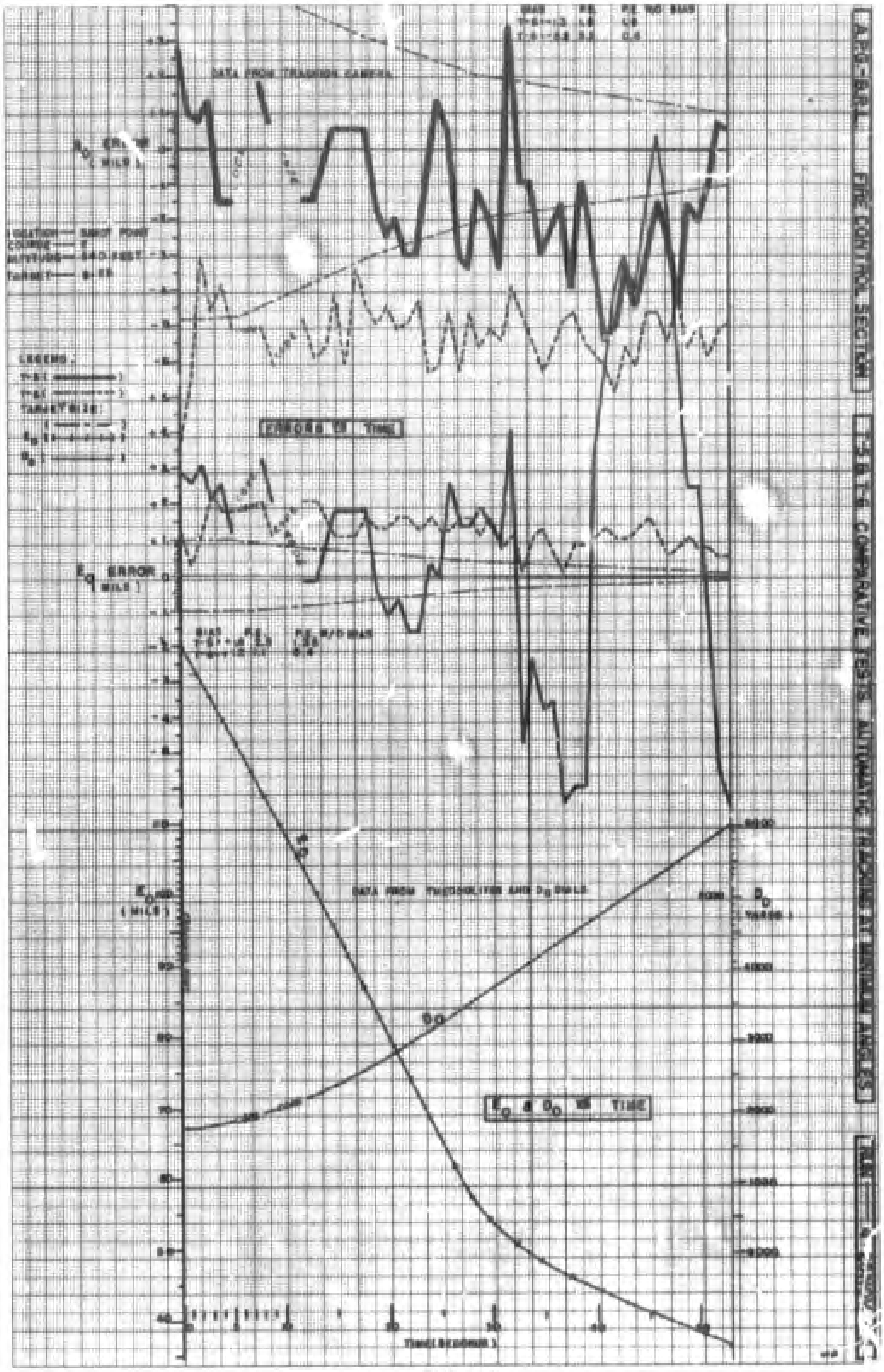

APG-BRL FIRE CONTROL SECTION
COMPARATIVE TESTS AUTOMATIC TRACKING AT MINIMUM ANGLES
DATA FROM TRACKING CAMERA
ERRORS VS TIME
ERROR
DATA FROM THEODOLITES AND D_0 DIALS
E_0 & D_0 VS TIME
TIME (SECONDS)

FIG 42

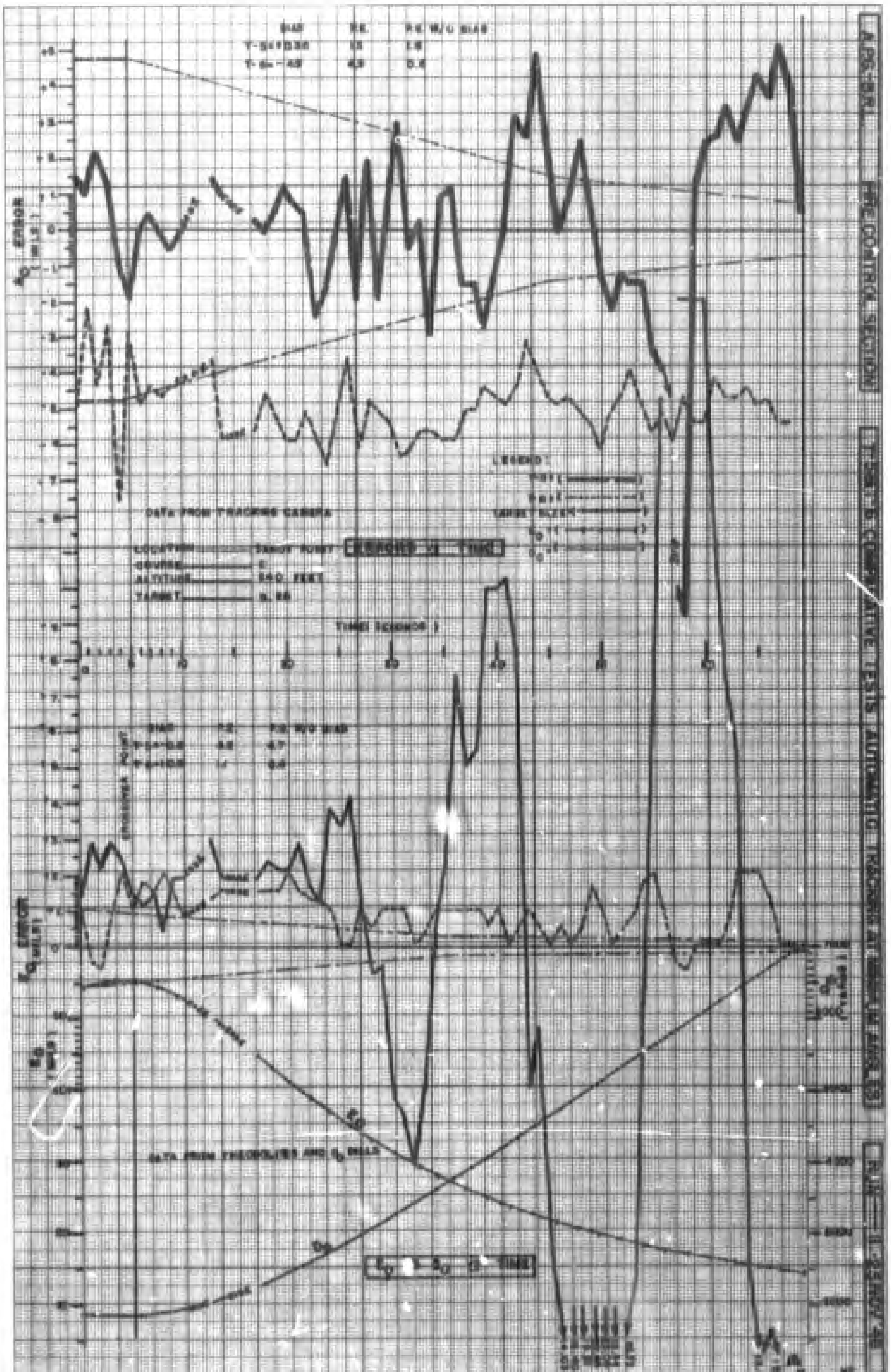


FIG 43

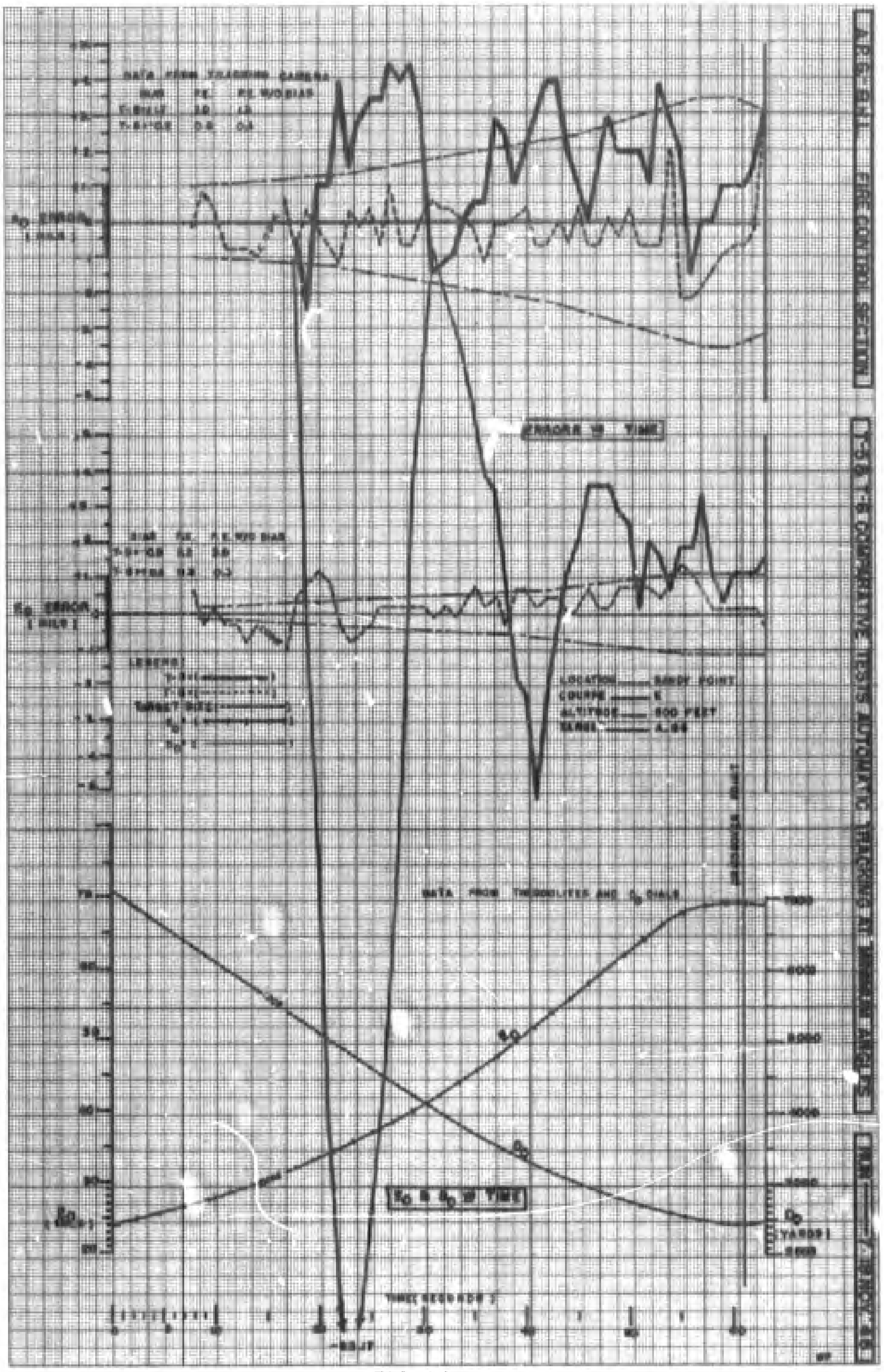


FIG 44

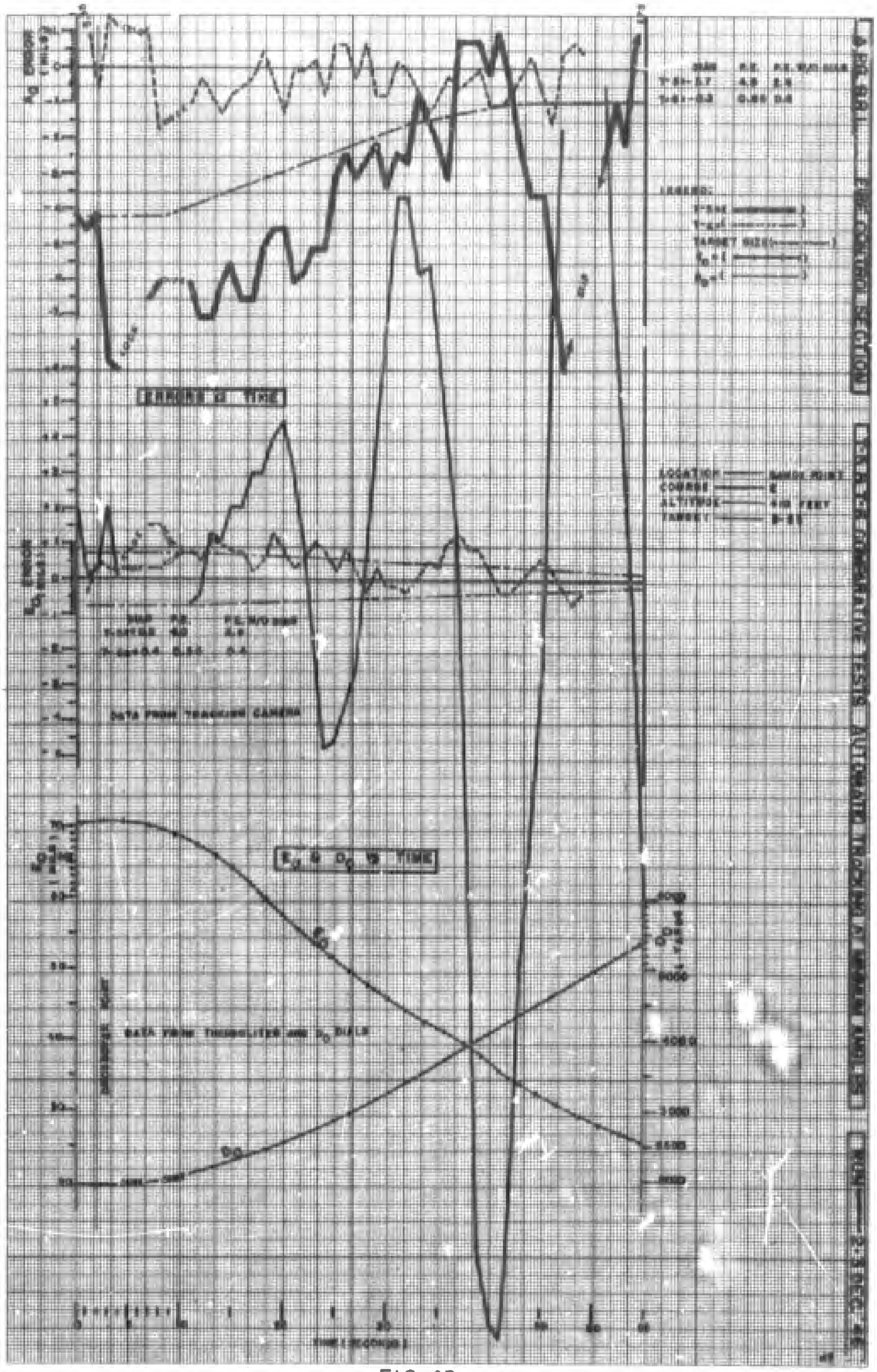


FIG 45

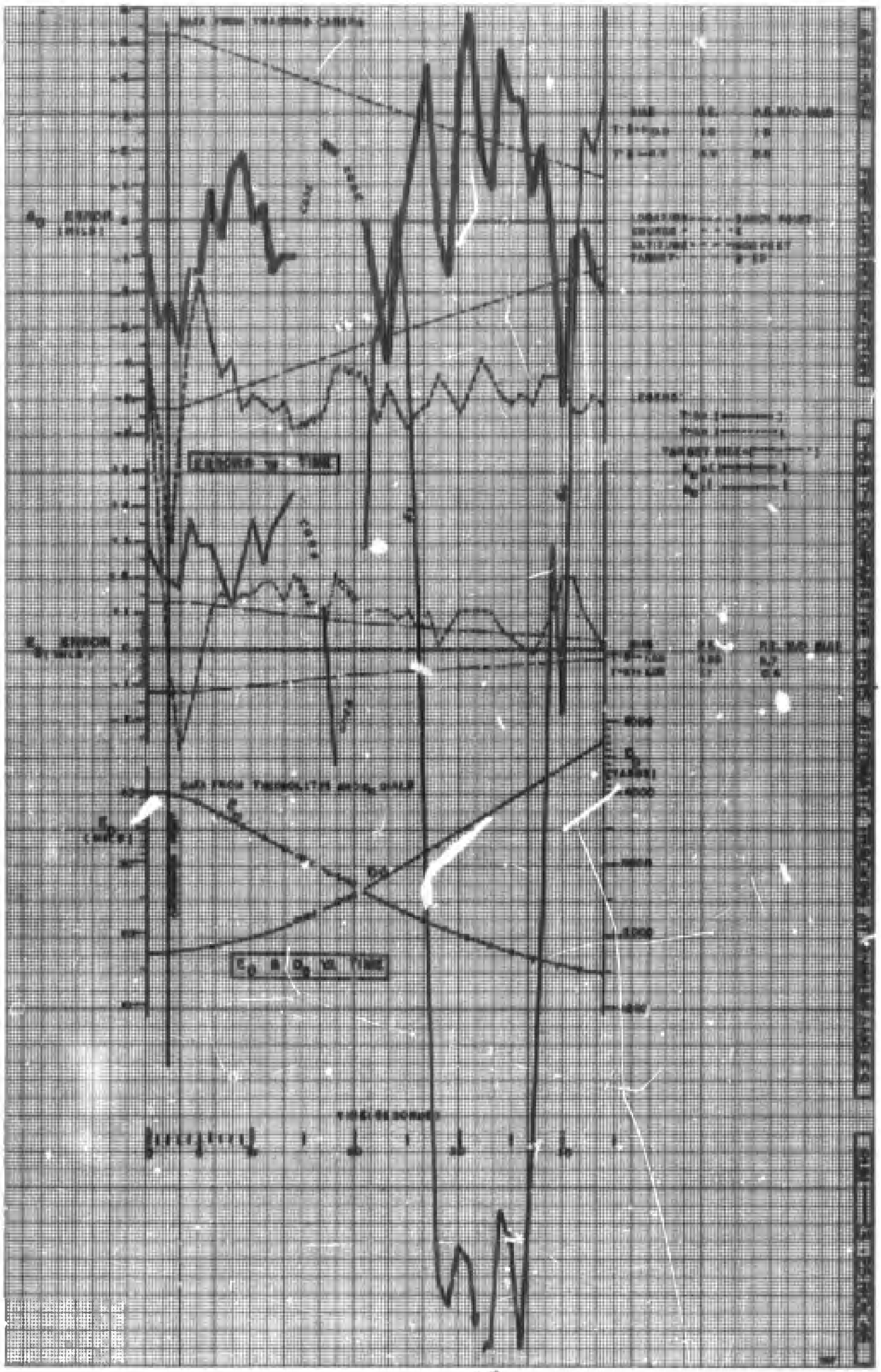


FIG 46

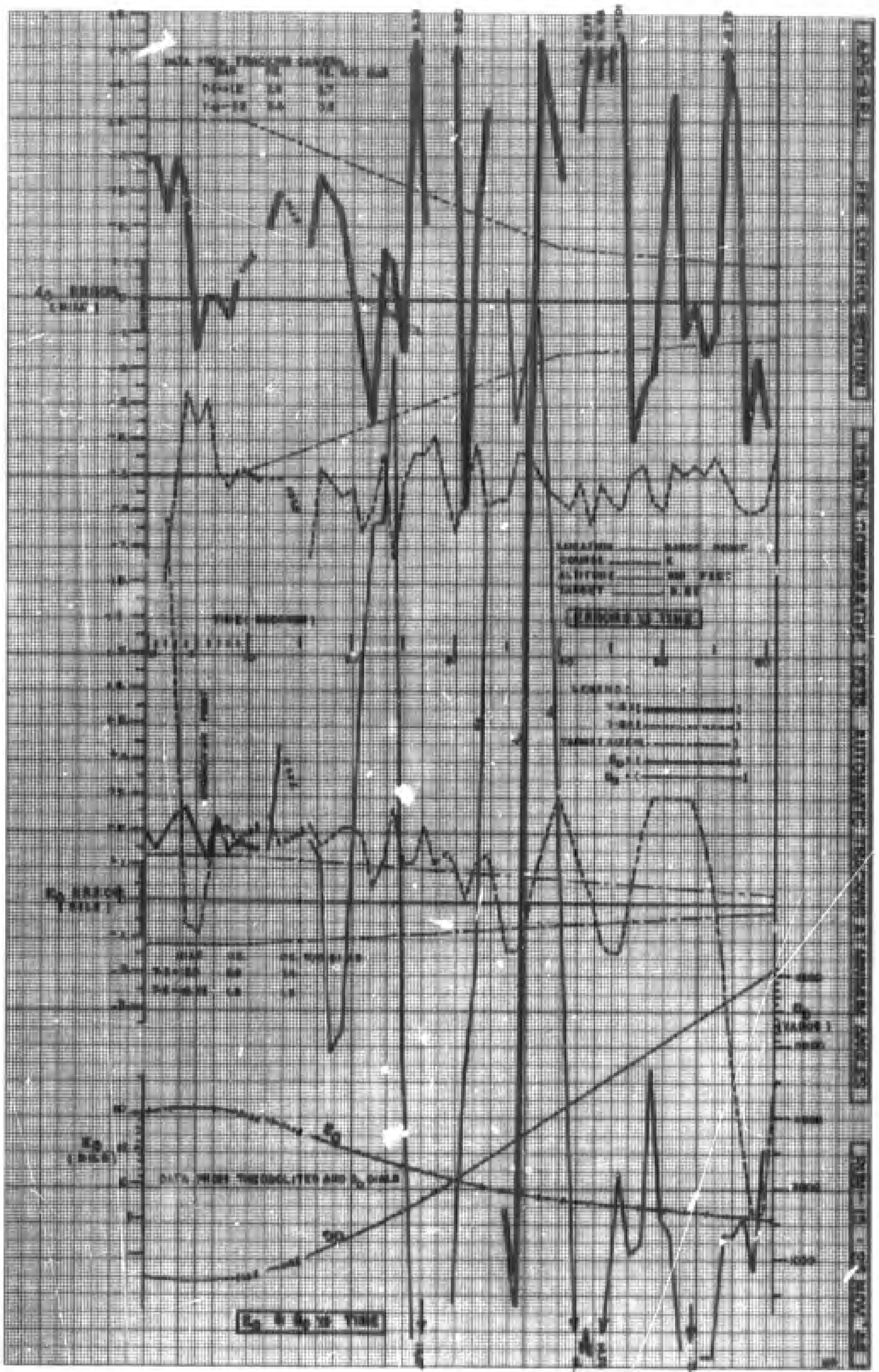


FIG 47

[redacted]

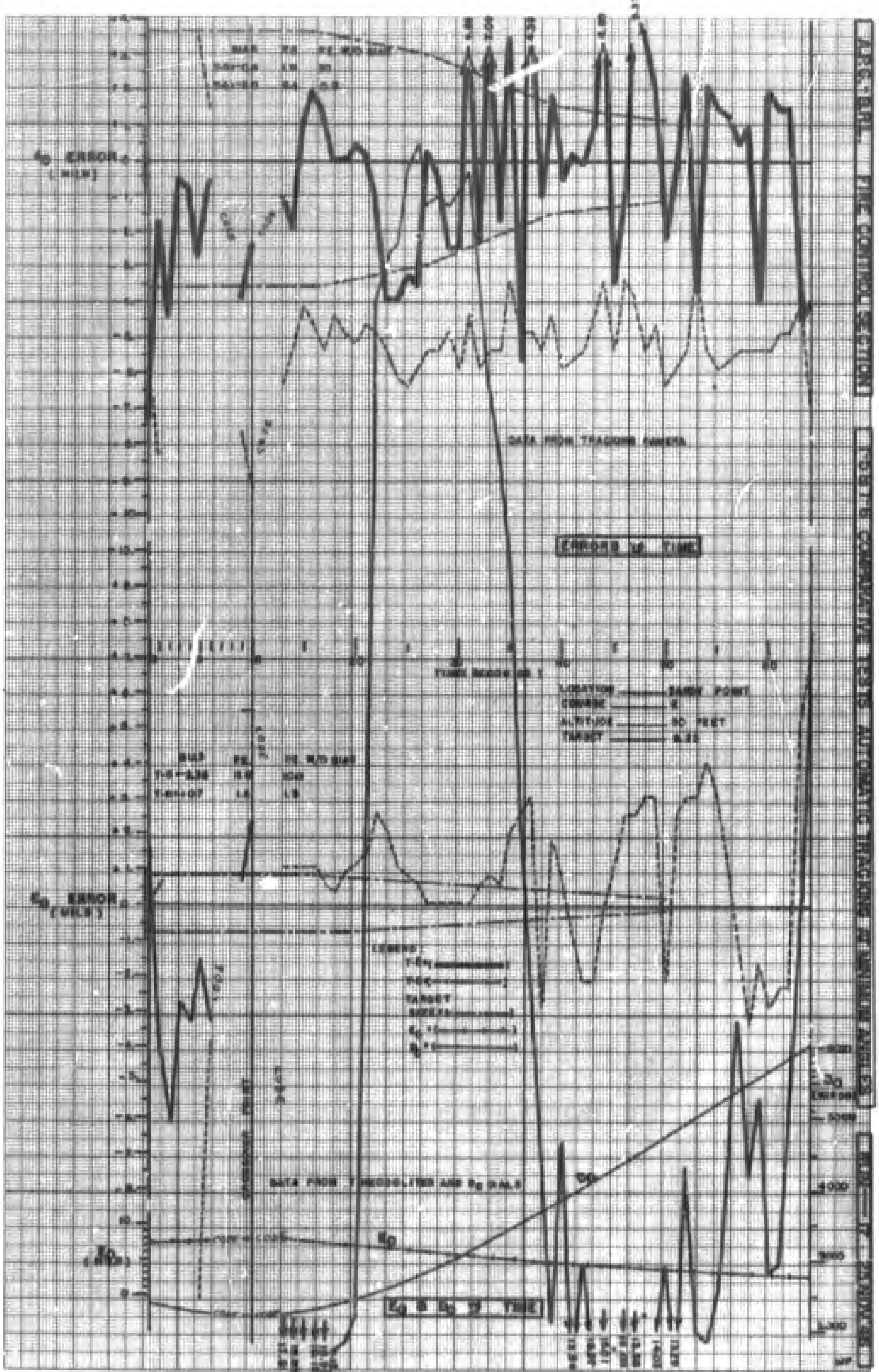


FIG 48

[redacted]

[redacted]

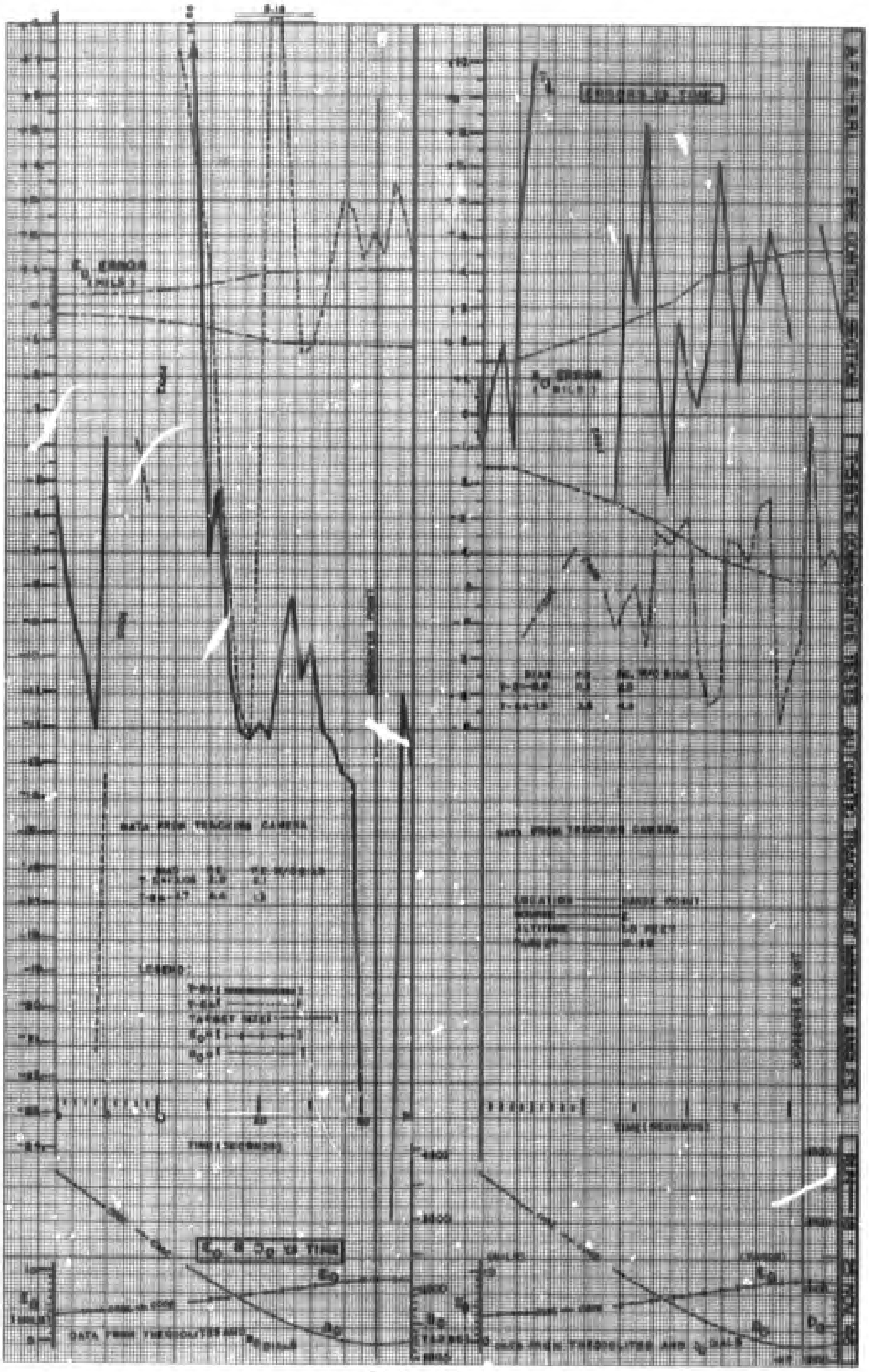


FIG 49

[redacted]

[redacted]

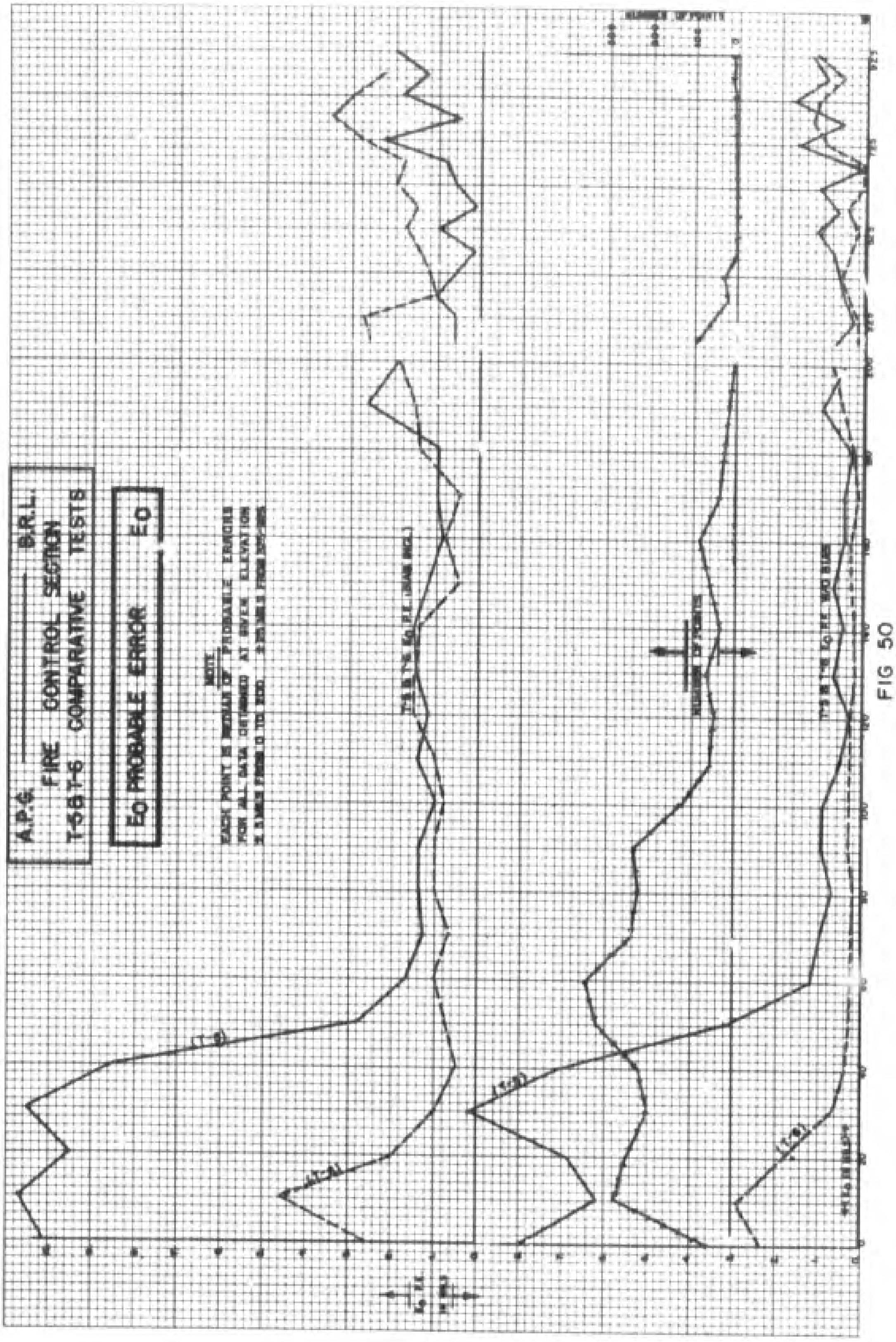


FIG 50

[redacted]

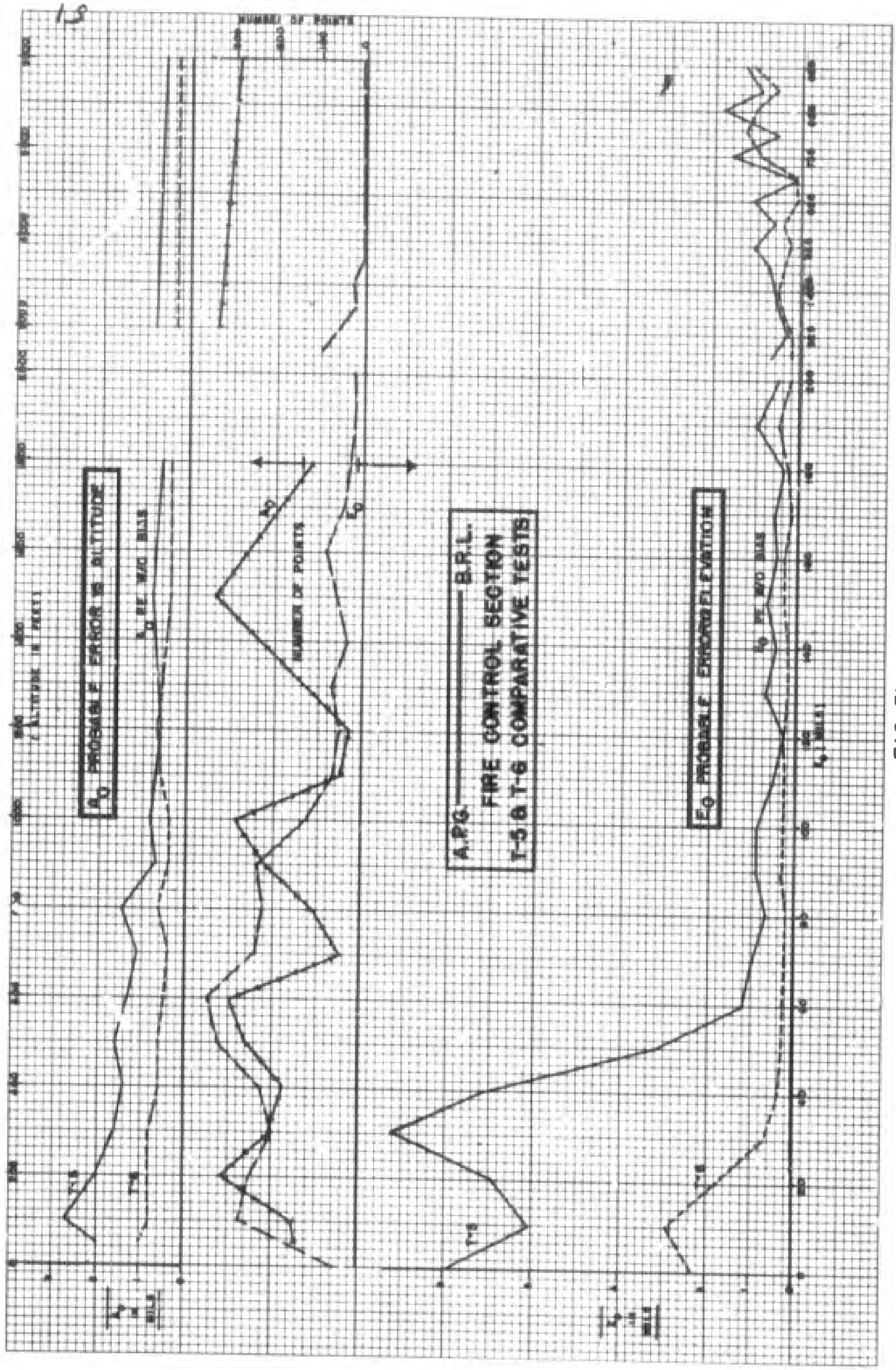

A.P.G. —— B.R.L.
FIRE CONTROL SECTION
T-5 & T-6 COMPARATIVE TESTS
NUMBER OF POINTS

FIG. 51

[redacted]

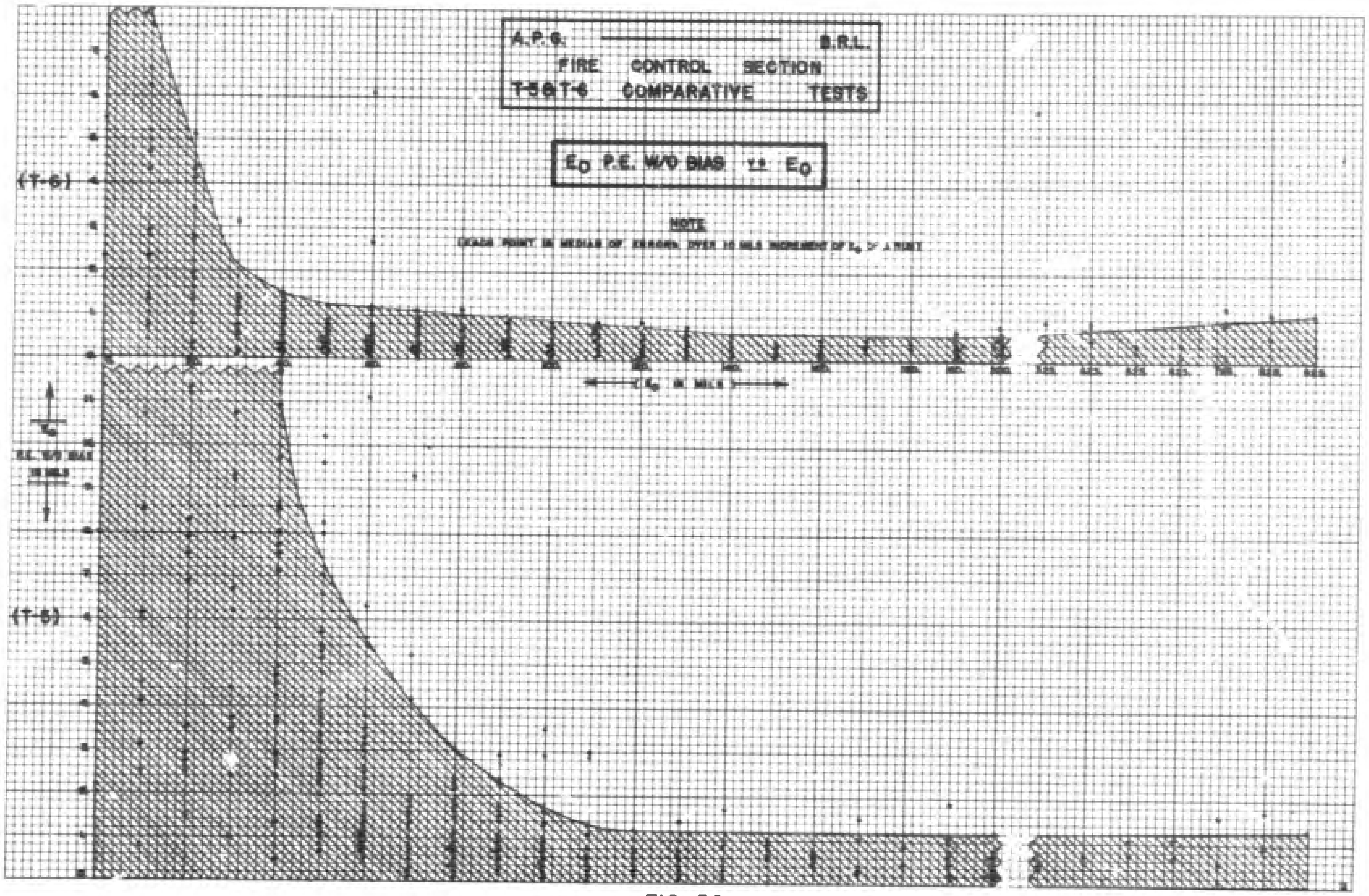


FIG 52

[redacted]

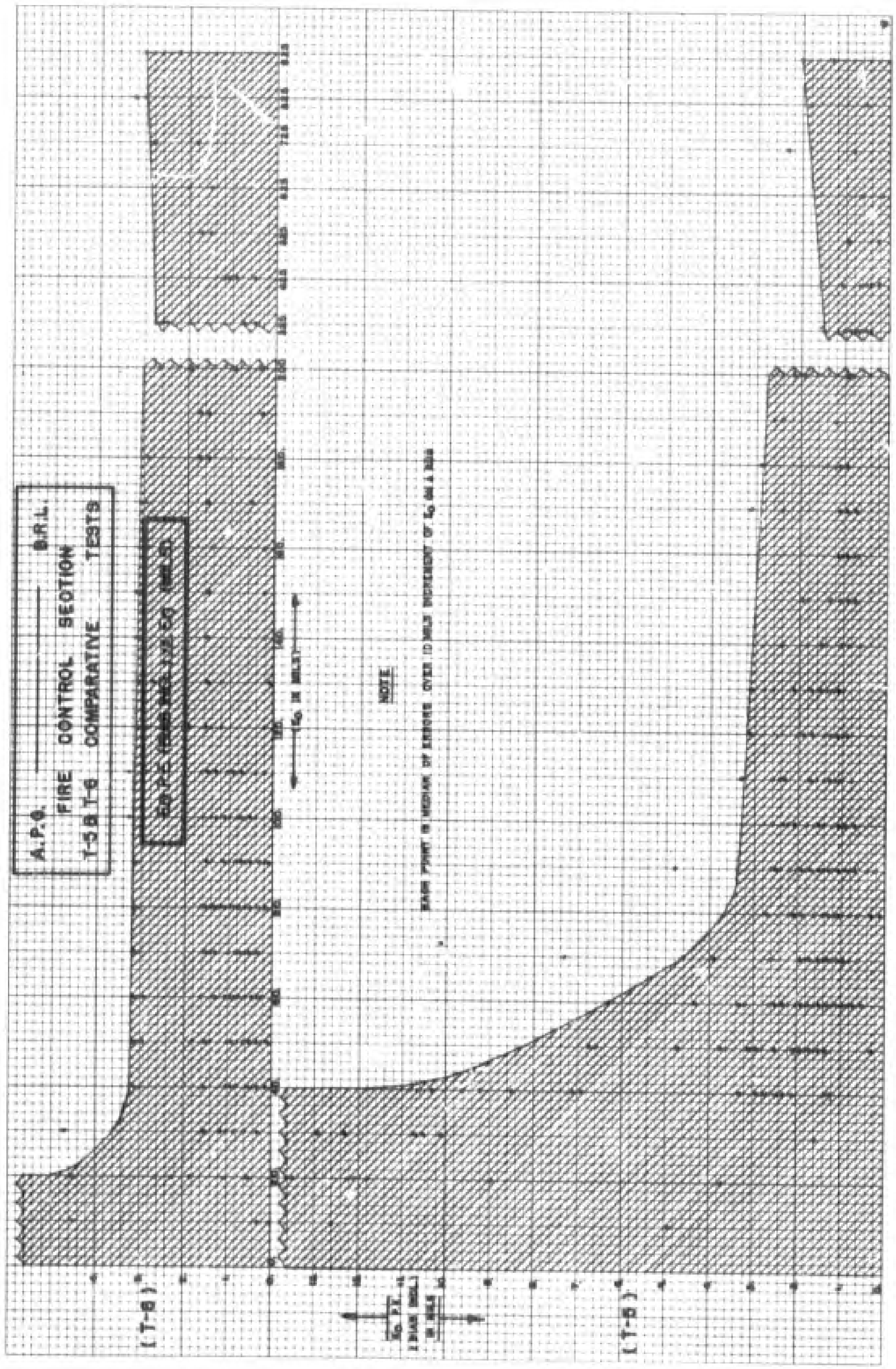

A.P.G. B.R.L.
FIRE CONTROL SECTION
T-5 & T-6 COMPARATIVE TESTS
NOTE
(T-6)
(T-5)

FIG 53

[redacted]

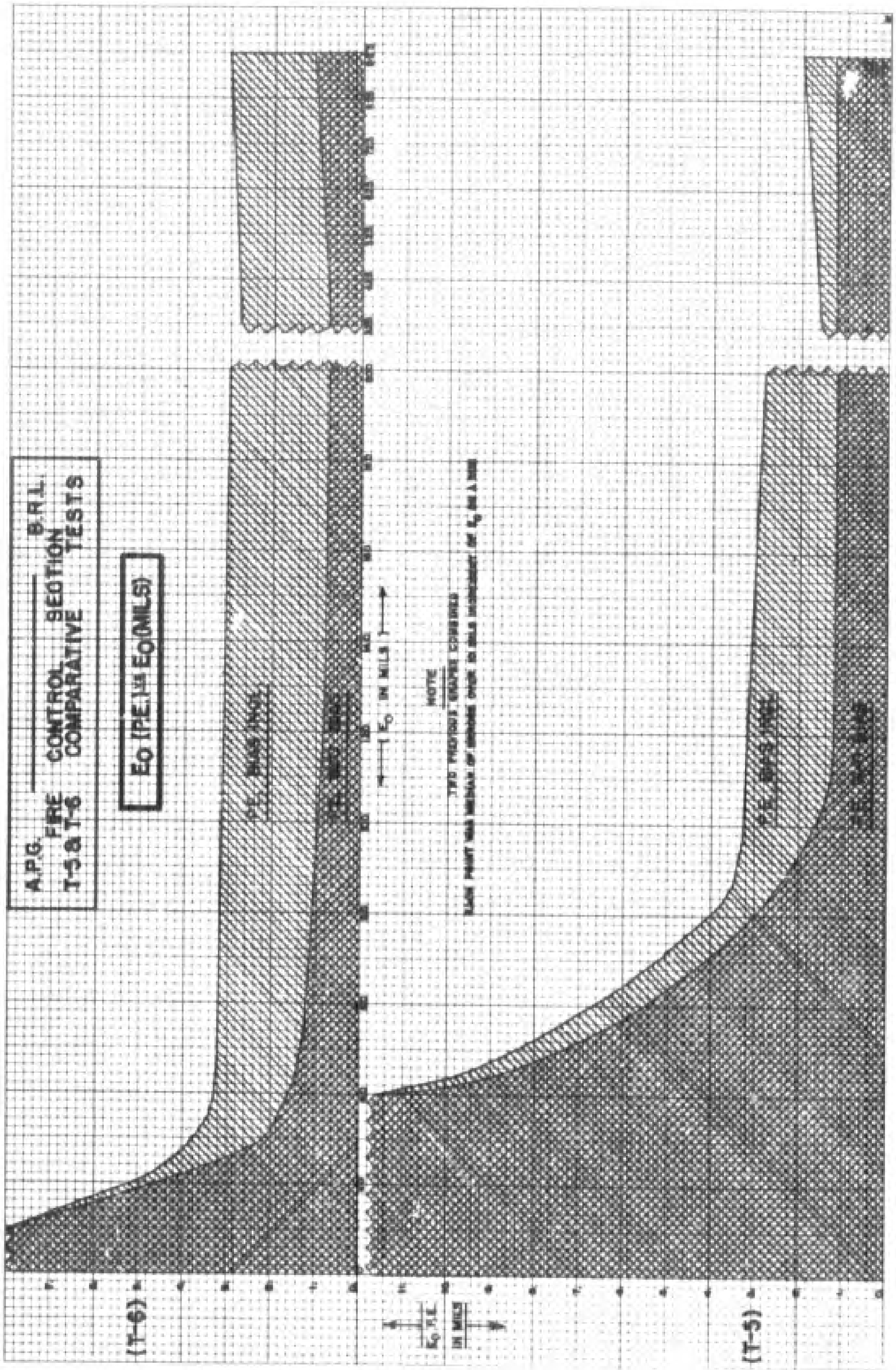


FIG 54

[redacted]

TABLE I

LIST OF GRAPHS FOR T.-5, T-6 TESTS WITH RESUME' OF TEST CONDITIONS

	Figure No: Report	Test Date 1946	Run No.	Altitude Ft.	Azim Direct *1	Min. D_o Yd *2	Target Speed Yd/Sec	Azimuth A_o mils: *3 PE W Bias	Azimuth A_o mils: Bias	Azimuth A_o mils: *4 PE W/o Bias	Elevation E_o mils: *3 PE W/ Bias	Elevation E_o mils: Bias	Elevation E_o mils: *4 PE W/o Bias	Slant Range D_o yds: PE W/ Bias	Slant Range D_o yds: Bias	Slant Range D_o yds: PE W/o Bias	
							AUTOMATIC TRACKING TESTS										
							SHORT RANGES										
		Location: Old Phillip Field										Target: B-25					
							COURSE B										
Short Ranges	1	31 July	3	1500	Dec	760	100	1.28	.7	1.6	1.48	-1.6	.8				T-5
							*N1	1.34	2.17	.6	2.12	2.6	.3				T-6
							COURSE C										
	2	30 July	5	4000	Inc	2510	100	1.2	-.7	1.6	1.2	-.5	1.1				T-5
								.8	.4	.9	1.6	1.6	.5				T-6
	3	30 July	6	4000	Dec	2740	100	1.04	.64	1.0	1.61	-1.19	1.20				T-5
								.83	.89	.6	1.07	1.10	.6				T-6
↑ High Azimuth Rates	4	8 Aug	2	6300	Inc	1700	104	2.90	2.19	1.8	.70	.70	.8	31.0	31.2	6.	T-5
							*N1	1.30	1.11	.4	2.0	1.93	.8	45.0	44.3	4.	T-6
	5	8 Aug	4	3100	Inc	7800	106	3.0	2.8	.8	1.0	- .2	.6	44.	45.	5.0	T-5
								.7	.4	.3	.8	.6	.4	54.	54.	4.5	T-6
	6	8 Aug	6	600	Inc	2300	103	3.2	3.6	1.3	1.4	.8	1.3	29.	32.	9.	T-5
								.7	.3	.5	.3	.1	.2	50.	52.	3.	T-6
							COURSE B										
	7	8 Aug	8	1600	Dec	578	106	4.4	4.9	1.4	1.9	.7	1.6	26.	27.	2.	T-5
								2.8	2.6	1.9	1.0	1.6	2.4	59.	58.	6.	T-6
	8	8 Aug	9	1600	Inc	1000	99	3.2	3.1	1.2	1.3	- .5	1.3	16.	15.	5.	T-5
								.7	.3	.6	.4	.6	.5	61.	61.	4.	T-6
↓	9	8 Aug	10	1680	Dec	871	106	5.6	4.1	2.3	1.5	- .3	1.6	38.	34.4	5.9	T-5
								1.7	2.3	1.2	.5	.8	.7	56.	58.4	4.9	T-6
							MEDIUM RANGES										
		Location: Balloon Hangar															
							COURSE B										
	10	17 Oct	3	6030	Inc	6525	121	.40	.18	.44	.84	- .85	.43	3.5	- .5	2.4	T-5
								.32	-.03	.29	2.77	-2.73	.17	17.3	-17.	4.2	T-6
	11	17 Oct	4	6090	Dec	6930	118	.60	.40	.60	.80	- .80	.60	23.	-21.	4.0	T-5
								.30	.10	.30	2.80	-2.80	.30	18.	-18.	5.0	T-6
	12	17 Oct	5	3000	Inc	5705	116	.50	-.05	.40	1.2	-1.1	.40	7.0	- 7.0	3.5	T-5
								.30	.10	.30	3.1	-3.1	.20	11.6	-12.	2.1	T-6
	13	17 Oct	6	2940	Dec	5990	108	.80	.50	.80	1.0	-1.1	.60	20	-22.	6.5	T-5
								.30	-.20	.35	3.1	-3.0	2.5	15	-15.	5.0	T-6
	14	17 Oct	7	1470	Inc	5395	102	.77	.49	.68	1.32	-1.13	.52	10.	-11.	4.0	T-5
								.32	-.12	.40	3.19	-3.24	.16	15.	-14.	3.5	T-6
	15	17 Oct	8	1530	Dec	5520	106	1.0	.5	.9	1.3	-1.0	.9	17.	-19.	7.	T-5
								.3	-.2	.4	3.1	-3.1	.2	12.2	-12.	3.	T-6
	16	17 Oct	9	1020	Inc	5310	112	.68	.46	.55	1.89	-1.03	1.34	13.	-14.	3.	T-5
								.52	-.10	.52	3.19	-3.11	.29	12.	-10.	3.	T-6
	17	17 Oct	10	1080	Dec	5425	109	.9	.6	.8	1.7	-1.3	1.2	24.	-24.	6.	T-5
								.3	-.3	.4	3.0	-3.0	.2	11.	12.	2.	T-6

*1 Azimuth Direction: Increasing (Inc) or Decreasing (Dec)

*2 Minimum Slant Range, D_o in yds. For illustration of coordinate system, see Plate I in text.

*3 Probable error with bias; see text for explanation

*4 Probable error without bias; see text for explanation

TABLE I (Con.)

Figure No. Report	Test Date 1946	Run No.	Altitude Ft.	Azim Direct	Min. D_o Yd	Target Speed Yd/Sec	Azimuth A_o mils PE W Bias	Azimuth Bias	Azimuth PE W/o Bias	Elevation E_o mils PE W/ Bias	Elevation Bias	Elevation PE W/o Bias	Slant Range D_o yds PE W/ Bias	Slant Range Bias	Slant Range PE W/o Bias	
PIP MATCHING TESTS, MEDIUM RANGES																
Location: Old Phillips Field																
Target: B-25																
Team 1 on T-5, Team 2 on T-6																
COURSE C																
18	20 Sept	3 AM	6450	Dec	3770	100	4.6	-3.3	4.2	7.6	1.2	7.4	49.	48.	2.	T-5
							3.7	.7	3.5	2.4	1.3	2.4	4.	2.	5.	T-6
Team 2 on T-5, Team 1 on T-6																
19	20 Sept	6 AM	6450	Inc	3230	100	10.4	-2.7	12.0	9.3	1.5	9.8	42.	44.	4.	T-5
							2.6	1.1	2.4	2.3	.7	2.2	7.	7.	3.	T-6
20	20 Sept	3 & 6		(D_o Errors vs Time for Runs 3 and 6)												
Team 1 on T-5, Team 2 on T-6																
21	20 Sept	1 PM	3150	Inc	2590	100	4.3	3.6	2.5	4.1	-2.1	2.3				T-5
							2.9	1.3	2.5	1.6	.9	2.4				T-6
22	20 Sept	2 PM	3150	Dec	2890	100	4.5	- .7	5.1	6.9	3.1	7.3				T-5
							2.6	1.5	2.9	2.1	.8	2.3				T-6
23	20 Sept	3 PM	2940	Inc	2170	106	5.5	-1.5	4.1	6.4	1.7	4.6	83.0	81.7	5.0	T-5
							2.6	1.0	1.7	1.6	.9	1.0	3.5	2.3	1.7	T-6
24	20 Sept	4	3000	Dec	3350	109	4.4	.1	4.3	3.5	2.8	3.7	74.7	73.5	4.4	T-5
							2.3	- .6	2.8	2.5	1.1	2.6	5.1	.9	4.6	T-6
Team 2 on T-5, Team 1 on T-6																
25	20 Sept	5	3120	Inc.	2245	105	9.8	-6.8	11.9	11.1	- .7	10.5	105.8	100.9	11.6	T-5
							1.9	.3	2.0	2.1	- .4	2.0	3.1	-1.3	3.9	T-6
26	20 Sept	6	3060	Dec	3400	112	8.2	-1.9	9.5	4.9	1.9	3.8	26.5	26.1	4.6	T-5
							1.7	.4	1.8	1.9	.1	1.7	3.3	- .5	2.9	T-6
27	20 Sept	7	3300	Inc	1980	100	12.0	- .4	11.8	6.8	-1.8	6.0				T-5
							1.8	.5	1.9	1.6	0.1	1.7				T-6
28	20 Sept	8	3300	Dec	3320	100	10.1	-4.3	9.7	5.4	1.8	4.5				T-5
							1.7	.9	1.5	1.6	.2	1.2				T-6
COURSE B																
Team 1 on T-5, Team 2 on T-6																
29	8 Oct	3	6000	Inc	5330	100	5.3	-3.7	4.6	3.7	-1.4	4.2				T-5
							3.8	-1.5	3.7	3.6	-1.1	2.7				T-6
30	8 Oct	4	6000	Dec	6295	100	6.1	-4.1	3.2	4.7	-2.3	4.7				T-5
							1.8	-0.6	2.0	2.3	-1.9	1.8				T-6
31	8 Oct	5	6000	Inc	5900	100	6.9	-3.4	5.1	3.6	-0.3	3.6				T-5
							2.9	-0.8	2.5	2.0	-0.6	1.9				T-6
32	8 Oct	6	6000	Dec	6425	100	5.6	-4.2	3.3	2.4	-0.6	2.4				T-5
							2.3	-0.6	2.4	2.2	-1.9	1.8				T-6
Team 2 on T-5, Team 1 on T-6																
33	8 Oct	7	6000	Inc	5975	100	12.2	-3.5	8.7	10.8	0.6	11.3				T-5
							1.2	0.1	1.3	2.2	-2.3	0.8				T-6
34	8 Oct	8	6000	Dec	6405	100	10.7	-0.1	10.9	7.4	-0.5	7.4				T-5
							1.0	0.2	1.0	2.3	-2.5	1.0				T-6
35	8 Oct	9	6000	Inc	5920	100	10.6	-2.0	11.6	12.0	0.3	12.3				T-5
							1.3	0.1	1.3	2.2	-2.2	0.9				T-6
36	8 Oct	10	6000	Dec	6360	100	12.2	0.0	12.2	10.3	0.0	10.3				T-5
							1.5	0.8	1.2	2.9	-2.8	1.0				T-6

[redacted]

TABLE I (Con.)

Figure No. Report	Test Date 1946	Run No.	Altitude Ft.	Azim Direct	Min. D_oYd	Target Speed Yd/Sec	Azimuth A_o mils PE W Bias	Bias	PE W/o Bias	Elevation E_o mils PE W/ Bias	Bias	PE W/o Bias	Slant Range D_o yds PE W/ Bias	Bias	PE W/o Bias	
MINIMUM ELEVATION TESTS AUTOMATIC TRACKING																
Location: Sandy Point								Target: B-25								
COURSE E																
37	5 Nov	2	1770				0.7	0.1	0.6	0.8	0.9	0.4				T-5
							0.5	0.2	0.4	0.5	0.4	0.4				T-6
38	5 Nov	4	1140				0.7	0.2	0.7	0.8	0.8	0.6				T-5
							0.5	0.1	0.6	0.5	0.5	0.1				T-6
39	5 Nov	5	1000				1.1	-0.6	0.9	1.5	1.1	0.9				T-5
							0.7	0.3	0.7	0.5	0.3	0.5				T-6
40	5 Nov	8	930				0.8	-0.6	0.7	1.3	1.2	0.7				T-5
							0.5	0.1	0.3	0.3	0.2	0.3				T-6
41	25 Nov	2	760				1.0	-0.5	1.45	2.4	1.5	1.1				T-5
							5.4	-5.2	0.6	1.2	1.3	0.2				T-6
42	25 Nov	4	640				1.5	-1.3	1.6	2.5	1.6	1.35				T-5
							5.2	-5.2	0.6	1.1	1.2	0.4				T-6
43	25 Nov	11	540				1.5	0.35	1.6	4.2	-0.6	4.7				T-5
							4.9	-4.9	0.6	1.1	0.9	0.6				T-6
								Target: A-26								
44	19 Nov	7	500				2.0	1.7	1.3	3.2	-0.8	3.9				T-5
							0.6	-0.2	0.4	0.3	0.2	0.3				T-6
								Target: B-25								
45	3 Dec	2	410				4.6	-3.7	2.4	4.0	0.2	3.8				T-5
							0.65	-0.2	0.6	0.55	0.4	0.4				T-6
46	25 Nov	13	200				1.5	0.3	1.8	4.35	-1.35	5.7				T-5
							4.9	-4.9	0.5	1.1	1.05	0.5				T-6
47	25 Nov	15	100				2.9	1.2	2.7	8.9	-2.0	7.4				T-5
							5.4	-5.2	0.5	1.8	0.75	1.3				T-6
48	25 Nov	17	50				1.9	-0.4	20.0	11.8	-2.35	10.0				T-5
							5.4	-5.0	0.5	1.8	0.7	1.3				T-6
49	25 Nov	18	50				11.1									
							3.5									

The maximum azimuth rates for the high azimuth rate and medium range test courses were determined to be:

Figure No. Report	Maximum Azimuth Rate mils/sec	Figure No. Report	Maximum Azimuth Rate mils/sec
4	64	12	22
5	47	13	19
6	45	14	24
7	524	15	20
8	122	16	21
9	162	17	16
10	20		
11	18		

TABLE II

SURVEY OF AVERAGE PERFORMANCE OF T-5 AND T-6
RADAR TRACKERS. (EXCLUDING HIGH AZIMUTH RATE AND MINIMUM ANGLE TESTS)

Date of Tests 1946	Flight Courses	Minimum Slant Ranges yds	Maximum Azimuth Rates (mils per second)	No. of Tests in Average	Average Probable Error With Bias A_o mils	E_o mils	D_o yds	Average Probable Error Without Bias A_o mils	E_o mils	D_o yds	
				SHORT RANGE TESTS							
30, 31	B and	760 to		3	1.2	1.4		1.4	1.0		T-5
July	C	2700			1.0	1.6		.7	.5		T-6
				MEDIUM RANGE TESTS							
17 Oct	B	5300 to		8	.71	1.3	15.0	.65	.75	4.5	T-5
		7000			.33	3.0	14.0	.37	.22	3.5	T-6
				MANUAL RADAR TRACKING TESTS (PIP MATCHING) AT MEDIUM RANGES							
				Operator Team 1 on T-5; Operator Team 2 on T-6							
20 Sept	B	2000 to		4 (2for				4.0	4.5	4.7	T-5
		3400		D_o)				2.5	2.1	2.2	T-6
				Operator Team 2 on T-5; Operator Team 1 on T-6							
20 Sept	C	2200 to		4 (2 for				11.0	6.2	8.1	T-5
		3400		D_o)				1.8	1.7	3.4	T-6
				Operator Team 1 on T-5; Operator Team 2 on T-6							
8 Oct	B	5300 to		4				4.1	3.7		T-5
		6400						2.7	2.1		T-6
				Operator Team 2 on T-5; Operator Team 1 on T-6							
8 Oct	B	5900 to		4				11.0	10.0		T-5
		6400						1.2	.9		T-6
				AVERAGE OF RESULTS FOR RADAR MANUAL TRACKING TESTS							
				Average of Operation of Team 1							
20 Sept	B and			8				4.0	4.1		T-5
8 Oct	C							1.5	1.3		T-6
				Average of Operation of Team 2							
20 Sept	B and			8				11.0	8.2		T-5
8 Oct	C							2.6	2.1		T-6