Kine Theodolite Tests on the A.P.F. Set for Britainn November, 1941

National Research Council of Canada. Radio Section

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NATIONAL RESEARCH COUNCIL OF CANADA

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KINE THEODOLITE TESTS ON THE A.P.F. SET FOR BRITAIN

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1. GENERAL

These tests, as originally planned, were to consist of a number of courses of each of the types outlined by Colonel H.M. Paterson in "Definitions of Accuracy and Rate Figures", Appendix A. The tracking in range, azimuth and elevation were to be recorded and the accuracy figures calculated as defined in the appendix referred to above. Because of the limited time that the Kine theodolites were available to us and bad weather conditions, we were able to complete only a ssmall part of the projected tests. The tests covered by this report consist of:

(a) short range courses with crossovers

(b) high angle short range courses

(c) random courses out to ranges of 8000 yards taken when the aircraft was flying about without wireless communication with the test group.

For all these courses range only was recorded, and the results are therefore confined to range following on courses of these three types.

2. FIXED ERROR

The A.P.F. range to a fixed target, which consisted of a copper lined trihedron 3500 yards from the A.P.F. set, was indicated as 3580 yards, the reset accuracy being less than +5 yards from day to day. The fixed error of the A.P.F., due to delay in the various transmitting and receiving circuits is, therefore, +80 yards. This is the error to be expected when the sweep is lined up on the calibration pips, as outlined in N.R.C. report PRA-25 entitled "GL Mark III C - Description and Preliminary Instructions". This error would normally be removed, as soon as it is known, by slipping the zero on the range indicating dial.

It seemed reasonable to expect that this fixed error would remain constant at about +80 yards when following aircraft. Actually the Kine theodolite tests show that it is much more erratic than was expected and seemed to depend

to some extent on the operator. This may be seen from the fixed errors found for the individual courses.

FIRST DAY'S RUN - OPERATOR A

Course	1	2	3	4	5	6	7	8	9	10
Fixed Error (Yds.)	46	44	44	52	43	40	27	36	69	75

SECOND DAY'S RUN - OPERATOR B

Course	12	14	15	16	17	18
Fixed Error (Yds.)	73	58	63	54	66	57

Operator B was much more experienced at following than Operator A, and it appears that his tracking is more consistent. The average fixed error for the second day with an experienced operator is +62 yards, noticeably less than the expected +80 yards. This difference may well be due to the different manner in which the operator keeps a moving echo on the hairline, as opposed to setting a fixed echo on the hairline, with time to make the final adjustments. However, the information we have to date does not preclude the possibility that this error, as well as the apparent change from day to day of the fixed error, is real and due to a defect in the apparatus. For the present, we prefer to attribute this to the tracking techniques of the operators, and believe that it will disappear with a well trained operator.

3. TRACKING ERRORS

Drawings #233 to #238, attached to this report, are plots of the observed tracking errors during the individual courses. The observations were taken at one-second intervals and the range error curves show the difference, positive or negative, between the A.P.F. range and the Kine theodolite range, henceforth referred to as the "true" range. For each course the following quantities are indicated:

(a) F.E. = fixed error as found by taking the average over the course of the differences between the A.P.F. range and the true range for each observation.

(b) P.E. = probable error as found by taking .845 x average error, the average error being found for each course after the F.E. for that course has been subtracted from the A.P.F. range values.

(c) The percentage of the time that the tracking is within certain values.

We consider data (c) to be the most informative, since it gives the percentage of the time when the ranges given by the A.P.F. do not depart by more than a given value from the true value. These figures may be taken as indicating the quality of the tracking during a particular course.

4. ACCURACY FIGURE

The term "accuracy figure" as used in this application is defined in Appendix A of "Definitions of Accuracy and Rate Figures", referred to in Paragraph 1 of this report, as follows.

If observations $O_1, O_2 \ldots\ldots\ldots\ldots O_n$ are made
at times $T_1, T_2 \ldots\ldots\ldots\ldots T_n$ when
the true values are $S_1, S_2 \ldots\ldots\ldots\ldots S_n$
then the errors are $O_1 - S_1 = E_1, O_2 - S_2 = E_2 \ldots$
$\ldots\ldots\ldots\ldots O_n - S_n = E_n$

and E shall not exceed $\pm E_A$ more often than 5% of the observations, where E_A is the "accuracy figure". The desired interval of time between observations is three seconds.

In these tests we have taken one-second observations but for the purpose of calculating the "accuracy figure" we have considered only three-second observations. The data for all courses has been considered as a whole, the three-second intervals for each course beginning with the first observation on that course. An error frequency chart (See Dwg. #239 attached to this report) has been plotted and from it the "accuracy figure" has been calculated. The percentages for different errors are given for the sake of completeness. The "accuracy figure" is 29 yards.

For the overall range accuracy the variation in the fixed error must also be considered. The spread of the fixed error is about $\pm$25 yards, and considering this

as a possible source of error in addition to the tracking errors we get 25 + 29, or say 50 to 55 yards as the overall range accuracy. As stated above, it is expected that the variation in fixed error will disappear with an experienced operator. If operational tests substantiate this assumption, it is to be expected that the range will be correct to $\pm$29 yards for 95% of the time.

5. RATE ERRORS

Referring again to Appendix A of "Definition of Accuracy and Rate Figures", the term "rate figure" is defined as follows. Where $E_2 - E_1 = D_1$, $E_3 - E_2 = D_2$... ... $E_{n+1} - E_n = D_n$, then D shall not exceed $\pm D_r$ more often than 5% of the observations, where D_r is the "rate figure". The time interval considered is three seconds. This "rate figure" has been calculated in these tests for the data as a whole, taking three-second intervals, the first observation on each course being taken as zero time for that course. A chart showing the frequency distribution of D's is shown in Dwg. #240 attached to this report. The "rate figure" is found to be 35 yards.

Instead of using this figure for specifying the rate accuracy of the set, we suggest that it would be more informative to refer to the rate figures on a percentage basis. The following considerations appear to be applicable.

The "wiggles" in the range accuracy curves (see Dwg. #233 to #238 attached to this report) are due to an incorrect rate being held for a certain time. The technique of operation in velocity tracking is to set a rate and maintain this rate until the indicator i.e. C.R.T. for range, and centre zero meters for azimuth and elevation, show that the set is getting off target. The rate is then corrected in the proper direction and maintained until the operator again gets an off-target indication. During these intervals the rate is wrong by an amount we can find from the range tracking curves. The magnitude and duration of these errors appear to be a good measure of the rate accuracy of the set.

(1) Assume that in normal tracking a wrong rate of duration three seconds or less can be tolerated.
(2) If W_R is the "rate accuracy" the rate is within $\pm W_R$ of being correct for 95% of the time.

This figure may be found from the range tracking curves by summing those times during which the error in rate is greater than $\pm W_R$. This amounts to selecting those portions of the courses where the slopes are greater than $\pm W_R$ and this slope is maintained for more than three seconds.

We find the following results for the courses here discussed:

The rate is correct to $\pm$7.5 yds./sec. for 73% of the time
The rate is correct to $\pm$10 yds./sec. for 90% of the time
The rate is correct to $\pm$12 yds./sec. for 95% of the time
The "rate accuracy" may then be given as 12 yds./sec.

With regard to assumption (1) on Page 4 of this report, we have not sufficient information on hand to decide whether or not this is reasonable. It would be very desirable to collect all the information available concerning the effect of wrong rates and their duration on a predictor. It is obvious, also, that the normal duration of a wrong rate is an important factor and is a characteristic of the method of tracking. Inspection of the "range tracking" curves shows that a wrong rate is normally held for something like 3 to 5 seconds. This may be called the "period of the set", that is the time needed for the operator to respond to an off-target indication and get a new rate established.

6. SUMMARY

(1) This report contains the results of tracking tests on an aircraft by the A.P.F. set. The types of courses followed were (a) short range with crossing point (b) high angle short range course (c) nondescript courses out to 8,000 yards. The elevation, azimuth and range of the beginning and end of each course may be seen on the data sheet (Page 7) of this report.

(2) The fixed error measured to a fixed, surveyed target is +80 yards.

(3) The fixed error in tracking aircraft varies between +27 and +75 yards. This variation is provisionally attributed to the operational technique of different inexperienced operators.

(4) The probable error in tracking is normally 10 to 12 yards. Considering the courses as a whole, the weighted probable error is 10.4 yards.

(5) Range following observed through seven crossover points shows no irregularities caused by the crossover.

(6) The "range tracking" curves are attached to this report as Dwgs. #233 to #238, inclusive. For each course the percentages for various accuracies are given.

(7) A chart showing the frequency of the range errors is attached to this report as Dwg. #239. The "accuracy figure" is 29 yards i.e. the range given by the A.P.F. set is accurate to within ±29 yards for 95% of the time.

(8) A chart showing the values of D, where $D_n = E_{n+1} - E_n$ (three-second intervals) is attached. The rate figure is 35 yards i.e. for 95% of the time the change in E per three-second interval is less than 35 yards.

(9) A suggestion is given for specifying the "rate accuracy". The rate is correct to ±12 yds./sec. for 95% of the time, neglecting wrong rates of duration less than three seconds, or the rate accuracy is 12 yds./sec.

W.J. Henderson.

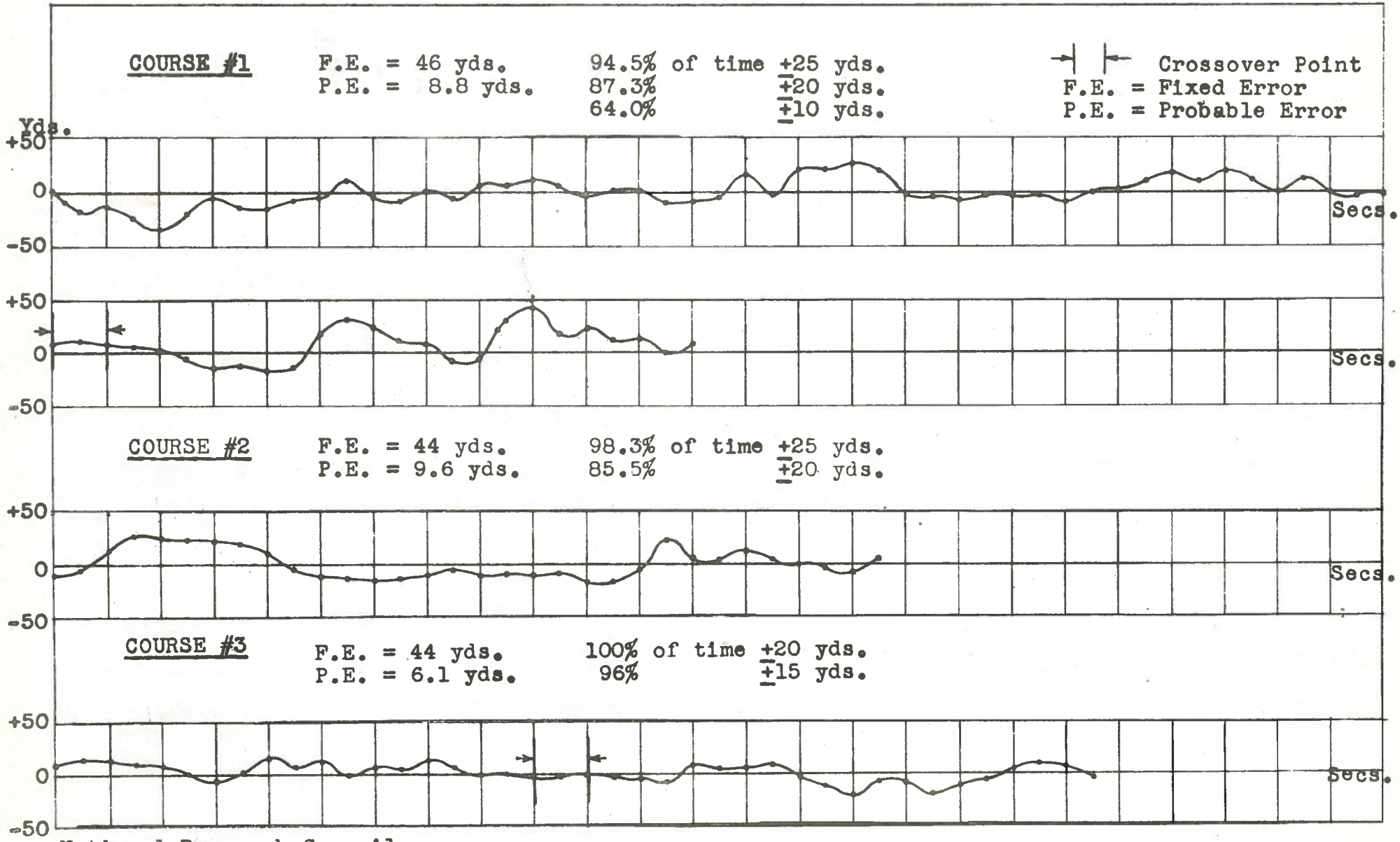
NOTE

It should be clearly understood that this report describes the results of initial trials made in the short period between completing the set and shipping it to Great Britain. More extensive tests will be carried out in Ottawa, when the next set is finished.

Further experience and operating practice may improve the above figures considerably.

DATA SHEET

COURSE NO.	ELEVATION		AZIMUTH		RANGE	
	START	FINISH	START	FINISH	START	FINISH
1	268	384	4601	6084	3750	2575
2	240	343	5511	5884	4320	3200
3	495	518	4059	5396	2585	2565
4	568	341	5223	5787	2235	3750
5	301	374	5420	4845	4075	3430
6	263	221	5065	5353	4725	5640
7	284	356	5422	4826	4545	3705
8	312	263	4494	5240	4220	5060
9	352	245	4316	5295	4025	5785
10	312	316	4198	4979	4645	4570
11	256	357	5241	4691	6125	4475
12	360	233	4618	5349	4135	6230
14	1073	687	4098	3846	4350	6070
15	835	1032	3809	4643	5400	4745
16	536	500	4142	3668	7800	8000
17	918	486	4364	5718	4440	7000
18	600	615	5602	4519	4015	3525



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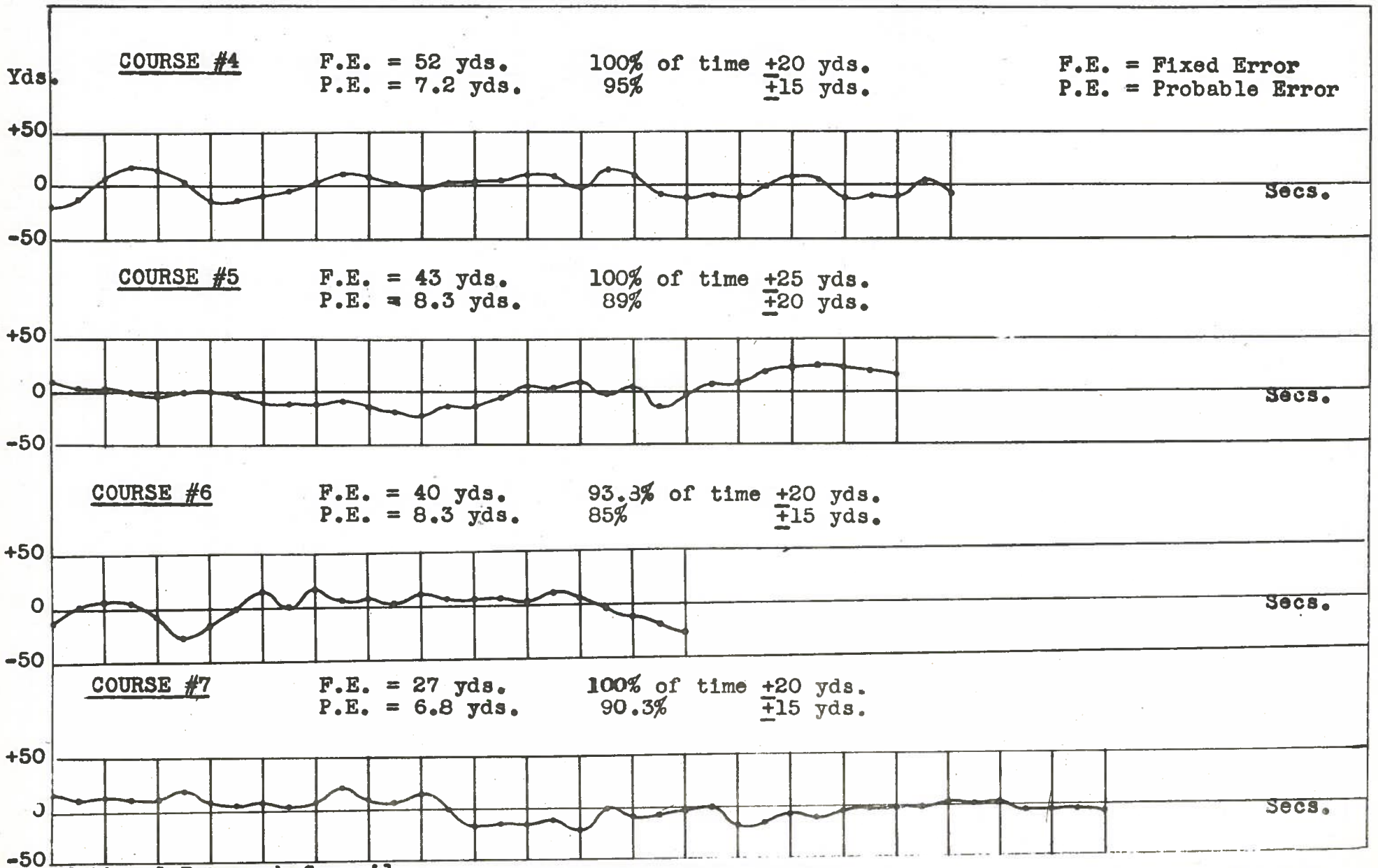
RANGE TRACKING - Courses 1, 2 and 3.

REF. #233

SECRET



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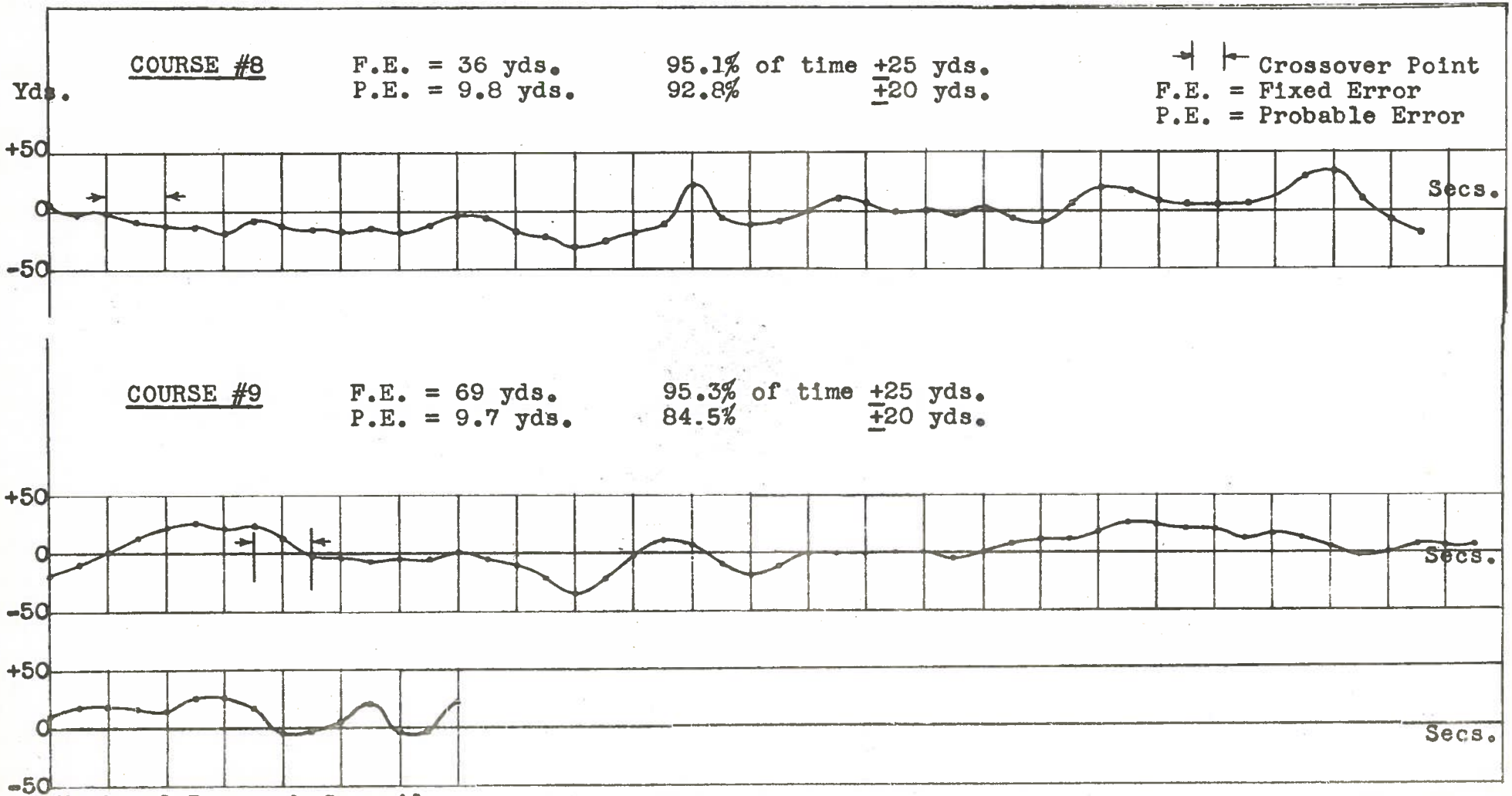
RANGE TRACKING - Courses 4,5,6 and 7.

REF.#234

SECRET



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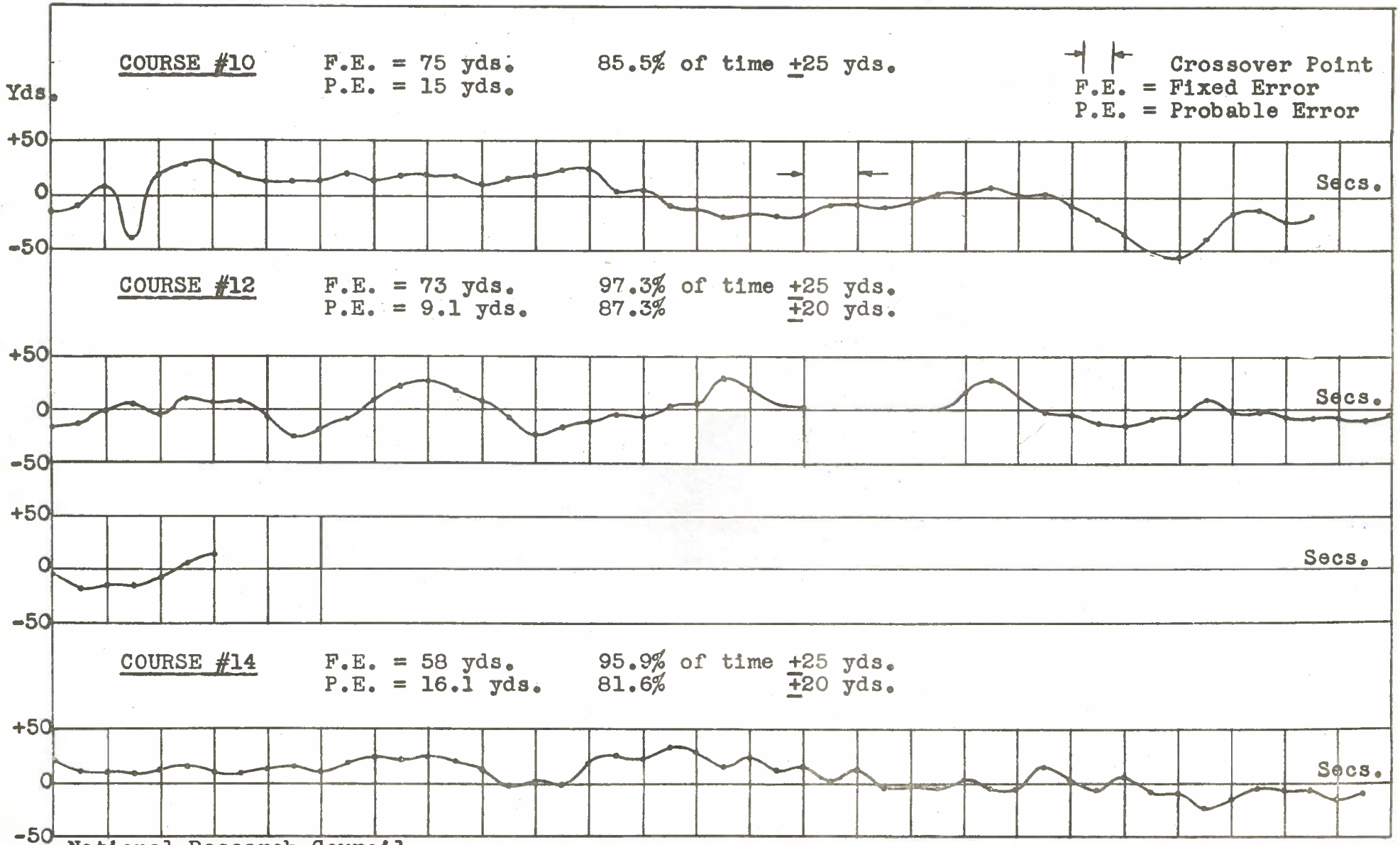
RANGE TRACKING - Courses 8 and 9.

REF. #235

SECRET



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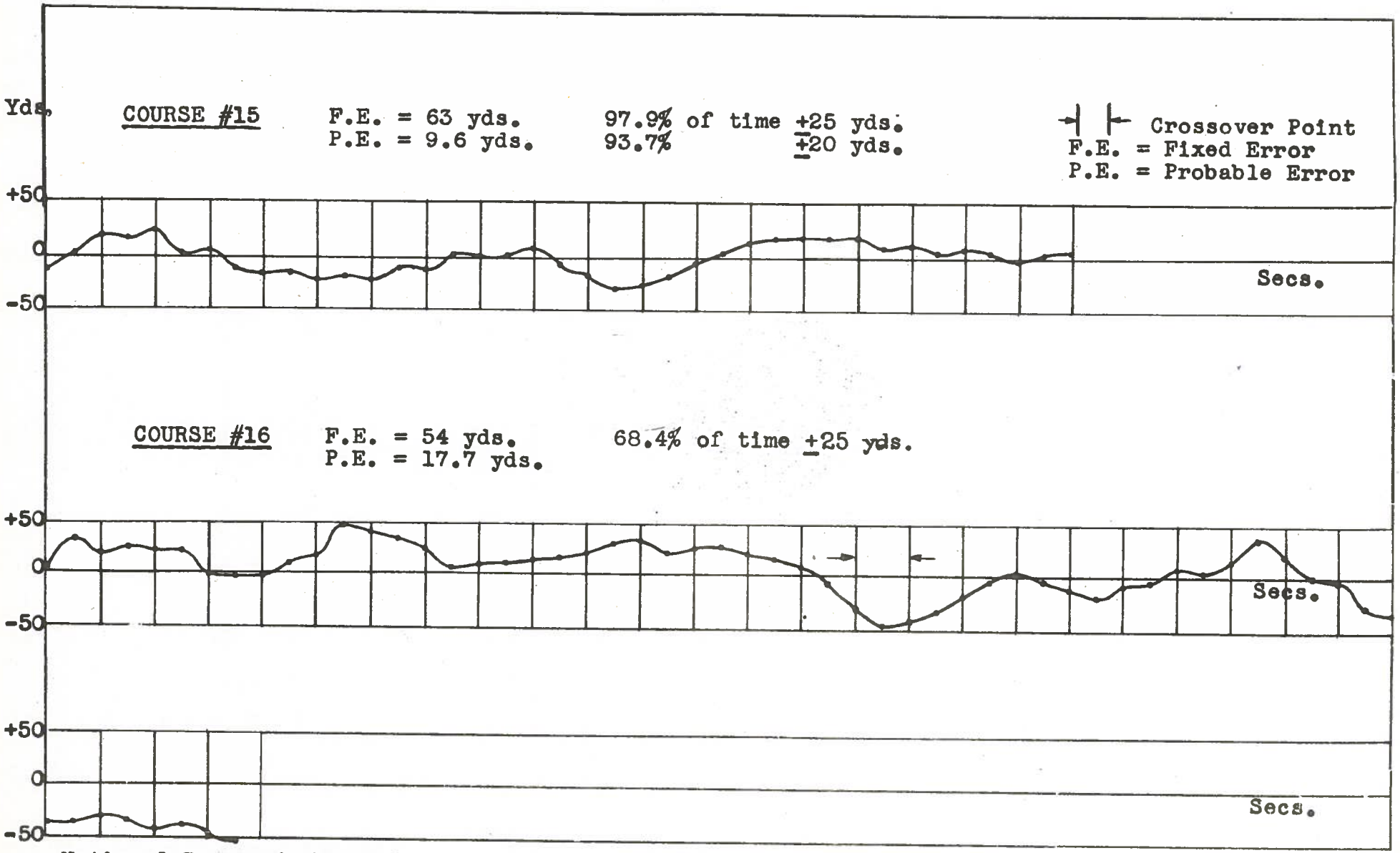
RANGE TRACKING - Courses 10, 12 and 14.

REF. #236

SECRET



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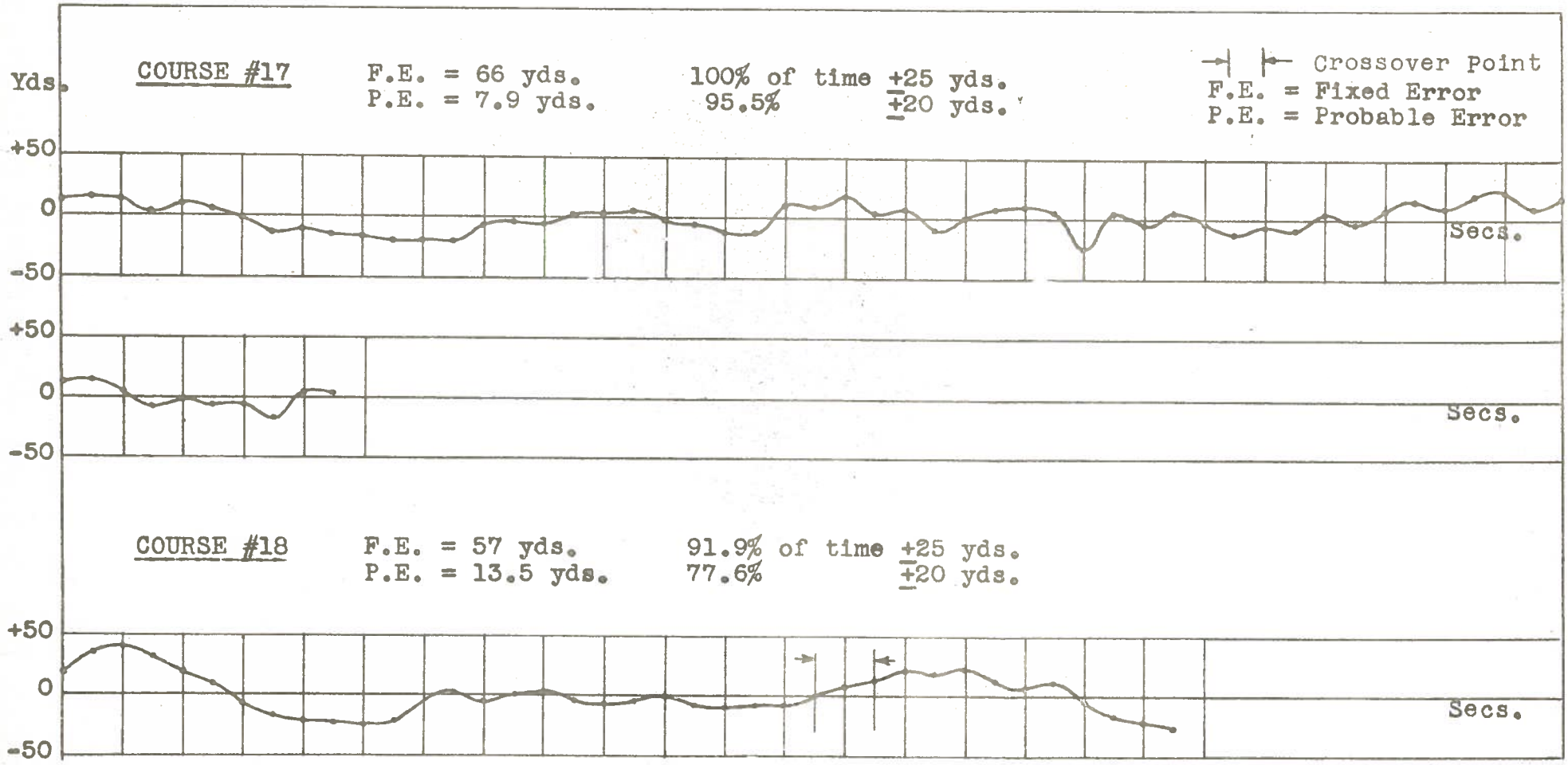
RANGE TRACKING - Courses 15 and 16.

REF. #237

SECRET



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RANGE TRACKING - Courses 17 and 18

REF. #238

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DEFINITION OF E

O_1 , O_2 , O_3 ..... O_n are observations

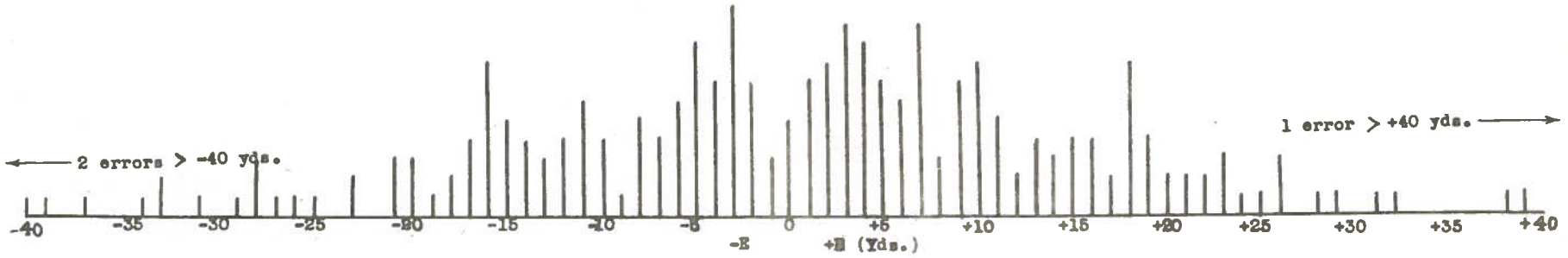
S_1 , S_2 , S_3 ..... S_n are the corresponding true values

$O_1 - S_1 = E_1$ $O_2 - S_2 = E_2$ ..... $O_n - S_n = E_n$

Time interval between observations is 3 seconds.

54.0% ± 10 yds.
70% ± 15 yds.
84.4% ± 20 yds.
90.3% ± 25 yds.
95% ± 29 yds.

ACCURACY FIGURE = 29 yds.



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FREQUENCY DISTRIBUTION OF THE ERRORS IN RANGE

REF. #239

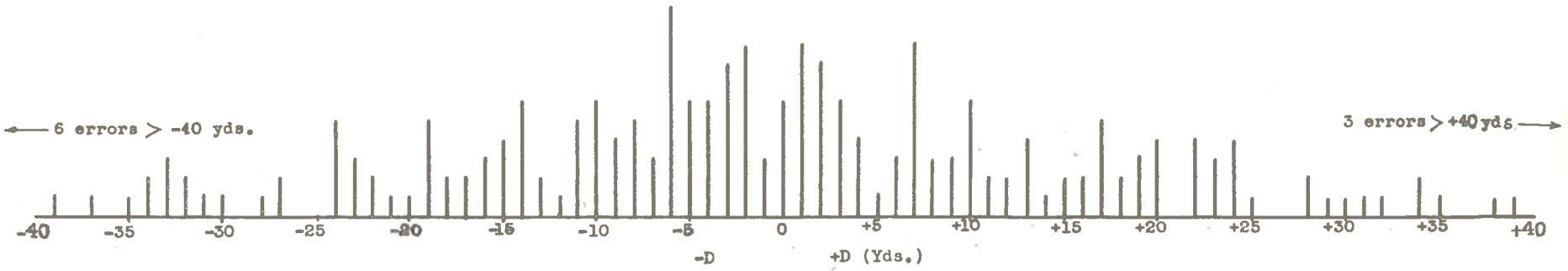
SECRET

DEFINITION OF D

$E_2 - E_1 = D_1 \quad E_3 - E_2 = D_2 \ldots\ldots\ldots\ldots E_{n+1} - E_n = D_n$

39% ± 7.5 yds.
65% ± 15 yds.
75% ± 20 yds.
87% ± 25 yds.
90% ± 30 yds.
95% ± 35 yds.

RATE FIGURE = 35 yds.



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