DECLASSIFIED

[redacted]

COPY NO. 26

NAVY DEPARTMENT - OFFICE OF RESEARCH AND INVENTIONS

DOWNGRADING AT 12 YEAR INTERVALS
NOT AUTOMATICALLY DECLASSIFIED
DOD DIR 5200.10

NAVAL RESEARCH LABORATORY
Washington, D.C.

* * *

MISSILE CONTROL DIVISION - OPERATIONAL RESEARCH SECTION

15 May 1946

FR-2819

TRACKING PERFORMANCE OF THE AUTOMATIC RADAR EQUIPMENT MARK 25 MOD 2 (Experimental Model) WITH THE GUN DIRECTOR MARK 37 AND COMPUTER MARK 1

By B.H. Stafford, T.W. Chappelle
P.B. Coggins, and V.C. Gallagher

DECLASSIFIED by NRL Contract
Declassification Team
Date: 6 OCT 2014
Reviewer's name(s): H. Do, P. HANNA
Declassification authority: NAVY DECLASS MANUAL, 11 DEC 2012

Report R-2819

DOWNGRADING AT 12 YEAR INTERVALS
[redacted]
NOT AUTOMATICALLY DECLASSIFIED
DOD DIR 5200.10

* * *

Approved by:

J.J. Fleming - HEAD, Operational Research Section
Dr. R.M. Page
Superintendent
Missile Control Division

Commodore H.A. Schade, USN
Director
Naval Research Laboratory

Preliminary Pages....a-c
Distribution List.... c
Numbered Pages..... 17
Plates..... 25

NRL Problem O-83,1T-C

[redacted]

DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by
UNLIMITED only.

DECLASSIFIED

COPY NO. 23

NAVY DEPARTMENT — OFFICE OF RESEARCH AND INVENTIONS

NAVAL RESEARCH LABORATORY
Washington, D.C.

* * *

MISSILE CONTROL DIVISION - OPERATIONAL RESEARCH SECTION

15 May 1946

TRACKING PERFORMANCE OF THE AUTOMATIC RADAR EQUIPMENT MARK 25 MOD 2 (Experimental Model) WITH THE GUN DIRECTOR MARK 37 AND COMPUTER MARK 1

By B.H. Stafford, T.W. Chappelle
P.B. Coggins, and V.C. Gallagher

Report R-2819

Approved by:

J.J. Fleming - HEAD, Operational Research Section
Dr. R.M. Page, Superintendent, Missile Control Division
Commodore H.A. Schade, USN, Director, Naval Research Laboratory

Preliminary Pages....a-c
Distribution List.... c
Numbered Pages..... 17
Plates..... 25

NRL Problem O-83,1T-C

[redacted]

ADDRESS REPLY TO
DIRECTOR, NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.
AND REFER TO:

NAVY DEPARTMENT
OFFICE OF RESEARCH AND INVENTIONS
NAVAL RESEARCH LABORATORY
WASHINGTON 20, D. C.

C-S67-7(1120:BHS)

C-1100-180/46
bel

JUN 26 1946

To: The Chief of the Bureau of Ordnance
Attn: Codes Re4f and Re4c

Subj: Radar - Fire Control - Missile Control Division Report No. R-2819, dated 6 May 1946, "Tracking Performance of the Automatic Radar Equipment Mark 25 Mod 2 (Experimental Model) with Gun Director Mark 37 and Computer Mark 1," Forwarding of.

Encl: (HW)
(A) Thirteen (13) copies of the subject report.

1. Enclosure (A) is forwarded herewith for information and retention.

W. J. Miller
Captain, USN
By direction of the Director
Naval Research Laboratory

Distribution:
See distribution list in report.

ABSTRACT

To provide an estimate of the performance to be expected from the automatic tracking Radar Mk 25 Mod 2, preliminary tests on an experimental model of this radar have been conducted at Bell Telephone Laboratories (Whippany, N.J.) by the Naval Research Laboratory with the cooperation of BTL engineers. The tests were carried out using aircraft flying at 170 and 230 knots on straight-line and evasive courses. The subject radar was mounted on an amplidyne-drive Gun Director Mk 37, and gun orders were generated by a Computer Mk 1 Mod 13. The radial dispersion "s" of the tracking errors was between 0.4 mil and 0.8 mil for portions of the runs where the angular velocity of the target with respect to the director was less than 25 mils per second and was between 1.1 mils and 3.2 mils for portions of the runs where angular velocities exceeded 25 mils per second. The value of "h", which includes the radar boresight error, was between 0.8 mil and 1.4 mils for all of the runs. A visual examination of the tracking error curves showed a basic frequency of oscillation of approximately 0.4 cycle per second. For the representative runs analyzed, both the tracking and gun order errors were comparable to those obtained using optical tracking with the Gun Director Mk 37 and Computer Mk 1 combination.

In conical scan the Radar Mk 25 Mod 2 could track an F4U aircraft automatically to about 40,000 yards. When the radar was operated in



spiral scan, the maximum observable range of this type of aircraft was 25,000 yards. Two aircraft targets could be discriminated by the radar in traverse angle when the target separation was about 1.5 degrees or larger. Range discrimination was possible in all of the runs made in the present tests since the range gate is nominally 40 yards wide and the minimum target separation achieved in range in the aircraft runs was 100 yards. A more thorough appraisal of the subject system can be made only after a production model has been subjected to complete operational, system, and type tests.

TABLE OF CONTENTS

ABSTRACT . . . . . -b-

INTRODUCTION 1

TESTING PROCEDURE 4

TRACKING AND SOLUTION ERRORS 6

TARGET DISCRIMINATION AND MAXIMUM RANGE FOR AIRCRAFT 11

CONCLUSIONS 12

ACKNOWLEDGEMENTS 12

REFERENCES 13

TABLE 1 Tracking Errors (Radar Mk 25) 14

TABLE 2 Solution Errors (Radar Mk 25) 15

TABLE 3 Survival Probabilities (Radar Mk 25) 16

TABLE 4 Comparison of Tracking and Solution Errors (Radars Mk 25 and Mk 12) 17

PLATES 1 through 25 Tracking and Solution Error Curves . . . .

DISTRIBUTION LIST

BuOrd, Re4f	(5)
BuOrd, Re4c	(5)
BuShips (938 for 917)	(2)
CHORI	(1)
CBA	(1)
BOTU	(1)
NEL	(1)
Via BuOrd, Re4f	
BTL, Whippany, N.J. Attn: F.E. Nimmcke	(2)
BTL, Murray Hill, N.J. Attn: B.D. Holbrook	(1)

[redacted]

INTRODUCTION

1. In accordance with the problem assignment of reference (1) and as agreed upon by representatives of the Bureau of Ordnance and of the Naval Research Laboratory, preliminary tests of an experimental model of the Radar Equipment Mk 25 Mod 2 were conducted at Bell Telephone Laboratories (Whippany, N.J.). As installed at Whippany, the subject radar was mounted on an amplidyne-drive Gun Director Mk 37 Mod 49 and operated in conjunction with the Computer Mk 1 Mod 13 Serial #599.

2. The purpose of the tests was to make a quick determination of the performance of the Radar Equipment Mk 25 Mod 2 when operated as a part of the Gun Director Mk 37 and Computer Mk 1 system. Therefore, an analysis has been made of tracking and gun order errors for various types of courses, including approach runs, pass runs, dogleg runs, and evasive S-shaped approach runs. In addition, measurements were made to give an indication of the angular and range discrimination of the radar when operated against two targets at the same time. Extensive tests of the operation of the Radar Equipment Mk 25 Mod 2 were not undertaken on the experimental model installed at Whippany, since a production model of the radar will be made available to NRL for complete evaluation some time in the near future. Also of interest is a comparison of the performance of this radar with the Radar Equipment Mk 12 Mod 2 as used with the Gun Director Mk 37.

3. The Radar Equipment Mk 25 Mod 2 is an automatic tracking, X-band equipment designed by BTL for use in the Gun Director Mk 37 fire control system. This radar can be made to scan in the following three ways:

(a) Small conical scan for tracking targets (total beam width including beam shift of 2.5 degrees).

(b) Large conical scan for spotting of surface fire (total beam shift of 10 degrees).

(c) Spiral scan for target acquisition (total field of view of 10 degrees).

In the Gun Director Mk 37, the pointer, the trainer, and the radar range operator have 5-inch cathode ray oscilloscopes upon which either B or modified E scans can be presented at will. The B scan has its range axis presented vertically and shows 5 degrees of traverse angle on either side of the direction in which the radar is pointed, whereas the modified E scan has its range axis presented horizontally and shows 5 degrees of elevation angle on either side of the direction in which the radar is pointed. In addition, the radar range operator has a 3-inch oscilloscope to give an A scan and the pointer has the possibility of using an E scan of 0 to 85 degrees with the range axis horizontal. The range sweeps for all of the oscilloscopes are chosen by the radar range operator as either 50,000 yards or ± 1000 yards centered about the range gate. The range gate is nominally 40 yards wide. When operated in standby condition, the trainer is provided with one-man control of all coordinates.

[redacted]

4. The laboratory model of the Radar Equipment Mk 25 Mod 2 tested differed in several ways from the proposed production equipment. The most important differences may be listed as follows:

(a) The transmitter and receiver of the Radar Mk 25 Mod 2 were not available so the transmitter and receiver of the Radar Mk 34 Mod 2 were modified and used. The modifications consisted of using a tunable magnetron Type 2J51 (3.4 cm) and a hydrogen thyratron modulator to give a peak r-f output of about 80 kilowatts and a pulse width of about 0.25 microsecond. The receiver used a Type D-153034 i-f strip having a bandwidth of about 10 megacycles and incorporating anti-jam features.

(b) The modulation generator keyed the transmitter at a fixed repetition rate of about 1800 pulses per second whereas the production model will be pulsed randomly between 1800 and 2000 pulses per second.

(c) The automatic tracking servo units as built for the Radar Equipment Mk 12 Mod 2 were used. The production design for the angle circuits of the Radar Equipment Mk 25 Mod 2 will be similar to these, but a new range unit will be used.

(d) The production equipment will utilize a scanner which will have the same scanning capabilities as the present unit but which will operate differently mechanically.

TESTING PROCEDURE

5. The subject fire control system was operated against single-engine Navy aircraft of the fighter type flying various courses as described in paragraph 7. The Radar Equipment Mk 25 Mod 2 tracked the target automatically in angle and in range for all of the runs. The Computer Mk 1, however, was operated with continuous rate control in one of the following three ways for a given run:

(a) Computer in automatic but no increment quantities transmitted to the director. (Some runs were made without the computer.)

(b) Computer in automatic and increment quantities transmitted to the director.

(c) Computer in semi-automatic and increment quantities transmitted to the director.

Approximately the same number of runs were made in each category. The runs of type (b) and (c) were of special interest since they would demonstrate the presence of any feedback from the computer that might cause deterioration of the tracking under certain conditions. Unless otherwise noted, all runs in this report were made with computer-aided tracking that is, increment quantities were transmitted to the gun director.

6. Tracking errors were recorded photographically through the pointer's telescope of the Gun Director Mk 37. Present director

[redacted]

position data from the Gun Director Mk 37 and Radar Mk 25 and gun order data from the Computer Mk 1 were transmitted to a dial box containing synchro receivers. A continuous record of these data was made by photographing the face of the dial box with a motor-driven moving-picture camera synchronized with the tracking camera in the director. For target discrimination runs in range and in traverse angle, another camera was added to photograph the presentation of the A-scope of the Radar Mk 25. All cameras were of the 16-mm magazine load type and were operated at 20 frames per second. Data obtained from the various films were analyzed at NRL by the usual methods.

7. For the present test, the average speed of the aircraft was 170 knots, except for high-speed runs where the average speed was about 230 knots. The types of runs used for tracking and gun order analysis were as follows:

(a) Pass runs, altitide 2000 feet, minimum range approximately 1200 yards.

(b) Pass runs, altitude 5000 feet, minimum range approximately 4000 yards.

(c) Pass runs, altitude 5000 feet, minimum range approximately 2000 yards.

(d) Approach runs, altitude 5000 feet.

(e) High speed approach runs, altitude 2000 feet.

(f) Dogleg runs, altitude 2000 feet, turning range approximately 3000 yards.

(g) Evasive S-shaped approach runs, altitude 5000 feet.

(h) Pass runs, altitude 5000 feet, minimum range approximately 2200 yards, for which Dummy Director Mk 1 Mod 3 was used to introduce periodic oscillations of 0.5° peak amplitude

and 4.5 second period into the increment channel of the director system. In a few cases, the Dummy Director was installed but not oscillated.

(i) Approach runs, altitude 3000 feet, lateral separation of two aircraft of 1000 yards, 300 yards, 200 yards, and 50 yards

(j) Approach runs, altitude 3000 feet, range separation of two aircraft of 500 yards, 300 yards, 200 yards, and 100 yards.

TRACKING AND SOLUTION ERRORS

8. The tracking and gun order error curves for representative runs have been presented in Plates 1 through 21, where the errors have been plotted against time and the present target range has been indicated along the time scale. From an inspection of the graphs for straight-line courses, it is apparent that there are regions of comparatively bad performance in nearly every run. Therefore, to give a clearer picture of this situation, the average tracking errors as summarized in Table 1 and the average gun order errors as given in Table 2 have been grouped to correspond to the "normal" and the "crossover" portions of the course. As determined by inspection, the "normal" part of a run is that portion where the present target range is greater than 2000 yards and the angular velocity (either lateral or vertical) of the target is less than 25 mils per second. The "crossover" part of the run is that portion where the present target range is less than 2000 yards or the angular velocity (either lateral

or vertical) of the target is greater than 25 mils per second. The angular acceleration of the target has caused a slight shift of the crossover region; this has been taken into account in grouping the data. For convenience, the turning portion of the dogleg runs has been listed in the "crossover" column of Tables 1 and 2 and the straight portion in the "normal" column.

9. As given in Table 1, the average lateral or vertical tracking error of the Radar Mk 25 Mod 2 is 0.3 mil to 0.8 mil for the normal portion of the run and 0.6 mil to 3.1 mils for the crossover portion. The corresponding values of the standard error "s" (which is the radius of a circle containing about 40% of the tracking errors) are between 0.4 mil and 0.8 mil for normal conditions and 1.1 mils to 3.2 mils for crossover conditions. The initial radar boresight was made on a water tower and then corrected on aircraft flying at low angular rates. Radar boresight errors throughout the set of runs were generally not larger than one mil as indicated by the fact that the value of "h" in Table 1 is between 0.8 and 1.4 mils. The average tracking errors of the Radar Mk 25 Mod 2 are comparable to those of the Gun Director Mk 37 Mod 49 employing computer-aided optical tracking ("h" is zero and "s" is 1.0 to 1.3 mils for slant ranges greater than 2000 yards as given in reference (4)). In the case of the S-shaped approach course, it should be noted that the increased average lateral tracking error is partly due to the effect

TRACKING ERRORS NOT CORRECTED FOR VERTICAL PARALLAX.

of the Computer Mk 1, which, in sending increments to the gun director, would tend to drive it off target under these conditions.

10. Inspection of the tracking error curves shows a primary frequency of approximately 0.4 cycle per second to be present. In the crossover region, there may be undesirable regeneration in the subject fire control system operated in automatic with the computer feeding increment quantities back to the director (see, for example, the tracking error curves of Plate 3). However, the increased tracking errors (about 10 mils peak-to-peak) occurring in such a crossover region are due not only to this effect but also to the increased size of the target, since the radar may not track the visually estimated center of the target. The same type of oscillation at crossover appeared in the tracking of the Radar Mk 12 Mod 2 (see reference (2)) but, in this case, the frequency of oscillation was about 0.1 cycle per second and the amplitude was as high as 60 mils peak-to-peak. To minimize the effect when using the Radar Mk 12 Mod 2, it was recommended in reference (2) that the rate keys be opened during crossover. The preliminary data obtained in the present report is not complete enough to make such a recommendation for the Radar Mk 25 Mod 2. If possible, it would be desirable to have the final design of the servo loop circuits reduce this defect.

11. To determine roughly how much disturbance could be introduced into the tracking of the Radar Mk 25 Mod 2 by the Computer Mk 1 when operated in automatic and transmitting incremental present position

data to the gun director, a dummy director was used to insert periodic oscillations (0.5° peak amplitude and 4.5 seconds period) into one of the angular incremental channels during a tracking run. The results of introducing such a signal into the train channel during a pass run are presented in graphical form in Plates 22 and 23. Both tracking and gun orders were affected to a considerable extent in the train channel and, due to interaction, to a much smaller extent in the elevation channel. The lateral tracking error corresponded very closely in both phase and amplitude to the oscillation introduced by the dummy director. The lateral gun order error corresponded to the dummy director's oscillation in phase but was from 3 to 4 times aslarge in amplitude. For control purposes, a run was made with the dummy director installed but not oscillated; the results are shown in Plate 13.

12. The average lateral and vertical gun order errors as presented in Table 2 are also seen to be comparable to those obtained when using optical tracking with the Gun Director Mk 37 (see Reference (5)). It will be noted in Run 141, Plate 8, that tracking and gun order errors are larger than those in other straight-line runs. This can be accounted for by the fact that no increment quantities were sent back to the director by the computer, hence no tracking aid was given to the system by the computer. The average lateral gun order error both in the case of the dogleg during the turn and throughout

the S-shaped course is expected to be large since the computer was designed to give an accurate solution only for straight-line courses.

13. As a further illustration of the effectiveness of the subject fire control system when operated under the ideal conditions of the present test, Table 3 has been included to show the survival probability of a Nakajima bomber flying high altitude and low altitude straight-line pass courses. As used here, the survival probability (Q) is given for each 500-yard advance range group of the runs and represents the probability of obtaining no burst within 47 feet of the target throughout that range group when proximity-fuzed 5"/38 projectiles are fired at the rate of one round per second. The assumptions and procedure used in making such calculations are explained in reference (5).

14. A comparison of the average tracking and gun order errors of the Gun Director Mk 37 and Computer Mk 1 system when operated with the Radar Mk 12 Mod 2 or the Radar Mk 25 Mod 2 has been presented in Table 4 for runs which were similar in their characteristics. The data for the Radar Mk 12 Mod 2 have been taken from the report of reference (2). The tracking errors of the Radar Mk 25 Mod 2 are seen to be about one-fifth as large as those of the Radar Mk 12 Mod 2 on comparable runs. For the pass runs of Table 4, the gun order errors of the Computer Mk 1 operated in semi-automatic in conjunction with the Radar Mk 25 and Gun Director Mk 37 are about one-third as large as those occurring when the Radar Mk 12 Mod 2 is operated similarly with the same director. Similar runs with the Computer Mk 1 operated in automatic show errors when operated with the Radar Mk 12 to be more than 10 times as large as those present during

operation with the Radar Mk 25. The large gun order errors present when using the Radar Mk 12 Mod 2 were due to a comparatively large amplitude oscillation that occurred in the automatic angle tracking under some conditions, particularly in the crossover region of pass runs, as discussed in paragraph (10).

TARGET DISCRIMINATION AND MAXIMUM RANGE

15. Plates 24 and 25 present tracking curves which are representative of the runs made to determine the ability of the subject radar to discriminate in traverse angle between two identical aircraft targets. Examination of the data shows that the Radar Mk 25 Mod2(operated with the Computer Mk 1 in automatic) consistently discriminated between two aircraft when the angular separation was about 1.5 degrees (25 mils) or greater.

16. Since the width of the range gate in the Radar Mk 25 Mod 2 is 40 yards, it would be expected that the minimum range separation possible between two aircraft targets without causing confusion would be approximately the same value. It was not possible to determine this value during present tests since the target separation could not be made less than 100 yards because of propeller "wash".

17. The maximum automatic tracking range of the Radar Mk 25 Mod 2 was found to be about 40,000 yards for an F4U type of aircraft. The maximum range at which this type of target was visible when the radar was operated in spiral scan was about 25,00 yards.

CONCLUSIONS

18. In general the Radar Mk 25 Mod 2 provided excellent operational performance when operated in conjunction with the Gun Director Mk 37 Mod 49 and Computer Mk 1 Mod 13. The performance was comparable to results obtained when the system is operated with optical tracking. However, before a complete evaluation of the system can be made, a production model of the equipment will have to be subjected to detailed operational, system, and type tests.

ACKNOWLEDGMENTS

19. The cooperative assistance rendered in the conduct of the subject tests by the following persons is greatly appreciated: Lt. Garmirian, and Lt (jg) Mason, of the Bureau of Ordnance; Mr. Hight, Mr. Nimmcke, and Mr. Johnson of the Bell Telephone Laboratories (Whippany, N.J.).

REFERENCES

1. BuOrd conf. ltr. S67(Mk 25)(Re4f) to NRL, "Request for Assignment of Problem O-83.1T-C: "Consultation, System, Operation and Type Tests of Radar Equipment Mk 25", dated 6 July 1945.

2. NRL secr. (now classified conf.) report RA3A231A, "Tracking Tests using the Automatic Radar Mk 12 Mod 2 with the Gun Director Mk 37 and Computer Mk 1" dated 12 April 1945 and forwarded to BuOrd by NRL secr. ltr. S-S67-7(397), Ser. #4798, dated 10 May 1945.

3. NRL conf. report RA3A233A, "Analysis of the Performance of the Automatic Radar Mk 12 Mod 2", dated 21 June 1945 and forwarded to BuOrd by NRL conf. ltr. C-S67-7(398A), C-395-435/45, dated 31 July 1945.

4. NRL secr. (now classified conf.) report S-S71-3(395A:BLS) "Optical and Radar Tracking Studies of Navy AA Fire Control Equipment tested at CBA from 1 March to 1 November 1944", dated 1 January 1945 and forwarded to BuOrd by NRL secr. ltr. S-S71-3(395a:BLS) Ser. #4218, dated 1 January 1945.

5. NRL conf. ltr. report C-S71-3(397C:TWC), C-395-690/45, "Comparative Non-Firing Anti-Aircraft Tests of Seven Gun Directors Systems Aboard USS WYOMING during July, August 1945", dated 11 February 1946 and forwarded to BuOrd by NRL conf. ltr. C-S71-3(397C:TWC), C-395-690/45, dated 13 March 1946.



TABLE 1

SUMMARY OF AUTOMATIC TRACKING ERRORS OF RADAR MK 25 MOD 2
USED WITH GUN DIRECTOR MK 37 MOD 49 AND COMPUTER MK 1
MOD 13

GUN TYPE	MIN RANGE (Yards)	ALT. (Ft.)	SPEED (Knots)	NO. OF RUNS.	MPI ERROR (MILS) COMPLETE RUN			DISPERSION (MILS) NORMAL REGION			DISPERSION (MILS) CROSSOVER REGION		
					Lat.	Vert.	Rad. "h"	Lat.	Vert.	Rad. "s"	Lat.	Vert.	Rad."s"
PASS	1400	2000	180	8	-1.2	-0.3	1.2	0.6	0.5	0.7	1.7	1.4	1.9
PASS*	1000	2000	150	2	-0.9	-0.2	0.9	0.7	0.6	0.8	3.1	1.7	3.2
PASS	1000	2000	150	2	-0.9	-0.2	0.9	0.6	0.5	0.7	3.0	1.3	2.9
PASS	1300	2000	225	2	-1.0	-0.3	1.0	0.5	0.4	0.6	2.2	1.5	2.4
PASS	3800	5000	190	4	-1.3	-0.4	1.4	0.6	0.6	0.8	1.1	0.6	1.1
PASS**	2000	5000	150	1	-1.3	-0.4	1.4	0.8	0.5	0.8	2.1	1.1	2.1
APPROACH		5000	185	2	-1.0	-0.8	1.3	0.4	0.4	0.5	___	___	___
APPROACH		2000	240	2	-0.8	-0.2	0.8	0.4	0.3	0.4	1.5	0.8	1.5
OGLEG	3000	2000	180	2	-0.8	-0.2	0.8	0.6	0.6	0.8	1.8	1.6	2.1
-APP.		5000	180	2	-0.8	0.0	0.8	1.1	0.7	1.2	___	___	___

Note: Averages with the Computer Mk 1 in semi-automatic and automatic operation have been lumped since the mode of operation appeared to have no effect on average error.

* No computer aid.

** The DG synchro used with the Dummy Director was inserted in the increment channel in this run; however, it was not oscillated.

TABLE 2

SUMMARY OF GUN ORDER ERRORS OF COMPUTER MK 1 MOD 13 USED WITH GUN DIRECTOR MK 37 MOD 49 AND RADAR MK 25 MOD 2

RUN TYPE	MIN RANGE (Yards)	ALT (Ft.)	SPEED (Knots)	NO. OF RUNS	AVERAGE G.O. ERRORS (MILS) NORMAL REGION Lat.	NORMAL REGION Vert.	CROSSOVER REGION Lat.	CROSSOVER REGION Vert.
PASS	1400	2000	180	8	2.3	3.0	9.4	5.1
PASS*	1000	2000	150	2	3.2	4.0	16.6	12.8
PASS	1000	2000	150	2	4.2	3.7	17.9	6.7
PASS	1300	2000	225	2	2.2	3.2	8.6	5.2
PASS	3800	5000	190	4	2.8	2.5	4.3	3.1
PASS**	2000	5000	150	1	4.2	1.9	6.9	2.4
APPROACH		5000	185	2	2.3	3.0	___	___
APPROACH		2000	240	2	3.1	2.6	4.7	4.5
DOGLEG	3000	2000	180	2	2.9	3.1	36.3	4.0
S-APP.		5000	180	2	62.1	4.9	___	___

Note: Averages with the Computer Mk 1 in semi-automatic and automatic operation have been lumped since the mode of operation appeared to have no effect on average error.

* No computer aid

** The DG Synchro used with the Dummy Director was inserted in the increment channel in this run, however, it was not oscillated.

TABLE 3

SURVIVAL PROBABILITY OF NAKAJIMA BOMBER AGAINST RADAR MK 25 WITH COMPUTER MK 1 AND GUN DIRECTOR MK 37

4 PASS RUNS - ALTITUDE 5000' - MINIMUM RANGE 3800 YD - SPEED 190 KNOTS

ADVANCE RANGE GROUP (YDS x 10	SURVIVAL PROBABILITY (Q)	EFFECTIVE TIME IN RANGE GROUP (SECONDS)
60-55	0.72	8.03
55-50	0.59	7.94
50-45	0.38	12.34
45-40	0.31	10.86
40-35	0.10	16.58
35-40	0.22	12.99
40-45	0.48	8.12
45-50	0.34	11.51
50-55	0.70	5.72
55-60	0.77	5.20
60-65	0.90	4.81

4 PASS RUNS - ALTITUDE 2000' MINIMUM RANGE 1400 YD - SPEED 180 KNOTS

ADVANCE RANGE GROUP (YDS x 10	SURVIVAL PROBABILITY (Q)	EFFECTIVE TIME IN RANGE GROUP (SECONDS)
40-35	0.44	5.41
35-30	0.42	6.09
30-25	0.25	6.31
25-20	0.17	6.45
20-15	0.07	7.52
15-min	0.04	9.94
min-15	0.53	7.13
15-20	0.34	6.32
20-25	0.44	4.92
25-30	0.44	4.68
30-35	0.57	4.49
35-40	0.62	4.27
40-45	0.51	4.16
45-50	0.62	4.34

Note: Survival probabilities are calculated according to the method described in reference (5), using the following constants: Lethal radius of target - 47 ft., Fuze operability 0.6, Radial Gun dispersion (standard deviation) - 5 mils, Rate of fire - 1 round per second. Ammunition - 5-inch projectile, RDX loading, Fuze Mk 32.

TABLE 4

COMPARISON OF AVERAGE TRACKING AND GUN ORDER ERRORS OF RADARS MK 25 MOD 2 AND MK 12 MOD 2 WHEN USED WITH COMPUTER MK 1 AND GUN DIRECTOR MK 37

TYPE OF RUN	NO OF RUNS	MODE OF COMPUTER OPERATION	AVERAGE ERROR IN MILS							
			Tracking				Gun Orders			
			Mk 12		Mk 25		Mk 12		Mk 25	
PASS RUNS			Lat.	Vert.	Lat.	Vert.	Lat.	Vert.	Lat.	Vert.
Alt. 5000 ft.		Off	3.7	2.7						
Rmin 3000 yd.	2	Semi-auto	5.5	4.1	1.6	0.6	10.5	7.5	3.3	3.1
Speed 170 kt.	2	Auto	7.4	8.3	1.3	0.7	152.0	30.0	1.9	3.2
"S" APPROACH		Off	5.4	2.6						
Alt. 5000 ft.	1	Semi-auto	5.1	3.4	1.5	0.6	41.0	29.8	63.0	5.5
Speed 140-180 kt.	1	Auto			1.5	0.7			61.4	4.4

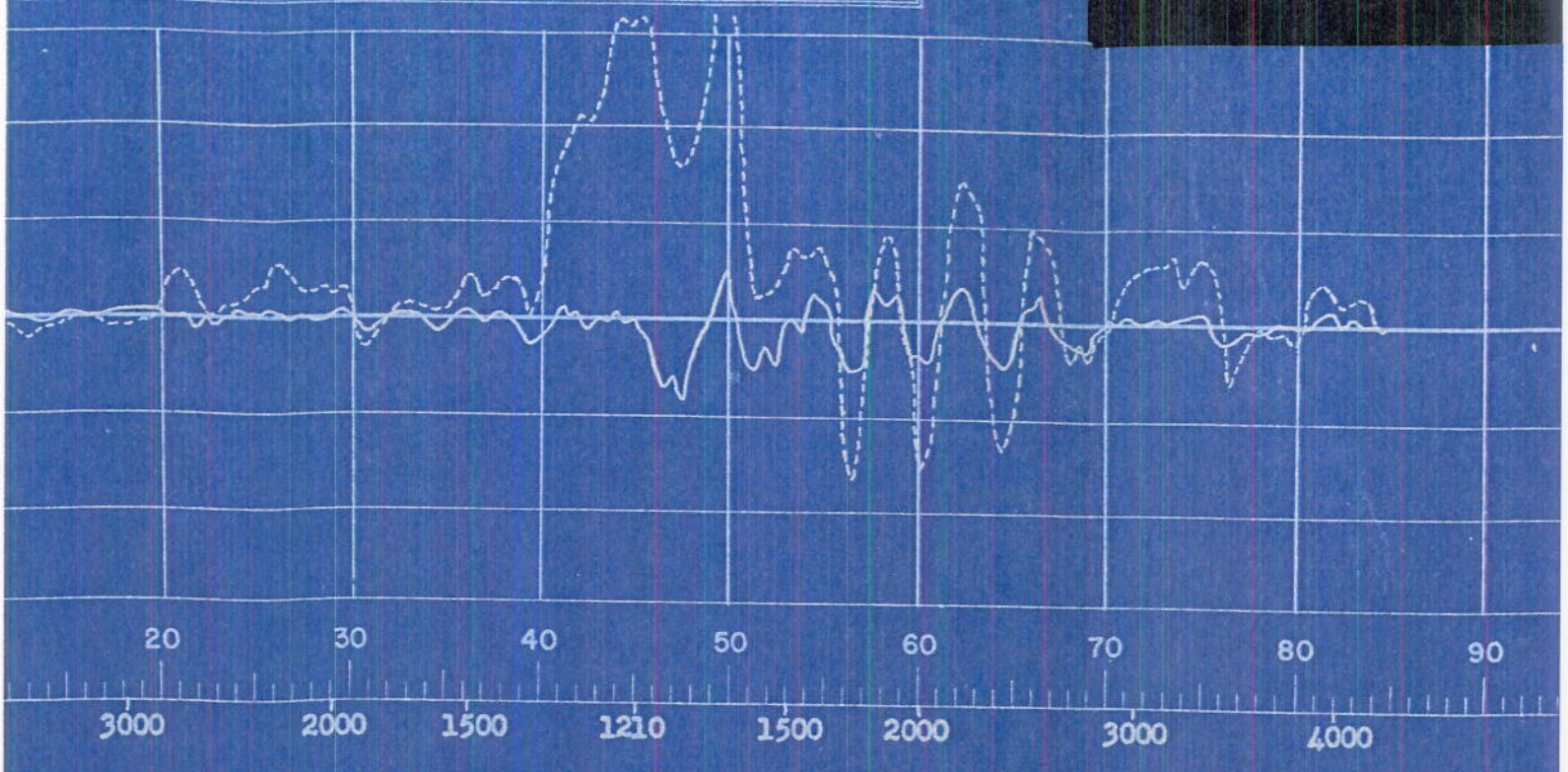
Note: Data on Radar Mk 12 Mod 2 were taken from reference (2). An attempt was made to choose runs from those taken in the present series of tests which matched as closely as possible the runs used in reference (2).

SER. 599

—TRACKING ERROR
---SOLUTION ERROR
Computer Operation - Automatic

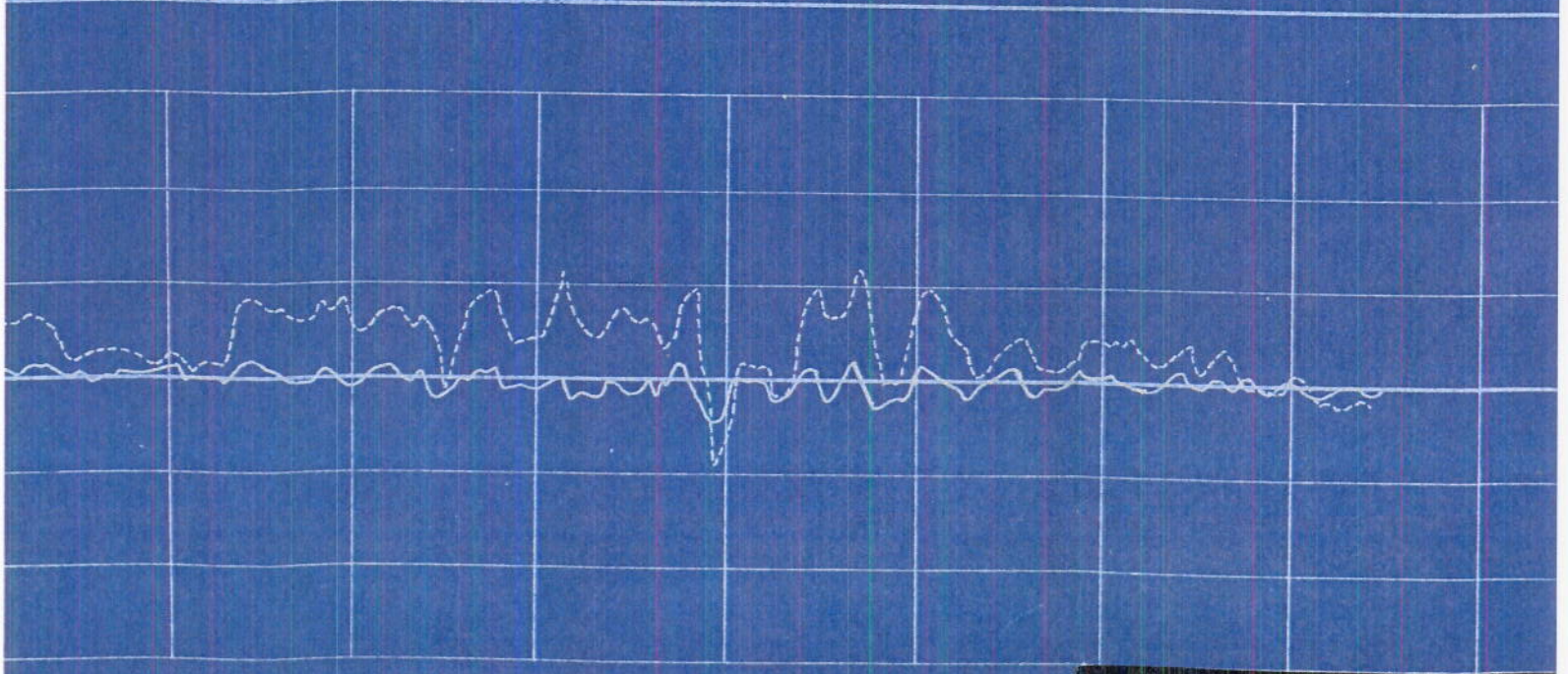
DWN. PBC APPR. JJ7

RUN 13 TEST 79
DATE 10/30/45 TARGET P4U
SPEED 220 KN, ALT. 2000 FT.
COURSE L-R Pass
TRACKING Radar



20 30 40 50 60 70 80 90

3000 2000 1500 1210 1500 2000 3000 4000



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

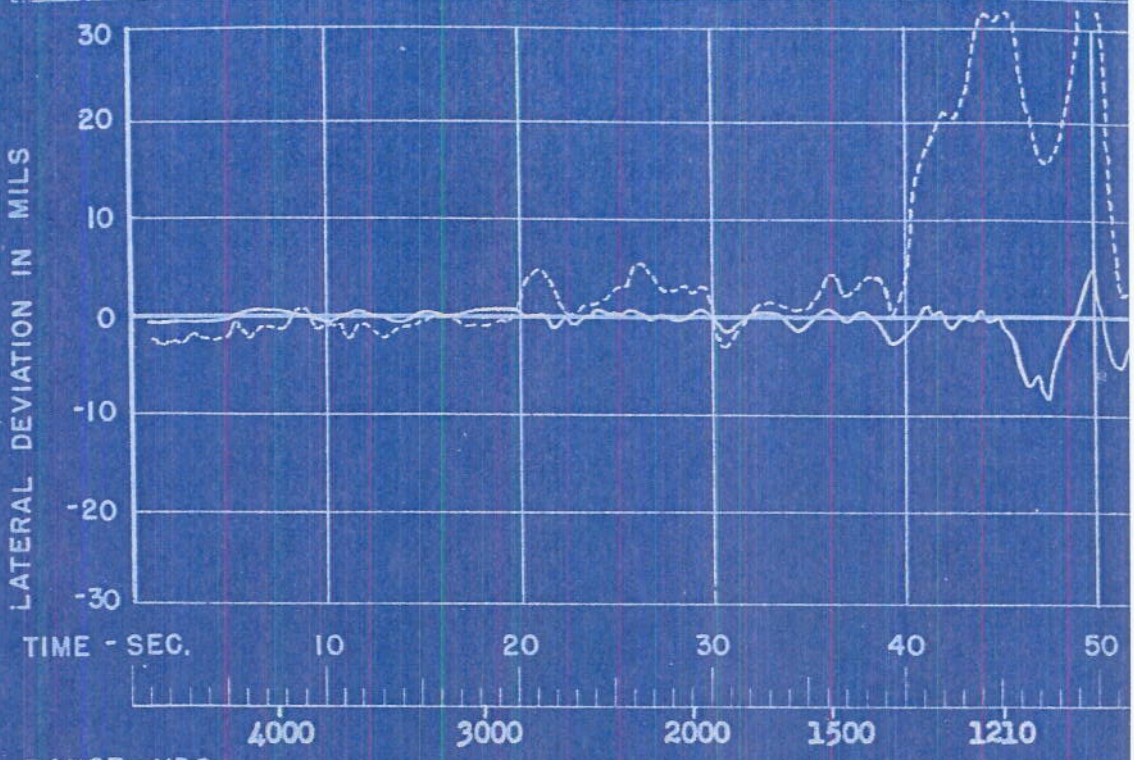
PLATE 1

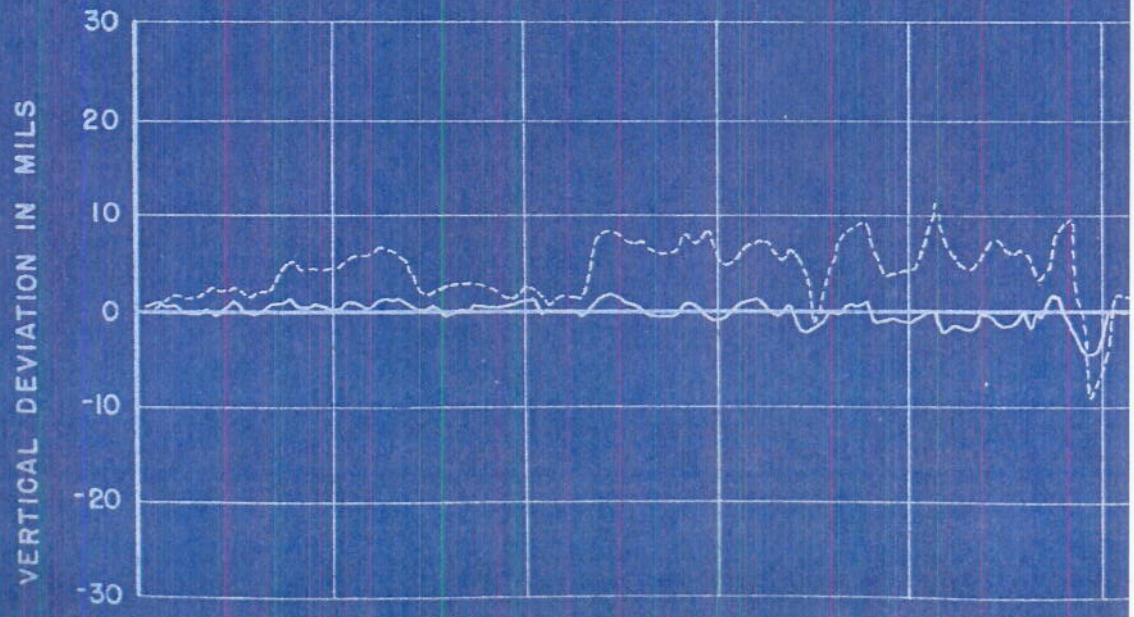
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—TRACKING ERROR
---SOLUTION ERROR
Computer Operation - Automatic
DWN. PBC APPR. JJ7

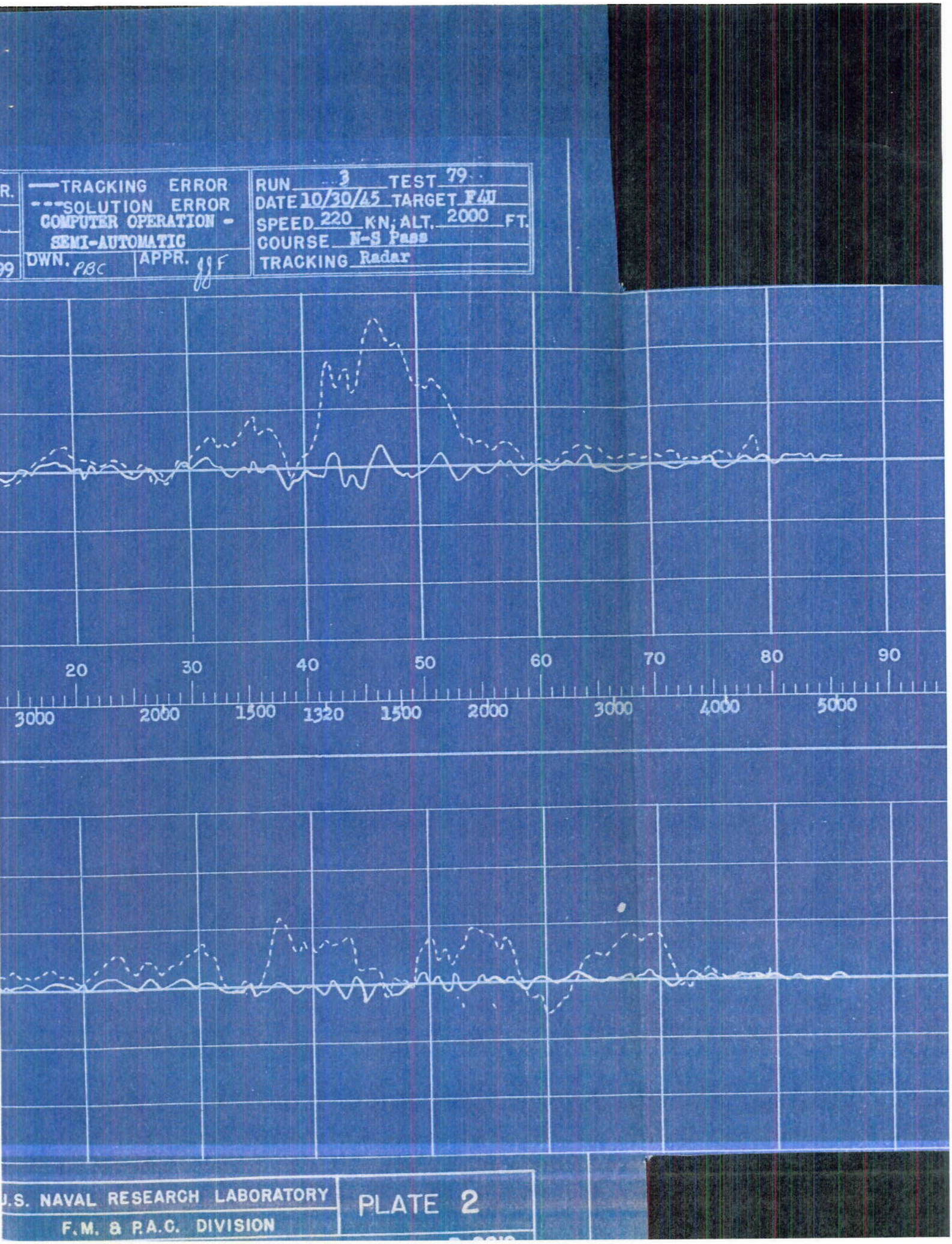
RUN 13 TEST
DATE 10/30/45 TARG
SPEED 220 KN, ALT.
COURSE L-R Pass
TRACKING Radar





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

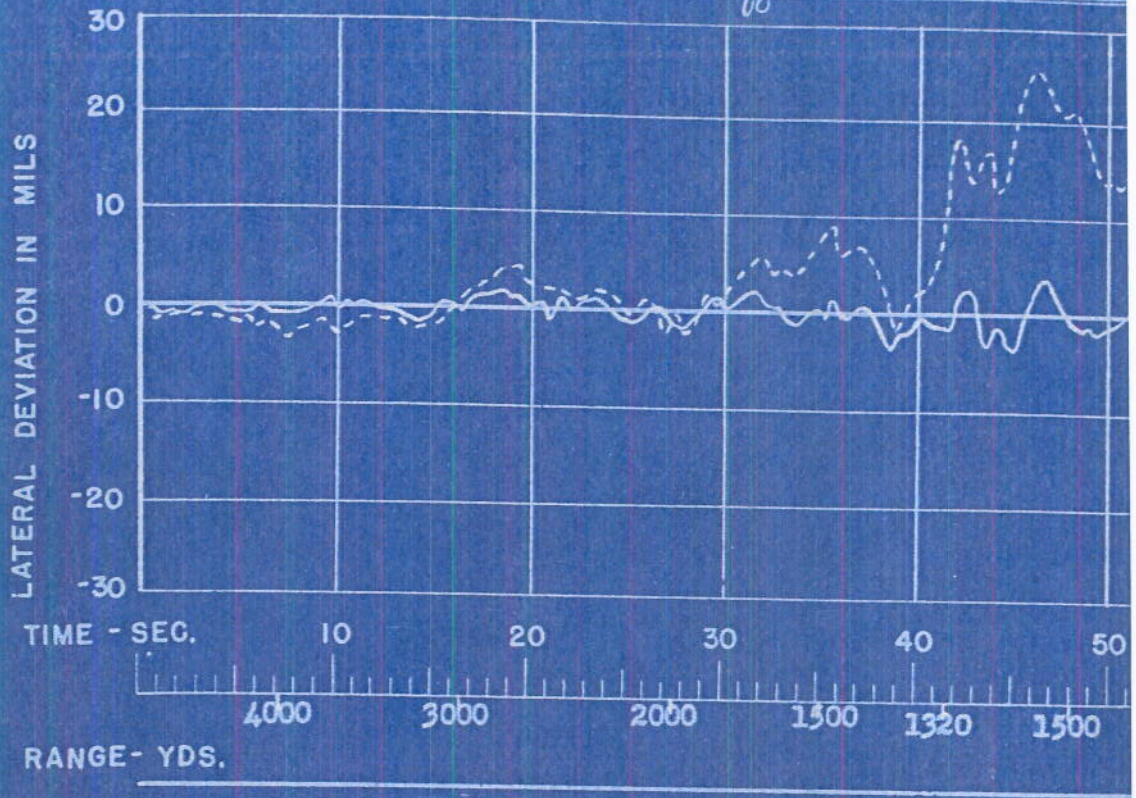
PLATE

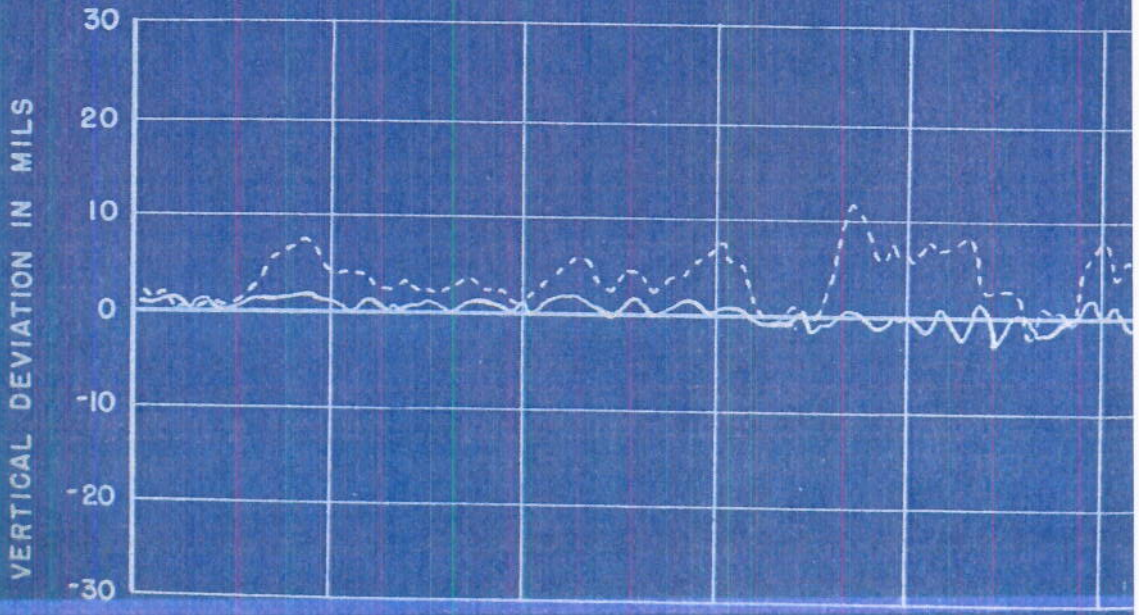

—TRACKING ERROR
---SOLUTION ERROR
COMPUTER OPERATION -
SEMI-AUTOMATIC
DWN. PBC
APPR. JJF
RUN 3 TEST 79
DATE 10/30/45 TARGET F4U
SPEED 220 KN; ALT. 2000 FT.
COURSE N-S Pass
TRACKING Radar
20 30 40 50 60 70 80 90
3000 2000 1500 1320 1500 2000 3000 4000 5000
U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION
PLATE 2

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC APPR. JJF

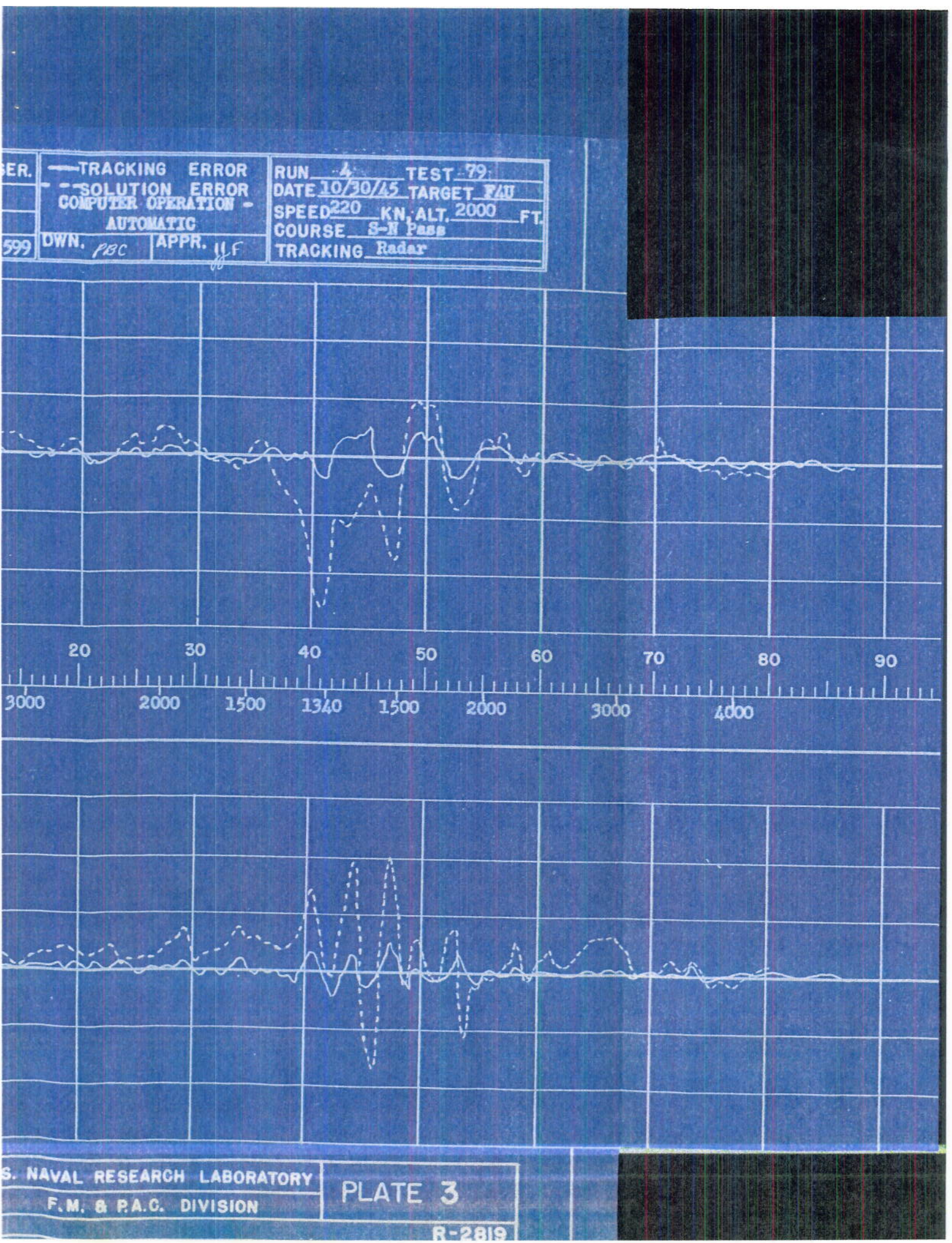
RUN 3 TES
DATE 10/30/45 TAR
SPEED 220 KN; AL
COURSE N-S Pass
TRACKING Radar





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

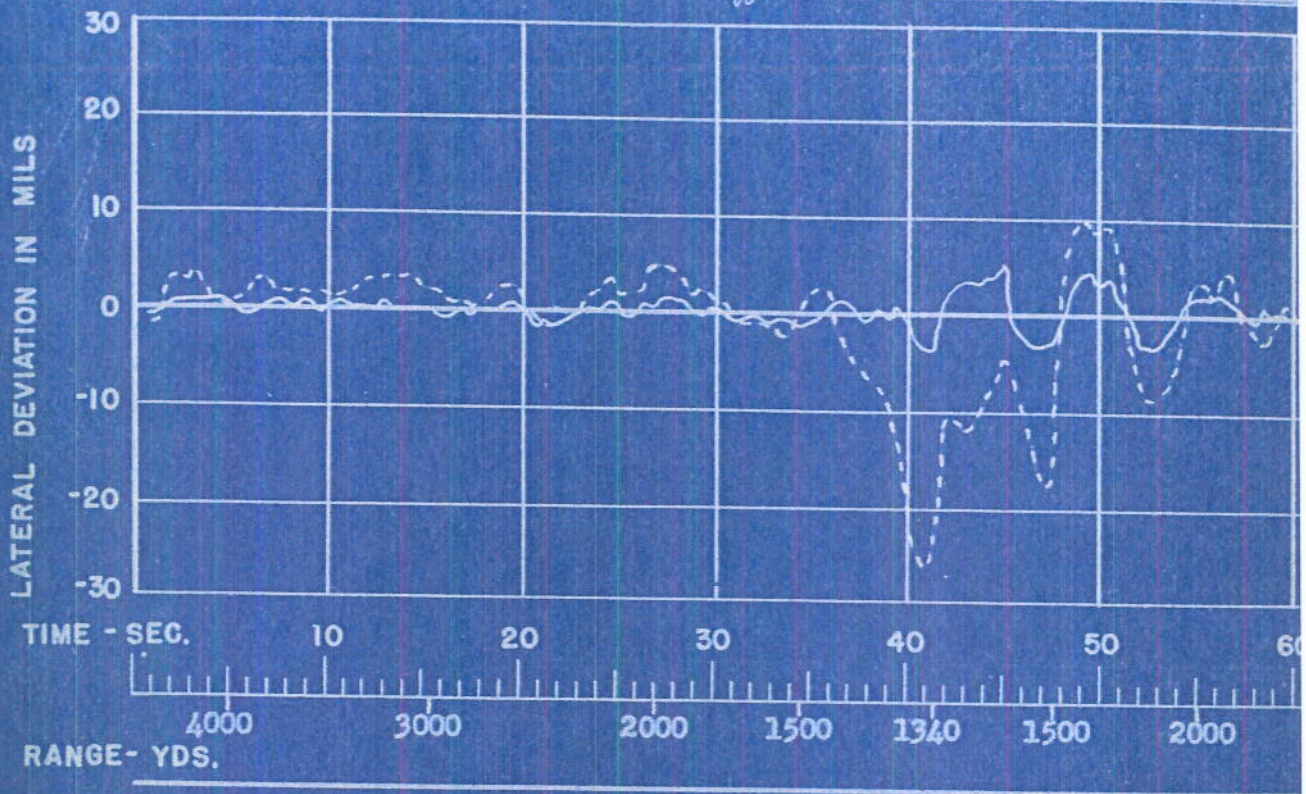
PLATE

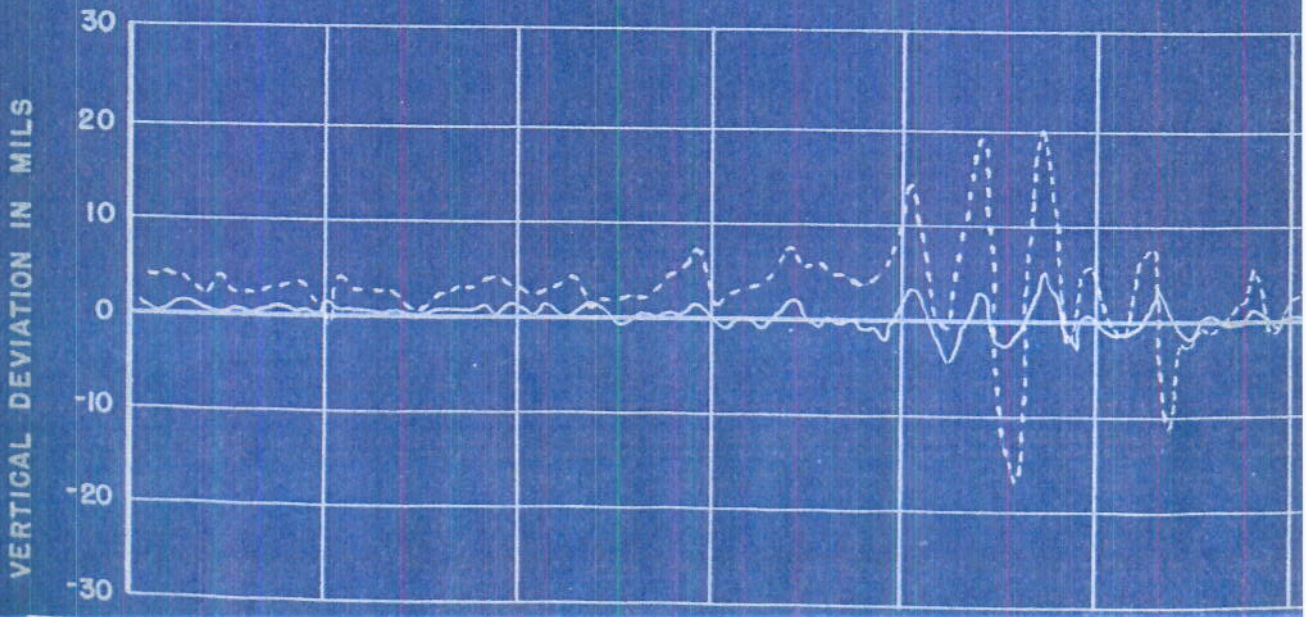

SER.
599
—TRACKING ERROR
- - SOLUTION ERROR
COMPUTER OPERATION -
AUTOMATIC
DWN. PBC
APPR. HF
RUN 4 TEST 79
DATE 10/30/45 TARGET F4U
SPEED 220 KN, ALT. 2000 FT.
COURSE S-N Pass
TRACKING Radar
20
30
40
50
60
70
80
90
3000
2000
1500
1340
1500
2000
3000
4000
S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION
PLATE 3
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—TRACKING ERROR
- - SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
DWN. PBC APPR. HF

RUN 4 TEST 79
DATE 10/30/45 TARGET F4U
SPEED 220 KN. ALT. 2000 FT.
COURSE S-N Pass
TRACKING Radar





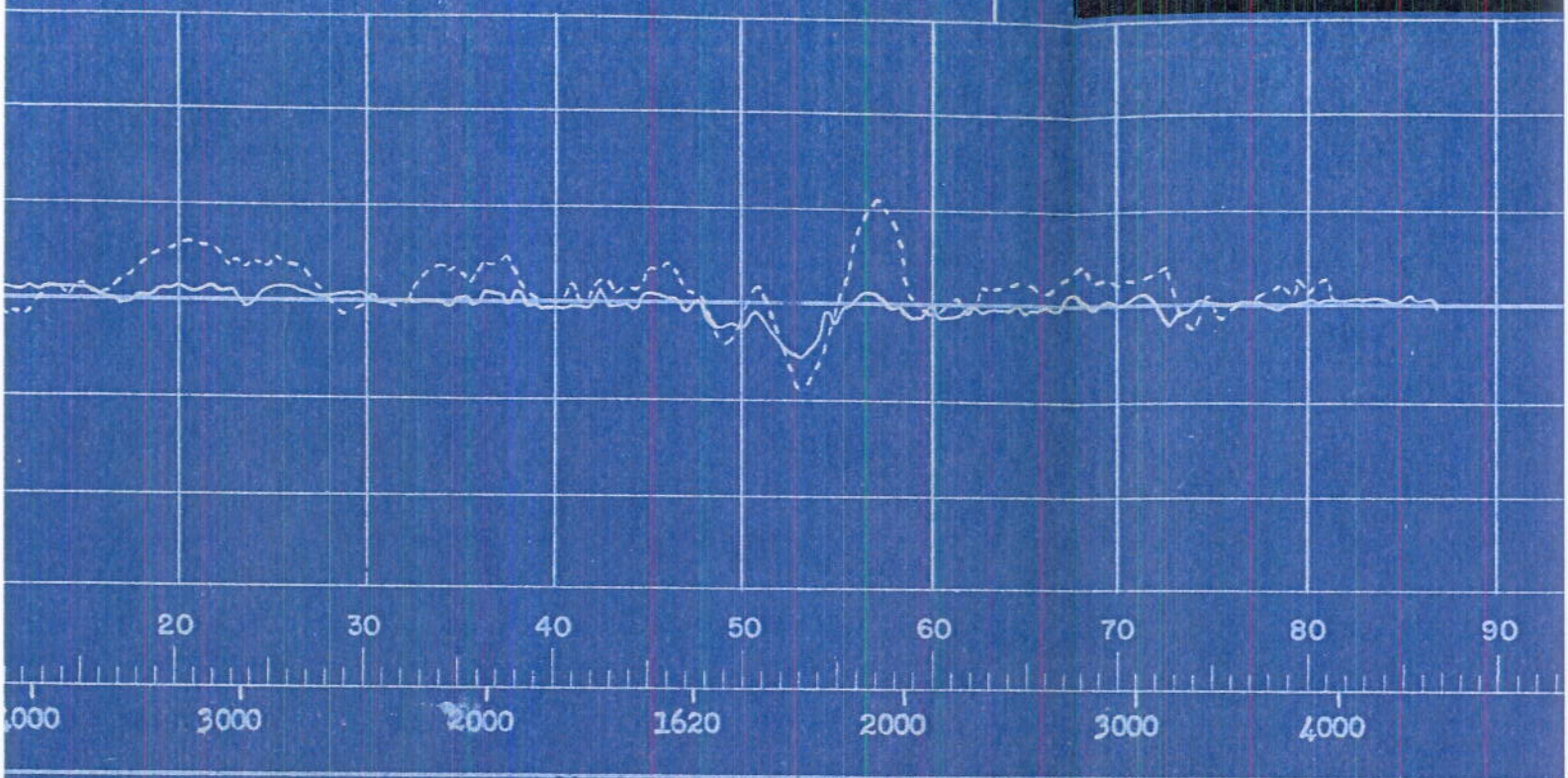
CONFIDENTIAL

U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 3

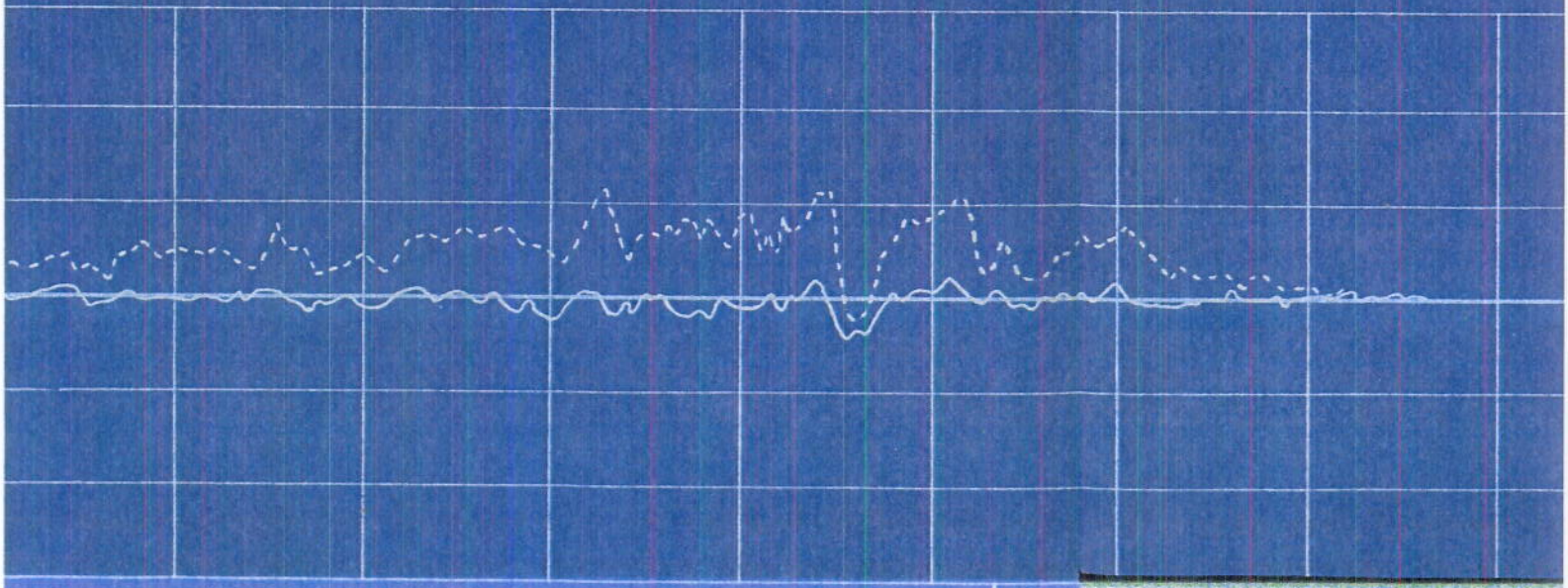
R-2819

SER.	—— TRACKING ERROR - - - SOLUTION ERROR. COMPUTER OPERATION - AUTOMATIC	RUN 93 TEST 79 DATE 11/8/45 TARGET F4U SPEED 180 KN; ALT. 2000 FT. COURSE L-R Pass TRACKING Radar
599	OWN. PBC APPR. JJF	



20 30 40 50 60 70 80 90

000 3000 2000 1620 2000 3000 4000



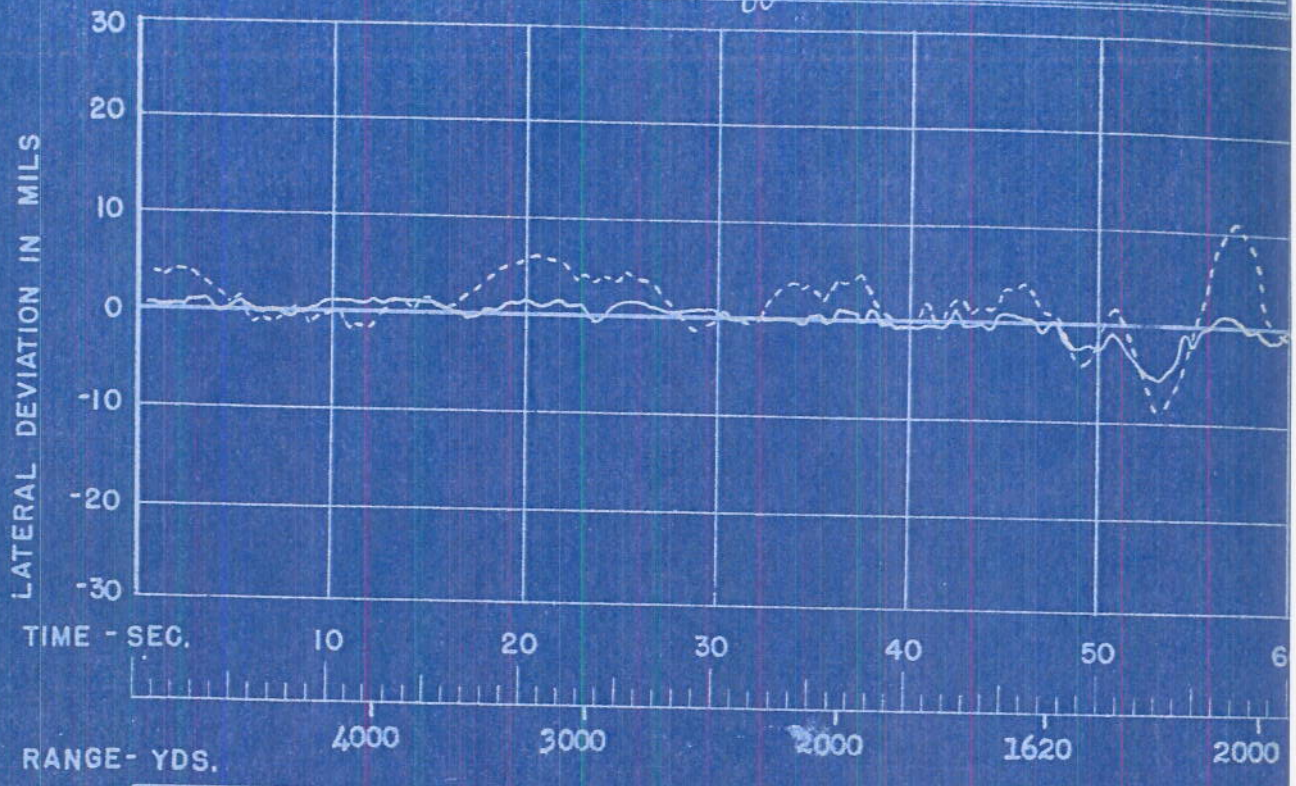
U.S. NAVAL RESEARCH LABORATORY	PLATE 4
F.M. & P.A.C. DIVISION	

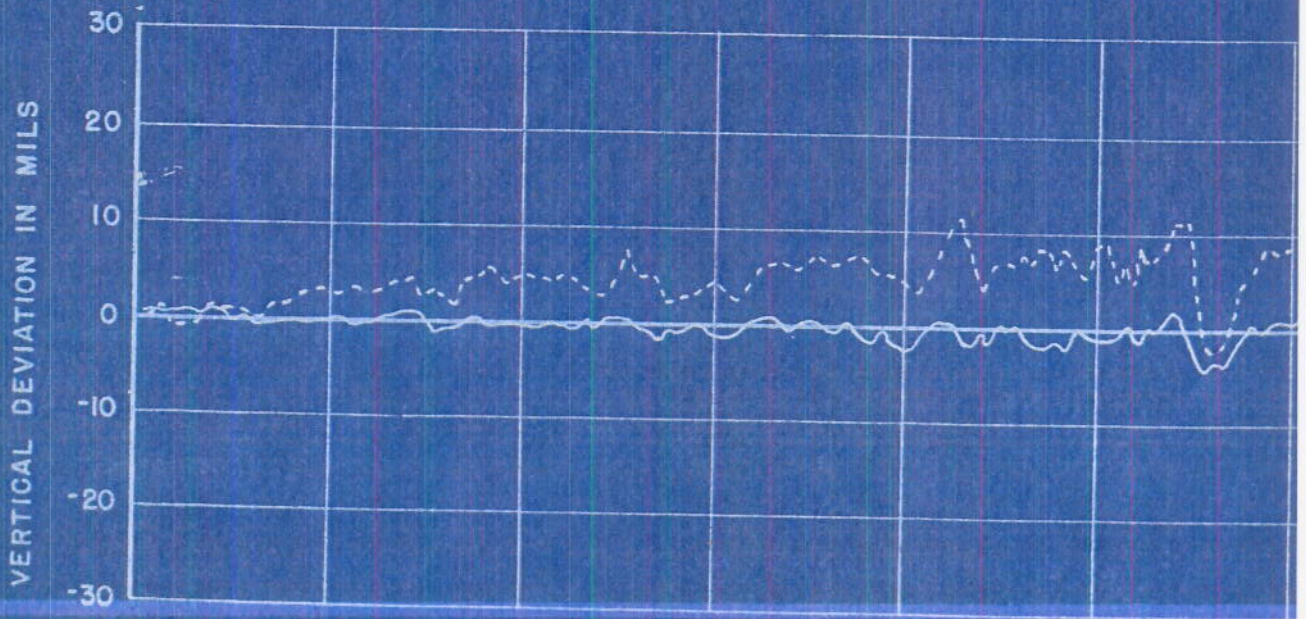
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

——TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
OWN. PBC APPR. [illegible]F

RUN 93 TEST 79
DATE 11/8/45 TARGET F4U
SPEED 180 KN. ALT. 2000 FT.
COURSE L-R Pass
TRACKING Radar

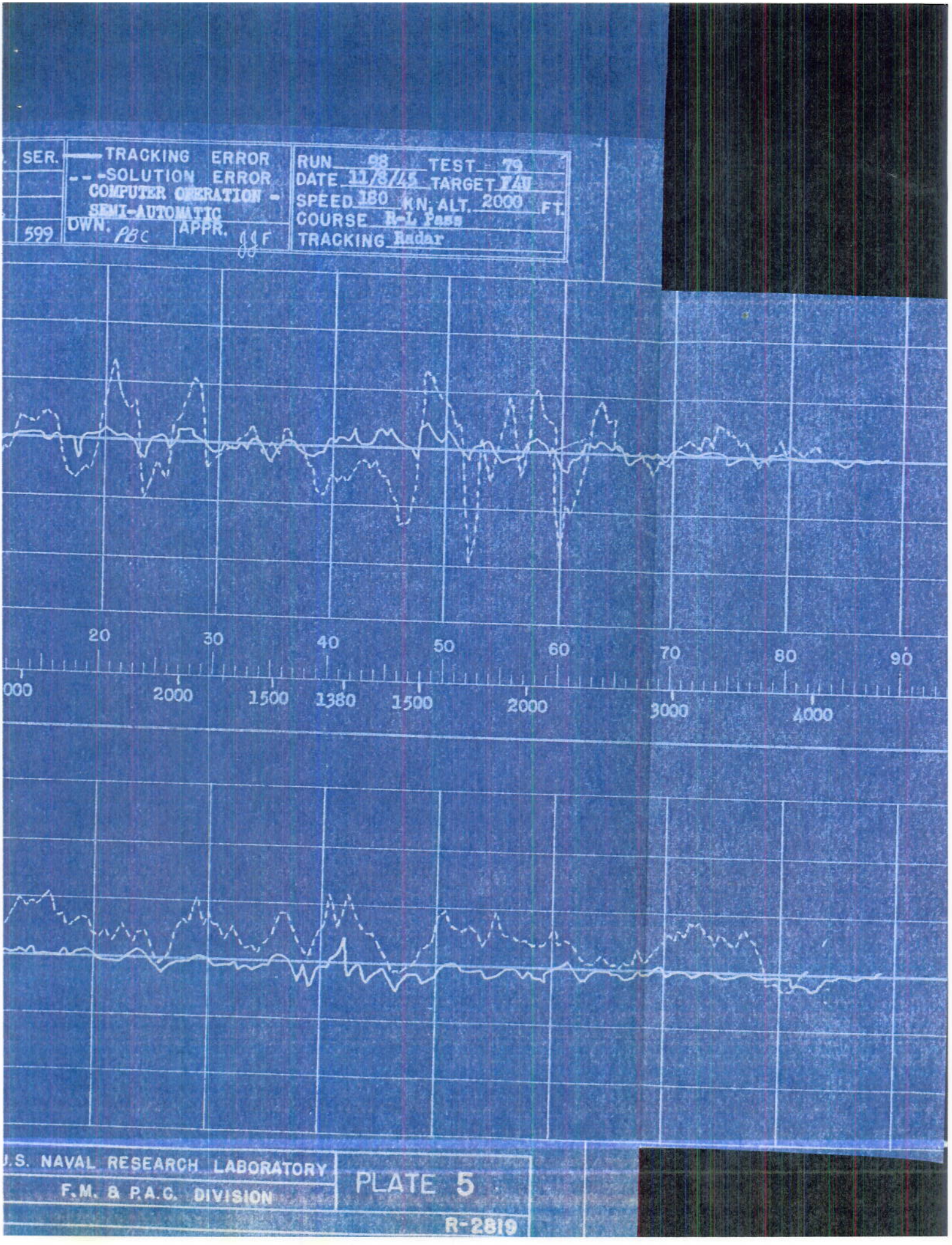




[redacted] U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 4

R-2919



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

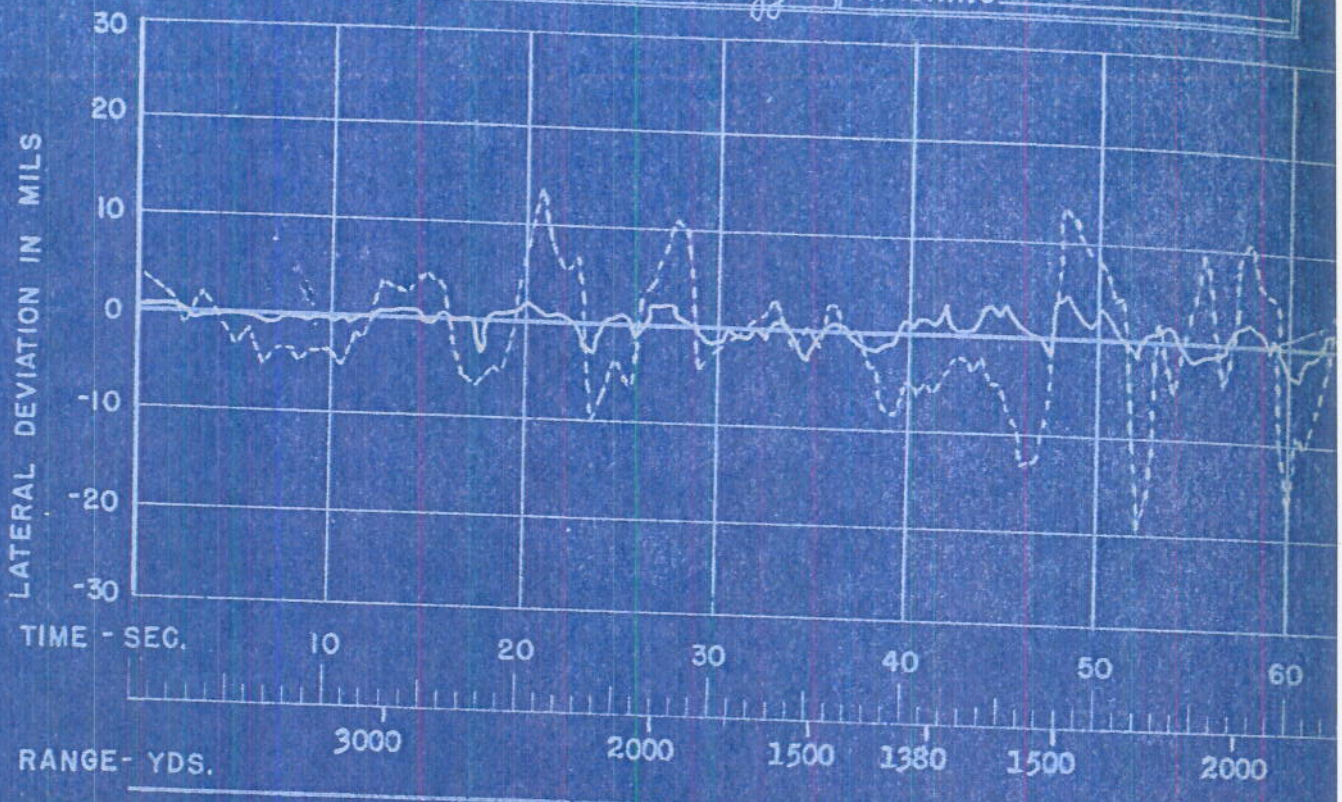
PLATE 5

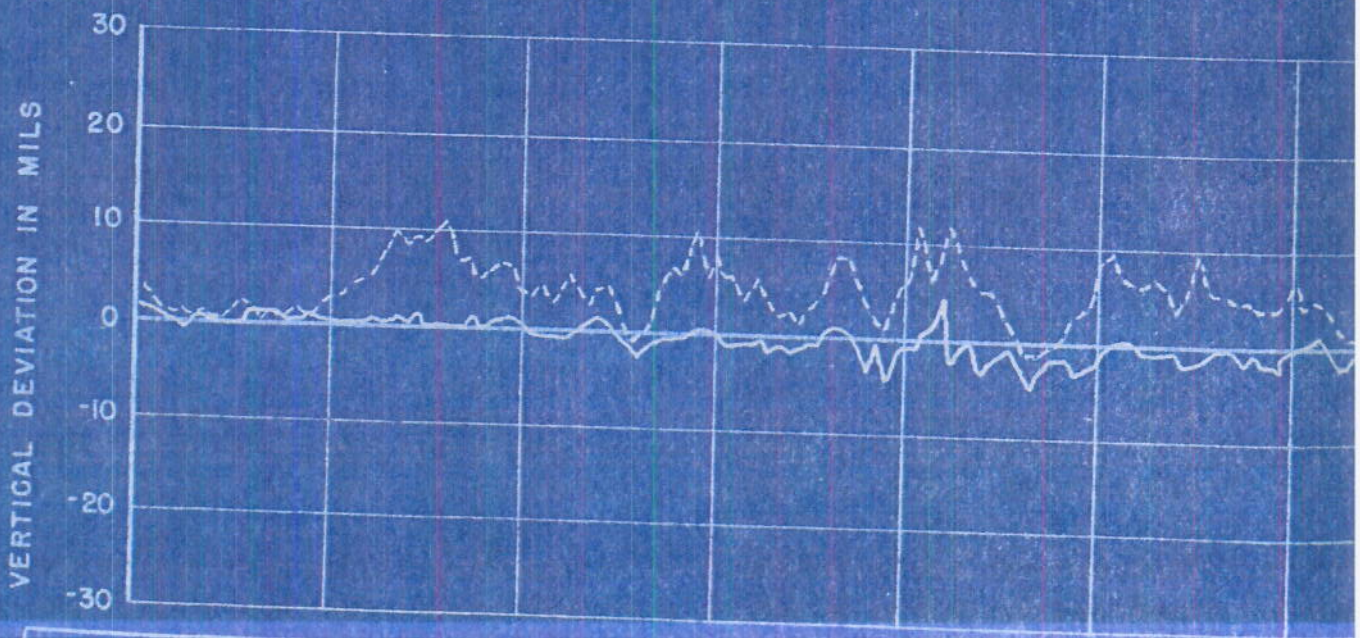
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

——TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC APPR. JJF

RUN 98 TEST 79
DATE 11/8/45 TARGET F4U
SPEED 180 KN, ALT. 2000 FT.
COURSE R-L Pass
TRACKING Radar





[redacted]

U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 5

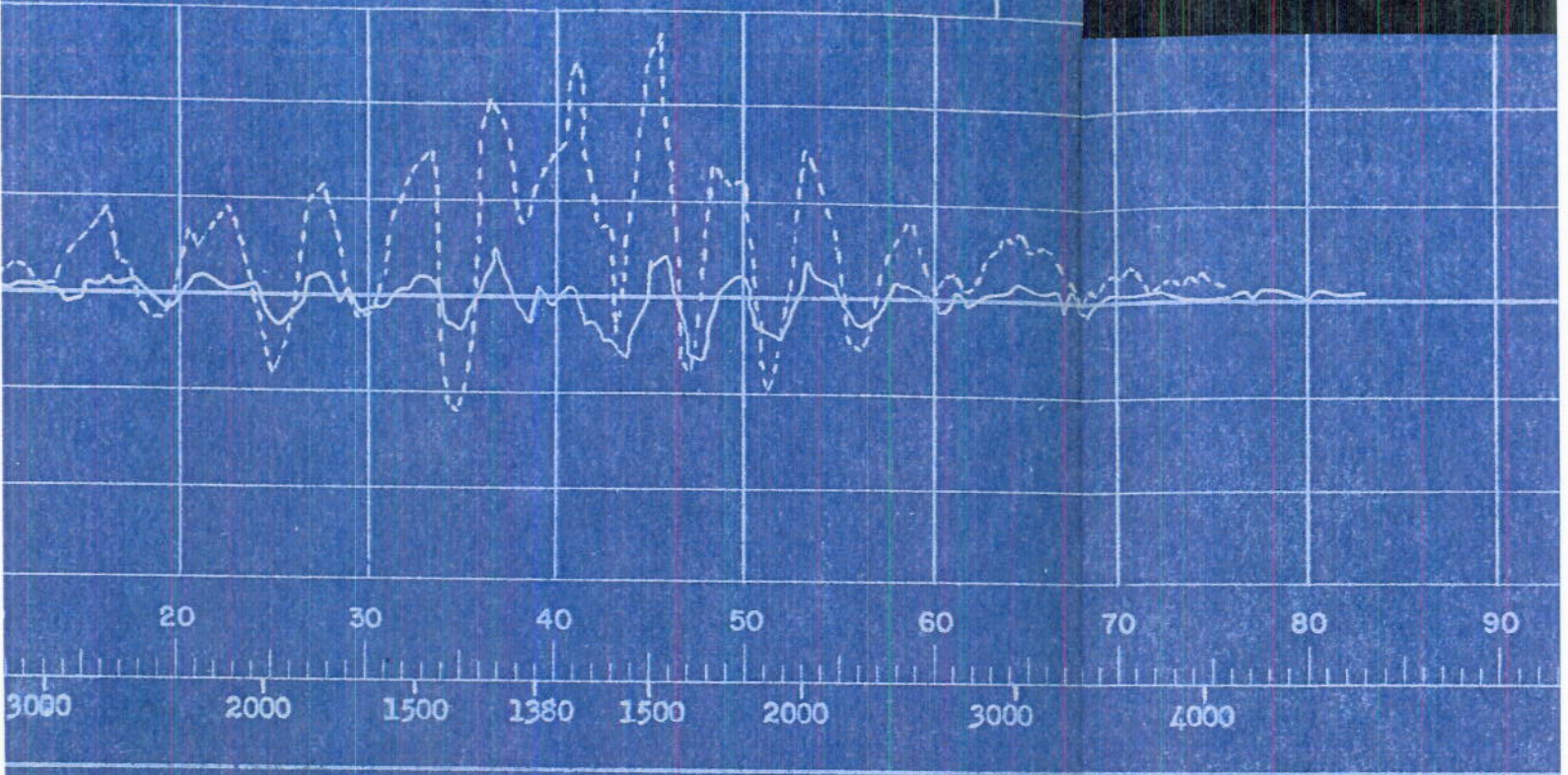
R-2810

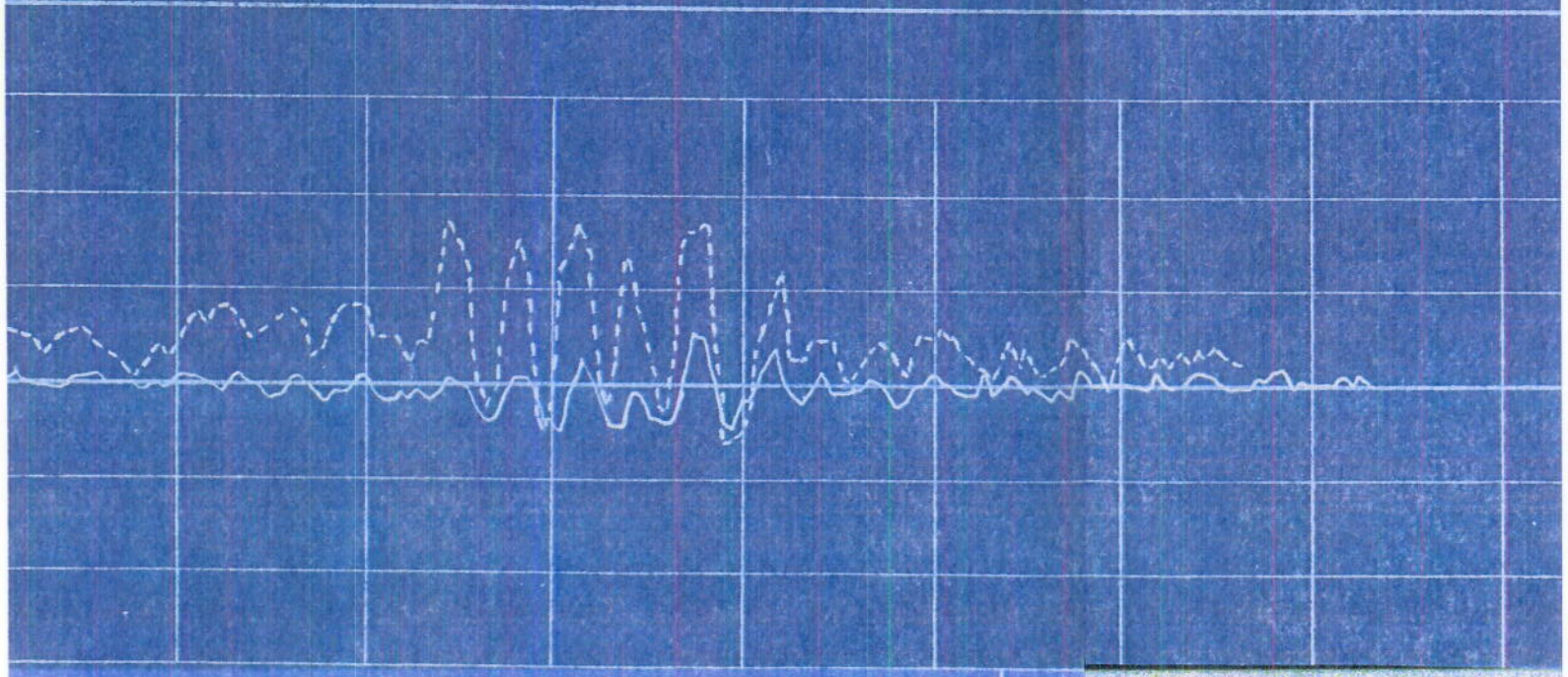
SER. 599

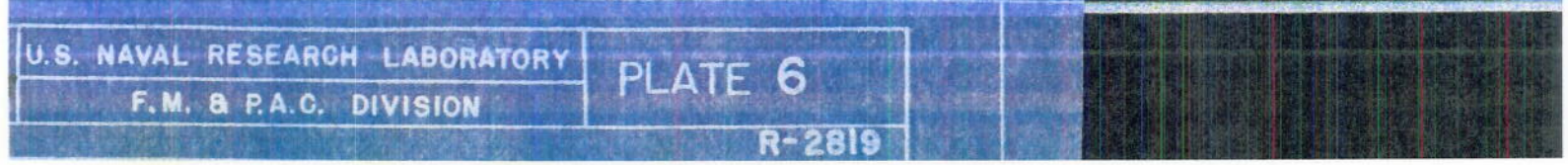
——TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC

DWN. PBC APPR. ggf

RUN 99 TEST 79
DATE 11/8/45 TARGET FAU
SPEED 180 KN, ALT. 2000 FT.
COURSE L-R Pass
TRACKING Radar







U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

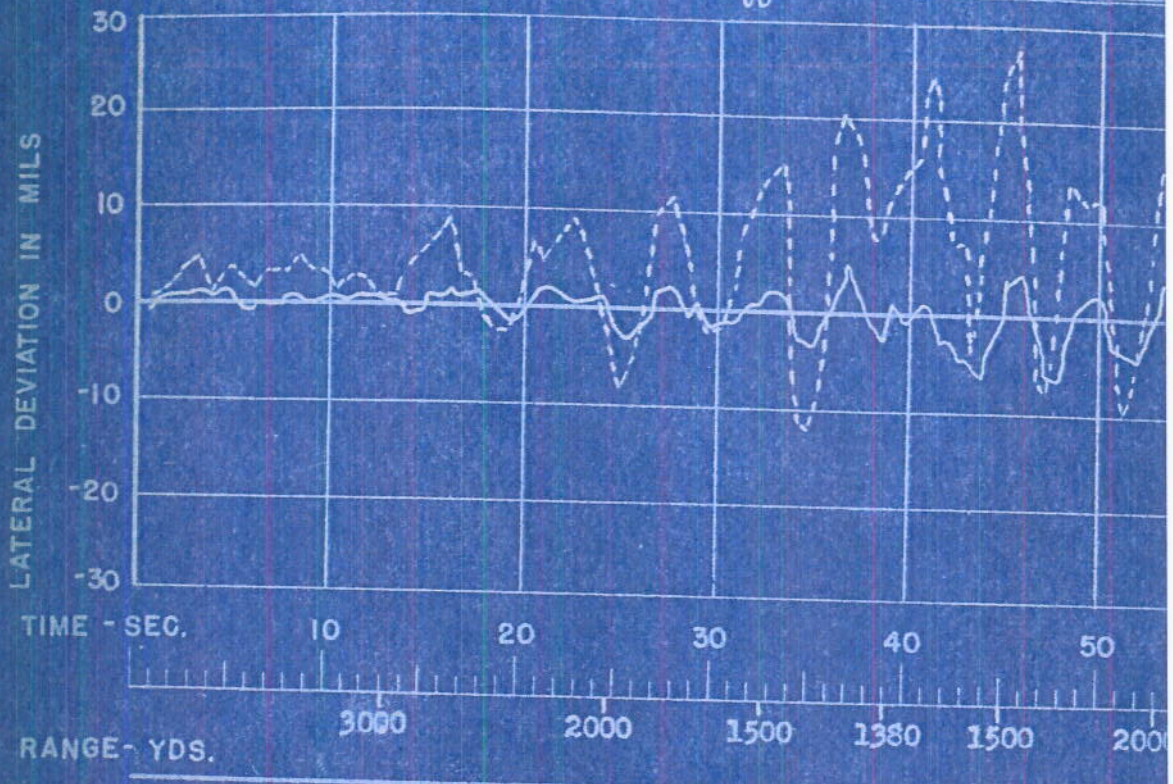
PLATE 6

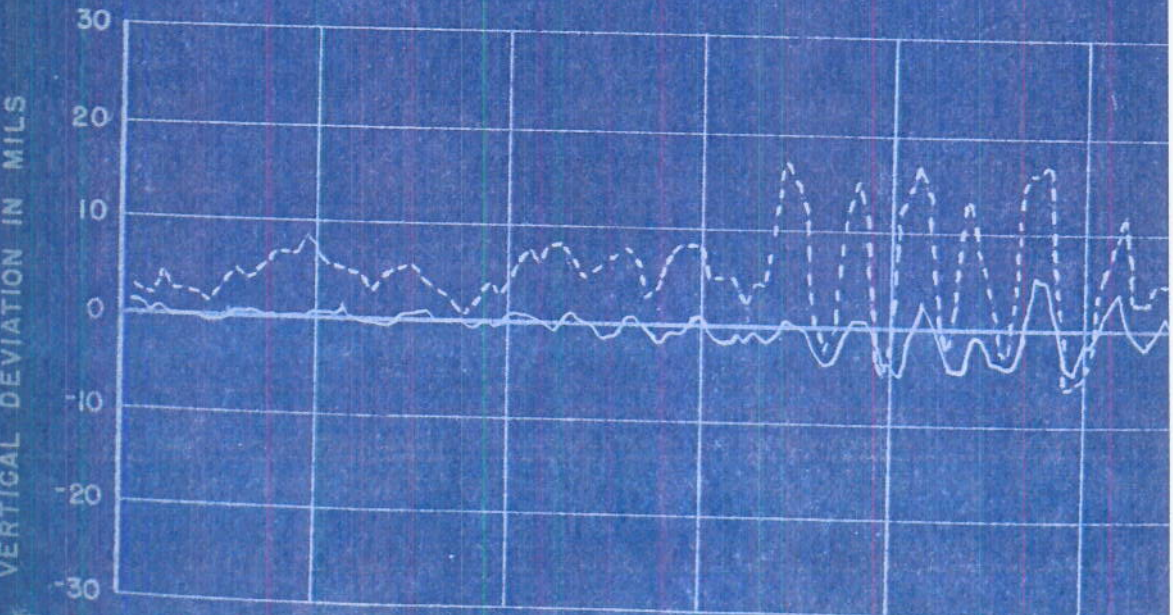
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

——TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
DWN. PBC APPR. JJF

RUN 99 TEST
DATE 11/8/45 TARGE
SPEED 180 KN, ALT. 2
COURSE L-R Pass
TRACKING Radar





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 6

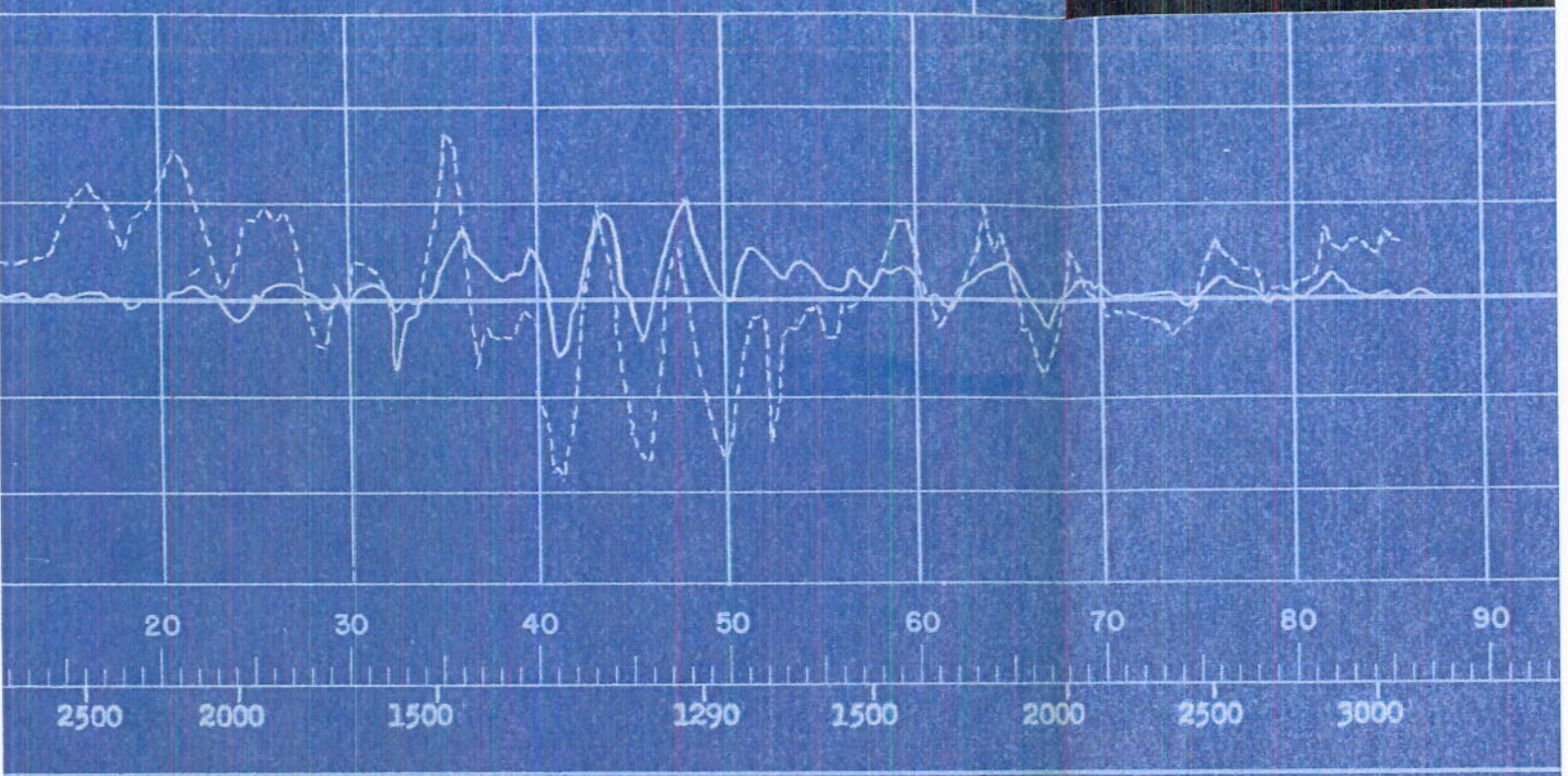
R-2

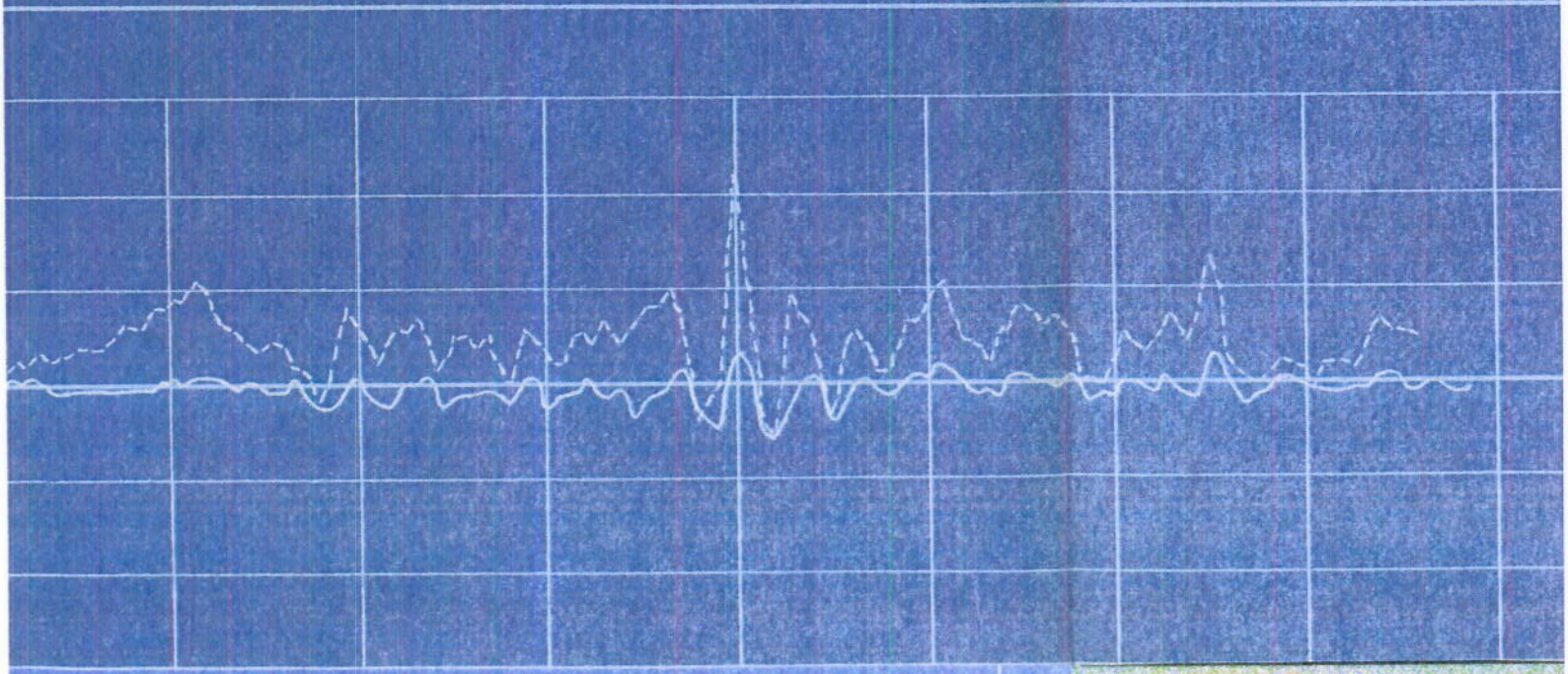
SER. 599

—TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC

DWN. PBC | APPR. JJF

RUN 139 TEST 79
DATE 11/16/45 TARGET TBF
SPEED 150 KN. ALT. 2000 FT.
COURSE R-L Pass
TRACKING Radar





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

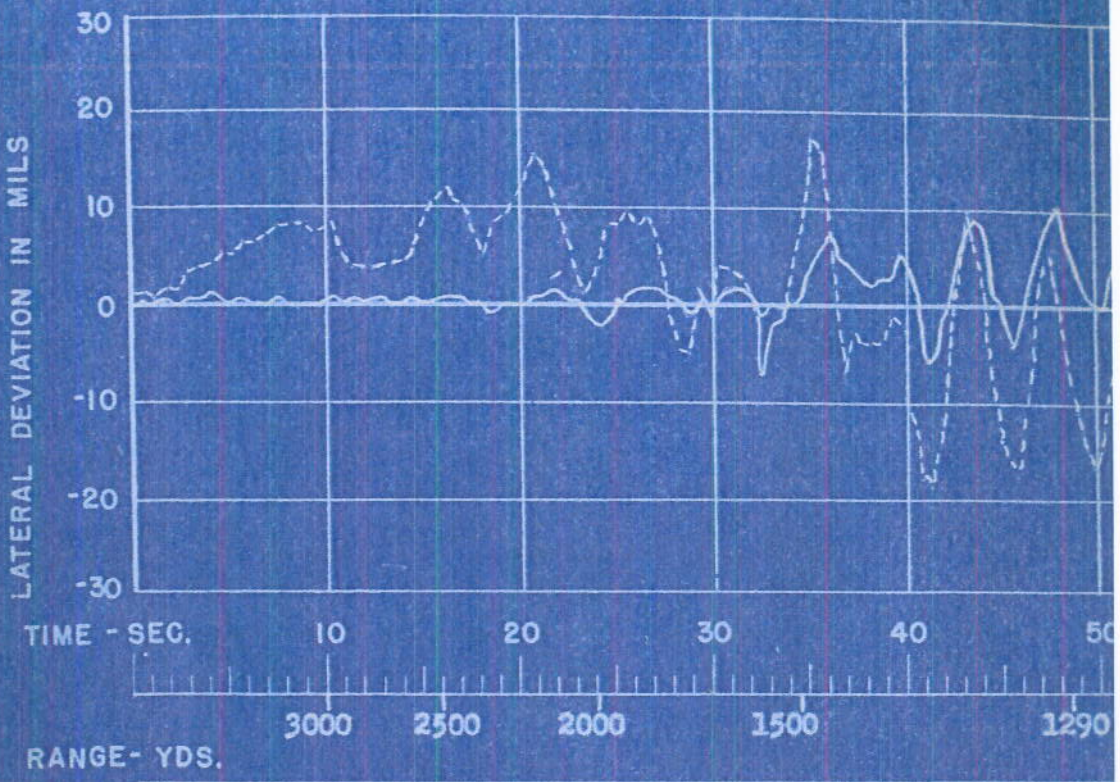
PLATE 7

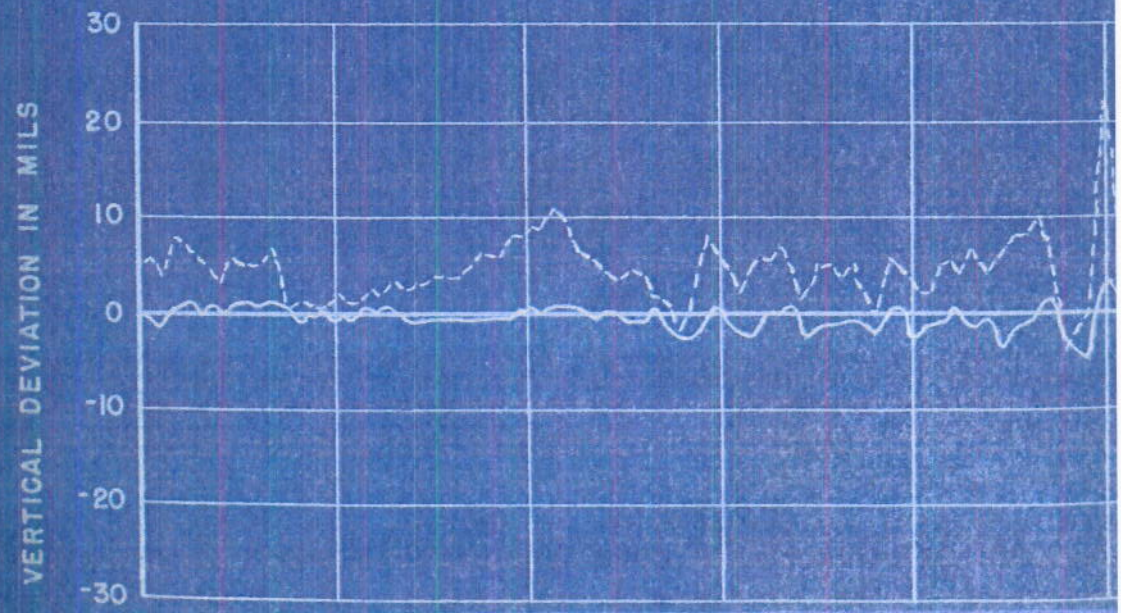
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

——TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
DWN. PBC APPR. JJF

RUN 139 TES
DATE 11/16/45 TAR
SPEED 150 KN, ALT
COURSE R-L Pass
TRACKING Radar



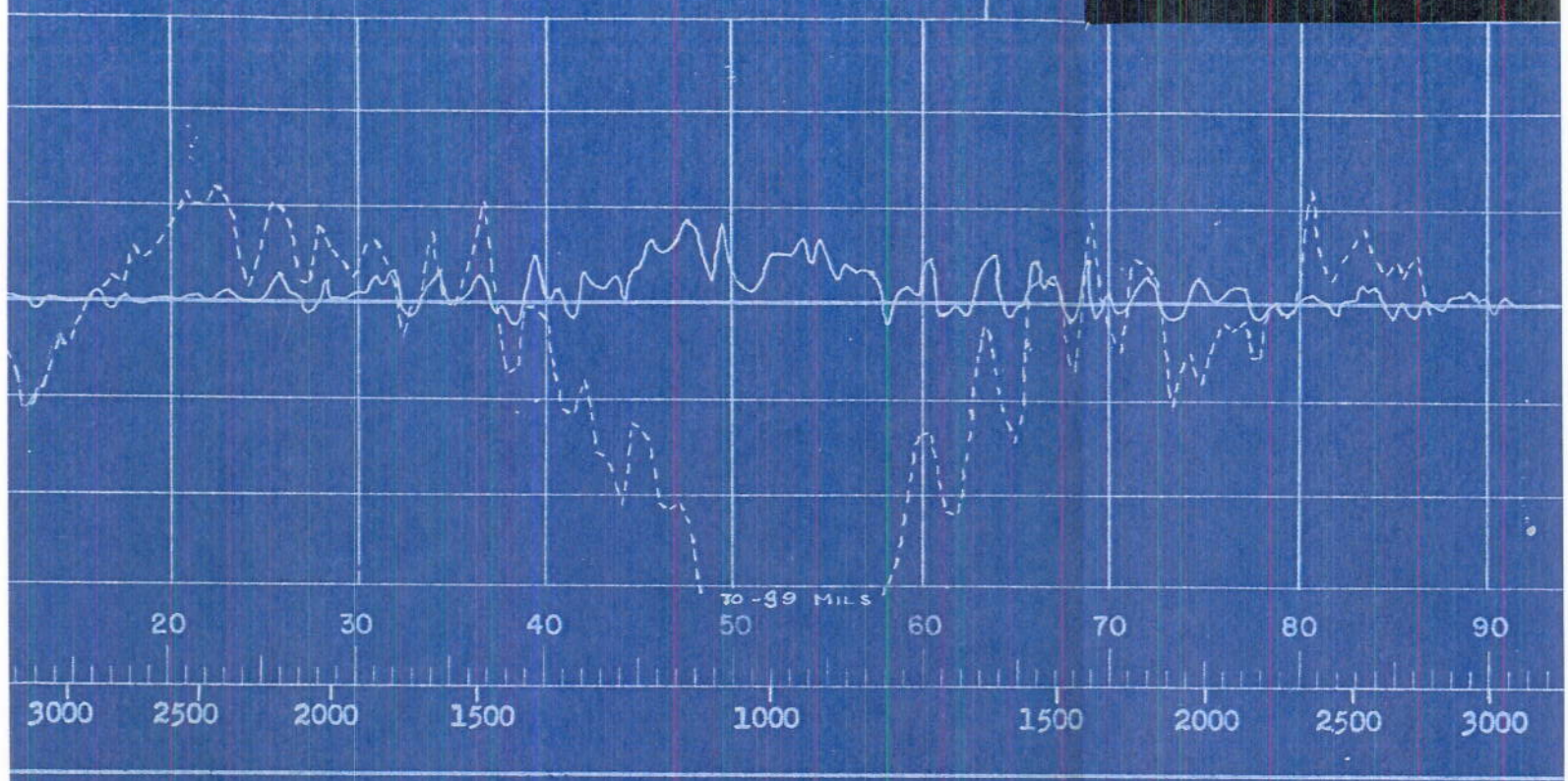


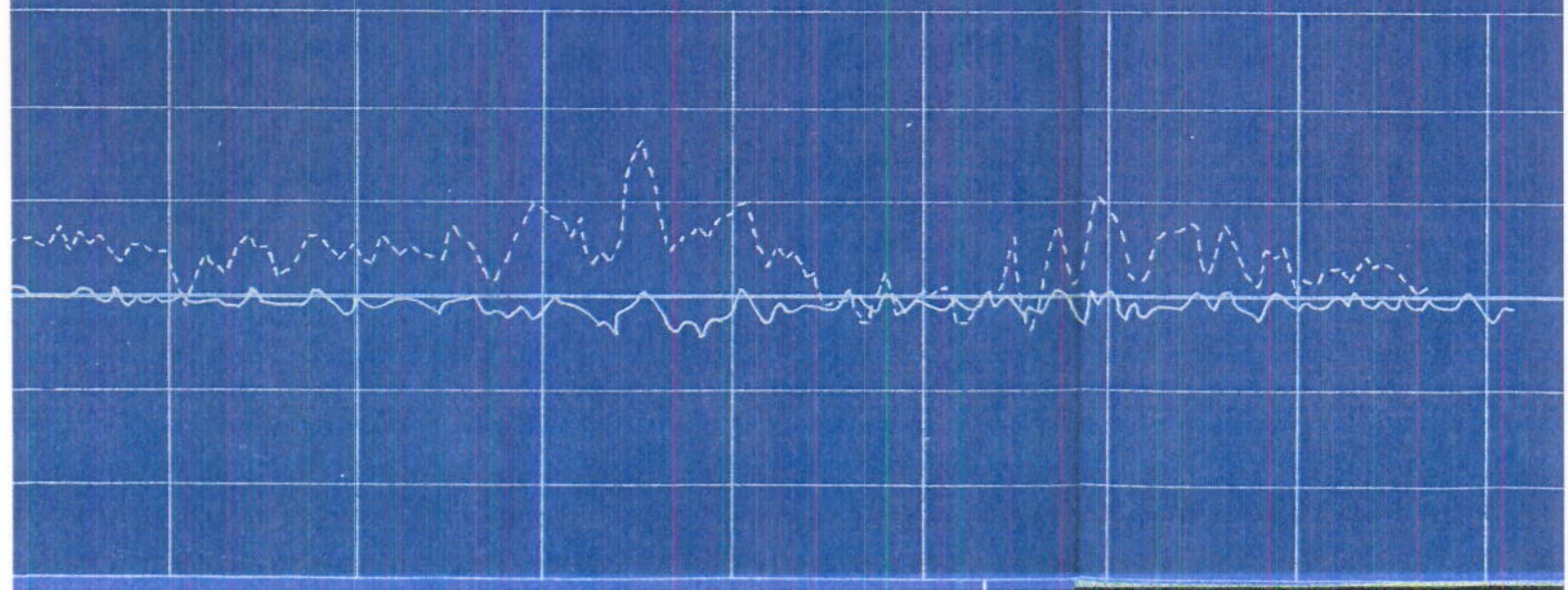
CONFIDENTIAL

U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE

SER.	——TRACKING ERROR - --SOLUTION ERROR COMPUTER OPERATION - AUTOMATIC - NO AID	RUN 141 TEST 79 DATE 11/16/45 TARGET TBF SPEED 150 KN, ALT. 2000 FT. COURSE R-L Pass TRACKING Radar
599	DWN. PBC APPR. JJF	





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

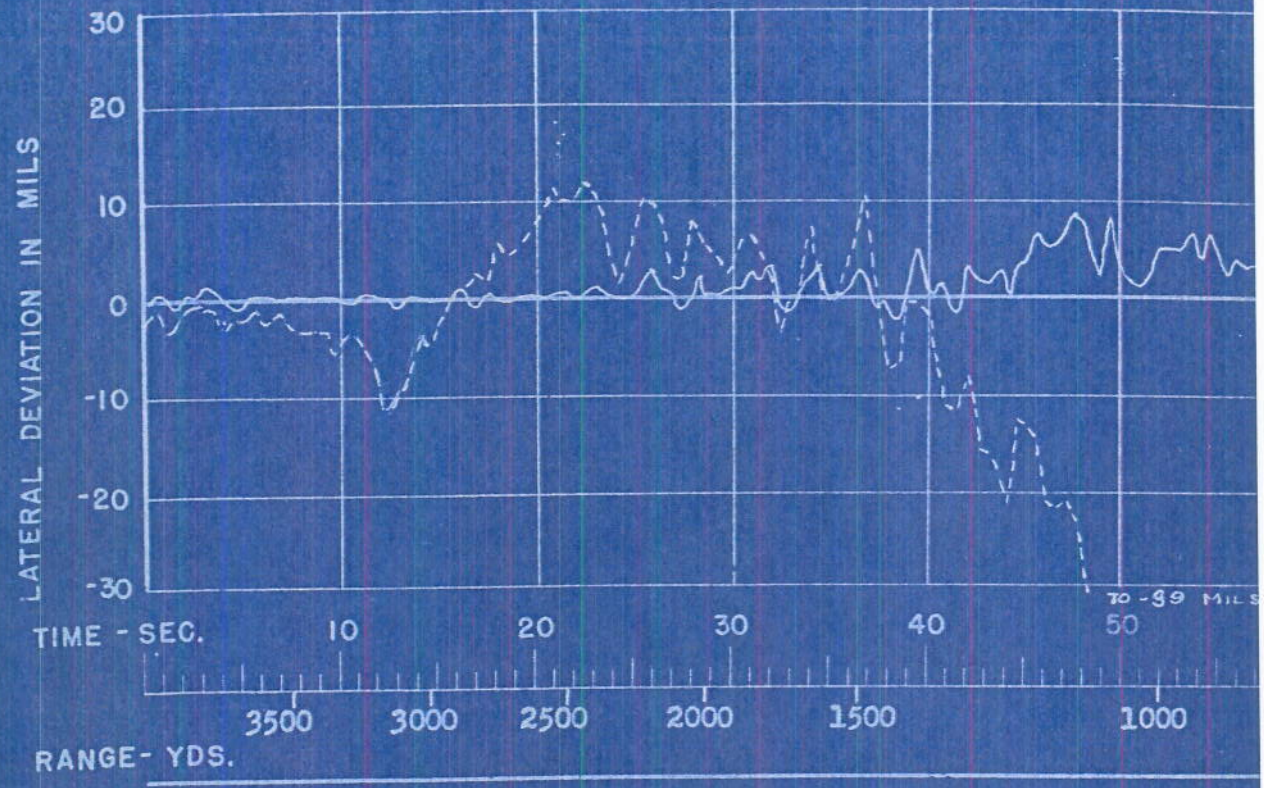
PLATE 8

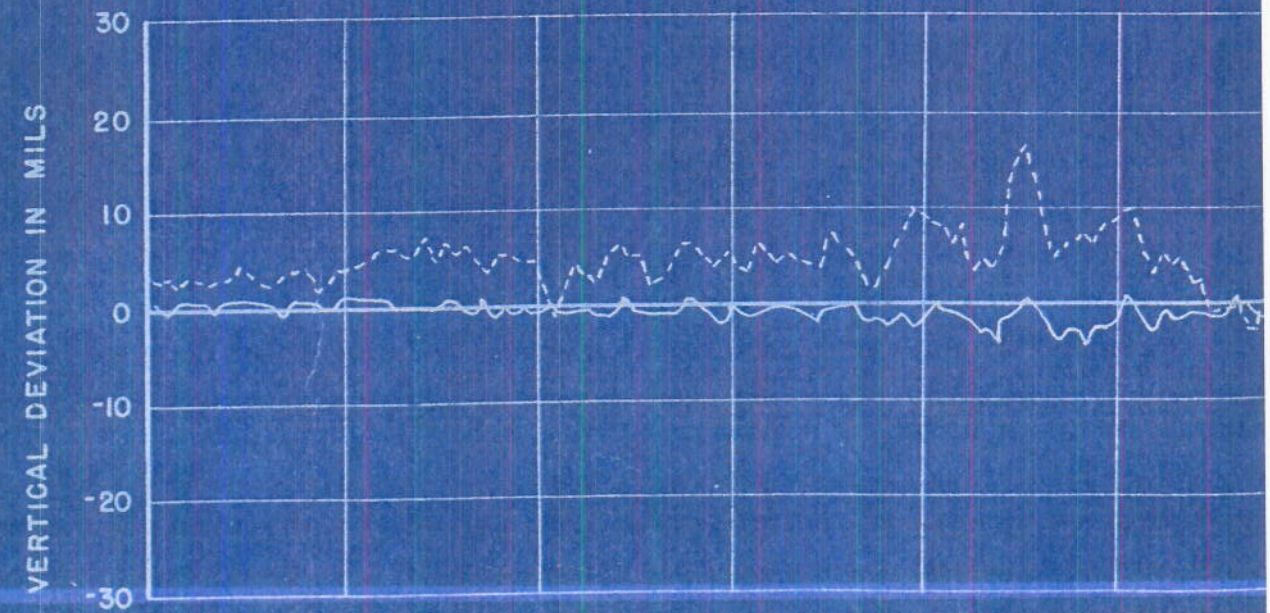
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

——TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC - NO AID
DWN. PBC APPR. JJF

RUN 141 TEST 79
DATE 11/16/45 TARGET TF
SPEED 150 KN, ALT. 2000
COURSE R-L Pass
TRACKING Radar



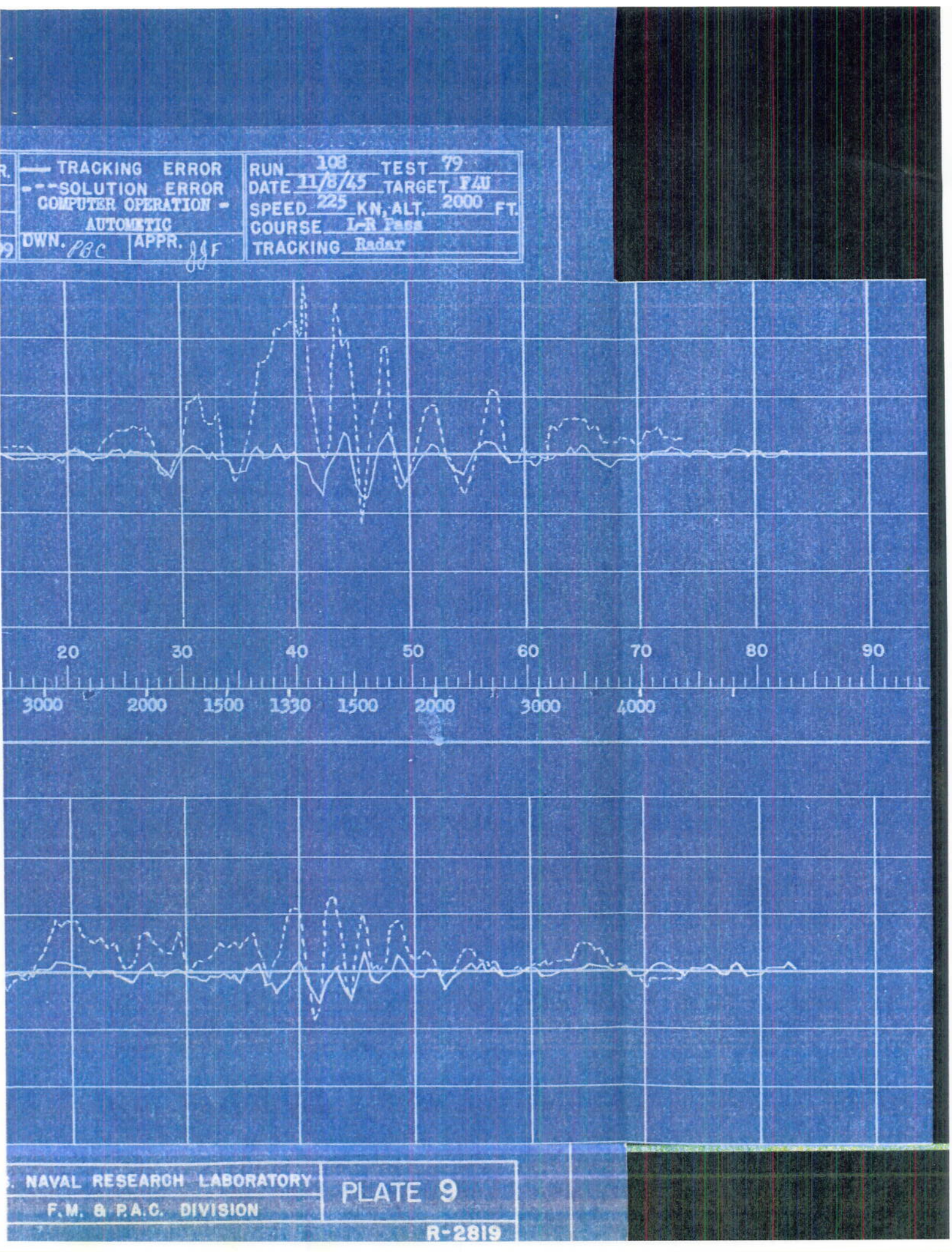


CONFIDENTIAL

U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 8

R-2819



NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

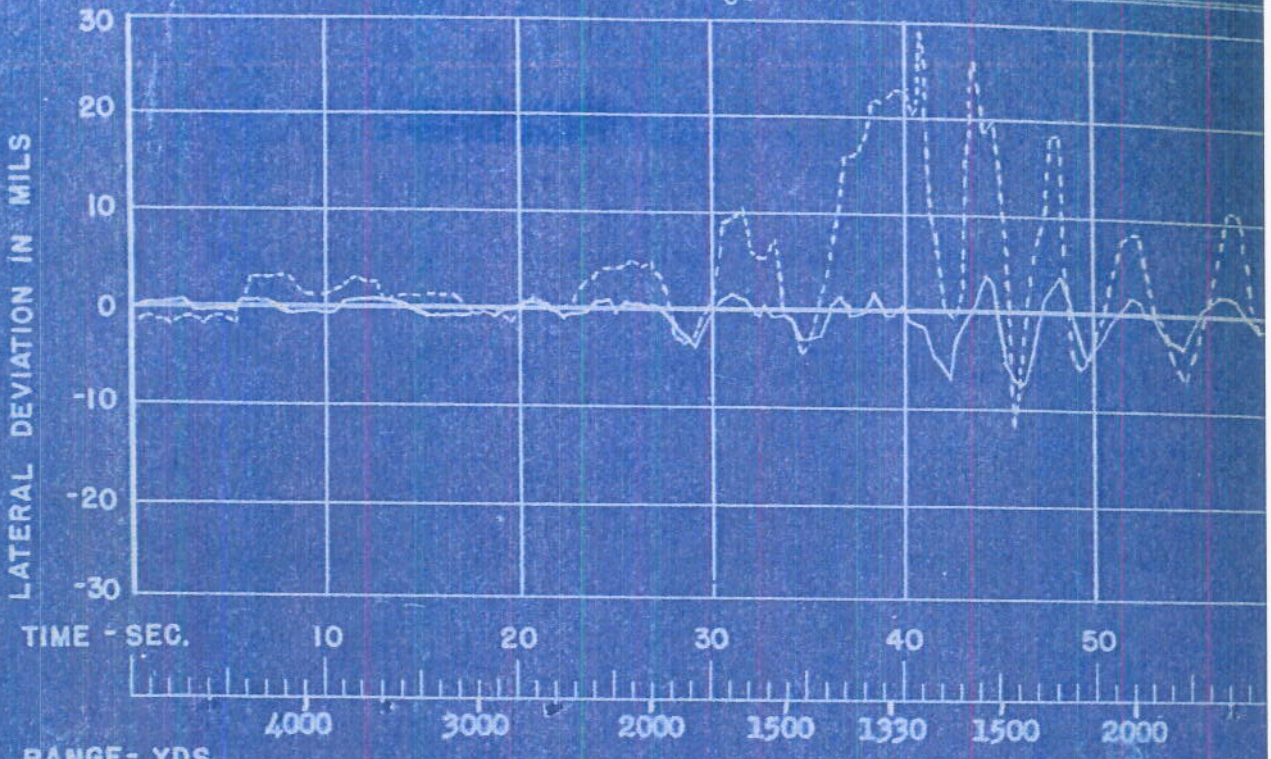
PLATE 9

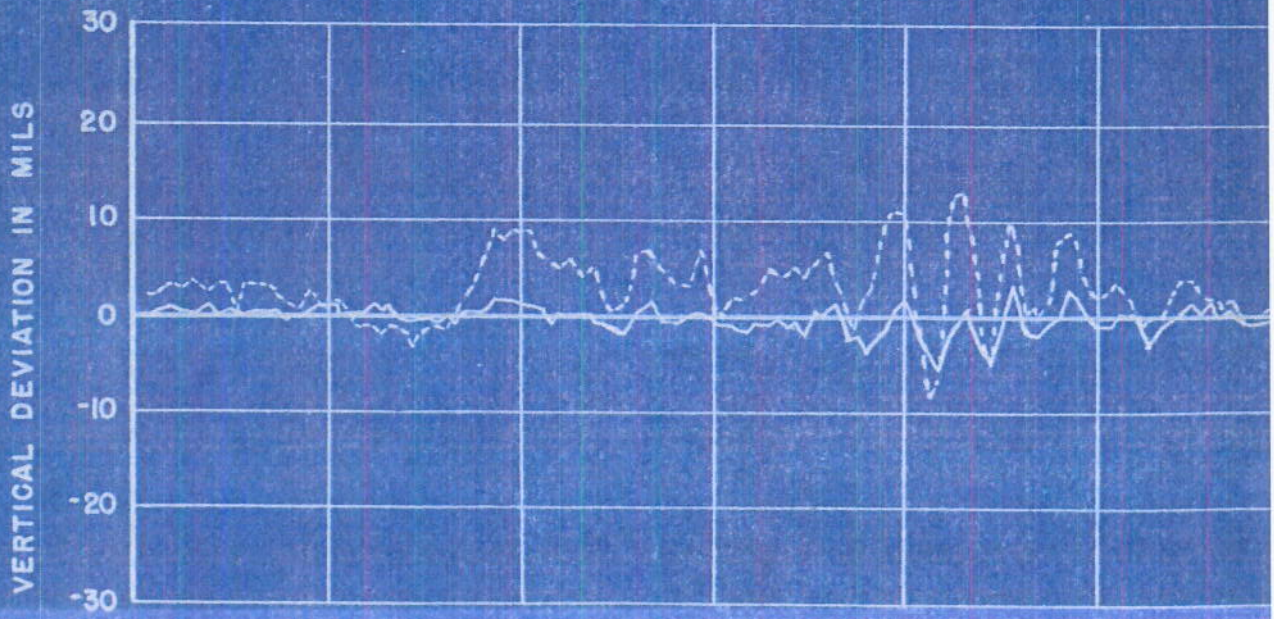
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
DWN. PBC APPR. JJF

RUN 108 TEST 79
DATE 11/8/45 TARGET F4U
SPEED 225 KN, ALT. 2000 FT
COURSE I-R Pass
TRACKING Radar



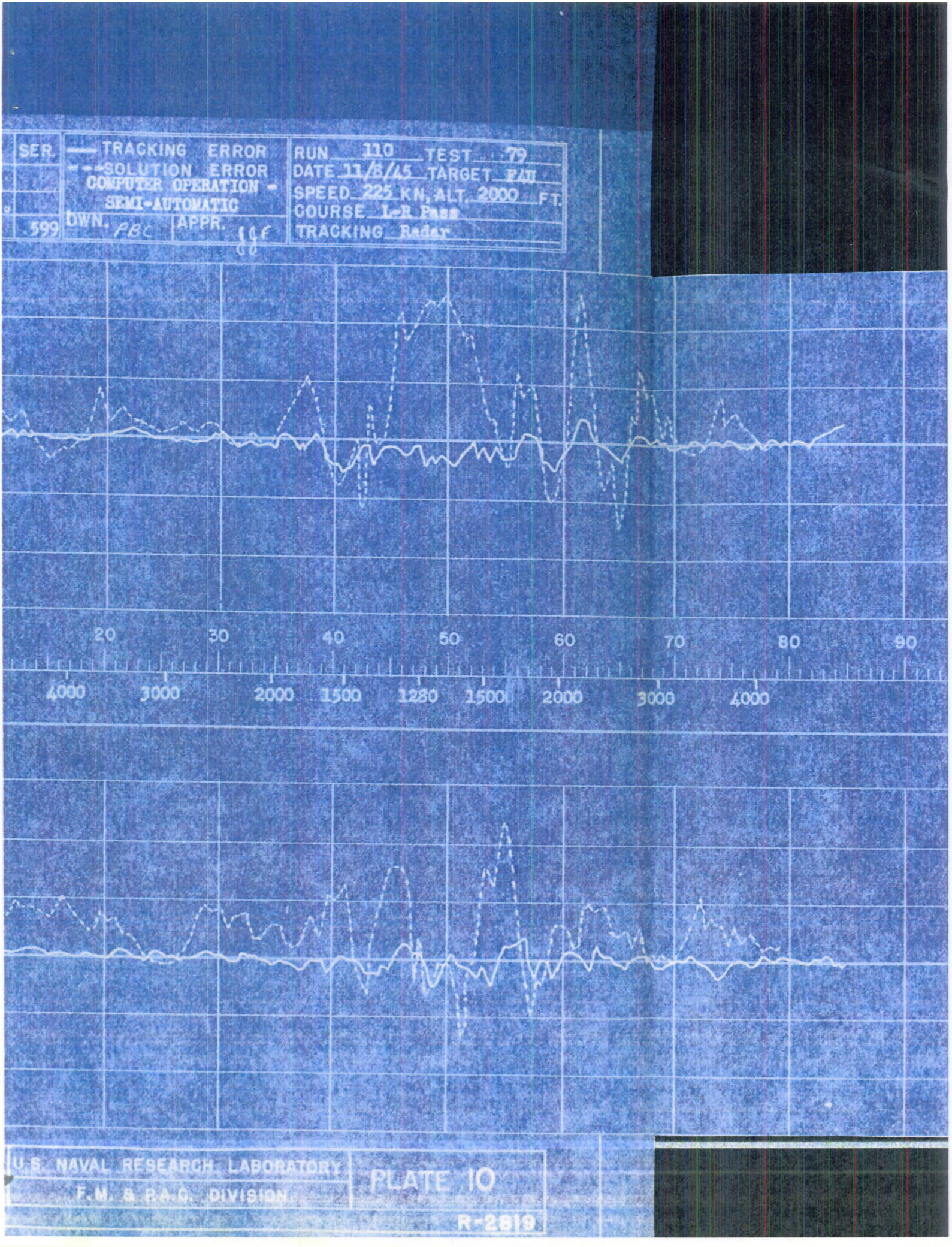


CONFIDENTIAL

U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 9

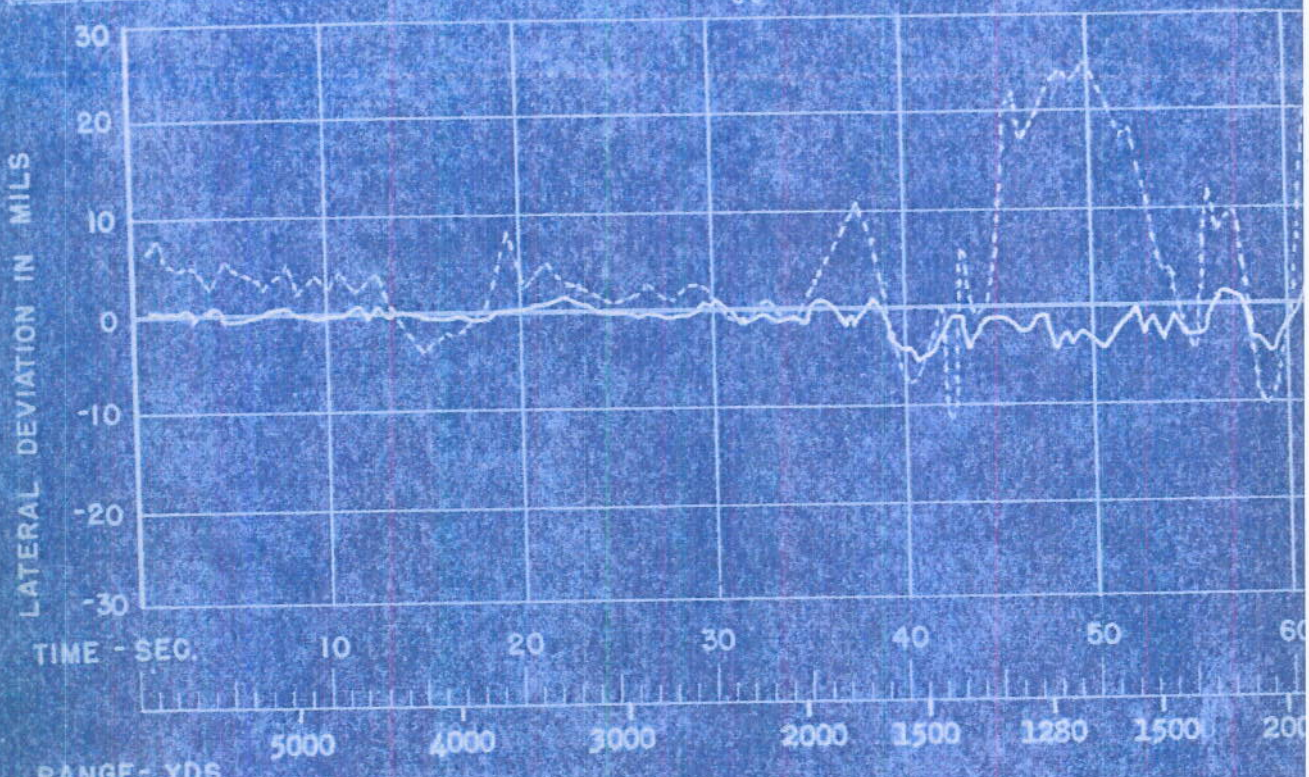
R-2819

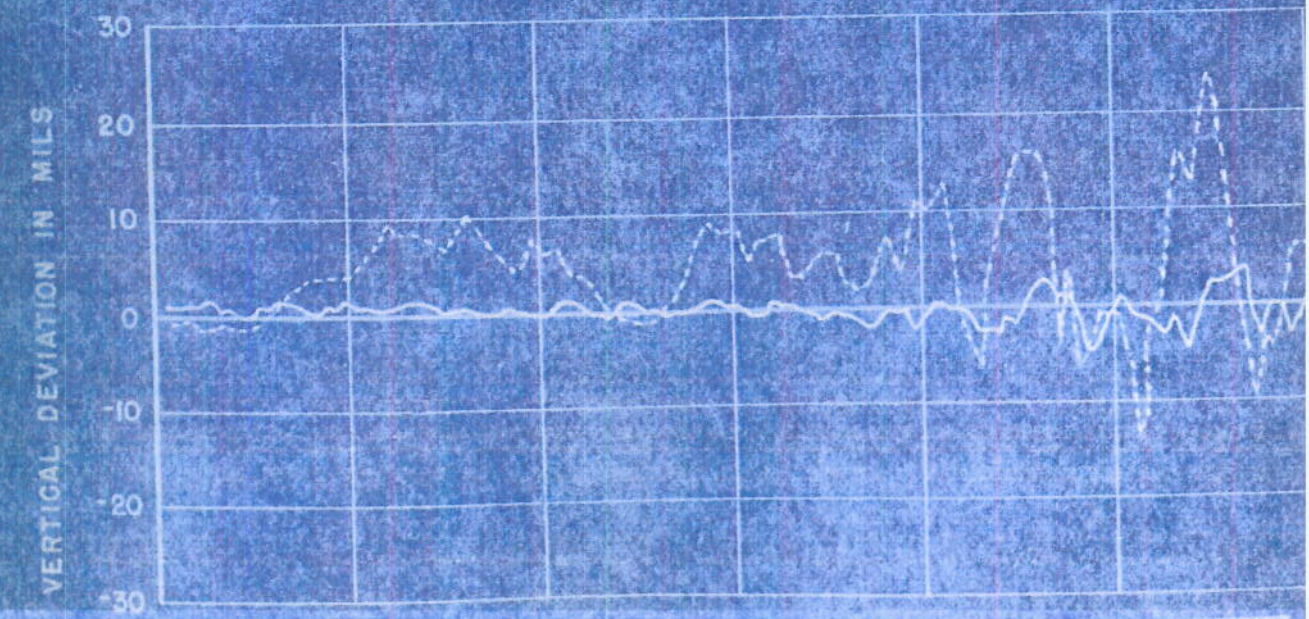

SER. 599
— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC
APPR.
RUN 110 TEST 79
DATE 11/8/45 TARGET PAN
SPEED 225 KN, ALT. 2000 FT.
COURSE L-R Pass
TRACKING Radar
20 30 40 50 60 70 80 90
4000 3000 2000 1500 1280 1500 2000 3000 4000
U.S. NAVAL RESEARCH LABORATORY
F.M. & R.A.D. DIVISION
PLATE 10
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC APPR. [illegible]

RUN 110 TEST 79
DATE 11/8/45 TARGET PAU
SPEED 225 KN, ALT. 2000 FT.
COURSE L-R Pass
TRACKING Radar

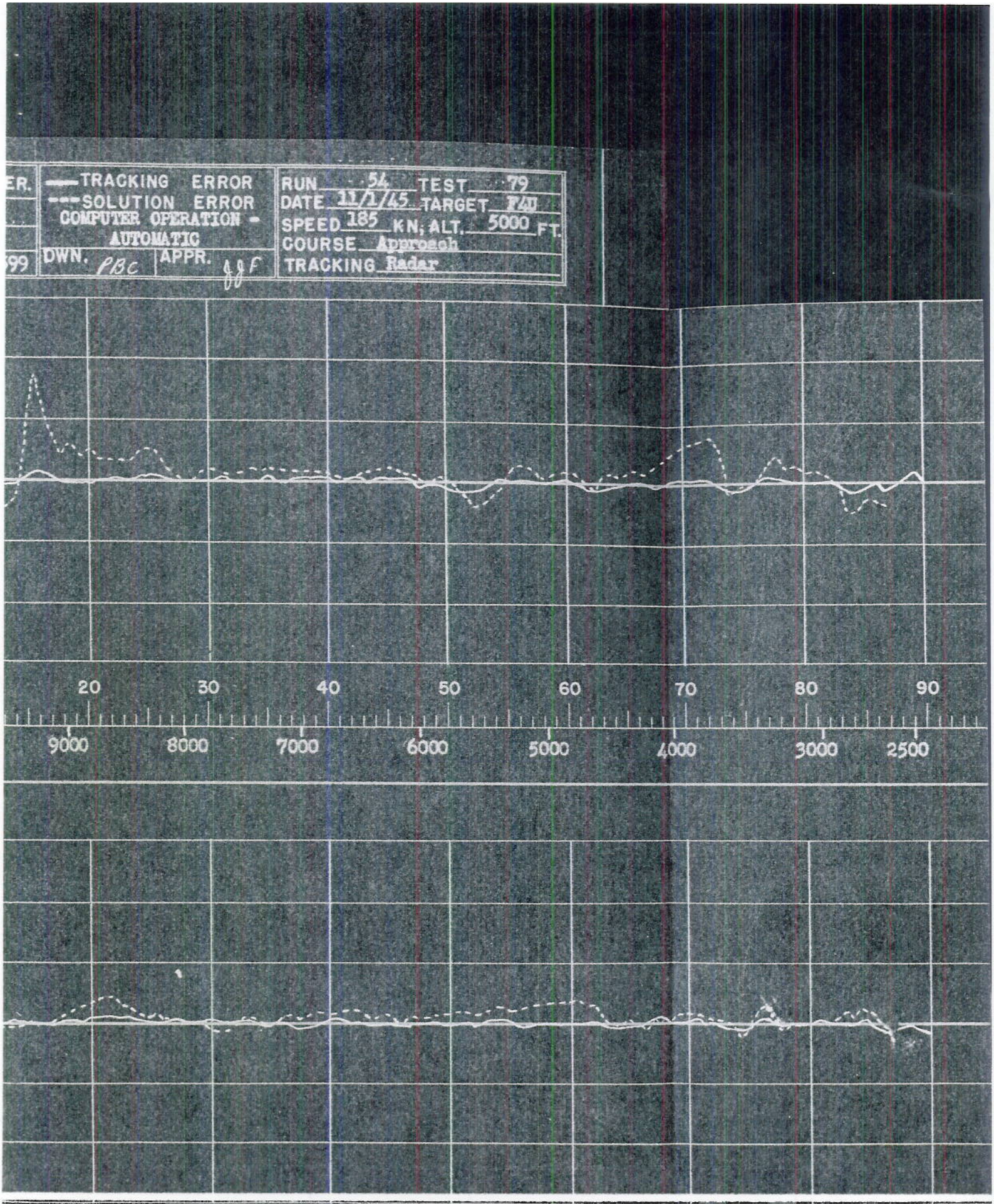




[redacted]

U.S. NAVAL RESEARCH LABORATORY
F. M. & P. A. D. DIVISION

PLATE 10
R-2819



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

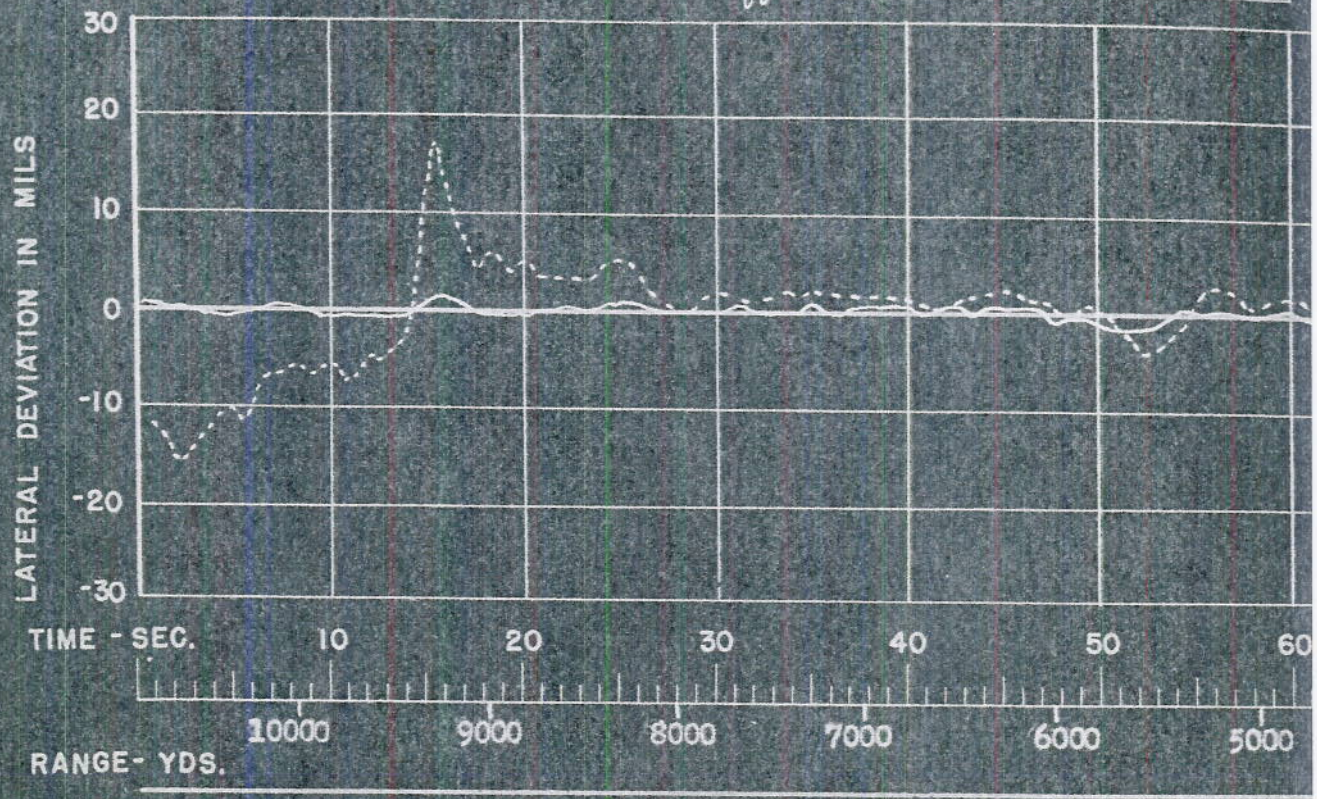
PLATE 14

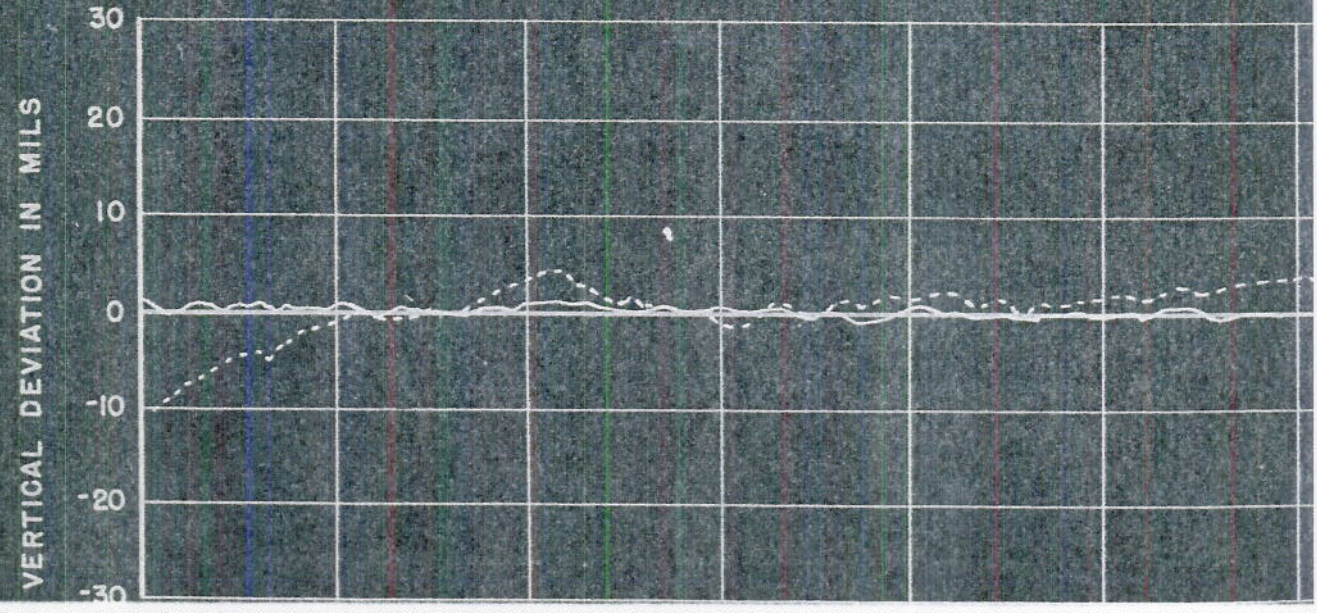
TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—TRACKING ERROR
---SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC

DWN. PBC APPR. JJF

RUN 54 TEST 79
DATE 11/1/45 TARGET F4U
SPEED 185 KN; ALT. 5000 FT.
COURSE Approach
TRACKING Radar

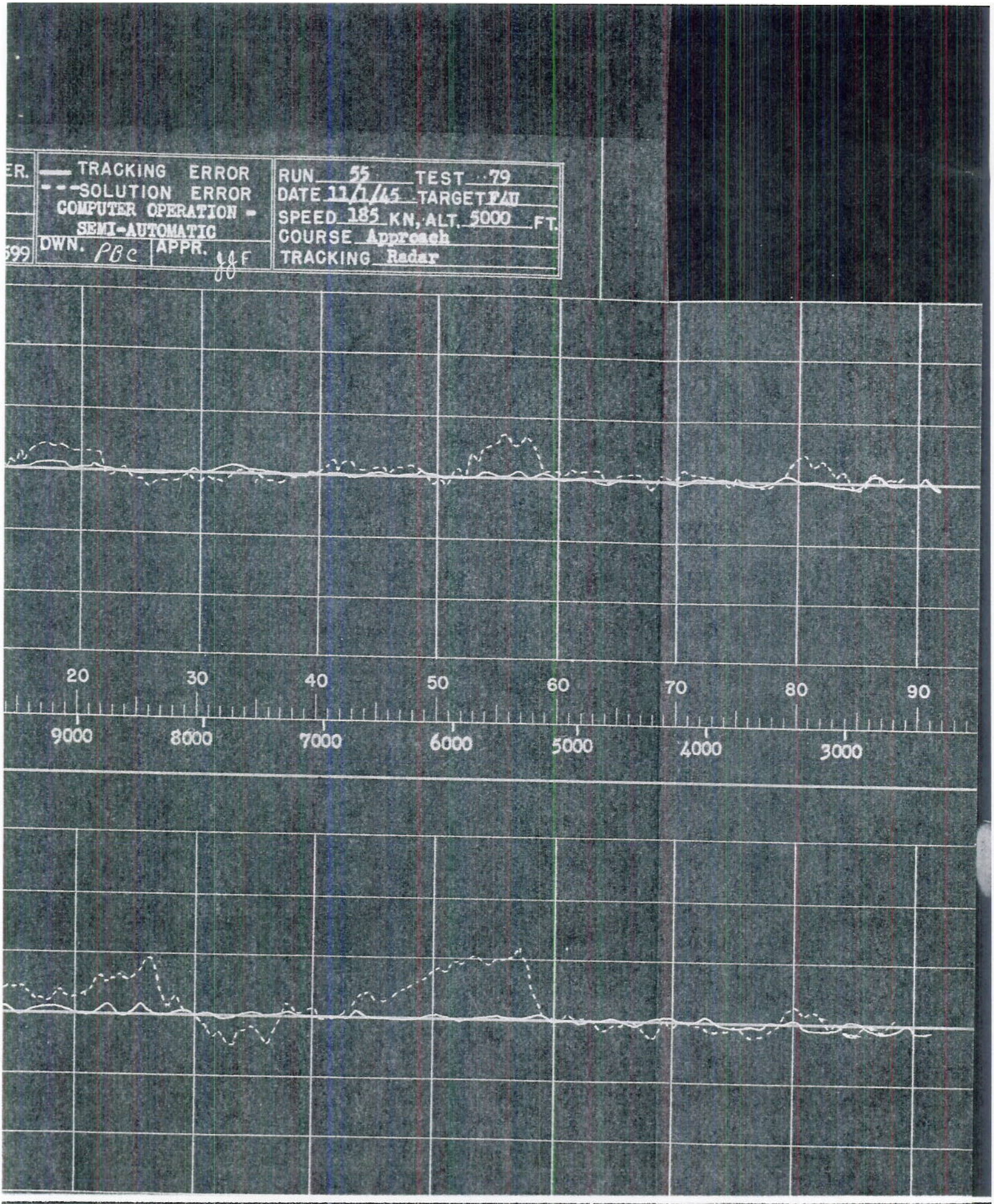




U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 14

R-2819



U. S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

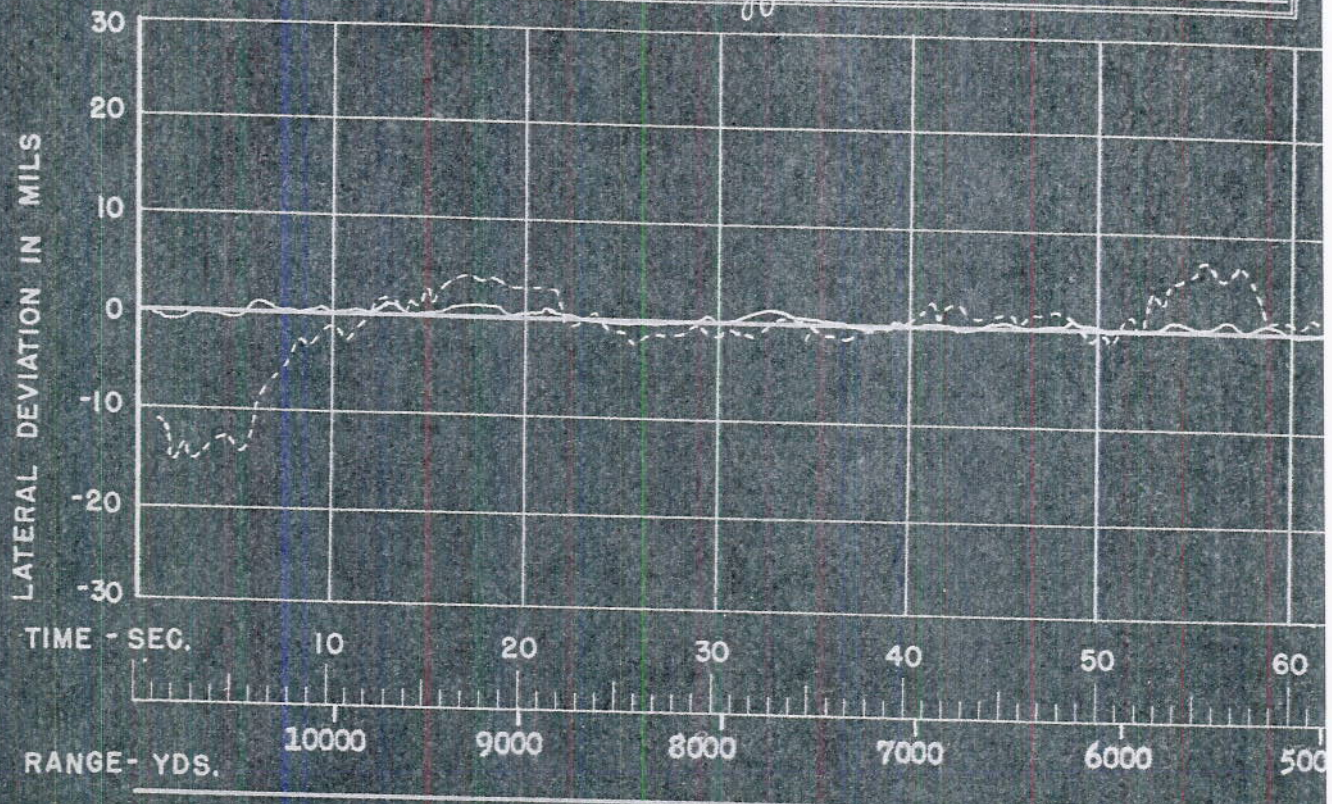
PLATE 15

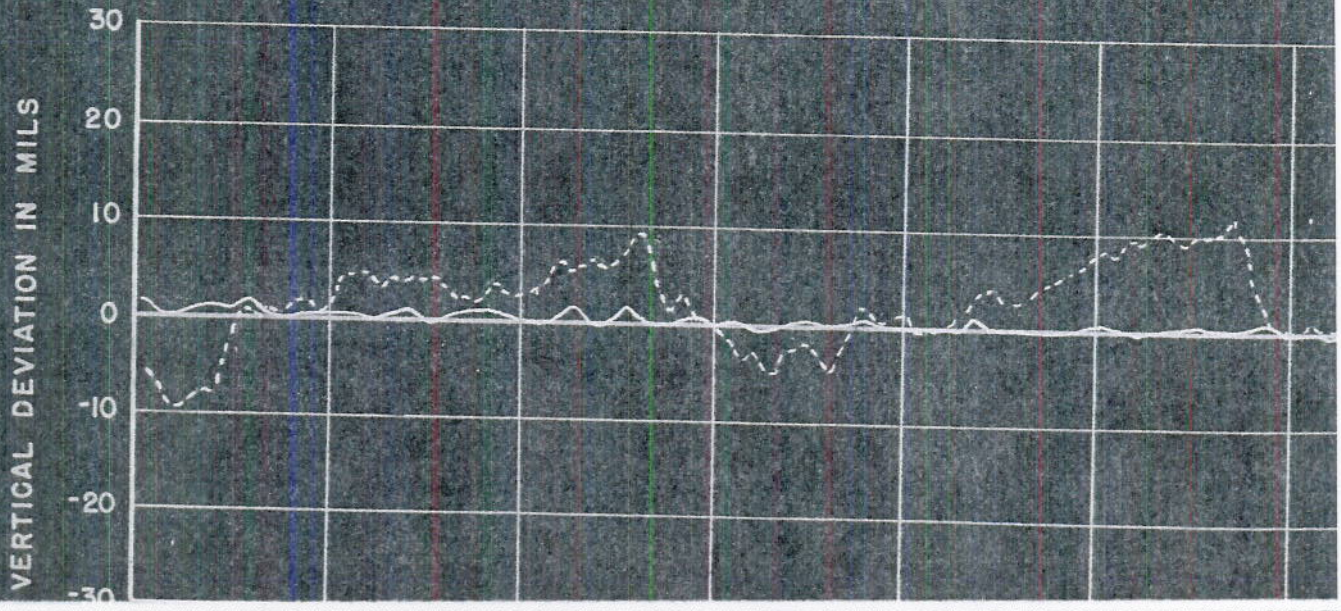
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC APPR. HF

RUN 55 TEST 79
DATE 11/1/45 TARGET F4U
SPEED 185 KN, ALT. 5000 FT.
COURSE Approach
TRACKING Radar





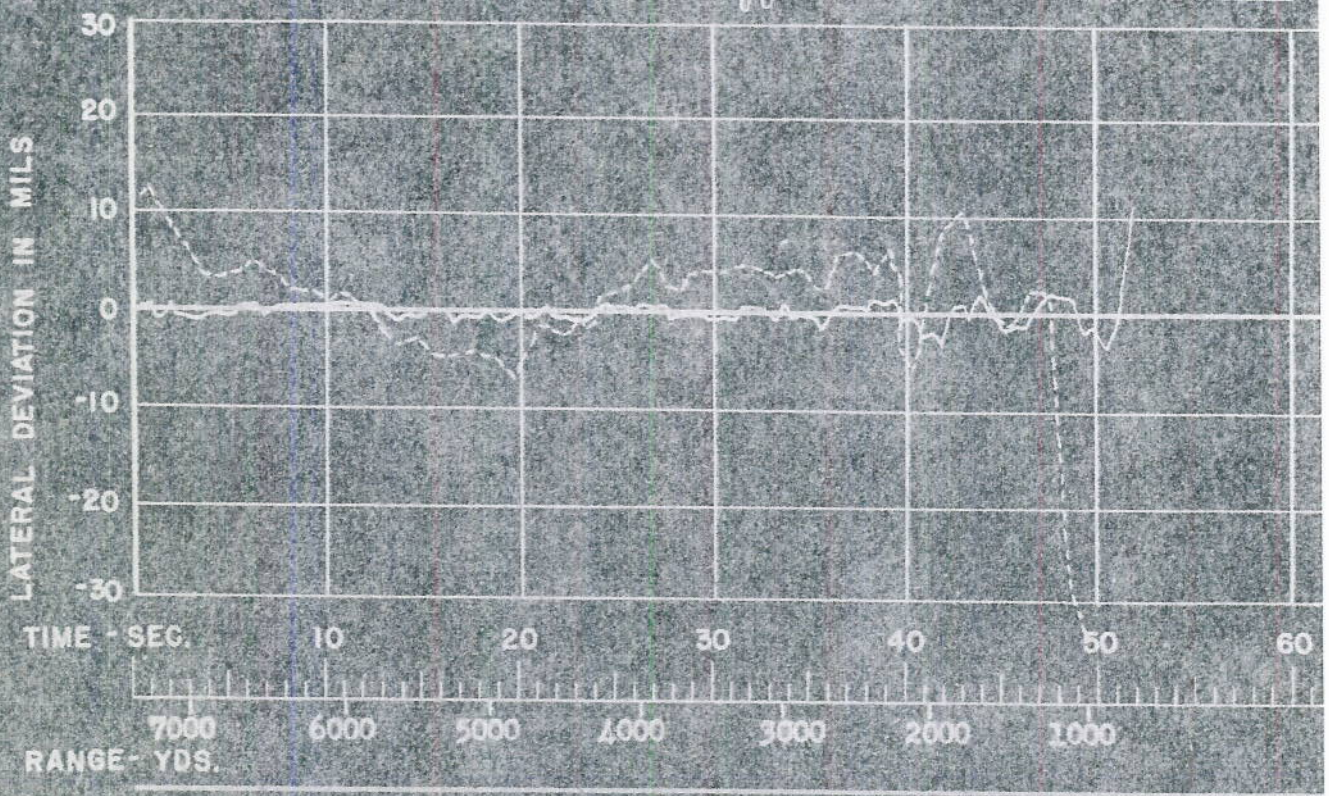
U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

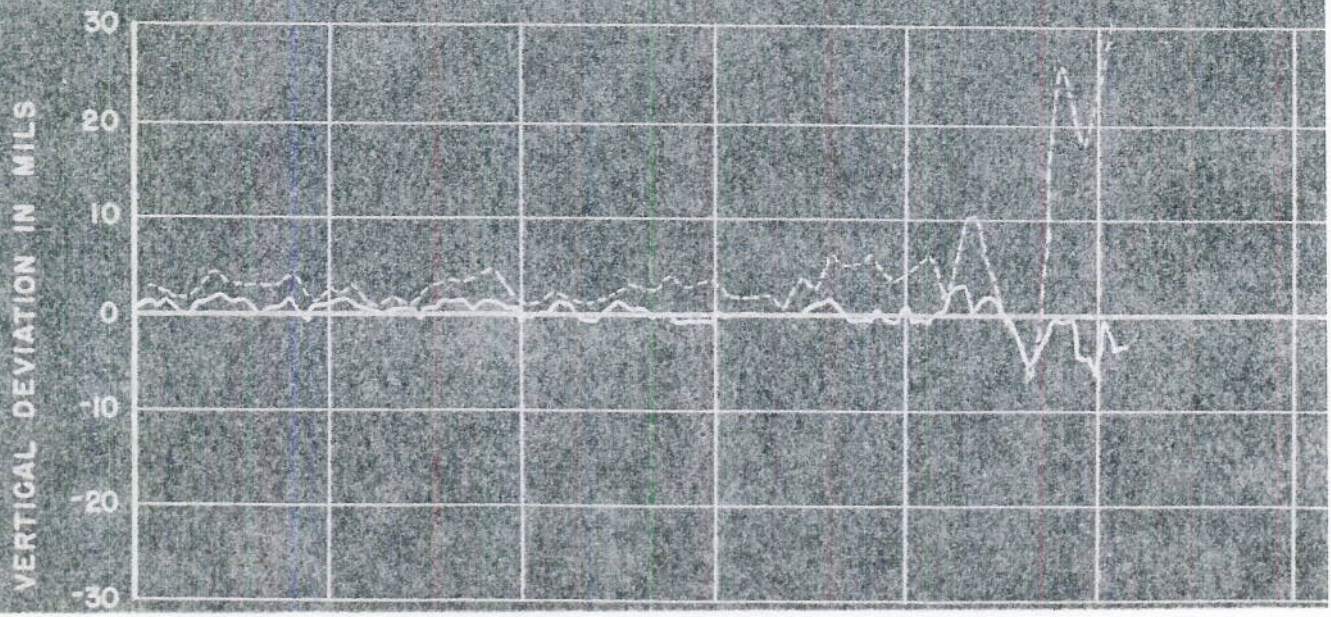
PLATE 15

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
--- SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
DWN. PBC | APPR. [illegible]

RUN 124 TEST 79
DATE 11/9/45 TARGET RAU
SPEED 240 KN. ALT. 2000 FT.
COURSE Approach
TRACKING Radar





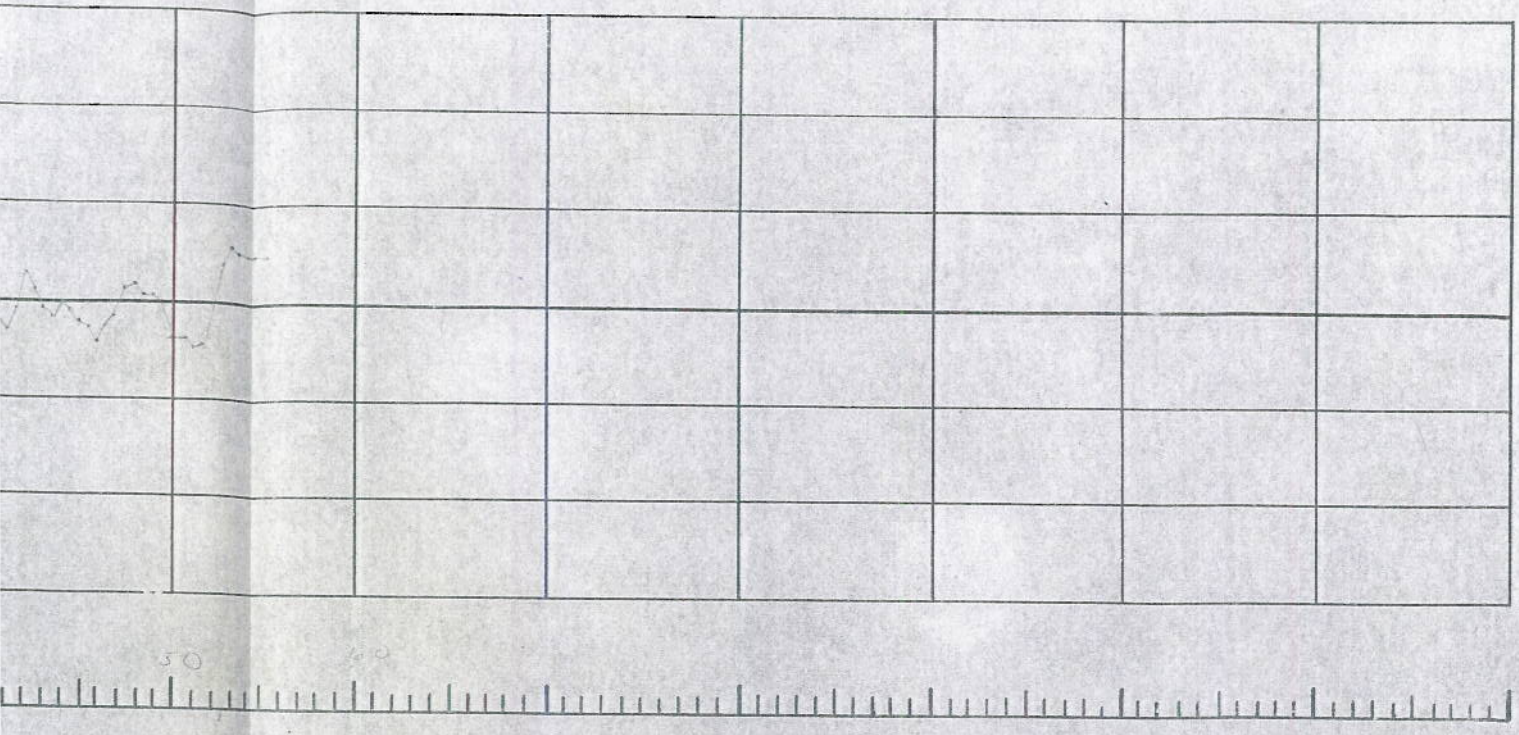
[redacted]

U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 16

R-2819

TARGET
KN, ALT. FT.
SE
KING





B.
Y

TEST OF	MK	MOD	SER
DIRECTOR			
RADAR			
COMPUTER			

RUN ____ TEST ____

——— TRACKING ERROR

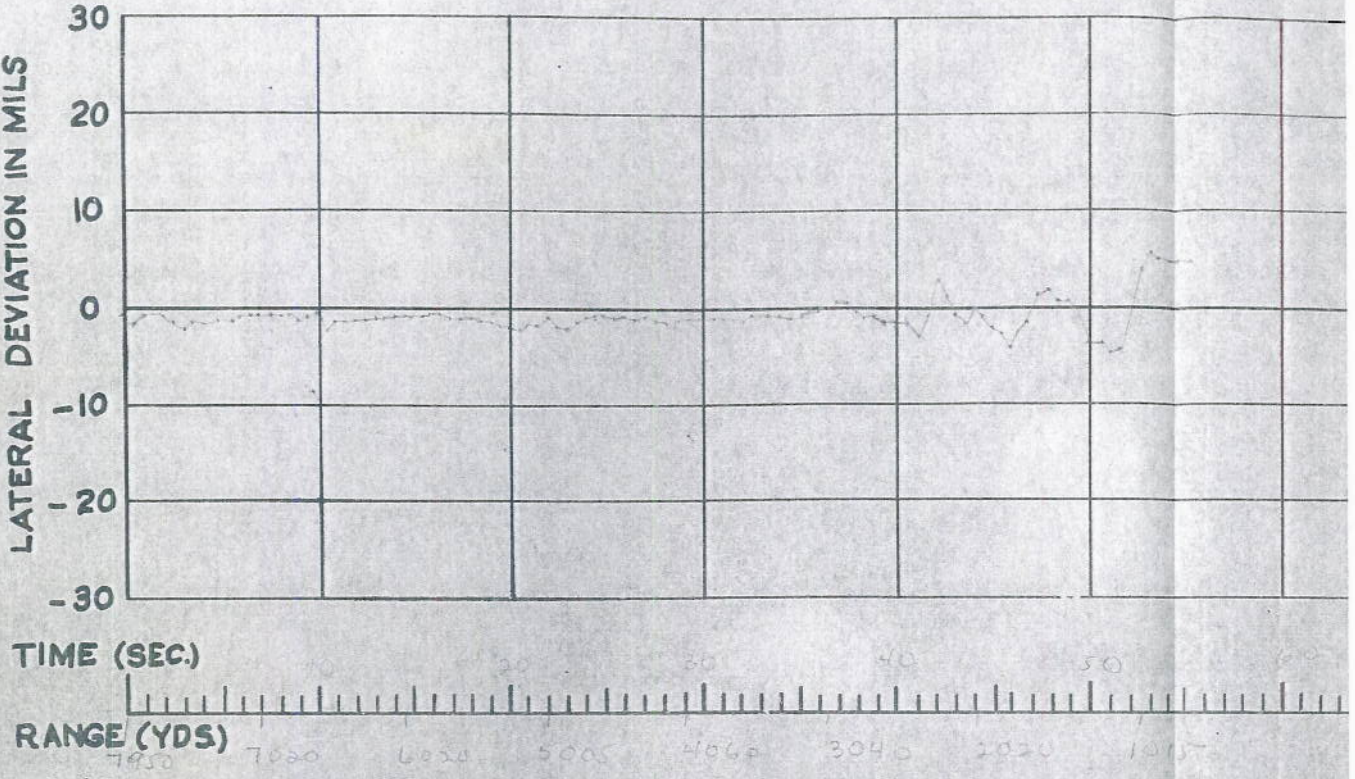
-·-·-· SOLUTION ERROR

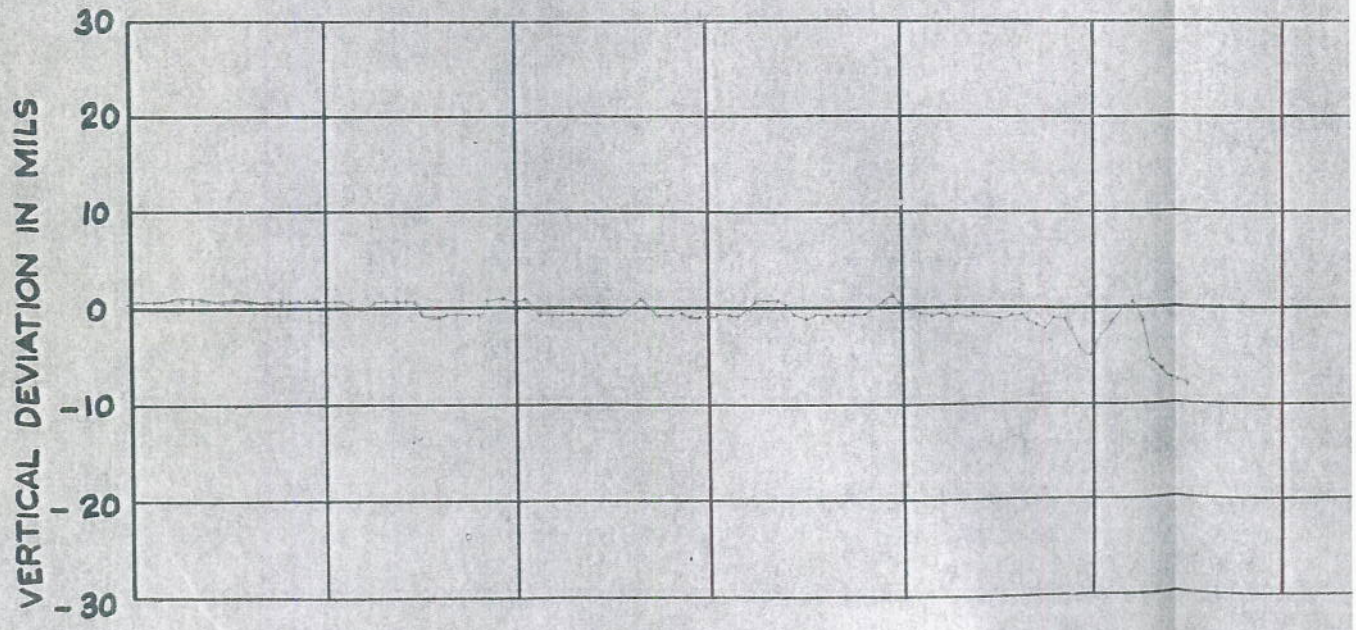
DATE ____ TARGET ____

SPEED ____ KN, ALT. ____ FT.

COURSE ____

TRACKING ____





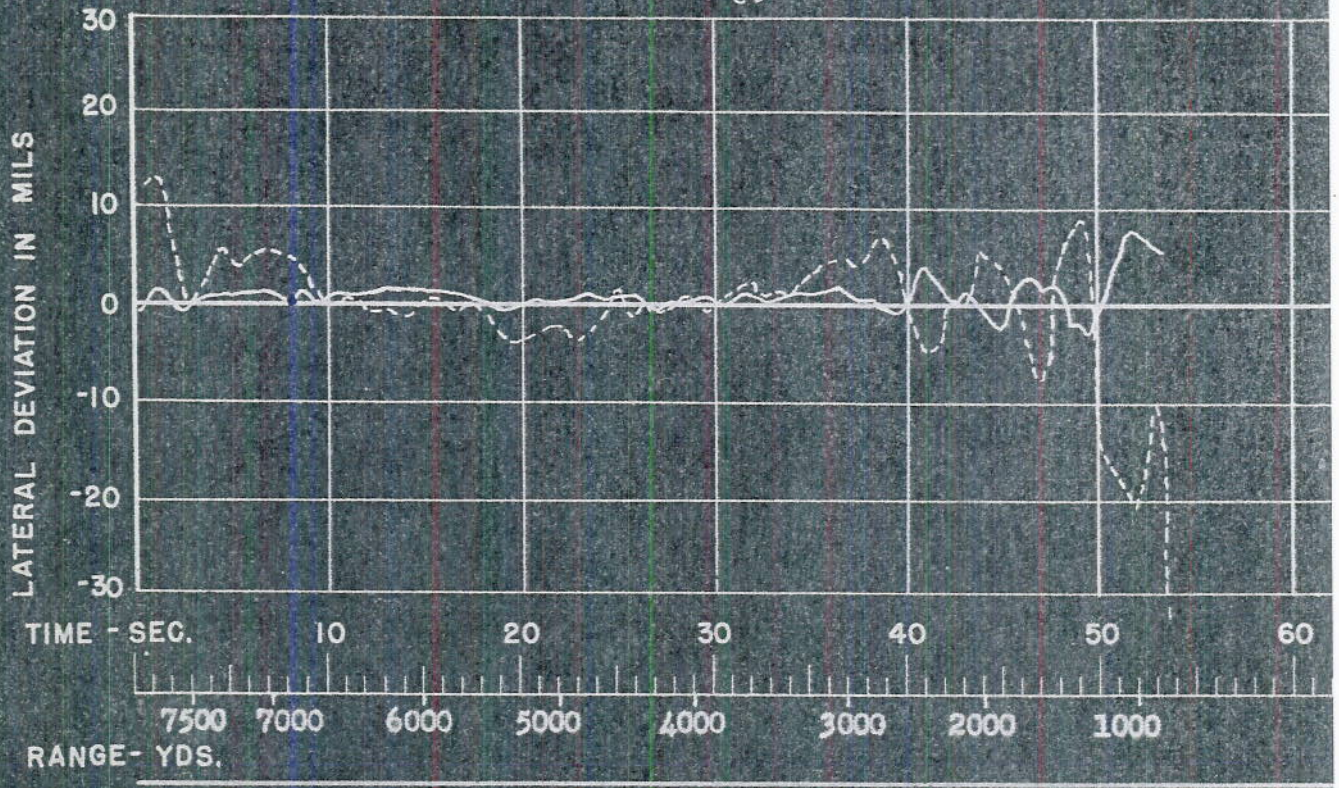
U.S. NAVAL RESEARCH LAB.

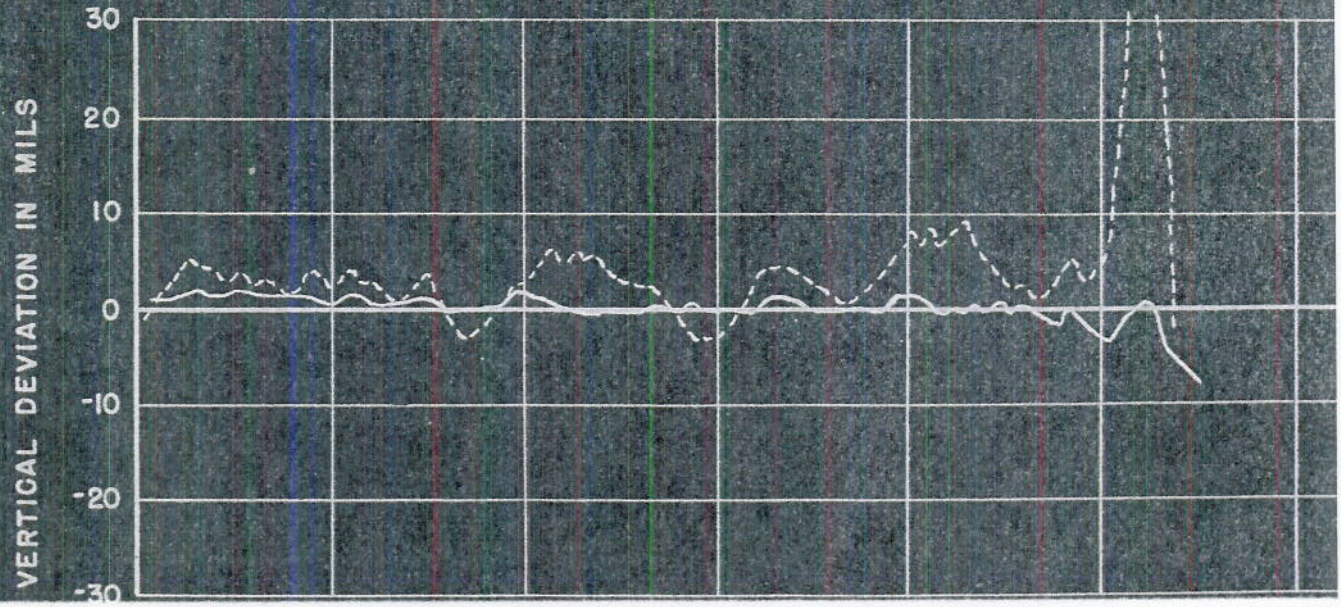
FIRE CONTROL DIVISION

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC APPR. [illegible]

RUN 125 TEST 79
DATE 11/9/45 TARGET PAU
SPEED 240 KN, ALT. 2000 FT.
COURSE Approach
TRACKING Radar

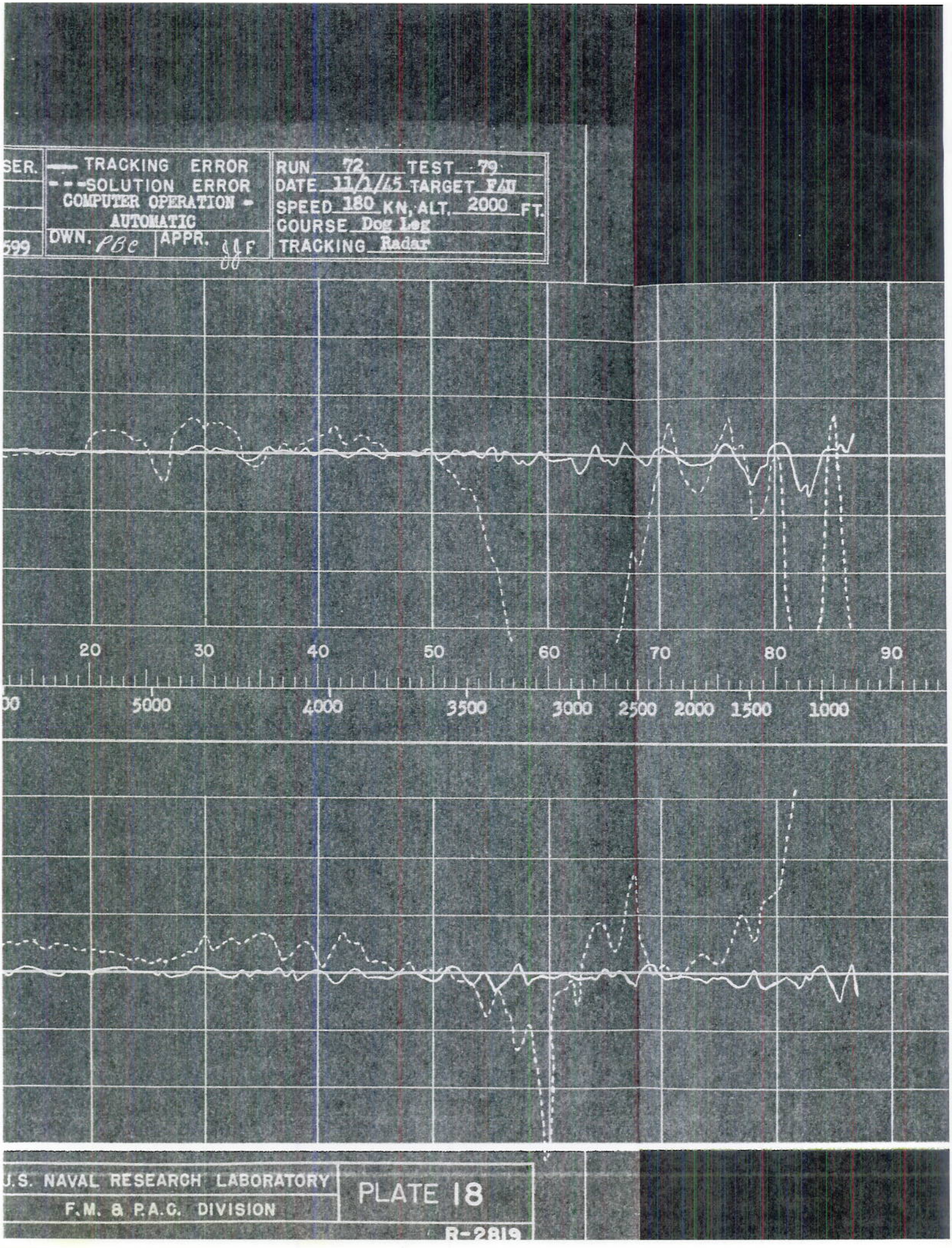




U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 17

R-2819



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

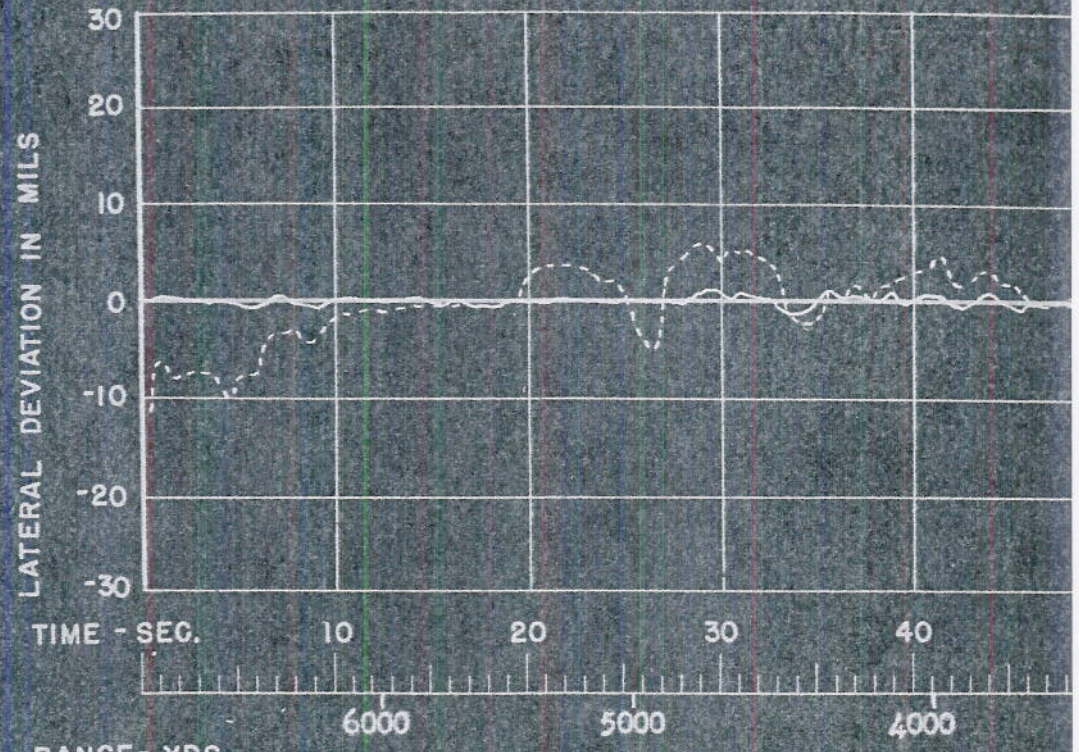
PLATE 18

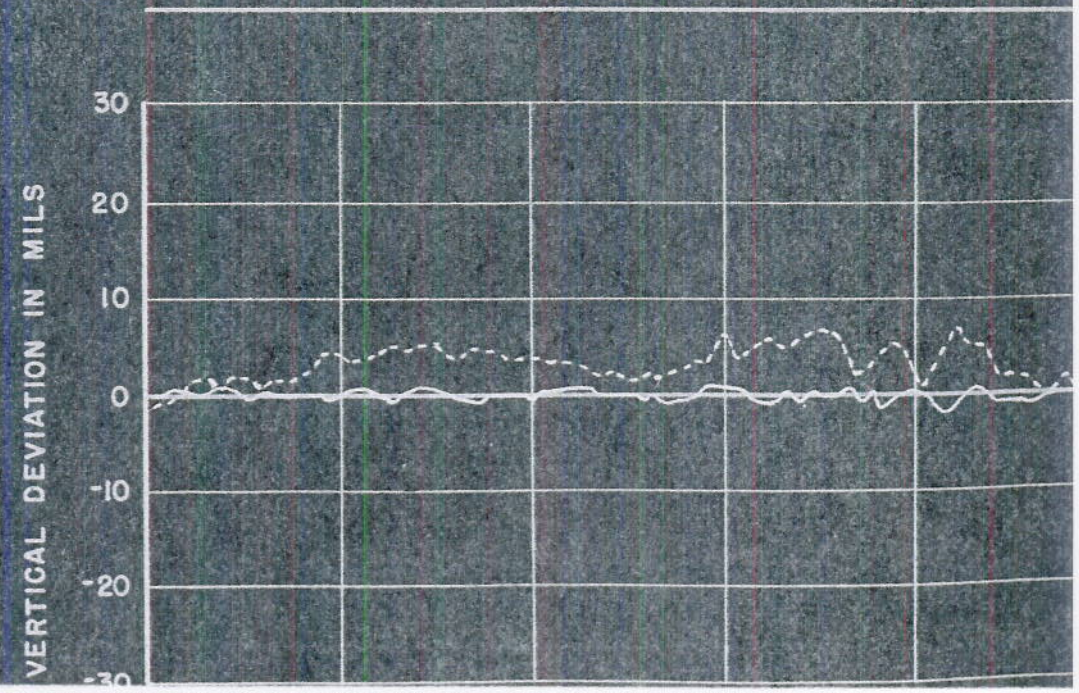
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
DWN. PBC APPR. GF

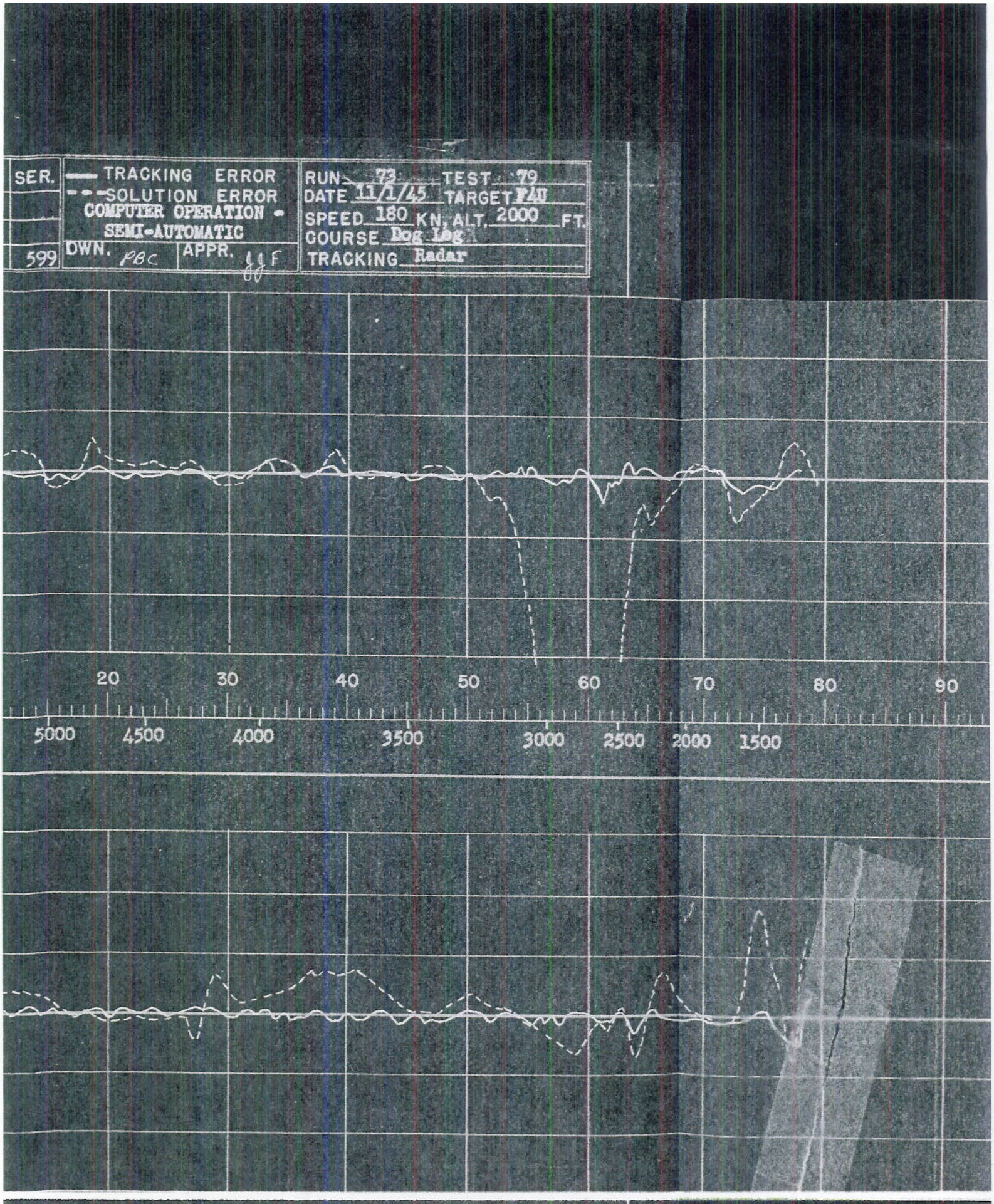
RUN 72 T
DATE 11/5/45
SPEED 180 KN,
COURSE Dog L
TRACKING Rad





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLA



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

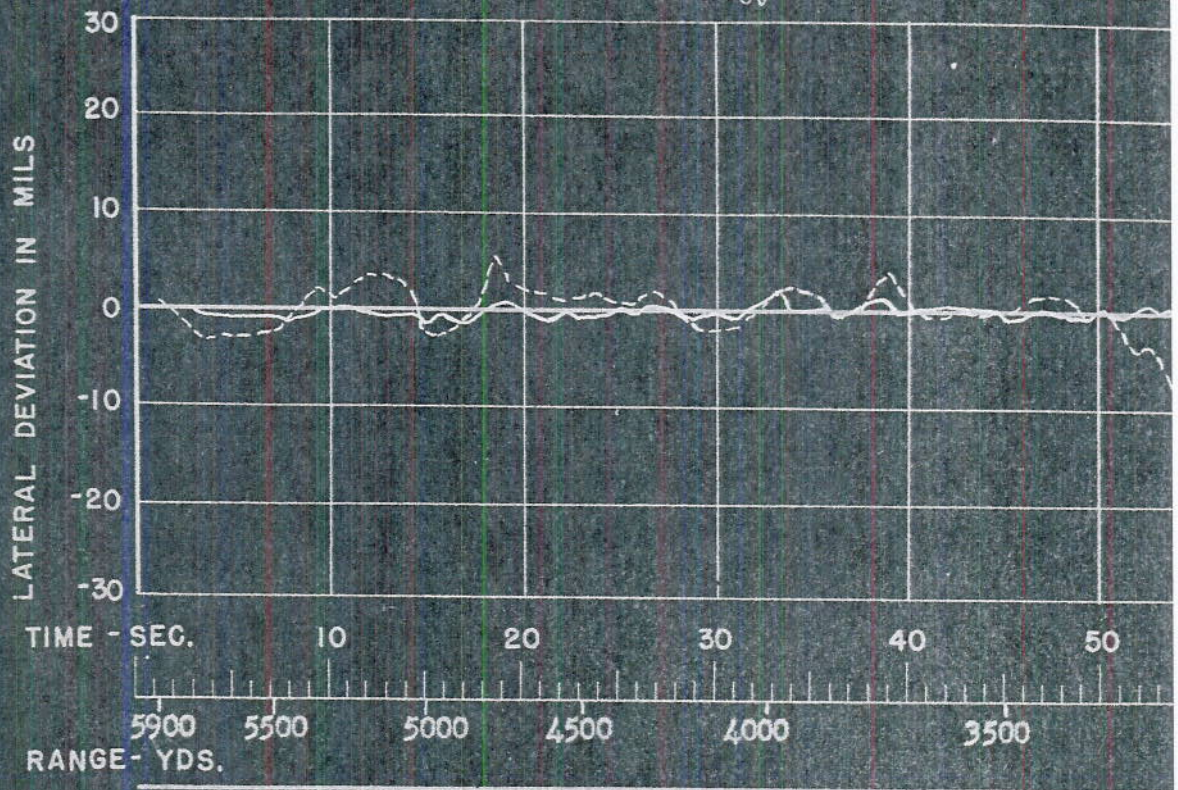
PLATE 19

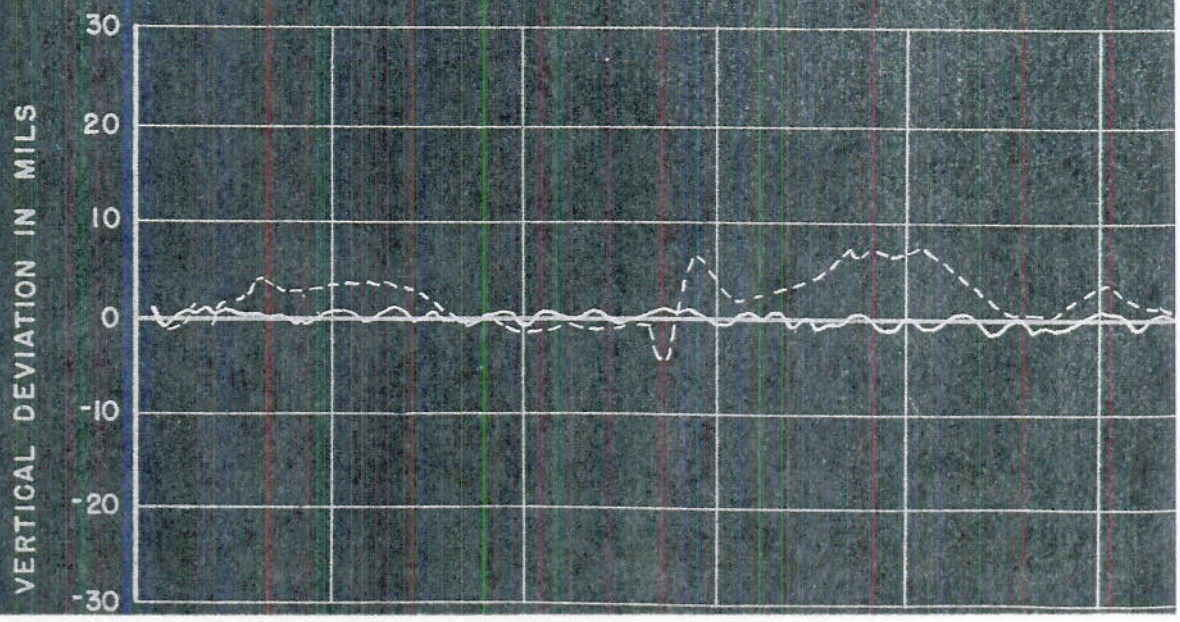
R-2819

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC APPR. JJF

RUN 73 TEST
DATE 11/1/45 TARGET
SPEED 180 KN. ALT. 2
COURSE Dog Leg
TRACKING Radar

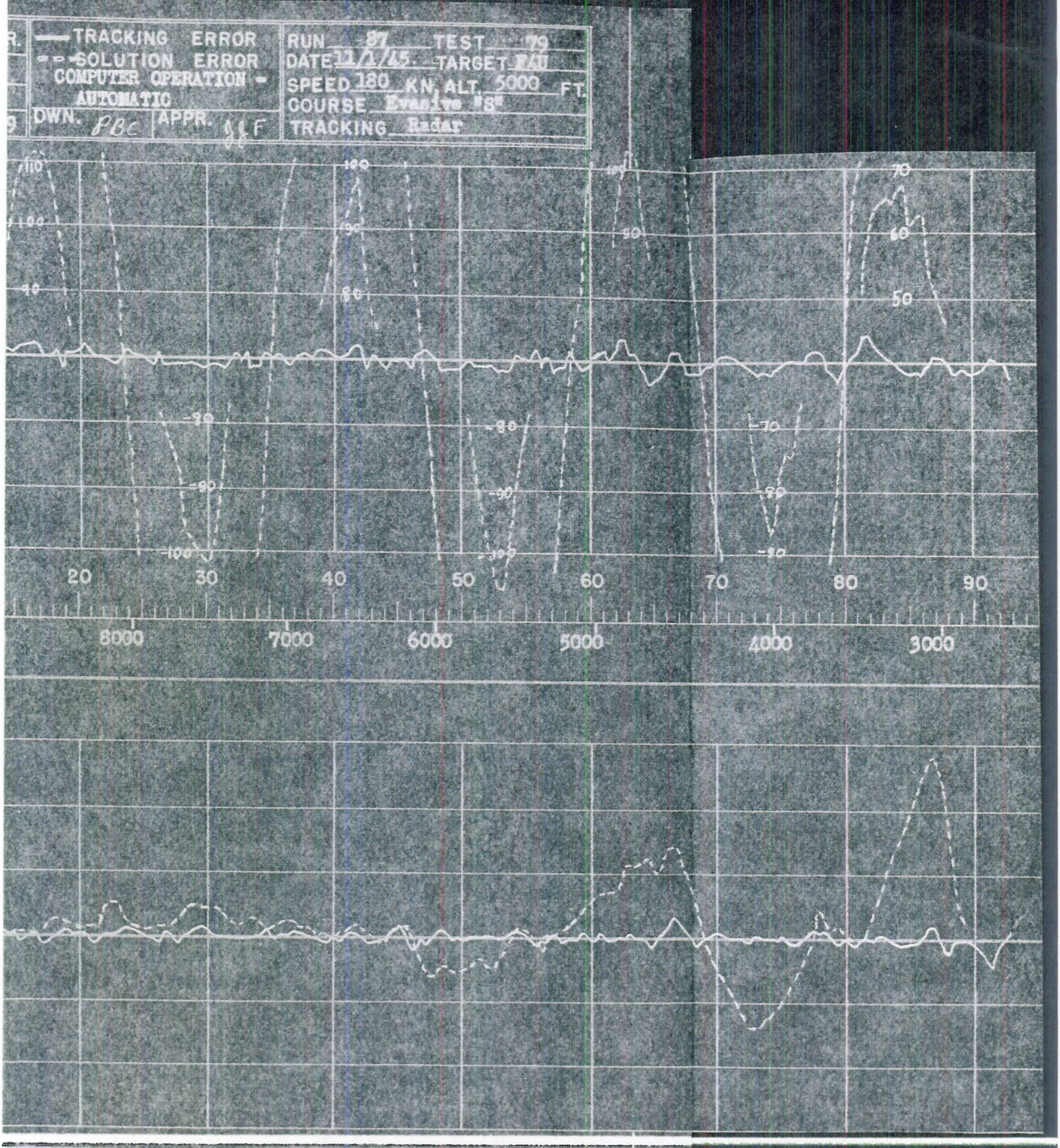




U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 19

R-2



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 20

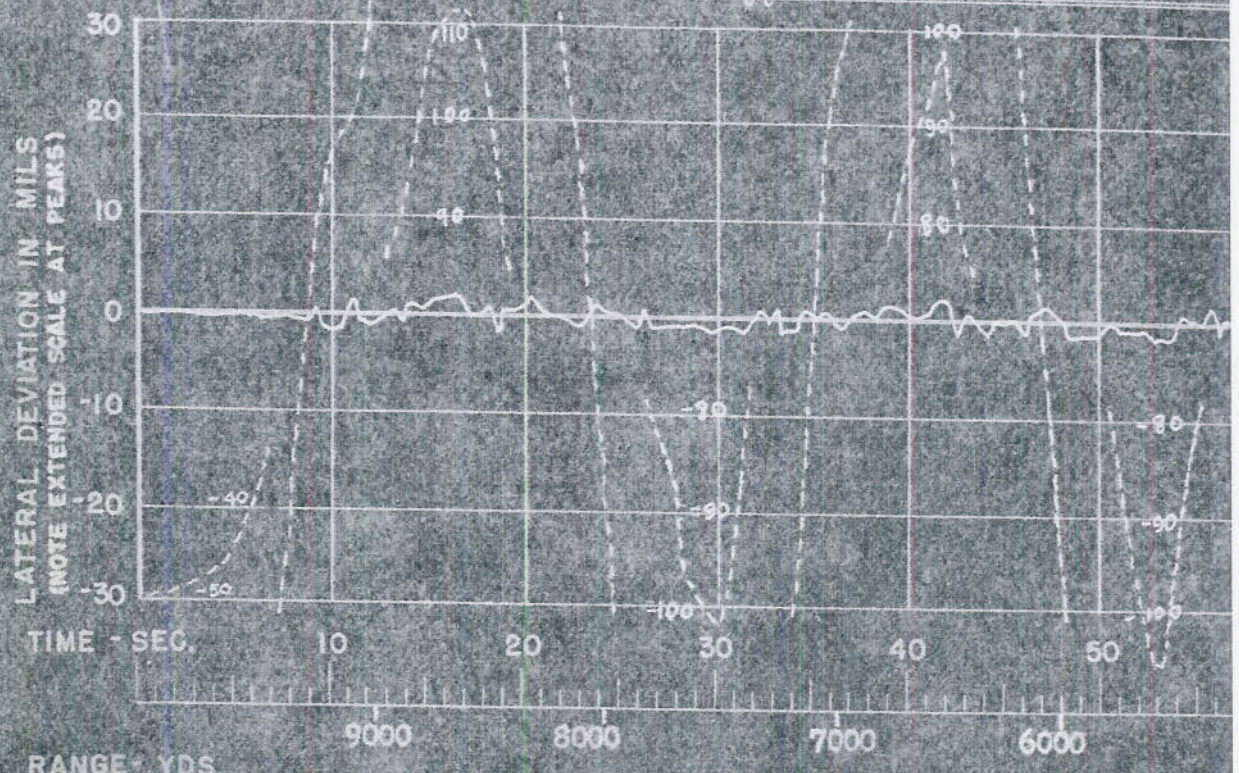
R-2819

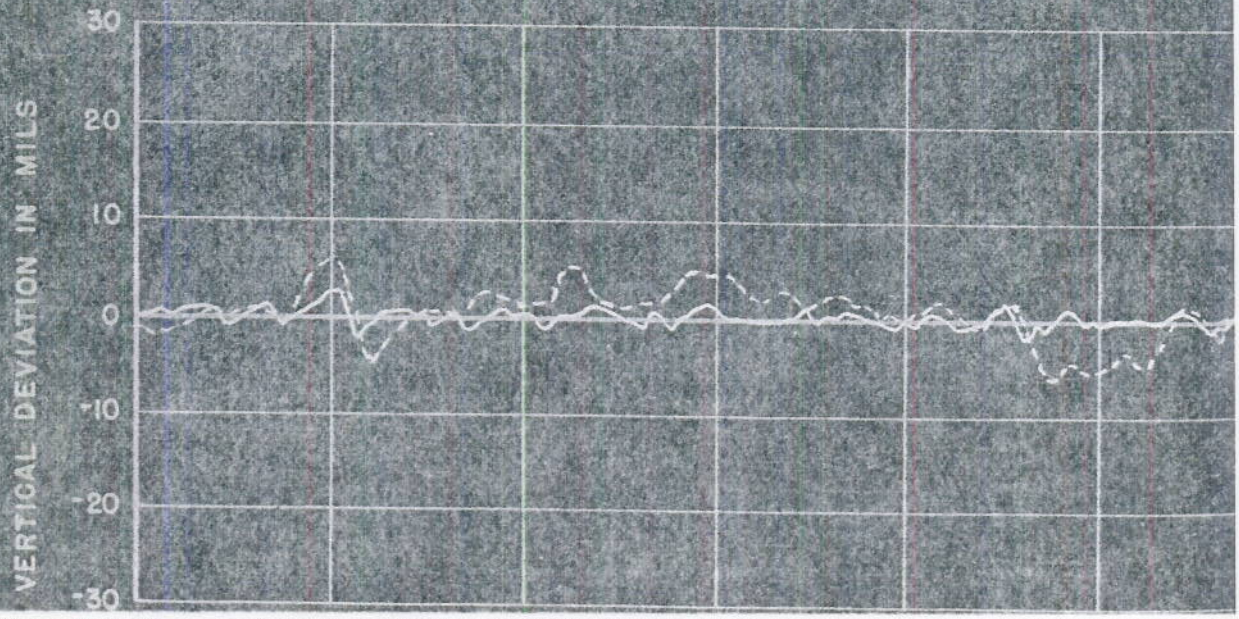
TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC

DWN. PBC APPR. JJF

RUN 87 TEST 79
DATE 11/1/45. TARGET RAT
SPEED 180 KN. ALT. 5000
COURSE Evasive "S"
TRACKING Radar





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 20

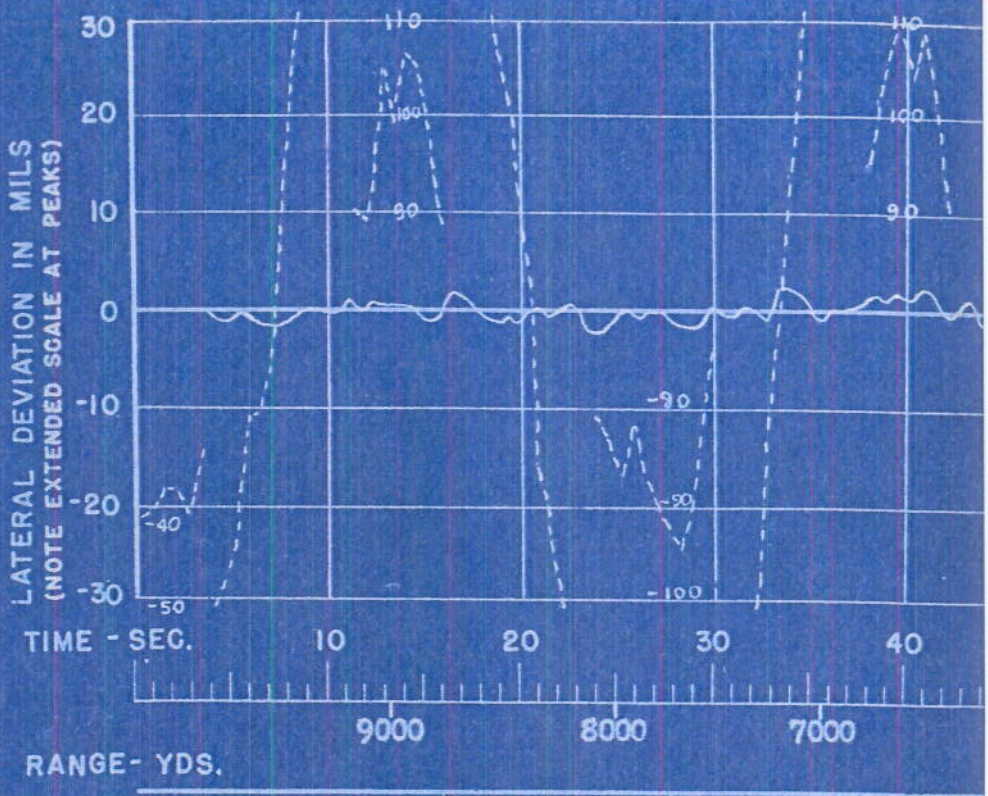
R-281

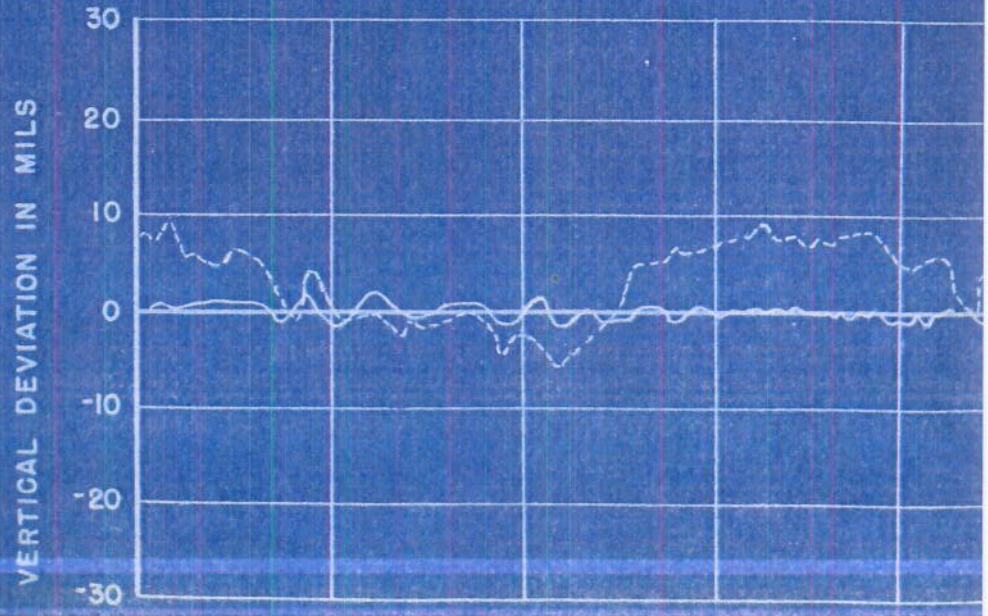

SER.
599
—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION -
SEMI-AUTOMATIC
DWN. PBC
APPR. JJF
RUN 88 TEST 79
DATE 11/1/45 TARGET F4U
SPEED 180 KN, ALT. 5000 FT.
COURSE Evasive "S"
TRACKING Radar
110
100
90
-90
-100
-80
-70
80
70
60
20
30
40
50
60
70
80
90
9000
8000
7000
6000
5000
4000
3000
U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION
PLATE 21

TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - SEMI-AUTOMATIC
DWN. PBC APPR. [illegible]

RUN 88
DATE 11/1
SPEED 18
COURSE
TRACKING





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

SER. 599

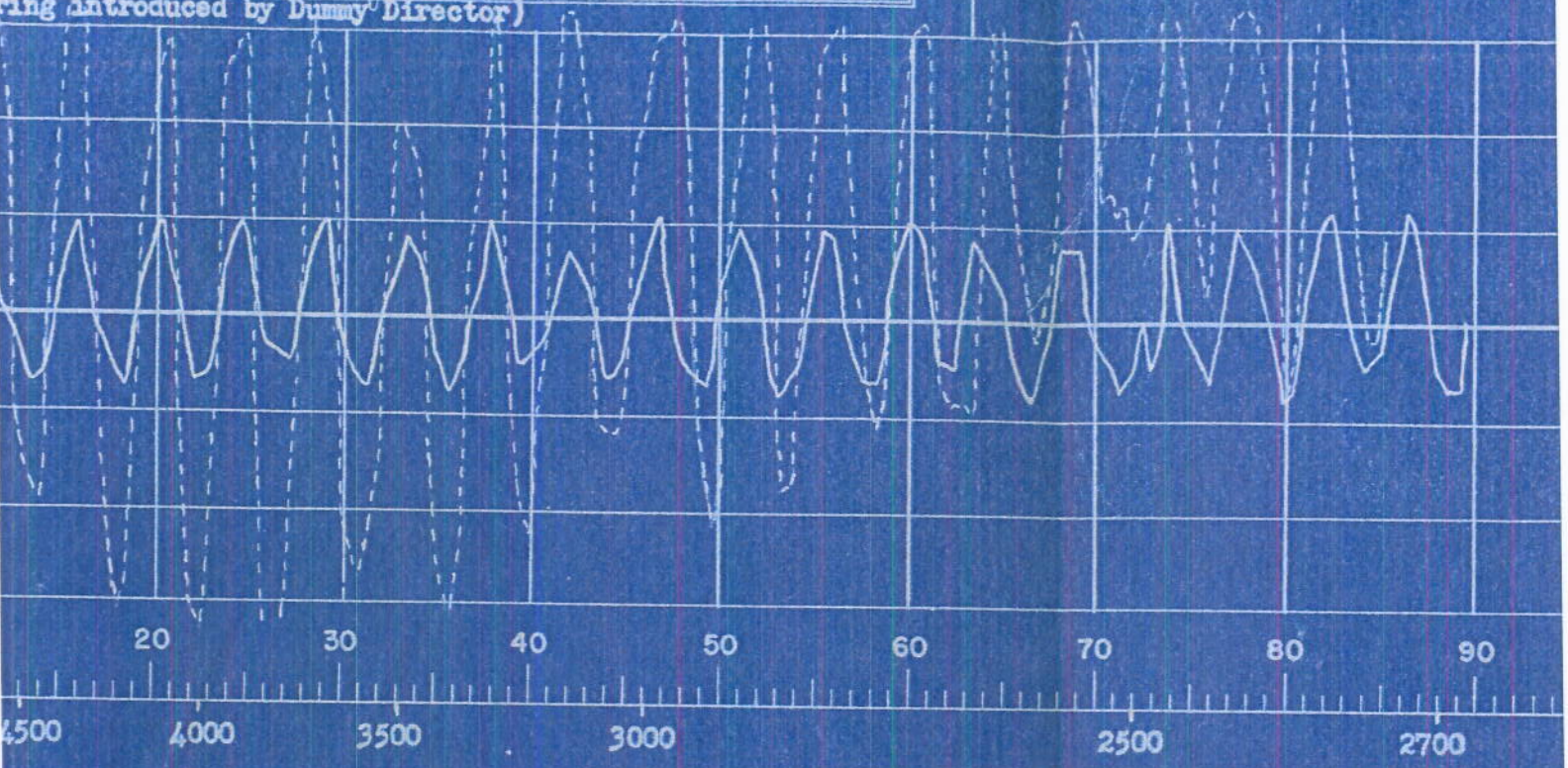
—TRACKING ERROR
- - -SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC

DWN. PBC APPR. LF

RUN 131 TEST 79
DATE 11/15/45 TARGET TBF
SPEED 150 KN; ALT. 5000 FT.
COURSE R-L Pass
TRACKING Radar

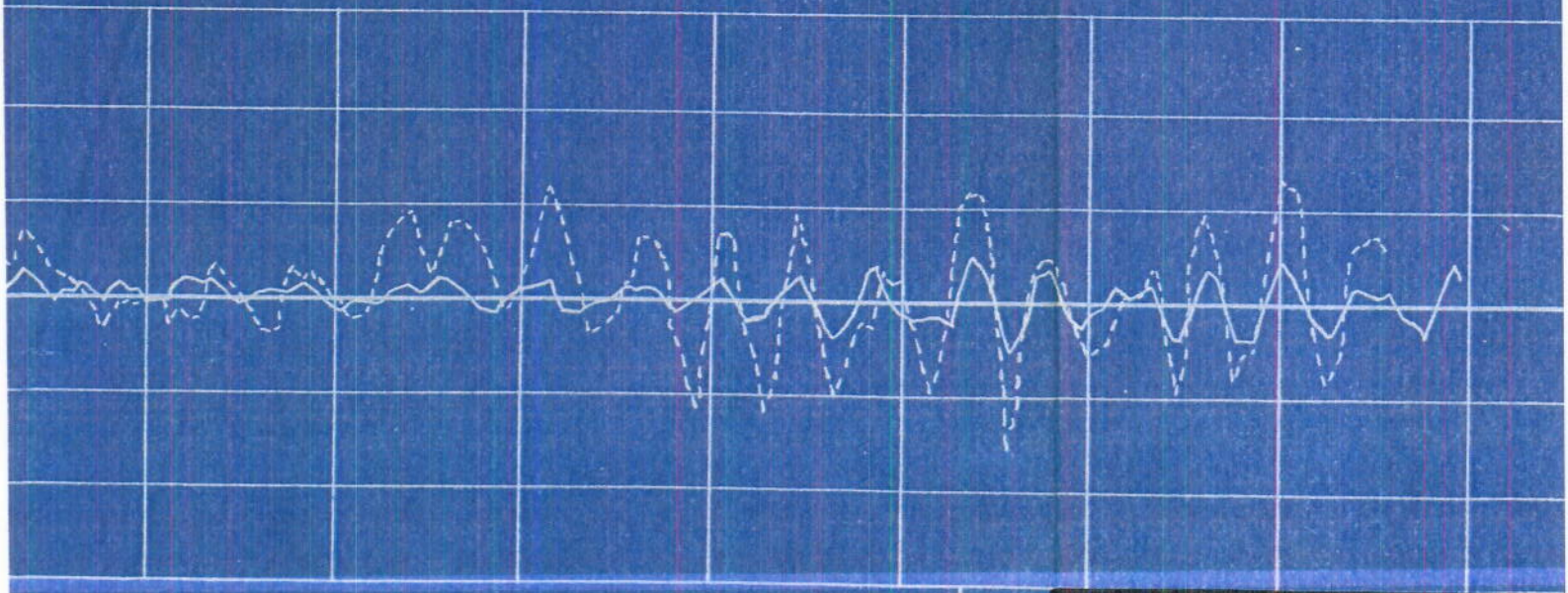
(Oscillations in Bearing introduced by Dummy Director)

ring introduced by Dummy Director)



20 30 40 50 60 70 80 90

4500 4000 3500 3000 2500 2700



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 22

R-2819

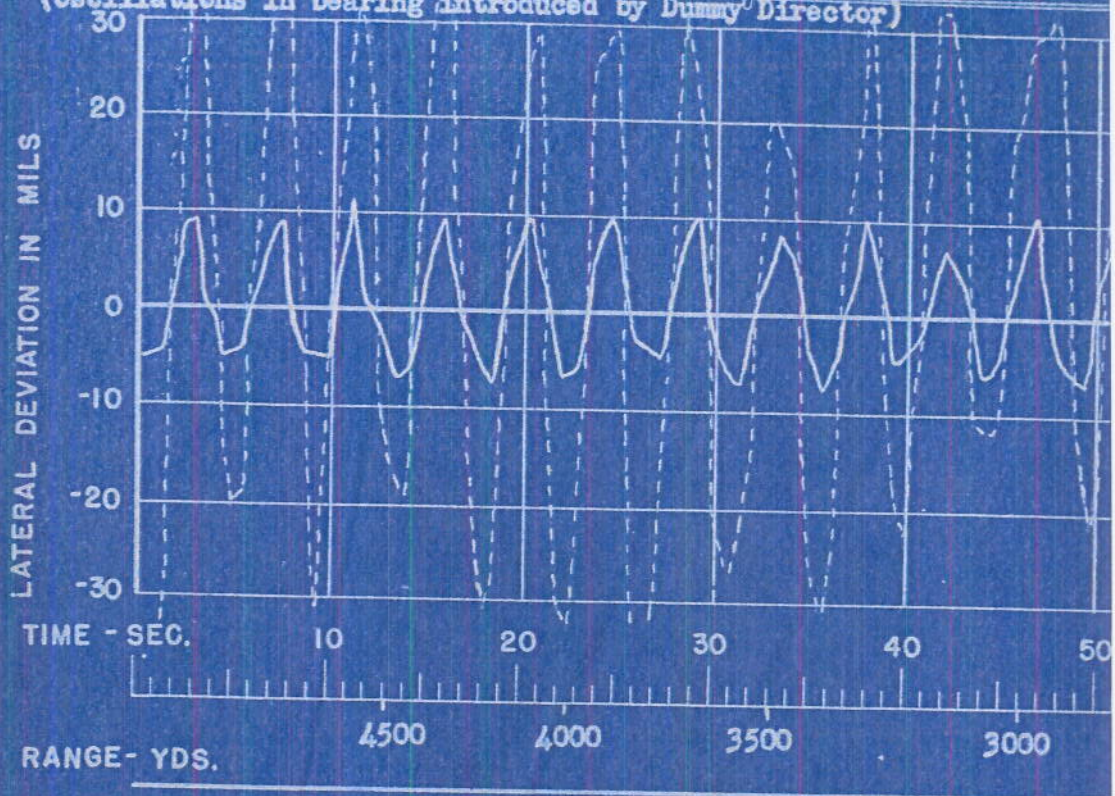
TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

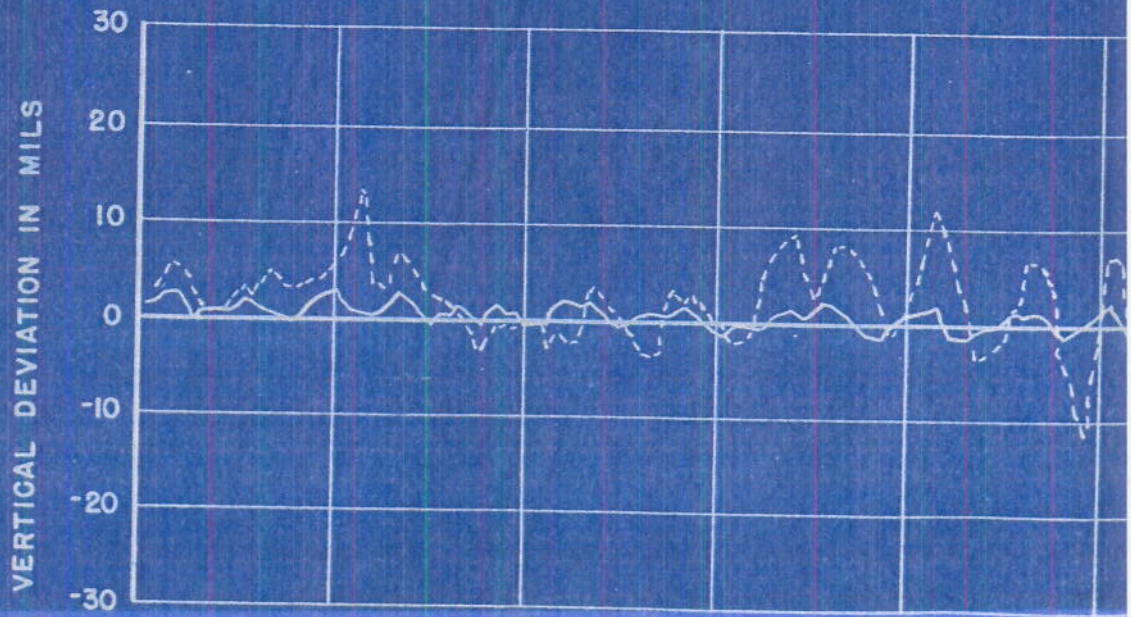
——— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC

DWN. PBC APPR. HF

RUN 131 TE
DATE 11/15/45 TA
SPEED 150 KN; AL
COURSE R-L Pass
TRACKING Radar

(Oscillations in bearing introduced by Dummy Director)





[redacted]

U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE

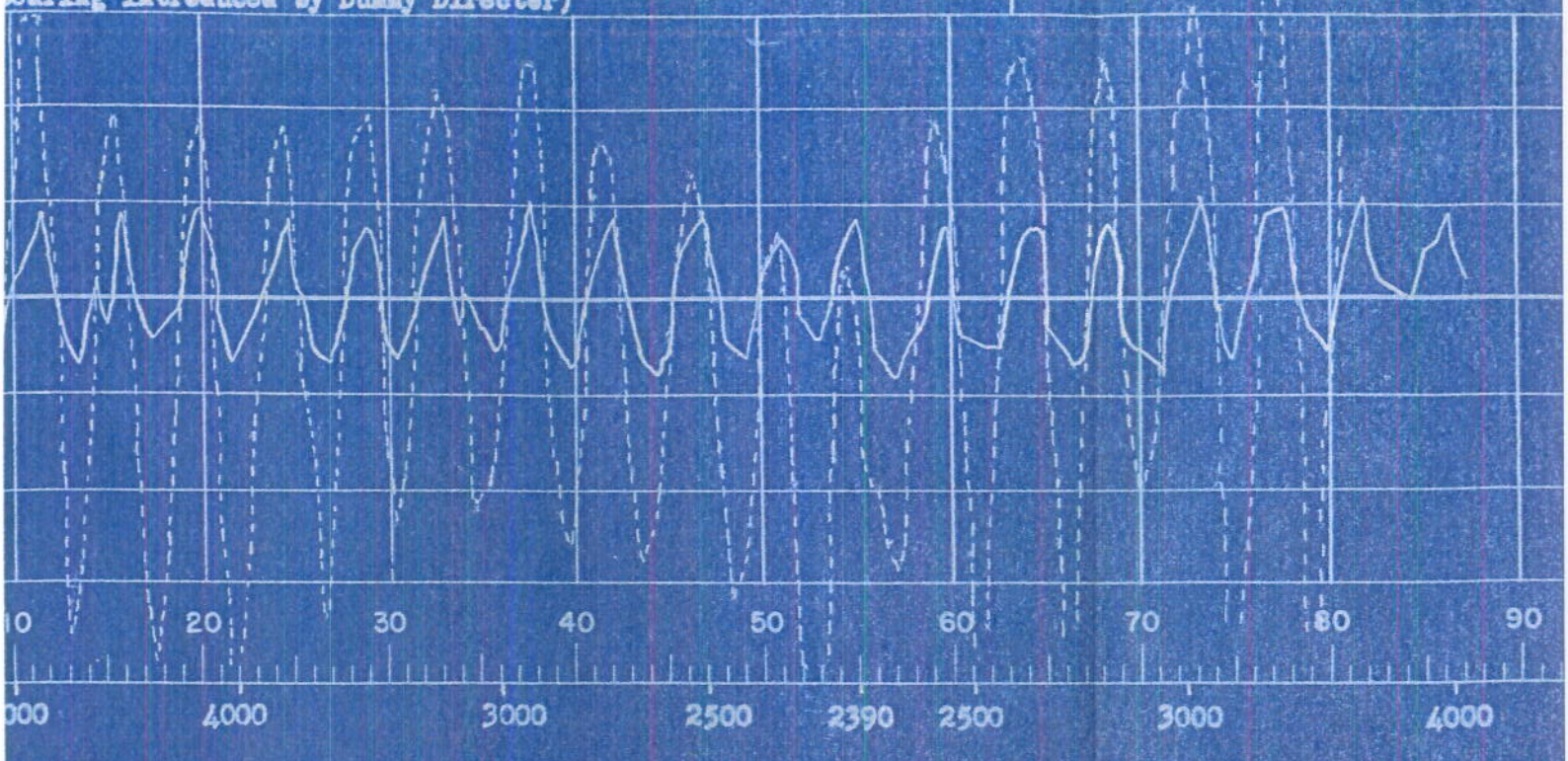
D. | SER. | 599

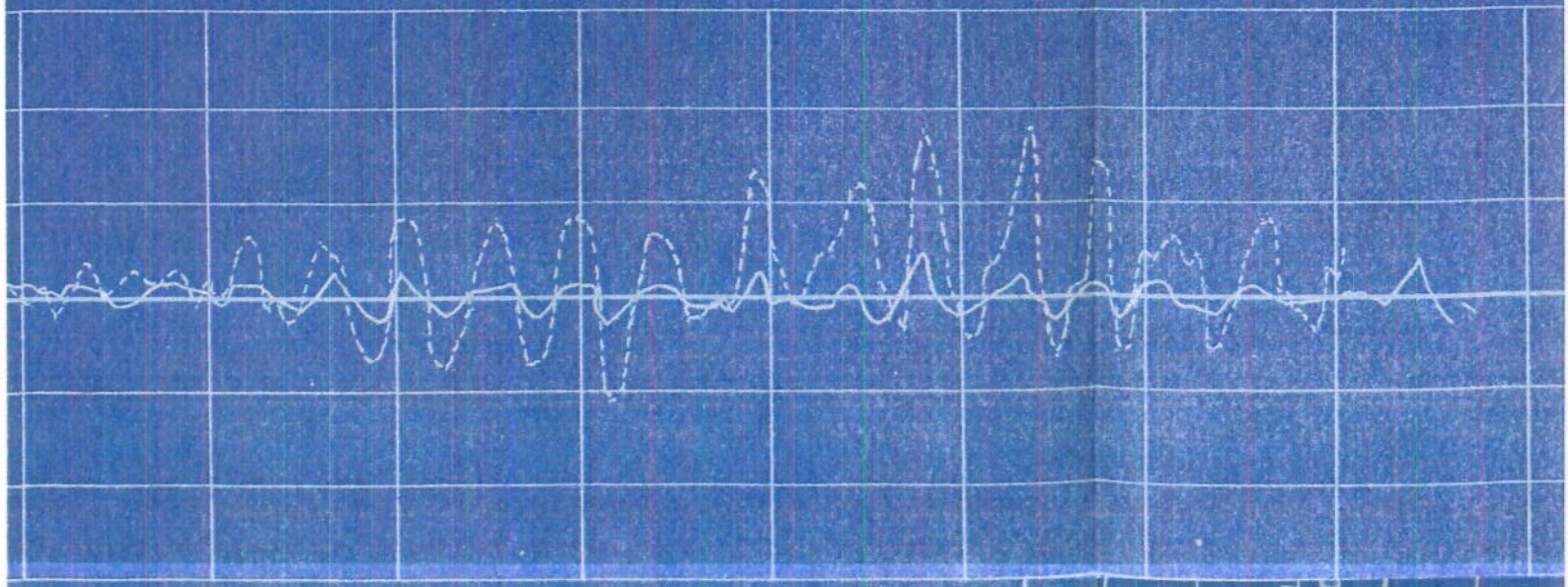
—— TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC
DWN. PBC | APPR. JLF

RUN 136 TEST 79
DATE 11/15/46 TARGET TDF
SPEED 150 KN, ALT. 5000 FT.
COURSE I-R Pass
TRACKING Radar

(Oscillations in Bearing introduced by Dummy Director)

bearing introduced by Dummy Director)





U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 23



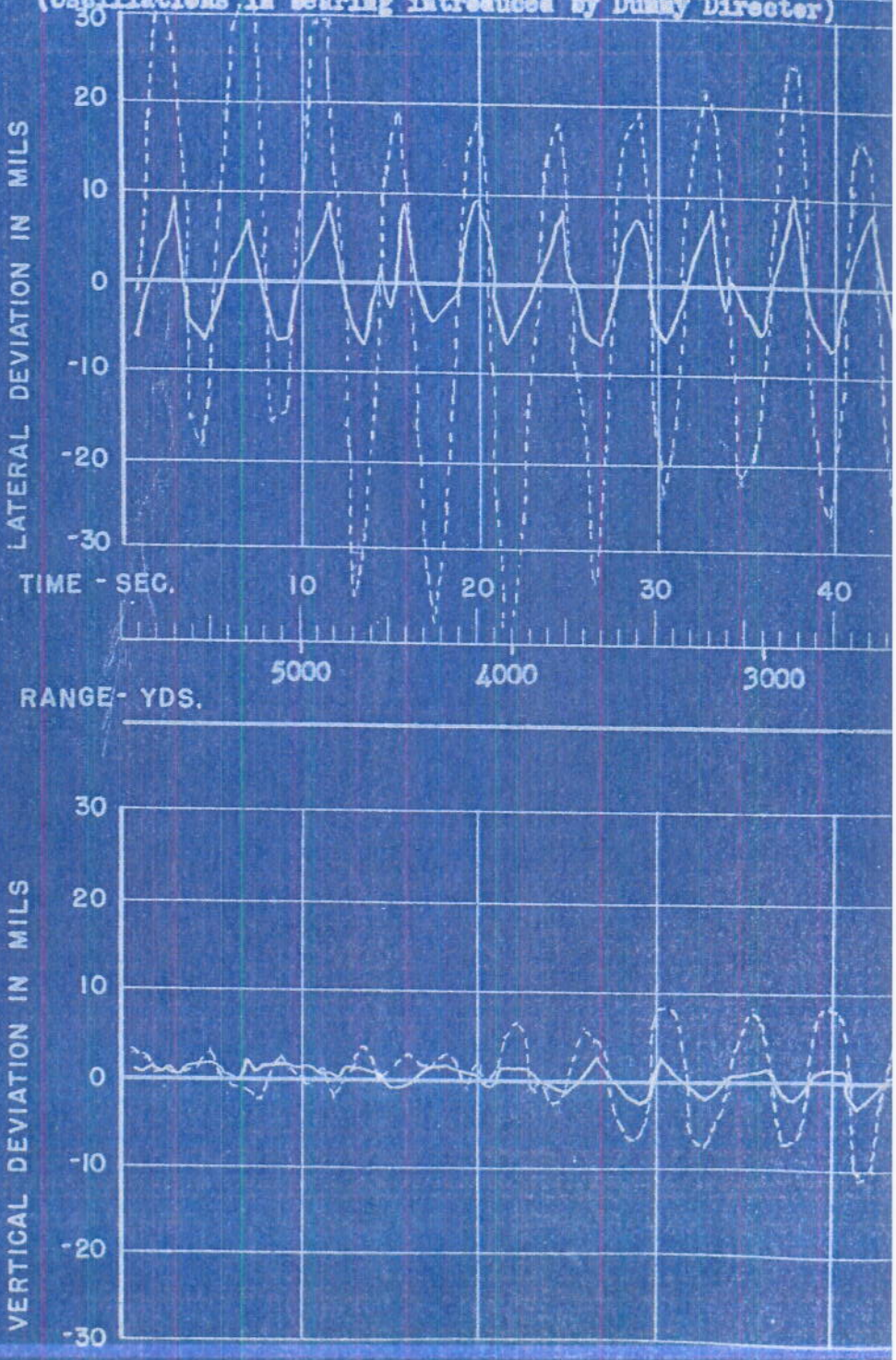
TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

——TRACKING ERROR
- - - SOLUTION ERROR
COMPUTER OPERATION - AUTOMATIC

DWN. PBC APPR. JJF

RUN 136
DATE 11/
SPEED 1
COURSE
TRACKIN

(Oscillations in bearing introduced by Dummy Director)

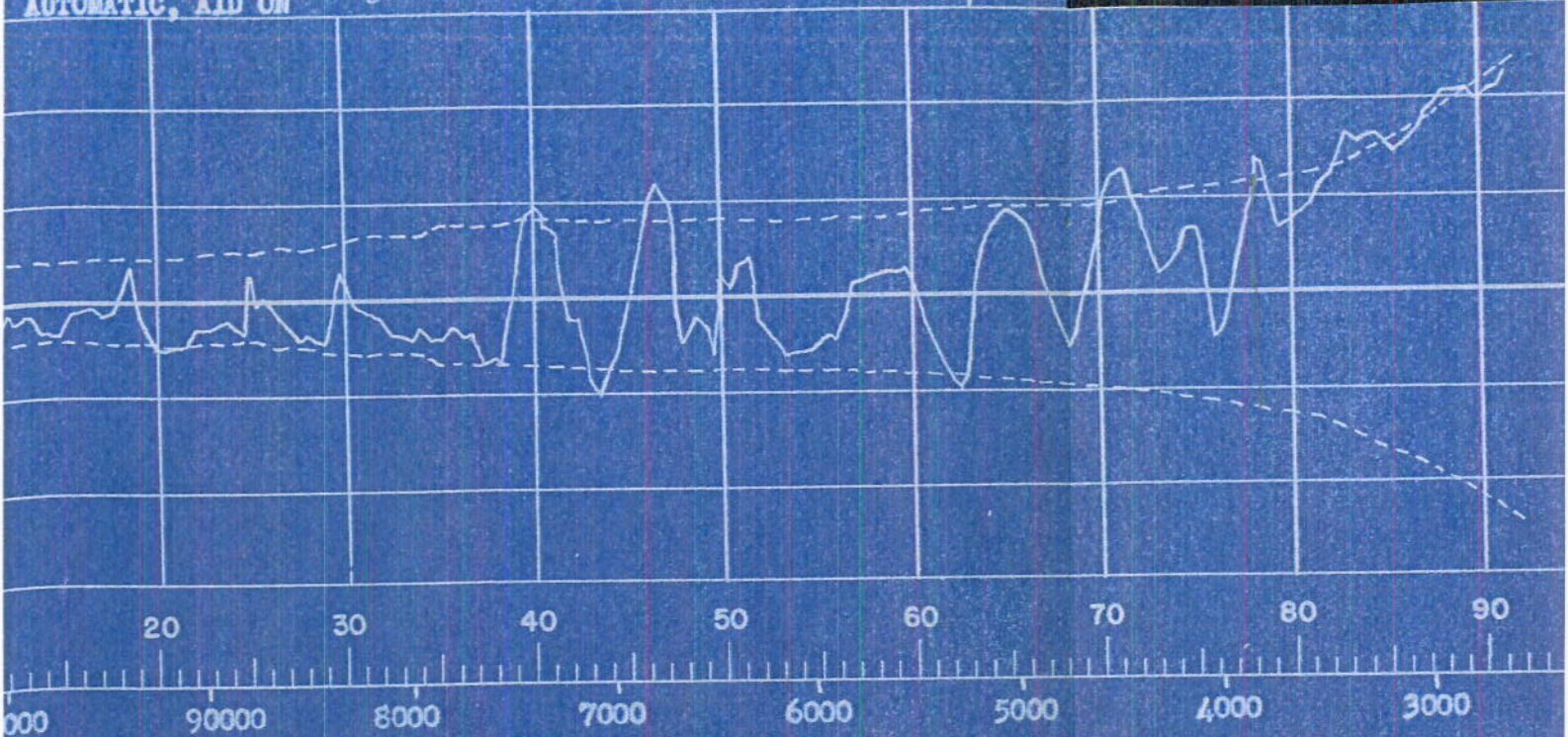


U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

SER. [redacted] ERROR
[redacted] SOLUTION ERROR
—— Radar Line of Sight
- - - Targets' Positions
599 DWN. PBC APPR. GF

RUN 153 TEST 79
DATE 11/20/45 TARGET TBF (2)
SPEED 170 KN, ALT. 3000 FT.
COURSE Approach Side by Side
TRACKING Radar

AUTOMATIC, AID ON



(Separation of targets in elevation very small, assumed zero.)



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 24

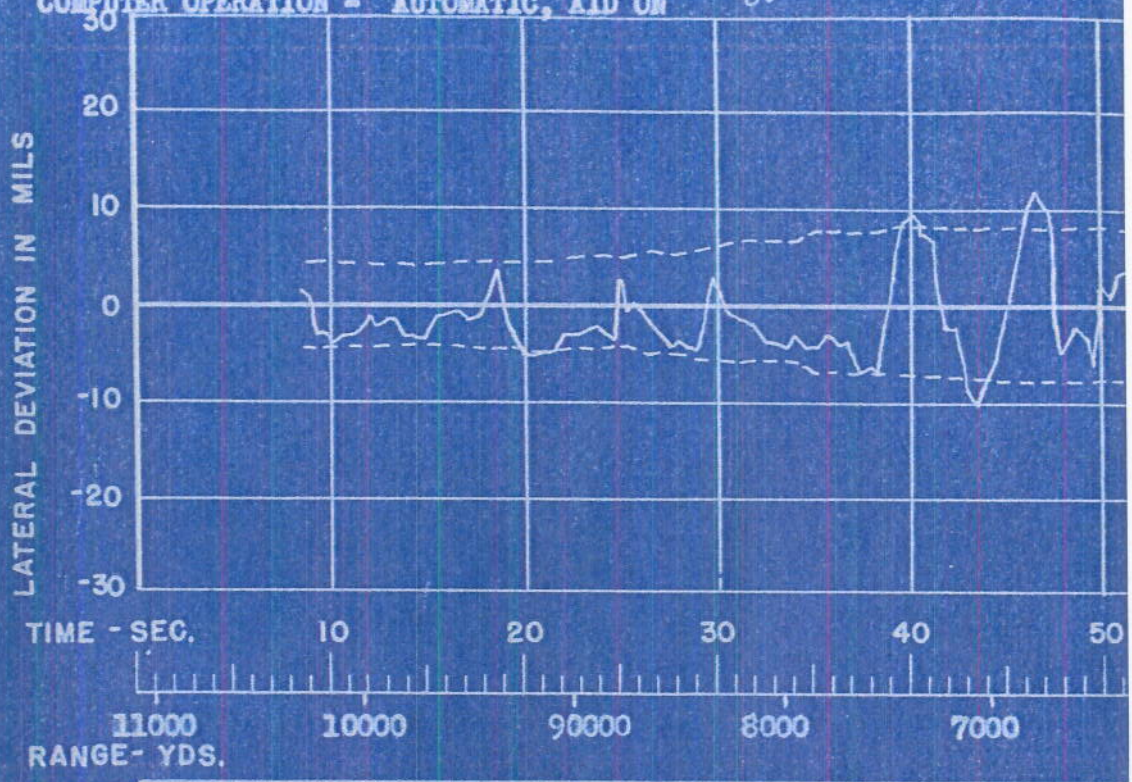
R-2819

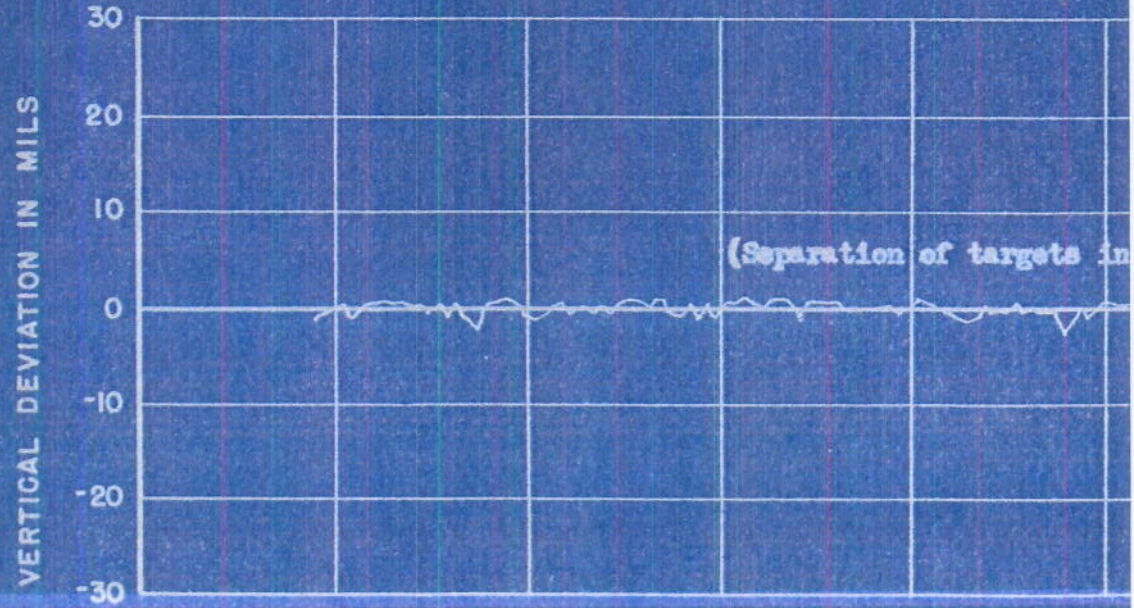
TEST OF	MK.	MOD.	SER.
DIRECTOR	37	49	
RADAR	25	Exp.	
COMPUTER	1	13	599

~~TRACKING ERROR~~
~~SOLUTION ERROR~~
—— Radar Line of Sight
- - - Targets' Positions
DWN. PBC APPR. JJF

RUN 153 TEST
DATE 11/20/45 TARG
SPEED 170 KN, ALT
COURSE Approach S
TRACKING Radar

COMPUTER OPERATION - AUTOMATIC, AID ON





[redacted] U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION
PLATE

SER. [redacted]

— Radar line of Sight

- - - Targets' Positions

599 DWN. PBC APPR. GF

RUN 148 TEST 79

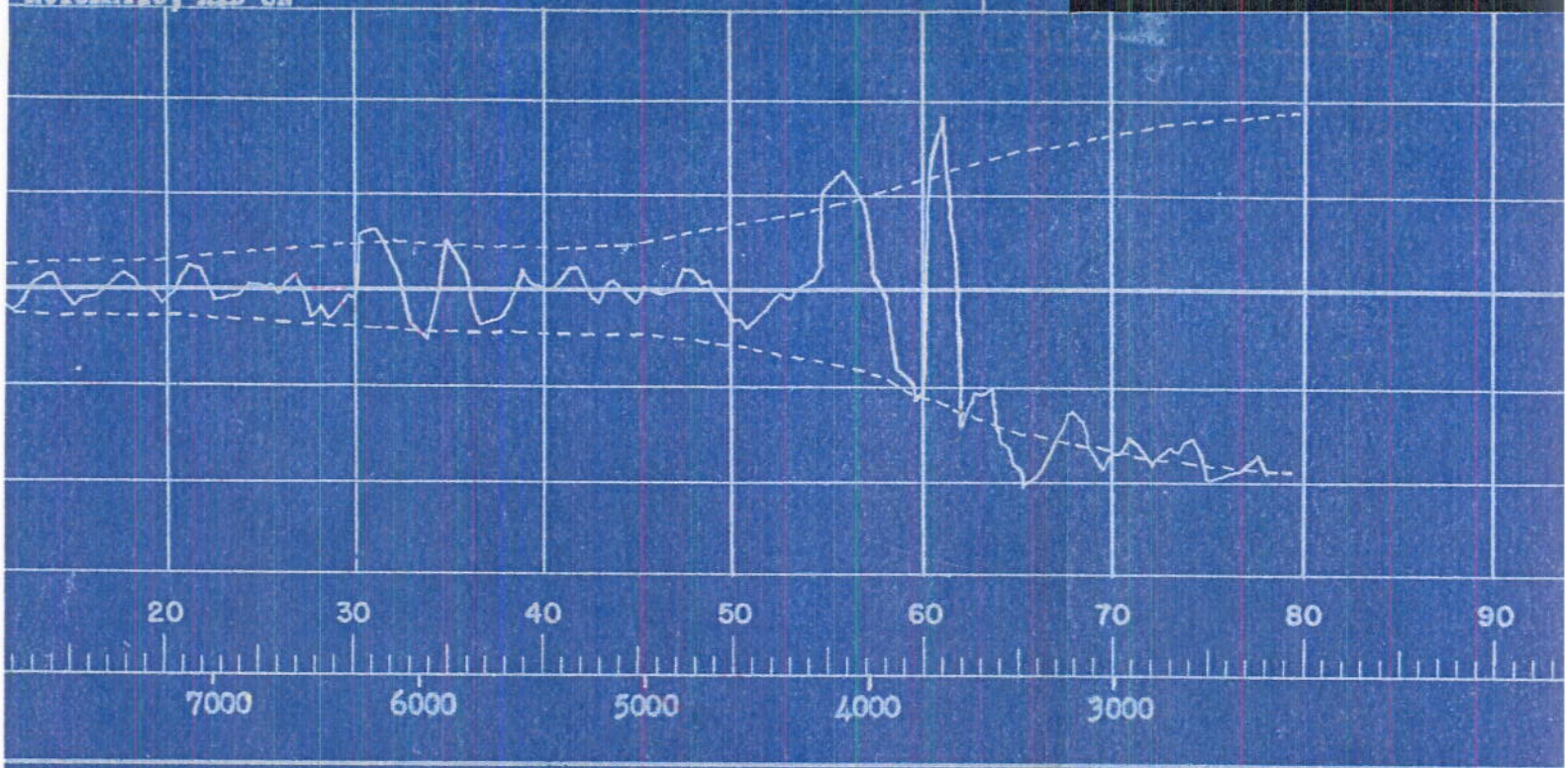
DATE 11/16/45 TARGET TBF (2)

SPEED 150 KN, ALT. 3000 FT.

COURSE Approach Side by Side

TRACKING Radar

AUTOMATIC, AID ON



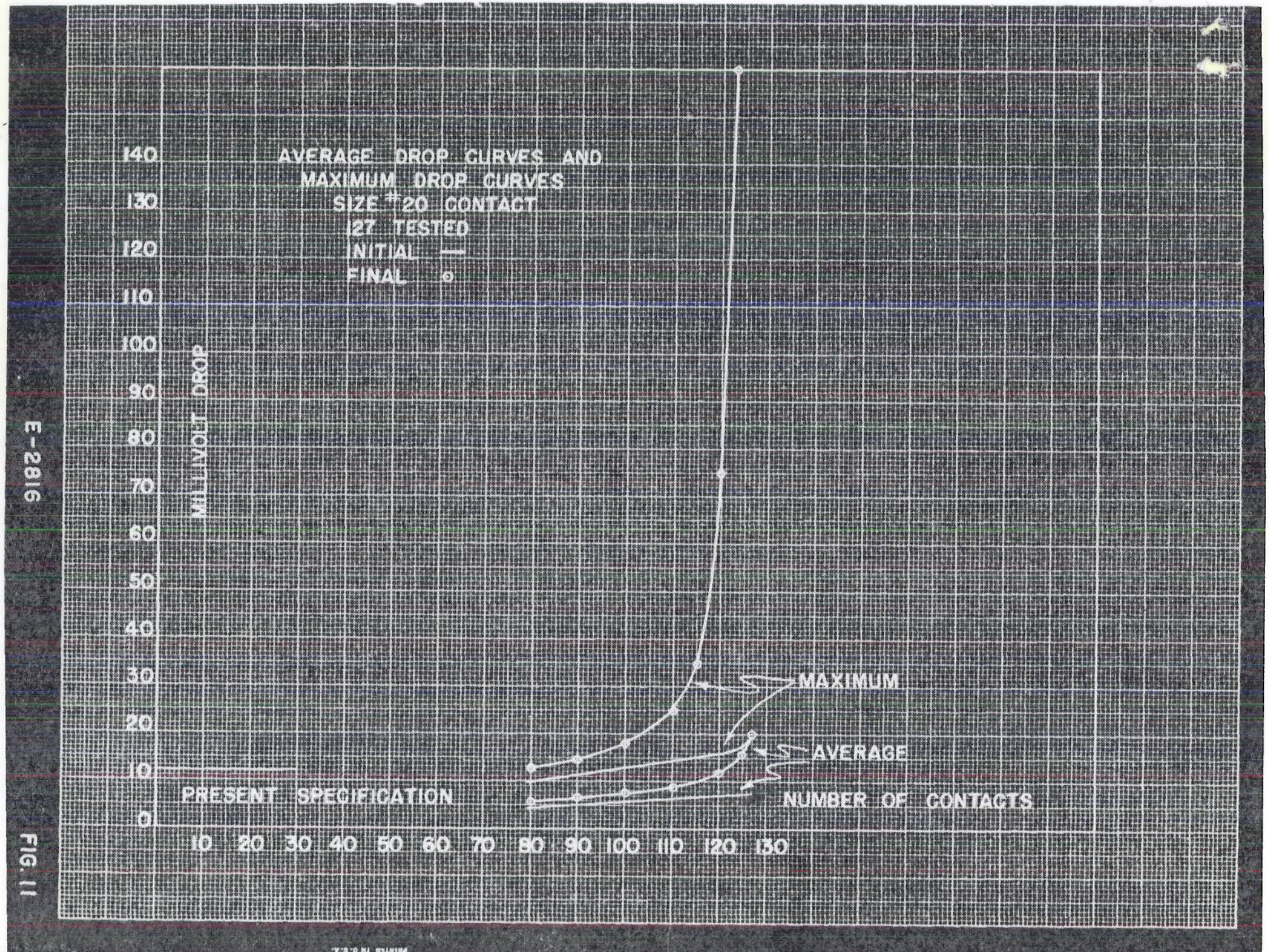
(Separation of targets in elevation very small, assumed zero.)



U.S. NAVAL RESEARCH LABORATORY
F.M. & P.A.C. DIVISION

PLATE 25

R-2819



E-2816

FIG. 11

CODEX BOOK COMPANY, INC., NORWOOD, MASSACHUSETTS.
PRINTED IN U.S.A.

NO. 319X. MILLIMETERS. 200 BY 250 DIVISIONS.