TECHNICAL AND OPERATIONAL EVALUATION OF THE TYPE IV PICTORIAL-DISPLAY EQUIPMENT

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Technical Development Report No 242

Prepared for

The Air Navigation Development Board

Under

Project No. 6 2.5

by

CIVIL AERONAUTICS ADMINISTRATION

TECHNICAL DEVELOPMENT AND

EVALUATION CENTER

INDIANAPOLIS, INDIANA

June 1954

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FOREWORD

The Air Navigation Development Board (ANDB) was established by the Department of Defense and Commerce in 1948 to carry out a unified development program aimed at meeting the stated operational requirements of the common military/civil air navigation and traffic control system This project, sponsored and financed by the ANDB, is a part of that program The ANDB is located within the administrative framework of the Civil Aeronautics Administration for housekeeping purposes only Persons desiring to communicate with ANDB should address the Executive Secretary, Air Navigation Development Board, Civil Aeronautics Administration, W-9, Washington 25, D. C.

SUMMARY

This report describes the technical and operational evaluation of the Type IV rotatable-panel pictorial display Laboratory tests revealed maximum errors of -0 4° and +0 5° in bearing, and of 0 75 nautical mile in distance in the pictorial-display portion of this equipment Errors in the course-line-computer unit in the display produced maximum displacements of 2 0 miles from the proposed course

Technical-evaluation flight tests showed that errors in aircraft position which are directly attributable to the display did not exceed 0 8 mile The operational flight tests demonstrated that aircraft using the pictorial display in areas providing OBD-signal coverage were able to comply with current navigation and traffic-control procedures based on L/MF and VHF facilities This compatibility of the pictorial display with current, interim, and new traffic-control procedures should be one of its most valuable characteristics

INTRODUCTION

The Type IV rotatable-panel pictorial computer[1] is the second of a series of such devices developed under Air Navigation Development Board Project 13 1 The development and evaluation of the first device, the Type III Portable Pictorial Computer, has been covered earlier in reports [2,3]

Two models of this display, designated as Types IV-A and IV-B, were manufactured by the Sperry Gyroscope Company, Inc , of Great Neck, Long Island The former model provides only a pictorial display, whereas the latter combines a pictorial display with a course-line computer Because of the additional features incorporated in this unit, the Type IV-B equipment was selected for the technical evaluation The Type IV-A was used in the operational tests

Although the technical evaluation is concerned only with the Type IV pictorial display, the operational evaluation produced information not only on the Type IV in particular but on pictorial displays in general A previous report[4] discusses in detail the operational advantages common to all pictorial-display devices

Additional operational tests appear desirable, however, the project was terminated in September 1953, at the request of the Air Navigation Development Board

[1]Special Committee 54 of the Radio Technical Commission for Aeronautics (RTCA) recommends that equipment of this type be referred to as a pictorial display rather than as a computer

[2]Logan E Setzer, "The Type III Portable Pictorial Computer, Part I, Development and Initial Tests," CAA Technical Development Report No 172, October 1952

[3]E M Blount, H A Kay, R E McCormick, F S McKnight, and M H Yost, "The Type III Portable Pictorial Computer, Part II, Technical and Operational Evaluation, CAA Technical Development Report No 209, June 1954

[4]Fred S McKnight, "A Preliminary Study of Operational Advantages of Pictorial Navigation Displays," CAA Technical Development Report No 241, June 1954

DESCRIPTION

The Type IV-B pictorial computer, shown in Fig 1, is a navigational aid for use in aircraft equipped with visual omnirange (VOR) and distance measuring equipments (DME), and with a Gyrosyn compass The display plots the track of the aircraft on a map and simultaneously indicates the heading of the aircraft Course-line-computer indications are also available for the pilot who prefers this type of presentation

This device consists of a display unit intended for mounting on the instrument panel and of an electronics unit which may be stored in the aircraft equipment rack Chart-changing and scale selection are manual operations Charts are printed on heat-sensitive paper and permit permanent recording of the track, if desired A block diagram of the equipment indicates the data flow and is shown in Fig 2 A detailed description of the unit is contained in an earlier report [5]

TECHNICAL-EVALUATION TESTS

Laboratory Tests, Pictorial Display

To obtain precision in measurements of bearing accuracy, a carefully machined, ten-inch-diameter, metal azimuth scale was used with a Type AY-201-3-B, 400-cps Autosyn as a laboratory standard This unit, which is shown in Fig 3, was calibrated to one-half degree, and tenths of a degree could be estimated with great accuracy In the measurements conducted on the pictorial display, the standard was first set to 0° and the display was adjusted to give an identical reading The standard was then advanced in 20° increments throughout 360° of rotation in a clockwise direction, and display indications were recorded The tests were repeated with the use of counterclockwise rotation to investigate the magnitude of errors introduced by the approach to check points from the opposite direction

Results of laboratory tests for bearing accuracy showed that the greatest errors occurring in the average results of repeated tests for a given point were +0 2° and -0 4° for clockwise rotation and were +0 5° and -0 2° for counterclockwise operation The maximum error found in any single test was 0 6° Table I shows the average results obtained in these tests

Distance accuracy was examined at two-nautical-mile intervals on the 17-mile range, which corresponds to a chart scale of 1:250,000, and at proportionately larger intervals on the other ranges Information, in the form of resistance values proportional to distance, was supplied to the computer by a calibrated precision potentiometer Readings were taken both inbound, or toward a station, and outbound, or away from a station, to determine the absolute magnitude of error produced in distance indication The largest of the average errors was 0 75 mile in distance indication This maximum was observed on the 136-mile scale Errors found on the 17-, 34-, and 68-mile scales were 0 34, 0 5, and 0 4 mile, respectively Table II shows the results obtained in a series of distance or range accuracy tests with the use of a chart having a radius equivalent to 17 miles Tables III, IV, and V show the results of similar tests on larger-scale charts

The change in distance required to produce a perceptible change in distance indication on the computer was measured with the same equipment used in the distance accuracy tests To determine the change in distance required to cause a change in indication when flight continues in the same direction along a radial, a predetermined value of resistance proportional to mileage was set into the precision potentiometer, the computer indicator was allowed to come to rest, and additional resistance was then added to cause a change in indication A conversion of resistance to miles revealed the distance changes required To check the accuracy of the servosystem when the direction of progress was reversed, the tests were repeated as described However, after the position indicator had come to rest, the wiper arm of the precision potentiometer was turned in the opposite direction until movement of the indicator was observed Table VI shows the average results of these tests with resistance values converted to their proportional distances in nautical miles

The accuracy of the heading indications of this computer is approximately ±8 0° In the same direction, an average of 5 7° change in heading is required to produce a perceptible change in indication With a reversal of direction, as in a 180° turn, a change of 10 3 is required before a perceptible change in indication can be observed Because large errors were noted in these preliminary tests and because difficulty was encountered in interpreting

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[5] Logan E Setzer, " The Type IV Rotatable-Panel Pictorial Computer, Part I, Development and Initial Flight Tests," CAA Technical Development Report No 195, April 1954

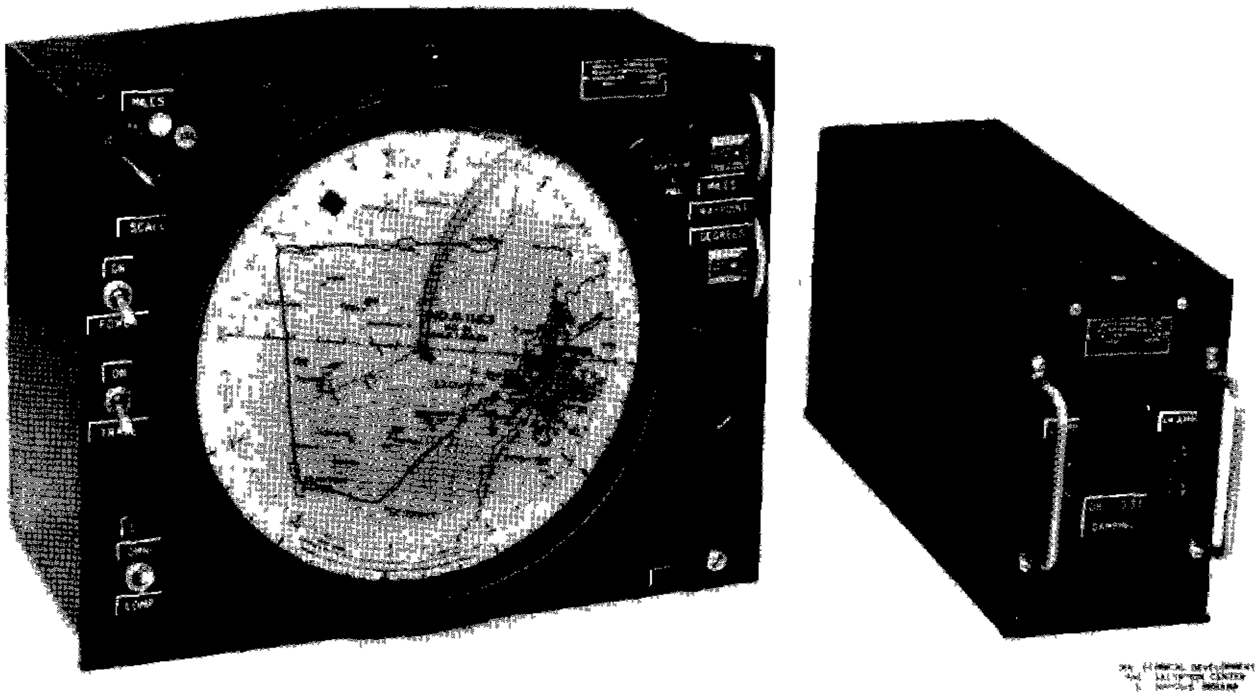


Fig 1 Type IV Pictorial-Display and Amplifier Unit

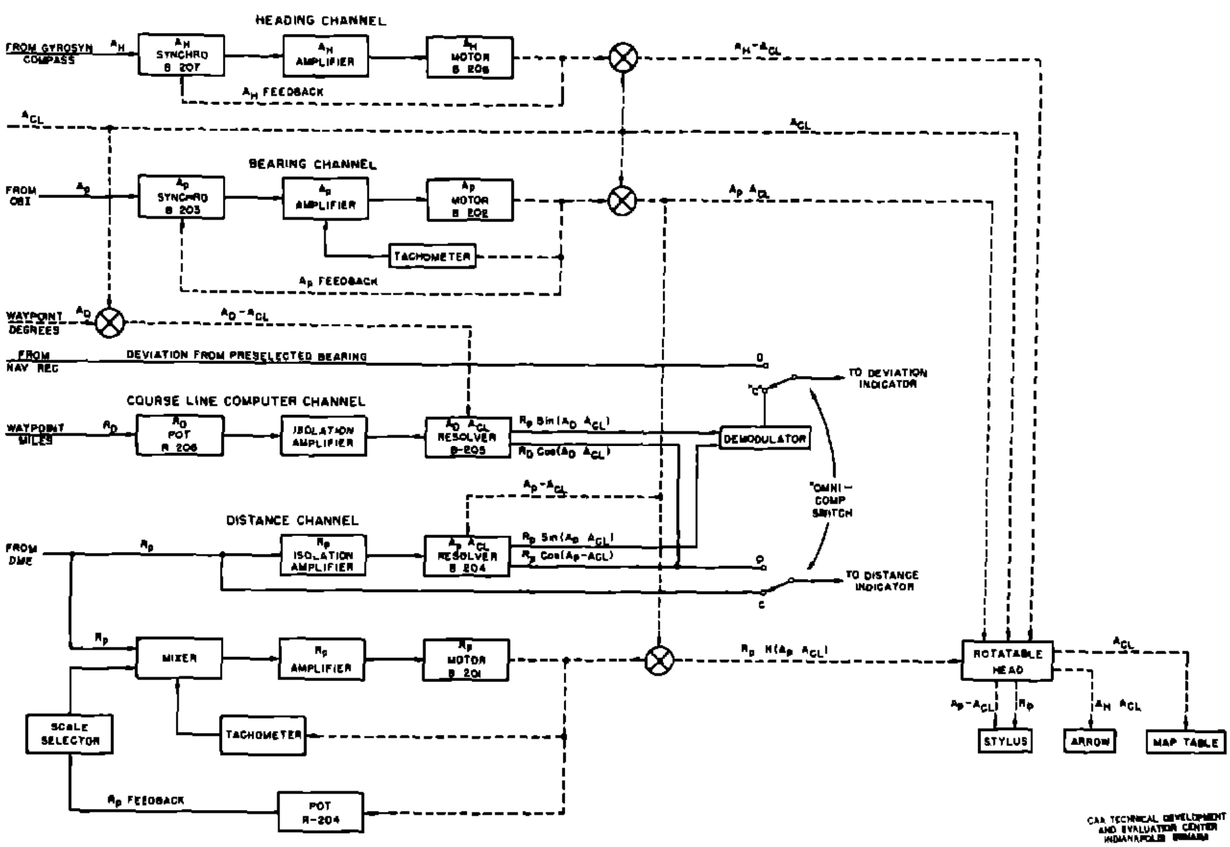


Fig 2 Data Flow in the Type IV Pictorial Display and Course-Line Computer

TABLE I

BEARING ACCURACY TESTS

Bearing to Station (degrees)	Clockwise Rotation		Counterclockwise Rotation	
	Average Computer Indications (degrees)	Average Error (degrees)	Average Computer Indications (degrees)	Average Error (degrees)
0	359 7	-0 3	0 1	+0 1
20	19 8	-0 2	20 1	+0 1
40	39 8	-0 2	40 0	0 0
60	59 8	-0 2	60 1	+0 1
80	79 9	-0 1	80 2	+0 2
100	99 6	-0 4	99 9	-0 1
120	119 7	-0 3	119 8	-0 2
140	139 8	-0 2	140 0	0 0
160	159 9	-0 1	160 2	+0 2
180	179 9	-0 1	180 2	+0 2
200	200 1	+0 1	200 3	+0 3
220	220 2	+0 2	220 2	+0 2
240	240 1	+0 1	240 5	+0 5
260	260 0	0 0	260 0	0 0
280	279 9	-0 1	280 0	0 0
300	299 9	-0 1	300 2	+0 2
320	319 9	-0 1	320 2	+0 2
340	339 9	-0 1	340 2	+0 2
360	359 8	-0 2	0 2	+0 2

TABLE II

DISTANCE ACCURACY TESTS

Chart Radius 17 Miles   Chart Scale 1 250,000

Simulated Distance (nm)	Outbound		Inbound	
	Average Computer Indications (nm)	Error (nm)	Average Computer Indications (nm)	Error (nm)
0	0 00	0 00	0 0	0 0
2	1 85	-0 15	2 2	+0 2
4	3 69	-0 31	4 15	+0 15
6	5 66	-0 34	6 1	+0 1
8	7 82	-0 18	8 1	+0 1
10	9 66	-0 34	10 1	+0 1
12	11 75	-0 25	12 1	+0 1
14	13 82	-0 18	14 25	+0 25

indications from the small heading arrow, no attempt was made to obtain absolute calibration curves

An investigation of the flag-alarm system of the display was made by the blocking of the indicator drive mechanism and the insertion of bearing and range information of various values until the error limits were exceeded and the flag appeared A bearing error of ±1 1° was found to be sufficient to actuate the flag system under all conditions of normal operation, while the necessary error in distance varied with the range scale employed Table VII shows the average results of a series of tests conducted to determine the distance error required for flag operation

TABLE III

DISTANCE ACCURACY TESTS

Chart Radius 34 Miles   Chart Scale 1 500,000

Simulated Distance (nm)	Outbound		Inbound	
	Average Computer Indications (nm)	Error (nm)	Average Computer Indications (nm)	Error (nm)
0	0 0	0 0	0 0	0 0
4	3 6	-0 4	4 1	+0 1
8	7 6	-0 4	8 0	0 0
12	11 6	-0 4	12 1	+0 1
16	15 6	-0 4	16 0	0 0
20	19 5	-0 5	20 0	0 0
24	23 6	-0 4	24 0	0 0
28	27 7	-0 3	28 1	+0 1

TABLE IV

DISTANCE ACCURACY TESTS

Chart Radius 68 Miles   Chart Scale 1 1,000,000

Simulated Distance (nm)	Outbound		Inbound	
	Average Computer Indications (nm)	Error (nm)	Average Computer Indications (nm)	Error (nm)
0	0 0	0 0	0 0	0 0
8	7 6	-0 4	8 0	0 0
16	15 6	-0 4	16 1	+0 1
24	23 6	-0 4	24 25	+0 25
32	31 7	-0 3	32 1	+0 1
40	39 7	-0 3	40 1	+0 1
48	47 9	-0 1	48 25	+0 25
56	55 75	-0 25	56 1	+0 1

TABLE V

DISTANCE ACCURACY TESTS

Chart Radius 136 Miles   Chart Scale 1 2,000,000

Simulated Distance (nm)	Outbound		Inbound	
	Average Computer Indications (nm)	Error (nm)	Average Computer Indications (nm)	Error (nm)
0	0 0	0 0	0 0	0 0
16	15 4	-0 6	16 1	+0 1
32	31 7	-0 3	32 1	+0 1
48	48 0	0 0	48 5	+0 5
64	64 0	0 0	64 75	+0 75
80	80 0	0 0	80 5	+0 5
96	96 0	0 0	96 5	+0 5
112	112 0	0 0	112 3	+0 3

If the position indicator fails to follow the VOR and DME inputs by the values previously shown, the increased error voltage drives the grids of the servo power-amplifier tubes positive When this occurs, the bias supply becomes more negative and prevents conduction in vacuum tubes, the plate loads of which are flag-alarm relays Release of these relays permits the alarm flag to operate and warns that display indications are unreliable Thus, the inputs and excessive errors are adequately monitored, but other vacuum-tube or component failures in the electronic unit will render the display inoperative without affecting the bias Many of these internal failures, therefore, will not actuate the flag system

The range of indicator damping in this display is satisfactory Provisions are included for varying the feedback from the tachometers in the bearing and distance servoamplifier channels to permit operation of the indicator from an underdamped to an overdamped condition A damping factor of 3 6 to 3 8 was found suitable for most installations The damping factor is a factor expressing the rate of decay of oscillations and is found by dividing the Napierian logarithm of the ratios of two successive amplitude maxima by the time interval between

The chart is illuminated by 29 small incandescent bulbs spaced around the periphery of the cover plate The intensity of light on the chart may be varied from an amount too small to be read with a General Electric Type DW-68 exposure meter to a maximum of 33 foot-candles at the edges of the chart The light intensity varies from 33 foot-candles at the edges to 5 foot-candles at the center of the chart

Power requirements for the unit are 0 9 ampere at 115 volts, 400 cps and 1 53 amperes at 26 volts d-c

A slewing circuit which moves the aircraft-position indicator to the bottom edge of the map when the access door is opened simplifies map-changing However, the preparation of charts for use in the display is too involved Much time and care is required to apply the adhesive tape, to properly center and orient the chart, and then to trim the paper to fit the metal backing Even after the chart has been affixed to the metal plate, escaping gas bubbles cause wrinkling of the paper and produce an uneven surface Tests showed that the use of a porous backing material such as cardboard was superior to metal since the bubbles could be pressed out easily The change from metal to cardboard also resulted in a reduction in weight of a finished chart

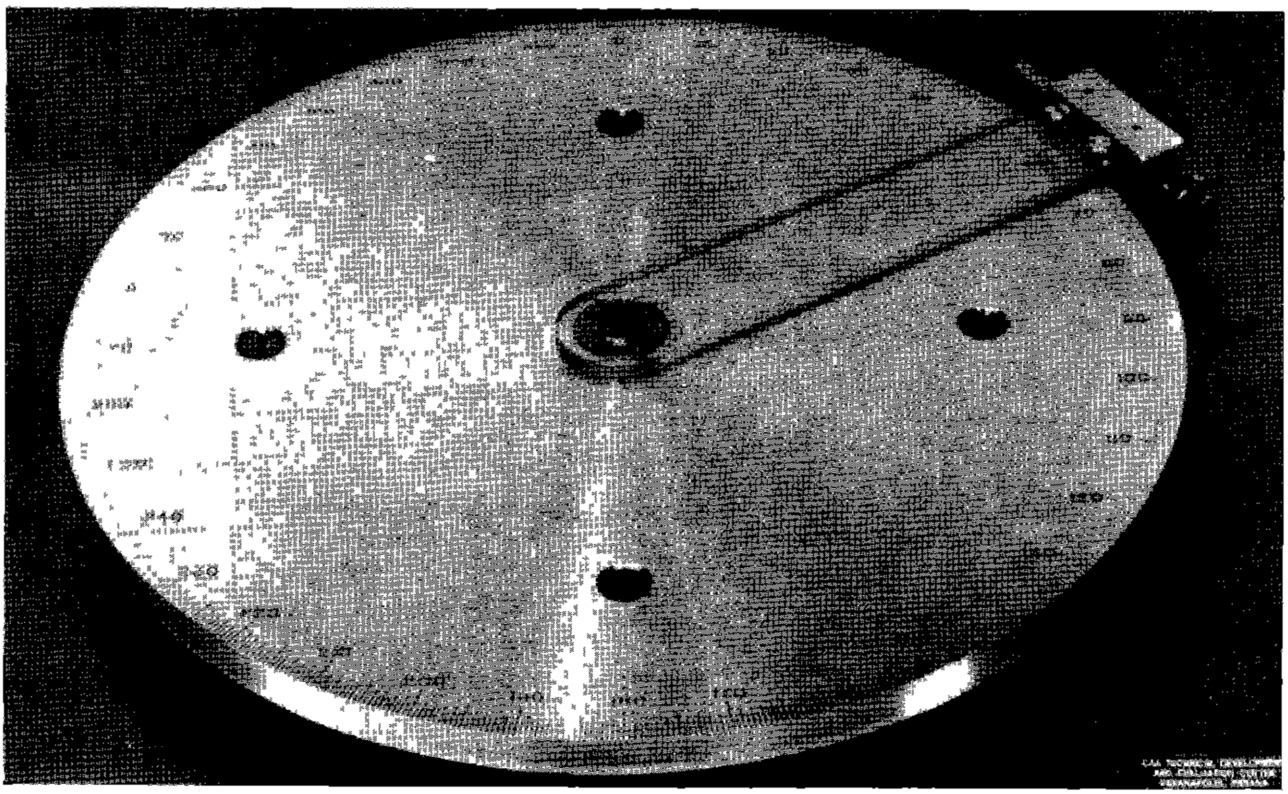


Fig 3 Laboratory Bearing Standard

TABLE VI

CHANGES IN DISTANCE REQUIRED FOR LEAST PERCEPTIBLE CHANGE IN COMPUTER INDICATIONS

Chart Radius (nm)	One Direction	Reversed Direction (nm)
17	Negligible	0 5
34	Negligible	0 5
68	Negligible	0 65
136	Negligible	0 75

TABLE VII

DISTANCE ERROR FOR FLAG OPERATION

Chart Radius (nm)	Activation Limits (nm)
17	+1 32 -1 25
34	+1 38 -1 12
68	+1 12 -1 19
136	+1 50 -1 12

Laboratory Tests, Course-Line Computer

The course-line-computer function of this equipment accepts the same VOR-DME inputs as the pictorial-display portion In the computer mode of operation, navigation information is presented on the deviation and distance-to-waypoint indicators as well as on a chart Since this portion of the equipment utilizes the inputs in a different manner, it is believed that definition of terms and a brief discussion of theory is desirable to understand fully the type of evaluation tests conducted

The course-line-computer channel continuously solves the trigonometrical problem shown in Fig 4 and thereby determines the deviation Y of the aircraft from the preselected course line and determines the distance X from the aircraft to the waypoint Other symbols used in a discussion of the computer follow

A_p = Bearing of the aircraft from the omnibearing-distance (OBD) station

Rp = Distance to the aircraft from the OBD station

A_d = Bearing of the waypoint from the OBD station

R_d = Distance to the waypoint from the OBD station

A_{cl} = Course-line angle with respect to magnetic north

A block diagram of the computer circuits is shown in Fig 5 Since

$$X = R_d \cos (A_d - A_{cl}) - R_p \cos (A_p - A_{cl}) \qquad (1)$$

and

$$Y = R_d \sin (A_d - A_{cl}) - R_p \sin (A_p - A_{cl}), \qquad (2)$$

it is possible to obtain the solution by the use of component resolvers Waypoint degrees A_d are inserted by a "Waypoint Degrees" control Course-line bearing A_{cl} is subtracted from A_d by a mechanical differential, and the output $(A_d - A_{cl})$ is used to position the rotor of component resolver B-205 The distance of the waypoint from the OBD station R_d is set into the

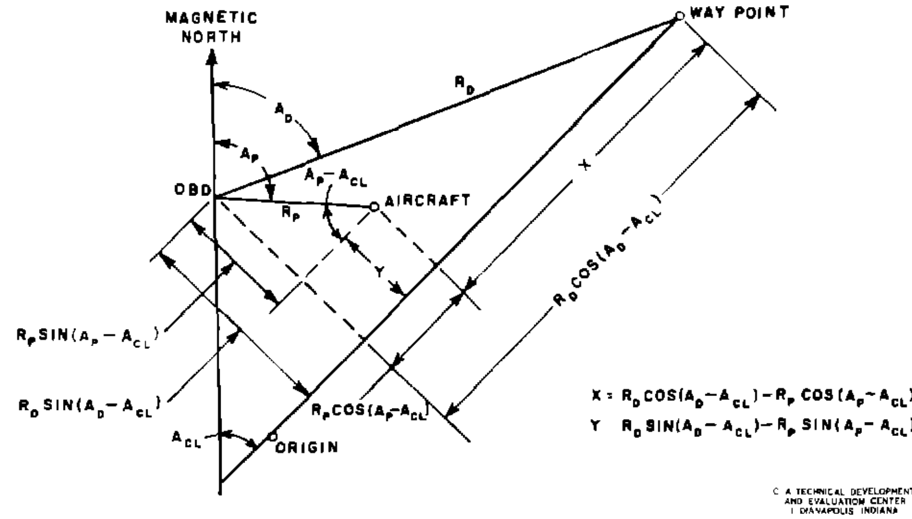


Fig 4 Course-Line Computations

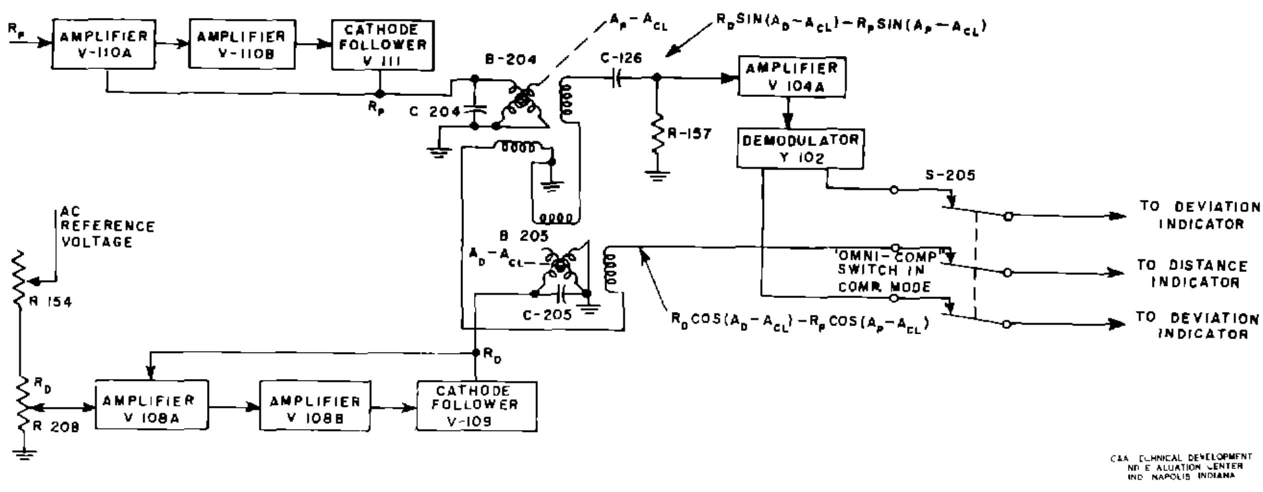


Fig 5 Diagram of Course-Line-Computer Circuits

computer by the "Waypoint Miles" control and is converted into an electrical signal by the R_d potentiometer R-208 The output of the R_d potentiometer is amplified in an isolation amplifier, the output of which energizes the $(A_d - A_{cl})$ resolver The outputs from this resolver are

$$R_d \sin (A_d - A_{cl}) \text{ and } R_d \cos (A_d - A_{cl})$$

A voltage R_p obtained from the follow-up potentiometer R-204, the output of which is proportional to DME input, is applied to resolver B-204 $R_p \sin (A_p - A_{cl})$ and $R_p \cos (A_p - A_{cl})$ are obtained as outputs of resolver B-204 The sine terms are subtracted, demodulated, and fed to an indicator which shows deviation from course The cosine terms are similarly subtracted and fed to a distance-to-waypoint indicator

In order to measure the linearity of R_p and R_d amplifiers, A_d, A_p, and A_{cl} were set to zero, and R_p and R_d distances were varied to produce voltages proportional to the distance to the waypoint plane These potentials were measured at the outputs of cathode followers V-III

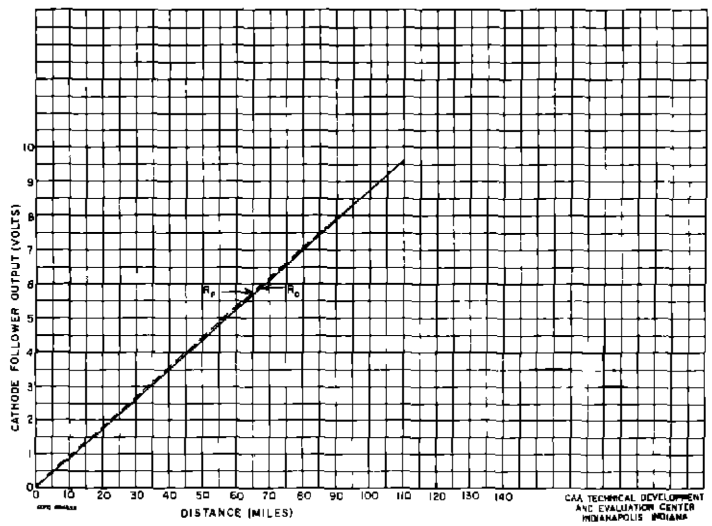


Fig 6 Measure of Errors Due to R_p and R_d Amplifier Nonlinearities

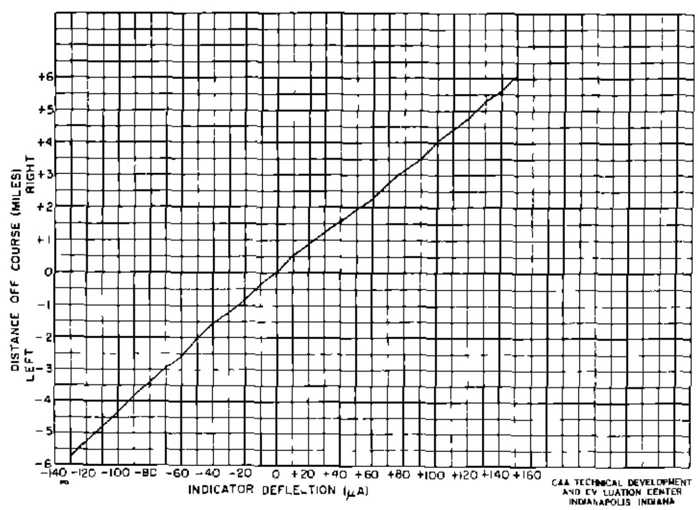
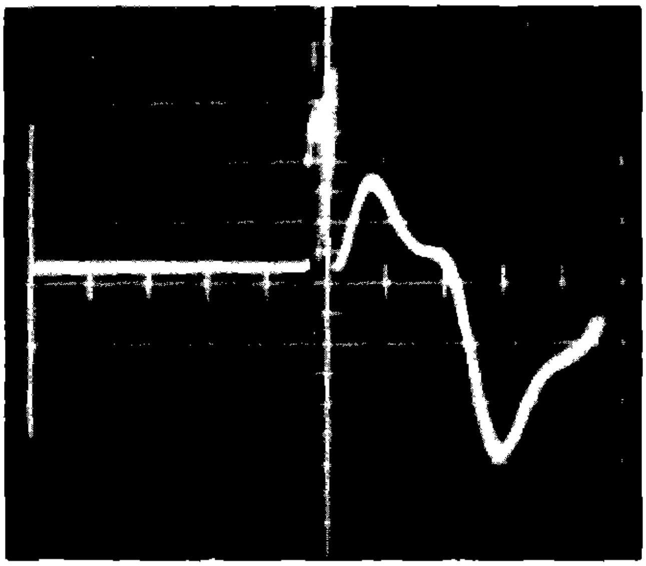


Fig 7 Relationship of the Meter Deflections of the Off-Course Signal Inputs

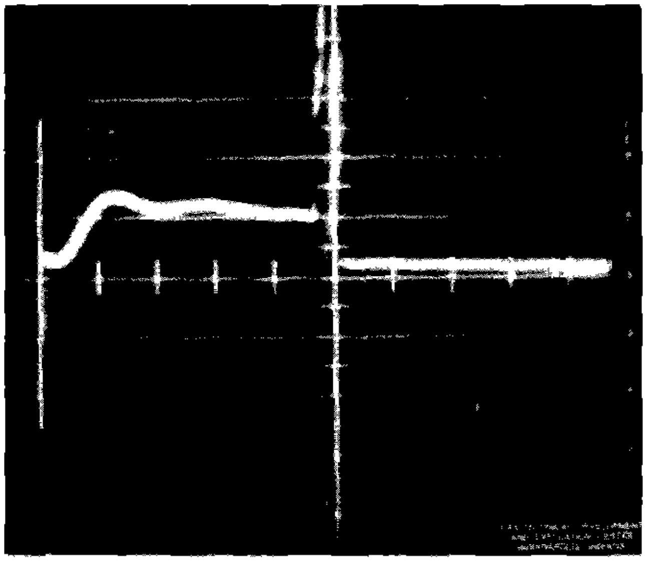
and V-109 with a Model 310-A Ballantine electronic voltmeter Errors due to R_p and R_d amplifier nonlinearities resulted in resolver-energizing voltages, the maximum errors of which were proportional to 1 0 and 0 2 mile, respectively These are shown graphically in Fig 6

To examine the linearity of the deviation amplifier and of the demodulator (chopper Y-102), R_d, A_{cl}, and A_d were set to zero The distance R_p to the station was set to 100 miles, and off-course deviations proportioned to increments of ten microamperes were introduced by varying the simulated VOR bearing As shown in Fig 7, equal magnitudes of right and left meter deflections required unequal magnitude of off-course signal inputs This error reaches a maximum of 0 8 mile at full-scale deflection of the deviation indicator Nonsymmetrical operation of the chopper is responsible for this lack of uniformity This condition can also be seen in Fig 8, which is an oscillogram of chopper-output voltage to the deviation indicator

Tests were also conducted to determine the accuracy with which angles (A_p - A_{cl}) and (A_d - A_{cl}) were generated First A_{cl} and A_d were set to zero, and A_p was varied to generate certain preselected difference angles Later the process was repeated with A_{c1} and A_p set to zero, and with A_d varying In each case the energizing voltage was equal to R_dK and R_pK, in which the constant is equivalent to the transformation ratio of the resolver The outputs of the resolvers were measured as voltages proportional to $R_d \sin \theta$, $R_d \cos \theta$, and $R_p \cos \theta$ Because of the extremely low voltage levels encountered in the measurement of the resolver output at difference angles of 0° and 180° and because of the very small variations in voltage at difference angles of 90° and 270°, measurements at these points were not obtained The total error measured in these tests was contributed by the mechanical differentials, the resolvers, the accuracy of A_p and A_d calibration, and the dial settings The greatest total angular error encountered was 2.0° Tables VIII and IX show the results of this series of tests



(a) Off Course to Right, Negative Polarity



(b) Off Course to Left, Positive Polarity

Fig 8 Oscillogram of Chopper-Output Voltages

TABLE VIII

ERRORS IN GENERATING $(A_p - A_{cl})$

A_p (degrees)	$R_p \sin\theta$ (volts)	θ (degrees)	Error (degrees)	$R_p \cos\theta$ (volts)	θ (degrees)	Error (degrees)
30	1 30	29	-1 0	2 34	29	-1 0
45	1 83	43	-2 0	1 90	45	0 0
60	2 28	59	-1 0	1 38	5 9	-1 0
120	2 33	120	0 0	1 34	120 5	+0 5
135	1 89	135	0 0	1 89	135	0 0
150	1 35	149 5	-0 5	2 33	150	0 0
210	1 30	209	-1 0	2 36	207 5	-2 5
225	1 83	223	-2 0	1 90	225	0 0
240	2 30	239	-1 0	1 38	239	-1 0
300	2 29	301	+1 0	1 32	299 5	-0 5
315	1 88	315	0 0	1 88	315	0 0
330	1 31	331	+1 0	2 30	329	-1 0

TABLE IX

ERRORS IN GENERATING $(A_d - A_{cl})$

A_d (degrees)	$R_d \sin\theta$ (volts)	θ (degrees)	Error (degrees)	$R_d \cos\theta$ (volts)	θ (degrees)	Error (degrees)
30	1 32	29 5	-0 5	2 33	30	0 0
45	1 88	45	0.0	1 89	45	0 0
60	2 30	59	-1 0	1 33	60 5	+0 5
120	2 30	121	+1 0	1 35	120 5	+0 5
135	1 84	137	+2 0	1 87	134 5	-0 5
150	1 31	151	+1 0	2 33	150	0 0
210	1 35	210 5	+0 5	2 32	210	0 0
225	1 88	225	0 0	1 88	225	0 0
240	2 30	239	-1 0	1 33	240 5	+0 5
300	2 30	301	+1 0	1 34	300 5	+0 5
315	1 87	315	0.0	1 88	315	0 0
330	1 31	331	+1 0	2 32	330	0 0

When the maximum errors observed in these tests were used and when R_p and R_d were less than 100 miles, it was determined by calculation that the greatest computer errors to be expected in operation would be 2 5 miles in distance-to-waypoint indication and 2 5 miles in deviation from course These two conditions will not occur simultaneously, however

As a further check on the over-all performance of the course-line computer, a hypothetical problem was prepared and set into the device in the laboratory Figure 9 shows the proposed course and the track made good by following deviation-indicator guidance It will be noted that the greatest displacement from the proposed course was two miles

Technical Flight Tests

Tests to determine the accuracy of the pictorial display under actual flight conditions were conducted in TDEC aircraft N-181, a Douglas DC-3 Flights were made three times clockwise and three times counterclockwise around a preselected course, and positions were noted at 30 ground check points for each trip Because this project was intended to evaluate the pictorial display rather than the OBD facilities, errors in the unit were expressed as deviations of display indications from those of the omnibearing indicator and the distance

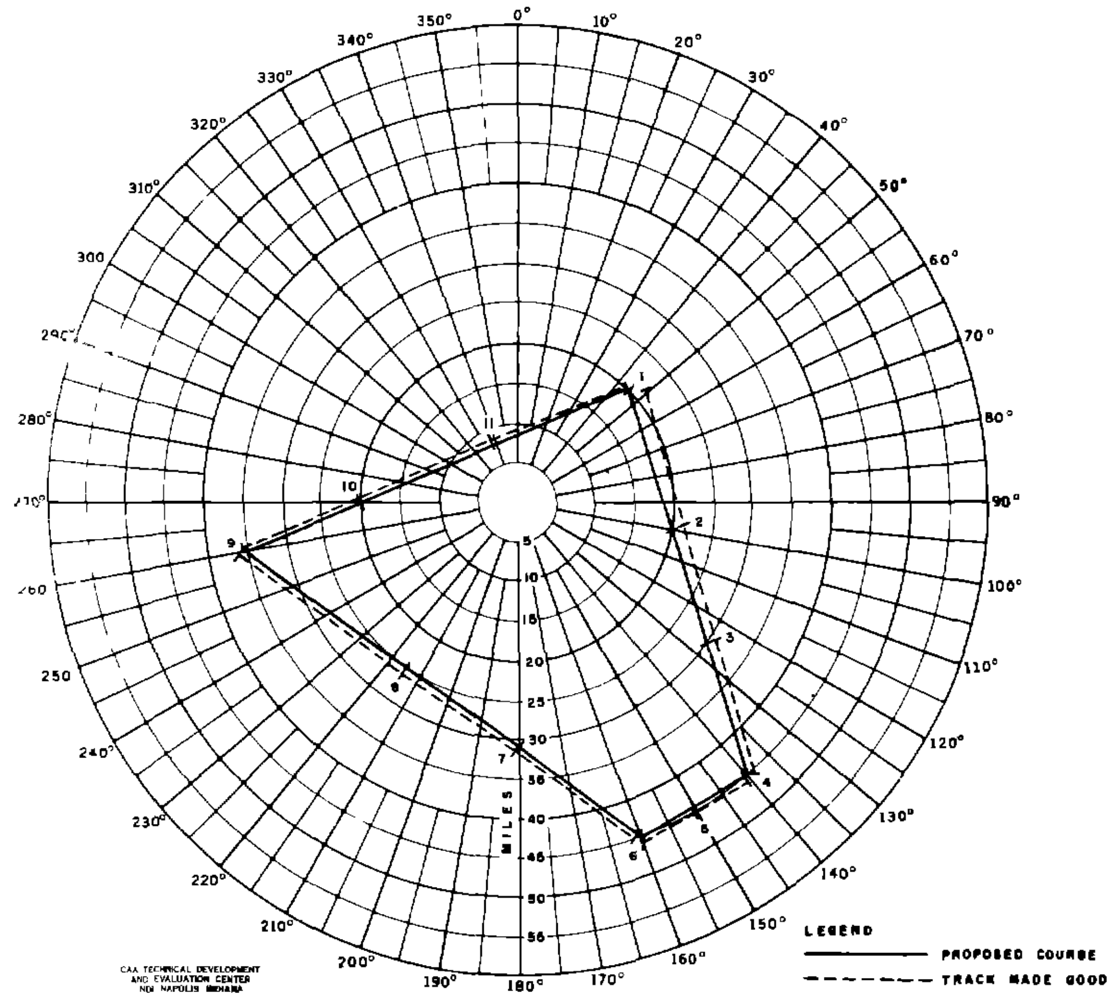


Fig 9 Plot of Hypothetical Test Following Deviation-Indicator Guidance

meter The greatest errors found in average results of repeated tests were 2 2° and 0 5 mile, respectively These errors resulted in a maximum displacement from course of 1 1 miles This magnitude of error was noted on a turn in which the distance to the station was first increasing and then decreasing This condition results in a maximum lag in display indication Table X shows the average indications obtained in the six flights, and Fig 10 shows the proposed course, the OBD instrument course, and the display indications observed

OPERATIONAL-EVALUATION TESTS

In the operational evaluation, five flight tests were conducted to determine the characteristics of this equipment when it is used for en route and terminal-area navigation with present and proposed air-traffic-control procedures These flights were made in the Indianapolis area, and all OBD information used by the pictorial display was provided by the Indianapolis VOR/DME facility Because of the air-traffic-control problems now being encountered in the transition from low-/medium-frequency (L/MF) to very-high-frequency (VHF) airways, special attention was directed toward the compatibility of use of the pictorial display with present air-traffic-control procedures and navigation equipment

TABLE X

TECHNICAL FLIGHT TESTS OF THE TYPE IV COMPUTER

Check-Point Number	Measured Values		Average Pictorial-Display Indication		Average OBD-Instrument Indication		Pictorial-Computer Error*	
	Bearing to Station (degrees)	Distance to Station (nm)	Bearing to Station (degrees)	Distance to Station (nm)	Bearing to Station (degrees)	Distance to Station (nm)	Bearing (degrees)	Distance (nm)
1	288 5	4 9	287 5	4 7	287 5	4 8	0 0	0 1
2	293	2 4	295 0	2 3	293 5	2 3	+1 5	0 0
3	329	0 5	333 6	0 7	338 6	0 5	-5 0	+0 2
4	92	1 6	88 2	1 7	88 5	1 6	-0 3	+0 1
5	97 5	2 6	94 2	2 4	94 6	2 9	-0 4	-0 5
6	100	4 3	97 0	3 9	98 3	4 3	-1 3	-0 4
7	101	5 1	98 5	5 0	99 3	5 1	-0 8	-0 1
8	101 5	6 5	99 8	6 3	100 8	6 5	-1 0	-0 2
9	102	7 8	100 3	7 8	100 8	8 0	-0 5	-0 2
10	102	9 2	100 6	9 0	100 8	9 3	-0 2	-0 3
11	110	9 5	106 6	9 5	109 8	[illegible]	[illegible]	-0 1
12	119	10 25	115 8	10 0	116 8	10 2	-1 [illegible]	-0 2
13	122	10 5	118 1	10 4	119 3	10 6	[illegible]	-0 2
14	127 5	11 5	124 5	11 [illegible]	125 3	11 3	-0 8	-0 1
15	133	12 5	130 1	12 5	130 6	12 5	-0 4	0 0
16	138	13 5	135 0	13 4	135 6	13 6	-0 6	-0 2
17	144	12 3	141 5	12 2	142 5	12 3	-1 0	-0 1
18	154	11 2	150 6	11 0	151 8	11 0	-1 2	0 0
19	163 5	10 5	160 1	10 1	161 1	10 4	-1 0	-0 3
20	171	10 2	169 5	10 0	168 6	10 1	+0 9	-0 1
21	185	10 2	180 8	10 0	181 3	10 1	-0 5	-0 1
22	196	10 5	191 3	10 3	191 8	10 5	-0 5	-0 2
23	206	11 5	202 0	10 7	202 5	11 3	-0 5	-0 4
24	212	10 6	208 3	10 2	209 5	10 4	-1 2	-0 2
25	218	9 7	214 5	9 4	215 5	9 7	-1 0	-0 3
26	229	9 0	225 8	8 8	226 8	9 0	-1 0	-0 2
27	239 5	8 5	237 5	8 3	238 3	8 5	-0 8	-0 2
28	248	8 4	246 3	8 3	247 8	8 4	-1 5	-0 1
29	257	8 5	255 0	8 2	256 3	8 5	-1 3	-0 3
30	261	8 5	261 0	8 1	261 5	8 6	-0 5	-0 5

*Bearing error is the difference, in degrees, between OBI and pictorial-computer indications Distance error is the difference, in miles, between DME-repeater and pictorial-computer indications

To duplicate instrument-flight-rule (IFR) conditions of operation as nearly as possible, all flight tests were conducted either "under the hood" or in actual instrument weather Preflight briefings were as limited as possible, and traffic-control instructions or clearances were issued to the pilot as the flight tests progressed

Flight paths were recorded by the stylus on the pictorial-display charts In addition, flight tests were monitored by the ASR-2 radar Radar and transponder returns or both were photographed as displayed on the ASR-2 radar indicator When possible, an observer in the aircraft also recorded visual check points on a special detail chart (1 250,000 scale) prepared by the U S Coast and Geodetic Survey Composites of these recordings were prepared with the use of a Model C Kodagraph Film Reader and a Saltzman projector The composites are included in Figs 11 through 25 The variation in recorded tracks is a result of all the errors involved, including those of the OBD facility, the VOR and DME receivers, the aircraft omnibearing-distance-indicator (OBI) and DME indicators, the pictorial-display device, and the radar equipment

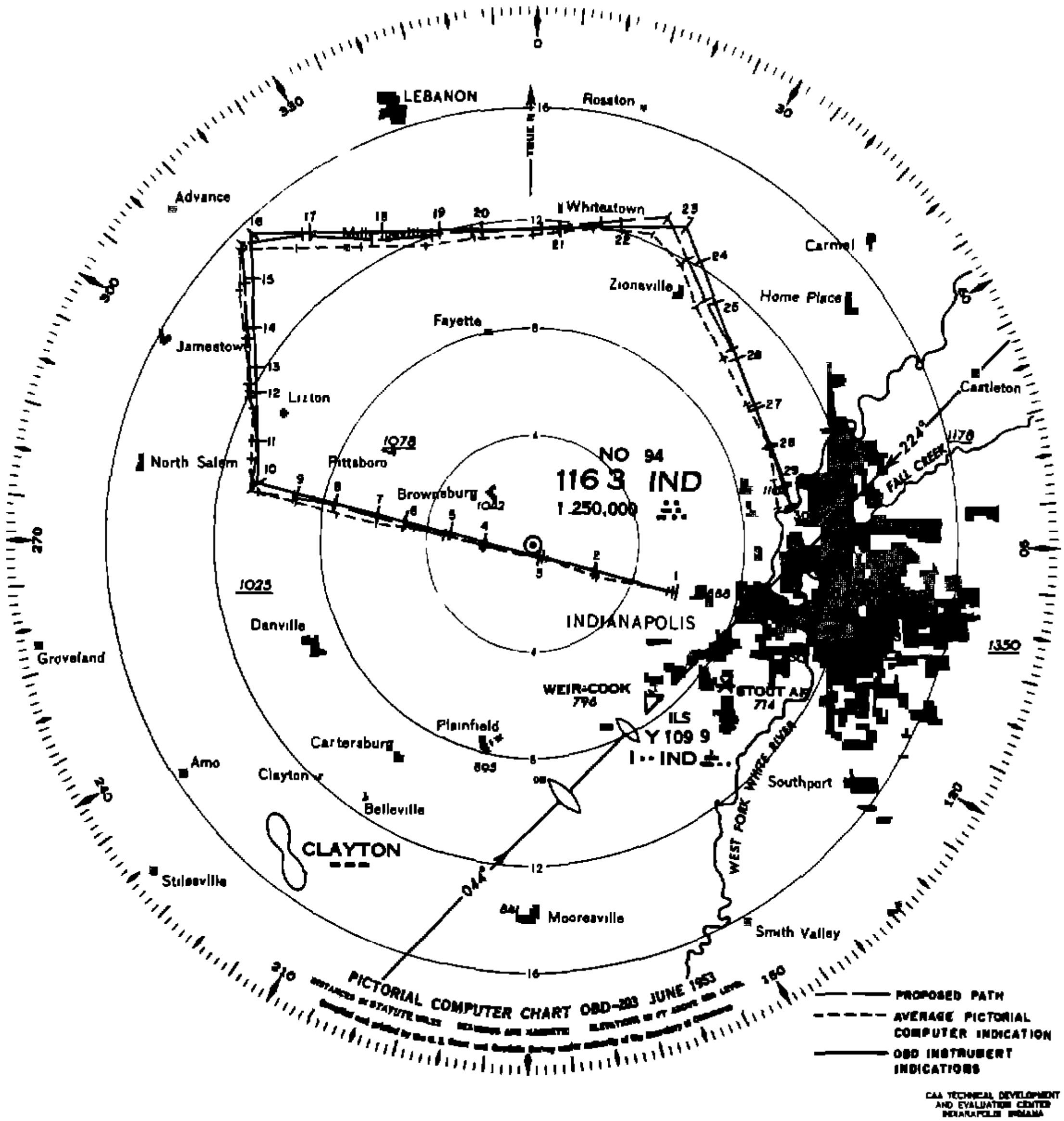


Fig 10 Plot of Computer Under Actual Flight Conditions

Flight Test No 1

Compatibility With Present L/MF Procedures

This test was conducted to determine the possible operational advantages or disadvantages encountered when the Type IV Pictorial Display is used for navigation along an airway implemented with L/MF ranges In order to provide a comparison, this test consisted of two parts In the first part, the face of the computer was concealed from the pilot's view and navigation was accomplished by aural reference to L/MF-range courses During part two, the pilot used the pictorial computer for course guidance

L/MF Navigation

The flight was initially cleared to the Terre Haute low-frequency-range station via Green Airway 4 to make good a track of 360° magnetic from Weir Cook Airport until well to

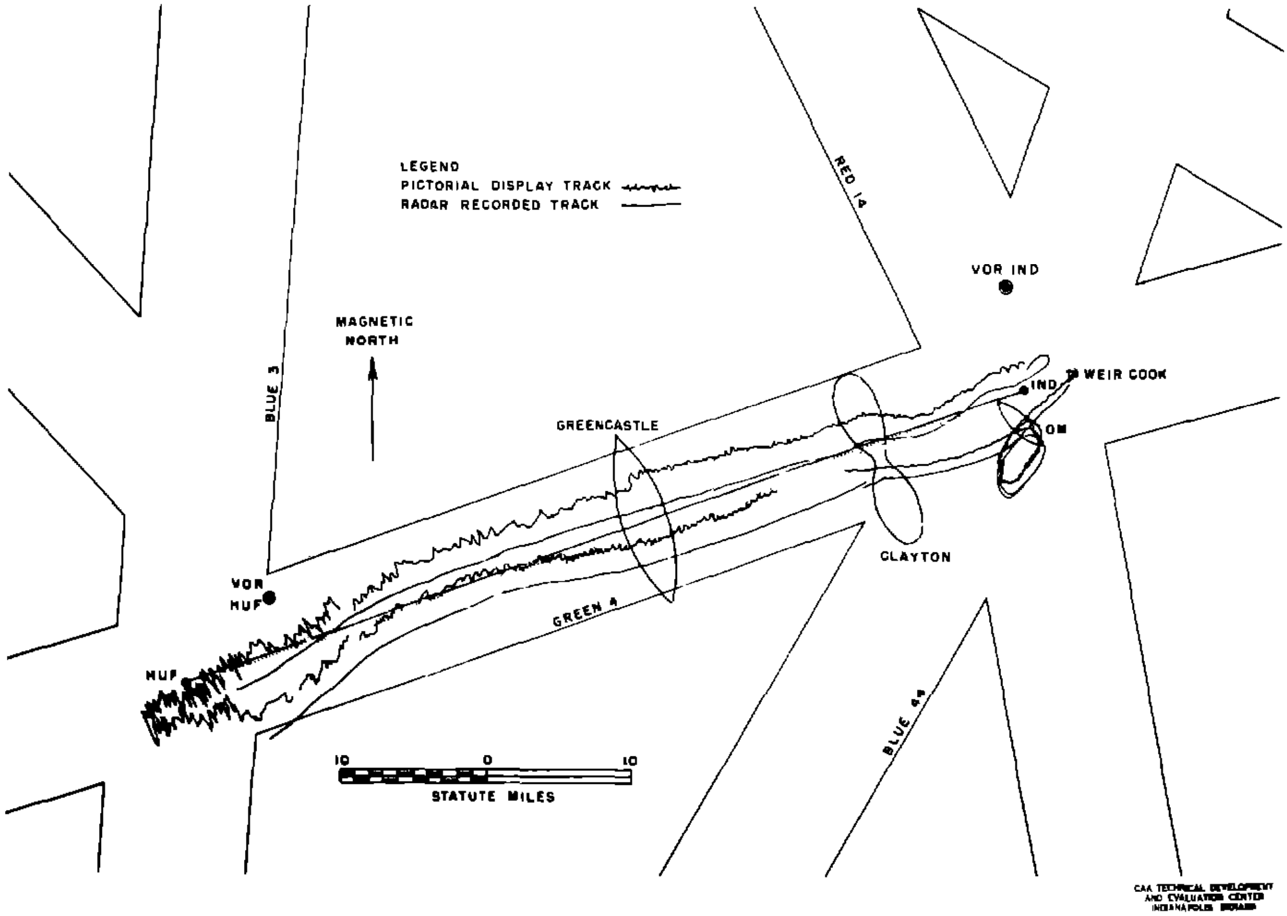


Fig 11 Flight Test No 1, L/MF and ILS Navigation

the right of the west course of the Indianapolis range and to remain well to the right of course until passing the north course of Terre Haute The flight was assigned an altitude of 3000 feet to Terre Haute and was then cleared to climb to 7000 feet in a holding pattern at that location Snow and light rime ice were encountered in the vicinity of Terre Haute, and during this period, there were several intervals of approximately 40 seconds each when the low-frequency-range signal could not be read The flight was then cleared to the Indianapolis outer compass locator, via the on-course of the LF range to the Clayton fan marker, and then direct to the compass locator After completing two holding patterns at the Indianapolis outer marker, the flight was cleared for an instrument-landing-system (ILS) approach to Weir Cook airport

Figure 11 illustrates the recordings obtained from this flight and indicates the difficulties encountered in maintaining the desired course immediately west of Indianapolis and again when approaching Terre Haute In each of these areas, the aural signals were virtually unreadable The computer continuously recorded position, and no flag-alarm activity due to insufficient signal occurred during the first 55 miles at 3000 feet MSL Beyond 55 miles, there was some DME searching accompanied by 50 seconds of flag activity which ended upon leaving 3500 feet MSL in the climb at Terre Haute

When Clayton was approached on the return portion of the flight, the chart change was made too soon As a consequence, when the new chart had been inserted the position of the aircraft was still outside the area shown on the new chart This condition caused the flag alarm to appear until a point within the range of this terminal-area chart (1 250,000 scale) was reached The aircraft-position indicator of the computer appeared to lag from one-half

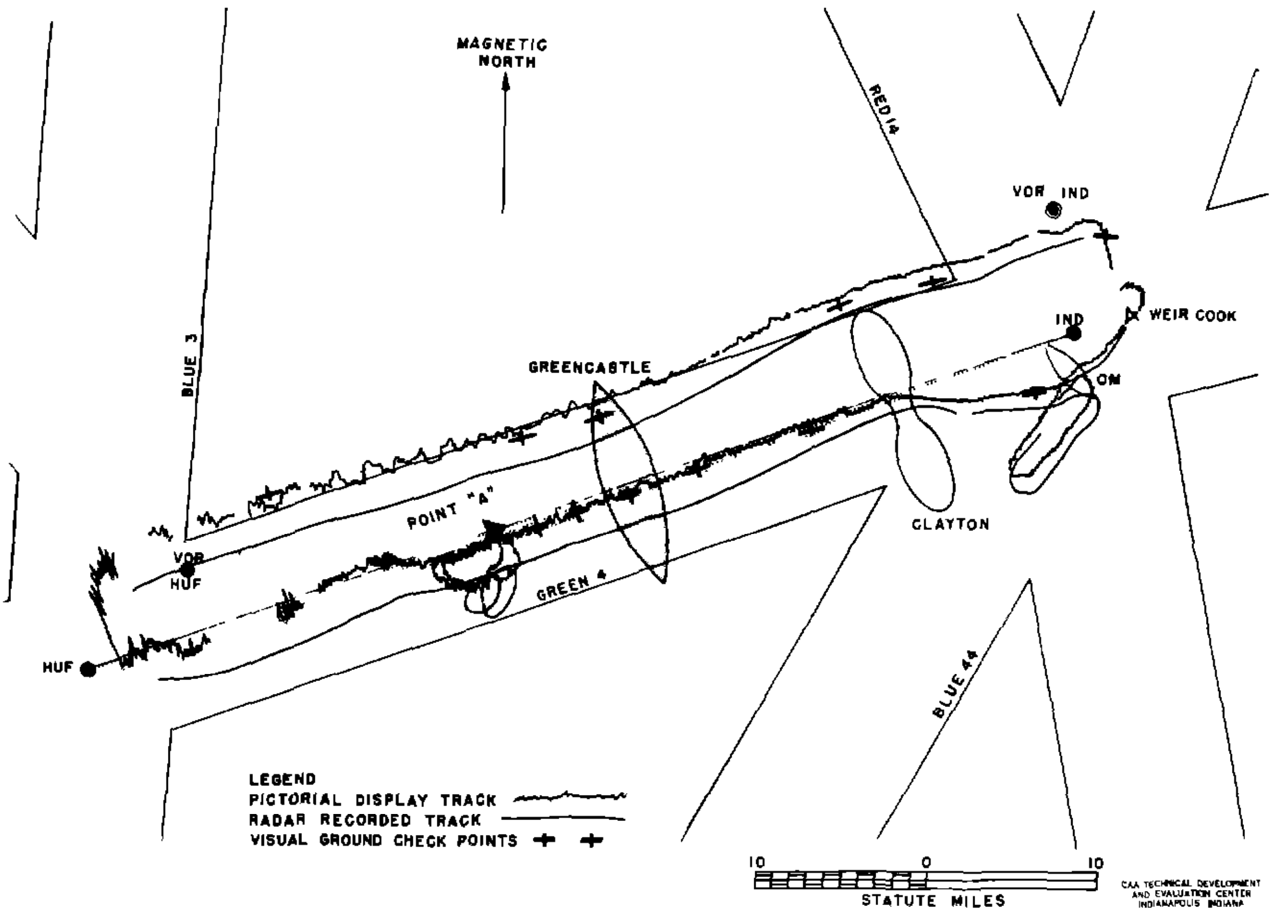


Fig 12 Flight Test No 1, Pictorial-Display Navigation

to one mile behind the actual position of the aircraft as indicated by reception of the fan, station-location and outer markers and lagged approximately one-third of a mile on final approach Part of this observed lag can probably be attributed to reading error, which is primarily caused by parallax

No flag alarm occurred during the final approach, which was conducted to an altitude of 300 feet above ground The trace of the pictorial display recorded the flight path 500 feet north of the actual position of the aircraft when it was visually aligned with the runway

Navigation by Reference to the Pictorial Display

In this part of the test, the flight was again initially cleared via Green 4 to the Terre Haute low-frequency-range station to make good a magnetic track of 360° from Weir Cook Airport to a point five miles north of the centerline of Green 4 and then to remain five miles to the right of the centerline until past Terre Haute The flight was instructed to remain at 3000 feet until past Clayton, to cross Greencastle at 4000 feet, and to maintain 4000 feet thereafter The pictorial-display charts used for this flight included the centerline of Green 4, the Weir Cook localizer course, the ILS outer marker, and a point designated as A and located five miles west of Greencastle The purpose of selecting this arbitrary point was to demonstrate the additional flexibility of control procedures which is possible in this type situation These additions to the charts enabled the pilot to follow the same clearance routings as during the previous flight, when only the low-frequency range and the ILS were used The results of this flight are shown in Fig 12

After departure, the pictorial display began providing usable navigational information at an altitude of 200 feet above the runway Upon the approach to Terre Haute, the DME went into memory for periods of 10 to 15 seconds and the flag alarm appeared intermittently Also, in passage over Terre Haute, the DME remained on a reading of 54 nautical miles for a period of approximately 70 seconds Prior to arrival at Terre Haute, the flight was cleared over Terre Haute to point A An altitude of 5000 feet was assigned, and the flight was instructed to hold west of point A in a standard holding pattern After completion of one holding pattern at point A, the flight was cleared to proceed via the centerline of Green 4 to Clayton and then to proceed direct to the Weir Cook ILS outer marker Descent from 5000 feet was begun at Clayton and after the completion of one holding pattern at the outer marker, the flight was cleared for final approach to Runway 4

The holding pattern at point A was easily executed No difficulty was experienced either in changing from the en route to the terminal-area charts or in the resulting transition to a different scale The final approach was discontinued at an altitude of 100 feet above ground The pictorial-display trace indicated that the aircraft passed directly over the runway The actual flight path, however, was estimated by visual observation to be 400 feet south of the runway

These tests demonstrated that, with the necessary reference information provided on the pictorial-display charts, all control procedures predicated upon L/MF navigation were more easily followed when the pilot navigated by means of the pictorial display than when he navigated by reference to aural signals from radio ranges Better course accuracy was also obtained when the pilot navigated by means of the pictorial display as compared to that obtained when he navigated by means of aural monitoring of the L/MF facilities

Flight Test No 2

Terminal-Area Navigation

In this test, complex terminal-area procedures were followed with the pilot using the pictorial display for navigational guidance These procedures corresponded, to some extent, to radar departure and arrival procedures currently used in some terminal areas Such procedures now require a large amount of vectoring with a rather high controller and communications workload

The first phase demonstrated three departure flights from the same runway These flights proceeded to a common point two miles from the end of the runway and then via three adjacent tracks separated by 15° and 30° The second phase illustrated use of three concentric paths orbiting the OBD station at 9, 12, and 15 statute miles, respectively The third phase included a transition to three parallel, straight, descent paths spaced three miles apart The fourth phase involved three separate multiapproach tracks from a common fix to the final-approach course in order to establish spacing between aircraft on final approach All of these tracks were preplotted on the display charts Each flight test included one path for each phase, that is, departure, orbit, descent, and approach

The first flight, shown in Figs 13 and 14, was initially cleared to point A, via point X, to maintain 3000 feet After departure on Runway 31 and during the approach to point A, the flight was cleared over point A and point B to point C in order to proceed via the 15-mile orbital track from point A to point B Upon approach to point C, the flight was cleared for a low approach via point F and approach track 14 (14 miles from point F to the outer marker via this track) After take-off, adequate OBD signals were received before the craft reached 150 feet above the ground, at which point the flag alarm disappeared From point A to B, the DME went into memory and caused overcorrection by the pilot when he attempted to follow the desired track After point B, deviation between the display trace and the desired track was primarily due to reading error On the final approach, the aircraft was approximately 500 feet south of the runway, and the aircraft position as indicated by the display appeared to lag about one-half mile behind the visually observed position

The second flight, illustrated in Figs 13 and 15, was cleared in the same manner as the first flight but via points X, D, E, F and approach track 10 This route from X to D diverged 30° from the route of the preceding flight from X to A Overcorrection resulted from reading error and from lag in the aircraft-position indicator Less trouble was encountered by the pilot when he was flying the orbital portion of the route than on the previous flight, perhaps because of a learning factor or because of the shorter distance The DME was intermittently in memory between Whitestown and point E and again from ten to seven miles north of point F The final approach was interrupted at the middle marker because of local traffic

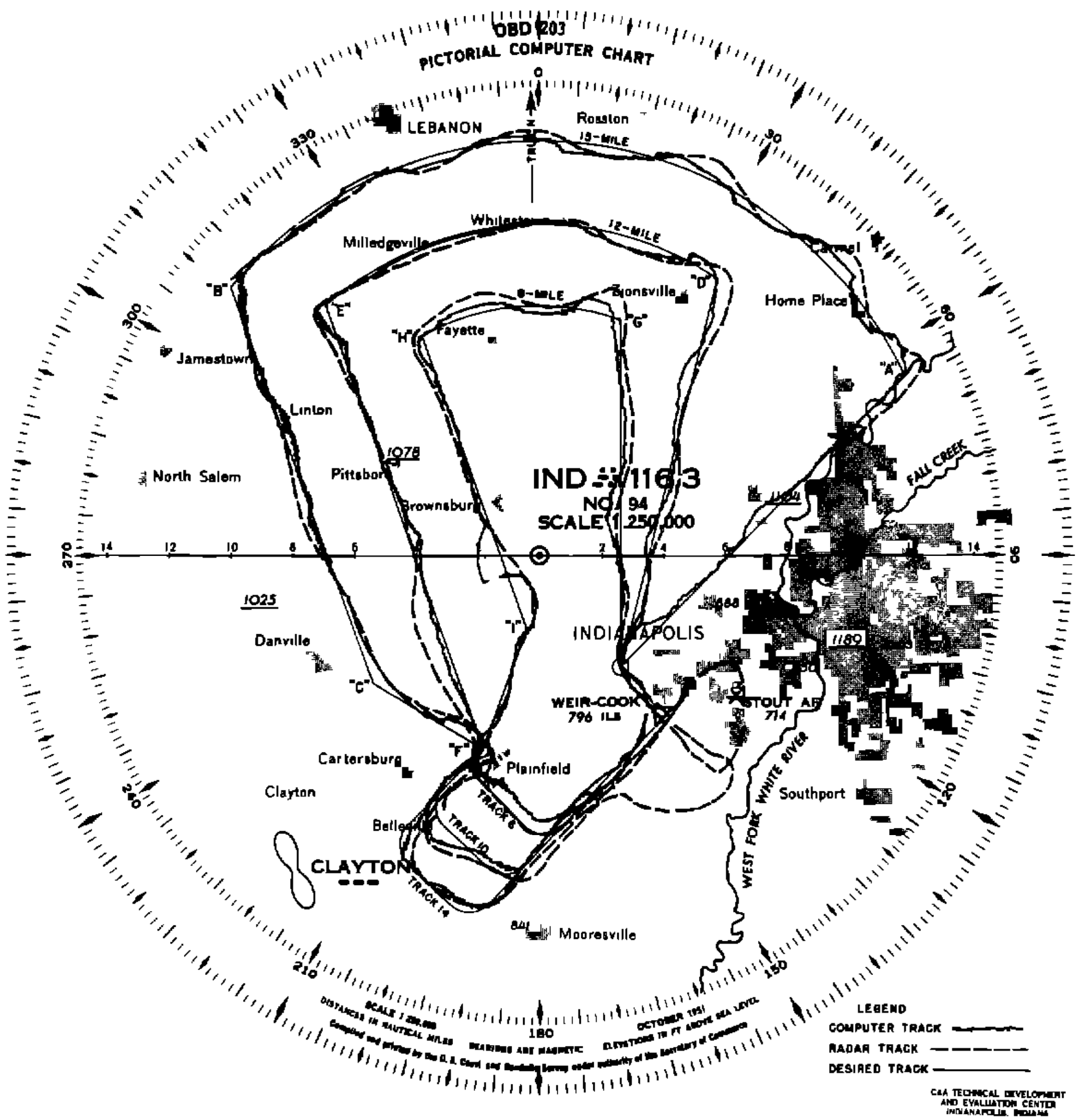


Fig 13 Flight Test No 2, Terminal-Area and Orbital Procedures

The third flight, shown in Figs 13 and 16, was cleared in the same manner as the two previous flights but via points X, G, H, I, F and approach track 6 The route from X to G diverged 15° from the route of the preceding flight Immediately after the craft turned west to the orbital path between G and H, the flag alarm was visible for five seconds The trace was interrupted, and the flag alarm appeared for approximately 20 seconds south of point I This approach was also interrupted at the middle marker because of local traffic During these tests, complex departure and arrival routes were easily followed to within one-eighth of an inch of the desired route indicated on a display chart Conditions such as lag in the position indicator, reading error due to parallax, and DME memory, all of which cause overcorrection, became increasingly evident when the pilot attempted to follow an orbital path

Flight Test No 3

Chart Presentation

This test was designed to determine the ability of a pilot to use fixes based on a Rho/Theta reference system of navigation and traffic control The effect of the trace feature as an aid to the pilot was also investigated Special charts were prepared with four-mile range circles and with 5°, 10°, and 15° azimuth lines Range circles and azimuth lines were drawn alternately in red and black The only topographical information included was the Weir Cook airport With the use of the pictorial display for navigational information, the pilot was initially cleared to proceed, after departure from Runway 4, to a point on the 110° radial at eight miles range The flight was subsequently cleared to the points shown in Table XI

TABLE XI

CLEARANCE POINTS FOR FLIGHT TEST NO 3

Radial (degrees)	Range (miles)	Trace
175	14	On
232	12	On
266	10	On
303	6	On
358	10	Off
035	4	Off
074	12	On
140	3	On

From the last of these fixes, the flight was cleared for a low approach to Runway 13 This entire route provided two fixes in each of the quadrants Each quadrant of the chart contained azimuth reference lines These were in increments of 5° in the first quadrant, of 30° in the second, of 10° in the third, and of 30° again in the fourth Flight in the fourth quadrant was conducted without the trace feature Some of the assigned fixes were at the intersections of radial and range reference lines, while the location of other fixes required that the pilot estimate the point of intersection

The first flight attempted in this series was unsatisfactory because of erratic DME-receiver operation and because of difficulty encountered with the stylus of the display mechanism To reduce any effect due to learning, a different pilot was used in the retest On the second test, after take-off the flag alarm disappeared at an altitude of 750 feet above the runway At an azimuth of 240° and a range of 13 miles, the alarm intermittently appeared for four minutes Upon reaching an azimuth of 358° and a range of ten miles, the trace was turned off until the aircraft was past the next two fixes Without the benefit of the trace for reference, the pilot experienced some degree of difficulty in reaching the next fix When the aircraft approached the fix at an azimuth of 035° and a range of four miles, the flight was cleared to the next fix at an azimuth of 074° and a range of 12 miles The pilot initially understood the radial as 174° Consequently, a right turn of approximately 225° was executed before the pilot proceeded to the correct fix During the final approach, the aircraft was observed to be 800 feet to the left of the runway, however, the display track indicated that the aircraft was 2000 feet to the left The results of this flight are shown in Fig 17

Flight Test No 3 indicates that azimuth and range co-ordinates (Rho/Theta fixes) could be used for general navigation and air-traffic-control purposes However, improved chart presentation of azimuth and range information would be required Azimuth reference lines should be provided at least every 15° and should be distinguished by alternate colors or types of printing The use of color differentiation would depend on cockpit lighting Range reference circles equivalent to four miles apart on the 1:250,000 scale chart (representing 16 miles radius) were satisfactory in this application, but these circles should also be alternate colors or styles of printing

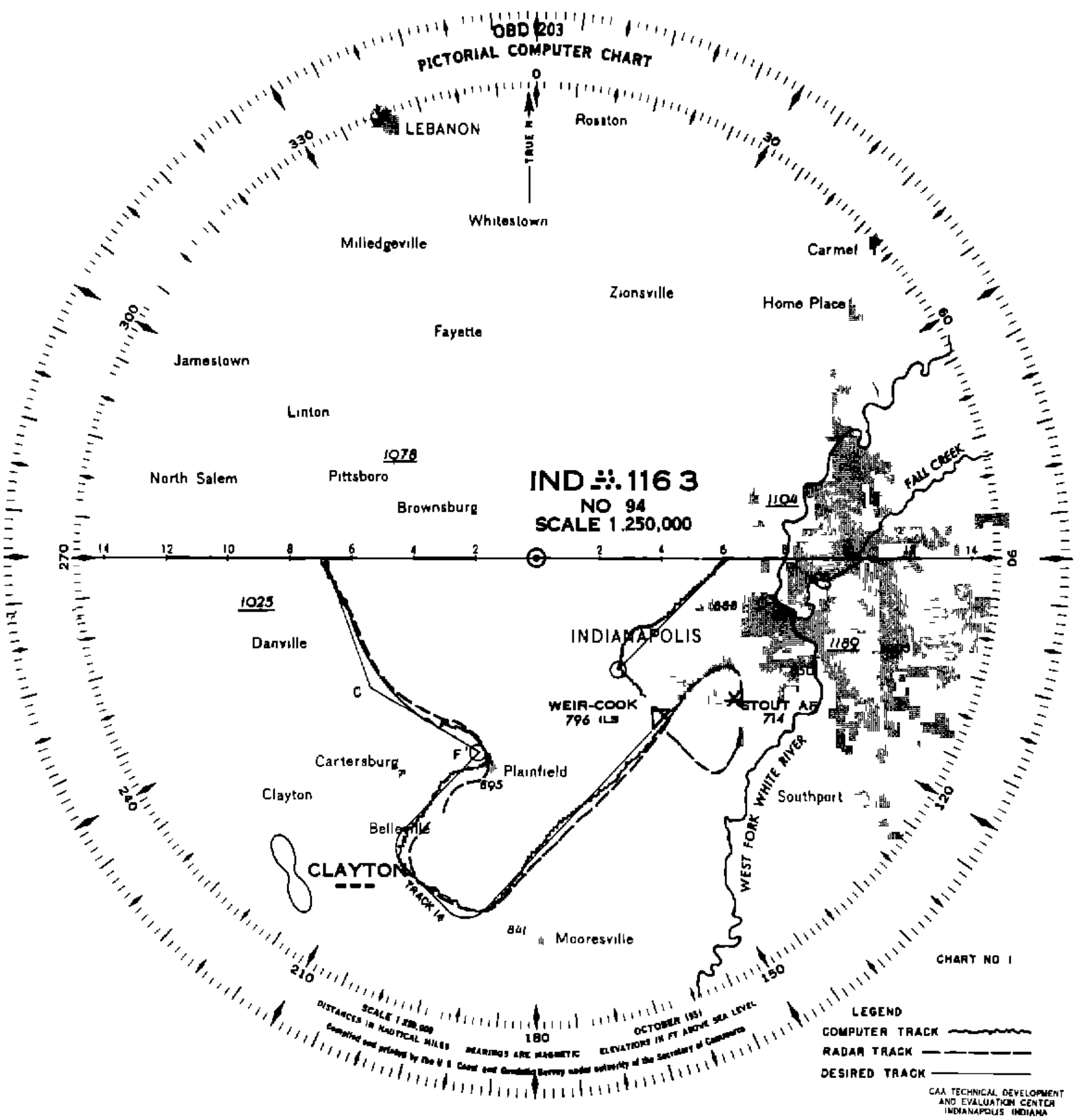


Fig 14 Flight Test No 2, Arrival and Approach Via Track 14

Flight Test No 4

Additional Compatibility Tests

This test was designed to evaluate again the ability of the pilot to fly in accordance with current and proposed air-traffic-control procedures in en route and terminal-area situations with the use of the Type IV pictorial display for navigation It was also designed to compare the accuracy of navigation when the various navigation methods were used For the departure phase, three diverging departure routes and three parallel flight paths within the present airway structure were selected This selection was made to permit a comparison of the control airspace required during navigation by means of the pictorial display with the space required during navigation by current methods Although the parallel flight paths were outbound in this test, results are also applicable to inbound tracks or to combination inbound and outbound parallel tracks The departure phase was conducted with the pictorial display used for all navigation The en route and final-approach phases were conducted with the use of L/MF-range

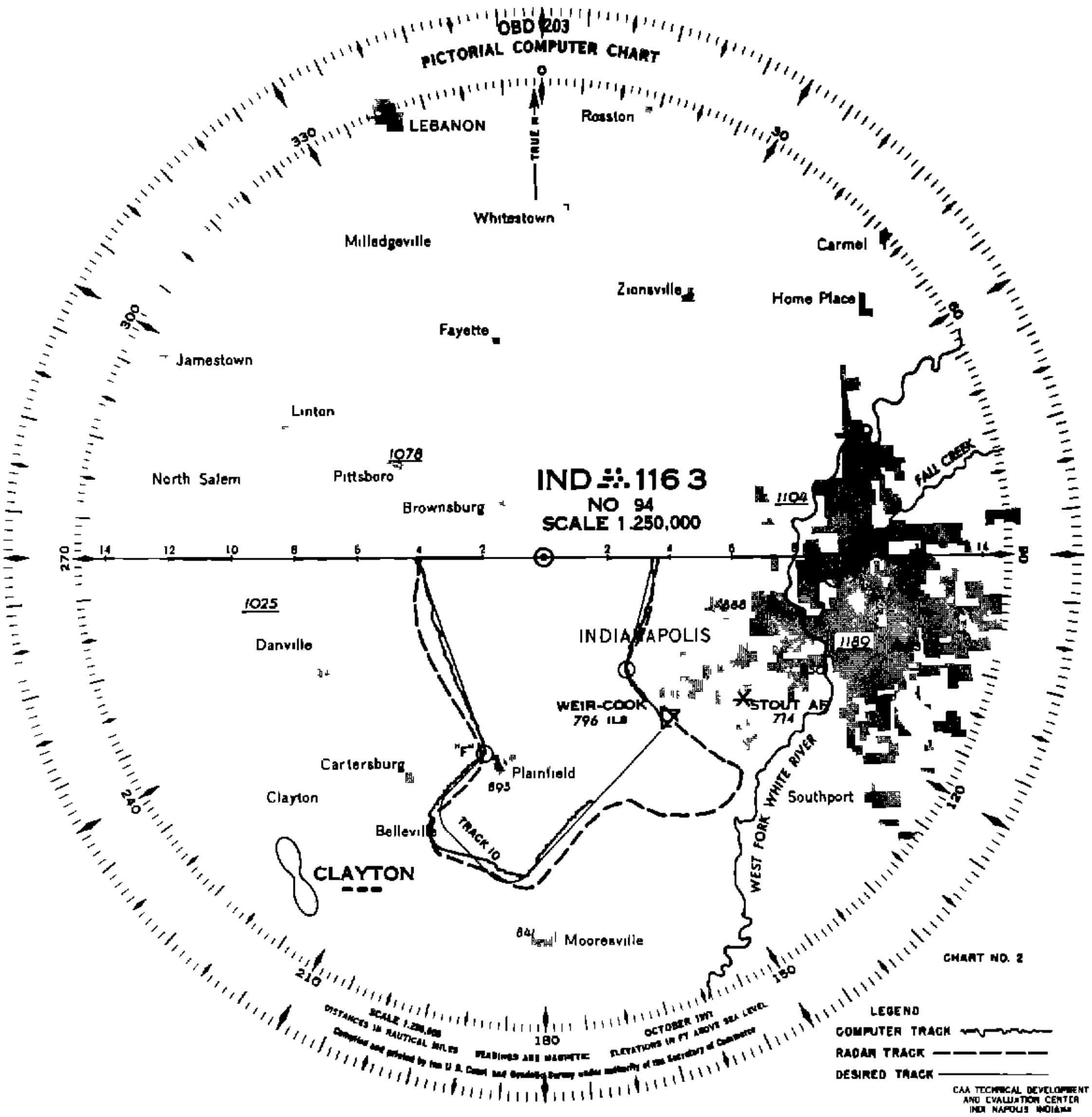


Fig 15 Flight Test No 2, Arrival and Approach Via Track 10

courses, automatic direction finder (ADF), and pictorial display for comparison of navigation on the same tracks En route holding patterns were also accomplished by these various methods of navigation

Radio-facility information was added, and much topographical data was deleted on some of the charts used in this test The 1 1,000,000-scale display charts used for the departure flights included only the airway boundaries, the five-mile range circles (alternately red and black), the Weir Cook Airport, and the azimuth compass rose

The departure phase is shown in Fig 18 On the first flight, the pilot was cleared for departure from Runway 4 to proceed to the intersection of the north edge of Green 4 and the 14-mile range circle, from there via the north edge of Green 4 to the 45-mile range circle, where he was to cruise at 3000 feet After the flag alarm had disappeared following departure, the aircraft-position indicator operated in an erratic manner, as indicated in Fig 18 This was found to be due to the DME equipment which caused the DME indicator to move in 1 1/2- to 2-mile increments The second flight was cleared for departure from Runway 9 to proceed

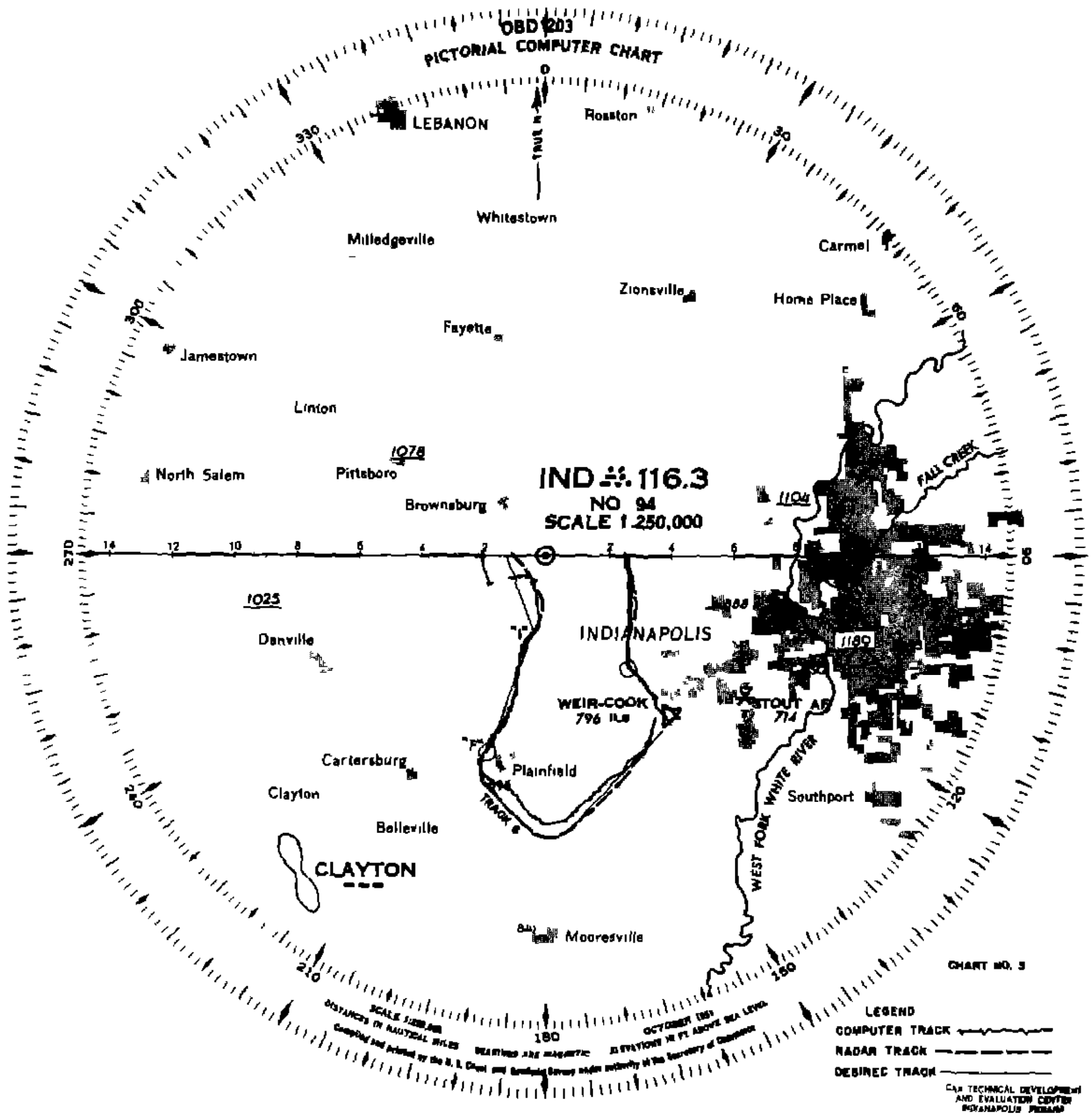


Fig 16 Flight Test No 2, Arrival and Approach Via Track 6

east via the centerline of Green 4 to the 45-mile range circle and there to cruise at 4500 feet The display chart included lines delineating the edges of Green airway 4 but did not contain the centerline and thus required the pilot to estimate the center of the airway

The third departure was simulated by flight over Runway 13 The pilot was cleared to proceed directly to the intersection of the south edge of Green 4 and the 15-mile-range circle, then east via the south edge of Green 4 to the 45-mile-range circle, where he was to cruise at 3000 feet No flag alarms occurred on this portion of the flight The pilot made a minor correction after departing Runway 13 in order to intercept Green 4 at the 15-mile-range circle This resulted in overcorrection

The Arrival Phase is illustrated in Fig 19 The first flight, after completion of a standard two-minute holding pattern west of the Greenfield fan marker, was cleared for ADF approach to the Weir Cook airport in order to make good a magnetic track of 254° until a magnetic track of 224° to the outer marker was intercepted This inbound track corresponds to the east course of the low-frequency range and of the ILS localizer The pilot performed all navigation by

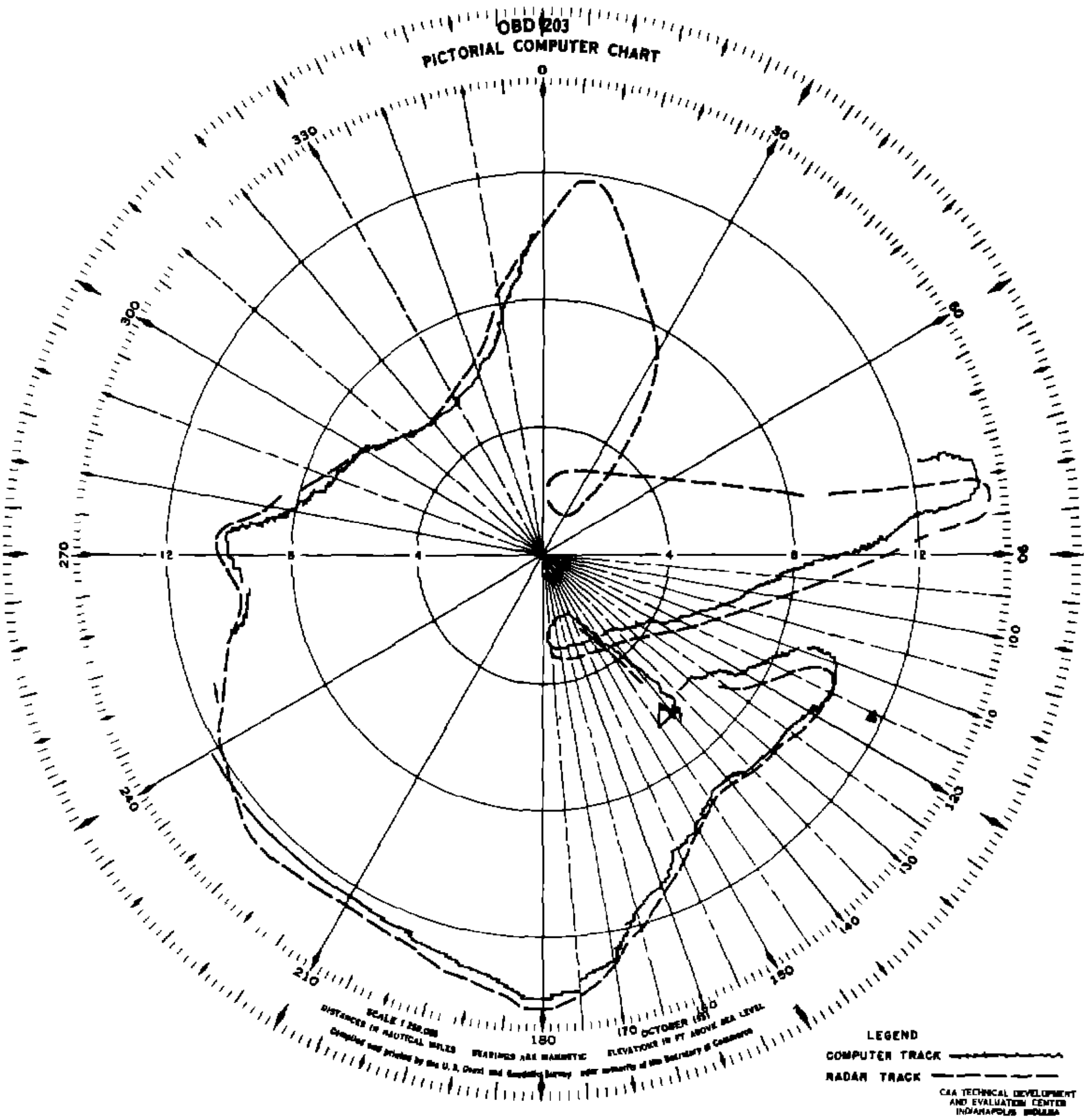


Fig 17 Flight Test No 3, Chart Presentation

means of dual ADF and was not permitted to refer to the pictorial display Because of a calibration error in one of the ADF instruments, the pilot had difficulty in initially establishing the desired tracks The faulty instrument was later recalibrated, and this portion of the flight was rerun as the return section of Test 5, Part 1, shown on Fig 22 No difficulty was encountered with the pictorial-display equipment as it monitored this test

The second flight, on its return, was cleared to the Greenfield fan marker to complete a standard two-minute holding pattern followed by a complete standard-range instrument approach to Weir Cook Navigation was based on aural L/MF-range signals and on VHF markers The pictorial display was used to record the flight path but was not available to the pilot for reference The recordings obtained from this flight are shown in Fig 20

The third flight was cleared to hold east of the intersection of VOR radials 087° from Indianapolis and 316° from Cincinnati These radials intersect at the Greenfield fan marker 34 miles from the Indianapolis-and 77 miles from the Cincinnati-VOR sites Although the flight was at 8000 feet, it was difficult to use the Cincinnati radial and to complete the holding

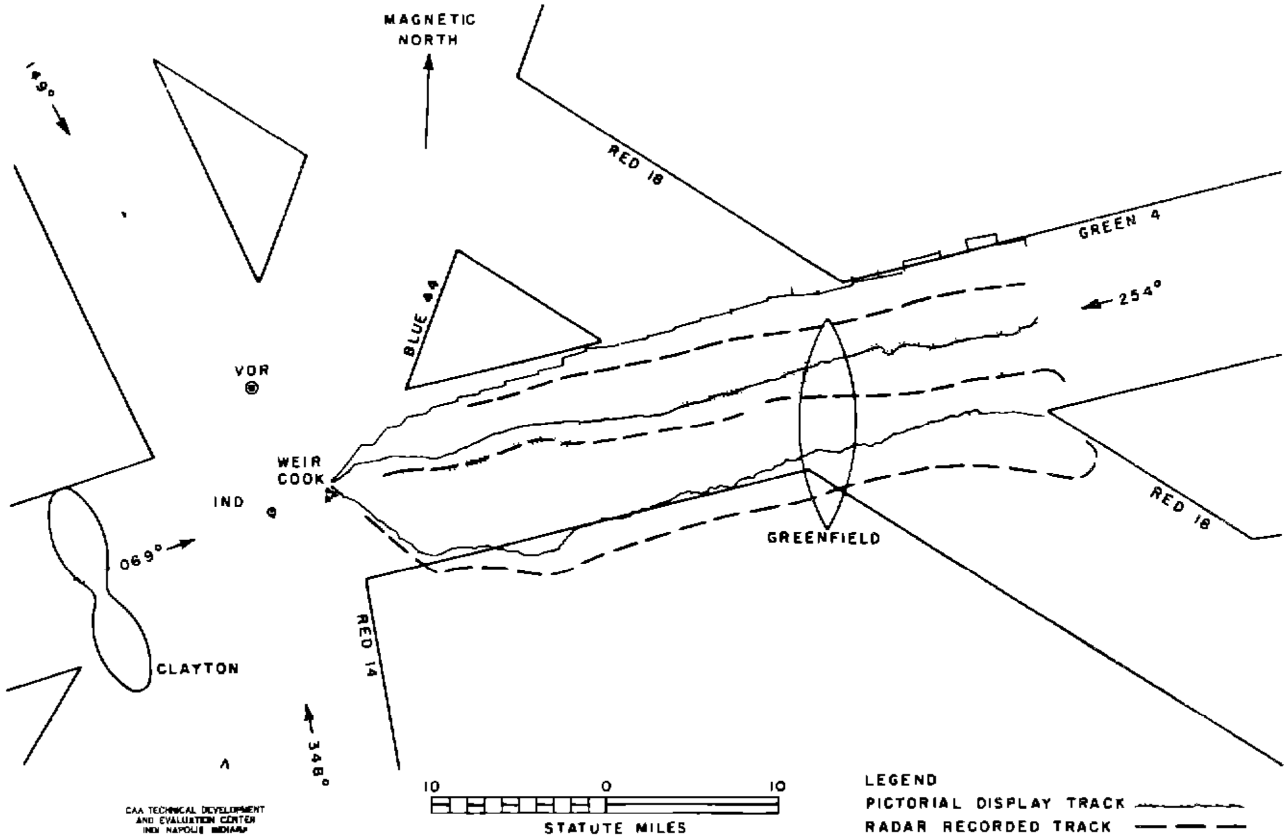


Fig 18 Flight Test No 4, Pictorial-Display Navigation on Three Departure Tracks

pattern As indicated in Fig 21, the pictorial display recorded a track six miles east of the theoretical intersection The display again was used only to monitor the flight path and was not available to the pilot, who navigated by means of the dual VOR course-deviation indicators

After completion of this holding based on the intersection of VOR radials, the pictorial display was used as the means of navigation and the flight was cleared to Greenfield to complete a standard holding pattern east of Greenfield From Greenfield, the flight was cleared for a straight-in approach to Weir Cook and was to proceed via the center of Green airway 4 Descent from 8000 feet was begun at Greenfield Trouble developed in the door lock of the display unit when the Greenfield holding pattern was entered This resulted in a flag alarm until the door was manually held and later taped in a closed position During this period, the DME receiver also displayed a flag alarm for approximately 60 seconds These factors contributed to the irregular holding pattern accomplished at Greenfield

On the approach to Runway 27, the aircraft was 2500 feet south of the runway according to visual checks The pictorial-display unit also recorded the track at this time as being 1/2 mile (1/8 inch) south, since the terminal-area chart used for this approach was a 1 250,000 scale Because of the erratic DME operation, this phase was retested in conjunction with Test 5, Part 2, Fig 23

With the use of pictorial-display charts which provided the necessary reference information (L/MF, VHF, or both, airways and control points) these test flights indicated that aircraft equipped with pictorial displays could comply with traffic control procedures predicated on either low-frequency or VHF systems of navigation There was little, if any, difficulty involved in making the nine chart changes required in this series of tests

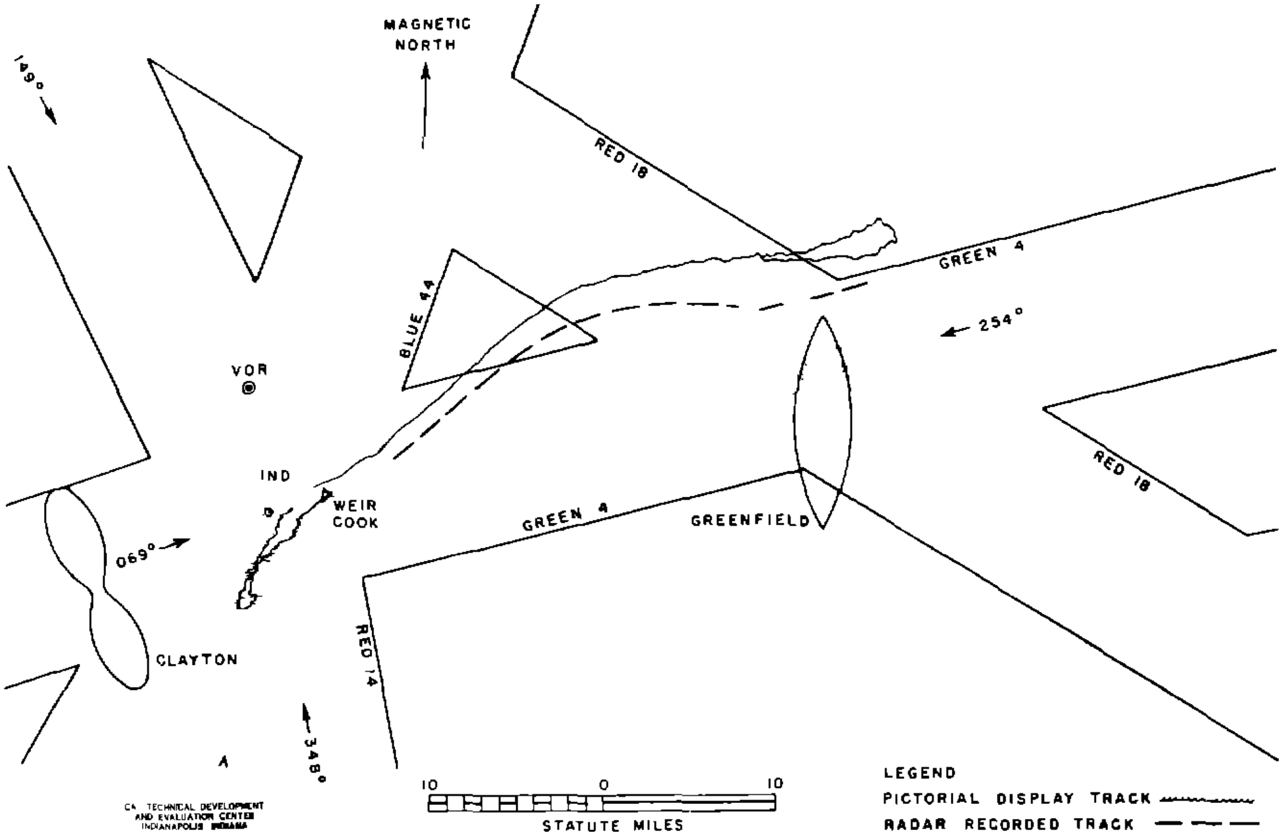


Fig 19 Flight Test No 4, ADF Navigation, En Route and Approach Tracks

Flight Test No 5

On- and Off-Airway Operation

This test was designed to determine the utility of the Type IV Pictorial Display for instrument approaches and for en route navigation procedures on and off airways The approaches were conducted at airports located 30 and 50 miles from the OBD site and at an airport only one mile from the OBD site Holding was accomplished at currently used L/MF and VOR intersections and at a point adjacent to a L/MF airway but prior to entrance to the airway Two parts of Flight test 4 were rerun at this time

As shown in Fig 22, this flight was first cleared to Zionsville, a VOR intersection which had been plotted in advance on the display chart and which is formed by radials 020° from Indianapolis VOR and 132° from Lafayette Two holding patterns were completed at this point with the use of the pictorial display for navigation The holding patterns were then repeated by means of only the dual VOR course-deviation indicators for reference A cruising altitude of 2500 feet was assigned, and the holding patterns were executed without incident However, the pilot had more difficulty in establishing the pattern without the use of the pictorial display

When the pictorial display was used for navigation, the flight was cleared to go from Zionsville to the Anderson airport and to hold east of Anderson After completion of one holding pattern, the flight was cleared for an approach to the Anderson airport The display chart used to include this approach was of a 1:500,000 scale, because Anderson is 40 miles from the OBD station With the use of radio-line-of-sight restriction, minimum OBD coverage

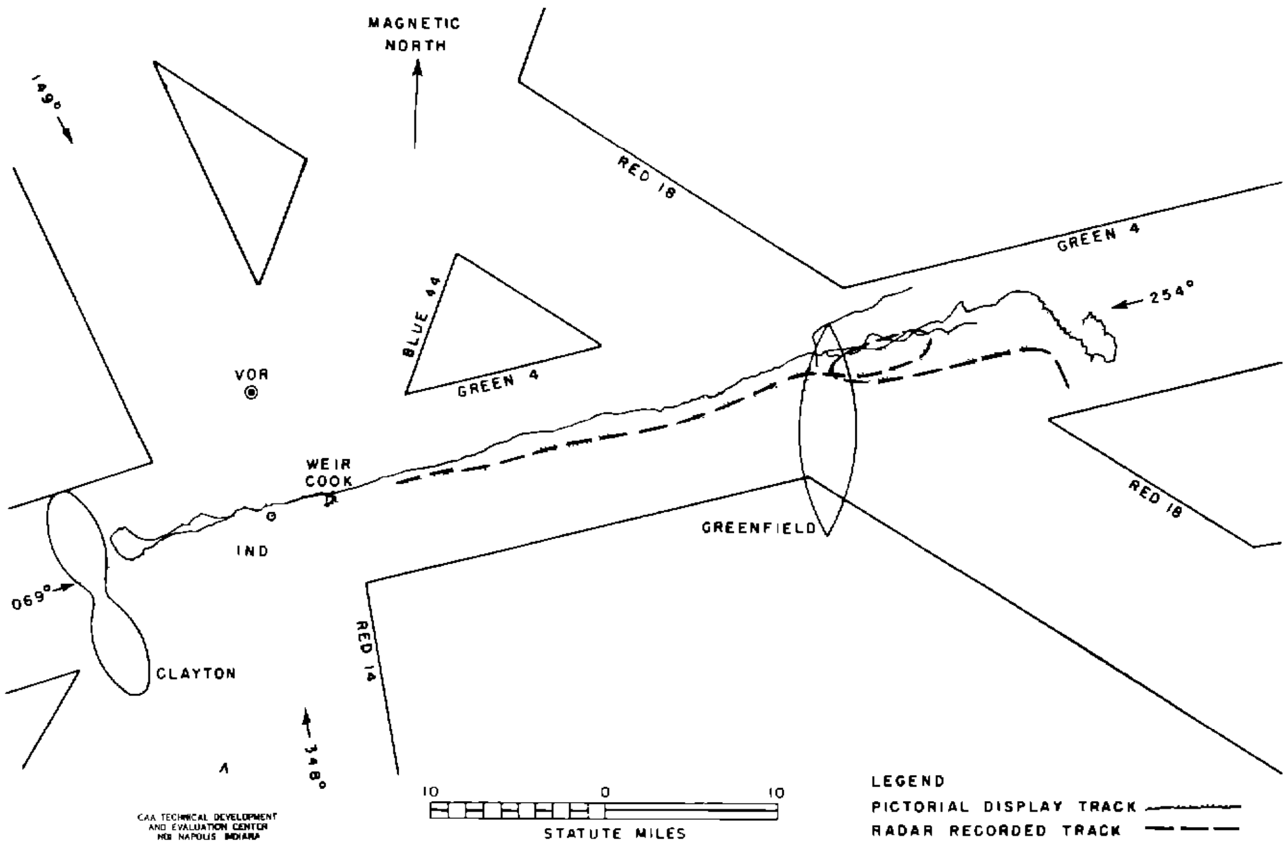


Fig 20 Flight Test No 4, L/MF Navigation,
En Route and Standard Instrument Approach

at this distance is 1700 feet MSL[6] However, no flag alarm occurred on the approach to 1375 feet MSL (400 feet above ground) The airport was approximately four miles to the north, as visually observed at the completion of the approach This corresponds to about 1/2 inch on the chart scale used Immediately upon start of the climb, a flag alarm was received and continued for a period of three minutes

After this approach, the flight was cleared to New Castle At that time the face of the pictorial display was concealed from the pilot, and the ADF-navigation phase of Test 4 was rerun Clearance was issued from New Castle to the Greenfield fan marker to make good a track of 254° magnetic and to hold east of Greenfield After completion of this holding pattern, the flight was cleared for a standard ADF approach to Weir Cook Airport to make good a track of 254° magnetic until interception of a track of 224° magnetic to the ILS outer compass locator This approach was interrupted at the outer marker because of local jet traffic Figure 22 illustrates the visual, radar, and display recordings of this flight The ADF portion of the flight from New Castle inbound to Weir Cook Airport may be compared with Fig 23, which shows a flight over the same route with the use of the pictorial display as the method of navigation

The second flight, shown in Fig 23, was cleared from Weir Cook Airport to the Martinsville VOR intersection to cruise at 2500 feet This intersection 28 miles south of the

[6] W R Rambo, J S Prichard, D P Duffy, and R C Wheeler, "Summary Report on Evaluation of Omni-Bearing-Distance System of Air Navigation," Airborne Instruments Laboratory, Incorporated, Report No 540-1, October 1950

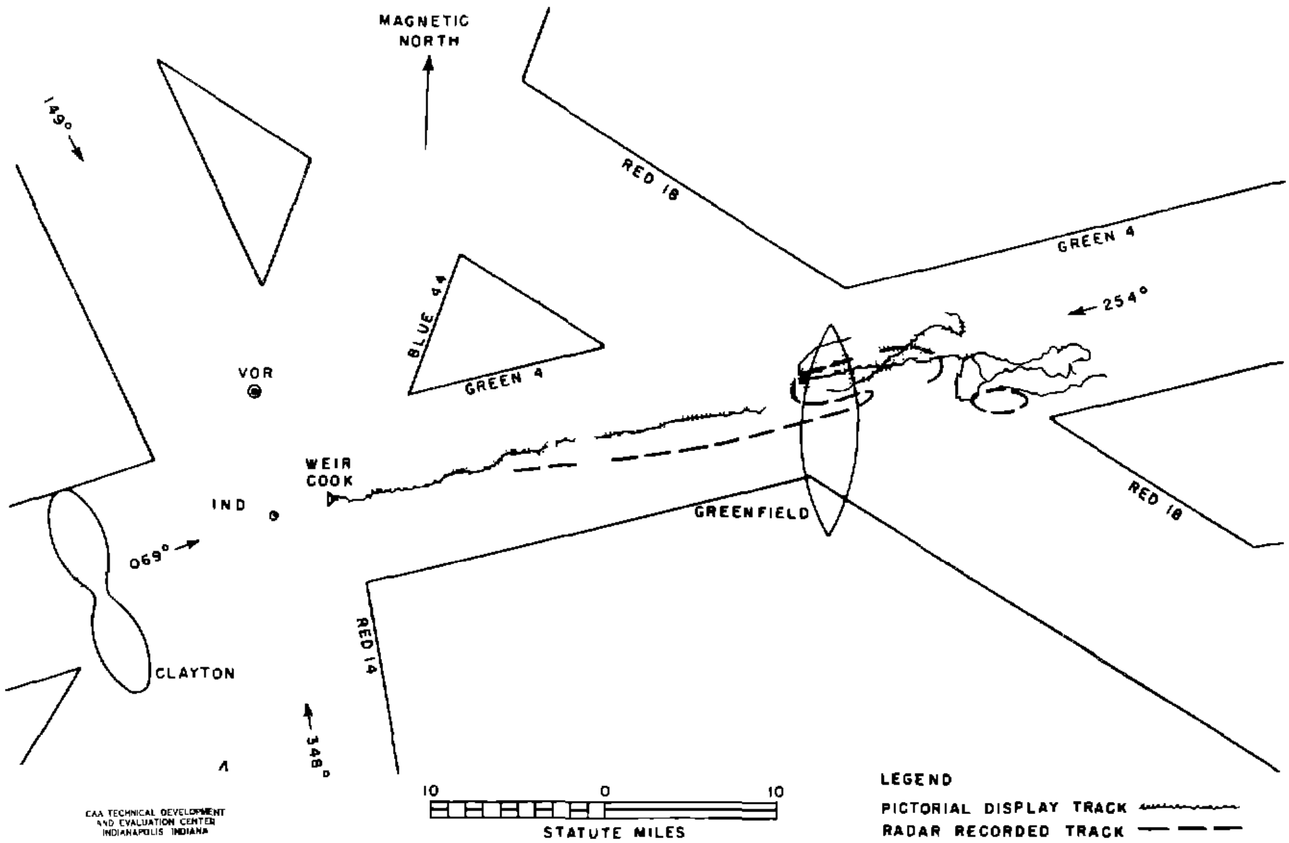


Fig 21 Flight Test No 4, VOR-Intersection and Fan-Marker Holding Patterns, Straight-In Approach With Pictorial Display

Indianapolis OBD site was added to the display chart used for this test At Martinsville, the flight was cleared to hold, with all turns to the right, in a one-minute pattern south of the intersection of radial 160° from Indianapolis and radial 094° from Terre Haute The first pattern was flown by means of the dual VOR deviation indicators, and the turns were inadvertently made to the left The same holding pattern was then flown with the pictorial display as the means of navigation From Martinsville, the flight was cleared to the Atterbury airport to proceed direct to a point ten miles north of Atterbury and then to proceed to Atterbury This routing circumvented the danger area west of the airport A cruising altitude of 2500 feet was assigned, and the pictorial display furnished the means of navigation After passing a point ten miles north of Atterbury, descent was begun The flag alarm appeared when an altitude of 1500 feet MSL was reached, at which time the aircraft was 39 miles from the OBD facility and 7 miles from Atterbury The approach was continued, and the aircraft passed 2 1/2 miles west of the field The pictorial-display trace at this time indicated the field as 1/8 inch, or approximately two miles, to the west on the 1 1,000,000-scale chart used

Upon continuation of navigation by means of the pictorial display, the flight was cleared from Atterbury, via Shelbyville, to New Castle It had originally been planned that the portion of this route from Atterbury to Shelbyville would be flown without the trace features, but because of inadequate radar return, the trace was left on to facilitate recording of the track

From New Castle, the remainder of this test corresponds to the last phase of the third flight in Test 4 Navigation was accomplished by means of the pictorial display, and the flight was cleared, via the centerline of Green 4, to the Greenfield fan marker At Greenfield, a standard holding pattern was completed and the flight was cleared for a straight-in approach

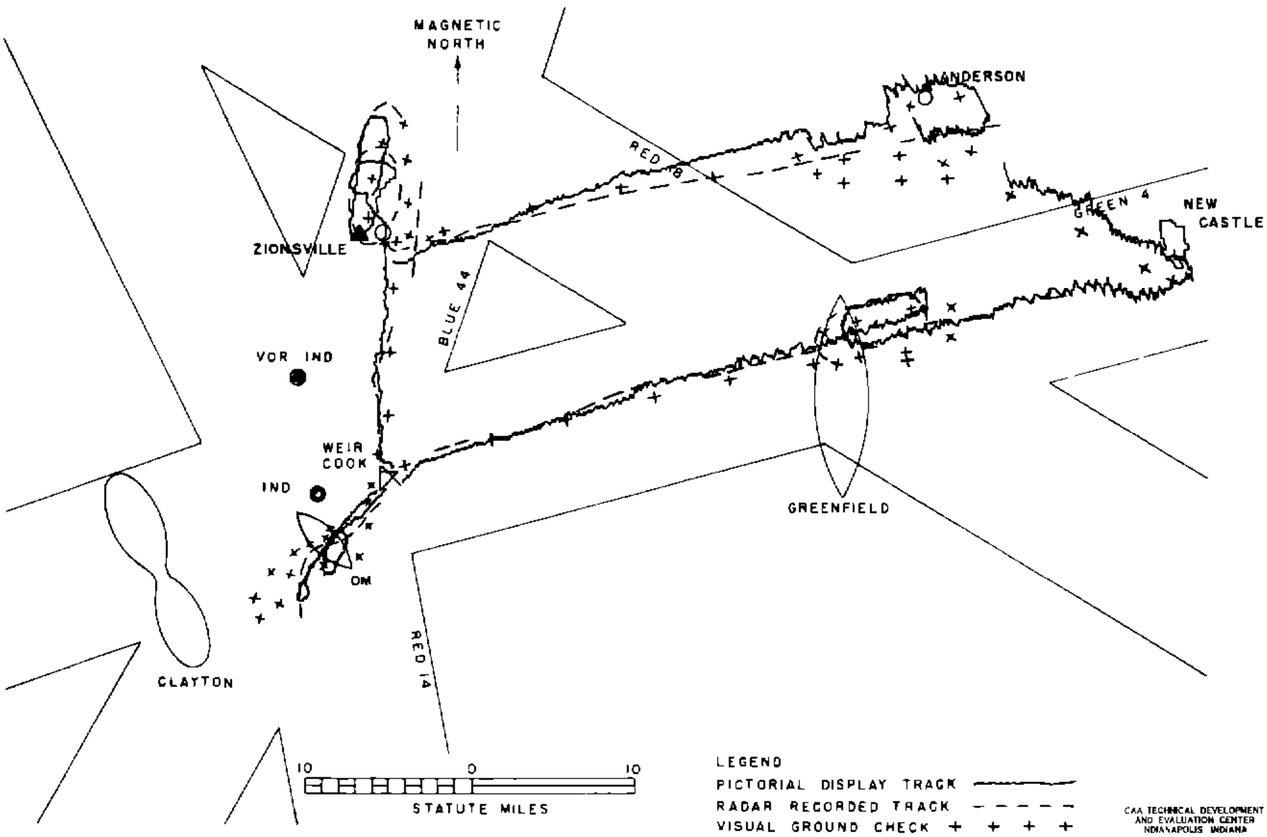


Fig 22 Flight Test No 5, Part I

to Weir Cook Airport As indicated in Fig 23, the airway boundaries were shown on the display chart used Owing to local traffic on return, the approach was discontinued east of the airport During this retest, no difficulties were experienced in complying with the conventional L/MF procedures when only the pictorial-display was used for navigation

The third flight is shown in Figs 24 and 25 In contrast to the approaches attempted at airports more distant from the OBD site, two approaches were made at Brownsburg, an airport which is one mile west of the OBD site Beginning five miles out, straight-in approaches were completed from the south and then from the north On the approach from the north, the flight turned east to avoid local traffic immediately after passing the airport boundary Both approaches were well aligned with the runways, and landings could easily have been accomplished During these tests, approaches conducted with the pictorial display were most successful at airports within 15 miles of the OBD facility At greater distances approaches were handicapped by the lack of an adequate signal at lower altitudes, the greater effect of VOR/DME errors, and the increased reading and parallax errors due to the use of 1 500,000 or 1 1,000,000 display scales

When the pictorial-display charts were appropriately marked, holding patterns predicated upon L/MF and VOR facilities were easily flown En route navigation both on and off airways was easily accomplished with the pictorial display, and the pilot was able to circumvent a danger area and to enter an airway at a given point

One condition concerning the flag-alarm system deserves comment A partial flag alarm frequently appears when the omnibearing selector is set to a radial approximately 90° from the radial on which the aircraft is located This tendency is more pronounced when the station is abeam of the aircraft and when the aircraft is in relatively weak signal areas In

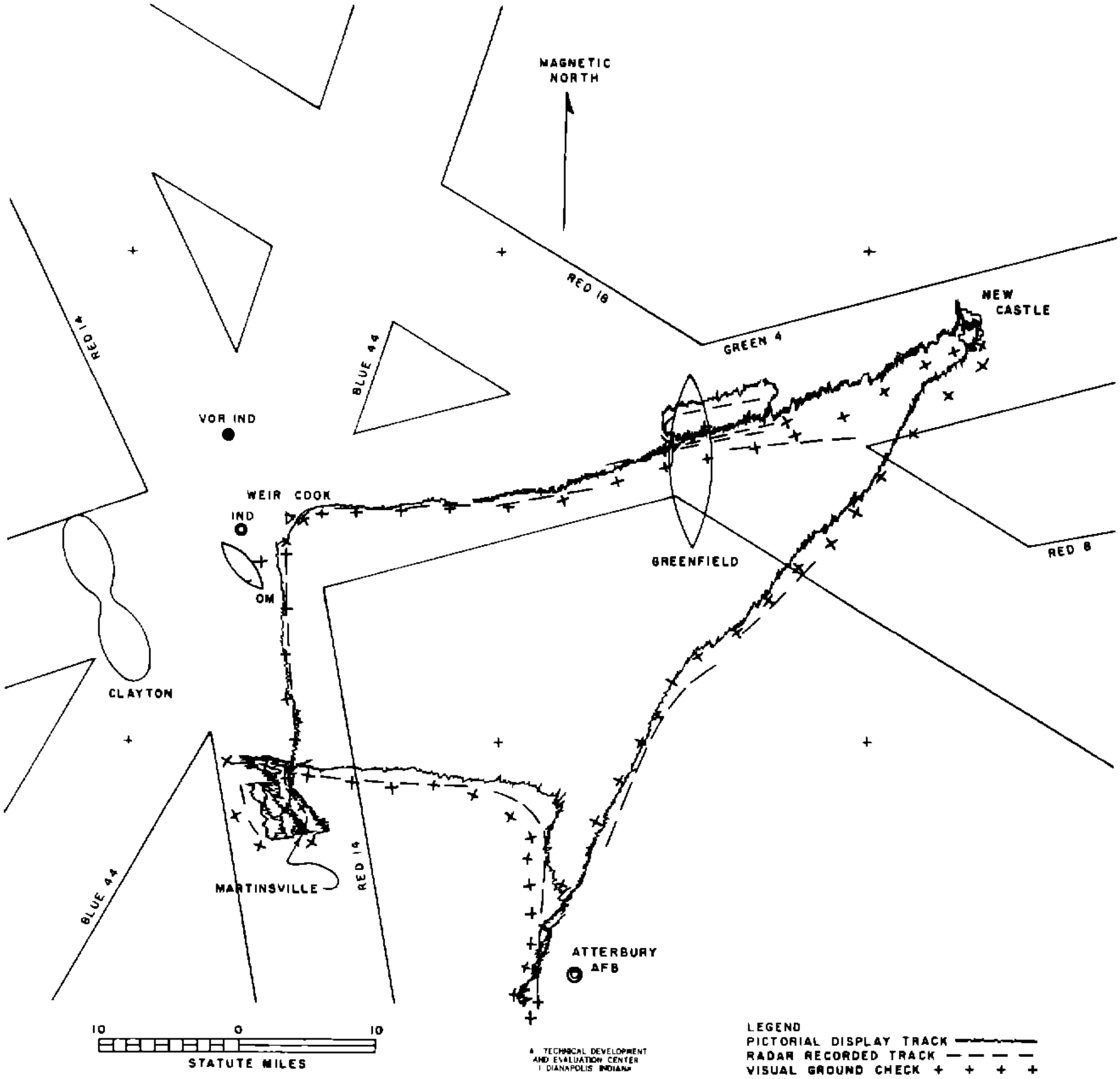


Fig 23 Flight Test No 5, Part II, Atterbury Approach

order to correct this condition or to be sure of the cause, the OBS must be changed or the course-deviation indicator must be checked for maximum deflection A pilot familiar with this indication should not be handicapped but instead should be aided, because proper interpretation offers valuable information as to communications which may be expected This same condition, however, might be a nuisance and misleading to some pilots

The process of chart preparation is difficult and time-consuming Gas generated by the adhesive forms blisters, which in turn cause wrinkles on the charts These rough surfaces are sometimes large enough to catch the stylus and to impair its movement A method of reducing or eliminating these undesirable features should be adopted

It is realized that a larger number of flight tests to determine the operational characteristics is desirable in order to provide a larger amount of data usually required for a more

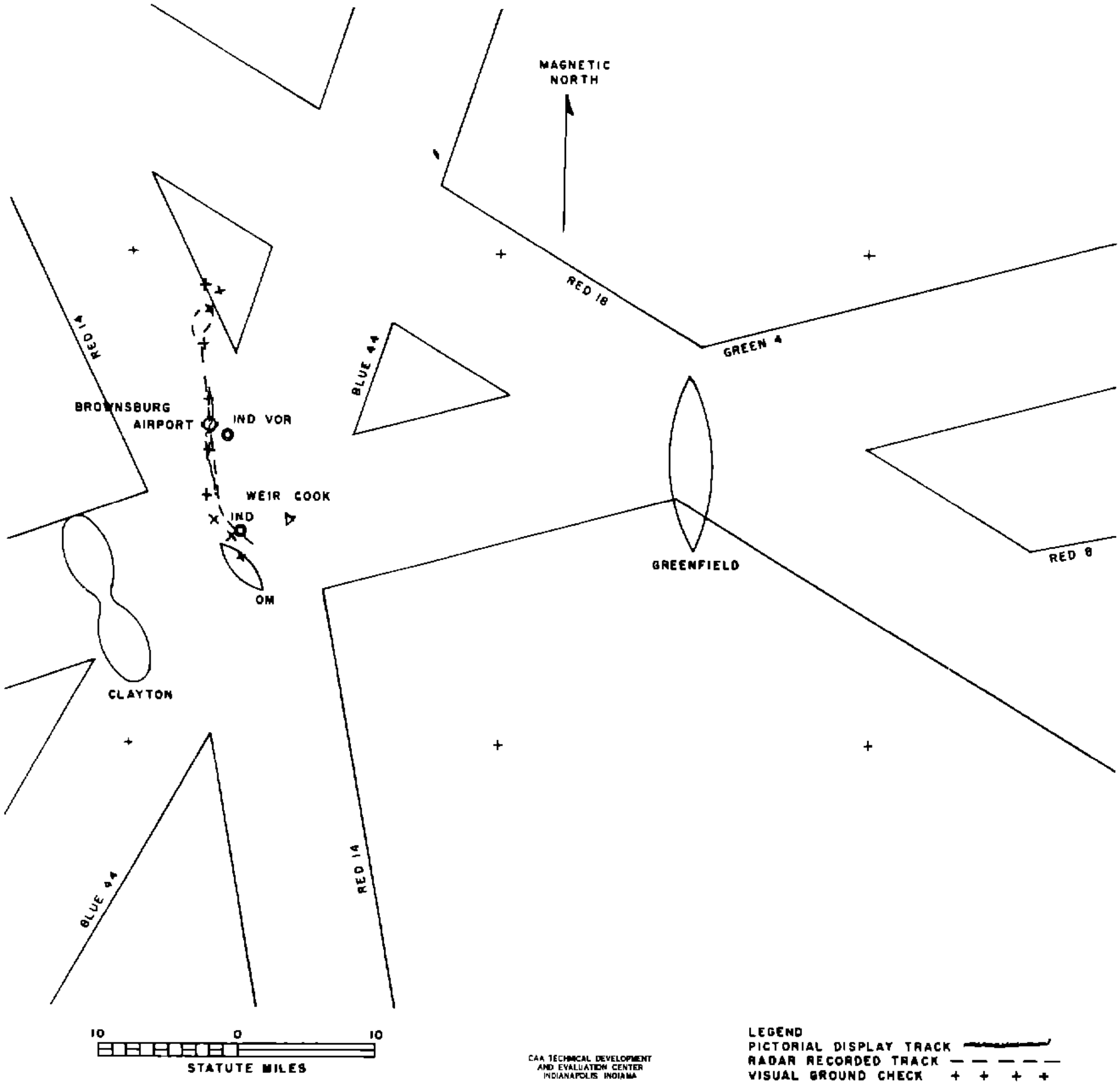


Fig 24 Flight Test No 5, Part III, First Brownsburg Approach

complete analysis However, it was necessary to terminate the project in September 1953 at the request of ANDB, before the additional testing could be accomplished

CONCLUSIONS

Regarding the equipment characteristics, the following conclusions were drawn from the technical evaluation.

1 The accuracy, with respect to bearing and distance, of the indications is adequate for present navigation requirements

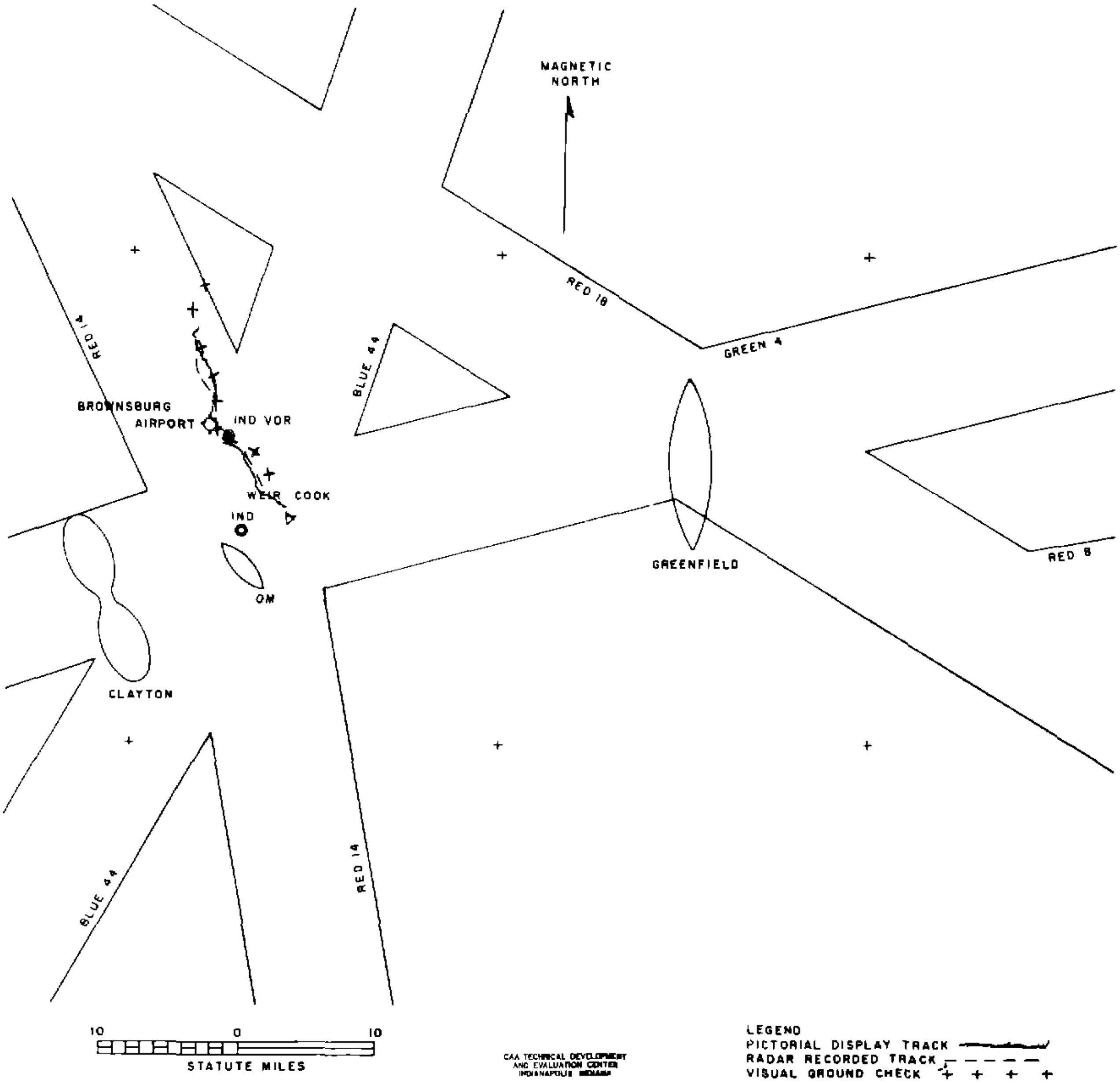


Fig 25 Flight Test No 5, Part III, Second Brownsburg Approach

2 Heading information is useful but is not sufficiently accurate to replace the directional gyro
3 An appreciable lag in the display of the aircraft position is noticeable in turns
4 The flag-alarm operation is not fail-safe
5 Damping of the position indicator is very satisfactory
6 Illumination of the chart is adequate, however, for night operation, the flag-alarm indicator should also be lighted
7 Chart preparation must be simplified
8 The method of recording the aircraft track made good is very effective, but it limits each chart to one-time usage

Although additional flight tests are believed desirable in order to obtain a more complete analysis of the operational usage of this device, the following conclusions can be made based upon the data obtained

1 In areas in which OBD-signal coverage is provided, flights using the Type IV Pictorial Computers were able to comply with current navigation and traffic control procedures based on L/MF and VHF facilities This demonstrated compatibility of the pictorial display with current, interim, and new traffic-control procedures should be one of its most valuable characteristics

2 With the exception of the ILS, the pictorial display provided accuracy comparable with that of presently used methods of navigation and afforded great advantage in ease of operation and in versatility

3 The continuous position information provided by the display permitted selection both of flight paths and of control points which cannot be used for routing and holding aircraft with present methods of navigation because of siting problems, frequency saturation, and costs involved in establishing multiple facilities

4 Pilots advised that the heading indicator definitely aided them in using the pictorial display

5 In these tests, the pilots did not find it necessary or advantageous to rotate the chart of the display unit

6 The trace provision of the display apparently aided the pilots in flying between points not preplotted on the charts and also served as a means of calling attention to gradual deviations between intended and actual flight paths Some of this apparent advantage of the trace feature may be attributable to the parallax introduced by the design of the aircraft-position indicator

7 No problems were encountered in the changing of charts during flight The process was completed in an average of five seconds, and no difficulty was observed in either the mechanical operation or in transition to a different scale

8 Virtually no mechanical trouble was encountered with the pictorial-display equipment At one time the stylus momentarily stuck and thus required minor adjustment, and at another time the display-door latch failed to catch

9 The central location of the pictorial display in the instrument panel facilitated viewing the flight-attitude and engine instruments However, this oblique view increases parallax and reading error

10 Complex terminal-area routings, which now require many communications and heavy personnel workload, were easily followed when navigation was accomplished with the pictorial display Improved control procedures should be possible for aircraft equipped with pictorial displays

RECOMMENDATIONS

1 Although illumination of the chart face is adequate, it would be desirable to obtain more even distribution The effect of a colored filter or of a source of light for night flight should also be tested

2 Chart presentation requires additional study Information on charts intended for use during instrument flight should more closely resemble radio-facilities charts The addition of contour lines might be valuable in some areas, and the use of various colors would certainly increase readability

3 The aircraft-position indicator, the heading indicator, and the stylus assembly should be redesigned or modified to reduce parallax and reading errors Improvement might be obtained by the use of a reticle and an optical system

4 A new method of preparing charts should be developed Attention should also be given to reducing the weight of charts

5 The available displays should be placed in actual operation to obtain additional results with regard to their operational suitability

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