THE TYPE V PICTORIAL COMPUTER WITH AUTOMATIC CHART SELECTION

PART II

TECHNICAL AND OPERATIONAL EVALUATION

By

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Technical Development Report No. 243

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 Departments 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 tests completed on the Type V pictorial display Laboratory tests revealed that errors occurring in the display do not exceed ± 0 6° in bearing or 0 53 nautical mile in distance Errors in aircraft-heading information were not greater than 1 5° Controlled flight tests conducted as a part of the technical evaluation showed a maximum display error in indicated position of the aircraft of 0 6 mile when a chart scaled to 1 250,000 was used

Operationally, this unit provided the pilot with continuous position and heading information in a simple pictorial form when the unit was used with appropriate omnirange-distance-measuring facilities Special features such as rapid chart selection from the front of the panel, automatic tuning of VOR/DME receivers, and automatic chart-scale selection made this unit very simple to use in flight Some difficulties were encountered in proper illumination of the display over the wide ranges of ambient lighting existing in aircraft cockpits

The project was terminated in September 1953, at the request of ANDB, because of the lack of funds required to complete the evaluation program As a result, the operational flight-test program was not completed

INTRODUCTION

The Type V pictorial computer[1] described herein is the third of a series of similar devices developed under Air Navigation Development Board project 13 1 The evaluation of this unit, like that of the two previous models, was conducted under ANDB project 6 2 5

Two models of this display, designated as Types V-A and V-B were developed by the Arma Corporation of Garden City, Long Island Since the only additional feature of the latter type was a second reticle providing mileage circles and a longer heading indicator which tended to obscure chart detail, all evaluation was conducted on the Type V-A display

In addition to the evaluation program at TDEC, it was felt desirable to request comments on features for pictorial displays for air navigation from the Aviation Psychology Laboratory, University of Illinois, a group which has conducted much study in this field Their comments are included as part of this report under the Appendix

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[1] In the original development work on this project, the term "pictorial computer" was used to identify the equipment The recent trend, however, is to replace this terminology with pictorial display because it more closely describes the function of the device

DESCRIPTION

The Type V pictorial computer shown in Fig 1 is a device for continuously displaying the position of an aircraft by utilizing a bearing input from a navigation receiver, a range input from distance-measuring equipment (DME), and a heading from a Gyrosyn or Fluxgate compass The equipment is made up of two basic parts a servoamplifier unit which may be mounted in the aircraft radio-equipment rack and a projection-type display unit which is usually installed on the instrument panel This display unit differs from others evaluated under this project in that an optical system is used to project charts, printed on 35-mm film, onto a 10-inch-diameter screen A slewing handle on the front panel of the display permits selection of any one of 750 charts contained on a 100-foot roll of film Tuning of the very-high-frequency-omnirange (VOR) and DME receivers and chart-scale selection are automatically achieved by a film-coding system A complete description of the development of this computer is provided in an earlier report [2]

TECHNICAL-EVALUATION TESTS

Laboratory Tests

To determine the bearing accuracy of the Type V display, the laboratory standard Autosyn described in another report[3] was first set to 0° and the computer was adjusted to

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	0 4	+0 4	0 7	+0 7
30	30 5	+0 5	30 7	+0 7
60	60 5	+0 5	60 6	+0 6
90	90 0	0 0	90 1	+0 1
120	119 7	-0 3	120 1	+0 1
150	149 4	-0 6	149 6	-0 4
180	179 5	-0 5	179 6	-0 4
210	209 6	-0 4	209 8	-0 2
240	239 6	-0 4	239 7	-0 3
270	269 4	-0 6	269 4	-0 6
300	299 5	-0 5	299 6	-0 4
330	330 0	0 0	330 3	+0 3

[2] Logan E Setzer, "The Type V Pictorial Computer with Automatic Chart Selection, Part I, Development and Initial Tests," CAA Technical Development Report No 199, June 1954

[3] Edward M Blount, Hugh A Kay, Raymond E McCormick, Fred S McKnight, and Marvin H Yost, "The Type III Rotatable-Panel Pictorial Computer, Part II, Technical and Operational Evaluation," CAA Technical Development Report No 209, June 1954

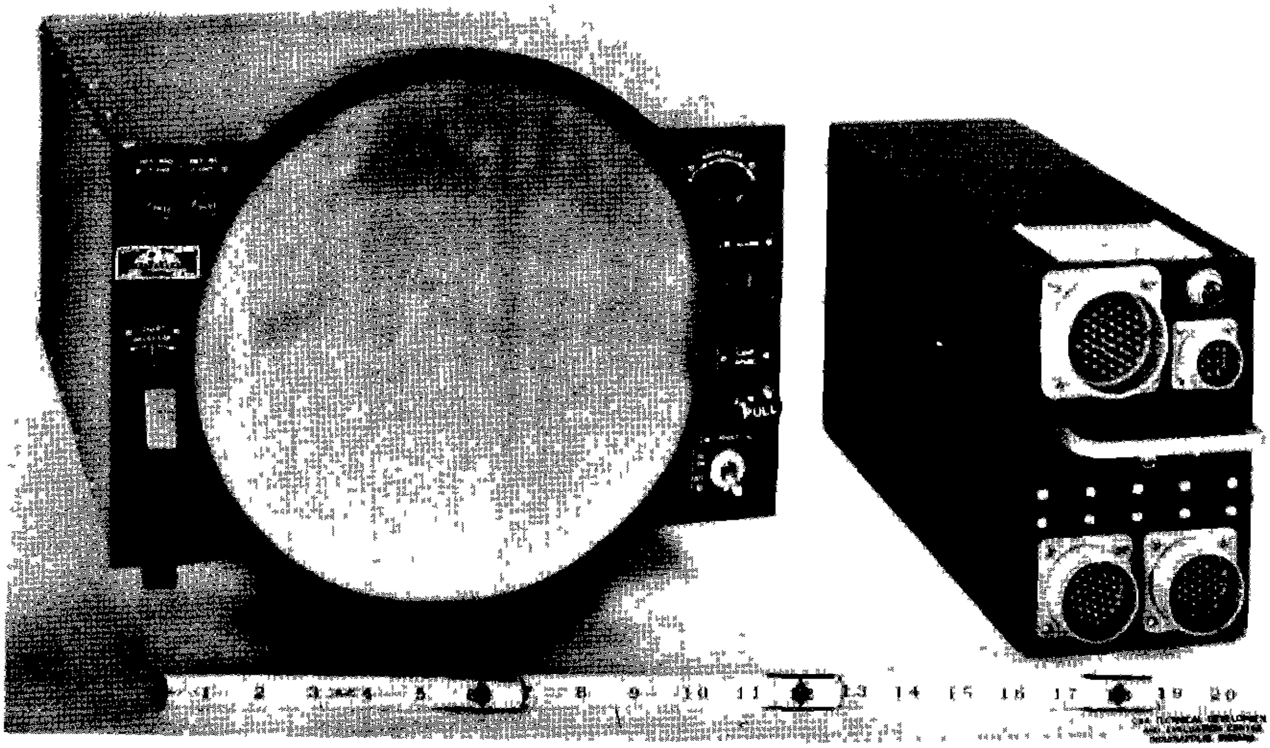

Fig I Model V Pictorial Display

the same reading Then the standard was advanced in 30° increments throughout 360° of rotation in a clockwise direction, and display indications were recorded All tests were later repeated with counterclockwise rotation in order to study the extent of the 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 5° to-0 6° for clockwise rotation and + 0 7° to-0 6° for counter-clockwise operation The largest error encountered in any one test was ± 1 0° Table I shows the average results obtained in these tests

Distance accuracy was examined at two-mile intervals on the 1 250,000 chart and at proportionately larger intervals on the charts scaled to 1 500,000, 1 1,000,000, and 1 2,000,000 To conduct these tests, distance information, in the form of resistance values proportional to nautical miles, was fed to the computer from a calibrated precision potentiometer Readings were obtained for flights both inbound and outbound to the station in order to determine the absolute magnitude of error produced in distance indications The largest of the average errors was 0 61 mile in distance indication This was observed on the chart scaled to 1 2,000,000 Errors found in the 17-, 34-, and 68 5-mile scales were 0 16, 0 26, and 0 58 mile, respectively Table II shows the average results obtained in a series of range-accuracy tests when a chart with a radius of 17 nautical miles was used Tables III, IV, and V display the results of similar tests at other ranges

By the use of the same voltage across the repeat-back potentiometer on all scales while the voltage across the DME potentiometer was varied inversely with the range scale, uniform sensitivity was obtained on all ranges

The heading accuracy of this display was examined at 30° increments throughout 360° of rotation, both clockwise and counterclockwise A precisely calibrated differential Autosyn was used to simulate heading information normally supplied by a Gyrosyn- or Fluxgate-controlled servotransformer

Tests showed a higher degree of accuracy in the heading indications of this unit than in other displays examined The greatest average error observed was 1 5° Table VI shows the average results obtained in a series of tests

TABLE II

DISTANCE ACCURACY TESTS

Chart Radius 17 miles, Chart Scale 1 250,000

Distance (nm)	Outbound		Inbound	
	Average Computer Indication (nm)	Error (nm)	Average Computer Indication (nm)	Error (nm)
0	- 0 11	-0 11	+ 0.11	+0.11
2	1.95	-0 05	2 11	+0 11
4	3 89	-0 11	4 0	0 0
6	5.89	-0 11	6 05	+0 05
8	7 84	-0 16	8.0	0 0
10	9.89	-0 11	10.05	+0.05
12	11.89	-0.11	12.05	+0.05
14	13.95	-0 05	14 05	+0 05

TABLE III

DISTANCE ACCURACY TESTS

Chart Radius 34 miles, Chart Scale 1 500,000

Distance (nm)	Outbound		Inbound	
	Average Computer Indication (nm)	Error (nm)	Average Computer Indication (nm)	Error (nm)
0	- 0.11	-0.11	+ 0.11	+0 11
5	4.78	-0.22	5 26	+0 26
10	9.95	-0 05	10 16	+0.16
15	14.95	-0 05	15 25	+0 25
20	19.95	-0 05	20 11	+0 11
25	24.84	-0.16	25.16	+0.16

TABLE IV

DISTANCE ACCURACY TESTS

Chart Radius 68.5 miles, Chart Scale 1 1,000,000

Distance (nm)	Outbound		Inbound	
	Average Computer Indication (nm)	Error (nm)	Average Computer Indication (nm)	Error (nm)
0	- 0 25	-0 25	+ 0.25	+0 25
10	9.42	-0.58	10.05	+0 05
20	19.71	-0.29	20 26	+0 26
30	29.50	-0.50	30.16	+0.16
40	39.71	-0.29	40.18	+0 18
50	49.63	-0.37	50.42	+0 42

The change in distance required to produce a perceptible change in display distance indication was measured with the same DME-type precision potentiometer mentioned previously. The tests were conducted by setting the potentiometer at some predetermined

TABLE V

DISTANCE ACCURACY TESTS

Chart Radius 137 miles, Chart Scale 1 2,000,000

Distance (nm)	Outbound		Inbound	
	Average Computer Indication (nm)	Error (nm)	Average Computer Indication (nm)	Error (nm)
0	- 0 48	-0 48	- 0.48	+0.48
20	19.47	-0.53	20 61	+0.61
40	39.57	-0 43	40.53	+0 53
60	59.57	-0.43	60 53	+0.53
80	79 52	-0 48	80.37	+0 37
100	99 47	-0 53	100.53	+0 53

TABLE VI

HEADING ACCURACY TESTS

Actual Heading (degrees)	Clockwise		Counterclockwise	
	Display Heading Indications (degrees)	Error (degrees)	Display Heading Indications (degrees)	Error (degrees)
0	0 0	0 0	0.0	0 0
30	29 5	-0 5	30 0	0.0
60	60 0	0.0	60 0	0.0
90	89.0	-1 0	89.5	-0.5
120	119.5	-0 5	120.0	0.0
150	149.0	-1.0	150 0	0.0
180	180 0	0.0	180 5	+0.5
210	209.0	-1.0	210 0	0 0
240	240.5	+0.5	240 0	0 0
270	268.5	-1 5	269 0	-1 0
300	300 0	0 0	300.0	0 0
330	329.0	-1.0	330	0 0

value of resistance, permitting the position indicator to come to rest, and then adding additional resistance to cause the least perceptible change in indication. This simulates distance changes through continuation in one direction along a radial.

The tests were repeated in order to examine the operation of the display under such conditions, in which the distance is first increasing and then decreasing, as would be encountered in the flying of a holding pattern Similar techniques were employed with the exception that 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 VII shows the results of these tests with resistance values converted to their proportional distances in nautical miles

A study of the flag-alarm system of the display was made by blocking of the indicator drive mechanism and insertion of bearing and range information of various values until the errors became of sufficient magnitudes to cause flag operation. In both clockwise and counterclockwise directions, the flag alarm was actuated when the bearing input and the aircraft-position indications differed by 4.5° In distance operation either inbound or outbound from a station, the errors shown in Table VIII resulted in actuation of the flag circuits

The system monitors the bearing and distance inputs satisfactorily and thus warns the operator if either signal is lost or if display indications differ from the inputs by the amounts shown A warning is also given if either the 28-volt d-c or the 115-volt, 400-cps power supply fails Bearing, distance, or heading functions may be rendered inoperative by tube or other component failure without actuating the flag alarm

TABLE VII

CHANGES IN DISTANCE REQUIRED FOR LEAST PERCEPTIBLE CHANGE IN COMPUTER INDICATIONS

Chart Radius (nm)	One Direction	Reversed Directions (nm)
137	Negligible	1.3
68.5	Negligible	0.79
34	Negligible	0.5
17	Negligible	0.22

TABLE VIII

DISTANCE ERROR FOR FLAG OPERATION

Chart Radius (nm)	Error (nm)
137	12
68.5	6
34	3.2
17	1.5

To determine the damping characteristics of the position indicator with respect to changes in bearing, distance, and heading, the amplitudes of successive oscillations of error voltage were measured at the grids of the first stage of each of the servoamplifiers To record the data, a Polaroid-Land camera was used to photograph oscillograms on a Model 512 Tektronix oscilloscope. Measurements of amplitude and time were made from the photographs. To substantiate this evidence, the amplitudes of oscillations of the position indicator were observed later and good correlation was found to exist Table IX shows the damping factor of the position indicator of the Type V computer for rapid changes in bearing, distance, and heading. The damping factor represents the rate of decay of oscillations and is found by dividing the Naperian logarithm of the ratios of two successive amplitude maxima by the time interval.

TABLE IX

DAMPING FACTORS OF POSITION INDICATOR

Bearing	3.05
Distance	2.14
Heading	1.12

The phase-shift networks incorporated in the servoamplifier circuits and the viscous damping employed in the display unit produce some damping of the position indicator, but these measures are not adequate. Furthermore, adjustments are not provided to obtain the necessary range for optimum damping. In previous tests on the Type IV display, it was determined that a damping factor between 3.6 and 3 8 was a satisfactory value for most operations

It was determined with a General Electric Type DW-68 light-intensity meter that illumination of the screen was not uniform Table X shows the illumination of various portions of the screen when a 150-watt projection lamp was used in the display. A blank chart was used in these tests to avoid differences in illumination through shaded areas.

The life of the projection lamp is appreciably shortened by the horizontal mounting position selected for this display. A representative of the Lamp Division of the General

TABLE X

UNIFORMITY OF SCREEN ILLUMINATION*

Bearing to Station (degrees)	Illumination (foot-candles)
0	4.00
90	4 90
180	2.75
270	3.75
Center of Screen	7.00

*With the exception of the reading at the center of the screen, all measurements were made around the periphery of the display at the greatest usable distance from the station.

Electric Company predicted less than half of the rated life for lamps mounted other than base down.

Power requirements for the equipment are 2.75 amperes at 115 volts, 400 cps, and 0.95 amperes at 26 volts d-c when a 200-watt projection lamp is used.

Some displacement of charts on the screen was observed Errors in bearing and in range of as much as 0.7° and 0.75 nautical mile, respectively, were noted

The size and the shape of the aircraft-position indicator were such that chart detail was obscured. The relative length of the indicator is 50 miles when a chart with a radius of 137 miles is used.

The changing of the chart film is an involved process requiring at least 30 minutes in the laboratory. If the equipment is mounted in an aircraft, the procedure is further complicated by the necessity of removing the display from the instrument panel.

Flight Tests.

Tests to determine the accuracy of the pictorial display under actual flight conditions were conducted in aircraft N-182, a Douglas DC-3. Flights were made three times clockwise and three times counterclockwise around the same course used in the investigation of the Types III and IV displays. Since there were no provisions for recording aircraft-track-made-good in this display, the unit was removed from the instrument panel and was placed in a supporting rack in a darkened cabin where 35-mm photographs of the screen were taken over each check point. See Fig 2. The 180 negatives obtained in this manner were later projected individually in a Model C Kodagraph Film Reader, and measurements of the bearing and the distance of the aircraft position to the VOR station were recorded for each check point Because the project was planned to evaluate only the pictorial display rather than the omnibearing-distance (OBD) system, errors are expressed as deviations of display indications from those of the omnibearing indicator and of the distance meter Maximum errors found in an average of the six trials were 3° in bearing and 0 3 mile in distance These errors resulted in a maximum displacement of 0 6 mile from the proposed course Table XI shows the average indications obtained in the several flights, and Fig 3 shows the proposed course, the course which the OBD instruments provided, and the course indicated by the pictorial display

OPERATIONAL COMMENTS

The relative merits and operational advantages of pictorial displays in general have been thoroughly discussed in previous reports.[4,5,6,7]

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[4] Setzer, op. cit.

[5] Blount, et. al., op. cit.

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

[7] RTCA Special Committee 54 Reports

TABLE XI

TECHNICAL FLIGHT TESTS OF THE TYPE V DISPLAY

Check-Point Number	Measured Values		Average Pictorial-Display Indication		Average OBD-Instrument Indication		Pictorial-Display 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	289	5.1	289	5 0	0	+0 1
2	293	2 4	296	2.4	296	2.4	0	0 0
3	329	0.5	338	0.5	336	0.7	+2	+0.2
4	92	1.6	91	1.1	90	1.6	+1	-0 4
5	97.5	2.6	97	2.6	97	2 8	0	-0 2
6	100	4.3	99	4.2	100	4 4	-1	-0 2
7	101	5.1	101	5 2	101	5.4	0	-0 2
8	101.5	6.5	101	6.4	102	6 6	-1	-0.2
9	102	7.8	103	7 8	102	8 0	+1	-0.2
10	102	9.2	104	9.1	103	9.2	+1	-0.1
11	110	9.5	111	9.7	110	9.7	+1	0.0
12	119	10.25	118	10.4	119	10.3	-1	+0.1
13	122	10.5	122	10.7	122	10.7	0	0 0
14	127.5	11.5	128	11.5	129	11.5	-1	0.0
15	133	12.5	134	12.6	135	12.6	-1	0 0
16	138	13.5	140	13.9	140	13.6	0	+0.3
17	144	12 3	145	12.6	147	12 3	-2	+0.3
18	154	11.2	155	11 1	156	11.2	-1	-0 2
19	163.5	10.5	167	10.6	165	10.6	+2	0.0
20	171	10.2	173	10.3	173	10.2	0	+0.2
21	185	10.2	185	10.3	185	10.2	0	+0.1
22	196	10.5	194	10.6	196	10.6	-2	0.0
23	206	11.5	203	11.4	206	11.4	-3	0.0
24	212	10.6	212	10.6	212	10.6	0	0 0
25	218	9.7	218	10.0	218	9.8	0	+0.2
26	229	9.0	230	9.1	229	8.9	+1	+0.2
27	239.5	8.5	241	8.6	239	8.5	+3	+0.2
28	248	8.4	248	8.5	250	8.4	-2	+0.1
29	257	8.5	257	8.6	257	8.5	0	+0.1
30	261	8.5	262	8.6	262	8.6	0	0.0

*Bearing error is the difference, in degrees, between OBD and pictorial-display indications. Distance error is the difference, in miles, between OBD and pictorial-display indications.

The Type V display shares these general advantages and in addition has certain features which make it even more desirable for operational use. Because of budget limitations, the operational-flight-test program could not be completed. However, one Type V display has been installed in a Douglas DC-3 aircraft at the CAA Technical Development and Evaluation Center since July 1952. Since its installation, this display unit has been used on many flights for en route navigation, transition to final approach, and other special flight situations imposed during technical tests of various equipment. The following comments are based on observations by TDEC pilots who have used the Type V and previous models of pictorial displays.

The outstanding and most frequently mentioned feature of the Type V pictorial display is its simplicity of operation Possible sources of error due to incorrect tuning or improper scale selection are eliminated. The speed with which these operations are accomplished is also important, because under certain conditions the pilot may be extremely busy and unable to afford extra time to perform these tasks manually.

The most frequent complaint of the pilots concerned the lighting of the display. If direct or reflected sunlight struck the glass face of the display, the projected map and the aircraft-position indicator could not be seen. For example, reflections from a white shirt or from

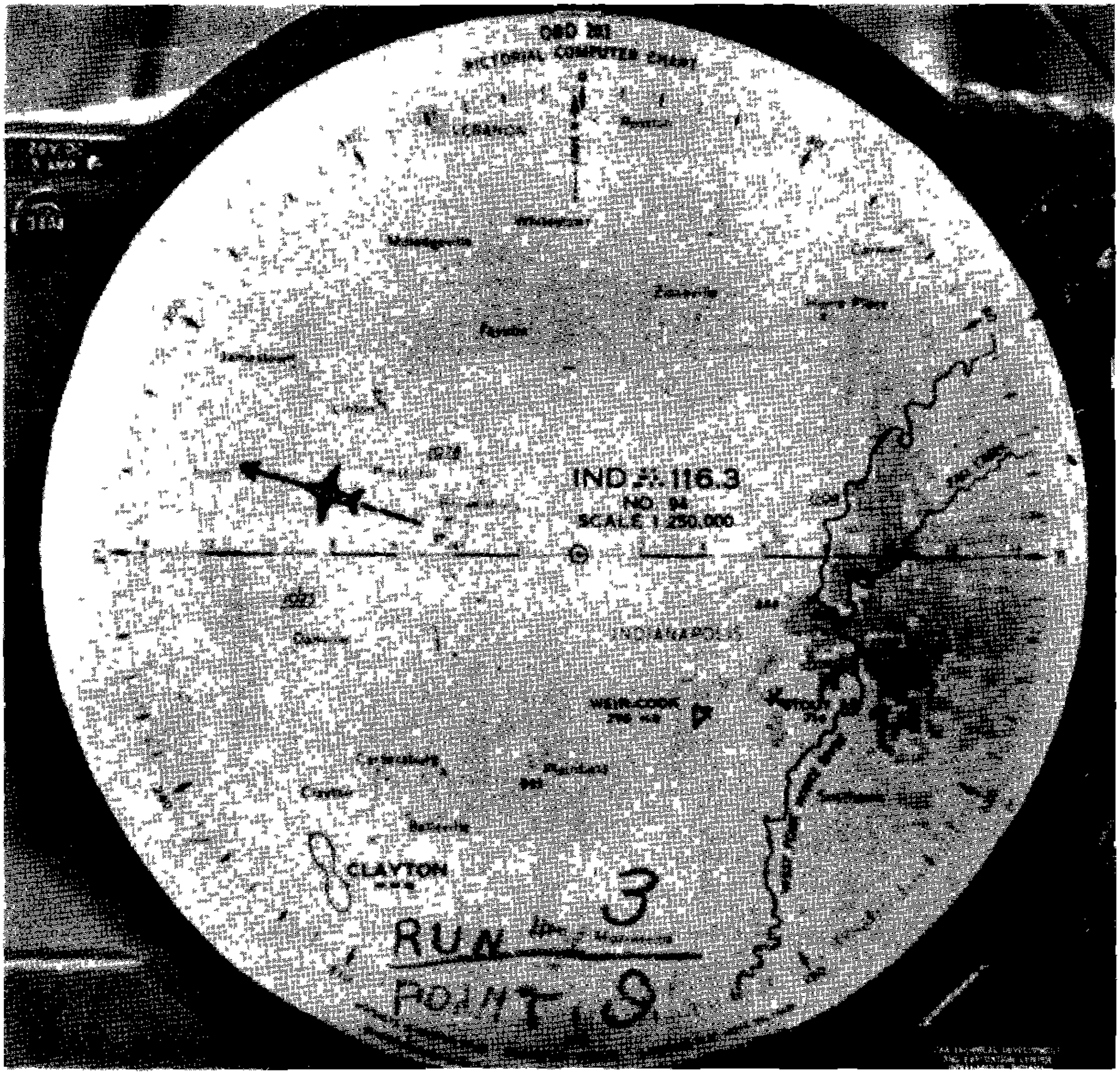

Fig. 2 Type V Display Screens With Equipment in Operation

light-colored clothing would make the display unreadable at times by one or both pilots in the cockpit Light shields or baffles might eliminate much of this difficulty. At night, the display was too bright and could not be dimmed sufficiently even though the unit is equipped with a variable-light-intensity control. A continuously variable light source with a much wider range of intensity is required.

An advantage of the projection system used in the Type V display was the elimination of possible reading errors due to parallax. In the Type IV display, the aircraft heading arrow at the end of the aircraft-position-indicator actuating arm was displaced from the surface of the chart about 1/4 inch. When viewed from an angle, as for example when the display was mounted in the center of the aircraft panel for use by both pilot and copilot, a large reading error could be introduced. If, for example, the pictorial display is viewed from an angle of 45°, the reading error due to parallax is equal to the displacement of the aircraft-position

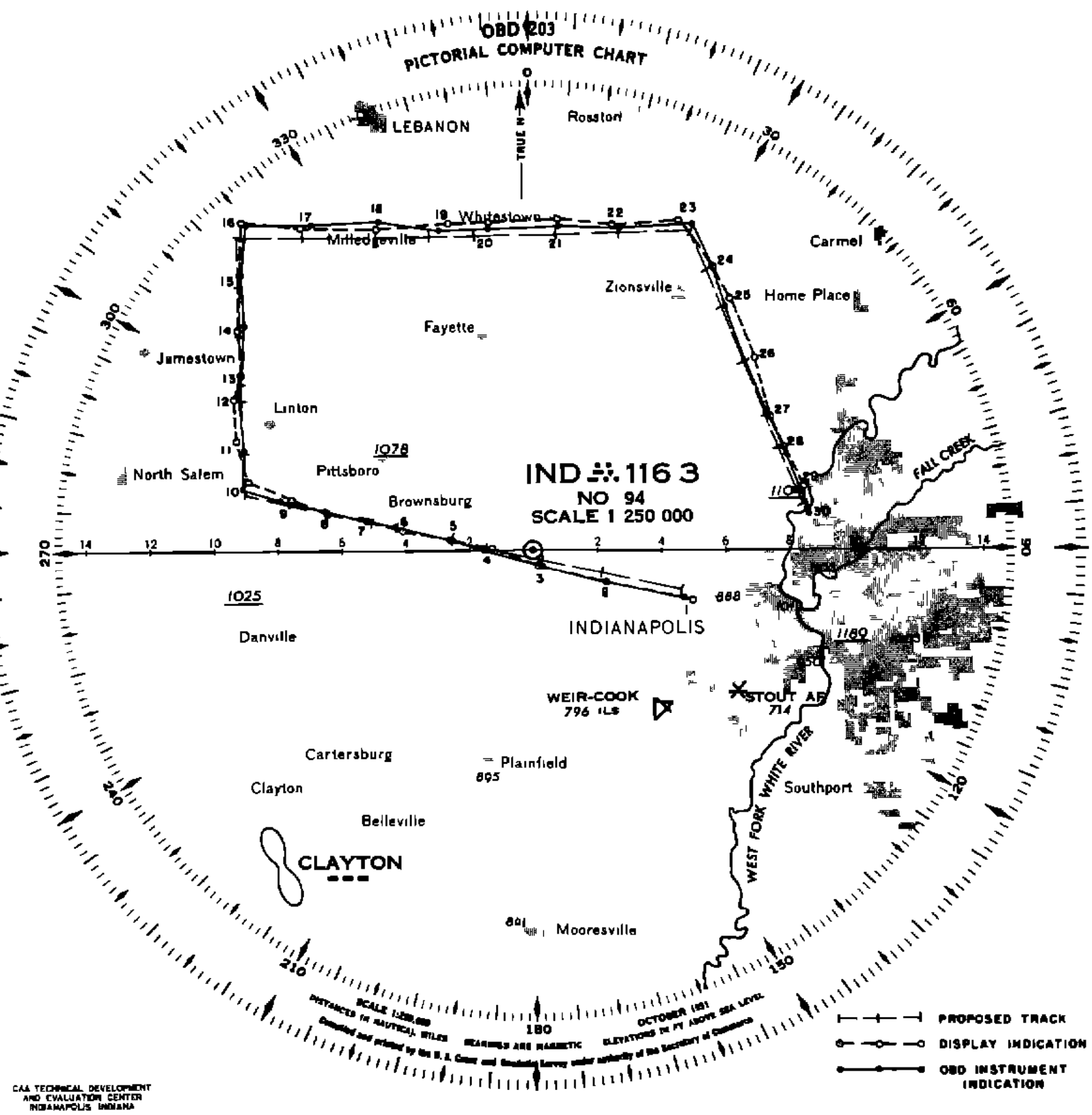

Fig. 3 Technical Flight Tests of the Type V Display

indicator from the chart surface. A displacement of 1/4 inch with a chart scale of 1 1,000,000 is equivalent to four miles. The projection system used in the Type V display effectively eliminates any reading error due to parallax.

This improvement in reduction of reading errors by means of a projection system is realized only when the projected image of the aircraft-position indicator is of suitable form and design. On the Type V display, a rather solid airplane silhouette is used with a long arrow to indicate heading. See Fig. 2. A small opening in the center of the airplane indicates the actual position of the aircraft. This small hole in the reticle tends to become clogged from dust and from particles of film emulsion. The heavy outline of the aircraft tends to obscure other chart detail. It is believed that cross hairs only, with a suitable extension or arrow on one leg to indicate heading of the aircraft, would be more satisfactory. The position-indicator image should be prominent enough to be picked up at a glance and yet should not be so large or massive that it obscures desired chart detail.

The need for the pictorial display to show exact heading on a compass rose was considered relatively unimportant by TDEC pilots because the display was not used as a primary flight-attitude instrument.

From the pilot's standpoint, storage and selection of charts left little to be desired. With the Type V display, however, it is necessary either to remove the entire unit from the instrument panel or to secure access to the back side of the unit through the nose section of the aircraft in order to change chart film rolls or projection lamps.

Pilots suggested that a horizontal mounting of the display would more nearly represent true spatial relationships. In addition, a preference was expressed for a mounting which would permit the moving of the display out of the way when necessary. This latter suggestion would eliminate the problem of mounting such a display in the already overcrowded instrument panels of most aircraft. In addition, the display unit could be moved out of the way when not needed such as during taxiing, warm-up, extended ground operation, or take-off and landing.

Recommended features for a "Type Deluxe" pictorial display, as developed by Payne and Williams of the University of Illinois, are given in the Appendix.

CONCLUSIONS

In regard to the equipment characteristics, it is concluded that

1. Accuracy of bearing indication is adequate for present flight conditions, although maximum errors in bearing in this display are somewhat greater than those in the Types III and IV displays.
2. Accuracy of distance indication is very similar in the three types of display tested. The Type V shows a little less error on the 120-mile range.
3. This display is much more accurate in heading indications than the Type IV was. The Type III computer did not include provisions for displaying aircraft heading.
4. On charts scaled to 1 250,000, this display requires less change in distance before the position indicator shows a change. This improves the accuracy with which holding patterns and similar maneuvers in terminal areas may be flown.
5. The flag-alarm circuits of all three computers tested were uniformly poor. Although they successfully monitor the d-c and a-c power supplies, certain error limits, and the input signals from DME and VOR, they do not monitor malfunctioning of the display unit itself.
6. Damping characteristics of this computer are not as good as those of the other types examined.
7. The automatic scale-selection and tuning feature is very desirable.
8. The changing of the chart films requires too much time
9. In flight, this equipment provides the pilot with an extremely flexible means of navigation by which he may comply with present and proposed traffic-control instructions based on L/MF or VOR navigation systems.
10. Because of its automatic functions, the Type V is the most easily operated and the least susceptible to pilot error of the displays tested.

APPENDIX

RECOMMENDED FEATURES FOR PICTORIAL-COMPUTER DISPLAYS FOR AIR NAVIGATION

by
T. A. Payne and A. C. Williams, Jr.
University of Illinois

Table XI shows the characteristics of three existing types of pictorial-computer displays for air navigation. A fourth type, "Type Deluxe," is listed incorporating the features that will be recommended by this paper. The following paragraphs will consider each feature of the "Type Deluxe," the corresponding features of the other three displays being discussed at the same time when applicable.

Azimuth Stabilized.

By "azimuth stabilized" it is meant that the map of the display is fixed, the figure representing the pilot's aircraft moving over it. Much research has been directed at the question of which should move, the map or the aircraft figure, on this kind of display In each case it was found that a fixed map and a movable aircraft figure provided the better performances. Williams and Roscoe,[8] in studying a number of instrument displays to be used with omnirange equipment, found that the fixed-map, aircraft-movement principle was superior to the movable-map, fixed-aircraft principle. Their subjects were presented with drawings of the displays together with navigation problems. They solved the problems with fewer errors when they were using drawings of a display making use of the fixed-map, aircraft-movement principle than when they were using any of the other display drawings

Another study by Roscoe, et al.,[9] did not make a comparison between the aircraft-movement and the map-movement principles but did show a high character of performance when the aircraft-movement display was being used.

In this case a 1-CA-1 Link trainer, equipped with an aircraft-movement pictorial display and with conventional omnirange instrumentation, was used. Not only were performances far superior when the aircraft-movement pictorial display was being used, but the absolute character of the performances using the pictorial were highly acceptable.

Payne[10] further investigated this problem of the moving part. Subjects used drawings of the pictorial display making use of the aircraft-movement principle and of the pictorial display making use of the map-movement (in this case station-movement) principle. Presented with a drawing and a navigation problem, they were able to solve more problems more rapidly

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[8] A. C. Williams, Jr., and S. N. Roscoe, "Evaluation of Aircraft Instrument Displays for Use With the Omni-Directional Radio Range," CAA Division of Research, Report No. 84, March 1949.

[9] S. N. Roscoe, J. P. Smith, B. E. Johnson, P. E. Dittman, and A. C. Williams, Jr., "Comparative Evaluation of Pictorial and Symbolic VOR Navigation Displays in the 1-CA-1 Link Trainer," CAA Division of Research, Report No. 91, July 1950.

[10] T. A. Payne, "A Study of the Moving Figure and Orientation of Symbols on Pictorial Aircraft Instrument Displays for Navigation," U. S. Navy, Special Devices Center, Technical Report SDC 71-16-6, July 1950

when they were using the drawing of the aircraft-movement pictorial. It took over seven times as long to work the station-movement problems, with only one-fifth of them correct, as it took to work the aircraft-movement problems, with four-fifths of them correct.

Another study by Payne[11] supported the superiority of the aircraft-movement pictorial display. Pilots holding instrument-flight ratings solved navigation problems using functional models of an aircraft-movement pictorial and of a map-movement pictorial. Using the aircraft-movement pictorial, the pilots initiated solutions more rapidly, made fewer control reversals, made fewer first turns in the incorrect direction, made fewer manipulations of the control switch, and attended to a secondary task more efficiently than when they used the map-movement pictorial

It would appear that a "population stereotype" is involved in this moving-part question. The moving of the aircraft symbol over a fixed map "mocks-up" the real situation that the pilots knows is occurring. It may be that a reversal of this condition, when displayed on an instrument, causes difficulty because the "wrong" thing moves

Heading.

The recommendation in this case is that the heading of the real aircraft be shown on the aircraft symbol of the pictorial-computer display. In the Payne study[12] it was demonstrated that when heading information was given on the aircraft symbol attempts at problem solutions were initiated more rapidly and more problems were solved than when heading information was not given on the aircraft symbol. There was some indication that fewer first turns were made in the incorrect direction when the aircraft symbol showed heading. In fact the superiority of the aircraft-movement pictorial, in terms of how rapidly the subjects initiated solutions, was dependent almost entirely upon the showing of heading on its aircraft symbol.

A form of heading was shown on the aircraft symbols used in the earlier experiments.[13,14] The drawings showed the aircraft symbol as an arrow approximately 1/2 inch long. The functional model of the pictorial display used in the 1-CA-1 Link trainer showed a form of heading in that the pip representing the aircraft left a luminous trace about 1/2 inch in length. Although this trace showed track-made-good rather than actual heading, it was not difficult to use it as heading information.

When heading information is presented on the aircraft symbol, the pilot is relieved of one subtask. By this it is meant that were heading not given on the aircraft symbol it could be "placed" there by the pilot by means of his observing the direction of movement of the aircraft symbol or by noting his compass or by both. Both of the latter alternatives are time-consuming

In the case of a large map with a small scale, observation of movement of the aircraft symbol would become a difficult task because the absolute rate of movement of the aircraft symbol would be very slow. If the pilot has to obtain heading information from the compass, he must translate it from numbers to something like an arrow on the aircraft symbol. This is not as simple as it might seem to be, especially when the entire display is rotated manually away from north-at-the-top orientation. This manual rotation will be discussed later.

Another advantage to showing heading on the aircraft symbol presents itself. During much of the navigation task the presentation of heading in numbers is not necessary when a pictorial-computer display is being used With the pictorial, the task becomes not one of "flying on a course of 130° (say)" but of flying from "here" to "there," the "heres" and "theres" being marked on the map. An alternative to this, when the pictorial is used, is the simpler task of making good a track drawn in on the map of the display. This will be mentioned under the section Desired Ground Track Shown.

In the experiments cited previously, the aircraft was represented on the pictorials in the form of an arrow rather than an airplane silhouette Although either would probably do the job it was felt that an arrow would obscure less map detail and thus could be used more accurately than the larger airplane silhouette.

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[11] T. A. Payne, "A Study of the Moving Part, Heading Presentation, and Map Detail on Pictorial Air Navigation Displays," U S. Navy, Special Devices Center, Technical Report SDC 71-16-10, November 1952.

[12] Ibid.

[13] Ibid.

[14] Roscoe, et. al., op. cit.

TABLE XI PICTORIAL-COMPUTER DISPLAYS*			
Type IIIa	Type IV (Sperry)	Type V (Arma)	"Type Deluxe"
Azimuth stabilized	Azimuth stabilized	Azimuth stabilized	Azimuth stabilized
Heading (Possibly as spot of light)	Heading (Arrow on arm)	Heading (Aircraft shadow)	Heading
Roll map	Paper map	Projected map (Films)	Clear map
Rotatable	Rotatable	Fixed	Rotatable
Does not record	Records	Does not record	Not record?
Manual map selection by crank Scale selection by switch Independent tuning by hand	Manual map selection Manual scale selection switch Independent tuning by hand	Single operation Map selection, Scale selection, Tuning	Map scale and tuning like Type V, plus minimum search for map
Programmed paths	Discontinuity in turns Programmed paths	Proposed paths only, with grease pencil Turns may be OK	Desired ground track shown Course indicator for off-airways, printed airways, approach and departure paths
	Damping factor is electric and is good	Damping factor is bad	

*These data were compiled on February 18, 1953 at the Aviation Psychology Laboratory, University of Illinois Airport, at a conference with R. E. McCormick, A. C. Williams, Jr., and T. A. Payne.

Further consideration of the form of the aircraft symbol suggested that there might be an advantage to be gained from extending a straight line forward from the nose of the aircraft symbol. It was suggested that such a line might facilitate the estimation of the heading of the aircraft. It was suggested further that distance lines could be marked along such a line. This would give the pilot immediate information concerning his distance from any place on the map toward which he was heading. These two points will be considered in turn.

For the purpose of this report, a small experiment was conducted. Thirteen students at the University of Illinois were presented with drawings of the face of a pictorial-computer display. The compass rose was marked around the periphery of the drawn displays. On the face of the displays was shown an aircraft symbol, again represented as an arrow 1/2 inch long. Different rotations of the compass rose were used (north at the top or some other compass point at the top). In the six problems, the aircraft symbols were placed at different positions on the display and were given different headings. Three of the six problems showed the aircraft symbol (arrow) with a line extending straight forward from the nose of the symbol (arrow head) to the periphery of the display. The other three had no such line. The task was to judge the heading of the aircraft, in degrees. The results showed no advantage to using the line except when the aircraft symbol was given in the exact center of the display. In this case, the judgments were superior to those of any other condition. The finding should not be surprising, because the degrees shown on the periphery of the display are oriented only to the exact center.

This would seem, however, to show no advantage to extending such a line forward from the aircraft symbol. The occasions during which the aircraft symbol will be in the exact center of the display are few. In the second place, it has already been suggested that the pictorial computer would be used more often in flying indicated tracks than in flying headings in degrees. Third, the writers would not like to predict what the effects of making the moving aircraft symbol so unwieldy would be. Whether or not this would reduce the over-all performance level, when the pictorial computer is used, is not quite predictable. Perhaps strange illusions would be developed by the movement of the aircraft symbol with a line projecting forward from its nose. Fourth, in the event that the pilot using a pictorial were requested to fly a given heading in degrees, he could take up such a heading accurately by using his compass.

There is an alternative to a line extending from the aircraft symbol. The pilot could be provided with a track selector in the form of a thin black line. This track selector could be positioned manually in any position on the display so that it formed a track between the aircraft symbol and any destination shown on the display. The aircraft symbol could be flown over such a track A distance scale could be marked along the track selector, enabling the pilot to tell immediately the distance to any point shown on the display merely by positioning the track selector

Clear Map.

This recommendation is just what it appears to be. Any features desirable for a given situation could be indicated on the map of the pictorial. Desired ground track (to be mentioned later), together with areas to be avoided (with altitudes given), destinations, and other such variables, might be shown. The point is that the map be legible. This applied chiefly to the projected-map principle listed for Type V (Arma) computer. If the map is to be projected on the face of the pictorial display by means of films, one danger must be avoided. This is the possibility of the washing out of the projected map by light from outside the cockpit. A chance for this to occur would be when the pilot is flying on top of an overcast but nevertheless is using the pictorial computer to navigate. Perhaps adequate shielding for such a pictorial computer would prevent this difficulty.

Rotatable

It is desirable that the entire pictorial display be manually rotatable Using this feature, the pilot could rotate the display whenever necessary so that the aircraft symbol could be made to move on an up heading toward the top of the display Payne[15] found that there was a definite decrement in performances when the task was to fly a definite down heading toward the bottom of the display when the aircraft-movement pictorial display was being used The greater frequency of control reversal which was observed when the aircraft symbol was heading down over that observed when the symbol was heading up was significant Apparently this increase in control reversals occurred because of the right-left ambiguity that occurs when the aircraft symbol is heading toward the lower hemicircle of the display In this case, the instruction "to the right" in terms of the aircraft symbol means "to the left" from the standpoint of the pilot's orientation When however, the display can be rotated manually so that the aircraft symbol is heading up, "to the right" means "to the right" for both the aircraft symbol and the pilot The manual-rotation feature of the pictorial display should be valuable especially when the pilot is approaching a destination, at which time he would want to perform as accurately as possible The incorporation of a manually rotatable display with film-projected maps might prove to be difficult

Not Record?

Whether or not the track-made-good by the aircraft should be recorded automatically on the map of the display might depend upon the purpose for which it is being used. For training purposes, a case might be made for a permanent recording. For ordinary navigation uses, it would seem to be unnecessary.

Map Selection, Station-Tuning, Map Scale.

The important point here is that steps be taken to assure that the appropriate map is used when the computer is tuned to a given station. Not only this, the scale of movement of

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[15] T. A. Payne, Technical Report SDC 71-16-10.

the aircraft symbol should agree with the scale of the map being used. This might be accomplished in one of two ways.

If the entire operation is automatic, such as with push-button tuning performing the triple duties of map selection, station-tuning, and scale selection, the use of an incorrect map or of an incorrect scale with a given station would be precluded. In such an automatic system, it would not seem unreasonable to require that the selection of the desired map-station-scale system take a maximum of 5 seconds. (This assumes that the computer has been in operation and is warmed up.) If the pilot were getting close to his destination and desired to switch to a larger-scale map (with appropriate scale movement of the aircraft symbol), a greater time delay would be a marked disadvantage.

If map selection is manual, the equipment should be so engineered that only the correct scale and the correct station can be employed. A map-selection technique should be incorporated that allows a minimum search for the map to be used at any particular time.

Desired Ground Track Shown.

The ground track to be made good should be shown on the map of the computer. Payne[16] found that when at least a portion of the ground track to be made good was shown on the map his subjects initiated solutions more rapidly and solved more problems than when such a track was not shown. When the aircraft symbol shows the heading of the real aircraft and when the desired ground track is shown on the map, navigation problems are reduced to simple tracking problems.

Airways and approach and departure paths from terminals can be printed on the maps. The track selector, mentioned at the end of the section concerned with heading, could be used for off-airways flying. Using the aircraft symbol that shows heading and either the printed track or the track selector, the pilot could tell something about the direction and velocity of the wind. This should be about as useful as the observation of crab angle in VFR flying.

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[16] Ibid.