COMPARATIVE EVALUATION OF PICTORIAL AND SYMBOLIC VOR NAVIGATION DISPLAYS IN THE 1-CA-1 LINK TRAINER

by

S. N. Roscoe
J. F. Smith
B. E. Johnson
P. E. Dittman
A. C. Williams, Jr.

A report on research conducted at the University of Illinois, under the auspices of the National Research Council Committee on Aviation Psychology, with funds provided by the Civil Aeronautics Administration.

October 1950

CIVIL AERONAUTICS ADMINISTRATION
Division of Research
Report No. 92
Washington, D. C.

National Research Council

Committee on Aviation Psychology

Executive Subcommittee

M. S. Viteles, Chairman

N. L. Barr — F. A. Geldard

D. R. Brimhall — W. F. Grether

Glen Finch — W. E. Kellum

Eric F. Gardner — S. Smith Stevens

The studies described in this report represent investigations supported jointly by the Civil Aeronautics Administration and the United States Navy. The report has also been issued as Division of Aviation Medicine, Bureau of Medicine and Surgery, UNITED STATES NAVY, National Research Council Committee on Aviation Psychology Report No. 10.

National Research Council

1950

LETTER OF TRANSMITTAL

NATIONAL RESEARCH COUNCIL

2101 Constitution Avenue, Washington, D.C.
Division of Anthropology and Psychology

Committee on Aviation Psychology

October 31, 1950

Dr. Dean R. Brimhall
Civil Aeronautics Administration
Room 5217, Commerce Building
Washington 25, D. C.

Dear Dr. Brimhall:

The attached report, entitled "Comparative Evaluation of Pictorial and Symbolic VOR Navigation Displays in the 1-CA-1 Link Trainer," by S. N. Roscoe, J. F. Smith, B. E. Johnson, P. E. Dittman, and A. C. Williams, Jr., is submitted by the Committee on Aviation Psychology with the recommendation that it be included in the series of technical reports of the Division of Research, Civil Aeronautics Administration.

The studies described in this report, conducted under the direction of A. C. Williams, Jr., at the University of Illinois, and supported jointly by the Civil Aeronautics Administration and the U. S. Navy, confirm the conclusion embodied in an earlier report concerning the superiority of "pictorial" as contrasted with "symbolic" VOR aircraft instrument displays in facilitating the rapid and accurate solution of navigation problems. The experimental findings show clearly the practical contributions to maximizing the usefulness of omni-range equipment which can be achieved through continued research bearing upon the optimal presentation of navigation information.

Cordially yours,

MSV:maf

Morris S. Viteles, Chairman
Committee on Aviation Psychology
National Research Council

EDITORIAL FOREWORD

Experiments described in this report represent a continuation of research initiated under the auspices of the Committee on Aviation Psychology, originally at the request of the Civil Aeronautics Administration, to determine the type of displays which will yield optimal results in the use of omni-directional range instruments for navigation purposes. Each study has involved a comparison of "pictorial" displays, which furnish the information provided by VOR in the form of graphic presentation of the spatial relations involved, with "symbolic" displays, which provide information in terms of dial readings, needle deflections, and numbers.

The first of these experiments,[1] involving the use of static mock-ups, showed that "pictorial" displays were generally superior to "symbolic" displays in helping the pilot decide in which direction he must fly in order to solve a series of navigation problems. The later studies, described in this report, utilizing functional displays installed in a 1-CA-1 Link Trainer, confirmed the superiority of the "pictorial" presentation, inasmuch as the findings showed that both experienced instrument pilots and inexperienced private pilots solved navigation problems with greater speed and accuracy when information was presented graphically than when it was presented symbolically.

The conclusions drawn from this experiment are necessarily limited to the types of "pictorial" and "symbolic" VOR aircraft instrument displays used in the investigation. There still remains the possibility that better types of both kinds of display could be designed. Nevertheless, the implication is clear that "pictorial" displays have peculiar advantages in the way of providing necessary information in a manner which facilitates the speed and accuracy of reading and of interpretation of navigation information, apparently because they permit the solution of problems at the "perceptual" as contrasted with the "cognitive" level. Of additional significance is the indication that the possibility of confusion or set-back in new or emergency situations appears to be less likely in the case of "pictorial" displays.

The three experiments described in this report, conducted on the 1-CA-1 Link Trainer, were not designed to answer definitively the question as to whether differences in pilot performance attributable to differences in VOR displays apply to actual flight as well as to performance on a synthetic flight trainer. There also remain other problems which can appropriately be investigated through the further use of a synthetic flight

---

[1] Williams, A. C., Jr., and Roscoe, S. N. Evaluation of aircraft instrument displays for use with the omni-directional radio range. Washington, D.C.: CAA Division of Research, Report No. 84, March 1949. (For an abbreviated version of this report see: J. Appl. Psychol., 1950, 34, 123-130.)

trainer equipped with improved recording devices. Provisions have been made for the continuation of research in this important area, with funds made available to the Committee on Aviation Psychology by the Bureau of Aeronautics and the Division of Aviation Medicine, Bureau of Medicine and Surgery, U. S. Navy, under a contract with the Office of Naval Research.

October 31, 1950

Morris S. Viteles, Chairman
Committee on Aviation Psychology

CONTENTS

Page

EDITORIAL FOREWORD v

SUMMARY ix

PART I. INTRODUCTION 1

A Review of the First VOR Display Evaluation Study 1
The Evidence for the Superiority of the Pictorial Type of Display 2
An Evaluation of the Evidence 4

PART II. THE VALIDATION OF THE STATIC MOCKUP EVALUATION TECHNIQUE FOR SYMBOLIC TYPE DISPLAYS 5

Description of the Experiment 5
The Results of the Experiment 7
Discussion and Conclusions 10
Implications of this Study for the Validation of the Static Mockup Technique 11

PART III. COMPARATIVE EVALUATION OF PICTORIAL AND SYMBOLIC VOR NAVIGATION DISPLAYS AS USED BY INSTRUMENT PILOTS IN THE 1-CA-1 LINK TRAINER 13

Description of the Experiment 13
The Results of the Experiment -- Measure 1: Incorrect Problem Solutions 24
Measure 2: Excess Distance Flown 26
Measure 3: Distance Flown Outside Flight Limits 29
Measure 4: Unnecessary Turns 30
Measure 5: "Hitting the Station" 31
Measure 6: Bracketing Performance 32
Measure 7: "Orientation Time" 34
Measures 8 and 9: Analysis of First Turns 36
Comparison with Results of Previous Experiment 36
Conclusion 37

PART IV. COMPARATIVE EVALUATION OF PICTORIAL AND SYMBOLIC VOR NAVIGATION DISPLAYS AS USED BY PRIVATE PILOTS IN THE 1-CA-1 LINK TRAINER 41

Description of the Experiment 41
The Results of the Experiment — Measure 1: Incorrect Problem Solutions 48
Measure 2: Excess Distance Flown 50
Measure 3: Unnecessary Turns 54
Measure 4: Bracketing Performance 62
Measure 5: "Orientation Time" 64
Measures 6 and 7: Analysis of First Turns 69

Page

PART V. AN INTERPRETATION AND CRITICAL EVALUATION OF THE RESULTS OF THESE EXPERIMENTS 83

Factors Affecting the Results 83

APPENDIX I: A STUDY OF THE MOVING FIGURE AND ORIENTATION OF SYMBOLS ON PICTORIAL AIRCRAFT INSTRUMENT DISPLAYS FOR NAVIGATION 91

APPENDIX II: QUESTIONS AND ANSWERS 95

APPENDIX III: TECHNICAL DESCRIPTIONS OF THE PICTORIAL AND SYMBOLIC DISPLAYS USED IN THE 1-CA-1 LINK TRAINER 99

APPENDIX IV: A DISCUSSION OF THE STANDARD CAA BY-PASS PROCEDURE FOR VOR STATIONS 111

SUMMARY

This report presents the results of three experiments which evaluated the performances of both private pilots and instrument pilots using a pictorial and a symbolic VOR display in solving a variety of common local navigation problems in a 1-CA-1 Link Trainer.

The first of the three experiments served to validate, in some measure, the results of a previous experiment[1] in which a group of symbolic and pictorial displays had been evaluated by the static mockup (paper and pencil) technique. Four instrument pilots flew eight problems each using a conventional symbolic display. They made the same types of errors and with approximately the same frequencies as pilots of equivalent experience had made using the corresponding display in the mockup experiment.

The second experiment compared the performances of eight instrument pilots who flew four problems each using the conventional symbolic type VOR display and a new pictorial type display. The third experiment compared (1) the performances of 15 private pilots who flew five trials on each of five types of navigation problems using the pictorial display with (2) the performances of an equivalent group who flew the same number of trials on the same types of problems using the symbolic display.

The results of these experiments consistently indicate the superiority of the pictorial type display when used for the types of navigation tasks which were sampled. In the two experiments in which the pictorial display was used, 407 navigation problems were flown without a single unsuccessful solution. Thirty-two of the problems were flown by instrument pilots and 375 by private pilots. In the three experiments in which the symbolic display was used, 439 similar navigation problems were flown of which 50 resulted in unsuccessful solutions. Of these 439 problems, 64 were flown by instrument pilots and 375 by private pilots. Thus, of all problems flown using the symbolic display, 11.4% resulted in unsatisfactory performances. In 348 of the problems the pilots were started from an unknown position and were required to orient before initiating a problem solution; of these 13.5% were unsolved.

Comparative results for the last two experiments favor the pictorial display significantly in terms of: (1) the excess distance flown on correct solutions, (2) the distance flown in which established flight tolerances for altitude and airspeed were exceeded, (3) the number of unnecessary turns which were made, (4) the time required to orient from an

---

[1]Williams, A. C., Jr., and Roscoe, S. N. Evaluation of aircraft instrument displays for use with the omni-directional radio range. Washington, D.C.: CAA Division of Research, Report No. 84, March 1949. (For an abbreviated version of this report see: J. Appl. Psychol., 1950, 34, 123-130.)

unknown position and initiate a problem solution, (5) the proportion of first turns which were made in the more economical direction, and (6) the proportion of first turns which resulted in a correct initial heading.

The experiments did not provide an accurate comparison of bracketing performances using the two displays. In general, inbound bracketing appeared somewhat more accurate with the symbolic display, while outbound bracketing was consistently better with the pictorial display. The differences in bracketing performances observed in these experiments were not judged to be important.

The data from the third experiment were analyzed to determine the effects of differences in problem difficulty and practice during the early stages of learning by private pilots. All types of problems sampled were solved with equal ease by the private pilots who used the pictorial display. These pilots solved all problems correctly. On the average they made less than one unnecessary turn per solution for each type of problem. Their average orientation time for each of the four orientation problems was about ten seconds. For the pilots who used the symbolic display the various types of problems were of unequal difficulty. Larger proportions of incorrect solutions and longer orientation times occurred, with the symbolic display, on the problems which involved intercepting specified radials. The average numbers of unnecessary turns differed significantly for the various problems when the symbolic display was used. The greatest numbers were made on problems which involved outbound bracketing.

Practice effects were not significant for the pilots who used the pictorial display. Their performances on first trials for each type of problem left little room for improvement in terms of incorrect solutions, unnecessary turns or orientation times. The first-turn performances of the pilots who used the symbolic display left ample room for improvement. The pilots showed a reduction in the number of incorrect solutions from first to fifth trials and significant improvement in the efficiency with which they executed their decisions as reflected by unnecessary turns. However, they showed no significant improvement in the time which they required to orient and decide which way to fly to initiate problem solutions.

COMPARATIVE EVALUATION OF PICTORIAL AND SYMBOLIC VOR NAVIGATION DISPLAYS IN THE 1-CA-1 LINK TRAINER

PART I

INTRODUCTION

The omni-directional radio range (VOR) together with distance measuring equipment (DME) are aircraft navigation aids which provide a pilot with continuous and precise position information in terms of bearing and distance to or from an omni-range station. They employ visual rather than auditory displays for the presentation of this information. Early in the development of this equipment it became apparent that certain psychological problems existed in the design of cockpit instrumentation for the display of information which the equipment provides.[1] An inspection of the early VOR instrument displays was sufficient to suggest that pilots would not be able to use these instruments either quickly or without frequent errors because of the inherent ambiguity in the immediate information presented.

In 1948 and '49 Williams and Roscoe[2] conducted the first experimental evaluation of a number of VOR displays under the auspices of the National Research Council Committee on Aviation Psychology with funds provided by the Civil Aeronautics Administration. This present report reviews that study and presents the results of subsequent experiments which have been conducted under an extension of that contract.

A REVIEW OF THE FIRST VOR DISPLAY EVALUATION STUDY

Pictorial versus Symbolic Displays

In a preliminary consideration of the various existing and proposed instruments which might be used to display the information provided by VOR and DME, Williams and Roscoe[3] classified such displays on logical

---

[1] Melton, A. W. Psychological problems on cockpit instrumentation for the omni-directional range (ODR) and distance measuring equipment (DME). Washington, D.C.: CAA Division of Research, Report No. 76, February 1948.

[2] Williams, A. C., Jr., and Roscoe, S. N. Evaluation of aircraft instrument displays for use with the omni-directional radio range. Washington, D.C.: CAA Division of Research, Report No. 84, March 1949. (For an abbreviated version of this report, see: J. Appl. Psychol., 1950, 34, 123-130).

[3] Ibid.

grounds into two major categories, symbolic presentations and graphic or pictorial presentations. This dichotomous classification was used earlier by Grether[4] and has been used since by Chapanis, Garner and Morgan,[5] and by others. All existing VOR displays in 1948 were of the symbolic variety in that they presented information by means of numerical pointer readings, needle deflections or numbers appearing in windows. These early displays presented most of their information in terms of numbers and made use of pointers which the pilot had to align with some fixed reference or index of desired performance. (In most cases the vertical pointer of the ILAS instrument was used.) The pilot had to know special rules in order to make sense out of these numbers and needle deflections which told him only an indirect story of where he was and where he was going.

In the first evaluation study[6] three pictorial or graphic displays were designed for purposes of comparison with the existing symbolic displays. These displays presented the actual horizontal spatial relations between aircraft, station and aircraft heading in miniature on the face of the instrument. In one of these displays the station was represented at the center of the scope (with North at the top) and the aircraft was represented by a "pip" which moved about the face of the scope. In the other two displays the aircraft was represented at the center and the station appeared to move.

In general, symbolic displays provide pieces of information appropriate for a cognitive solution to a navigation problem, while pictorial displays provide cues appropriate for a perceptual solution to a problem. This logical dichotomous classification has proved both realistic and useful in studying and understanding the many display problems in the cockpit instrumentation of VOR and DME.

The Evidence for the Superiority of the Pictorial Type of Display

The first display evaluation study tested the speed and accuracy with which 48 pilots could use static mockups (drawings) of eight dif-

---

[4]Grether, W. F. Discussion of pictorial versus symbolic aircraft instrument displays. Dayton, Ohio: Wright-Patterson Field, Army Air Forces, Headquarters Air Materiel Command, Engineering Division, Aero-Medical Laboratory Section, Serial No. TSEAA-694-8B, 4 August, 1947.

[5]Chapanis, A., Garner, W. R., and Morgan, C. T. Applied experimental psychology: human factors in engineering design. New York: John Wiley & Sons, 1949, 156-162.

[6]Williams, A. C., Jr., and Roscoe, S. N. Op. cit.

ferent VOR aircraft instrument displays to solve typical navigation problems. The displays tested included five existing symbolic type displays and three proposed pictorial displays. The pilot group tested included 16 non-instrument pilots, 16 commercial pilots with instrument ratings, and 16 scheduled airline pilots.

The instrument and airline pilots made fewer errors than the non-instrument pilots, but there was no significant difference in the time scores for the different groups. The rank order of displays based upon error scores was highly correlated with their rank order based on time scores both within each pilot group and between groups. The displays which could be used more rapidly were also used with less errors.

The speed and accuracy with which the various pilot groups used each display are shown in Table I. The time scores represent the average time required to complete each set of ten problems. The error scores represent the average number of problems incorrectly solved per set of ten.

TABLE I[7]

AVERAGE TIME AND ERROR SCORES PER SET OF TEN PROBLEMS FOR EACH OF THE EIGHT DISPLAYS TESTED
(Time scores are in minutes)

Display	Private Pilots		Instrument Pilots		Airline Pilots	
	Time	Errors	Time	Errors	Time	Errors
Pictorial A	7.9	2.8	5.6	0.9	6.0	1.5
Pictorial B	9.5	4.4	6.4	2.6	9.9	2.1
Pictorial C	10.0	4.3	8.5	2.8	10.4	2.5
Radio Magnetic Indicator	15.2	5.8	15.4	4.0	14.9	3.1
Air Line Indicator	17.2	6.3	15.4	4.1	15.9	4.1
Air Force Indicator	20.3	6.6	19.9	3.8	21.1	4.8
Experimental Symbolic	14.2	6.0	13.4	4.3	13.3	5.0
Conventional Symbolic	18.4	6.9	19.4	4.3	18.8	4.6

With respect to both time and error scores there were significant differences between displays, similar differences being found for all groups. The three pictorial displays, which presented information in terms of a graphic representation of the actual spatial relations in-

---

[7] Williams, A. C., Jr., and Roscoe, S. N. op. cit.

volved, were significantly superior to any of the symbolic displays, which presented information in terms of dial readings, needle deflections and numbers. There was little to choose among the five symbolic displays tested. However, one of the pictorial displays, the one showing the station in a fixed position in the center of the scope with North at the top and the airplane as a pip which moved about the station, was found superior to all others.

3. An Evaluation of the Evidence

Whether these results obtained from static mockups are directly applicable to functional instruments used in actual flight depends upon the significance of the discrepancies between the experimental task and the flight task. In the use of any functional display, the pilot's task involves two aspects of performance, one of discrimination in which the pilot must decide what to do, and one of manipulation in which he must execute his decision. Using static mockups it is possible to get at only the first aspect of the pilot's task, namely: his decision concerning which way to fly in order to solve the navigation problem at hand.

It must be remembered, however, that VOR and DME are primarily navigation devices. Their chief purpose is to supply the pilot with information with which he can orient himself and from which he can decide on a proper direction in which to fly. VOR might also be used as a flight instrument for controlling heading, etc., but if the display fails as a navigation aid so that the pilot makes wrong decisions, then whatever excellence it might have as a flight instrument is wasted. Thus it was believed that the results from the static mockup study were pertinent to the flight situation.

PART II

THE VALIDATION OF THE STATIC MOCKUP EVALUATION TECHNIQUE FOR SYMBOLIC TYPE DISPLAYS

To test the hypothesis that the results from the static mockup study were valid predictors of the types of performance which could be expected in the actual flight situation, the first experiment in the series covered by this report was conducted. The method of this validation study was to compare performances obtained using a functional display with those obtained using the static mockups. If the same types of errors were made with approximately the same frequency, and if these errors proved to be the most important ones made, the static mockup results would be in some measure validated and the generalizations which were based upon them justified.

For this experiment a functional display of the conventional symbolic type[1] was installed in a 1-CA-1 Link trainer. The display consisted of a Course Line Selector, an Ambiguity Indicator, a Course Line Deviation Indicator (vertical ILAS pointer) and a Directional Gyro. At the time this was the only functional display available for use in the Link trainer, since the Functional Pictorial A display which has been used in later experiments had not yet been completed.

Description of the Experiment

Four experienced pilots holding valid CAA instructor and instrument ratings each flew eight problems similar to those used in the static mockups. The eight problems included two of each of the four following types:

(1,5) To fly to the station from present position,
(2,6) To fly away from the station from present position,
(3,7) to fly to the station along a designated track, and
(4,8) To fly away from the station along a designated track.

On all problems the pilots were started from positions unknown to them and had to orient in order to initiate a solution.

The problems were flown in a different order by each of the four pilots in an effort to balance the effects of practice and fatigue. The problems were flown in two sessions, four problems to a session. Problems 1 to 4 were flown in the first session; problems 5 to 8 were flown in the second session. There was a period of approximately two weeks between sessions.

---

[1]This equipment was designed by Dr. David Saunders of the Dept. of Psychology, University of Illinois and was constructed by Saunders and Mr. Albert Bowmar of the Aviation Psychology Laboratory, Univ. of Ill.

Instructions to the subjects. The subjects were required to read the standard instructions used in the mockup study. Following this there was a period of informal discussion and then the subjects flew one practice problem. The same practice problem was used for each subject. After this there was another short discussion period. The subjects then flew the test problems in a specified sequence, the sequence being different for each subject. In addition to the navigation task the subjects were instructed to hold flight tolerances of plus or minus 100 ft. for altitude and five mph for air speed.

Records obtained. Two records of performance were kept. One was a tracing of the flight path made by the trainer recording crab. A second record was kept by the experimenter and consisted of comments and remarks pertinent to the flight.

When the records were obtained a system for scoring them was developed. Since there are many ways the records could be scored, selecting a system is actually an arbitrary procedure. In this case the problem was to develop a scoring system which would reflect faithfully in summary form the deviations and wanderings which often occurred and which would distinguish between tracings which were "obviously" good and "obviously" poor when received and viewed in their raw form. Above all, the scoring system had to be meaningful in terms of the flight situation so that by analyzing the scores it would be possible to tell what happened in each case or any combination of cases.

Measures employed. The scoring system selected consisted of a battery of six objective measures. The measures were:

(1) Was the problem solved?
(2) Was the first turn in the correct (more economical) direction?
(3) Was the first turn to the correct heading?
(4) Did the subject orient himself at the start of the problem?
(5) What was the number of orientations made after the start of the problem?
(6) If the problem was solved, what was the percentage of excess distance traveled (excess distance / correct distance X 100)?

In Measure 1 the problem was considered solved if the pilot eventually met the requirements as stated within a track tolerance of plus or minus five degrees. Measures 2 and 3 were based upon comparing actual performance with a track representing the most economical solution of the problem. However, if the first turn were in the wrong direction, the problem still could be solved by assuming a heading which would be correct for the new position resulting from the less economical turn. This heading would not always be the same as the correct heading for the proper direction of turn. With respect to Measures 4 and 5 the pilot was scored as having oriented himself as he zeroed the course line deviation indicator by turning the course selector knob. The fact of his having done so does not imply that his interpretation of the readings so obtained was correct. In Measure 6, the distance it was necessary to travel for the most efficient solution to each problem was measured. This minimum distance was compared with the actual distance flown in each case, and the difference between them was expressed as a percentage of the minimum distance. Distances were measured along the track by means of a map measure.

The Results of the Experiment

It was possible to combine the scores for these measures in a way which accounts for the outcome of each of the 32 problems flown. This analysis, which is shown in Tables 2 and 3, was made in the following manner. Thirty-two problems were flown in all. Of these, 26 were solved and six were not. In the 26 solutions the first turn was made in the correct direction in 19 cases and in the incorrect (less economical) direction in seven cases. Of the 19 cases in which the direction of turn was correct, 14 turns were to the correct heading and five were to an incorrect heading. In four of the seven cases in which the initial turn was in the wrong direction, compensation was made by turning to the correct heading for the direction of turn taken. In the other three cases the turn was to an incorrect heading. Considering now the six cases in which the problem was not solved, in three the initial turn was in the correct direction and in the other three it was not. However in no case was a correct heading assumed as a result of the turn.

In those cases, 18 in all, in which a correct heading for the solution of the problem was assumed regardless of the direction of turn, it is not difficult to understand why the problem was solved. Having selected the correct heading out of 36 possible headings, allowing a tolerance of plus or minus 5 degrees per heading, the pilot apparently had already solved the problem, and it was only necessary for him to execute his decision. In no case where a correct heading was assumed did the pilot fail to solve the problem. As would be predicted, in the cases in which the turn was in the correct direction the percentage of excess distance flown was at a minimum, averaging 18%. Those who turned in the wrong direction but to the correct heading flew an excess of 29%, which is slightly more as would be expected from a less economical solution. In eight cases the problem was solved even though the initial heading assumed was incorrect. In these cases the average excess distance flown was 33% and 50%, respectively, depending upon the direction of the initial turn.

Thus far it is evident that assuming the correct initial heading is indicative of a successful outcome but that assuming an incorrect heading does not necessarily result in failure. In 14 cases pilots took up an incorrect heading as a result of their first turns. In eight of these cases the problem was solved and in six it was not. The next step must be to account for this difference in outcomes.

TABLE 2

DISTRIBUTION OF [illegible] FOR 32 PROBLEMS ACCORDING TO [illegible] DIRECTION OF FIRST TURN AND HEADING ASSUMED

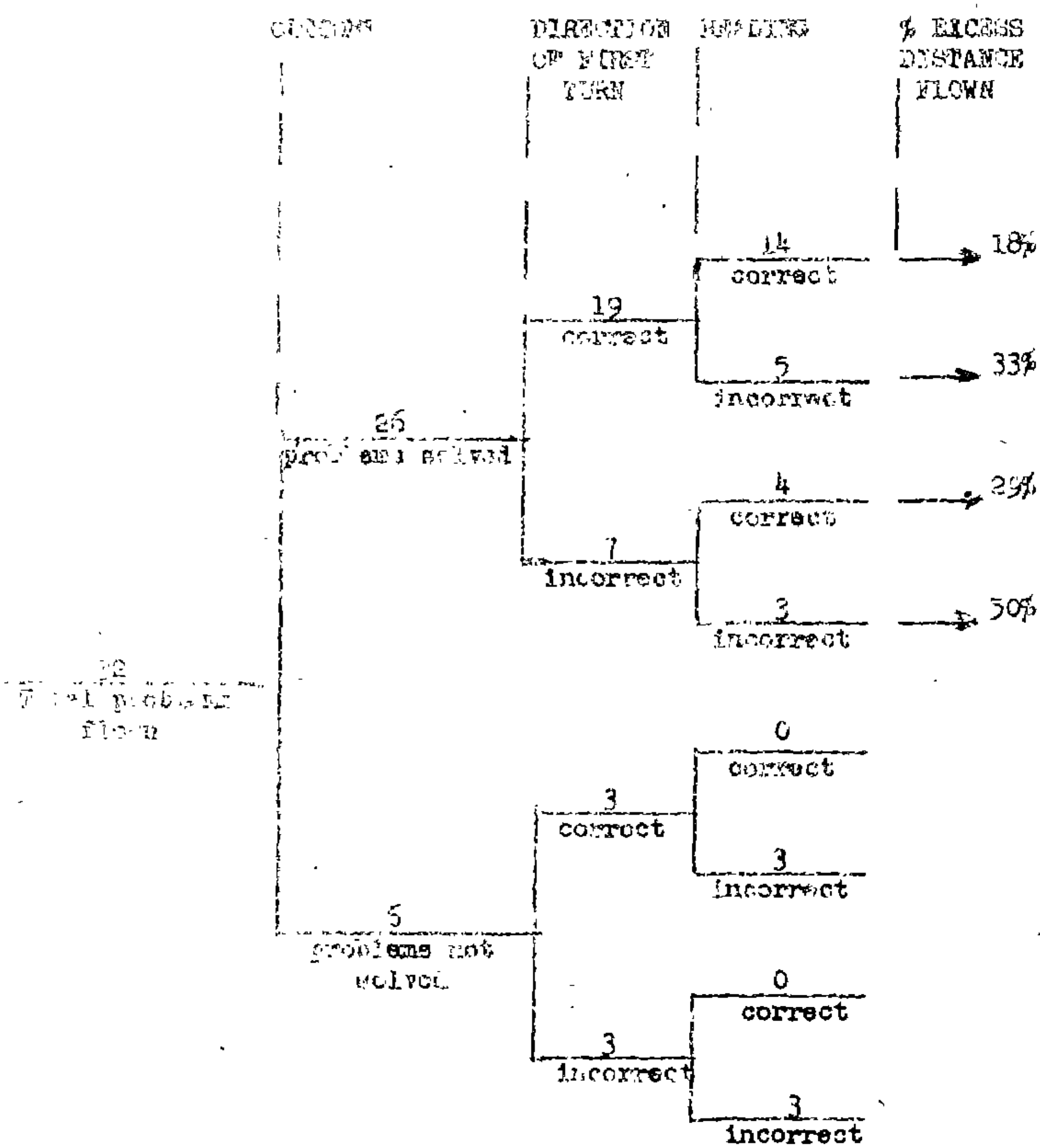


TABLE 3

CLASSIFICATION OF 14 PROBLEM SOLUTIONS IN WHICH INITIAL TURN WAS TO INCORRECT HEADING ACCORDING TO OUTCOME AND REORIENTATION FOLLOWING FIRST TURN

	OUTCOME	REORIENTATION FOLLOWING FIRST TURN
14 Total problems in which initial turn was to an incorrect heading	8 problem solved	6 did reorient
		2 did not reorient
	6 problem not solved	2 did reorient
		4 did not reorient

Table 5 shows [illegible] in which an incorrect heading was assumed. In six of the eight cases in which the problem was solved the pilots reoriented themselves one or more times following the first turn. In two cases they did not. From an inspection of the records it is fairly evident that as a result of these orientations the pilots assumed a proper heading for solving the problem and that a solution was therefore achieved. Among the six cases in which the solution was not achieved, in two cases the pilots did reorient and in four cases they did not. It is understandable how failure to reorient would in general prevent a solution, and yet among the successful cases as noted above two achieved a solution in spite of not reorienting. An examination of these records shows that in one of these cases the pilot did a "double take." He originally turned to the wrong heading, flew for a short distance, and then without hesitation and with no further orientation turned to exactly the correct heading and solved the problem. In the other case the solution can only be described as lucky. The problem was to fly away from the station along a designated track. Without any orientation the pilot set his course selector for the designated track and then turned to an incorrect heading for the approved solution. However, the heading he assumed was acceptable since it did eventually intercept the designated track so that the problem could be solved. If his azimuth position had been as little as 20 or 30 degrees away from his original location, the procedure used would not have resulted in a solution to the problem.

Finally the two cases in which the pilot did reorient and yet failed to solve the problem should be examined. In one of these, after reorienting, the pilot did solve the problem from the new position in which he found himself. The problem required that he fly away from the station from his present position. The pilot did not do this from his initial position and so failed the problem as given. But from his new position, after turning the wrong way and reorienting, the pilot did fly away from the station. In the other case the pilot was evidently completely lost and disoriented. After turning to the wrong heading in the first place, he then reoriented himself four times. His flight pattern during this time appeared aimless. It progressed in the same general direction with minor heading changes which were apparently unrelated to the orientations. He finally wandered off the chart.

Discussion and Conclusions

The analysis presented above includes every case and assigns reasons why the problems were or were not solved. The analysis emphasizes the importance of proper orientation. None who turned to the proper heading failed to solve the problem. When the proper heading was not originally assumed, the flight could, in many cases, be salvaged by reorientation which then permitted the pilot to turn to the proper heading. The implication is clear that, first, a correct initial heading is generally a sufficient condition for a solution and, second, a correct heading sooner or later is a necessary condition for a solution. The selection of a correct heading by the pilot is attributed to proper orientation. The conclusion follows that successful use of VOR, at least with this display, depends heavily upon how well the pilot can use the device to make his initial directional decisions and not upon how well he can use it as a flight instrument in executing his decisions.

There is, however, one small catch to the conclusions presented above. The procedure used in arriving at them has been clinical. In each case the pilot was found to have done certain things and therefore the outcome was ascribed to those things which the pilot did. The fundamental cause of a successful outcome has been assigned to proper orientation, as indicated by the record data with reference to correct direction of turn and correct heading. The key assumption implicit in this clinical analysis is that a correct turn to a correct heading is the result of proper orientation. It is indeed interesting to note, therefore, that in three cases the correct initial heading was assumed without the pilot's having oriented himself at all. In all three cases the problem was solved. In two of them the pilot did not orient himself at any time; in the third case the pilot oriented himself twice later on in the problem. The fact that this was possible at all was simply a function of the problems used. In many cases the pilot's initial position was close enough to the designated track so that the track could be intercepted with any one of a number of different headings before going out of the VOR range or passing the station. Thus by simply selecting the designated bearing on the course selector, the subject could find out whether he was to the right or left of the designated track, and then turn accordingly to a heading which would cause him to intercept that track at an angle of about 45 degrees. During the course of the experiment the subjects apparently realized that they were usually started from a position for which this procedure would work, even though it was not the procedure required by the instructions.

Implications of this Study for the Validation of the Static Mockup Technique

It was concluded above that the successful use of a symbolic type VOR display depends heavily upon how well the pilot can use the device to make his initial directional decisions and not upon how well he can use it as a flight instrument in executing his decisions. Since the former function is one which was measured in the earlier static mockup study, these results obtained using a functional display tend to support the validity of the technique employed in the earlier study. Furthermore, the results of this study were clearly in agreement with those from the mockup experiment.

Considering only the pilots' initial decisions as to the direction in which to fly in order to start a correct solution, the same types of errors were made using the functional display, and with approximately the same frequencies, as had been made using the corresponding static display. Using the static conventional symbolic display the Instrument Pilot Group had failed to solve 43% of the problems and the Airline Pilot

Group 46%. Either a turn in the wrong direction or a turn to a wrong heading was counted as an error. Considering only the first turns made in the 32 problems using the functional display in the Link trainer, 18 were either in the wrong direction or to the wrong heading or both. Thus, using the same criteria for error, 56% of the solutions would be considered incorrect. (In 12 of these 18 cases the subjects were able to detect their errors and make appropriate corrections leading to successful solutions, as would be expected using a functional display.)

The slight increase in the proportion of the first turn errors made using the functional display was to be expected since the pilots flying the trainer were under more pressure to act quickly than were the pilots taking the paper and pencil test. In neither case was a stated time limit imposed; however, using the functional display the pilots had to make a directional decision and act upon it before flying out of the VOR range. In addition, the paper and pencil problems were in a double multiple choice form in which the subjects would be expected to get one correct in 15 by chance. Using the functional display the pilots would be expected to turn in the correct direction to a correct heading only once in 72 times by chance.

COMPARATIVE EVALUATION OF PICTORIAL AND SYMBOLIC VOR NAVIGATION DISPLAYS AS USED BY INSTRUMENT PILOTS IN THE 1-CA-1 LINK TRAINER

While the study just described suggested that the results of research using the mockup technique were valid for one particular type of display, the conventional symbolic type, it offered no direct evidence concerning the comparison of performances using various types of displays as was done in the mockup study. It was still possible that the apparent superiority of the pictorial type displays, for example, might not hold up with functional instruments. To investigate this possibility an experiment was designed to compare the performances of pilots when flying two different functional displays.

In this experiment, conducted by Smith, the performances of eight experienced instrument pilots using the conventional symbolic VOR display were compared with their performances using a new pictorial type display in the 1-CA-1 Link trainer. (See Figures 1 and 2.) The conventional symbolic display had proved to be one of the worst of the eight displays studied by the mockup technique, while the Pictorial A display had appeared to be the best of any as yet proposed. The Pictorial A display[1] was a cathode ray oscilloscope which showed the station as a small dot in a fixed position in the center of the scope. North was located at the top of the display. The airplane was represented by the pip which moved about the face of the scope showing the airplane's position in relation to the station. The pip left a long-persistence trace, thus giving a comet tail effect which served as a rough indication of heading and rate of turn.

DESCRIPTION OF THE EXPERIMENT

Subjects. Eight experienced pilots with valid CAA instrument ratings were used as subjects.

Problems. Two equivalent sets of four problems each were flown by the subjects, one set for each display. The equivalence of the two sets of problems was assumed since the problems were identical except that their starting positions and designated tracks were rotated so that the problems would not be recognized as the same. The problems were designed to sample the normal uses to which such displays would be put. The problems, together with the best and worst correct solutions flown using each display are graphically illustrated in Figures 3, 4A and 4B. In addition, four of the incorrect solutions flown using the symbolic display are shown in Figure 4B. There were no incorrect solutions flown with the pictorial display.

Each of the two problem sets included problems of the following types:

---

[1]This equipment was designed and constructed by Mr. John M. Bell of the Aviation Psychology Laboratory, University of Illinois.

I. With the aircraft already oriented and on course, to continue flying to the station and to depart from the station on a given departure track, not the same as the inbound track.

II. With position unknown, to orient and fly directly to the station.

III. With position unknown, to orient and fly to the station along a designated track.

IV. To bypass the station according to standard CAA change of altitude procedure for use with VOR (See Appendix IV).

These four problem types can be further classified into two categories: those in which the pilot was required to orient himself and those in which he was not. In the first and fourth problems the pilot was started from a known position and was simply required to execute a specified pattern; in the second and third problems the pilot was started from an unknown position and was required to orient himself before initiating a solution.

Instruction to subjects. All subjects were instructed to the point of equivalent understanding of the two displays. For instructions they were required to read the pertinent parts of the standard instructions used in the mockup study. Following this there was an informal "chalk talk" at the blackboard in which a further explanation of the functions of each display was presented. During this discussion the experimenter described each of the four problem types which the subjects would encounter and the appropriate methods of solution to be used with each display. Finally the subjects were required to demonstrate their ability to solve practice problems of each type at the blackboard.

Performance required. The subjects then flew the experimental problems in the trainer. All eight problems were flown in one session by each subject. In an effort to balance the effects of practice and fatigue, four of the pilots flew using the pictorial display first, while the other four pilots used the symbolic display first. The four problems in each set were flown in a different order by each of the eight pilots. In addition to the navigation task the subjects were instructed to hold flight tolerances of plus or minus 100 feet for altitude and five mph for air speed.

The performances were recorded by a tracing of the flight path made by the trainer recording crab. Along this record the experimenter marked the portions of the flight in which the subject exceeded the established flight tolerances.

Records and measures. In all, 32 flight records were obtained for each display. For the records of the 16 problems in which the subject was first required to orient himself, the scoring system used was essentially the same as that used in the previous study. However, for the 16 pattern problems some of these measures were not applicable. Altogether

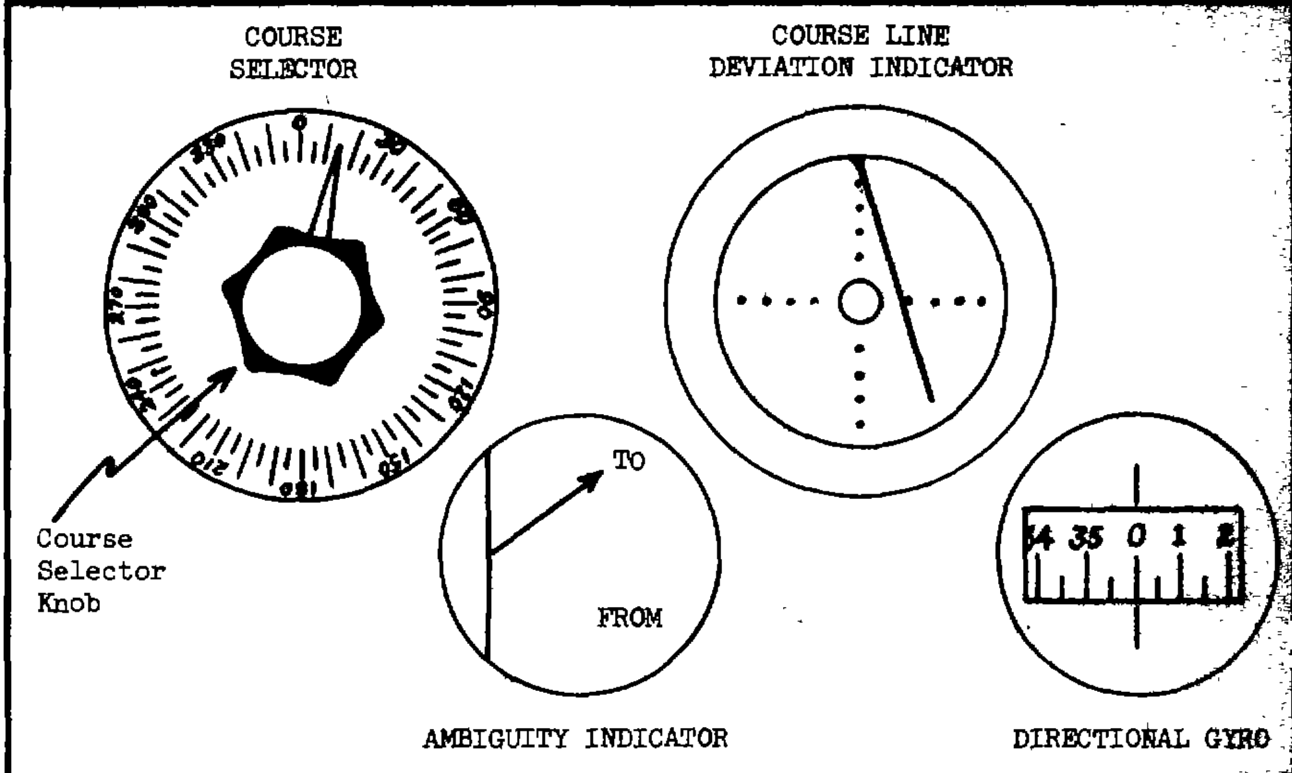


Figure 1. THE CONVENTIONAL SYMBOLIC DISPLAY. The display indicates that the aircraft is somewhere to the left of a course of 15° to the station, heading N.

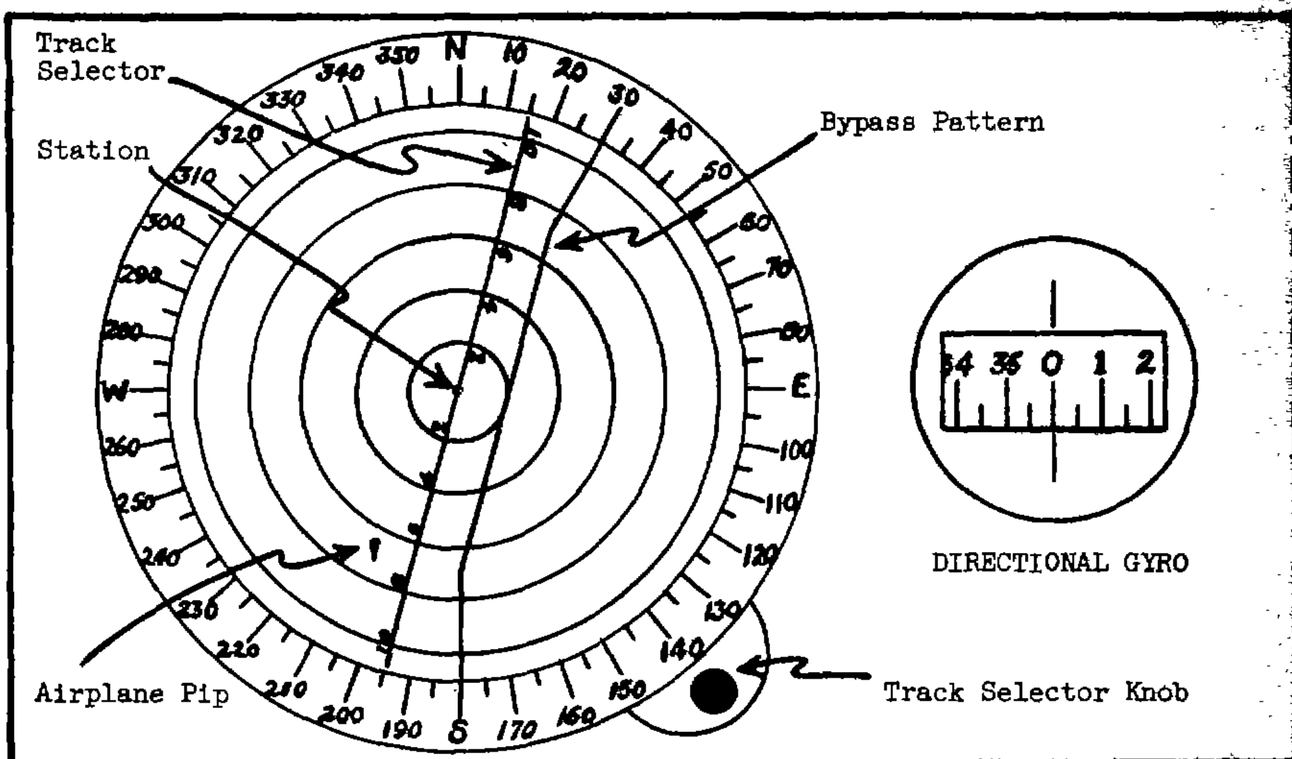


Figure 2. THE STATION-CENTERED PICTORIAL DISPLAY. The display indicates directly the position and heading of the aircraft in relation to the station.

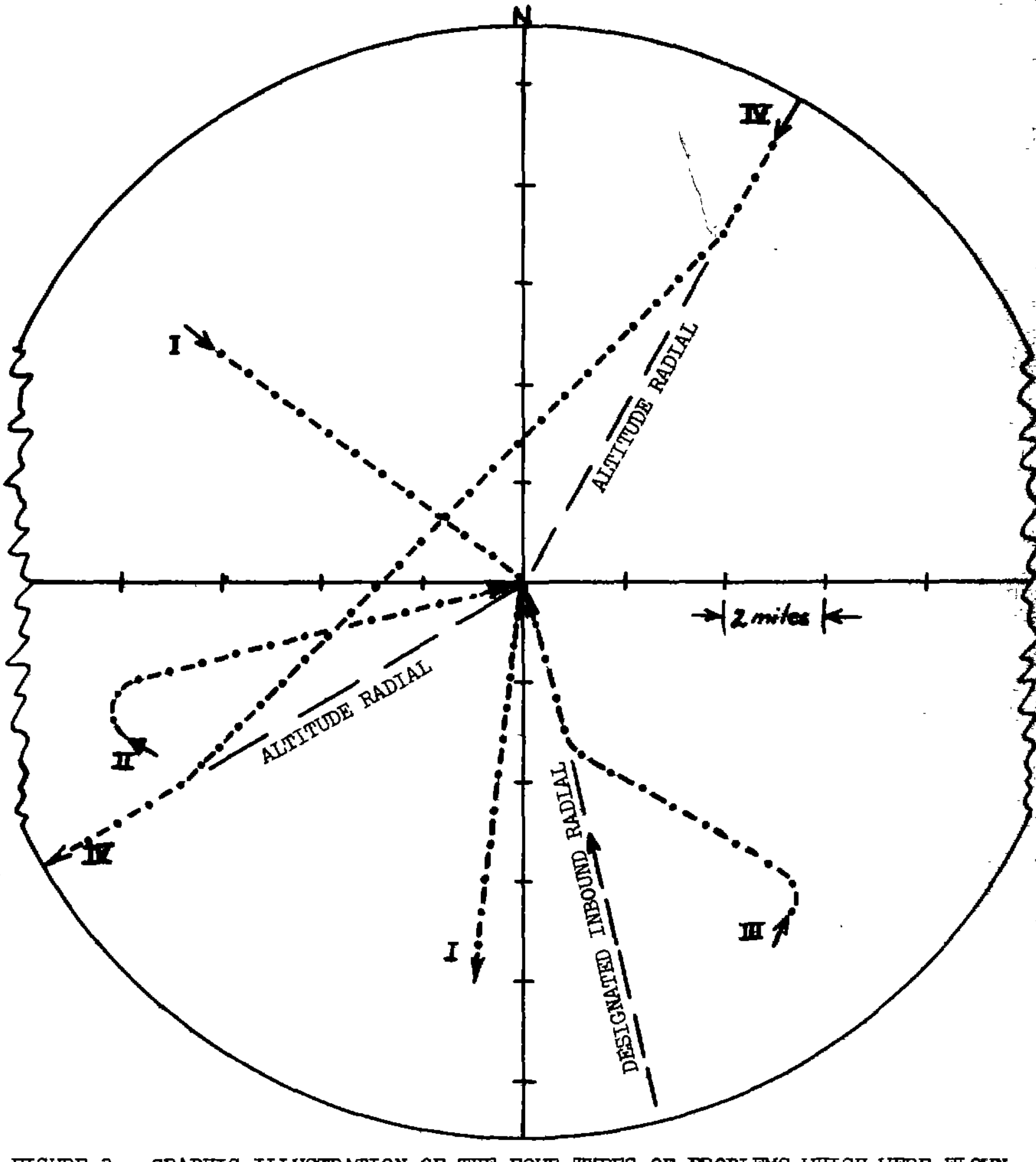


FIGURE 3. GRAPHIC ILLUSTRATION OF THE FOUR TYPES OF PROBLEMS WHICH WERE FLOWN BY INSTRUMENT PILOTS USING BOTH THE PICTORIAL AND SYMBOLIC VOR NAVIGATION DISPLAYS IN THE LINK TRAINER

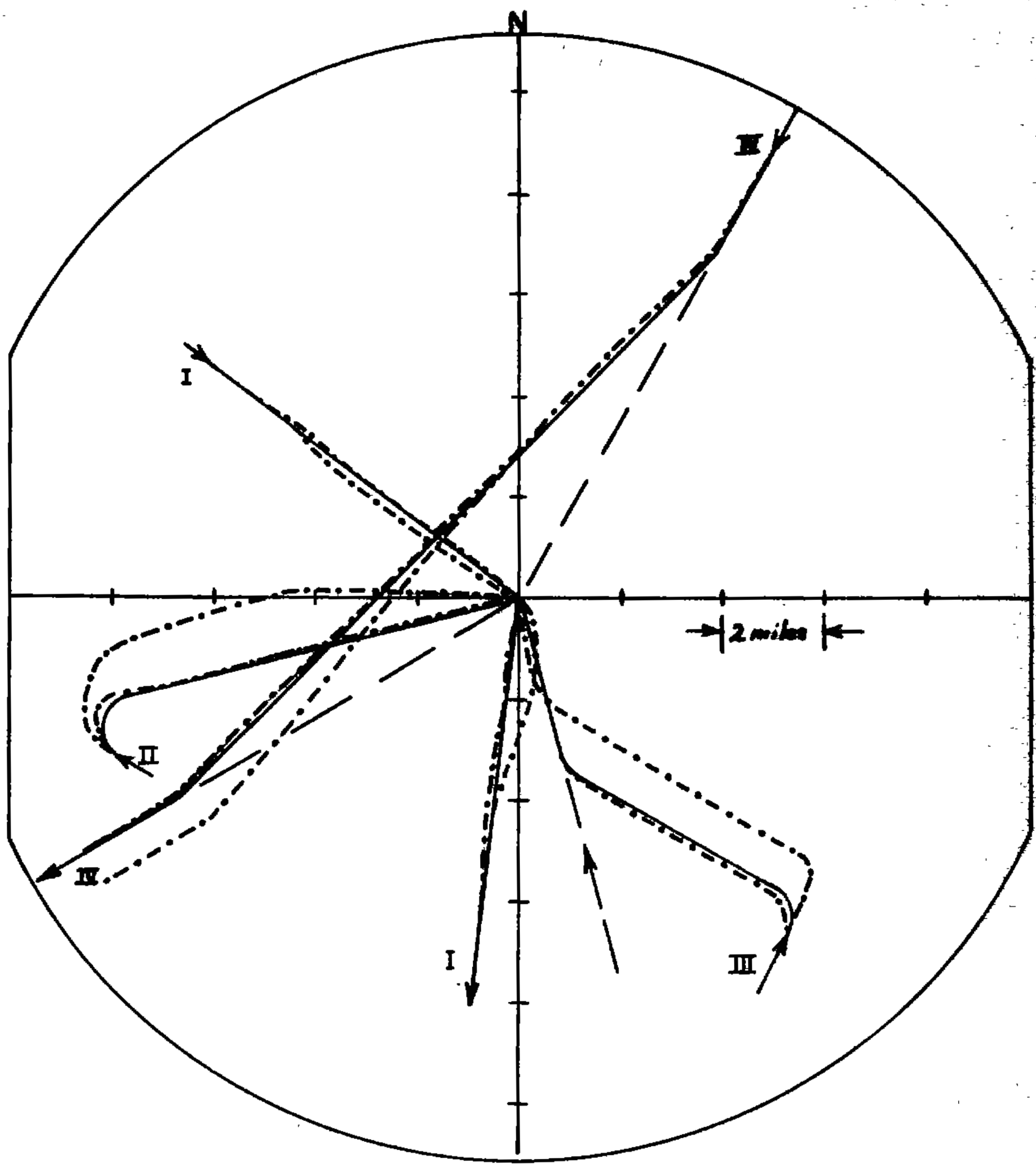


FIGURE 4A. EXAMPLES OF PROBLEM SOLUTIONS WHICH WERE FLOWN USING THE PICTORIAL DISPLAY

The dot-dash lines represent tracings of the tracks made by the trainer recording crab during the best and worst solutions which were flown on each of the four problems. There were no incorrect solutions using the pictorial display. In most cases the best patterns correspond so closely with the desired patterns that they are indistinguishable. (The desired solutions are shown by solid lines.)

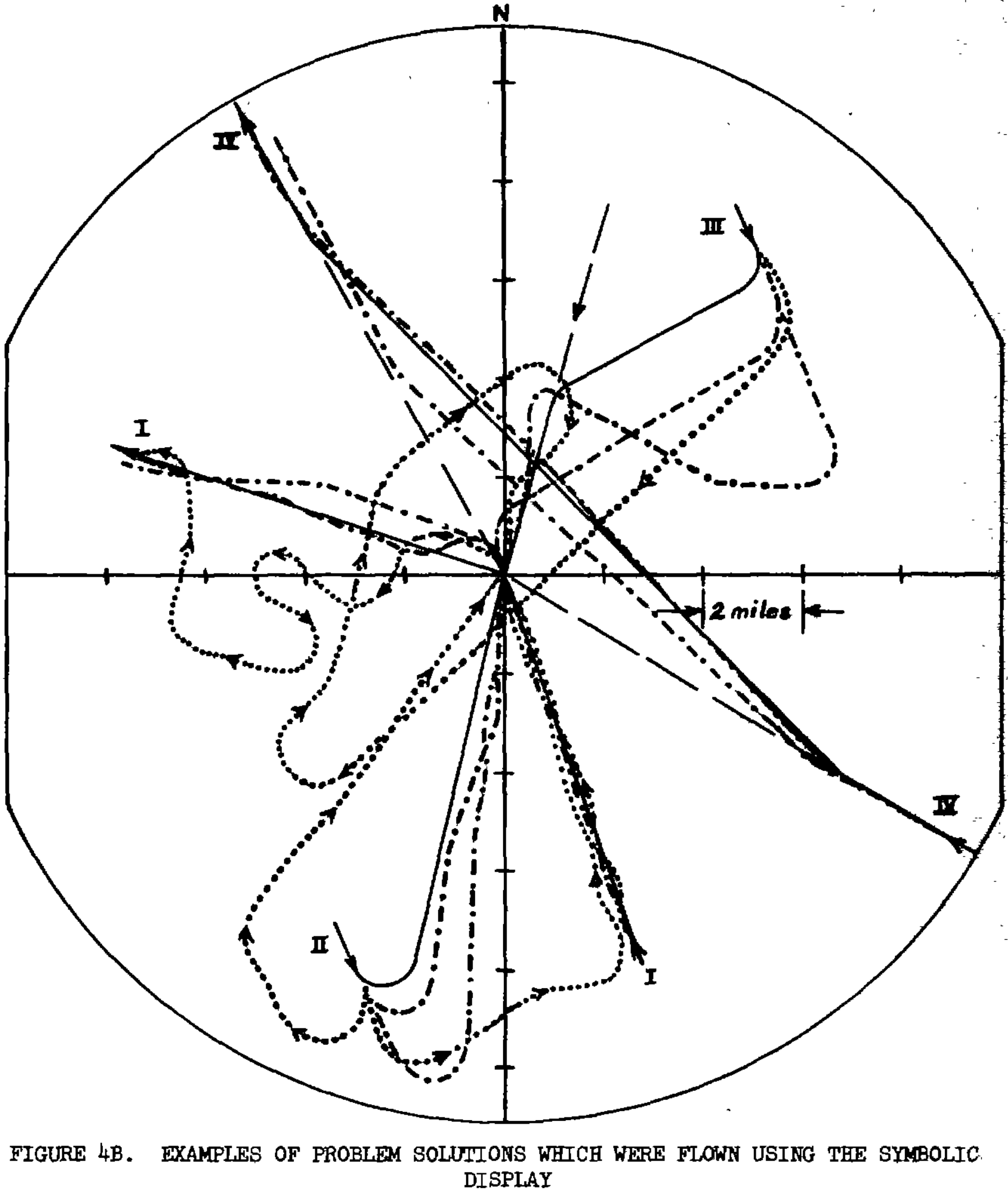


FIGURE 4B. EXAMPLES OF PROBLEM SOLUTIONS WHICH WERE FLOWN USING THE SYMBOLIC DISPLAY

The dot-dash lines represent tracings of the tracks made by the trainer recording crab during the best and worst correct solutions which were flown on each of the four problems. The dotted lines represent four of the five incorrect problem solutions which were flown using the symbolic display. (The desired solutions are shown by solid lines.)

nine objective measures were used, five of which were applicable to all problems, three of which were applicable to the orientation problems only, and one of which was applicable to the pattern problems only.

The measures upon which the records were scored were as follows:

(a) Measures pertinent to all problems:

(1) Was the problem solved?

(2) If the problem was solved, what was the percentage of excess distance traveled (excess distance / correct distance X 100)?

(3) Whether the problem was solved or not, what percentage of the distance flown was outside the established tolerances for altitude and airspeed (distance outside limits / total distance flown X 100)?

(4) What was the number of unnecessary turns of greater than 15 degrees made away from the desired track?

(5) What was the extent of the errors made in "hitting the station," or, in the case of problem 4, what was the extent of the deviations from the designated track abeam of the station?

(b) Measure pertinent to pattern problems only (problems I and IV):

(6) What was the extent of the deviations from the designated track or pattern?

(c) Measures pertinent to orientation problems only (problems II and III):

(7) What was the time from the start of the problem until the beginning of the first turn?

(8) Was the first turn in the correct (more economical) direction?

(9) Was the first turn to the correct heading?

In Measure 1 a problem was considered unsolved for any one of the five following reasons:

a. if the subject flew out of the VOR range before intercepting the desired track.

b. if the subject became disoriented while attempting to intercept or bracket a desired track,

c. if the subject flew to (or away from) the station along an incorrect track (±15° tolerance),

d. if the subject flew past the station along an incorrect track, or

e. if the subject flew past the station without noting such passage, even though his track may have been approximately correct.

In Measure 2 the distance traveled was measured in tenths of a mile with a map measure and was used to show excessive wanderings during a problem solution. In Measure 3 distances were measured in the same manner as in Measure 2, and the proportion of the distance flown in which the pilot exceeded the established tolerances for altitude and airspeed was considered as an index of flight performance. The number of unnecessary turns, Measure 4, was considered an index of flight efficiency. Only turns of 15 degrees or more away from the desired track were counted, since smaller turns were frequently unintentional. In Measure 5 the errors in "hitting the station" were measured in sixteenths of a mile perpendicular to the flight track as the pilot passed the station.

The sixth measure consisted of deviations measured in sixteenths of a mile at one-half mile intervals along the designated track or school solution. This measure was applicable only to the pattern problems and was intended primarily to be an index of the accuracy of bracketing.

The seventh measure was intended to represent the discrimination time, or the time required by the pilot to interpret the readings of the display, orient himself, and decide what to do in order to solve the problem.

Data on Measures 8 and 9 were obtained by comparing the actual performances with a track representing the most economical solution of a problem. Measure 9 differed from the corresponding measure in the previous experiment in that headings were considered correct if they were within plus or minus 15 degrees of the desired heading rather than plus or minus 5 degrees. This 15 degree tolerance was selected since it discriminated more clearly between "obviously" correct and incorrect headings for the particular navigation problems used.

THE RESULTS OF THE EXPERIMENT

Measure 1: Incorrect Problem Solutions

Considering all criteria for Measure 1, five problems of the 32 flown using the symbolic display were unsolved, and 32 problems flown using the pictorial display were solved correctly. The five incorrect solutions using the symbolic display were distributed among four subjects and three different types of problems, one on Problem I, two on Problem [illegible] and two on Problem [illegible]. [illegible] of these five wrong solutions are illustrated in Figure [illegible].

Problem I. The incorrect solution on problem [2] resulted from the subject's becoming disoriented after passing the station while involved in bracketing a new outbound course from the station. This can be attributed to confusion in interpretation of right and left indications on the course line deviation indicator while flying outbound. With the new outbound course selected the deviation indications were actually the same as for inbound but were interpreted as being reversed.

Problem II. An examination of the wrong solutions for Problem II[3] shows that both resulted from initial turns to an incorrect heading and each required the solution of a new problem from the resulting position and therefore resulted in an incorrect track to the station. The new problems were of the same type, namely, to fly directly to the station, but were started from the new position and heading resulting from the incorrect first turn. The subjects solved the new problems without error, but the time and distance consumed in the second orientations as compared with the first orientations in the same problems were 350% greater for one subject and 225% greater for the second.

Problem III. A study of the two incorrect solutions in Problem III[4] indicates that both of these errors resulted indirectly from the subject's taking too long to orient himself before turning to a heading to intercept the designated inbound track to the station. In neither case did the subject have the desired track bracketed before passing the station. In one case the subject did intercept the inbound track about one mile from the station, but while attempting to bracket from so close in, he failed to notice a change in the ambiguity indicator which would have told him that he had passed the station. When he finally had bracketed the track, the subject noted this change.

In the second case the subject did not intercept the desired track until after he had passed the station. His failure resulted from the fact that, after a slow orientation, he took up an insufficient angle of interception. That the instructions were clear to the pilot is indicated by the fact that, without further instructions, he did eventually return to a position from which he was able to solve the problem as given. In each of these cases the instrument had failed to tell the pilot that he was not intercepting the desired track at a sufficient angle to complete the interception and bracket the track before passing the station. This type of error did not occur and probably never would occur using the pictorial display.

In general. From a consideration of these incorrect solutions using the symbolic display it would seem that, for the problems in which the

---

[2]Problem I: aircraft oriented, and on course, subject continues flying to station, departs from station on different track.

[3]Problem II: position unknown, subject orients and flies directly to station.

[4]Problem III: position unknown, subject orients and flies to station along designated track.

task was to fly directly to the station, a little more time spent on initial orientation prior to making a turn probably would have resulted in correct solutions. However, in those problems in which some designated track to the station was to be intercepted and bracketed, a very quick orientation and first turn were sometimes necessary if the pilot was to complete the interception and bracketing before passing the station or getting into some other unfavorable position.

Thus it appears that in certain types of problems it is to the pilot's advantage to strive for accuracy of orientation rather than for speed, while for other problems a very rapid directional decision must be made in which case speed and accuracy are equally important. Probably the greatest single advantage of the pictorial display over the symbolic display lies in the fact that it insures the pilot both a rapid and accurate initial orientation (see discussion of measure number 7).

Problems I and IV were pattern problems in which no orientation was required, and in general a pattern could be flown as well with one instrument as with the other (as far as success in solution was concerned) except for the difficulty encountered in outbound bracketing using the symbolic display.

Measure 2: Excess Distance Flown

On Measure 2, the average distances flown for the correct solutions of Problems I, II, and III[5] were significantly less using the pictorial display than they were using the symbolic display. Table 4 gives the school solution distance for each problem, the average distance flown on correct solutions for each problem using each display, the average excess distance and the per cent excess distance on each problem for each display. The mean differences, as evaluated by the _t_ test, were found to be significant at the .01 level of confidence for Problem I, at the .02 level for Problem II and at the .05 level for Problem III. The mean difference for Problem IV[6] was insignificant by inspection.

Problem I. The difference observed for Problem I is spurious and warrants further consideration. On this problem the task was to fly

---

[5]Problem I: Aircraft oriented and on course, subject continues flying to station, departs from station on different track.

Problem II: Position unknown, subject orients and flies directly to station.

Problem III: Position unknown, subject orients and flies to station along designated track. (See page 23).

[6]Problem IV: Bypass station according to standard procedure. (See page 2[illegible]).

TABLE 4

A COMPARISON OF DISTANCES FLOWN BY EIGHT SUBJECTS ON FOUR PROBLEMS USING THE PICTORIAL AND SYMBOLIC DISPLAYS
(in miles)

The comparisons are based upon distances flown on correct solutions only. The X's designate incorrect solutions, and the distances flown on these solutions are omitted. The distances for the corresponding correct solutions with the pictorial display are shown in parentheses to indicate that they were not used in computing the statistics shown in the summary portion of the table.

Subject	Distance Flown on Correct Solutions Only: Problem I		Problem II		Problem III		Problem IV	
	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.
1	(16.0)	X	10.3	11.0	9.3	10.3	19.5	19.6
2	15.3	16.4	(10.[illegible])	X	9.7	11.1	19.6	19.7
3	16.1	16.5	9.6	11.0	9.5	13.2	19.5	19.5
4	16.0	15.2	10.4	13.0	9.1	10.5	19.5	19.5
5	15.8	16.4	10.0	13.3	(9.4)	X	19.6	19.6
6	15.8	16.4	10.1	10.8	9.7	9.8	19.7	19.6
7	16.0	16.4	10.4	13.6	9.7	15.4	19.5	19.5
8	16.2	16.5	(11.3)	X	(9.0)	X	19.3	19.5
Sum	112.2	114.8	60.8	73.2	57.0	70.3	156.2	156.5
N	7	7	6	6	6	6	8	8
Mean solution distance	16.03	16.40	10.13	12.20	9.50	11.72	19.52	19.56
School solution distance	16.00	16.00	9.50	9.50	9.20	9.20	19.50	19.50
Average excess distance flown	0.03	0.40	0.63	2.70	0.30	2.50	0.02	0.06
% excess distance flown	0.2%	2.5%	6.6%	28.4%	3.3%	27.2%	0.1%	0.3%
D	0.37		2.07		2.22		0.04	
σdiff	0.07		0.54		0.85		----	
t	5.286		3.833		2.612		----	
df	6		5		5		----	
P	.01		.02		.05		----	

directly to the station and then away along a different outbound track. The mean distance flown on this problem using the pictorial display was 16.03 miles, the excess distance being only 0.2% of the school solution; while the mean distance flown using the symbolic display was 16.40 miles, 2.5% in excess of the school solution. This mean difference of 0.37 miles is small, but the individual differences favored the pictorial display for each subject and the mean difference was significant at the .01 level. These consistent small differences can be explained partially by the fact that the symbolic display did not include distance measuring equipment, and it was therefore impossible for the subject to predict when he would reach the station so as to anticipate the turn to the outbound heading. With the pictorial display, distance information was shown by the distance of the pip from the station, and the subject could predict his arrival at the station and anticipate the turn. Such consistent differences in favor of the pictorial display would not be expected on this problem if distance measuring equipment were included in the symbolic display. (The fact that some subjects flew a shorter distance than the school solution resulted from their making one or more turns which were faster than the standard rate (3°/sec) at which they were instructed to turn. The school solutions were of course based upon standard rate turns.)

<u>Problem II</u>. In problem II, in which the task was to orient from an unknown position and then fly directly to the station, the average distance flown with the pictorial display was 10.13 miles. The same pilots flew an average distance of 12.20 miles while solving the problem using the symbolic display. The excess distance flown using the pictorial display was 4.6% as compared with 28.4% for the symbolic. This large difference was primarily a function of the time required for orientation (time flown before making first turn) and will be considered further in the discussion of measure 7.

<u>Problem III</u>. In problem III the average distances flown using the pictorial and the symbolic displays were, respectively, 9.50 miles: an excess of 3.3%, and 11.70 miles: an excess of 27.2%. In this problem the task was to orient and fly to the station along some specified track. Again this difference is largely a function of the distance flown while orienting. Although the absolute size of this difference is greater than the difference for problem II, its level of significance is slightly lower (.05 as compared with .02) because of the greater variability in the distributions of scores for this problem.

<u>In general</u>. In neither problem II nor III was there any overlap in the distributions for the two displays. In neither case was the best score for the symbolic display as good as the worst score for the pictorial display.

On problem IV the excess distance flown was negligible and did not discriminate between the two displays.

On the average, for all problems combined, the excess distance flown using the pictorial display was 1.6% of the average school solution distance as compared with an average excess distance of 9.1% for the symbolic (see Table 5).

TABLE 5

COMPARISON OF DISTANCES FLOWN ON ALL CORRECT SOLUTIONS BY EIGHT SUBJECTS USING THE PICTORIAL AND THE SYMBOLIC DISPLAYS
(in miles)

Displays	Total school solution dist.	Total distance flown	Total excess distance	Per cent excess dist.
Pictorial	380.2	386.2	6.0	1.6%
Symbolic	380.2	414.8	34.6	9.1%

TABLE 6

COMPARISON OF DISTANCE FLOWN OUTSIDE LIMITS ON AIRSPEED, ALTITUDE, OR BOTH, DURING 32 SOLUTIONS FLOWN BY EIGHT SUBJECTS ON EACH OF TWO DISPLAYS
(in miles)

	Problem I		Problem II		Problem III		Problem IV		Total	
Items	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.
Total dist. flown	128.2	139.5	82.2	103.3	75.4	115.9	156.2	156.5	442.0	515.2
Dist. out of limits	0.0	17.7	0.9	12.6	0.8	14.1	1.4	18.5	3.1	62.9
Per cent out of limits	0.0	12.7	1.1	12.2	1.1	12.4	0.9	11.8	0.7	12.3

Measure 3: Distance Flown Outside Flight Limits

Measure 3, the distance flown outside of established flight tolerances for altitude and airspeed (plus or minus 100 feet and 5 mph, respectively), was used as an index of pilot performance while engaged in the various navigation tasks using the two displays. These results are summarized in Table 6. The difference between the distance flown out of limits on each problem using two displays was judged significant by inspection. Table 6 shows that on all problems combined, 0.7% of the total distance flown using the pictorial display was outside limits on either altitude or airspeed, or both, as compared with 12.3% for the symbolic display. Between problem comparisons reveal that the subjects exceeded the tolerances approximately the same percentage of the time on each of the four problems, being out of limits about 1% of the time on each problem while using the pictorial display and about 12% of the time while using the symbolic. This would indicate either that the problems were all equally difficult, or that problem difficulty had little effect on time flown out of limits.

It was possible that one very poor pilot could have been responsible for all of the time flown out of limits for both displays. However, a further analysis of the records revealed that while only one subject exceeded the tolerances for airspeed using the pictorial display, seven different subjects did so using the symbolic. The altitude records showed that only two subjects exceeded the tolerances using the pictorial display while six were out of limits at one time or another using the symbolic.

Measure 4: Unnecessary Turns

Measure 4, the number of unnecessary turns (defined as turns of greater than 15 degrees away from the desired track), was designed as a measure of flight efficiency. Using the pictorial display only one unnecessary turn was made during the 32 problem solutions. Using the symbolic display 10 unnecessary turns were made. They were distributed among four of the eight pilots and seven of the 32 solutions. At least one unnecessary turn was made on each of the four problems (see Table 7). The salient feature of this measure is the fact that there was no good reason for such turns being made at all. The fact that 10 such turns were made during 32 problem solutions using the symbolic display indicates that the information presented was being misinterpreted frequently. Misinterpretations of this type border closely upon disorientation.

TABLE 7

COMPARISON OF THE NUMBER OF UNNECESSARY TURNS (GREATER THAN 15° AWAY FROM THE DESIRED TRACK) FLOWN BY EIGHT SUBJECTS ON FOUR PROBLEMS USING EACH OF TWO DISPLAYS

Display	Problem I	Problem II	Problem III	Problem IV	Total
Pictorial	0	0	0	1	1
Symbolic	4	2	3	1	10

Measure 5: "Hitting the Station"

For Measure 5, the deviations from the desired track when abeam of the station were measured in sixteenths of a mile and were used to compare the two displays for accuracy in hitting the station or, in problem IV, a point two miles from the station. On this measure the symbolic display proved more accurate than the pictorial on Problems I, II and III. This was to be expected, since the pip on the pictorial display covered an area on the scope representing an outside area ¼ mile in diameter. (The pip was about 1/16 inch in diameter and the five inch scope represented an outside area 20 miles in diameter.) Thus to hit the station accurately the subject had to keep an equal portion of the pip showing on each side of the selected track line, a very difficult visual discrimination. Furthermore, the difference on Problem I[7] is something of an artifact since with the pictorial display the pilots could anticipate the turn to the outbound track; hence they started the turn just before reaching the station.

Qualification. On Problem IV, in which the task was to bypass the station by two miles, greater accuracy was attained using the pictorial display. In this case, however, the results are spurious.[8] The accuracy of the patterns flown on this problem using the symbolic display was purely a function of timing the first turn correctly and holding the proper heading. According to the standard CAA change of altitude instructions for VOR (see Appendix IV), a pilot is supposed to be able to determine the bypass track he is making good over the ground by the application of a formula to the information supplied by the symbolic VOR display. This formula was found to be restricted to a special case and was unusable in this experiment. Therefore, without off-course computing equipment or DME, the pilot did not have the information necessary to make the appropriate corrections which would cause him to bypass the station by exactly two miles. (In actual practice the station is bypassed by four miles.) On the pictorial display this information was presented. Not only did the pip show the pilot's exact momentary position, but also the desired pattern was drawn on the track selector (see Figure 2), so that the pilot could see immediately whenever he deviated seriously from his desired flight path.

It is the opinion of the investigators that all of the results from this measure are suspect and should be evaluated very critically before considering them for purposes of selecting a display. As has been pointed out above, the results for two of the problems (I and IV) are

---

[7]Problem I: aircraft oriented and on course, subject continues flying to station, departs from station on different track.

[8]The change of altitude bypass procedure seems to be an inappropriate test of this equipment. It discriminated unfairly between the two displays on Measures 4 and 6, and it did not discriminate at all on Measures 1, 2 and 5.

obviously spurious. Furthermore, the pictorial display installation was sufficiently disturbed by the earth's magnetic field so that the pip was displaced in different amounts and in different directions depending upon the heading of the trainer.[9] Thus it was impossible to make an accurate determination of how well pilots can be expected to "hit the station" using such a display.

The inaccuracies introduced by the relatively large pip size for the small pictorial display have already been discussed. With a larger scope (perhaps ten inches in diameter rather than five inches) and/or a finer pip, much greater accuracy in hitting the station would be expected. Furthermore, some better way of showing heading, such as an arrow shaped pip, should further improve the accuracy of performance. With these modifications of the pictorial display, it does not seem unreasonable to expect accuracy on the final approach to the station to equal that obtained using the conventional cross-pointer instrument.

Measure 6: Bracketing Performance

Problems I and IV. Measure 6, the extent of the deviations from the desired track, pertains only to the pattern problems (I and IV). However, during the course of the experiment it became apparent that this measure discriminated unfairly between the two displays on the bypass problem (IV) for the same reasons discussed in relation to measure 5. Thus only the results for problem I will be reported. On this problem the task was to fly directly to the station from a known starting position and then fly away from the station along a different outbound track. The average deviations for seven[10] subjects scored at ½ inch intervals along the school solution track are shown graphically for each display in Figure 5.

Comparison of two displays. This figure reflects some of the differences in the characteristic types of bracketing performances obtained using the two displays. It will be noted, first, that inbound bracketing is

---

[9]Due to the earth's magnetic field, when the trainer was rotated manually the pip described an oval with a mean diameter of about ¼ inch. The displacement of the pip from its correct position was constant for any particular trainer heading. Thus before starting each problem, the pip was adjusted to its proper position for one particular heading, the one which would be the final heading for a correct problem solution, thus reducing the distortion to a minimum. This effect could probably be eliminated by adequate shielding of the equipment as discussed in Appendix II.

[10]One of the subjects made an incorrect solution on this problem using the symbolic display. Since this solution could not be scored on this measure, the scores for his correct solution of the problem using the pictorial display were also excluded.

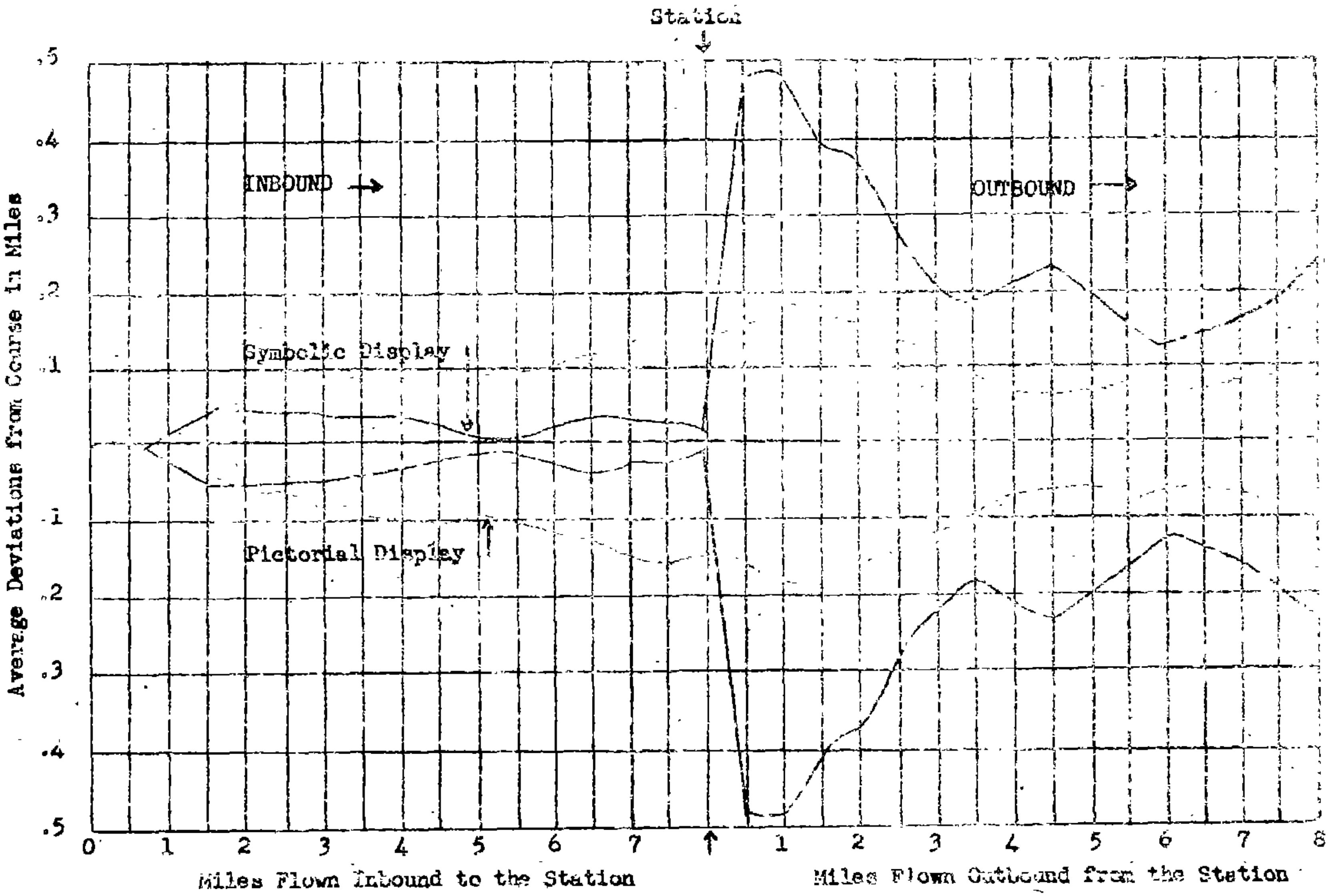


FIGURE 5. AVERAGE DEVIATIONS FROM COURSE FOR SEVEN PILOTS BRACKETING INBOUND AND OUTBOUND COURSES USING PICTORIAL AND SYMBOLIC VOR DISPLAYS.

more accurate using the symbolic display. However, outbound bracketing using the symbolic display is very inaccurate. The pilots were slow in making the turn to the outbound heading after passing the station and therefore considerably overshot the desired outbound track. This was to be expected since they did not have DME and could not anticipate their arrival at the station. Once they had overshot the outbound track they were forced to start bracketing the outbound course in order to get back on the track again. This outbound bracketing proved a very difficult task using the conventional cross-pointer instrument.

The accuracy of performance obtained on this problem using the pictorial display left something to be desired but can be explained partially by the inaccuracies in the instrument discussed previously in relation to accuracy in hitting the station (measure 5). It is considered significant however, that outbound bracketing using the pictorial display is no worse than inbound bracketing. Thus if the display were modified and improved, as suggested earlier, both inbound and outbound bracketing using the pictorial display should be as accurate as the inbound bracketing now obtained using the symbolic display.

Measure 7: "Orientation Time"

The final three measures (7, 8 and 9) pertain only to the two orientation problems (II and III). Measure 7, the time before starting the first turn or the "orientation time," is probably the most important single measure used in this experiment. This measure discriminates most critically between the two displays when used for orientation and track interception purposes, probably the most important uses of VOR equipment. The use of this measure assumes that the pilot spends the time from the start of the problem until he starts his first turn in orienting himself and making a decision as to which way to fly in order to initiate a solution to the problem. It is further assumed that by the time the pilot starts the first turn he has oriented himself and has made some directional decision. No assumption is made concerning the correctness of his orientation or his decision to fly in a certain direction.

Table 3 gives the distributions of orientation times for the eight subjects on the two problems using the two displays. On problem II the mean orientation time was 9.4 seconds using the pictorial display and 32.6 seconds using the symbolic. This difference was found to be significant at the .01 level by the t-test for correlated means. On problem III the mean time was 13.0 seconds for the pictorial as compared with 52.0 seconds for the symbolic. Here the difference was significant at the .02 level. Furthermore, inspection of Table 3 indicates that there was no overlap between the distributions for problem II. The fastest orientation using the symbolic display was slower than the slowest for the pictorial. The distributions for problem III overlapped in only one case.

TABLE 8

A COMPARISON OF "ORIENTATION TIMES" (MEASURE 7: TIMES TO FIRST TURN) FOR EIGHT SUBJECTS ON TWO PROBLEMS USING PICTORIAL AND SYMBOLIC FOR DISPLAYS

Subject	Problem II Pictorial	Problem II Symbolic	Problem III Pictorial	Problem III Symbolic
1	9 sec.	25 sec.	9 sec.	12 sec.
2	7	46	6	41
3	8	17	17	80
4	[illegible]	21	13	30
5	10	60	7	37
6	8	21	13	30
7	12	53	30	155
8	14	18	10	31
Sum	75	261	105	416
Mean	9.375	32.625	13.125	52.000
σ	1.996	16.317	7.201	42.948
σ_M	.754	6.167	2.721	16.232
r	.162		.911	
D	23.250		38.875	
σ diff.	6.090		13.799	
t	3.818		2.817	
P	.01		.03	

Measures 8 and 9: Analysis of First Turns

The results for measures 8 and 9, which deal with the direction of the first turn and the initial heading assumed, can be combined with the results for Measure 1, as they were in the previous experiment, so as to account for the outcome of each of the 16 orientation problem solutions flown using each display. The results of these analyses are shown in Tables 9 and 10.

All of the 16 orientation problems flown using the pictorial display were solved correctly. As shown in Table 9, in all cases the first turn was in the correct (more economical) direction, and in 14 of the 16 cases the turn was also to the correct initial heading. In the two cases in which an incorrect initial heading was assumed, the pilots subsequently made heading corrections in time to solve the problem as given.

Using the symbolic display the same pilots failed to solve four of the 16 orientation problems. As reference to Table 10 will indicate, in all 12 of the correct solutions, the first turn was in the more economical direction, but in four of these cases the turn was to an incorrect heading which was subsequently corrected. Considering now the four cases in which the problem was not solved, in three cases the first turn was in the correct direction and in one it was not. However, in only one case was a correct initial heading assumed as a result of the turn.[11]

COMPARISON WITH RESULTS OF PREVIOUS EXPERIMENT

In general the results obtained with the symbolic display in this experiment are directly comparable to those of the previous experiment. In the earlier experiment, 19% of the problems were unsolved. In this experiment 25% of the comparable orientation problems were unsolved. For the two experiments, respectively, 56% and 44% of the first turns were either in the less economical direction or to an incorrect heading, or both. The slightly lower percentage of first turn errors in the present experiment was to be expected since the scoring tolerance for heading was increased from 5 to 15 degrees.

In the two experiments combined, 48 solution records have been collected for orientation problems using the symbolic display, and in only one case did a turn to a correct initial heading fail to lead to a correct solution. (In that one case the problem would have been scored as correct if the pilot had not failed to notice passing the station.) In contrast, of the 21 turns to incorrect initial headings, nine proved to be the first false step toward an incorrect problem solution.

---

[11]In this one case the subject turned in the correct direction and assumed the proper heading, but passed the station without noticing it.

Since the results obtained for orientation problems using the symbolic display in the two experiments have been so similar, the discussion of the results of the first experiment is equally pertinent to the second. Both experiments emphasize the importance of rapid and correct initial orientation as reflected by the time to the first turn and the correctness of the heading assumed as a result of the first turn. Making a quick first turn to a correct initial heading almost invariably leads to a correct problem solution, while making a delayed first turn or one to an incorrect initial heading frequently results in a failure to solve a local navigation problem correctly.

CONCLUSION

The results of this experiment indicate that experienced instrument pilots are able to orient from an unknown position more rapidly and turn to a correct initial heading more frequently using the pictorial display than when using the symbolic display. Furthermore, using the pictorial display all problem solutions to date have been correct, while about 17% of all solutions using the symbolic display have been unsatisfactory. Of the solutions for problems which involved orienting from an unknown position, about 21% have been incorrect.

TABLE 9

CLASSIFICATION OF SOLUTIONS FOR 16 ORIENTATION PROBLEMS USING THE PICTORIAL DISPLAY ACCORDING TO OUTCOME, DIRECTION OF FIRST TURN AND HEADING ASSUMED

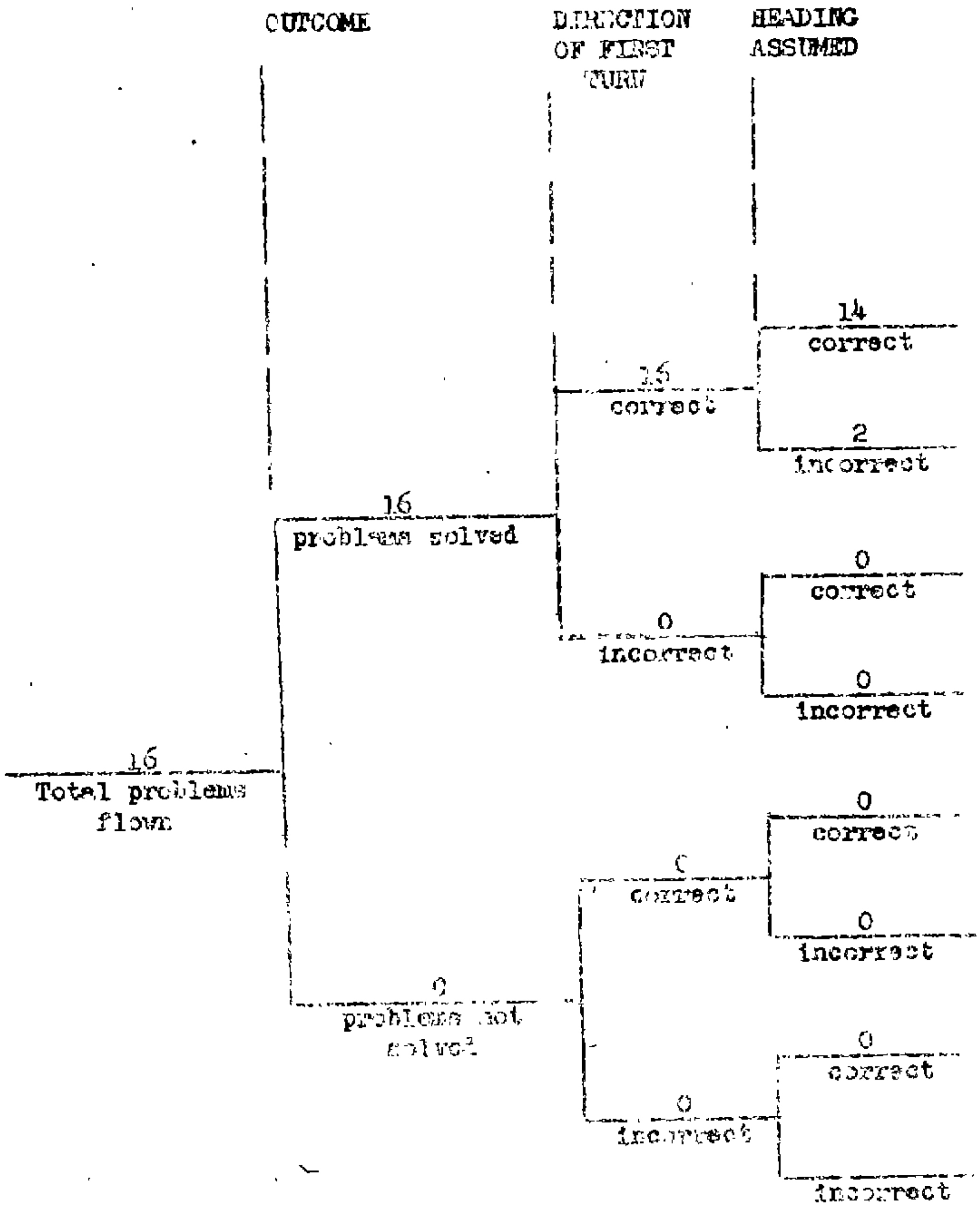
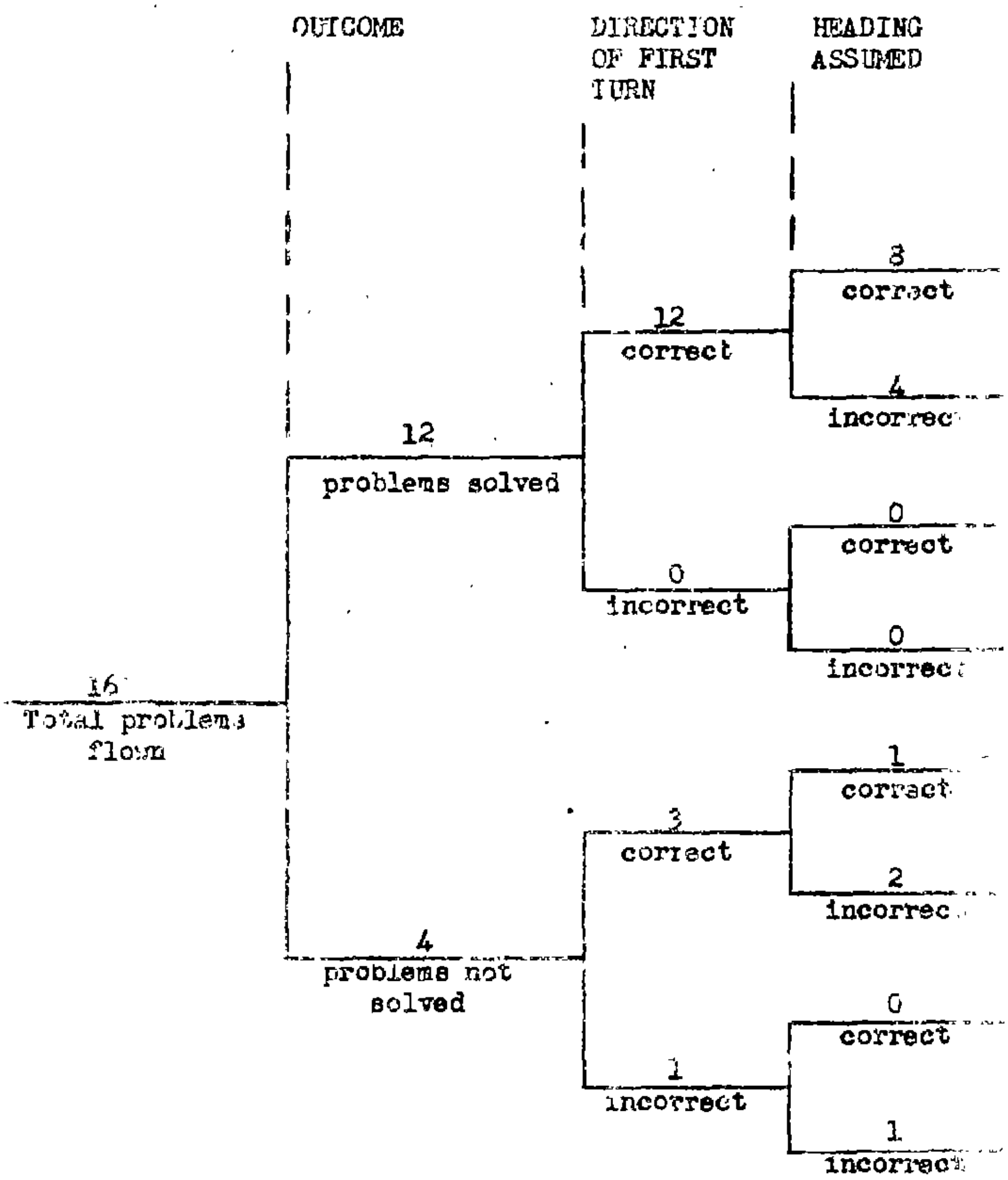


TABLE 10

CLASSIFICATION OF SOLUTIONS FOR 16 ORIENTATION PROBLEMS USING THE SYMBOLIC DISPLAY ACCORDING TO OUTCOME, DIRECTION OF FIRST TURN AND HEADING ASSUMED



[illegible] THE PICTORIAL [illegible] AS USED BY PRIVATE PILOTS IN THE LINK TRAINER

The experiment [illegible] provided a critical comparison between the pictorial and the symbolic VOR navigation displays as they are used by experienced [illegible] pilots. However, it is not enough to know that highly experienced pilots, with several thousand hours of flight time, find one type of display better than another. VOR equipment will soon come into use by private pilots with limited experience as an aid to contact cross-country navigation. If this expensive equipment is to be of maximum use to all concerned, the [illegible] display [illegible] should be [illegible] [illegible] [illegible] requirements.

[illegible] are certain general design principles for [illegible] display [illegible] to the [illegible] one would expect that the display [illegible] best for pilots of one level of experience [illegible] experience levels. To test that hypothesis [illegible] similar to the one just described [illegible] conducted using [illegible] private pilots of limited navigation experience and [illegible] either in the airplane or in the [illegible] trainer.

This experiment, conducted by Johnson, [illegible] and Smith, compared the performance of 15 [illegible] pilots using the conventional symbolic display with the performance of a second group of 15 pilots using the new pictorial type display. The [illegible] used in this experiment were the same as those used in the previous experiment. Since it is anticipated that private pilots will make use of VOR equipment as an aid to contact cross-country navigation, in this experiment the subjects were allowed to fly the solutions for navigation problems under contact conditions, that is, with the hood of the trainer open.

I. [illegible] OF THE EXPERIMENT

The plan of the experiment was as follows:

a. Thirty private pilots were trained to the same criterion or proficiency level in Link trainer flying ability.

b. These 30 subjects were divided into two equal groups:

Group A was trained in the use of the symbolic display.

Group B was trained in the use of the pictorial display.

c. Five navigation problems were selected which were designed to sample the various tasks which private pilots might be expected to perform using VOR equipment.

d. Each subject in each group performed five trials, each from a different starting position, on each of the five navigation problems using the display on which he had been trained.

e. The performances of the two groups using the different displays were evaluated and compared.

These five steps in the plan of the experiment will now be considered in greater detail.

Pre-training. The subjects were first instructed in flying the Link trainer. They were given a condensed instruction syllabus which included only the procedures and information which would be needed in order to fly the trainer through satisfactory solutions for the navigation problems. The syllabus included the following:

1. Cockpit familiarization.

2. Starting and stopping procedures.

3. Pitch, bank and straight and level flight.

4. Return to straight and level flight from a climbing or gliding attitude.

5. Turning flight.

The subjects were given a few practice trials after each of the above sections of the instruction syllabus. At the completion of Link instruction, the subjects were given a test of their ability to employ the skills they had learned during the instruction period. The test consisted of two flight patterns which included straight and level flight, standard rate turns and turns to specified headings. To pass the proficiency test each subject was required to complete both patterns within the flight tolerances of plus or minus 100 ft. for altitude, 5 degrees for direction and 10 mph for airspeed.

After a subject had successfully completed the flight proficiency test in the trainer, he was instructed in the use of the display which he would use for solving the experimental problems. All subjects using a given display received the same instructions. However, time was taken to answer any question which a subject had on the use of the display. In each case the instructions included first a brief explanation of the general use of VOR equipment for orienting from an unknown position and navigating according to some specified plan of flight.

Those subjects who were to use the symbolic display were instructed on the function and use of each instrument in the display. They were shown how to use the course line selector, the course line deviation indicator and the ambiguity indicator to determine their azimuth position in relation to the VOR station. They were shown how to use the course line selector to select a designated radial which they were to intercept and along which they were to make good a track either to or from the station. They were instructed in the procedures to be used in bracketing a course. They were shown how the directional gyro is used to determine and control heading.

Those subjects who were to use the pictorial display were told the meaning of each part of the display, that the scope was to be thought of as a map of the area about the VOR station which appeared in the center of the display. They were shown that the display was oriented with North at the top and that azimuth positions could be determined by reference to the compass rose about the circumference of the display. They were shown how the pip, which represented the aircraft, moved about the face of the scope giving a constant indication of present position. They were shown how to rotate the track selector line so as to select any radial along which they were to make good a track. They were shown how the directional gyro is used to determine and control heading.

Before starting a set of five trials for a given problem, each subject received specific instructions for that type of problem.

<u>Problems</u>. The five problems used in this experiment are listed below in the order in which they were presented and are presented graphically in Figure 6.

I. The subject was started on a known radial heading directly toward the station. He was required to fly directly to the station. A 10 mph wind was introduced at right angles to the desired track from either direction in a random order.

II. The subject was started from an unknown position and was required to orient and fly directly to the station. (No wind.)

III. The subject was started from an unknown position and was required to orient, fly directly to the station and then fly away from the station along a designated radial to the outer limit of the VOR range. (No wind.)

IV. The subject was started from an unknown position and was required to orient, intercept a designated outbound radial from the station and follow an outbound track along that radial to the limit of the VOR range. (No wind.)

V. The subject was started from an unknown position and was required to orient, intercept a designated inbound radial and fly to the station along that inbound track. (No wind.)

The problems were presented, as listed above, in the order of their predicted difficulty, except for problems IV and V which were believed to be of approximately equal difficulty. Each problem was presented five times in succession to each subject in an effort to obtain some estimate of the rate of improvement during early practice using the two displays. The subjects were started from different azimuth positions for each of the five trials on any given problem, but their starting positions were always approximately equidistant from the station for any problem. In the interception problems (problems IV and V) the radials to be intercepted, as well as the starting positions, were different for each trial, but the starting positions and designated radials were always in approximately the same relative position to each other.

The 25 problem solutions flown by each subject could not be completed in one testing session. In most cases three sessions were required.

Records. The performances were recorded by a tracing of the flight path made by the trainer recording crab, as in the previous experiment. In addition to the navigation task, the subjects were requested to hold the same flight tolerances which had been required for the passage of their Link trainer flight proficiency test. However, deviations in excess of these tolerances were not scored in this experiment, since for these private pilots the task was considered as a test of contact rather than instrument flight performance. This was unfortunate, since informal observation of the performances using the two displays indicated that these deviations should have been recorded and probably would have shown significant differences in favor of the pictorial display.

In all, 375 flight records were obtained for each display. They included 25 records for each of the 15 subjects in each group. The 25 records for each subject represented the five trials for each of the five problems. Since each of the 15 subjects in each group performed five trials on each problem, there were 75 records for each of the five problems for each display.

Scoring. The scoring system for these records was similar to that used in the previous experiment. Four of the five problems required the subject to orient himself for an unknown position. The other problem (Problem [illegible]) was a simple bracketing problem in which the subject was required to bracket a course straight in to the station from a known starting position. Altogether seven objective measures were used, three of which were applicable to the four orientation problems only, and one of which was applicable to the bracketing problem only. The other three measures were applicable to all problems.

The measures upon which the records were scored were as follows:

a. Measures applicable to all problems:

(1) Was the problem solved?

(2) If the problem was solved, what was the percentage of excess distance traveled (excess distance/correct distance × 100)?

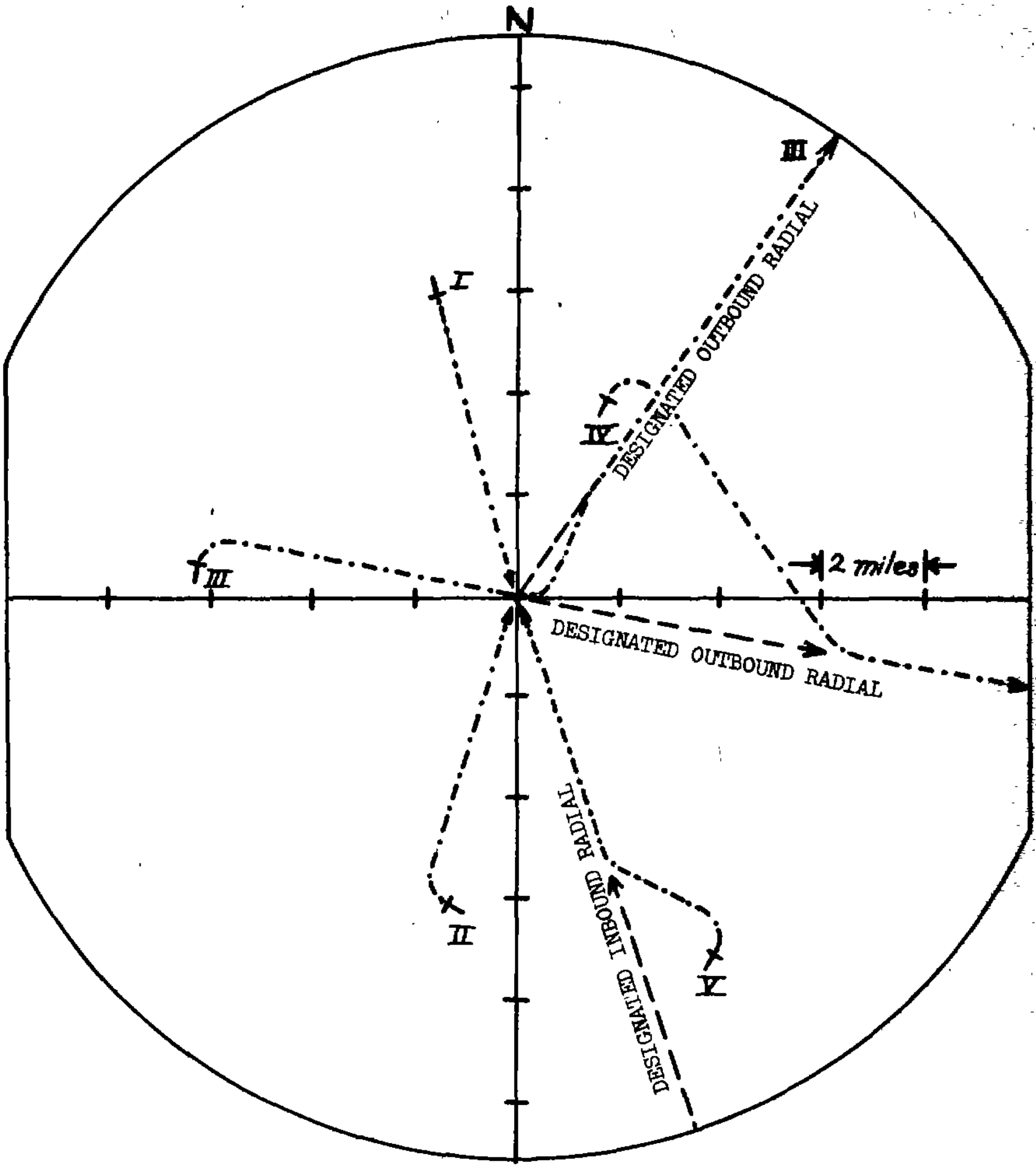


FIGURE 6. GRAPHIC ILLUSTRATION OF THE FIVE TYPES OF PROBLEMS WHICH WERE FLOWN BY PRIVATE PILOTS USING BOTH THE PICTORIAL AND THE SYMBOLIC VOR NAVIGATION DISPLAYS IN THE LINK TRAINER

(3) [illegible] than 15 [illegible] problem?

b. Measures pertinent to the bracketing problem only:

(4) What was the extent of the deviations from the designated track?

c. Measures pertinent to the loss orientation problems only:

(5) What was the distance flown from the start of the problem until the beginning of the first turn?

(6) Was the first turn in the correct (more economical) direction?

(7) Was the [illegible] turn to the correct heading?

It will be noted that two of the measures used in the previous experiment have been omitted here and two of them have been slightly altered. The measure "percentage of distance flown outside the established tolerances for altitude and airspeed" was omitted for reasons already discussed (although as it turned out this measure probably should have been included). The measure "extent of errors made in hitting the station" was omitted because, in the previous experiment, it proved to reflect little more than the differences in the inaccuracies of the indications of the particular instruments used in the trainer.

In measure 3, above, the number of unnecessary or excess turns was determined on a different basis than in the previous experiment. In that experiment only turns of more than 15 degrees away from the desired track were counted. Scored in this manner, this measure was an index of incorrect or "harmful" directional decisions. The fact that such turns were made frequently by experienced instrument pilots using the symbolic display and almost never using the pictorial display was considered a significant piece of information. In the present experiment, all turns of greater than 15 degrees -- whether toward or away from the desired track -- were counted. Scored in this way, this measure becomes an index of turning activity in general, which reflects inefficiency in intercepting and bracketing a course.

Measure 5, the "discrimination" or "orientation" time, was based upon the distance flown, rather than the time, from the start of the problem until the beginning of the first turn. The two measures are practically equivalent.

All other measures (1, 2, 4, 6, and 7) were scored in the same manner as in the previous experiment.

2. THE RESULTS OF THE EXPERIMENT

Measure 1: Incorrect Problem Solutions

Considering all criteria for measure 1, 39 of the 375 problems flown using the symbolic display were unsolved. Incorrect solutions were flown on each of the five types of problems and were distributed among 12 of the 15 subjects who used the display. The number of incorrect solutions for each of the five problem types was, respectively, 2, 7, 4, 16 and 10. As in the previous experiment, all of the problems flown using the pictorial display were solved successfully.

Types of errors in incorrect solutions. An examination of the 39 incorrect solutions flown using the symbolic display reveals that each of the failures can be placed in one of four categories, depending upon what the pilot did which rendered the solution unsatisfactory. In Table 11 the 39 unsuccessful solutions are classified according to problem and reason for failure.

TABLE 11

CLASSIFICATION OF 39 INCORRECT PROBLEM SOLUTIONS USING THE SYMBOLIC DISPLAY ACCORDING TO PROBLEM AND REASON FOR FAILURE

Reason for Failure	Problem[1] I	II	III	IV	V
(a) The pilot flew out of the VOR range before intercepting the desired track	0	0	0	12	5
(b) The pilot became disoriented while attempting to intercept or bracket a desired track	2	0	2	3	0
(c) The pilot flew to (or away from) the station along an incorrect track	0	7	2	1	1
(d) The pilot flew past the station along an incorrect track	0	0	0	0	4

[1] Problem I: Subject flies on known radial directly to station; Problem II: From unknown position, subject orients and flies directly to station; Problem III: From unknown position subject orients and flies directly to station and then away on designated radial; Problem IV: From unknown position subject orients and intercepts designated outbound radial from station; Problem V: From unknown position subject orients, intercepts designated inbound radial and flies to station.

Flying out of range. The above table shows that [illegible] a pilot flew out of the VOR range[2] before intercepting the desired track. Twelve of these cases occurred on Problem IV in which the task was to orient, intercept a designated outbound radial and then fly away from the station. In three of these cases the pilot made no turn whatever but simply flew straight ahead from his starting position until he passed out of the VOR range. In several other cases a pilot did make one or more small turns which bore no relation to the correct track. There was no evidence that the pilots were correctly oriented at any time during these trials. In other cases the pilots apparently were correctly oriented but failed to intercept the desired track because they did not take up a sufficient angle of interception. The remaining five cases in this category occurred on problem V in which the task was to orient, intercept a designated inbound radial and fly to the station. Once again the pilots apparently were at no time correctly oriented during these trials.

"Disorientation." The second reason-for-failure category includes six cases in which a pilot, at some time during the trial, "obviously" became disoriented. This implies that at some time during the trial the pilot was apparently correctly oriented. In most of these cases the pilot did eventually complete the task as set by the problem,[3] and in none of these cases did a pilot fly out of the VOR range without getting on the desired track at one time or another. Two of these cases occurred on Problem I in which the task was simply to bracket a course from a known position straight in to the station. In each case the pilot's bracketing efforts became so "violent" that he was soon making turns of 180 degrees or more with short tangents back and forth at right angles to the desired track. In each case the station was missed completely. The one case on Problem III involved bracketing an outbound radial from the station. The pilot apparently misinterpreted the reading of the course line deviation indicator, thinking he was on one side of the course when he was actually on the other. He flew away from the course for several minutes trying to intercept it. Eventually he discovered his error and made the appropriate correction. In the three cases of disorientation on Problem IV the pilot wandered about the map with an apparently random selection of headings until he eventually intercepted the designated outbound radial from the station. The distance flown on these three trials was excessive, and in each case the record indicates that the pilot was definitely lost for several minutes.

Flying wrong track. The third reason-for-failure category in Table 11 includes 12 cases in which a pilot flew to (or away from) the station along some track other than that required by traffic control as stated in the problem. Seven of these cases occurred on Problem II and resulted either from the pilot's taking too long to make his initial orientation or turning to an incorrect initial heading. In either event the pilot flew to a

---

[2]The range of the simulated VOR equipment used in the Link trainer was slightly over 10 miles.

[3]Criteria for "incorrect solution" are discussed on page 24.

position from which a direct approach to the station brought him in along an incorrect track (outside of the plus or minus 15 degree tolerance). There were three failures of the same type on Problem III. In the one case which occurred on Problem IV the pilot made his initial turn to the correct heading and intercepted the designated outbound radial, but he made no effort to bracket it. He flew right across the desired track on his interception heading and continued flying away from it until he passed out of the VOR range. In the one case which occurred on Problem V the pilot selected an incorrect inbound radial on the course selector. The track he flew was approximately 25 degrees off from the required inbound track to the station.

Flying past the station. The fourth reason-for-failure category includes four cases, all of which occurred on Problem V in which the task was to fly to the station along some particular track as specified by traffic control. In three of these cases the pilot flew past the station before intercepting the designated track. In the fourth case the pilot flew across the track but did not get back on before passing the station.

Practice effects. In addition to giving a direct comparison of private pilot performances using the pictorial and symbolic displays, this experiment was designed to yield some estimate of the improvement in performance of private pilots during the early stages of practice in the use of the two displays. Since there were no incorrect problem solutions using the pictorial display, this measure provided no estimate of the rate of improvement of the pilots who used this display. (There was no room for improvement on this measure). However, there were sufficient incorrect solutions using the symbolic display to show that there was consistent improvement from first trials to fifth trials on all problems combined. Of the 39 incorrect solutions using the symbolic display, 14 occurred on first trials of all problems, ten on second trials, six on third trials, seven on fourth trials and two on fifth trials. No accurate estimate could be made of the improvement from problem to problem since the relative difficulty of the problems was not known, although in general they were progressively more difficult.

The reduction in the number of incorrect solutions from first to fifth trials on all problems can be attributed in part to general improvement in the use of the symbolic display but probably in large part to practice in solving problems of a given type during five successive trials.

Measure 2: Excess Distance Flown

On measure 2, the average excess distances flown for all solutions in which the problem task was completed[4] were significantly less using the

---

[4]On 12 of the incorrect solutions using the symbolic display on Problem IV and five of the incorrect solutions using the symbolic display on Problem V a subject flew out of the VOR range before intercepting the

pictorial display [illegible] of all prob-
lems except [illegible] Table [illegible] gives a comparison of the average dis-
tances flown, the average school solution distances, the average excess
distances and the per cent excess distances flown using the two displays
on each of the five problems.

<u>Problem I.</u> On the first problem the task was to bracket a course straight in to the station from a known starting position, and on this problem the excess distance flown was insignificant for both displays, being less than 2% in each case. Even in this case, however, the excess distance flown using the pictorial display was slightly less than it was for the symbolic display, although the difference was not significant.

<u>Problem II.</u> On problem II, in which the task was to orient from an unknown position and then fly directly to the station, the excess distance flown using the pictorial display was 7.09% of the school solution distance compared with an excess distance of 16.94% for the symbolic display. The average excess distances flown were 0.470 and 1.125 miles respectively. The difference was significant at the .01 level of confidence. The records indicate that this difference was primarily a function of the time spent orienting before making the first turn and secondarily a function of the correctness of the heading assumed as a result of the first turn. The subjects using the pictorial display almost always turned quickly to the correct inbound heading. The subjects using the symbolic display frequently flew straight ahead for as much as two minutes before making any turn at all, and their first turns were frequently to an incorrect heading which later had to be corrected. Only one initial turn was made to an incorrect heading on the 75 trials using the pictorial display on this problem. Thus the significant difference in the distances flown on this problem using the two displays was apparently a consequence of the greater efficiency in using the pictorial display to orient from an unknown position.

<u>Problem III.</u> On problem III, in which the task was the same as in problem II except that after passing the station the pilots had to depart from the station along some designated outbound radial, the excess distance flown was once again significantly less at the .01 level using the pictorial display. The average excess distance for the pictorial display was 0.188 miles, an excess of only 1.05%, as compared with 0.643 miles, an excess of 3.58%, for the symbolic. Although this problem was in general

---

4(Cont.) desired track and therefore could not complete the task set by the problem. In each of these cases the distance flown before passing out of the VOR range was less than the school solution distance. These distance scores were not used when computing the means for the 15 subjects who used the symbolic display. However, the excess distances flown on all incorrect solutions in which the problem task was eventually completed were included together with distances flown on correct solutions for computing these means upon which the excess distance comparison was based.

TABLE [illegible]

[illegible] OF THE AVERAGE EXCESS DISTANCES FLOWN FOR 75 TRIALS ON EACH OF FIVE [illegible] USING THE PICTORIAL AND SYMBOLIC DISPLAYS

[illegible] are expressed in miles. Each value is based upon 15 subject means. In most cases the [illegible] were based upon five trials. However, in those cases in which a subject flew out of [illegible] completing the problem task, his score for that trial was omitted. The standard [illegible] are based upon subject means rather than individual trials and thus reflect between in[illegible] variability. [illegible] df = (2N-2), or 28, since the t's are based upon independent groups of [illegible]

Problem	I		II		III		IV		V	
[illegible]	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.
[illegible]	[illegible].270	[illegible].315	[illegible].111	[illegible].765	[illegible].168	[illegible].677	[illegible].831	[illegible].020	8.899	[illegible].328
[illegible]	[illegible].305	[illegible].290	[illegible]	5.640	17.980	17.[illegible]	[illegible].780	11.676	8.520	[illegible].529
[illegible] excess [illegible]	0.073	0.[illegible]3	0.471	1.125	0.188	[illegible]	[illegible].241	[illegible].344	0.379	1.799
[illegible]	[illegible]%	[illegible].023%	[illegible].053%	[illegible].945%	1.046%	[illegible].576%	[illegible]%	20.075%	4.448%	21.093%
	[illegible].089	[illegible]	[illegible].276	0.716	[illegible].257	0.479	0.725	1.691	0.355	1.074
[illegible] $= \bar{x}_s - \bar{x}_p$	0.040		0.654		[illegible]		[illegible].300		1.420	
[illegible]	[illegible].036		[illegible]		[illegible]		[illegible]		0.302	
	[illegible].055		[illegible]90		[illegible].36		2.048		4.[illegible]	
[illegible]	[illegible]8		28		28		28		28	
[illegible]	[illegible]		[illegible]		[illegible]		[illegible]		[illegible].001	

solved more efficiently than [illegible]; the lower percentages of excess distance are partially a function of the long additional outbound tangent, which made the total solution distance over twice as long as problem II.

In this experiment the subjects were instructed not to start the turn to the outbound radial before passing the station, as the subjects in the previous experiment frequently did using the pictorial display. For this reason the difference in the distances flown on this problem using the two displays in this experiment was almost exclusively a function of the time spent orienting before making the first turn to the inbound heading. Thus the discussion of problem II is equally applicable to problem III in this respect.

Problem IV. On problem IV, in which the task was to orient from an unknown position and then intercept and fly away from the station along some designated outbound radial, the excess distance flown still favored the pictorial display, this time at the .02 level of confidence. The average excess distances using the pictorial and symbolic displays were 1.041 and 2.344 miles respectively, the per cent excess being 8.84% and 20.08% respectively. On this problem the excess distances flown were a function not only of the time spent orienting but also of the efficiency of the two displays when used for intercepting a desired track. The subjects using the pictorial display could see directly whether or not their interception headings were causing them to intercept the desired track at an efficient angle. Such information is not provided directly by the symbolic display.

Problem V. On problem V the excess distance results favored the pictorial display even more strongly, this time at the .001 level of confidence. The task on this problem was to orient and then intercept and fly to the station along some designated track. It is on this type of task that the pictorial display has consistently shown its greatest superiority. In this case, the excess distance averaged 0.379 miles for the pictorial display and 1.799 miles for the symbolic, the difference between the two being significant at the .001 level, and the per cent excess being 4.45% and 21.09% respectively. The task is similar to the task in problem IV, except that the pilot must fly inbound; and as in problem IV, the difference is due to the greater efficiency in intercepting a designated track as well as to the rapid orientations which are made possible by the pictorial display.

In general. Thus on problems which involved orienting from an unknown position and on problems which involved intercepting some designated radial, whether inbound or outbound, the private pilots who used the pictorial display in this experiment solved their problems more economically than an equivalent group of private pilots who used the symbolic display. On the one problem which involved a straight-in bracketing task, the two displays were used about equally well in terms of excess distance flown.

As was stated previously, the excess distance comparisons which have just been made were based upon all solutions in which the problem task was completed. This requirement caused 17 of the 75 solutions flown with the symbolic display to be eliminated from consideration in making these comparisons. In Table 13 the average excess distances and the per cent excess distances are given for all trials using each display. In addition the table gives the corresponding values for all correct solutions and all incorrect solutions, and then finally for those incorrect solutions in which the task was completed and those in which it was not. The table also shows the number of solutions upon which each value is based.

In general the table speaks for itself. However, it should be noted that on incorrect solutions in which the problem task was eventually completed (using the symbolic display) the per cent excess distance flown was much greater than on correct solutions. This was true for each of the five problems. However, on these incorrect solutions on problems IV and V in which the subjects flew out of the VOR range before completing the problem task, the average distances flown were, respectively, about 30% and 20% less than the school solution distances. On problem IV, 12 of the 16 incorrect solutions were of this type with the result that the average distance flown on all incorrect solutions of this problem was less than the school solution distance. This served to reduce in a spurious manner the value of the average excess distance for all 75 trials using the symbolic display on this problem. It was for this reason that the statistical comparisons of the distance results for the two displays were based upon only those solutions in which the problem task was completed.

<u>Practice effects</u>. The effects of practice during the five successive trials on each problem are shown in Table 14 in terms of the average excess distances flown. These results are not as clear cut as might be expected. The average excess distances flown during the five successive trials on all problems could have been tested for improvement by the analysis of variance technique. However, the test was considered unnecessary since the values appeared so irregular that the improvement for both displays could be judged insignificant by inspection. The variability in the excess distances flown on the five trials for each of the five problems using either display appears to be little more than a matter of chance.

The first three problems required the pilots to fly directly to the station. Apparently these pilots could orient from an unknown position and fly directly to the station about as economically as private pilots could ever be expected to do using the two displays.

The fourth and fifth problems were much more difficult, and while the solutions using the pictorial display were quite efficient, the solutions using the symbolic display were not so efficient. Apparently five trials on each of these problems was not sufficient practice for the pilots to show any marked improvement in the economy with which they solved either of the problems using either display in terms of this particular measure.

Measure 2: Unnecessary Turns

Measure 2, the average number of turns of greater than 15 degrees made in solving each of the problems, was [illegible]

TABLE [illegible]

AVERAGE EXCESS DISTANCES FLOWN USING THE PICTORIAL AND SYMBOLIC DISPLAYS CLASSIFIED ACCORDING TO THE OUTCOME OF THE PROBLEM SOLUTION
(in miles)

PROBLEM	I		II		III		IV		V	
DISPLAY	Pic.	Symb.	Pic.	Symb	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.
Totals	75	[illegible]	75	75	75	75	75	75	75	75
Average excess distance	0.079	0.10[illegible]	0.471	1.125	0.188	0.643	1.041	1.151	0.379	1.505
Per cent excess distance	[illegible]	1.[illegible]	7.09%	16.94%	1.05%	3.58%	8.84%	9.77%	4.45%	17.65%
Correct Totals	75	75	75	68	75	71	75	59	75	65
Average excess distance	0.079	0.09[illegible]	0.471	0.965	0.188	0.447	1.041	1.964	0.379	1.564
Per cent excess distance	1.18%	[illegible]	7.09%	14.53%	1.05%	2.49%	8.84%	16.89%	4.45%	18.33%
Incorrect Totals	0	[illegible]	0	7	0	4	0	16	0	10
Average excess distance		[illegible]		2.685		4.100		-1.306		1.120
Per cent excess distance		[illegible]		40.50%		22.87%		-11.65%		[illegible]
Incorrect: Task Completed		[illegible]		7		4		4		5
Average excess distance		[illegible]		2.685		4.100		5.875		3.940
Per cent excess distance		1[illegible].74%		40.50%		22.87%		47.57%		46.57%
Incorrect: Not Completed		0		0		0		12		5
Average excess distance								-3.700		-1.700
Per cent excess distance								-30.02%		-20.26%

(in miles)

[illegible] ... subjects
for all [illegible] ...

[illegible]	DISPLAY	SCALE 1	2	[illegible]	4	5
[illegible]	Pictorial	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Symbolic	[illegible]	[illegible]	[illegible]	0.02	[illegible]
[illegible]	Pictorial	[illegible]	0.68	[illegible]	[illegible]	[illegible]
	Symbolic	[illegible]	1.05	0.77	[illegible]	[illegible]
[illegible]	Pictorial	[illegible]	-0.24	[illegible]	0.39	-0.05
	Symbolic	[illegible]	[illegible]	0.69	1.07	[illegible]
IV	Pictorial	[illegible]	1.02	[illegible]	[illegible]	[illegible]
	Symbolic	[illegible]	2.29	[illegible]	3.01	[illegible]
V	Pictorial	[illegible]	0.67	0.20	[illegible]	[illegible]
	Symbolic	[illegible]	0.94	[illegible]	[illegible]	[illegible]
[illegible]	Pictorial	[illegible]	[illegible]	2.42	[illegible]	1.62
	Symbolic	6.71	4.85	5.30	6.80	5.15

efficiency. When the minimum number of turns necessary for a correct solution of a given problem is subtracted from the average number which was actually made on that problem, the remainder becomes an index of unnecessary turning activity.

Pictorial vs. symbolic displays. Table 15 gives a comparison of the turning activity obtained with the pictorial and the symbolic displays. The table shows the average number of turns which were made on correct solutions by each subject during his five trials on each problem. The distributions of average performances for the 15 subjects in the two groups are then compared by use of the t-test for differences between independent means.

The subjects who used the pictorial display made on the average less than one unnecessary turn per solution on all problems. The subjects who used the symbolic display averaged more than one unnecessary turn on their correct solutions for all problems and made an average of 2.52 unnecessary turns on problem III. On the incorrect problem solutions made using the symbolic display, which were excluded when computing the averages shown in Table 15, the number of turns ranged from less than the minimum number necessary for a correct solution to as many as 12 turns on one incorrect solution of problem IV. For example, of the 16 incorrect solutions which were made on problem IV using the symbolic display, there were three cases in which a subject made no turn at all, three more in which only one turn was made (the minimum necessary number was two), and three cases at the other extreme in which ten or more turns were made.

The results of the t-tests indicate that the differences for problems I and II, while small, are significant at the .10 level of confidence. The differences are much more pronounced on problem III which involved outbound bracketing as well as orientation and inbound bracketing and on problems IV and V which involved intercepting a designated radial as well as orientation and bracketing. The differences on problem III and V are significant at the .001 level of confidence and on problem IV at the .05 level.

The results from this measure of unnecessary turning activity demonstrate clearly the superior over-all efficiency of the pictorial display for use in planning and executing some of the more difficult common navigation tasks. In addition these results provide excellent material for an analysis of the effects of practice and of differences in problem difficulty upon performance using the two displays. The average numbers of unnecessary turns made by 15 subjects during each of five trials on each of the five problems while using the pictorial and symbolic displays, respectively, are shown in Table 16 and 17. Each table includes a summary of the analysis of variance for the data presented.

Practice effects. Considering practice effects first, Table 16 shows a small but consistent reduction in the average number of unnecessary turns made from first to fifth trials on all problems combined using the pictorial display. However [illegible] high level starting from the

[illegible] OF AVERAGE NUMBER OF [illegible] OF [illegible] OF THE FIVE
PROBLEMS USING THE [illegible] DISPLAYS

The numbers in the body of the table represent the average number of turns of greater than 15 degrees made by a given subject on a given problem. The averages are based upon all correct solutions which were flown during a subject's five trials on the problem. Subjects 1 to 15 used the pictorial display, and subjects 16 to 30 used the symbolic display.

Problem:		I		II		III		IV		V	
Subject		Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.
1	16	1.0	1.0	1.5	1.0	2.2	4.8	2.4	2.8	2.0	3.0
2	17	0.4	0.6	1.4	1.8	2.4	3.8	2.0	6.0	2.2	4.4
3	18	0.4	0.6	2.[illegible]	1.8	4.6	4.6	3.8	2.8	2.2	3.8
4	19	3.0	2.2	2.[illegible]	3.2	3.8	5.4	2.4	7.5	2.0	4.8
5	20	0.0	1.8	1.6	1.6	2.6	5.2	2.4	3.5	2.0	3.0
6	21	0.2	0.4	1.4	[illegible]	2.6	3.8	2.6	2.2	2.4	2.4
7	22	0.2	2.0	1.2	2.6	2.0	5.8	2.4	4.0	2.2	3.2
8	23	0.4	0.2	2.2	1.2	5.0	3.2	3.0	2.3	2.4	3.3
9	24	0.2	0.8	1.2	2.0	3.0	4.4	3.0	4.2	2.6	3.7
10	25	1.2	1.0	2.4	2.4	3.8	3.0	3.0	2.2	4.0	3.6
11	26	0.2	1.2	1.6	2.8	3.0	3.3	3.0	3.5	2.4	2.8
12	27	0.0	0.8	1.6	3.0	2.4	5.8	2.2	2.8	2.2	3.0
13	28	0.4	1.0	1.4	3.0	2.0	4.8	2.2	3.2	2.0	3.3
14	29	0.0	0.8	2.0	2.0	2.2	5.5	3.2	2.7	2.8	3.0
15	30	0.8	1.4	1.2	1.8	2.8	4.4	2.5	3.6	2.4	3.2
Mean		0.56	1.05	1.71	2.09	2.81	4.52	2.61	3.56	2.39	3.37
Number Necessary		0.	0.	1.	1.	2.	2.	2.	2.	2.	2.
Average Number Excess		0.56	1.05	0.71	1.09	0.81	2.52	0.61	1.56	0.39	1.37
Diff.		0.49		0.38		1.71		0.95		0.98	
σ diff.		0.250		0.211		0.300		0.399		0.201	
t		1.960		1.801		5.700		2.381		4.876	
df		28		28		28		28		28	
P		0.10		0.10		0.001		0.05		0.001	

TABLE 16

AN ANALYSIS OF THE EFFECTS OF PRACTICE AND DIFFERENCES IN PROBLEM DIFFICULTY AS REFLECTED BY UNNECESSARY TURNING ACTIVITY USING THE PICTORIAL DISPLAY

The numbers in the body of the table represent the average number of unnecessary turns made by 15 subjects during each of five trials on each of five problems. The averages are based upon the scores for all trials in which the problem was solved correctly. The table includes a summary of the analysis of variance for the data presented.

Problem	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Sum	Mean
I	1.20	0.53	0.27	0.27	0.53	2.8-	0.56
II	1.07	0.93	0.60	0.73	0.20	3.53	0.71
III	1.13	1.27	0.93	0.33	0.40	4.06	0.81
IV	0.87	0.33	0.73	0.47	0.67	3.07	0.61
V	0.20	0.53	0.20	0.60	0.40	1.93	0.39
Sum	4.47	3.59	2.73	2.40	2.20	15.39	(3.08)
Mean	0.89	0.72	0.55	0.48	0.44	(3.08)	0.62

Source of Variance	Sum of Squares	df	Variance Estimate	F	Level of Significance
Between trials	0.710	4	0.178	2.094	n.s.
Between problems	0.513	4	0.128	1.506	n.s.
Residual	1.366	16	0.085		
Total	2.589	24			

AN ANALYSIS OF THE EFFECTS OF PRACTICE AND DIFFERENCES IN PROBLEM DIFFICULTY AS REFLECTED BY UNNECESSARY TURNING ACTIVITY USING THE SYMBOLIC DISPLAY

The numbers in the body of the table represent the average number of unnecessary turns made by 15 subjects during each of five trials on each of five problems. The averages are based upon the scores for all trials in which the problem was solved correctly. The table includes a summary of the analysis of variance for the data presented.

Problem	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Sum	Mean
I	2.29	0.93	1.00	0.40	0.73	5.35	1.07
II	1.45	1.15	0.67	0.93	1.29	5.49	1.10
III	3.38	3.47	2.00	2.15	1.67	12.67	2.53
IV	2.56	1.15	2.09	0.67	1.14	7.61	1.52
V	1.93	1.60	1.23	1.43	1.00	7.19	1.44
Sum	11.61	8.30	6.99	5.58	5.83	38.31	(7.66)
Mean	2.32	1.66	1.40	1.12	1.17	(7.67)	1.53

Source of Variance	Sum of Squares	df	Variance Estimate	F	Level of Significance
Between trials	4.828	4	1.207	5.831	.01
Between problems	7.074	4	1.769	8.546	.001
Residual	3.309	16	0.207		
Total	15.211	24			

first trial on each type of problem that the gradual subsequent improvement did not prove statistically significant. What little improvement there was occurred during the earlier problems only. For the pilots who used the symbolic display, however, performance during initial trials on all types of problems was most inefficient, and their improvement with practice, as reflected by the reduction in the average number of unnecessary turns during subsequent trials, did prove significant at the .01 level (see Table 17). Apparently there was little transfer from one problem to the next, for the pilots had to learn how to use the display for solving each new type of problem as it was presented.

Differences in problem difficulty. The analysis of the effects of differences in problem difficulty provides another striking comparison between the two displays. These analyses are also summarized in Tables 16 and 17. The experiment was designed so that the five problems were presented in an order which corresponded approximately with their increasing difficulty. However, the pilots who used the pictorial display made no more unnecessary turns on the supposedly more difficult problems than they did on the easier problems. The averages for the various problems did not differ significantly one way or the other. It is possible that there was a great amount of transfer from practice on one type of problem to performance on other subsequent problems. This is unlikely however, in view of the insignificant improvement from trial to trial on problems of the same type. It seems more reasonable to conclude that when the pictorial display was used all of the problems became equally difficult, or rather they became equally easy. This is supported by the fact that all problems were solved correctly from the very first trial by all pilots who used the pictorial display.

For the pilots who used the symbolic display the averages for the various problems differed significantly at the .001 level of confidence. Relatively few unnecessary turns were made on problems I and II which involved flying directly to the station. More unnecessary turns were made on problems IV and V which involved intercepting specified radials to or from the station. The greatest number of unnecessary turns was made on problem III which involved outbound bracketing, among other things. In general the larger numbers of unnecessary turns are associated with problems of greater difficulty.

Number of turns and length of problem. Although the number of unnecessary turns corresponds roughly with the estimated relative difficulty of the problems, it bears an even closer relationship to the over-all length of the various problems. The length of the average school solution distances for the five problems ranged from about six miles on problem I to about 18 miles on problem III. It will be noted that the smallest number of unnecessary turns occurred on problem I and the largest number on problem III. As a matter of fact, the pilots who used the symbolic display made about 0.156 turns per mile of problem solution distance on all problems. The respective averages for the five problems were: 0.173, 0.166, 0.141, 0.130 and 0.169 unnecessary turns per mile of solution distance. The product moment correlation between average number of unnecessary turns and problem solution distance was .98. Although a correlation coefficient based upon only five pairs is of little reliability, a coefficient of .98 is a most uncommon value. The implication is that when pilots were using the symbolic display they tended on the average to make an unnecessary turn about every six miles no matter what type of problem they were solving.

It is difficult to see just how this strange piece of information fits into the picture and to decide just how unnecessary turning activity is related to problem difficulty when using the symbolic display, especially when one considers that there was no relation between the number of unnecessary turns made using the pictorial display and the length of the problem solutions.

<u>In general</u>. Considered together, the results for the two displays on this measure can best be explained something like this. Pilots have to learn how to use the symbolic display for solving each new type of problem that is presented. Using the pictorial display this is not the case; the index of desired performance is always directly apparent for any type of problem the first time it is encountered. Performance on first trials using the pictorial display left little room for improvement during subsequent trials. For those using the symbolic display average performance on first trials for any problem was always less efficient than average performance on fifth trials for the preceding problem. Following the inefficient first trials on each problem there was significant improvement during subsequent trials.

The conclusion follows that, although pilots with sufficient practice using the symbolic display might learn to solve frequently encountered problems as well as they do with the pictorial display, their performance would often be unsatisfactory when they encountered new problems, especially in emergency situations.

<u>Measure 4: Bracketing Performance</u>

On measure 4 another comparison of performance using the pictorial and symbolic displays was obtained by measuring the deviations from the desired track made while bracketing a specified course. This measure was applied to problem I to obtain an estimate of inbound bracketing performance from a known position straight in to the station. For an estimate of the performance to be expected from private pilots on bracketing outbound from the station along a specified course, the last half of problem III was used. The first half of problem III could not be used because the pilots were started from an unknown position and had a 15 degree tolerance in the courses which they could elect to bracket inbound.

Figure 7 gives a graphic representation of the bracketing performance of the two groups of subjects who used the two displays. The deviations from the desired track were scored at 1/2 mile intervals along the

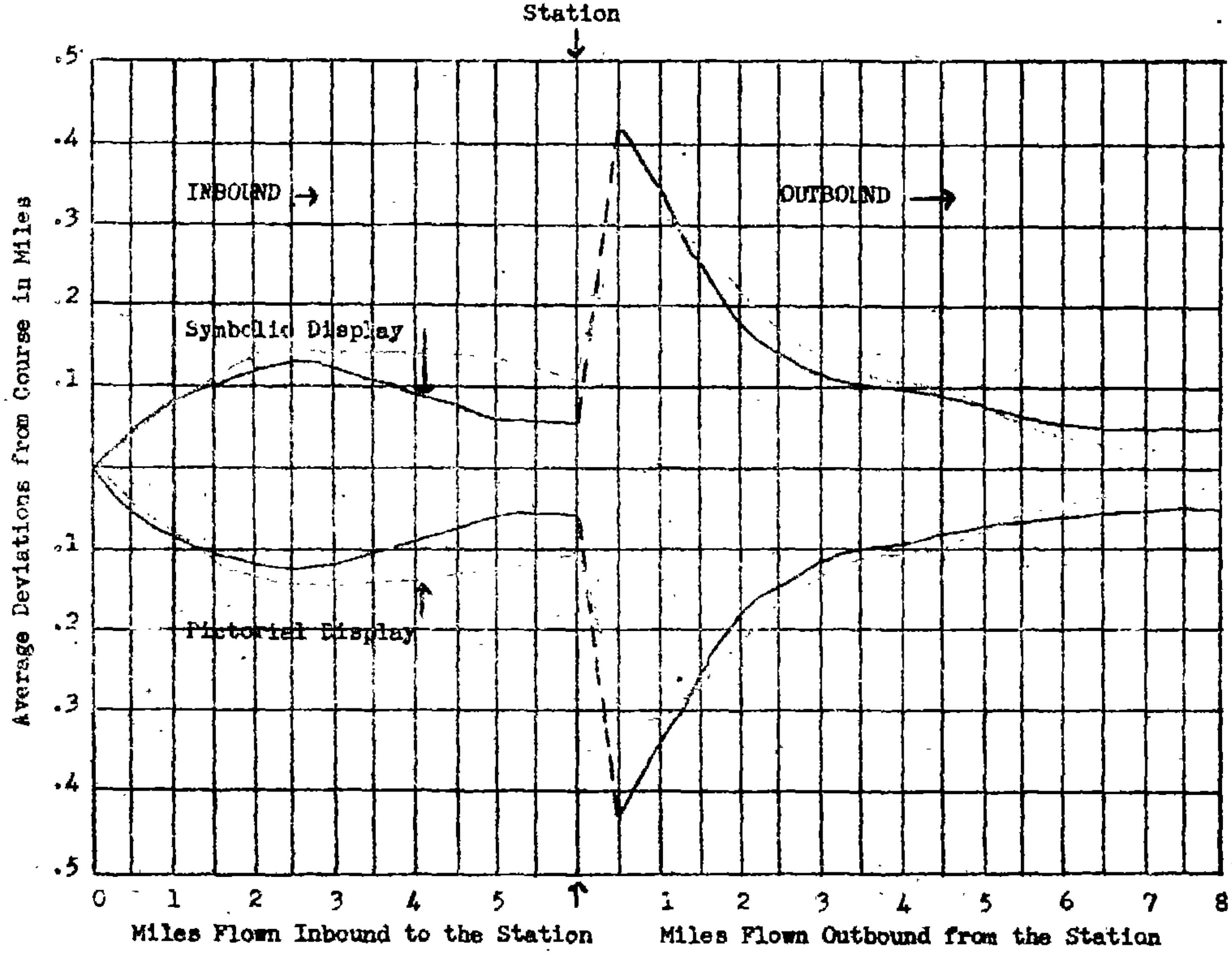


FIGURE 7. AVERAGE DEVIATIONS FROM COURSE WHILE BRACKETING INBOUND AND OUTBOUND FOR 15 PRIVATE PILOTS USING THE PICTORIAL DISPLAY AND FOR 15 OTHER PRIVATE [illegible] USING TH[illegible] SY[illegible] DISPLAY.

track and then averaged for each cross section and plotted on the graph. The graph shows that the bracketing performance on the two displays did not differ greatly. Inbound bracketing using the symbolic display was slightly more accurate as the station was approached. Both curves rise sharply at the beginning of the outbound leg. This was due to the fact that both groups were instructed to fly over the station before beginning the turn to intercept the outbound radial on problem III. The graph shows that the pilots using the pictorial display did not overshoot the course as much as did the pilots using the symbolic display. Although the pilots who used the pictorial display did not start their turns before passing the station, they could anticipate their arrival at the station, and apparently they were prepared to make the turn more quickly than were the pilots using the symbolic display.

The results for this experiment tend to confirm the interpretation that the apparent superiority of the pictorial display for outbound bracketing observed in the previous experiment was largely a function of the fact that the pilots were allowed to make their turns to the outbound radial just before reaching the station.

No estimate was made of the effects of practice upon bracketing performance.

Measure 5: "Orientation Time"

The final three measures (5, 6 and 7) were applicable only to the first phase of the orientation problems, namely, the first turn which was made to initiate a problem solution. Measure 5, the distance flown before starting the first turn, was used as an index of the time spent orienting. As in the previous experiment, it is assumed that the pilot spends the time from the start of the problem until he starts his first turn in orienting himself and making a decision as to the direction in which to fly in order to initiate a solution to the problem. It is further assumed that by the time the pilot starts the first turn he has oriented himself and has made some directional decisions. No assumption is made concerning the correctness of his orientation or his decision to fly in a certain direction.

Distance flown before first turn. Table 18 gives the average distances flown by 15 subjects before making the first turn for each of the four orientation problems using the pictorial and symbolic displays. As in the previous experiment, the differences in "orientation times" favored the pictorial display significantly for each type of orientation problem. The differences were significant at the .01, .05, .01, and .001 levels for problems II, III, IV and V respectively. The average distance flown before making the first turn for all problems combined using the pictorial display was about one-third of a mile, which represents about ten seconds. The corresponding average distance for the symbolic display was about four-fifths of a mile, which represents about 24 seconds.

TABLE 28

A COMPARISON OF "ORIENTATION TIMES" (DISTANCE TO FIRST TURN) FOR 15 PILOTS ON FOUR PROBLEMS USING PICTORIAL AND SYMBOLIC DISPLAYS

The distances are expressed in miles. Each value in the table is based upon five trials for each of 15 subjects. The standard deviations are based upon subject means rather than individual trials and thus reflect between individual variability. Hence: df = (2N-2), or 28, since the t's are based upon independent groups of 15 subjects each.

	Problem 2		Problem 3		Problem 4		Problem 5	
	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.	Pic.	Symb.
M	0.367	0.619	0.333	0.485	0.321	0.857	0.335	1.154
σ	0.146	0.221	0.128	0.223	0.178	0.589	0.175	0.646
σ_M	0.039	0.059	0.034	0.060	0.048	0.157	0.047	0.173
$D=M_s-M_p$	0.252		0.152		0.536		0.819	
σdiff.	0.071		0.069		0.164		0.179	
t	3.549		2.203		3.268		4.575	
df	28		28		28		28	
P	.01		.05		.01		.001	

Practice and problem difficulty. The scores from this measure were also submitted to treatment by the analysis of variance technique to test the effects of practice and differences in problem difficulty upon orientation times. Tables 19 and 20 show the average distances flown by 15 subjects before making their first turns for each of the five trials on each of the four orientation problems using the two displays. Each table includes a summary of the analysis of variance for the data presented.

Practice. Considering practice effects first, the two tables show that the averages for all problems combined for each of the five trials did not decrease significantly with practice on either display. With the pictorial display the orientation times on first trials for each problem were so short that there was little room for improvement on subsequent trials. With the symbolic display orientation times on first trials were not so rapid, but apparently the amount of practice received during five successive trials on each type of problem was not sufficient for any significant improvement to occur. It would be expected that with sufficient practice on each type of problem there would be a substantial reduction in the time required to orient and decide which way to fly using the symbolic display. This is suggested by the fact that there was improvement, significant at the .01 level, from first trials on problem II to fifth trials on problem III. The orientation tasks at the start of each of these problems was the same, namely, to orient and fly directly to the station. The fifth trials on problem III actually represented the tenth time the subjects had performed the same type of orientation task, and their average orientation time for these trials (9.3 seconds) was approximately the same as the corresponding value (8.7 seconds) for the pilots who used the pictorial display. Thus with sufficient practice, in this case ten successive trials, the pilots learned to perform this one particular type of orientation task almost as rapidly as it could be done using the pictorial display. However, this statement does not apply to any of the other orientation tasks performed in this experiment.

Problem difficulty. The analysis of the effects of differences in problem difficulty upon orientation times yields results similar to those obtained from the corresponding analysis of unnecessary turns. For the pictorial display the average orientation times for the four problems requiring orientation were almost identical, approximately ten seconds in each case (see Table 19). For the pictorial display the average orientation times for the four problems were significantly different at the .001 level. The average orientation times for problems IV and V, in which the pilots were required to take up a heading to intercept some specified radial, were much greater than they were for the problems II and III, in which the pilots were to fly directly to the station (see Table 20).

In general. Considered together, the results of the analyses of unnecessary turns and orientation times suggest the following conclusions. When pilots use the pictorial display, all common navigation problems are solved rapidly and efficiently from the very first time they are encountered. All problems are of equal difficulty and first trial performances leave little room for improvement. When pilots use the symbolic display,

TABLE [illegible]

AN ANALYSIS OF THE EFFECTS OF PRACTICE AND DIFFERENCES IN PROBLEM DIFFICULTY AS REFLECTED BY "ORIENTATION TIME" USING THE PICTORIAL DISPLAY

The numbers in the body of the table represent the average distance in miles flown before the first turn by 15 subjects during each of five trials on each of four problems. The means for problems and trials are expressed in seconds as well as miles. The averages are based upon all trials, both correct and incorrect. The table includes a summary of the analysis of variance for the data presented.

Problem	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Sum	Mean	M in sec.
II	0.47	0.31	0.39	0.35	0.33	1.85	0.37	11.1
III	0.32	0.32	0.34	0.40	0.29	1.67	0.33	9.9
IV	0.34	0.30	0.32	0.36	0.28	1.60	0.32	9.6
V	0.38	0.38	0.34	0.32	0.26	1.69	0.34	10.2
Sum	1.51	1.31	1.40	1.43	1.16	6.81	(1.36)	
Mean	0.38	0.33	0.35	0.36	0.29	(1.71)	0.34	
M in sec.	11.4	9.9	10.5	10.8	8.7			10.2

Source of Variance	Sum of Squares	df	Variance Estimate	F	Level of Significance
Between trials	0.018	4	.0045	3.000	n.s.
Between problems	0.007	3	.0023	1.533	n.s.
Residual	0.018	12	.0015		
Total	0.043	19			

TABLE 20

AN ANALYSIS OF THE EFFECTS OF PRACTICE AND DIFFERENCES IN PROBLEM DIFFICULTY AS REFLECTED BY "ORIENTATION TIME" USING THE SYMBOLIC DISPLAY

The numbers in the body of the table represent the average distance in miles flown before the first turn by 15 subjects during each of five trials on each of four problems. The means for problems and trials are expressed in seconds as well as miles. The averages are based upon all trials, both correct and incorrect. The table includes a summary of the analysis of variance for the data presented.

Problem	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Sum	Mean	M in Sec.
II	0.82	0.58	0.56	0.55	0.58	3.09	0.62	18.6
III	0.67	0.46	0.47	0.52	0.31	2.43	0.49	14.7
IV	0.70	0.69	1.18	0.90	0.81	4.28	0.86	25.8
V	1.22	1.12	1.32	1.23	0.88	5.77	1.15	34.5
Sum	3.41	2.85	3.53	3.20	2.58	15.57	(3.12)	
Mean	0.85	0.71	0.88	0.80	0.65	(3.89)	0.78	
M in Sec.	25.5	21.3	26.4	24.0	19.5			23.4

Source of Variance	Sum of Squares	df	Variance Estimate	F	Level of Significance
Between trials	0.156	4	0.039	1.950	n.s.
Between problems	1.292	3	0.431	21.550	.001
Residual	0.237	12	0.020		
Total	1.685	19			

first trial performances are neither rapid nor without frequent unnecessary turns, and the various common navigation problems are not of equal difficulty. With practice using the symbolic display pilots improve rapidly in terms of the efficiency with which they employ the equipment as a flight instrument to execute their decisions as demonstrated by the significant reduction in the number of unnecessary turns from first to fifth trials on all problems. (See Table 17). However, practice in using the symbolic display does not result in rapid improvement in terms of the time required to orient from an unknown position and make a decision as to the direction in which to fly in order to solve a problem. This requires a considerable amount of practice, and the improvement is not general but specific to the types of problems practiced.

Measures 6 and 7: Analysis of First Turns

The results for measures 6 and 7, which deal with the direction of the first turn and the initial heading assumed, can be combined with the results for measure 1, as they were in the two previous experiments, so as to account for the outcome of each of the 300 orientation problem solutions flown using each display. The analyses of the results for each of the four orientation problems for each display are shown in Tables 21 through 28. The tables are self explanatory and will not be discussed. However, the combined results for all problems, which are summarized in Tables 29 and 30, will be discussed briefly. Also the combined results for all first turns made using the symbolic display are analyzed from a slightly different point of view in Table 31.

Comparison with previous experiments. In general the results obtained for the private pilots in this experiment are directly comparable to the results obtained for the instrument pilots in the two previous experiments. The private pilots who used the pictorial display in this experiment solved all of their navigation problems correctly, just as the instrument pilots in the previous experiment had done. They solved the problems with a minimum amount of "trial and error," as witnessed by the fact that 97% of their first turns were in the more economical direction, 96% were to the correct initial heading, and 94% were both in the correct direction and to the correct heading. In the few cases in which they turned in the less economical direction or to an incorrect initial heading, they quickly made the necessary corrections to solve the problems as required by traffic control. These results require no further discussion.

The results for the private pilots who used the symbolic display were quite different, just as were the results for the instrument pilots who used the symbolic display in the two previous experiments. In those experiments the instrument pilots had failed to solve 19% and 25% of their orientation problems, respectively. The private pilots in this experiment failed to solve 12.3% of their comparable orientation problems. The lower percentage in this case was to be expected since the private pilots were presented each type of problem five times in succession, while the instrument pilots in the first experiment solved each type of problem only twice and those in the second experiment only once.

TABLE 21

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM II FLOWN BY 15 SUBJECTS USING THE PICTORIAL VOR NAVIGATION DISPLAY

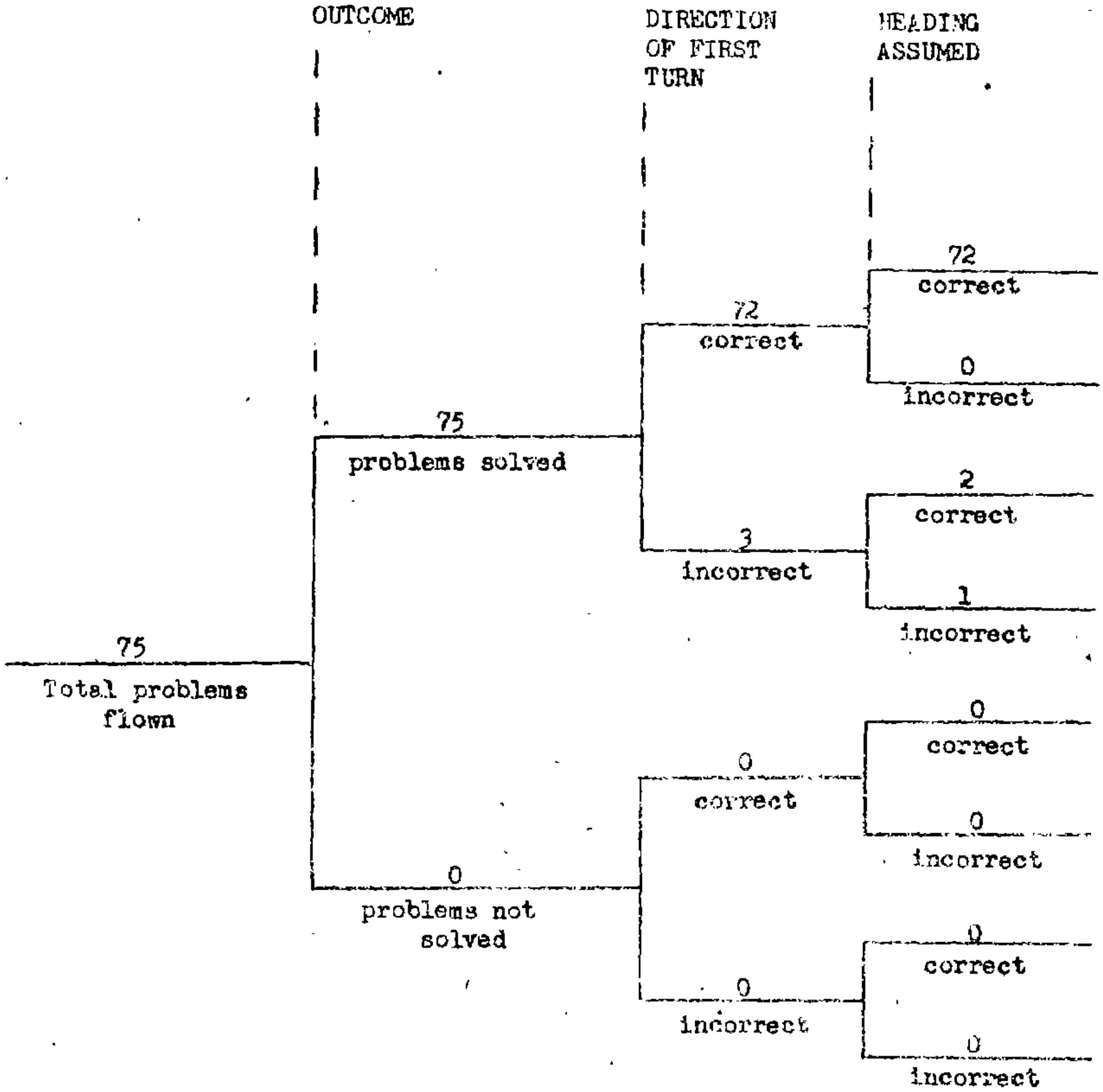


TABLE 22

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM II FLOWN BY 15 SUBJECTS USING THE SYMBOLIC VOR NAVIGATION DISPLAY

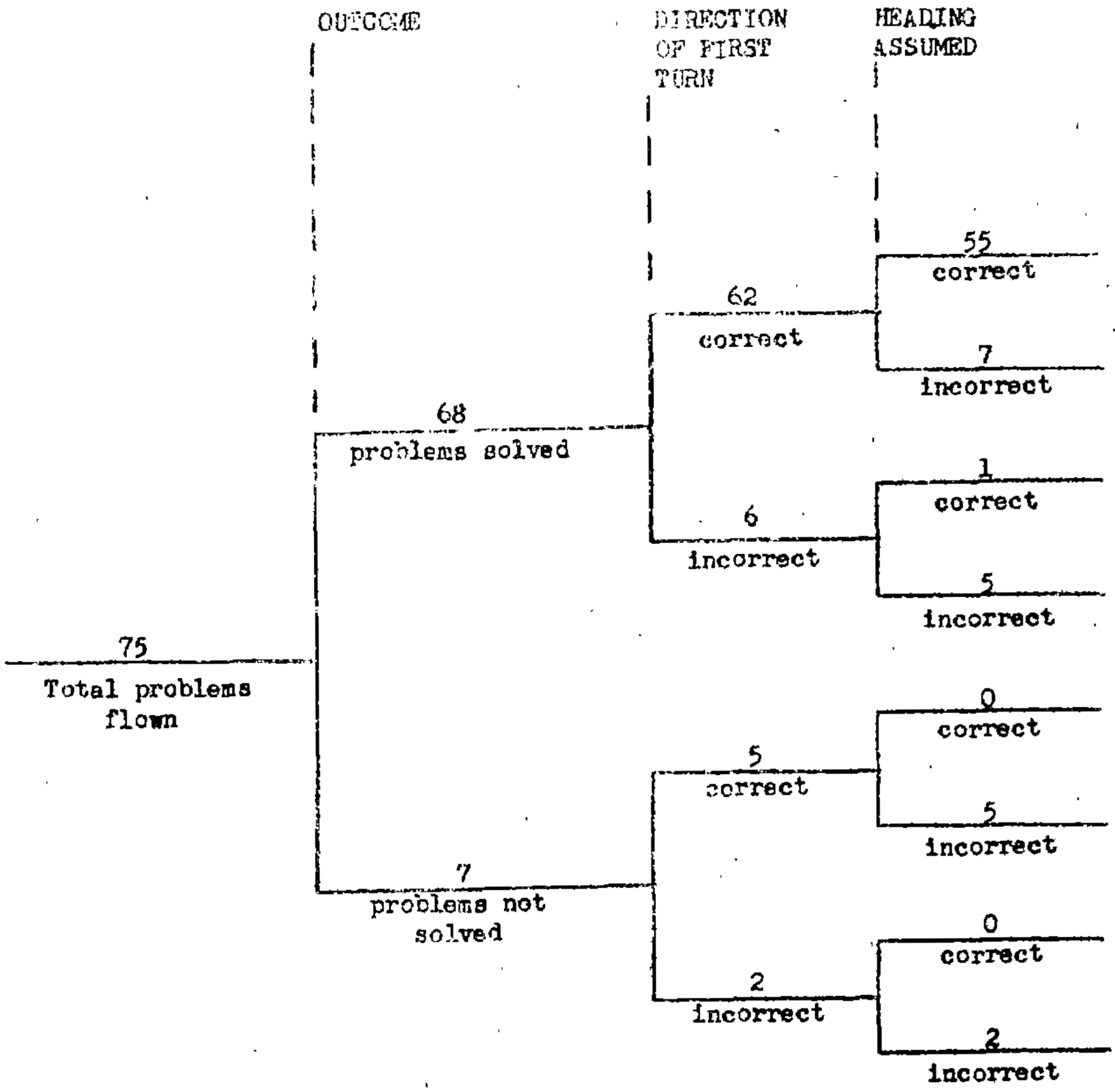


TABLE 23

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM III FLOWN BY 15 SUBJECTS USING THE PICTORIAL VOR NAVIGATION DISPLAY

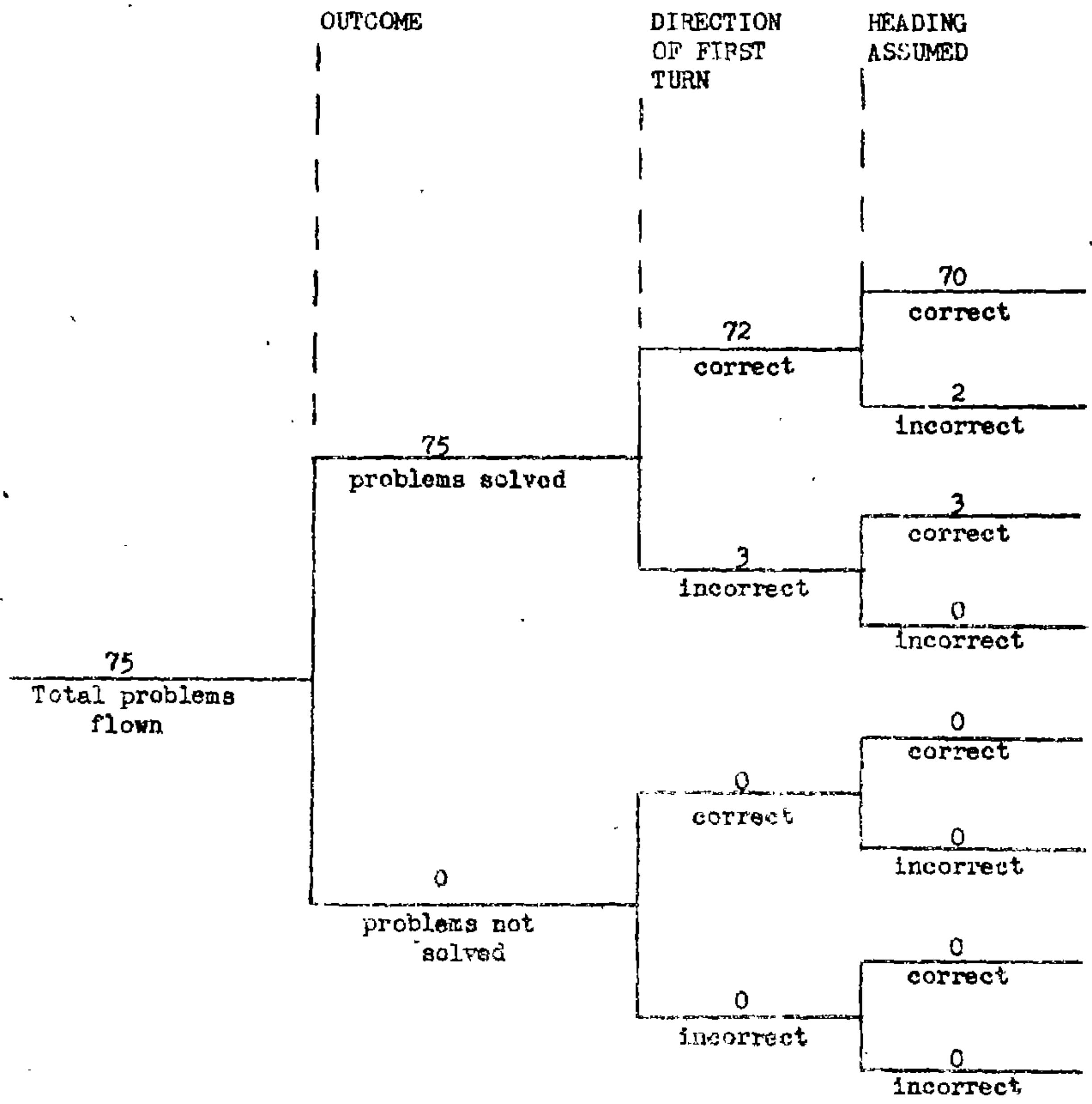


TABLE 24

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM III FLOWN BY 15 SUBJECTS USING THE SYMBOLIC VOR NAVIGATION DISPLAY

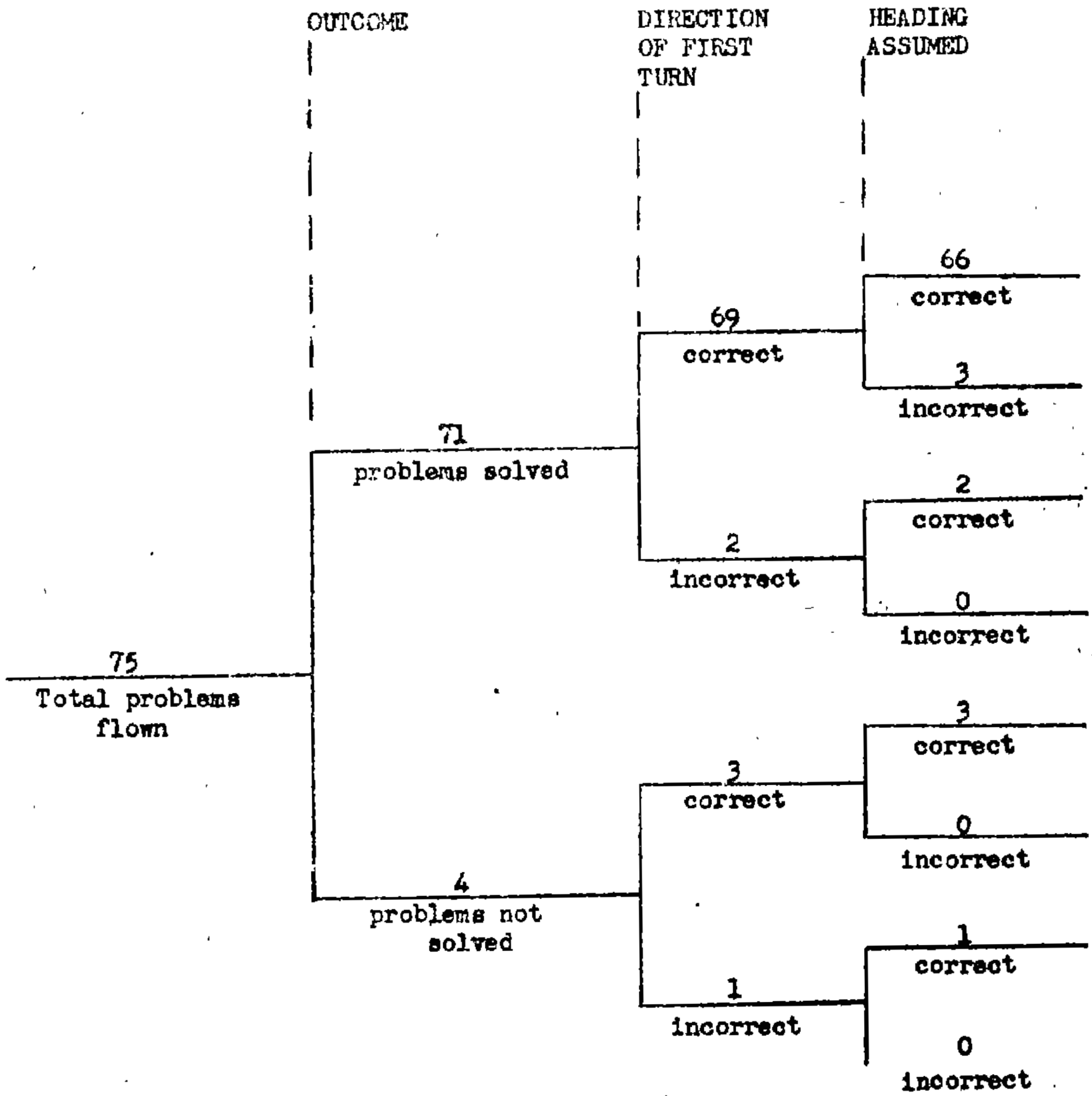


TABLE 25

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM IV FLOWN BY 15 SUBJECTS USING THE PICTORIAL VOR NAVIGATION DISPLAY

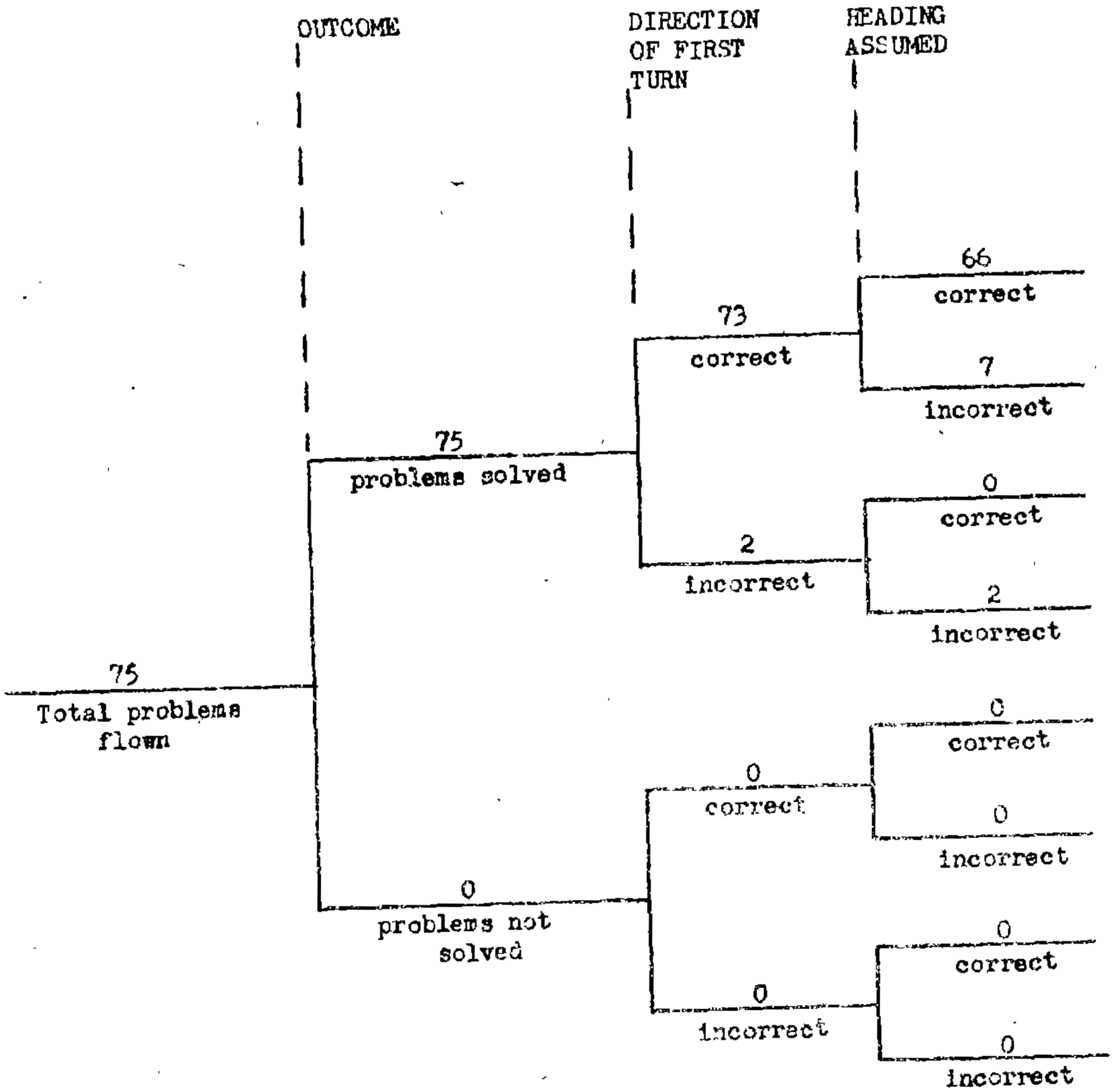
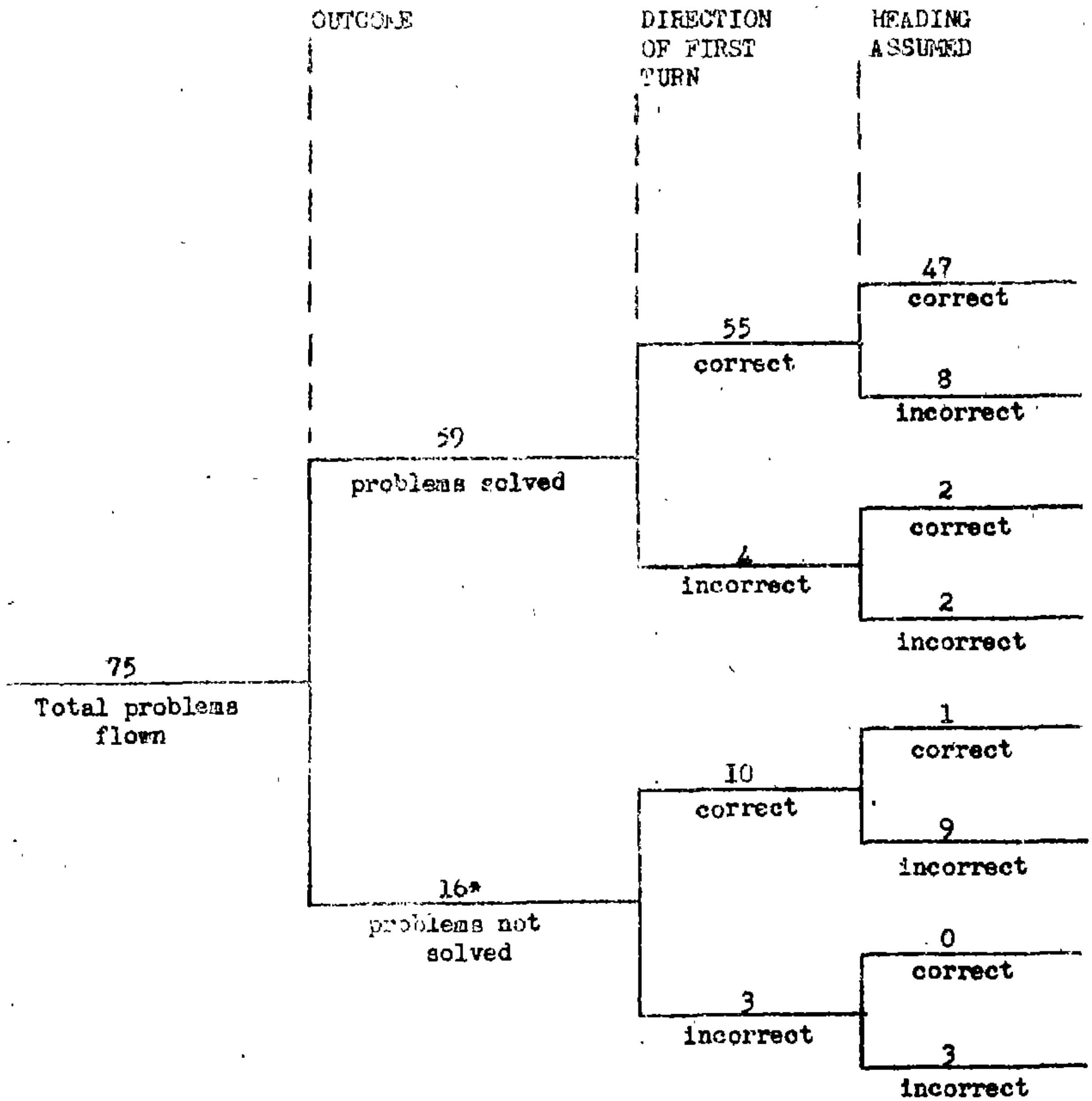


TABLE 25

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM IV FLOWN BY 15 SUBJECTS USING THE SYMBOLIC VOR NAVIGATION DISPLAY



*In three of these 16 incorrect solutions no turn was made: in each case the subject simply flew straight ahead from his starting position until he had passed out of the VOR range.

TABLE 27

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM V FLOWN BY 15 SUBJECTS USING THE PICTORIAL VOR NAVIGATION DISPLAY

	OUTCOME	DIRECTION OF FIRST TURN	HEADING ASSUMED
75 Total problems flown	75 problems solved	74 correct	74 correct
			0 incorrect
		1 incorrect	1 correct
			0 incorrect
	0 problems not solved	0 correct	0 correct
			0 incorrect
		0 incorrect	0 correct
			0 incorrect

TABLE 28

CLASSIFICATION OF 75 SOLUTIONS FOR PROBLEM V FLOWN BY 15 SUBJECTS USING THE SYMBOLIC VOR NAVIGATION DISPLAY

Total problems flown	OUTCOME	DIRECTION OF FIRST TURN	HEADING ASSUMED
75	65 problems solved	59 correct	45 correct
			14 incorrect
		6 incorrect	1 correct
			5 incorrect
	10 problems not solved	5 correct	1 correct
			4 incorrect
		5 incorrect	0 correct
			5 incorrect

TABLE 29

CLASSIFICATION OF 300 SOLUTIONS FOR ALL ORIENTATION PROBLEMS COMBINED FLOWN BY 15 SUBJECTS USING THE PICTORIAL VOR NAVIGATION DISPLAY

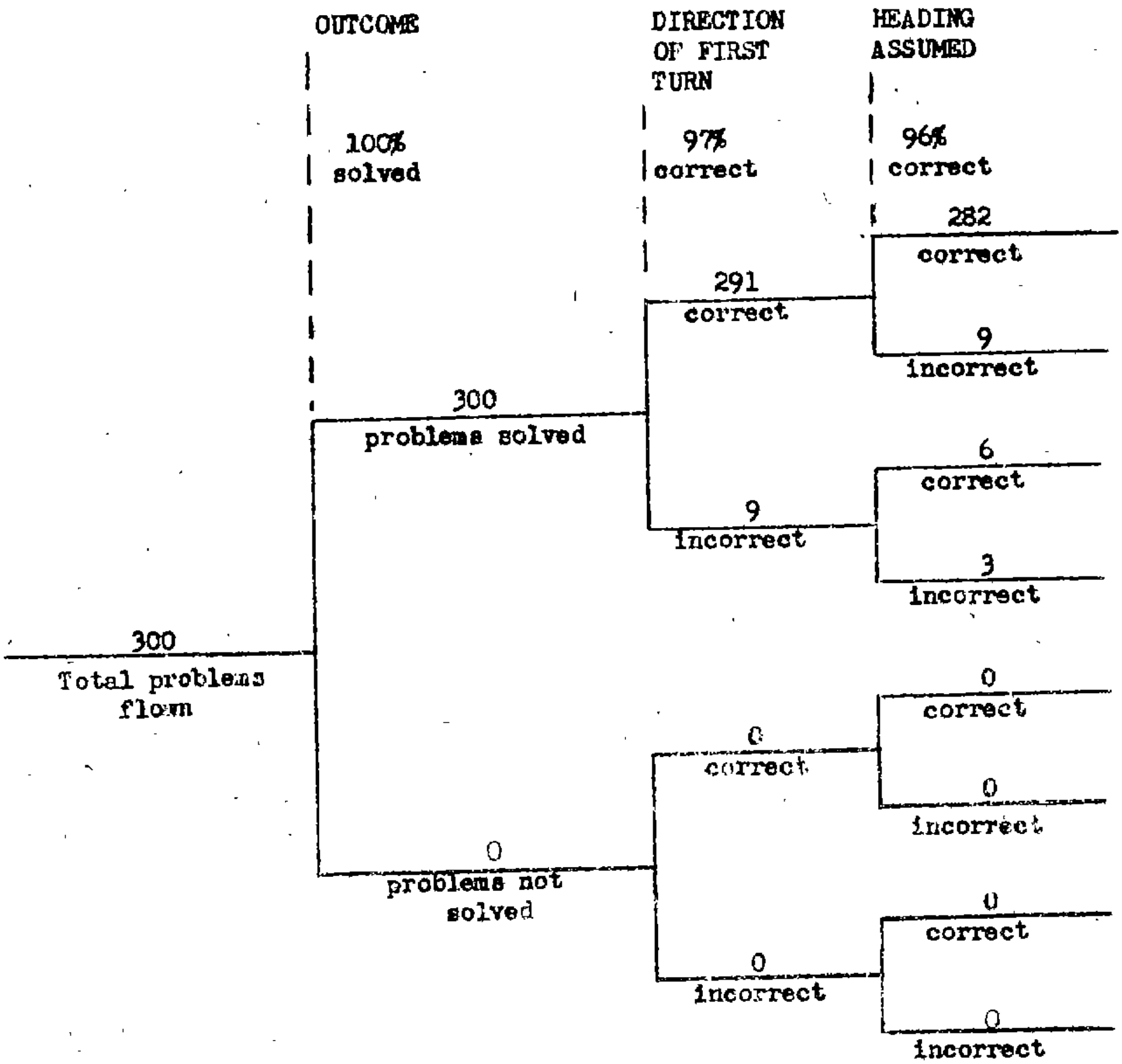
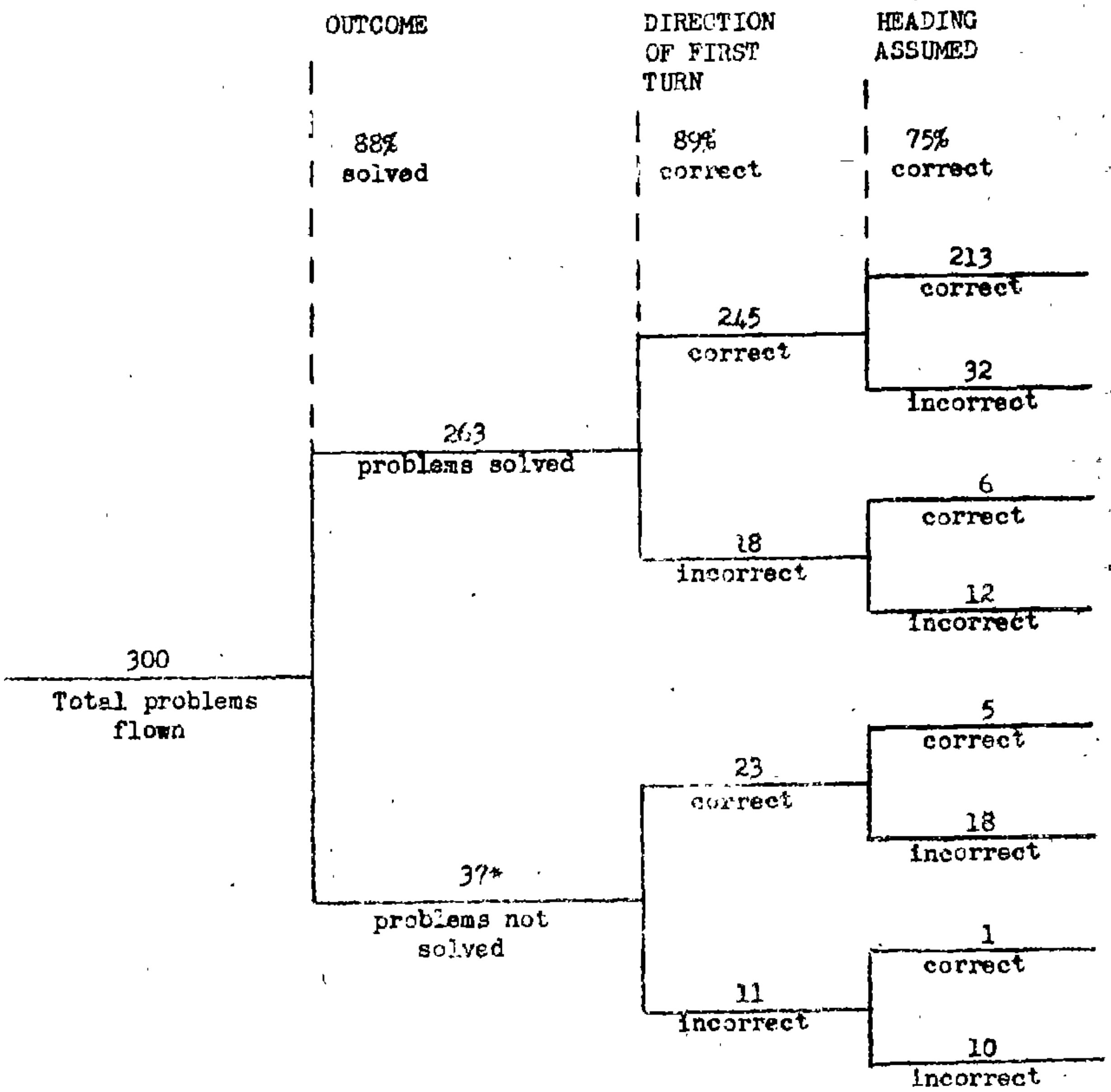


TABLE 30

CLASSIFICATION OF 300 SOLUTIONS FOR ALL ORIENTATION PROBLEMS COMBINED FLOWN BY 15 SUBJECTS USING THE SYMBOLIC VOR NAVIGATION DISPLAY

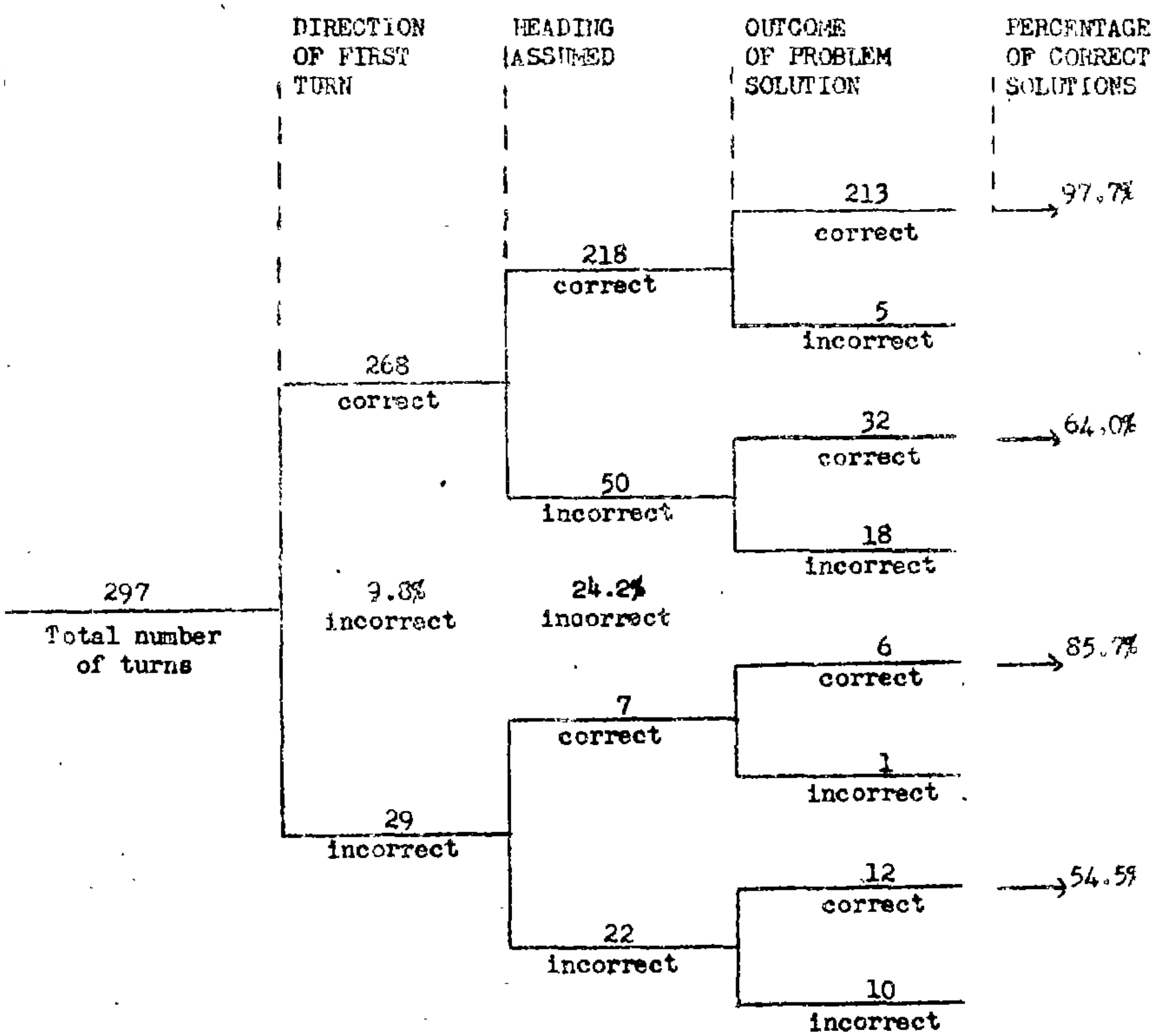


*In three of these incorrect solutions no turn was made.

TABLE 37

CLASSIFICATION OF 297 FIRST TURNS MADE ON ORIENTATION PROBLEMS BY 15 SUBJECTS USING THE SYMBOLIC VOR NAVIGATION DISPLAY

The turns are classified according to whether or not they were in the correct direction, whether or not they were to the correct heading and whether or not they led to a correct problem solution. The percentage of correct solutions is given for each category, together with the percentage of turns which were in the incorrect direction and the percentage which were to an incorrect heading.



The private pilots who used the symbolic display engaged in a considerable amount of "trial and error" turning activity as shown in Table 31. Of the 297 first turns which were made on the 300 problems (on three problems no turn was made at all), 9.8% were in the less economical direction and 24.2% were to an incorrect heading. The 29 turns which were in the incorrect direction led to incorrect problem solutions 40% of the time; the 72 turns which were to an incorrect heading led to incorrect problem solutions 39% of the time. In contrast, the 268 turns which were in the more economical direction led to correct solutions 91% of the time; and the 225 turns which were to the correct heading led to correct solutions 97% of the time. Finally, the 22 turns which were both in the incorrect direction and to an incorrect heading resulted in incorrect solutions 45.5% of the time; while the 218 turns which were both in the correct direction and to the correct heading resulted in correct solutions 97.7% of the time.

In general. Thus the results of this experiment, as of the previous experiments, emphasize the importance of rapid and correct initial orientation for the correct solution of local navigation problems using VOR equipment. This is reflected by the results for measure 5, the time from the start of the problem to the first turn, and measures 6 and 7, the direction of the first turn and the heading assumed as a result of the first turn. The correctness of the heading assumed is more important than whether or not the first turn is made in the more economical direction. Making a quick first turn to the correct initial heading almost invariably leads to a correct problem solution using either the pictorial or the symbolic display. The big difference between the two displays seems to be that with the pictorial display pilots can orient from an unknown position more rapidly and turn to a correct initial heading more frequently than they can using the symbolic display. The private pilots in this experiment turned to a correct initial heading 96% of the time; those who used the symbolic display did so only 75% of the time. The average orientation times for the pilots using the two displays were about ten and 24 seconds, respectively. These values correspond approximately with the corresponding values for the instrument pilots in the previous experiment. Furthermore, the pictorial display had the additional important advantage that the index of desired performance is always directly apparent so that incorrect turns can be immediately perceived and corrected. With the symbolic display the result of a turn to an incorrect heading is not immediately apparent.

The net result, observed in all three experiments in which the symbolic display has been used to solve orientation problems, is that problems are frequently solved incorrectly, both by private pilots and by experienced instrument pilots. To date, 47 of the 348, or 13.5%, of all orientation problems flown by both types of pilots have been performed in an unsatisfactory manner. All 316 orientation problems have been solved correctly using the pictorial display.

PART V

AN INTERPRETATION AND CRITICAL EVALUATION OF THE RESULTS OF THESE EXPERIMENTS

The over-all results of these experiments show the superiority of the pictorial type VOR display over the symbolic type display. The questions now are, how much confidence can be placed in these results and to what extent can we extrapolate from them to the actual flight situation with real aircraft. As the results stand now they clearly indicate that a pictorial VOR display should be used in the cockpit. However, before accepting this conclusion the possibility that different results would have been obtained had the circumstances surrounding the experiments been different should be examined. Should this be proven to be the case, results of the present experiments would have to be qualified and certain reservations attached to them.

Factors Affecting the Results

The particular results obtained in these experiments probably depend upon the contributions of several factors. In the first place, had different displays been used it is quite possible that different results would have been obtained. In order to generalize it must be assumed that the particular displays used were representative of their respective types. It is wise to examine the possibility that this is not the case and to estimate the consequences had other displays been used.

Second, the results of this experiment probably depend upon the pilots who were used as subjects. Although the statistical treatment of the data answers many of the problems posed by sampling, no statistical treatment can define the population from which the samples were drawn. It is certain that the results achieved obtained in terms of the pilots who served as subjects will hold for the populations which they represent, but exactly what are these populations? Pilots of all ages, for example, or of all nationalities, or of all socio-economic groups were not sampled. Again it is a question of how representative the pilot samples are of the total pilot population. It is important to determine whether the sampling of subjects contributed to the results obtained.

Third, had other navigation problems been employed the results quite possibly would have been different. Again, it is a question of sampling and representativeness. Effort should be made to discover whether the results obtained are pertinent only to the particular navigation problems used or whether they might be expected to occur if different problems were used.

Fourth, the fact that all of these results were obtained in a synthetic flight trainer must be considered. Had the results been obtained during flight in real aircraft would they have been different? This last point is probably the most important of all and warrants considerable inspection. Each of these points will be considered in turn to see whether any important qualifications must be attached to a statement of the experimental results, and consequently to the conclusions drawn therefrom.

1. The displays. Had other displays been used in this experiment it is safe to assume that the results would have been somewhat different. Findings to date indicate, however, the results would never be so different as to favor the symbolic type of display. In the original mockup study there was little basis for making a choice among the five symbolic displays used. There is no reason to expect that use of one of the others in the trainer would have resulted in any improvement. On the other hand, in the original study, two of the three pictorial displays used were significantly inferior to the one which was eventually chosen for use in the present experiments. Had one of these other displays been used in the trainer one would expect to find smaller but still significant differences in favor of pictorial displays.[1]

This does not rule out the possibility that a symbolic display could be built which would be superior to any pictorial displays now contemplated. In the same manner it is possible that a so-called pictorial display could be designed which would be inferior to any of the symbolic displays. Indeed, suggestions have been received concerning the design of pictorial displays which might well fall in this category. Just because a display is pictorial does not guarantee that it is easy to use. By the same token it is not believed that the pictorial display used in these experiments is the best possible display of its type. The display could undoubtedly be improved, for example, by the addition of heading information to the aircraft pip. Since the possibility of improving the pictorial display is at least as great as the possibility of improving a symbolic display we feel that their relative standings as shown in this experiment would remain much the same, and that the results of the experiment are valid in this respect.

2. The pilots. Had other pilots been used in this experiment, would the difference between the pictorial and symbolic displays have disappeared or perhaps occurred with opposite sign? It is true that the pilot samples used were not representative of the general pilot population. As indicated above the samples were rather homogeneous with respect to age, education, and socio-economic status.

---

[1]In the original "mockup study" all pictorial displays were superior, to a statistically significant degree, to all symbolic displays. See Williams, A. C., and Roscoe, S. N., op. cit., Table 4, p. 6.

With respect to training and past experience the private pilots were an extremely homogeneous group. The majority of them were recent graduates of the same training course. Few of them had much post graduate experience as private pilots. The instrument pilots were less homogeneous as a group since they represented diverse backgrounds of military and civilian experience. Because of the homogeneous composition of the [illegible] one might expect that their absolute performance would not be representative of the total pilot population. Thus, had the total population of pilots been tested the mean number of incorrect solutions, the mean amount of excess distance flown, etc. might have been different. Nevertheless, it does not appear likely that the relative standing of the two displays would change a great deal. A different sample might have performed differently with both displays but probably not on one display at the expense of the other.

Of more serious concern than sampling is the amount of practice the subject pilots had with these displays. All of the pilots must be considered naive in this respect. The results obtained therefore applied to pilots who have had only limited practice with the displays. It is true that all of them received intensive instruction before starting the experiment but this does not compare with practice extending over several months or years. It would be expected that as the amount of practice increased, the difference between the displays would tend to diminish. Eventually, after an unknown but fairly large amount of practice, there would be little difference between pilots' ability to fly with either display, as far as routine navigation problems are concerned. One would expect, however, that if new problems were presented, other than those upon which the pilots had practiced, then a difference would once more occur in favor of the pictorial type display.

Similarly it is felt that in emergency situations when the pilot is working under considerable pressure the pictorial display would once again prove superior even though the problem at hand were one upon which the pilot had a great deal of practice. This is of course a matter of speculation. The evidence for this contention, meager though it is, comes from the private pilots' part of the present study. It will be recalled that five different problems were presented and that the pilots had the opportunity to perform on each problem five times before the next one was presented. There was little improvement with practice in the case of either display, but the introduction of new problems did not deter the group working with the pictorial display at all. They obtained a high level of proficiency even on the first trial with a new problem. Those working with the symbolic display, however, responded as if they had to learn all over again whenever a new problem was presented.

Apparently pilots using the symbolic display did not benefit from their previous practice throughout the duration of the experiment. Introduction of new problems evidently interfered with any gains that had previously been made. With the pictorial display there was likewise no marked improvement with practice but for quite a different reason. With this display performance was already at such a high level that there was little room for improvement.

Extrapolating from these results one would expect that with the symbolic display a large amount of practice with any problem or group of problems would ultimately result in improvement but that the introduction of new problem types might conceivably set the pilots back to a lower level of proficiency. The same might be said for performance under emergency conditions. Using the pictorial display, however, with performance already at a high level without practice, the chances of a set back upon the introduction of new problems or emergency conditions would not be so great nor so severe.

3. The problems. The results obtained in these experiments depend most certainly upon the problems used. Seven different kinds of problems were used in all. Different results were obtained for each problem. Therefore it would be expected that had other problems been used still other results would have been obtained. Unlike the use of different samples of pilots, the use of different navigation problems would probably have a differential effect upon the relative standing of the displays. For the easy problems the displays were more nearly alike than for the difficult problems. Had only simple problems been used throughout, the superiority of the pictorial display would not have been so striking. In a sense, all the problems were more difficult than those normally encountered during en route navigation. This is true because all problems involved navigation entirely within a radius of ten or eleven miles from the station. When this close to the station, changes in azimuth position occur with greater speed. Precision flying and navigation within a polar coordinate system close to the station is more difficult than it is farther away from the station. Far out from the station a pilot can fly in the wrong direction for two minutes without causing a major change in his orientation problem. Close to the station this is not possible.

Nevertheless there is considerable justification for testing these displays under difficult rather than easy conditions. It is not enough to know that pilots can navigate adequately with a display when precision is not required, even though precision may not be required three-quarters of the time. Close to the station precision is required for purposes of traffic control, and the penalty for lack of precision is great. Since, as far as the pilot is concerned, precision is more difficult to achieve close to the station because changes happen so quickly, this seems to be the logical situation under which to test the displays.

All this simply means that when a pilot is 20 to 30 miles away from the VOR station in a slow aircraft and his only task is to fly directly to or away from the station, one would expect to find little difference between his performances using the two displays. But the fact that he is in this position most of the time is no reason to use it for testing the displays. There will be times, and not infrequently so, when he will be directed to fly along designated tracks to or from the station while he is still close to the station. This is a much more difficult feat to perform and carries with it a premium on accuracy. Should the pilot be unable to use his display at this point it makes little difference how well he can use it when far out from the station with no pressure on him. For this reason it is felt that the problems used in this study were well chosen and that the conclusions need not be qualified because of them.

4. Trainer vs. aircraft. To what extent can the results obtained in a synthetic flight trainer be considered valid for the actual flight situation? With respect to the problems used in these investigations one can expect the validity to be high. Ability to solve the problems used in the present experiment, and consequently ability to score well on the measures used, does not depend upon the "flight" characteristics of the trainer. The pilot's task is essentially a perceptual and intellectual one, that of perceiving where he is and deciding which way to fly in order to solve the problem as presented. Thus the accuracy with which the trainer simulates the feel of the aircraft is not involved here.

It is therefore believed that the task was no more difficult in the trainer than it would be in the aircraft. If anything, the task was easier in the trainer than in the aircraft. Being on the ground in the trainer the pilot does not carry the same responsibility as when he is in the air. Presumably this may free him to devote a larger amount of effort to the navigation task. If the task is easier in the trainer than in the aircraft one would then expect that the difference between displays found in the trainer would be an underestimate of the difference found in the air. It has already been shown that the difference between displays increases as the task is made more difficult. There is no reason to suppose that this would not be the case when going from trainer to aircraft. For these reasons it is felt that the results of these experiments provide a valid prediction of results to be expected in the air.

Conclusion. It is therefore concluded that the results of these experiments indicate a marked superiority of pictorial, as opposed to symbolic type airborne VOR display. It is not possible to predict from these results the frequency with which errors in navigation will be made using either display in the air. Nor can one predict the probable size of the errors with any accuracy. Nevertheless one can predict that whatever their frequency and size, there will be relatively fewer and smaller errors made if a pictorial display is used than if the symbolic display is used.

APPENDIX I

A REVIEW OF: A STUDY OF THE MOVING FIGURE AND ORIENTATION OF SYMBOLS ON PICTORIAL AIRCRAFT INSTRUMENT DISPLAYS FOR NAVIGATION

by

Thomas A. Payne

APPENDIX I

A STUDY OF THE MOVING FIGURE AND ORIENTATION OF SYMBOLS ON PICTORIAL AIRCRAFT INSTRUMENT DISPLAYS FOR NAVIGATION

The following is a review of a recent study which was done by Thomas A. Payne[1] at the Aviation Psychology Laboratory, University of Illinois, under the auspices of Special Devices Center, Office of Naval Research (SDC Human Engineering project 20-L-1).

This study consisted of two separate experiments. In both experiments private pilots drew solutions to navigation problems, using printed drawings of pictorial aircraft instrument displays. The purpose of the first experiment was to compare performances of the subjects in drawing the movement which would be made by the moving figure of the display throughout the solution of the problem, when the moving figure represented (1) the station, and (2) the aircraft. (When the station moved, the aircraft was represented at the center of the display. When the aircraft moved, the station was in a fixed position.)

Results of the first experiment showed that 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-fifth of them correct.

The purpose of the second experiment was to compare performances of private pilots in drawing the figure movement for the solutions to navigation problems when the moving figure always represented the aircraft and in which there were different arrangements of two variables, namely, (1) the location of the fixed station, and (2) the orientation of the compass rose ("North" at the top of the display or "North" not at the top).

Error scores in the second experiment indicated that it made no significant difference whether the compass rose was oriented with "North" at the top or rotated so that "North" appeared at some other position. The time scores, however, showed small but consistent differences in favor of having "North" at the top of the display although no individual comparison proved significant beyond the 10% level.

Both time and error scores indicated that it does make a difference where the station is located, the center position being significantly better than any peripheral location.

---

[1]Payne, Thomas A. A study of the moving figure and orientation of symbols on pictorial aircraft instrument displays for navigation. Port Washington, N.Y.: U. S. Navy, Special Devices Center, Technical Report SDC 71-16-6, July, 1950.

APPENDIX IV

QUESTIONS AND ANSWERS

APPENDIX II

In a memorandum, dated October 17, 1949, from Director, Technical Development and Evaluation Center, CAA, entitled "Study Contract for Airborne Pictorial Display of Positional Information Obtained from VHF Omnirange and Distance Measuring Equipment," six questions were raised concerning desirable characteristics for a pictorial navigation display. These questions are listed below together with the best answers we can give at this time.

1. QUESTION: "Assuming that the ground station, from which the aircraft is obtaining its positional information, is located in the center of the display on a map, should the map be oriented with

(a) north direction always at the top of the display,

(b) the desired course of the aircraft located directly up on the display, or

(c) the actual heading of the aircraft located directly up on the display?"

1. ANSWER: The important thing is that the compass rose be fixed in position. In no case should the compass rose rotate automatically so that the heading of the aircraft appears always at the top of the display. For most navigation tasks it is best to have the compass rose fixed with north at the top. However, if it would be possible for the entire display, including the fixed compass rose, to be rotated manually by the pilot so that his desired course appears at the top, this would have the advantage that departures from the desired course would be properly oriented as to right and left. This advantage might be of some importance for accurate final straight-in approaches to a station.

2. QUESTION: "What is the optimum size of the map and display? Assuming that the display is located at the normal distance as the present instrument panel is located from the pilot's eyes, should the display be

(a) ten inches in diameter with a scale of eight miles per inch,

(b) ten inches in diameter with a scale of four miles per inch, or

(c) x inches in diameter with a scale of y miles per inch?"

2. ANSWER: We have no direct evidence concerning the optimum size and distance scale of the display. Our pictorial display used in the Link trainer is five inches in diameter with a scale of approximately four miles to the inch. It is our opinion that a larger display, perhaps ten inches in diameter, would be better, and that there should be different scales for cross country navigation and for close-in procedures.

3. QUESTION: "Should the changing position of the aircraft on the display be made a permanent trace line or just a spot noting present position?"

3. ANSWER: We have no comparative evidence pertinent to permanent trace lines versus a single pip or spot denoting present position. Our display presents a bright pip denoting present position which leaves a short trace giving a rough indication of heading and rate of turn. The trace appears as a comet tail about one-fourth of an inch long. This is undoubtedly better than no trace at all. The question is closely related to the more important question of how to present heading on the display.

4. QUESTION: "Should the center of the display denote the aircraft's position or the station's position?"

4. ANSWER: The center of the display should denote the position of the <u>station</u>.

5. QUESTION: "In the case the display listed in subparagraph 1 above is used, should the aircraft's position be displayed as a spot or as an arrow showing the heading of the aircraft?"

5. ANSWER: We do not have direct comparative evidence pertinent to this question; however, it is our observation that a comet tail trace is better than a spot alone, and it is our opinion that an arrow showing heading would be even better.

6. QUESTION: "To what extent can the pictorial display be used as a flight instrument? For example, can the instrument be used to replace all of the functions provided by the present VOR and DME instrumentation?"

6. ANSWER: This question is difficult to answer because it depends upon what is meant by the term "flight instrument." This much can be said. There is evidence to show that the pictorial display can be used to replace with great advantage all of the functions provided by the present VOR and DME instrumentation except one. That one exception, for which we do not have clear-cut evidence one way or the other, is the accuracy with which the display can be used for a final straight-in approach to a station. When used in this way the display is being used almost exclusively as a "flight instrument" for the accurate control of heading. The evidence to date indicates that heading can be controlled more accurately using the vertical pointer of the ILAS instrument. However, the pip on our pictorial display was sufficiently disturbed by the earth's magnetic field, depending upon the heading of the trainer, to prevent us from accurately determining how well pilots can be expected to "hit the station" using the display. With a more dependable pip and a larger scale display it would be expected that performance would be quite accurate.

APPENDIX III

TECHNICAL DESCRIPTIONS OF THE PICTORIAL AND SYMBOLIC DISPLAYS USED IN THE 1-CA-1 LINK TRAINER

by

John M. Bell

APPENDIX III

TECHNICAL DESCRIPTIONS OF THE PICTORIAL AND SYMBOLIC DISPLAYS USED IN THE 1-CA-1 LINK TRAINER

I. THE PICTORIAL DISPLAY

The device used to produce the pictorial display receives a mechanical position signal from the trainer recording crab and transforms this information into voltages proportional to its location in a system of rectangular coordinates. These voltages are simplified and impressed on the deflection anodes of a cathode ray tube in order to deflect the electron stream so that the "pip" will appear on the face of the tube in a position proportional to that of the trainer recording crab.

The mechanical arrangement used to transform the position of the crab into proportional voltages is shown in Figure 1.

As the crab moves along the map it causes rod "a" to rotate about shafts "b" and "c" and to slide through bearing "d." When the crab moves along an east-west line (there is no north-south component), it causes a rotation of shaft "b," and shaft "c" remains fixed. Attached to shaft "b" are the two sliding contacts which run along resistors R_1 and R_2. This causes a voltage to be developed between these contacts that is proportional to the distance of the crab east or west of the center of the map.

Conversely, motion of the crab along a north-south line causes a rotation of shaft "c," which in turn causes a voltage to be developed between the contacts on R_3 and R_4 that is proportional to the north or south displacement of the crab. These voltages are identical and description of one will apply to the other.

Figure 2 shows a schematic diagram of the amplifier and power supply sections.

The position resistors R_1, R_2, R_3 and R_4 are connected through low-pass filters (R_6, C_1) to the grids of the 6AC5 tubes. Resistors R_5 are used to adjust the voltage appearing between these grids when the crab is located at the edge of the map. These should be adjusted so that the "pip" will appear on the ten mile circle. The voltage impressed on the grids is amplified and appears across resistors R_9. These points are bypassed by capacitors C_3 to remove any alternating current components, and they are connected to the deflection plates of the 5UP7 cathode ray tube.

Resistors R_{19} are used to balance the grid voltages so that when the crab is in the center of the map, the "pip" will be in the center of the tube face. Resistors R_{10} are used to adjust the screen voltage of the tubes so that the amplification factor of the N-S amplifier will be identical to that of the E-W amplifier.

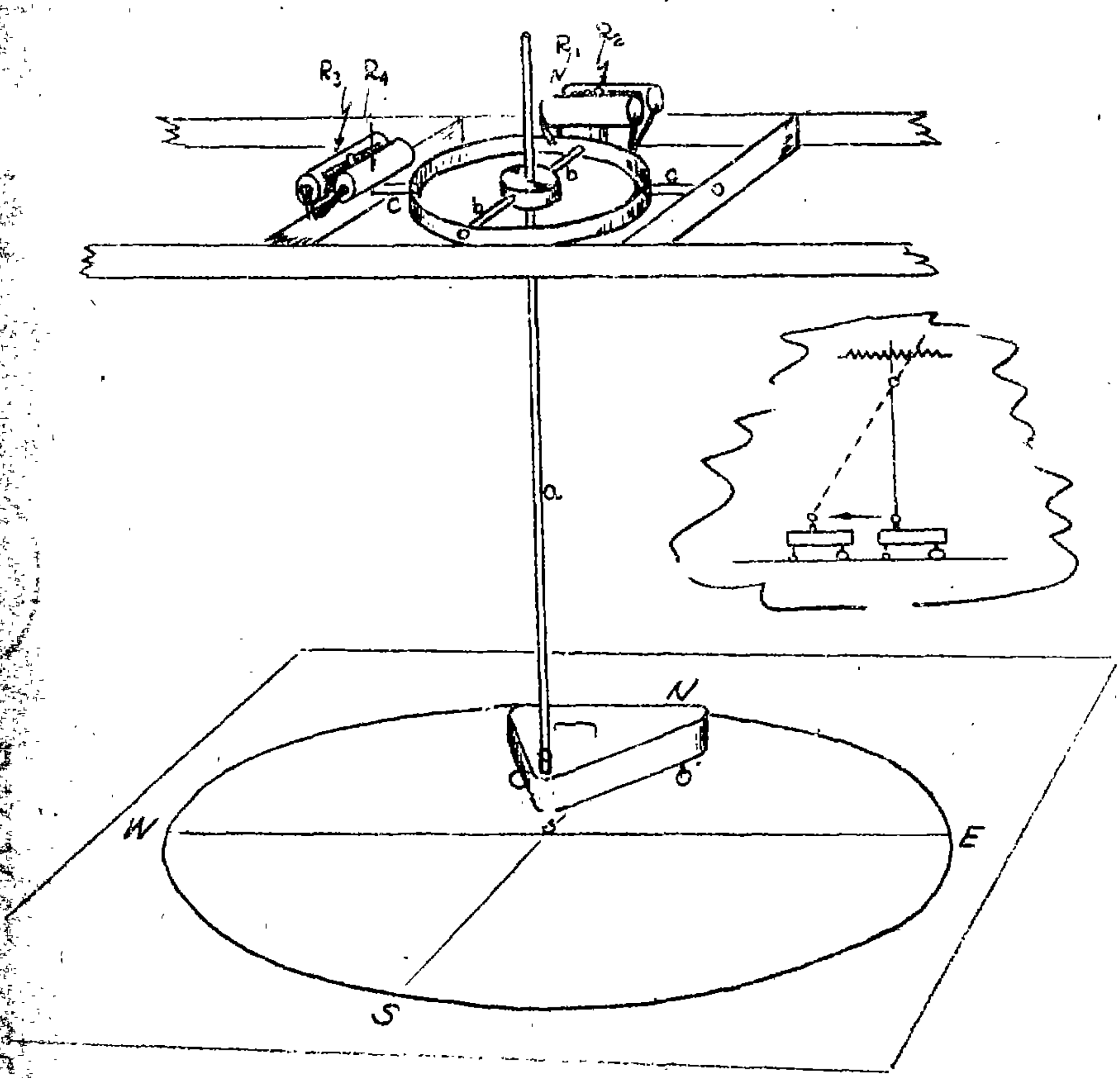


FIGURE 1. SCHEMATIC DRAWING OF THE PICTORIAL DISPLAY EQUIPMENT

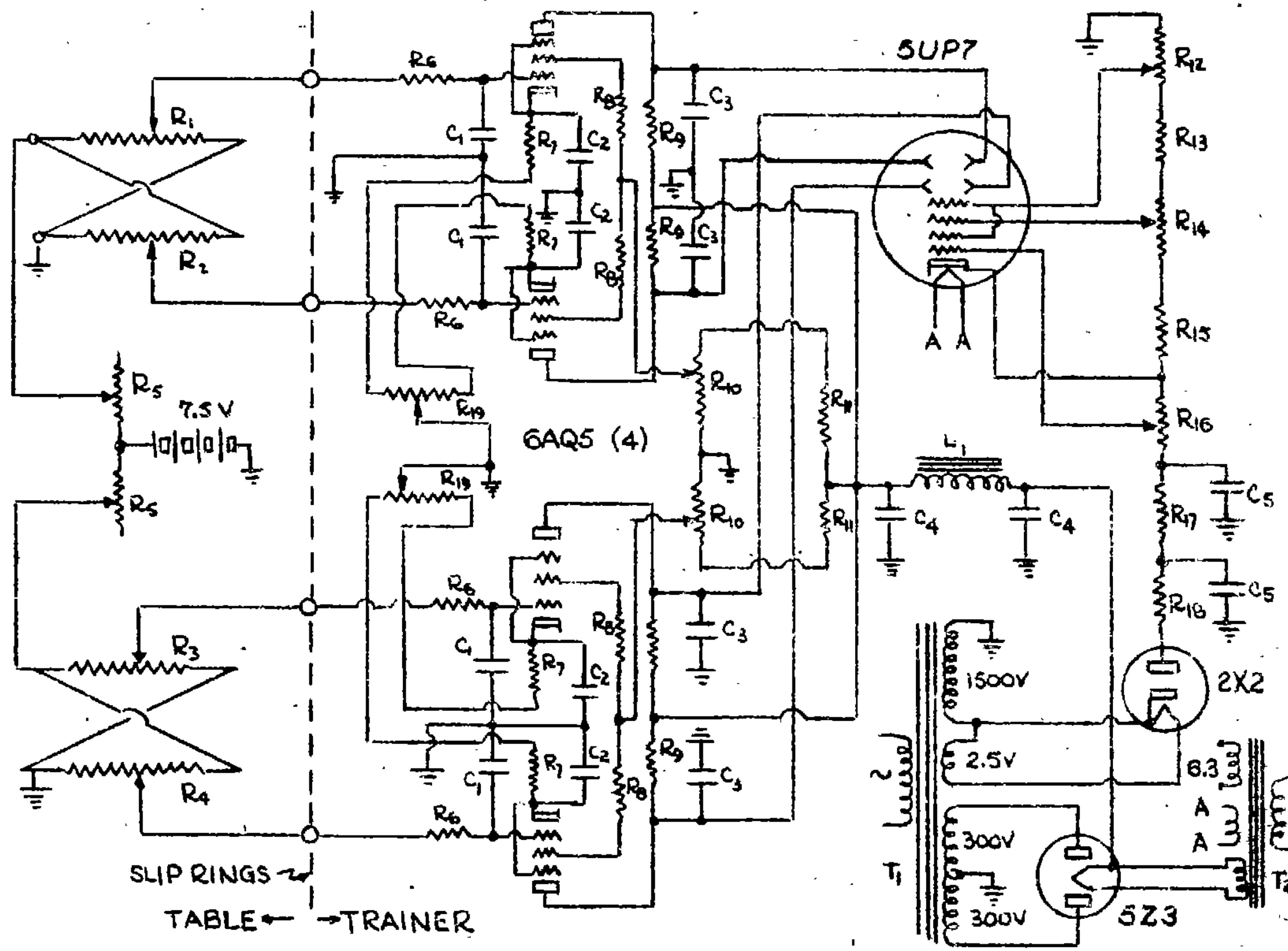


FIGURE 2. CIRCUIT DIAGRAM OF THE PICTORIAL DISPLAY EQUIPMENT

The function of potentiometer R_{12} is to adjust the anode No. 2 voltage so that it is equal to the average of the voltages on the deflection plates. This adjustment enables the pilot to obtain sharper focus of the "pip" when he adjusts R_{14}. The potentiometer R_{15} is used to vary the intensity of the "pip."

The power supplies and filter networks are conventional, and the schematic diagram will provide an adequate description of them.

The system was tested for linearity in the following manner:

On the map and on the face of the display tube are inscribed circles with an interval of two miles. If the crab is moved from the center of the map along any radial to any of these circles, the "pip" should appear on the corresponding circle on the tube face and on the corresponding radial.

When this test was made with the trainer stationary, the results were excellent. With the trainer in actual use, however, it must rotate on its base and thus its relation to the earth's magnetic field is not constant. Since the cathode ray tube is mounted in the trainer, it is subject to a constantly changing magnetic field. This field was found to bend the electron stream and displace the "pip" about a quarter of an inch on the face of the tube.

This effect could probably have been greatly reduced by enclosing the tube in a "Mu-Metal" shield. This was, however, deemed inadvisable because of the difficulties encountered in obtaining a specially made shield. As a substitute, a shield was constructed of 20-gauge cold rolled steel and cast iron pipe, and the effect was reduced to half of its previous value.

The inaccuracy caused by the remaining magnetic displacement was overcome by adjusting the centering controls with the trainer turned to the final heading of each problem.

Considering the error due to the earth's magnetic field, changing line voltage and tube temperature, and the limit of accuracy of reading the position of the "pip" due to its diameter, it is estimated that the position of the trainer can be determined within a quarter of a mile by reading the pictorial display.

Part List for the Pictorial Display Equipment:

Resistors:

R_1, R_2, R_3 and R_4	10,000 ohm	10 watt wire wound
R_5	2,500 ohm	wire wound pot
R_6	100 K	$\frac{1}{4}$ watt carbon
R_7	200 ohm	1 watt carbon
R_8	100 K	$\frac{1}{2}$ watt carbon
R_9	25,000 ohm	5 watt wire wound
R_{10}	50,000 ohm	wire wound pot
R_{11}	50,000 ohm	5 watt wire wound
R_{12}	100 K	carbon pot
R_{13}	(6) 1 meg	resistors (1-watt)
R_{14}	2 meg	carbon pot
R_{15}	1 meg	1 watt carbon
R_{16}	1 meg	carbon pot
R_{17}, R_{18}	50 K	1 watt carbon
R_{19}	200 ohm	wire wound pot

Capacitors:

C_1, C_2 and C_3	0.1 mfd	400V. paper
C_4	10 mfd	400V. electrolytic
C_5	0.1 mfd	3500V. oil

II. THE SYMBOLIC DISPLAY

The device used to produce the symbolic display consists of a resistance bridge circuit that is actuated by the motion of the trainer recording crab. (See Figure 3.)

A plexiglass block is mounted on the trainer crab and is free to rotate about its vertical center line. This block contains two carbon brushes that contact copper strips "a" mounted on either side of arm "b." These strips are connected to the halves of the bridge circuit as shown in the circuit diagram, Figure 4. The drum on which the bridge circuit is mounted is mechanically connected to rotate with arm "b."

A voltage is fed through the brushes and copper strips to the bridge circuit and connected to the course line deviation indicator (CLDI) and to the ambiguity (TO-FROM) indicator through arms "f." These arms are rotated by the selsyn receiver "g" connected to the course line selector selsyn transmitter in the trainer.

When the pair of contact arms connected to the CLDI are in contact with the center of resistance elements "d," the CLDI will be centered. The pair of arms connected to the TO-FROM indicator will then supply it with voltage of the proper polarity to make it read "TO" or "FROM."

If the course line selector is rotated and the contact arms moved, the CLDI will give an off course indication. The copper contact strips mounted on the sides of arm "b" are connected so that the passage of the trainer over the station will produce a reversal in the polarity of the voltage fed to the bridge circuit. (See Figure 4.) The passage of the crab over the station will not effect the reading of the CLDI if the crab remains on the proper course, but the reversal in the polarity of the voltage supplied to the TO-FROM indicator will cause the reading to swing from "TO" to "FROM" or vice versa.

To put this equipment into use the pilot may turn the course line selector knob, which will rotate arms "f" until he receives a zero reading on the CLDI. At this time the pair of arms connected to this meter will be in the center of the resistance bridge element, and the pair of arms connected to the TO-FROM indicator will be contacting the copper strip on drum "c" giving a reading of "TO" or "FROM." As the pilot follows his selected course to the station, the bar "b" will remain stationary, and there will be no change in the readings of his instruments until he has crossed the center of the station. At this time the TO-FROM indicator will swing from "TO" to "FROM."

If the pilot wishes to fly to the station on a given course he may turn the course line selector to the proper bearing causing arms "f" to rotate to the proper position. He will then fly the trainer in such a way that the crab will rotate drum "c" until the resistance elements "d" fall under the arms connected to the CLDI. He will then receive a zero

FIGURE 3. SCHEMATIC DRAWING OF THE SYMBOLIC DISPLAY EQUIPMENT

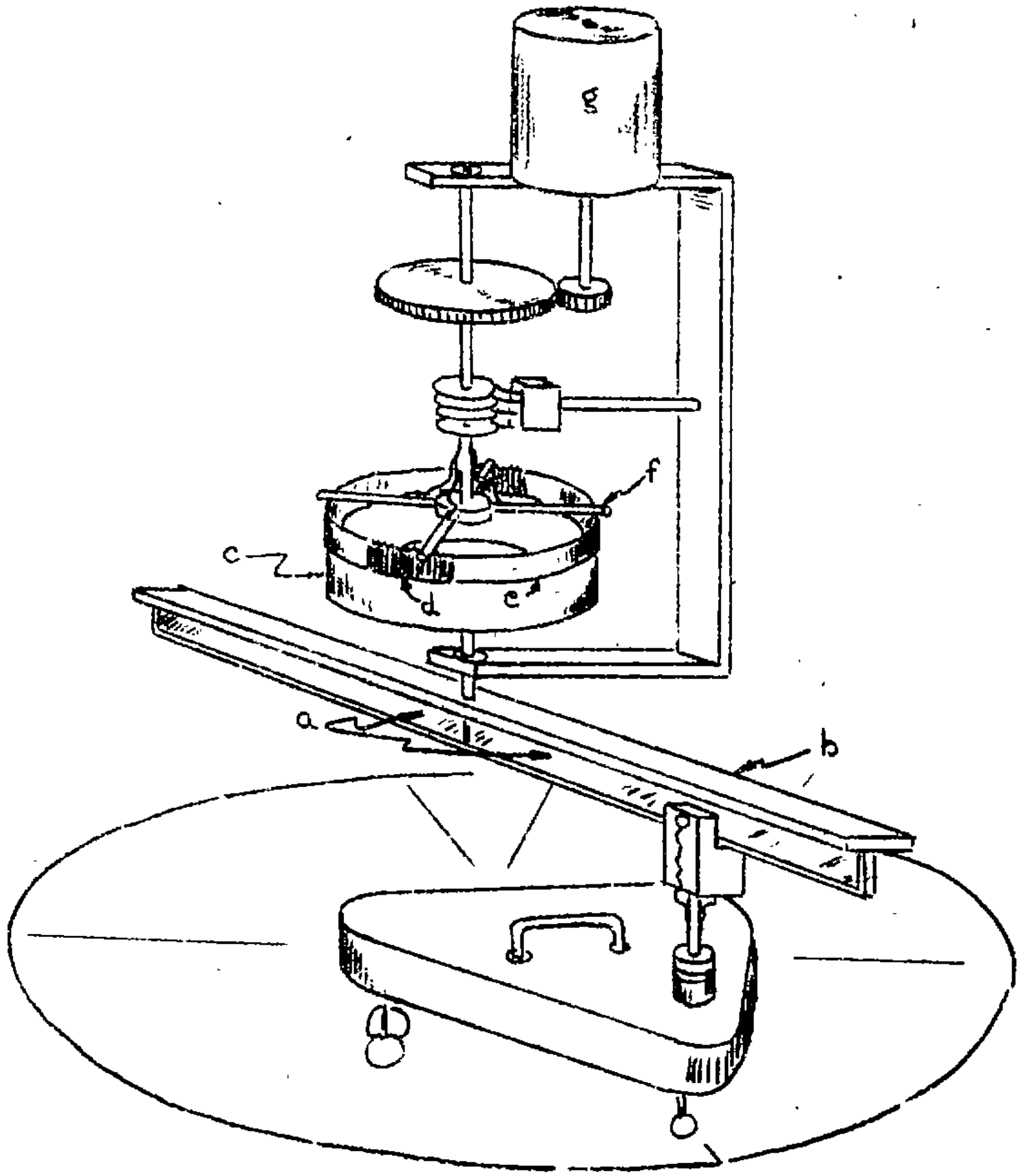
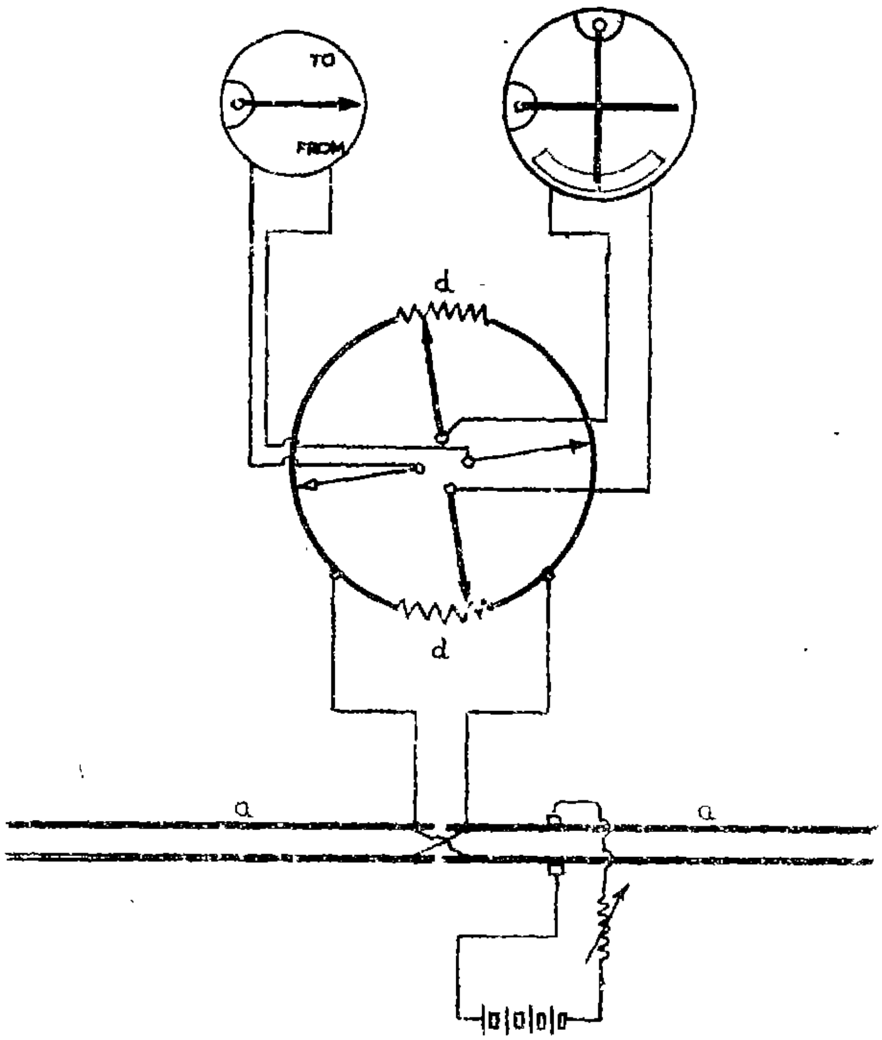


FIGURE 4. CIRCUIT DIAGRAM OF THE SYMBOLIC DISPLAY EQUIPMENT



reading and can turn the trainer to the course he has selected to fly to the station.

The accuracy of this equipment depends largely upon the sensitivity of the bridge circuit and upon the accuracy with which arms "f" follow the course line selector selsyn in the trainer. It is estimated that the accuracy of the equipment is within two degrees regardless of the distance from the trainer recording crab to the station.

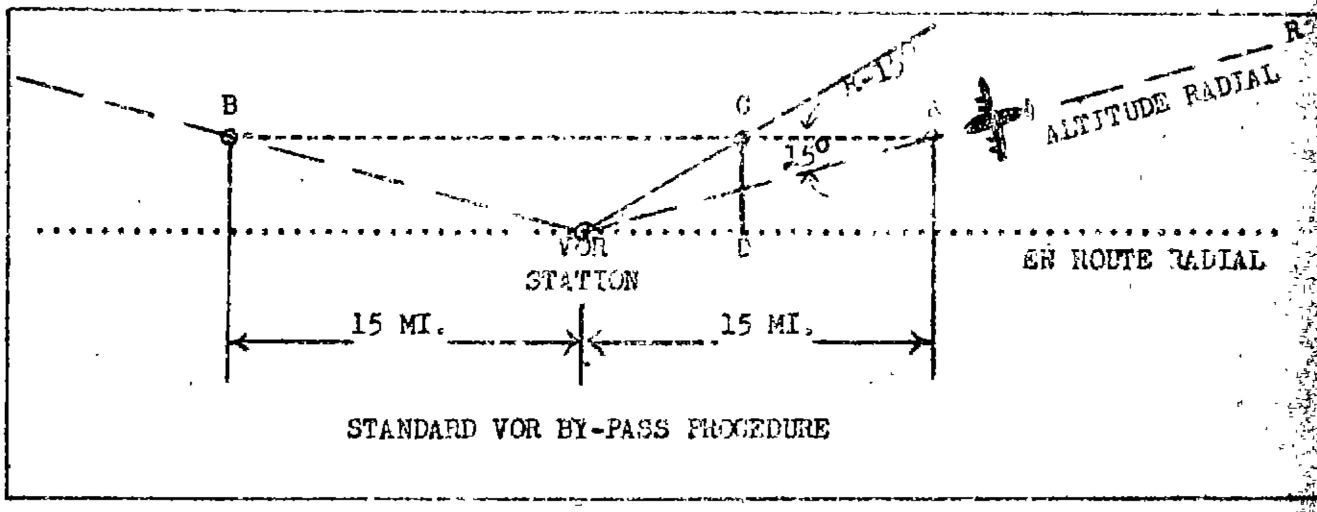
APPENDIX IV

A DISCUSSION OF THE STANDARD CAA BY-PASS PROCEDURE FOR VOR STATIONS

APPENDIX IV

A DISCUSSION OF THE STANDARD CAA BY-PASS PROCEDURE FOR VOR STATIONS

The figure shown below is an actual copy of the standard CAA change of altitude by-pass procedure for VOR stations (as printed on the OM-1 Experimental Omni Chart by the U.S. Coast and Geodetic Survey, under the authority of the Secretary of Commerce, Washington, D.C., August, 1948).



STANDARD VOR BY-PASS PROCEDURE

By-Pass Procedure for VOR station assuming that an aircraft has not completed change of altitude upon reaching the 15 mile point from the VOR station.

Example of by-pass procedure.
(Although not required by the procedure, a method for checking distance from station when flying approximately parallel to the en route radial is included.)

If aircraft reaches point A" on altitude radial "R" and has not completed altitude change, the aircraft turns 15° to the right to follow a track "A-B" approximately parallel to the en route radial. The distance at which the aircraft will pass the station is determined as follows:

(a) The time at which the aircraft turns 15° to the right from the altitude radial is noted to the nearest 5-second increment.

(b) The azimuth selector is then set to the radial which is 15° less than the altitude radial "R."

(c) The time at which the aircraft intersects the R - 15° radial at "C" is noted to the nearest 5-second increment.

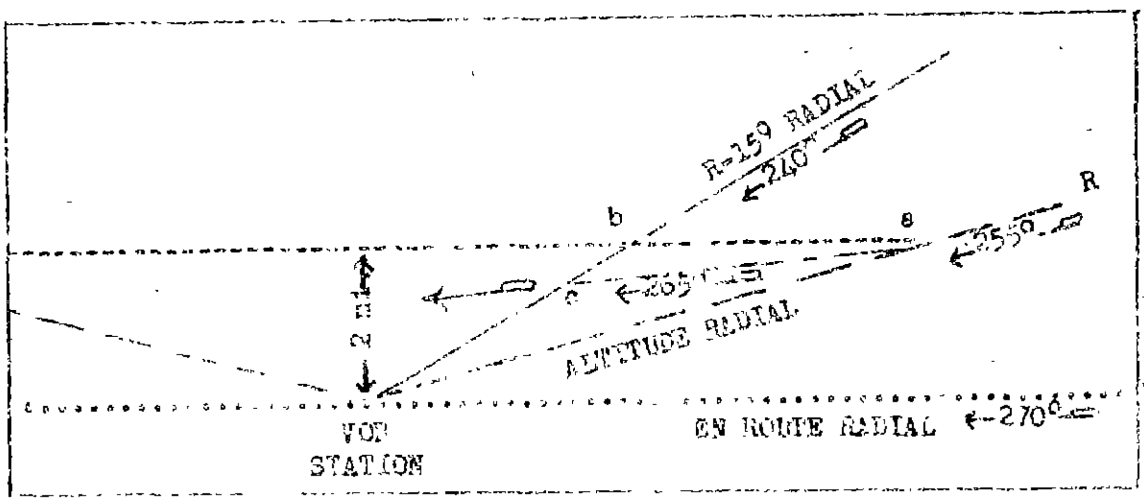
(d) The distance flown between "A" and "C" is then determined by applying the ground speed to the elapsed time between "A" and "C."

(e) The distance flown is divided by two (2) and the result is the distance "C-B" at which the aircraft will pass the station when abeam thereof and on the heading taken at "A."

The instrument pilots who flew the by-pass problem in the Link trainer using the conventional symbolic VOR display were instructed to follow the above procedure in order to determine whatever heading corrections were necessary in order to by-pass the station by exactly two miles. (In actual practice pilots are supposed to by-pass the station by four miles.)

However, a further study of the procedure discloses that it is applicable only if the track flown after making the initial 15° turn is exactly parallel to the desired track. Thus, a wind shift, an improper correction for drift or a failure to maintain exactly the desired heading would cause the correction indicated by the procedure to be inappropriate.

Suppose, as in the diagram below, that a pilot intended to make good a track of 270° (a-b), but for some reason he actually made good a track of 265° (a-c). Now, the time flown between points "a" and "c" would be longer than the time normally required to fly between points "a" and "b." Thus, when the time actually flown is converted into distance and divided by two, the indication would be that the pilot would by-pass the station by more than two miles. Actually, if he maintained his present track, he would by-pass the station by less than two miles.



If the pilot were to make the correction indicated in the above example, he would turn even more toward the station with the result that he would pass even closer to the station. It will be noted also that if the pilot had made good a track of 275° from point "a" rather than 265°, this too would have resulted in an incorrect indication, but of the opposite sign and not quite so serious. Considering that a tracking error of as little as five degrees will result in a serious misindication, we conclude that the procedure is of little practical value for actual use and may even be an additional source of confusion for the pilot.

In the present experiment, due to the restricted area of a ten mile radius about the station which could be used with the Link trainer, the time to start the first turn was strictly a function of time flown from a known starting point on the inbound 15° altitude radial. As a result some of the pilots didn't bother to use the recommended procedure at all, and few made any precise corrections from its use.

On the basis of these facts we conclude that the standard by-pass pattern cannot be flown accurately using only the information provided by the conventional symbolic VOR display. Two additional pieces of information are necessary: (1) a correct knowledge of the wind, from which ground speed and drift can be computed, and (2) the exact position along the inbound 15° altitude radial at which the initial 15° turn is to be made. This information is provided by off-course computing equipment and was presented by the pictorial display used in these experiments.