EVALUATION OF AIRCRAFT INSTRUMENT DISPLAYS FOR USE WITH THE OMNI-DIRECTIONAL RADIO RANGE

by

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and

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

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LETTER OF TRANSMITTAL

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

Committee on Aviation Psychology

March 2, 1949

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

Dear Dr. Brimhall:

The attached report, entitled Evaluation of Aircraft Instrument Displays for Use with the Omni-Directional Radio Range, by A. C. Williams, Jr., and S. N. Roscoe, 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.

This research represents the first of a series of investigations initiated following a general survey of psychological problems in cockpit instrumentation for the use of omni-directional range (ODR) equipment in navigation, conducted for the Committee on Aviation Psychology by Dr. A. W. Melton. The present study is limited in scope, dealing only with the first of the two aspects of the pilot's performance in using ODR instruments; viz., that of deciding in which direction he must fly in order to solve the navigation problem at hand. Additional research, utilizing a specially constructed Link Trainer and operating displays, has been initiated in which selected displays will be evaluated under conditions more nearly approximating the flight situation, in order that the effectiveness of the displays as flight instruments can be determined. In addition, consideration is being given to the similar evaluation of Teleran equipment.

Cordially yours,

MViteles

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

MSV:maf

EDITORIAL FOREWORD

Maximum advantage can be taken of advances in air navigation equipment only when information made available through such equipment is presented to the pilot in a form which ensures rapid and accurate observation and interpretation. Research on the omni-directional range instrument undertaken by the Committee on Aviation Psychology at the request of the Civil Aeronautics Administration represents an effort to determine through controlled experimentation the types of presentation which will yield optimal results in the way of pilot performance.

As a preliminary to such research, a survey was made of psychological problems in cockpit instrumentation arising from the introduction of omni-directional range (ODR) and distance measuring equipment (DME). Following this survey, conducted by A. W. Melton,[1] of The Ohio State University, a series of studies involving the evaluation of specific ODR displays was undertaken.

The first of these studies, carried out at the University of Illinois under the direction of Dr. A. C. Williams, Jr., is described in this report. This study is limited in scope, in that it pertains to only the first of two aspects of the pilot's performance in using ODR instruments; viz., that of deciding in which direction he must fly in order to solve the navigation problem at hand. In terms of this aspect of the situation certain "pictorial displays," which present information by graphic representation of the actual spatial relations involved, were found to be significantly superior to certain "symbolic displays," which present information in terms of dial readings, needle deflections, and numbers.

It is of interest to note that although the "pictorial" displays proved to be superior, a relatively large number of errors was made in the use of both types of displays by experienced pilots. This indicates the need for further research on the ODR instrumentation problem. With respect to both types of displays, further analyses of types of errors might yield valuable information. It is possible, for example, that certain types of errors may be considered as less critical than other types, in that they represent alternative although less desirable solutions to navigational problems rather than completely "wrong answers." Such analyses, which are under consideration, would be of particular significance in the case of "symbolic" indicators, in view of the wide use made of such indicators in the instrumentation of airplanes.

Additional research is necessary in order to evaluate the effectiveness of the instruments with respect to other aspects of the pilot's per-

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[1]Melton, A. W. Psychological problems in 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.

formance particularly in regard to the use of the equipment as a flight instrument in executing his decision. Research on this aspect of the problem, utilising operating displays in the Link Trainer, is under way at the University of Illinois, under the auspices of the Committee on Aviation Psychology.

March 2, 1949

Morris S. Viteles, Chairman
Committee on Aviation Psychology

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SUMMARY

The speed and accuracy with which 48 pilots could use mockups of eight different VOR aircraft instrument displays to solve typical navigation problems were measured. The pilot group was composed of 16 non-instrument pilots, 16 commercial pilots with instrument rating, 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 time scores. The rank order of displays based on error scores was highly correlated with their rank order based on time scores both within each pilot group and between groups.

With respect to both time and error scores there were significant differences between displays, similar differences being found for all groups. So-called pictorial displays which presented information in terms of a graphic representation of the actual spatial relations involved were significantly superior to the so-called symbolic displays which presented information in terms of dial readings, needle deflections and numbers. One pictorial display was superior to all other displays.

The reliability of the techniques used was inferred to be adequate from measures of internal consistency and from the similarity of results obtained from independent groups. Inspection of the data suggested that no marked trends indicating dependence between problems and displays were evident. No effects of practice or fatigue were found for error scores although time scores tended to improve during the early part of testing sessions. This tendency did not influence the comparison of displays because the effects of practice and fatigue were balanced in the main experimental design.

EVALUATION OF AIRCRAFT INSTRUMENT DISPLAYS FOR USE WITH THE OMNI-DIRECTIONAL RADIO RANGE

INTRODUCTION

The omni-directional radio range (VOR) provides the pilot with continuous visual information concerning his bearing to or from an omni-range station. This makes it possible to fly to a station along any desired track or from a station in any desired direction, representing a considerable advantage over the conventional 4-leg auditory radio range. In addition, VOR employs a very high frequency signal which provides static-free reception. It is, however, limited to line of sight distance.

The purpose of this study has been to evaluate selected aircraft instrument displays which could be used with VOR. The basis for evaluation has not been concerned with engineering criteria. Instead, evaluation has been based on the speed and accuracy with which representative pilots could use the displays involved. An inspection of various existing 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.[1]

The problem seemed essentially to be one of mode of display. The information presented by all displays was both correct and adequate, but it was often difficult to interpret. For this study, three new displays were devised which it was believed might represent an improvement in ease of interpretation compared with conventional displays. For comparison these three were evaluated in conjunction with five conventional displays of varying design. In all, eight displays were evaluated. These were: (1) CAA Indicator, (2) Air Line Indicator, (3) Air Force Indicator, (4) Experimental Symbolic Indicator*, (5) Radio Magnetic Indicator, and (6), (7), (8) special displays designed for this study. Each of these displays is shown in Appendix 1.

Designs (1) - (5) represent primarily symbolic modes of display because they present information by means of numerical pointer readings, needle deflections, or numbers appearing in windows. Designs (6), (7) and (8) were intended to be graphic or pictorial displays because the actual horizontal spatial relations between aircraft, station and heading are shown in miniature on the face of the instrument. 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. In this case the dichotomy was not absolute because some of the symbolic displays also provided cues which could be interpreted perceptually, while the pictorial displays provided some symbolic quantitative information.

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[1] Melton, A. W. Psychological problems in 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.

*Editor's note. Hereafter designated "Grether's Indicator."

PROCEDURE

The displays evaluated were mockups instead of actual flight instruments. The mockups were made by drawing a schematic picture of the display, the indications of which were made to read as they would on the real instrument had the aircraft been in a given position with respect to a VOR station. A series of ten navigation problems was made up based upon ten different positions of the aircraft with respect to the VOR station. The problems were selected so as to sample a variety of flight situations in which VOR might be used. Each problem had a task which the pilot was supposed to solve by reading the display. The tasks in general were either to fly to or away from the station along a track through the aircraft's present position, or to fly to or away from the station on some other designated track as might be required by traffic control. To indicate his solution the pilot was given a double multiple choice of answers. On the first part he had to indicate whether he would turn right, fly straight, or turn left to initiate his solution. On the second part he had to choose one of four headings to which he would turn if in the first part he decided to turn otherwise he could indicate he would maintain the same heading if he chose not to turn. Sample problems are shown in Appendix 2.

A set of ten mockups representing the ten problems was drawn for each display. The problem sets were similar for all displays but not identical. The basic spatial relations involved remained the same, but bearings, headings, and tracks were systematically varied between displays so as to prevent pilots from memorizing the problems as they went from one problem set to the next. The order of problems within each set of ten was different for each display so as to further discourage learning the problems.

The problem sets were given to forty-eight pilots divided into three groups as follows: Group 1 -- sixteen non-instrument pilots with approximately 100 hours flight experience; Group II -- sixteen commercial pilots with CAA instrument ratings, most of whom were also flight instructors; Group III -- sixteen scheduled airline pilots.

In order to introduce the pilot-subjects to their task it was found necessary to prepare elaborate written instructions supplemented by verbal briefing concerning the displays and the types of problems to be solved. A set of general instructions covering all displays and problem types was issued followed by a specific set of instructions for each display. These instructions can be found in Appendix 1.

Since all displays could not be used simultaneously by all pilots it was necessary to arrange the sequence in which they were used so as to balance the effects of practice and fatigue. The order in which the displays were presented is shown in Table 1. By virtue of this arrangement each display was presented once and only once in each serial position and also each display occurred only once in each sequence. Two subjects from each group, or six subjects in all, were assigned to use the displays in an order according to each sequence.

How well displays could be used by the pilot-subjects was measured by the time required for them to complete each set of ten problems and also by the number of incorrect answers in each set. A problem was considered incorrectly solved if either part of the double answer was wrong.

The problems and procedure were pretested using a separate group of eight subjects. As a result of the pretest it was found necessary to change some of the mockups because of previously undetected errors in their readings. Likewise it was found necessary to rewrite many parts of the instructions because they were not understood by the pre-test subjects. In general the instructions had to be amplified.

TABLE 1

ORDER OF PRESENTING DISPLAYS SO AS TO BALANCE EFFECTS OF PRACTICE AND FATIGUE

Sequence	Order of Presentation							
	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth
1	#3	#4	#7	#2	#8	#1	#5	#6
2	#7	#8	#1	#6	#5	#4	#2	#3
3	#2	#6	#5	#8	#1	#3	#7	#4
4	#6	#3	#8	#5	#2	#7	#4	#1
5	#1	#5	#3	#4	#6	#2	#8	#7
6	#5	#1	#6	#7	#4	#8	#3	#2
7	#8	#2	#4	#3	#7	#6	#1	#5
8	#4	#7	#2	#1	#3	#5	#6	#8

Numbers in Boxes Indicate Displays

RESULTS

1. Comparison of the Groups. Before any data pertaining to differences among displays were analyzed, both the time scores and the error scores for the three groups were tested for homogeneity by use of the t-test. The three groups did not differ significantly in their time scores. With respect to error scores the groups were different, both of the more experienced groups making significantly fewer errors than the non-instrument group. Because of this difference the three groups will be treated separately in the evaluation of the displays.

The speed and accuracy with which the various pilot groups used each display are shown in Table 2. 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.

There was a strong relationship between the speed and accuracy with which the three groups used the various displays. This is shown by the rank order correlation coefficients listed in matrix for in Table 3.

TABLE 2

AVERAGE TIME AND ERROR SCORES PER SET OF TEN PROBLEMS FOR EACH OF THE EIGHT DISPLAYS TESTED.

Display	Non-Instrument Pilots Time (minutes)	Non-Instrument Pilots Errors	Instrument Pilots Time (minutes)	Instrument Pilots Errors	Airline Pilots Time (minutes)	Airline Pilots Errors
Pictorial "A"	7.9	2.8	5.6	0.9	6.0	1.5
Pictorial "B"	9.5	4.4	6.4	2.8	9.9	2.1
Pictorial "C"	10.0	4.8	8.5	2.8	10.4	2.5
Radio Magnetic Indicator	14.2	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
Grether's Indicator	14.2	6.0	13.4	4.3	13.3	5.0
CAA Indicator	18.4	6.9	19.4	4.3	18.8	4.6

TABLE 3

MATRIX OF RANK ORDER COEFFICIENTS BETWEEN TIME AND ERROR SCORES FOR DIFFERENT DISPLAYS BY THE THREE SUBJECT GROUPS.

Variables: T_I = time scores for Group I, E_I = error scores for Group I, T_{II} = time scores for Group II, etc.

	T_I	E_I	T_{II}	E_{II}	T_{III}	E_{III}
T_I						
E_I	.97					
T_{II}	.98	.94				
E_{II}	.72	.83	.68			
T_{III}	.99	.95	.99	.69		
E_{III}	.82	.83	.76	.80	.76	

These correlations indicate that displays which were used more rapidly also tended to be used more accurately. This relationship obtained for all groups of subjects and even when the time scores for one group were correlated against the error scores of a different group.

2. Comparison of the Displays. Table 2 shows considerable variability among the time and error scores for the different displays. For example, the air line pilots required on the average 6 minutes to solve ten problems, of which only 1.5

were wrong, using Pictorial A whereas they required 21.[illegible] minutes and made 4.8 errors per ten problems, using the Air Force Indicator. Similar ranges were found for all three groups.

As a preliminary test to determine whether differences between displays were significant enough to warrant more detailed treatment, analyses of variance were made for the raw speed and accuracy scores of the 16 subjects in each of the three groups. These six analyses showed the results to be consistent for all three groups. There were in all cases significant amounts of variance (at the 1% level) attributable to differences among the displays. All of the variance could be accounted for in terms of two sources: (1) differences between displays and (2) differences between subjects.[2] In the case of the time scores of Group II (instrument pilots) all variance was accounted for by the differences between the displays. In other cases, both the displays and the subjects contributed significantly to the total variance. In no case was the residual variance significant, all variance being accounted for by the two above sources.

On the basis of the indicated differences among the displays, individual comparisons were made by the method of chi-square. The error scores for each group on each display were pitted against the corresponding scores for each of the other displays. Because of the strong relationship between time and error scores (shown in Table 3) and since accuracy seems to be a more critical criterion than speed, only the error scores were treated in this manner. The results of these comparisons are shown in matrix form in Table 4.

In Table 4 the displays are listed at the left according to their rank order based on error scores. Across the top they are listed in the reverse order. Any given percentage appearing in the matrix refers to the level of significance of the superiority of the display indicated to the left over the display indicated above.

The matrix could be constructed in this way because there were no reversals in the hierarchy of differences. Although a higher ranking display was not always <u>significantly</u> better than all lower ranking displays (see lower part of matrix) a lower ranking display was never superior, for any group of subjects, to one ranking above it.

There were virtually no significant differences among the five displays designated as symbolic. In four scattered cases the Radio Magnetic Indicator was used more accurately than the three lowest ranking displays. In three of these four cases this advantage obtained only for the airline pilots who may have had some additional experience with some similar type of display.

In general, this matrix emphasizes the dichotomy, discussed earlier, between pictorial and symbolic type displays. Also it indicates the advantage of having pictorial displays oriented about the omnirange station rather than about the aircraft, as demonstrated by the superiority of Pictorial A over either Pictorial [illegible] or [illegible].

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[2] The design was categorized by displays and subjects, analysis [illegible] [illegible] being feasible [illegible] [illegible] were [illegible] [illegible]

TABLE 4

Matrix of significant differences in error scores for Groups I, II, and III on the different displays. Percentages in boxes indicate the level of significance of the superiority of the display indicated at the left over the display indicated at the top. The single division line emphasizes the dichotomy between the "pictorial" and the "symbolic" displays. The double division line emphasizes the superiority of the station oriented pictorial display over all others, including the airplane oriented pictorials.

Composite Error Rank	Display	Group	C.A.A.	G.S.I.	A.F.I.	A.L.I.	R.M.I.	Pic C	Pic B	Pic A
1	Pic A	I	1%	1%	1%	1%	1%	1%	1%	
		II	1%	1%	1%	1%	1%	1%	1%	
		III	1%	1%	1%	1%	1%	5%	—	
2	Pic B	I	1%	1%	1%	1%	2%	—		
		II	1%	1%	—	2%	2%	—		
		III	1%	1%	1%	1%	5%	—		
3	Pic C	I	1%	5%	1%	1%	—			
		II	1%	1%	—	2%	2%			
		III	1%	1%	1%	1%	—			
4	R.M.I.	I	5%	—	—	—				
		II	—	—	—	—				
		III	1%	1%	1%	—				
5	A.L.I.	I	—	—	—					
		II	—	—	—					
		III	—	—	—					
6	A.F.I.	I	—	—						
		II	—	—						
		III		—						
7	G.S.I.	I	—							
		II	—							
		III	—							
8	C.A.A.									

3. Reliability and Internal Consistency of Test. Inasmuch as the experimental technique employed consisted of a paper and pencil test, such a test should meet certain standards of reliability, internal consistency, range of difficulty, etc.

No direct reliability data were available since a single form of the test was given only once to any one subject, and since the individual problem sets were hardly long enough to employ the split half method. However, a measure of the reliability of the test may be inferred from the consistency of the results for the three independent groups of subjects. Furthermore, an item analysis showed each of the ten test items or problems to correlate acceptably with the total test error scores for each of the three groups, as listed in Table 5, below.

As for the range of difficulty of the ten problems, Table 6, below, shows that the 16 non-instrument pilots of Group I made totals of from 52 errors on problem "8" to 101 errors on problem "6" out of a possible 128 (16 x 8) errors on each of the problems. The 16 instrument pilots of Group II made totals of from 20 errors on problem "1" to 87 errors on problem "6" out of an equal number of possible errors. The 16 airline pilots of Group III made totals of from 22 errors on problem "1" to 70 errors on problem "5". The differences in the difficulty of the 10 problems, as indicated by the frequencies shown in Table 6, were found to be significant at the 1% level by the method of chi-square. The rank difference coefficients for the relative difficulty of the ten problems for the three groups are as follows: $rho_{12} = .73$, $rho_{13} = .62$, $rho_{23} = .58$.

TABLE 5

RANK ORDER CORRELATION COEFFICIENTS BETWEEN THE ERROR SCORES OF THE 16 SUBJECTS IN EACH GROUP ON EACH OF THE TEN TEST PROBLEMS AND THEIR TOTAL ERROR SCORES ON THE ENTIRE TEST.

Test Item	Group I	Group II	Group III
1	.71	.66	.62
2	.74	.65	.50
3	.79	.75	.55
4	.74	.64	.57
5	.41	.70	.65
6	.42	.59	.59
7	.59	.24	.72
8	.69	.76	.35
9	.64	.69	.67
10	.83	.47	.72

TABLE 6

TOTAL FREQUENCIES OF ERRORS ON EACH OF THE TEN TEST PROBLEMS BY EACH OF THE THREE GROUPS OF 16 SUBJECTS WORKING ON THE PROBLEMS BY THE USE OF THE EIGHT DIFFERENT DISPLAYS. THE POSSIBLE NUMBER OF ERRORS ON ANY ONE PROBLEM WAS 128.

	Problems										
	1	2	3	4	5	6	7	8	9	10	Total
Group I	54	72	68	67	76	101	63	52	73	71	697
Group II	20	30	35	36	65	87	32	33	56	35	429
Group III	22	50	34	50	70	62	46	40	44	26	444

4. Dependence between Problems and Displays. It would be of interest to determine whether some instruments are relatively more effective than others in working certain types of problems; i.e., whether there is any "interaction" between instruments and problems. Unfortunately, however, the data are not such as to yield a ready answer to this question. The interaction could not readily be evaluated by analysis of variance procedures[3] and the assumptions underlying use of certain other statistics, such as chi-squared were not completely justified. Inspection of the data suggested, however, that no marked trends indicating dependence between problems and displays were evident. It is planned to evaluate interaction between problems and displays more definitively in further research on the problem now in progress.

5. Practice and Fatigue Effects. The experimental design was purposely constructed so as to balance any effects of practice and fatigue. However, by reshuffling the data, it is possible to determine whether there was any improvement or deterioration in performance as the testing sessions progressed. This was done by rearranging the data for each subject in terms of the sequence in which he worked the eight different problem sets. Table 7 shows the total frequencies of errors made by each group of 16 subjects in the eight serial positions. Table 8 shows the total time in minutes required by each group in each of the eight serial positions. Each value in these two tables represents the composite score for 16 subjects.

Inspection of these tables indicates no trend suggesting a marked relationship between number of errors made by subjects in the respective groups

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[3]Analysis of variance, categorical in terms of Displays, Problems, and Individuals was not made since (a) error scores were dichotomous, i.e., the solution of individual problems was either correct or incorrect, and (b) time scores for individual problems were not obtained, i.e., only the time necessary to complete the entire series of problems was recorded.

and the serial order in which problems were presented. However, in terms of time scores the effect of practice is readily apparent, marked decrease in time scores being evident particularly during the first four or five presentations.

DISCUSSION OF RESULTS

Within the scope of this experiment the results have shown that pictorial type VOR displays can be used to solve navigation problems with greater speed and accuracy than can symbolic type VOR displays. Whether these results are applicable to flight depends upon the significance of the discrepancies between the experimental task and the flight task. In the use of any such instrument 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.

In this experiment, it was 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. For this task it is felt that the results are pertinent to the flight situation. On the other hand, by using mockups some information was lost which could have been obtained in flight by watching the trend of the instrument readings. But this handicap would apply equally to all displays and would probably not affect their relative standing.

A second disadvantage to mockups is that the subjects could not manipulate the instrument so as, for example, to change a "to" course to a "from" course or vice versa, as could be done with some of the actual instruments. At the same time the opportunity to manipulate an instrument is also an opportunity to make an error in manipulation as has been found to be the case in a Link trainer equipped with VOR. Even though the inability to manipulate the mockup might handicap some of the symbolic displays, the same handicaps existed for the pictorial displays in the case of their track selector which could not be manipulated on the mockup but could on the real instrument. For this reason it is doubtful that lack of manipulation discriminated unfairly between the various types of displays. On the whole it is the opinion of the investigator that so far as the pilot's initial task of orientation and discrimination is concerned the results of this experiment would recur in the actual flight situation.

After deciding what to do as a result of reading and interpreting a display, the pilot must then make good his decision by flying the airplane accordingly. To do this the pilot uses additional instruments such as the artificial horizon, altimeter, etc. But he also uses the VOR display as a source of direction information along with the compass and directional gyro. When used in this way the display can be considered to be a flight instrument and, as is true in the case of other flight instruments, the pilot's task is chiefly one of alignment. Using the aircraft controls the pilot must align a moving indicator of some sort with a previously determined fixed reference on the display.

TABLE 7

TOTAL FREQUENCIES OF ERRORS MADE IN EACH OF THE EIGHT SERIAL POSITIONS

	Order of Presentation								Total
	1	2	3	4	5	6	7	8	
Group I	93	98	80	103	81	76	87	79	697
Group II	66	50	60	41	54	49	57	52	429
Group III	58	66	56	68	55	50	49	42	444

TABLE 8

TOTAL TIME IN MINUTES REQUIRED BY SIXTEEN SUBJECTS TO SOLVE SIXTEEN SETS OF TEN PROBLEMS, TWO SETS ON EACH OF EIGHT DIFFERENT DISPLAYS, IN EACH OF THE EIGHT SERIAL POSITIONS.

	Order of Presentation								Total
	1	2	3	4	5	6	7	8	
Group I	363	286	221	221	174	153	187	181	1786
Group II	303	253	224	171	188	177	162	183	1666
Group III	299	265	228	237	200	170	203	162	1765
Totals	965	810	673	629	562	500	552	526	

This sort of performance cannot be evaluated by use of static mockups because there are no controls and no moving parts involved in the mockup. It would be unfair and unwise to suppose that the results of this experiment could be used to infer the adequacy of these displays in their capacity as flight instruments. To the contrary there is reason to believe on theoretical grounds that a more accurate flight path can be achieved using some of the symbolic displays than by using the pictorials. Symbolic displays using the couse line deviation indicator are more sensitive to displacement from the selected track than are the pictorial displays. Both the Air Force Indicator and Grether's Indicator were designed so that an asymptotic approach to a selected track could be achieved by maintaining a simple alignment on the face of the display. Presumably the ease of accomplishing this performance using these displays would not be surpassed using pictorial displays. Certainly an evaluation based on mockups is not relevant in this respect.

On the whole it is accurate to say that this experiment has thrown no light on the adequacy of the displays when they are used as flight instruments. There is reason to suspect that those displays which were found in the experiment to be superior would not necessarily be superior when used in this manner.

It must be remembered, however, that VOR is primarily a navigation device. Its chief purpose is to supply the pilot with information from which he can orientate himself and from which he can decide on a proper direction in which to fly. If the VOR display fails in this respect so that the pilot makes wrong decisions, then whatever excellence it might have as a flight instrument is wasted. If it were a case of the pilot doing the wrong thing very well as opposed to, perhaps, doing the right thing passably well, the latter alternative is to be preferred. This experiment has contributed evidence bearing on the inclination of pilots to make correct or incorrect decisions as a result of using different kinds of VOR displays. For this reason it is felt that the experiment is pertinent to the problem as it exists in flight and that the experimental results should be considered when making a choice of displays for actual use.

PLANS FOR FUTURE RESEARCH

Because this study was limited in scope as described above, additional work is necessary in order to evaluate VOR displays in their capacity as flight instruments. Some of this work is now being done, with more planned for the future. At the present a display similar to the CAA indicator has been built for use in a 1-CA-1 Link trainer. Equipment necessary to simulate VOR automatically has been constructed in conjunction with the display and a sample of pilot-subjects has been tested flying problems similar to those used in the mockup study. Their performance using this display will be compared with their performance using a display similar to Pictorial A which is now under construction. Preliminary results with the CAA indicator in the Link show that subjects tend to make the same kinds of errors as were made when the display was used in mockup in addition to new errors which are solely manipulatory in character. By themselves these results are of no great importance even though they tend to validate the mockup technique in the case of the GAA indicator. Only when comparable data have been obtained for Pictorial A can a useful comparison be made.

For the future it has been decided to study displays used for making instrument approaches and landings. R.T.C.A. has recommended that the same display should be used both for instrument landing and for point to point navigation. From the pilot viewpoint the former requires more precision than the latter and is more difficult to perform. It is likely therefore that a display suitable for instrument landing would also be suitable for VOR but that displays suitable for VOR might not always be suitable for instrument landing.

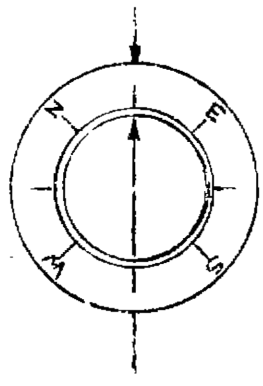
A program of research has been approved in which various instrument landing displays will be evaluated and studied in an SNJ Link trainer. The displays were selected so as to sample various kinds and combinations of information pertinent to instrument landing. Both symbolic and pictorial type displays are included and in some cases pictorial and symbolic elements are combined in a single display. It is hoped that the results will allow conclusions to be drawn concerning general principles of display in addition to the relative effectiveness of specific displays.

APPENDIX 1

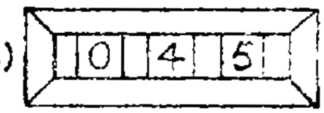
Instructions for using VOR displays in this experiment including general instructions for solving the navigation problems and specific instructions for each display used.

INSTRUMENTS TO BE USED IN VARIOUS ODR INSTRUMENT DISPLAYS

Course Line Selectors:



(Both read 45 degrees)

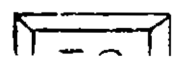


Counter Type

Compass Rose Type

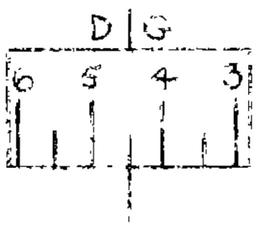
TO - FROM Ambiguity Indicators:

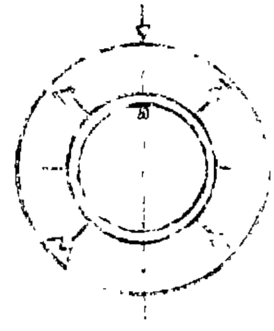
(All read: "Indicated Course is TO the station.")

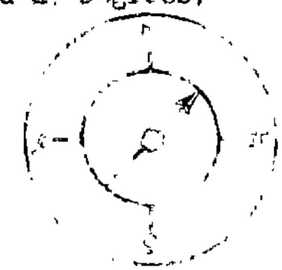


Directional Gyros and/or Gyro Stabilized Compasses:

(All read 45 Degrees)







Window Type

Compass Card Type
Card Rotates

[illegible]

Pointer Type

Type

Type

APPENDIX 1

THE EVALUATION OF VARIOUS OMNI-DIRECTIONAL RANGE COCKPIT INSTRUMENT DISPLAYS

General Instructions

A new kind of navigation device is being developed for use by pilots. It is called the omni-directional range (VOR) and will soon replace all of the conventional four-leg radio ranges. It differs from the old type radio range in that it enables a pilot to approach a radio station from any desired direction or to fly away from a station in any desired direction. This is made possible by the fact that the ODR gives the pilot continuous information as to either the direction from his plane TO the radio station or the direction FROM the station to his plane. Like the conventional four-leg range, however, it gives no information as to the present heading of his airplane. Since the plane's heading is independent of its position, and since both heading and position must be known in order to know which way and how much to turn in order to fly to or away from a given ODR station, heading information must be obtained by the use of some direction instrument such as a gyro stabilized compass or a Directional Gyro (DG).

Just how this position and direction information obtained from different sources is to be integrated and presented to the pilot in the cockpit has not been decided. In this test which you are about to take you will do some problems using eight different possible instrument displays, each of which gives you the necessary information to solve the problems. The test is so designed as to determine which of the eight proposed displays you are able to use most effectively in solving certain navigation problems.

The displays are essentially different in the following ways. Some are dial type instruments in which a pointer lines up with a lubber line or reference mark to give you your position and/or heading. Some are counter type instruments in which a number appears in a window to give you this information. And some are pictorial displays in which your airplane is represented by a silhouette, an outline, or an arrow, and the ODR station by a pip (-ϕ-) on a radar-type screen.

There are certain gadgets shown on the cover which are common to several of the displays. First is the Course Line Selector. It is used in this way. As soon as the pilot has tuned in the particular ODR station he wishes to fly, he must find out where he is with respect to the station. To do this he rotates a knob on the lower right corner of the instrument (not shown in the problems). This knob can be rotated in either direction. It is mechanically linked to the Course Line Selector which is either a compass rose or a direction counter, as the case may be for the particular instrument being used. To determine the plane's position with respect to the station with this instrument it is necessary to refer to a second instrument, the Course Line Deviation Indicator (CLDI). The CLDI is a pointer (similar to a runway localizer needle) which is free to move through an arc to the right or left of a lubber line. The position of this pointer is affected by the reading on the Course Line Selector and by the position of the plane with respect to the station. In actual practice the pilot rotates the Course Line Selector knob until the Course Line Deviation Indicator (CLDI) is centered on the lubber line. When the CLDI is centered then the course shown on the compass rose, or on the direction counter, gives the correct direction of the plane to or from the station. In order to decide whether this reading gives the direction TO or FROM the station, an Ambiguity Indicator is provided which gives this information. On some instruments there is a needle which is free to point either to the "TO" or to the "FROM" which are painted on the face of the instrument. On other instruments either "TO" or "FROM" will appear in a window. If "TO" is indicated, this means that the reading on the compass rose, or the direction counter, of the Course Line Selector is the direction <u>to the station</u> from where you are. If "FROM" is indicated, then the reading is the direction <u>from the station</u> to your position.

Since the problems which you will solve are already set up for you, it will not be necessary or possible for you to manipulate the Course Line Selector knob. Also on some of the instrument displays, such as the pictorial type, this manipulation is all done automatically for the pilot.

In some of the problems to be solved the CLDI will be centered so that all you will have to do is observe the selected course line and the TO-FROM indicator to determine your position in relation to the station, and then observe the Directional Gyro (DG), or whatever direction instrument is provided, to determine in what direction your plane is headed. With this information you will be able to decide which way to turn and how far in order to get on the desired track to or from the station as required by the problem.

However, the problems are not all this simple. So far we have considered only the case in which the CLDI needle is centered, indicating that the course shown on the Course Line Selector is the one which you are on at present. In some problems the CLDI needle may <u>not</u> be centered with the lubber line. When this is the case, the direction it is off center tells you roughly where you are with respect to the course shown. Thus you can see the way the two instruments work together. The CLDI needle is centered only when your plane is on the course TO or FROM the station shown by the reading on the Course Line Selector. If you are not on the course shown, then the needle will be off one way or the other depending on which side of the designated course you are. It should be clear then that the instrument can be used in two ways. You can center the CLDI needle by rotating the Course Selector, and that will give you the course you are on at the moment. Or you may select any desired course TO or FROM the station by rotating the Course Line Selector and then read the CLDI needle to tell you where you are with respect to that selected course. In the problems in which the CLDI needle is <u>not</u> centered, it will be necessary for you to do just that, that is, you must decide where you are in relation to the course which is shown on the Course Line Selector.

However there is sometimes a little confusion as to how to interpret the direction in which the CLDI needle is off from center. The rule is this: if the needle is off to the right, then you are on the left-hand side of the selected course (either the course TO or the course FROM the station, as indicated). If the needle is off to the left, then you are on the right-hand side of the selected course. You can think of it as if you are always on the lubber line and the needle is always the course. So if the needle is to the left of the lubber line then, of course, you are on the right-hand side of the course. This is not the same as saying that the course is to your left, as we shall see in an example.

Suppose a "track" to the station of North or zero degrees is selected. (In these instructions and problems the word "track" is used to refer to the flight path you are to make good over the ground in relation to the station; it may or may not be the same as the course to the station shown on the Course Line Selector.) Now suppose that you have selected this track of North on the Course Line Selector, and suppose that the CLDI pointer is off to the left. If the pointer represents the track and the lubber line represents you, then this means that you are on the right-hand side of the track. The track is a North track. To be on the right-hand side of a North track is to be on the East of the track. You are somewhere to the East, or on the right-hand side, of a North track which runs through the radio station. Now if you should happen to be headed North then it would be true that the track is to your left. But if you happen to be headed West, then the track would be directly in front of you. If you were headed South the track would be on your right, or if you were headed East the track would be directly behind you. In all these cases your position with respect to the track would be the same, that is, you would be on the right-hand side, or to the East of the track, and that is what the CLDI pointer would consistently indicate. It makes no difference whether the track selected is a "TO" or a "FROM" track. The pointer always tells you whether you are on the right-hand side or on the left-hand side of it, or, of course, whether you are directly on it. If you are on the right-hand side of a "TO" track, that means you are on the right-hand side of the selected track to the station; if you are on the right-hand side of a "FROM" track, that means that you are on the right-hand side of the selected track from the station.

Within certain limits, the amount of deflection or the distance that the CLDI needle is off from the lubber line indicates roughly how far you are from the selected course or track. If the needle is off less than a full scale deflection, for example, you know that you are very near the indicated course.

The above instructions apply to some but not all of the instruments you are about to use. Individual instructions will be given for each of the instruments before you attempt to use it, so that you will know which instruments these instructions apply to. Some of the instruments are almost completely automatic in their operation and give you directly the information necessary to solve the problems. For example, on the three pictorial display instruments there are no Course Line Selectors, no Course Line Deviation Indicators, and no TO - FROM Ambiguity Indicators. Both the position of the station and the position of your plane, as well as your present heading, are shown graphically upon the face of the instrument. On these pictorial instruments, however, there is one new device which the pilot uses in the actual flight situation. It is called the Track Selector and is simply a fine straight line pointer mounted over the center of the instrument and extending to each outer edge of the scope. The pilot may rotate this needle to his desired track so as to have a reference line along which to fly. In all of the problems, this Track Selector is set for the desired track called for in the particular problem.

The Problems and How To Solve Them

In the problems you are about to solve using the various instruments and groups of instruments certain things have been done for you. It is always assumed that you are tuned in on the station. Any necessary manipulation, whether of the Course Line Selector, the Track Selector, or any other manipulatory devices has been done already. The instruments are all set up to solve the problems. In certain cases it would be possible to obtain more or different information and thereby solve the problems more easily if it were possible to manipulate the instrument, but always the problems can be solved with the present settings of the instruments. Sometimes an instrument is set so that the course shown is the one you are on at the moment; sometimes you must determine where you are in relation to the selected course or a desired track. A "No wind" condition is to be assumed for all problems.

The problems are of two general types. (1) Either your task is to fly to or from the station on a track passing through your present position, or (2) you have to fly to or from the station along some other track which does not run through your present position. In the former case it is not necessary that you pass over your present position again on your way to or from the station. Instead, you turn so as to rejoin the track as quickly and simply as possible, usually at an interception angle of about 45 degrees to the track. Suppose that your present position were due West of the station and you wanted to fly to the station. Then a track through your present position to the station would be an East track, and that would be the one you would want to fly. But suppose you were headed South. It would be impossible to turn so quickly that by the time you headed toward the station you would still be on the East track. You would have flown somewhat to the South of the desired track in making your left turn to a heading of East. Therefore it would be necessary for you to continue your left turn beyond the desired heading of East, say to a heading of 45 degrees, so as to regain a position over the ground along an Eastbound track to the station. This is the procedure you should use when working this type of problem. In the above example there might be some question as to whether a left turn or a right turn would offer the most "economical" method of turning to your new heading of 45 degrees to your desired track. In solving these problems the rule to use in deciding which way to turn is this: always make the shortest turn to your new heading, that is, always make your initial turn toward, and never away from the desired track to or from the station, even though you might not always do it this way in the actual flight situation.

In the second type of problem, the one in which your desired track is not determined by your present position, you have to figure out the relationship between where you are and the track you eventually want to be on, and taking into consideration your heading, plan the most economical way to fly in order to get on the desired track. Once again, a 45 degree angle of interception is usually the most economical. If, however, your angular distance from the desired track is very great, that is, more than 45 degrees, it would be necessary to intercept the track at about 90 degrees in order to be sure of getting on the track before passing over the station. On the other hand, if you are very close to the desired track, it may be better to intercept at an angle of less than 45 degrees. Use your best judgment in these matters.

The possible solutions to the problems are given below each problem in a double multiple choice manner. For example, if your problem were "To approach the station along a track through my present position," your double multiple choice of answers might be:

		North.
	turn right	90 degrees.
I should	fly straight to/on a heading of	same as present.
	turn left	180 degrees.
		270 degrees.

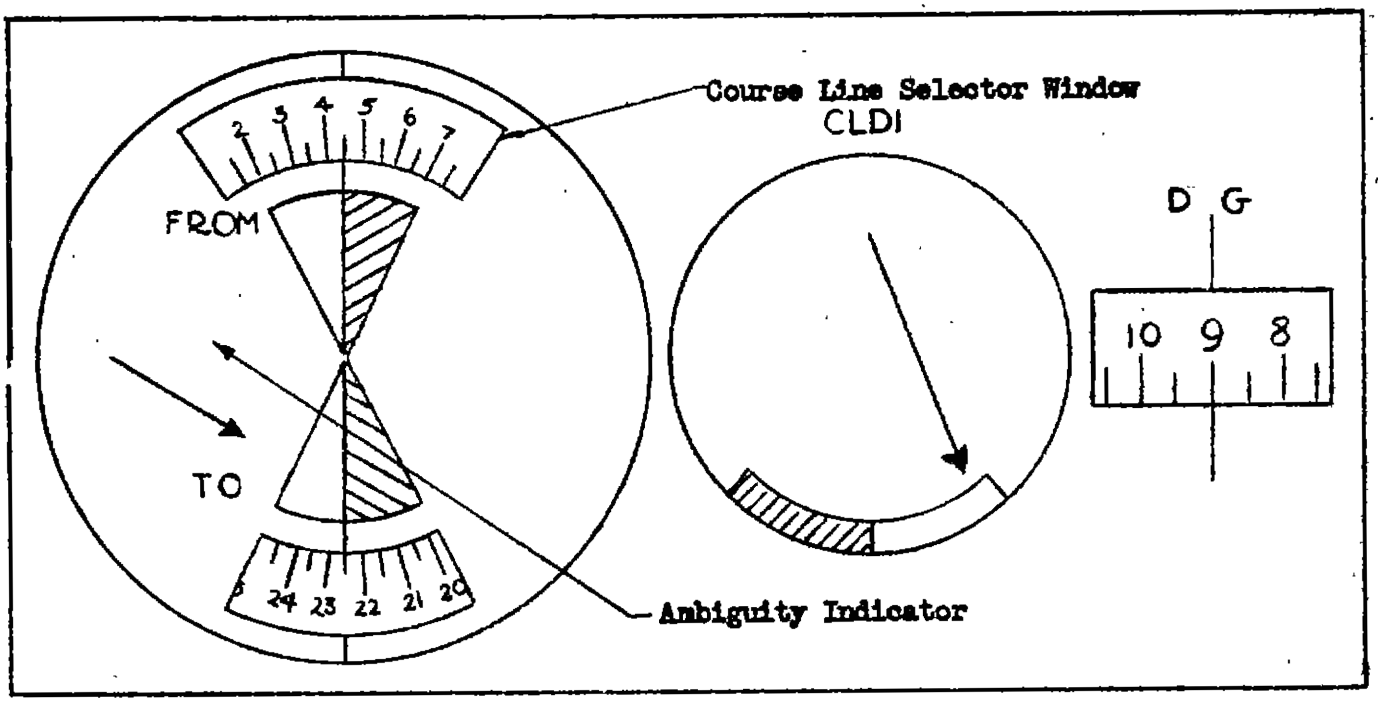
All of the answer choices are in this form. You are to select the direction to turn and the heading to which you would turn, thus making a complete statement of the best of the offered solutions. You will be scored both upon whether your solutions are correct and upon the time it takes you to solve each set of ten problems (one set for each different instrument display), so you should work both as quickly and as accurately as you can.

Read these instructions until you believe you understand them. Then read the special instructions for the first instrument you are to use. When you have done this you may start the first set of ten problems. Just before you start any set of problems, record the time in the space provided. Then when you have finished any set of problems record the time once more. Remember to do this for each set of problems. Once you have started any given set of problems you may refer back either to the instructions for the particular instrument being used or to the general instructions, but the time spent doing this must be included in the total time required for that set of ten problems. Work the eight problem sets in the order in which they are presented. As you finish each set of problems and record the finishing time, place the set to one side, face down, keeping the sets in the same order as they are presented to you. Once you have finished any set, do not return to it again.

Answer all problems, even if you are not sure of your solution. Remember always to record the time before you start and after you finish any part of the test and work as quickly and as accurately as you can.

INSTRUCTIONS FOR THE CAA INDICATOR

(#1)



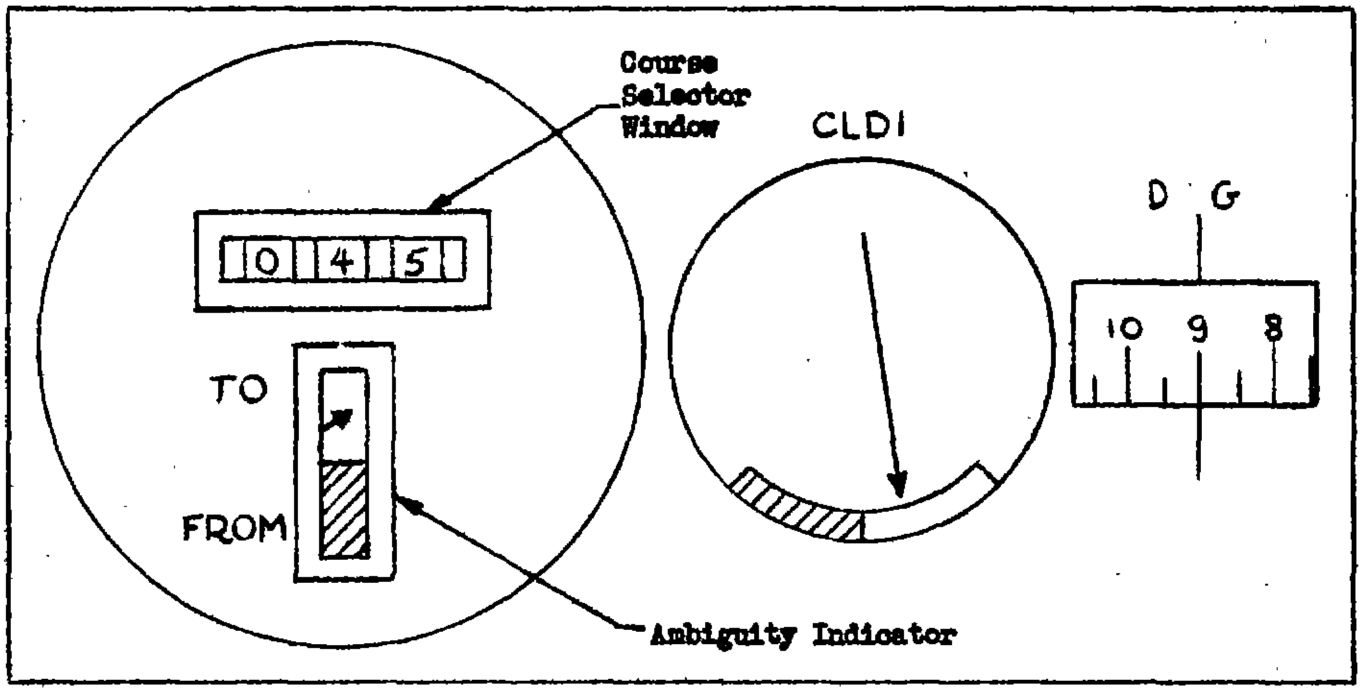
This instrument display includes a compass rose type Course Line Selector, a TO-FROM Ambiguity Indicator, a conventional Course Line Deviation Indicator (CLDI), and a Directional Gyro (DG). These instruments are all used exactly as described in the general instructions.

Your selected course is shown in the upper window of the Course Line Selector. The vertical center line of the instrument serves as a lubber line. The reciprocal of your selected course is shown in the lower window.

The cross hatch markings on the CLDI and the Ambiguity Indicator are of some additional assistance in locating your position in relation to the selected course. If the CLDI needle is off to the left in the cross hatched area, this means that your position is in one of the cross hatched sectors to the right of the vertical center line of the Ambiguity Indicator. This vertical center line represents your selected course, so it follows that you are to the right of that course shown in the upper window. If the CLDI needle is off to the right in the white area, as shown, your position is in one of the white sectors to the left of the course. Whether you are in the TO sector on the bottom or the FROM sector on the top is shown by the TO-FROM pointer.

INSTRUCTIONS FOR THE AIR LINE INDICATOR

(#2)

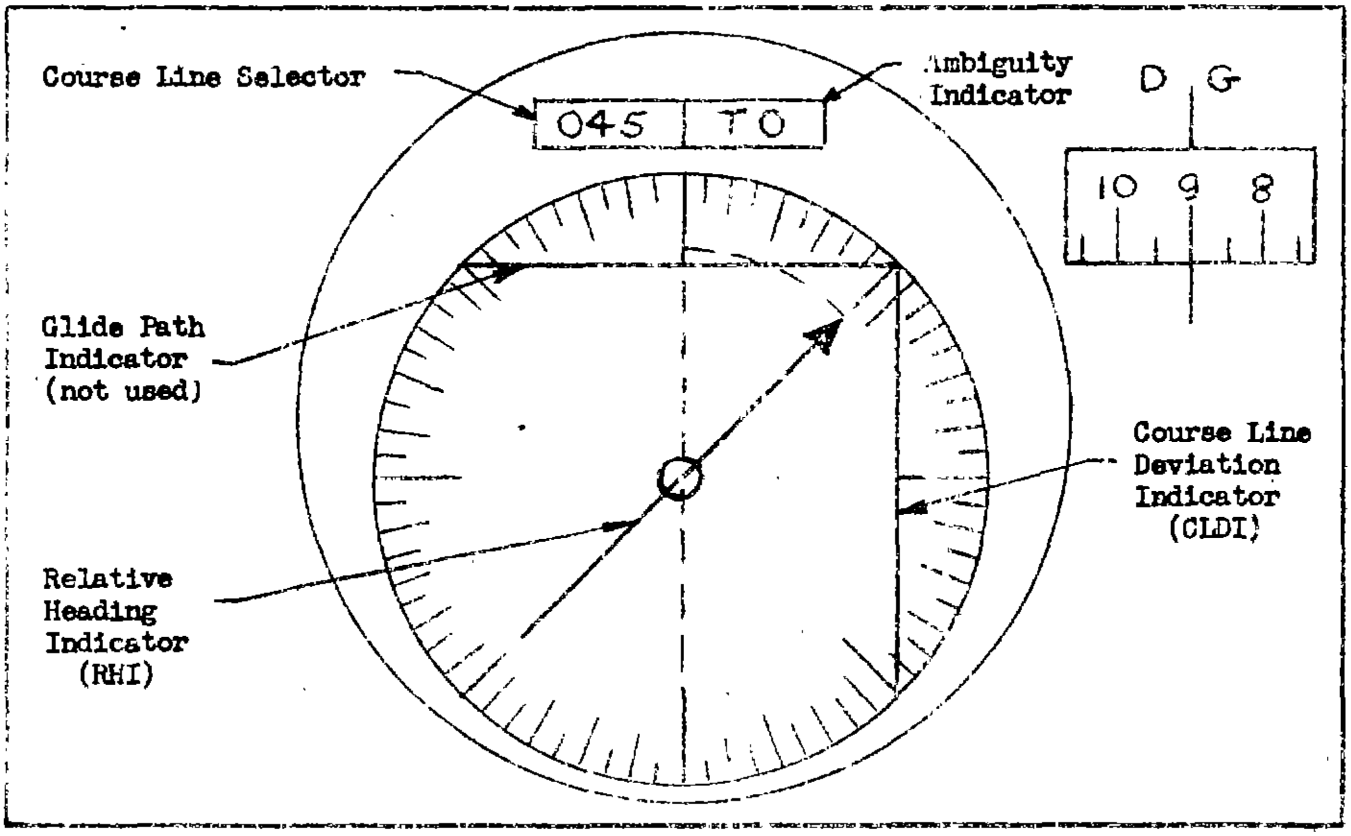


This instrument display includes a counter type Course Line Selector, a pointer type TO-FROM Ambiguity Indicator, the point of which appears either in the TO or the FROM area of the vertical window just below the horizontal counter window, and a conventional Course Line Deviation Indicator. Your heading is given by the Directional Gyro (DG) in the usual manner.

These instruments are all used exactly as described in the general instructions.

INSTRUCTIONS FOR THE AIR FORCE INDICATOR

(#3)



This instrument includes a counter type Course Line Selector, a TO-FROM Ambiguity Indicator, a Course Line Deviation Indicator, and a Directional Gyro (DG), all of which have been described in the general instructions. The CLDI differs from the conventional type in that it is always vertical (and perpendicular to the Glide Path Indicator, which may be ignored in solving these problems). However, it moves to the left or to the right indicating your position in relation to the selected course in the same way as the conventional pointer type CLDI.

There is one gadget found only on this instrument which has not been described previously. It is the Relative Heading Indicator (RHI). It is the pointer pivoted at the center of the instrument. Its deflection from the top dead center of the dial face gives you the angular difference to the right or to the left between your magnetic heading and the selected course as shown in the counter window. This difference, that is, the angular deflection of the needle to the right or left, tells you which way and how much you would have to turn your plane in order to get back onto a heading parallel to that shown in the counter window of the Course

Selector. If the RHI pointer is off to the right, as shown, you should turn to the left to bring it back to center, and vice versa.

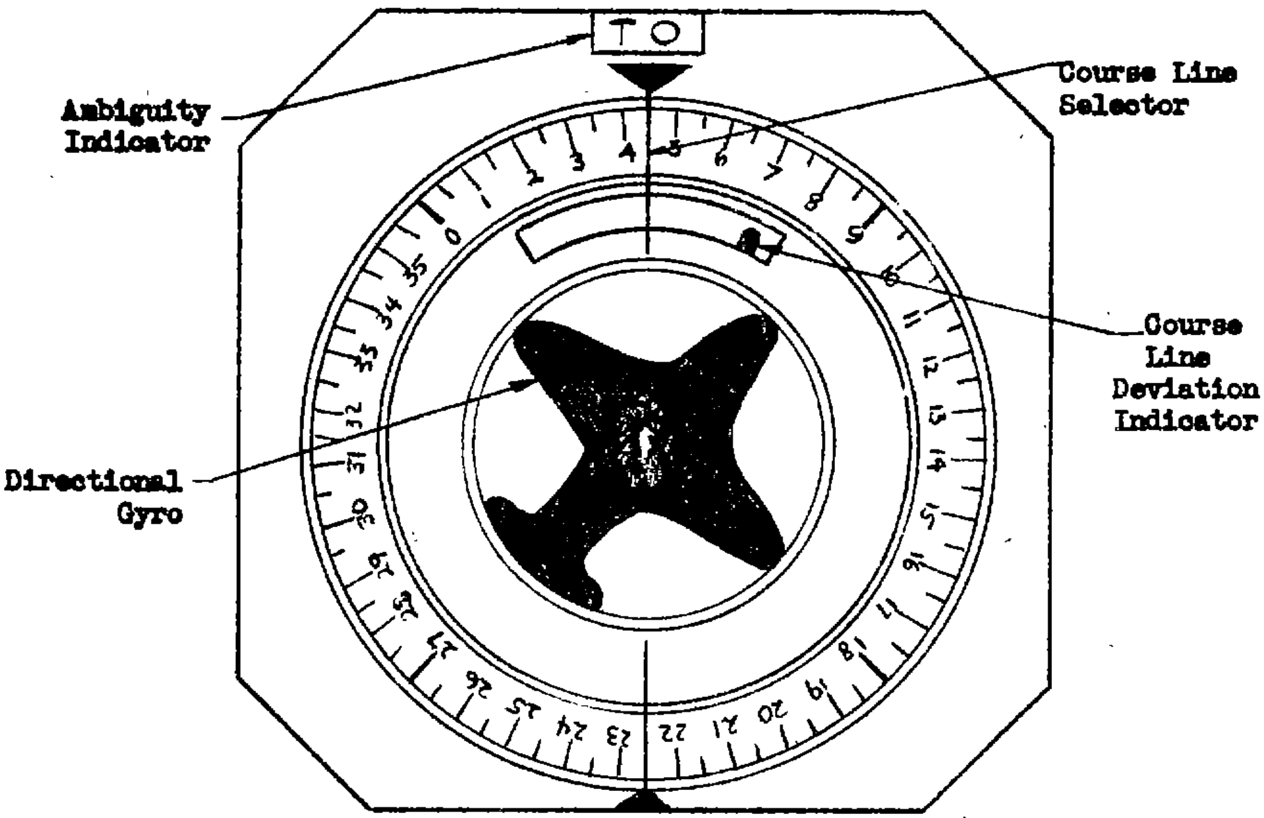
In the present problems, as you know, the task is not to fly parallel to the desired track, but to fly so as to get back directly on the desired track. To do this you should use the instrument in this way. If you want to fly <u>to</u> the station, and if your desired track is the same or the reciprocal of that shown in the counter window, you should turn in the most economical direction until the arrow pointer of the RHI is lined up with one end of the CLDI. You can decide which end of the CLDI to line the pointer up with in this way. If the Ambiguity Indicator shows TO, turn to the upper end of the CLDI; if it shows FROM, turn to the lower end. (This rule applied if you want to fly <u>to the station</u>.) Then notice how much and which way this new pointer position deviates from the selected course shown in the counter window to determine the new heading to which you have turned.

Now if your problem is to fly <u>away from</u> rather than to the station, and the course shown in the window is the same or the reciprocal of the track you are to fly, then the procedure is the same except that you line up the RHI pointer with the opposite end of the CLDI. In other words, if the Ambiguity Indicator shows TO, you would turn until the RHI pointer is lined up with the lower end of the CLDI; if it shows FROM, turn to the upper end of the CLDI. (This rule applies when you want to fly <u>away from the station</u>.) Once again you will have to decide what heading you have turned to by observing the difference between your new position of the RHI pointer and the course shown in the counter window.

For the problems in which the desired track is <u>not</u> the same as the course shown in the counter window of the Course Selector, you will have to use the CLDI and the TO-FROM Ambiguity Indicator in the usual manner to determine your position in relation to the desired track and the Directional Gyro to determine your present heading. With this information you will be able to decide which way and how much to turn in order to intercept your desired track.

INSTRUCTIONS FOR THE EXPERIMENTAL SYMBOLIC INDICATOR

(#4)



This instrument combines the Course Line Selector, the Course Line Deviation Indicator, the TO-FROM Ambiguity Indicator, and the Directional Gyro in one instrument.

The compass rose is the Course Line Selector and is rotated by a knob on the instrument which is not shown in the diagram. The compass rose is read at the lubber line at the top.

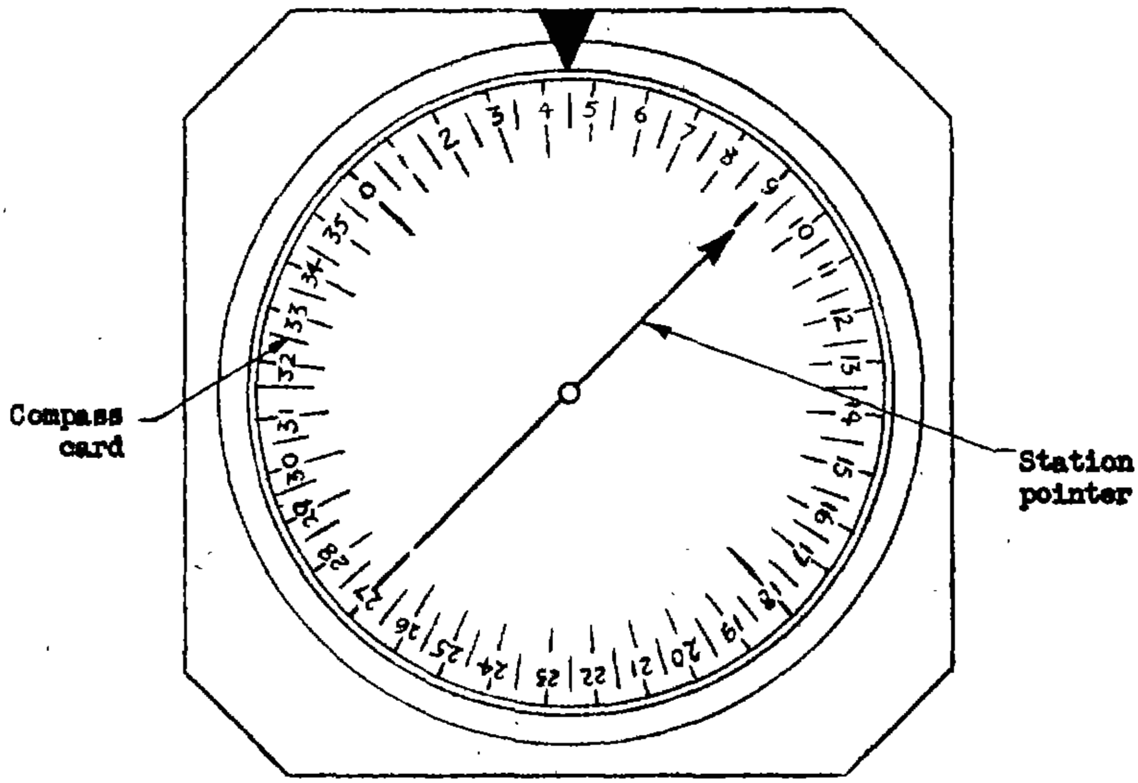
In the curved window just below this is the needle point of the Course Line Deviation Indicator. Its center position is the same lubber line.

Above both of these is the Ambiguity Indicator which tells whether the course shown on the compass rose is TO the station or FROM the station.

At the center of the instrument is an airplane silhouette and this serves as the Directional Gyro. It points to a number on the compass rose and that is the heading of your airplane.

INSTRUCTIONS FOR THE RADIO MAGNETIC INDICATOR

(#5)



This instrument combines the magnetic heading of the airplane as obtained from a gyro stabilized compass and a direct indication of the direction from the airplane to the ODR station as determined automatically by the mechanism of the instrument. It therefore gives a continuous reading of the magnetic heading of the plane and the direction to the station.

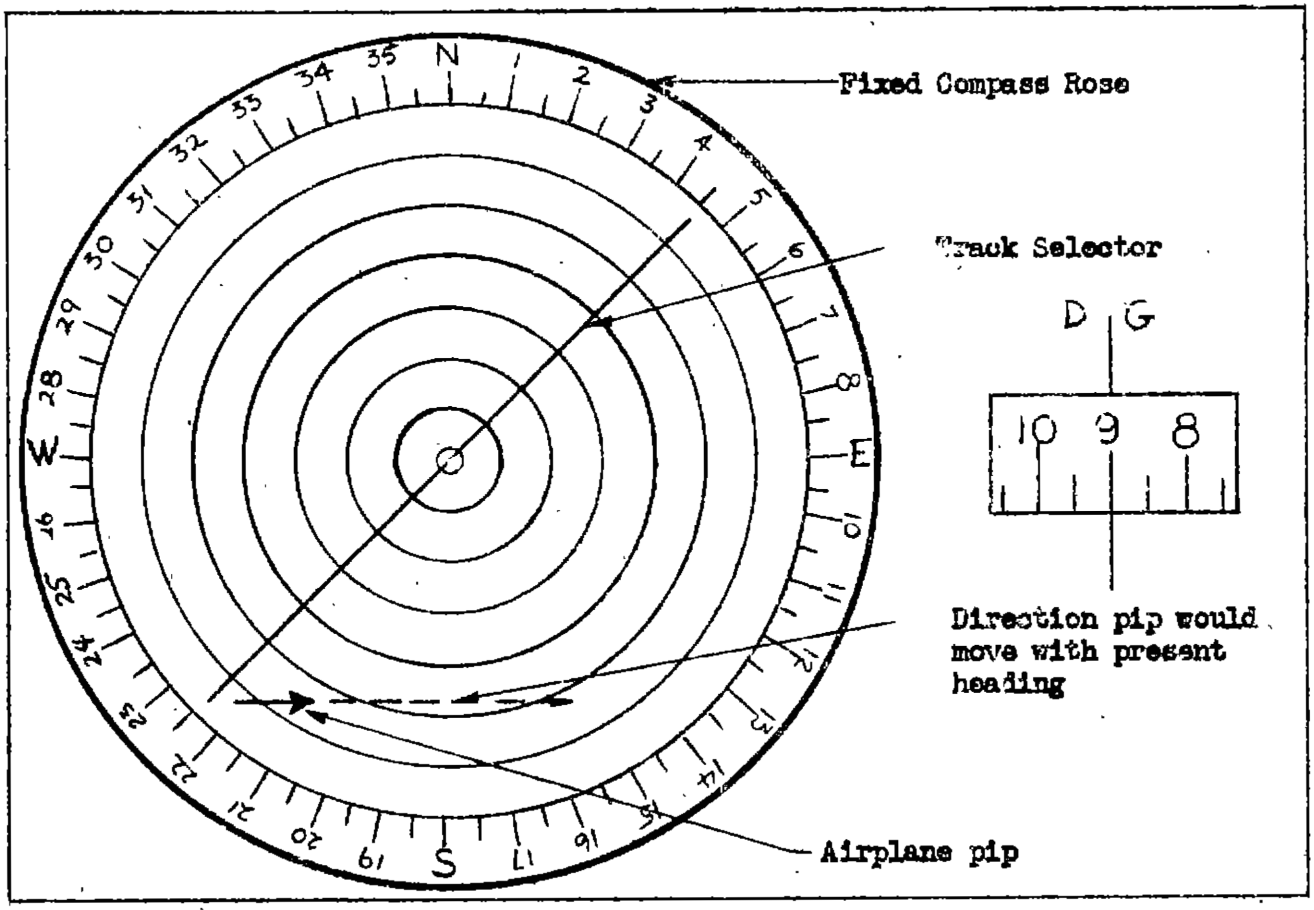
The magnetic heading of the plane is read at the lubber line at the top of the dial. The lubber line is stationary, and the compass card rotates as the plane turns. Thus the number on the compass rose which lines up with the lubber line is the heading of the airplane. Thus your present heading as shown is 45 degrees.

The pointer mounted on the face of the instrument is free to rotate about its pivot at the center of the instrument and indicates the direction to the station from the airplane. For example, if the pointer lines up with the "9" on the compass rose, as shown, then the direction to the station is 90 degrees, no matter what the heading of the plane may be.

Since the arrow head of the pointer always indicates the direction to the station, the opposite end of the pointer gives the direction away from the station. So to fly along a certain track away from the station, you would use this opposite end of the pointer.

INSTRUCTIONS FOR EXPERIMENTAL PICTORIAL "A"

(#6)



This instrument is a visual exhibit of an area on the ground extending approximately 120 miles in all directions from any ODR station. The station always appears as a circle in the center of the scope and your airplane as an arrow-shaped pip somewhere on the scope.

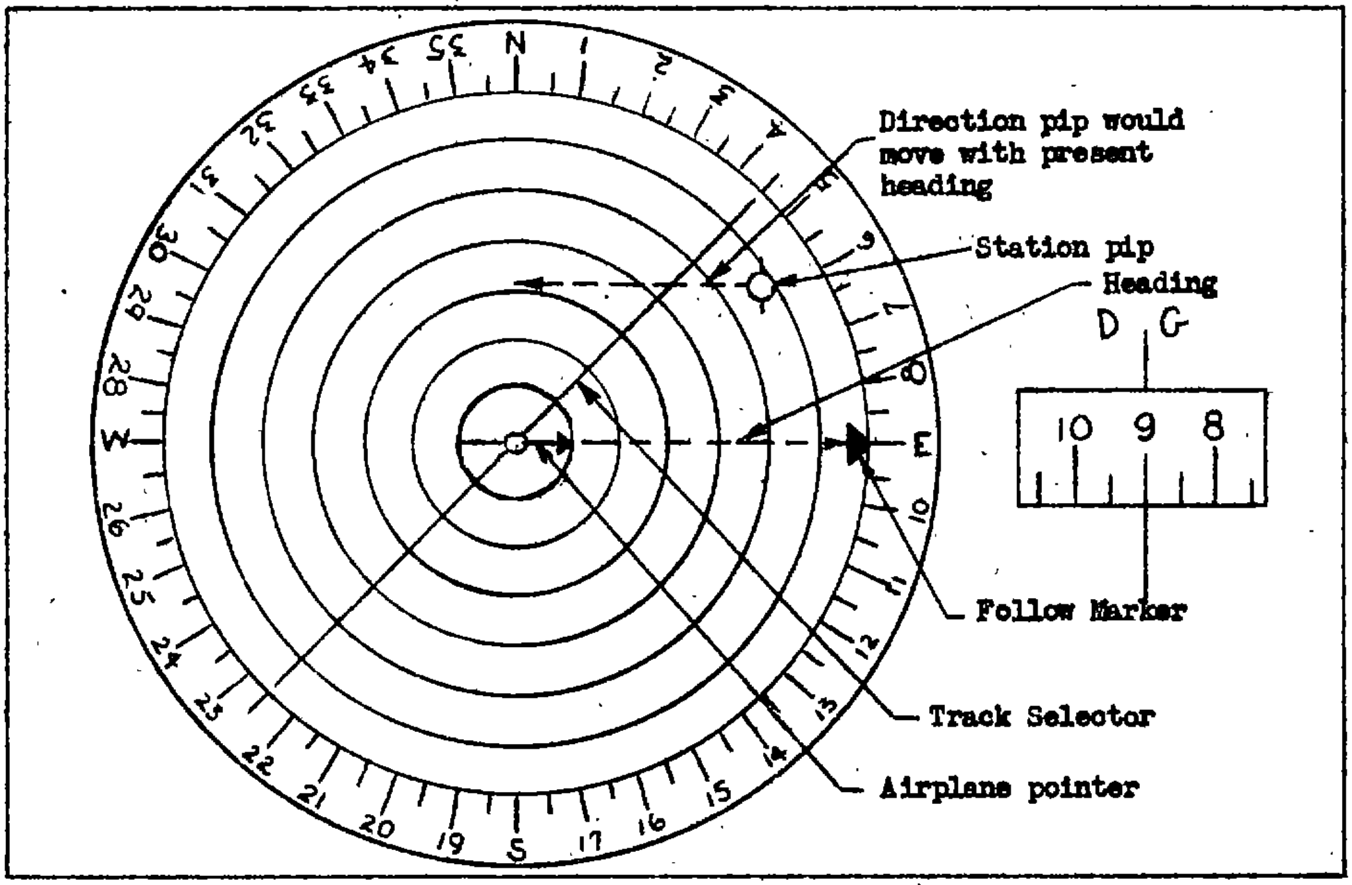
The direction that the pip, or your airplane, is moving may be determined either by observing the direction the pip is pointed, or by cross checking with your Directional Gyro (DG), which would be quicker and more accurate. The pip will move across the scope in the same manner that your airplane moves over the face of the earth.

The scope has six concentric circles on it, representing distances from the station. It will not be necessary to use these in solving the problems. A seventh circle forms a compass rose marked off every 5°. The Track Selector needle appears as a fine straight line on the face of the scope. It rotates about the center of the scope and in actual practice is operated manually by the pilot. In each problem it is set in the proper position to indicate your desired track.

In solving these problems you are to decide in what way your airplane should be turned in order to make the arrow-shaped pip move to the desired track as specified for each problem.

INSTRUCTIONS FOR EXPERIMENTAL PICTORIAL "B"

(#7)



This instrument is a visual representation of the ground for an area extending 120 miles in all directions about your own aircraft. Your plane is represented by the arrow-shaped pointer which is pivoted at the center of the instrument. It is free to rotate as your plane turns and always points to the heading on the stationary compass rose which corresponds to the magnetic heading of your airplane.

The station always appears as a pip (-ф-) somewhere on the face of the scope. It shows the position of the station in relation to your airplane. In actual flight, this station pip is moving constantly, thus giving at any given moment a graphic representation of the position of the station in relation to your plane.

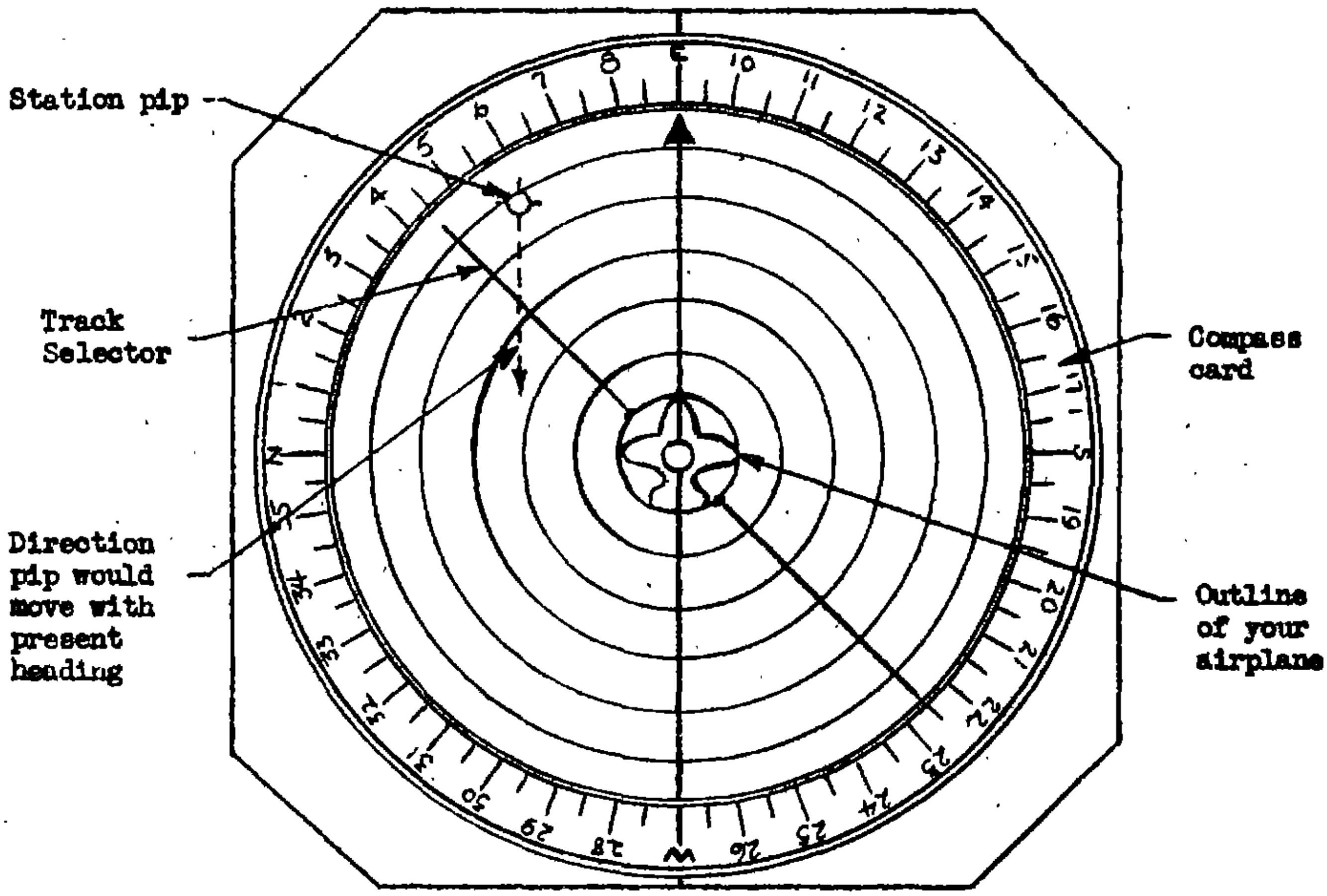
The scope has six concentric circles on it, representing distances from your airplane. It will not be necessary to use these in solving the problems. However, it is apparent that if you were flying toward the station, the station pip would move toward the center of the scope; while if you were flying away from the station, the station pip would move away from the center of the scope. Thus it is apparent that the station pip always moves in the opposite direction to the heading of your airplane as shown by the pointer. For example, if you were flying on a heading of North and the station pip appeared somewhere to the right of you, that is, to the East, the pip would move slowly down the face of the scope parallel to your center pointer and in the direction of the tail end of the pointer.

Although it is not necessary for solving problems with this instrument, a Directional Gyro (DG) is provided, giving you an accurate reading of the present heading of your airplane. Your heading may be determined equally well by observing the center pointer and/or the follow marker at the edge of the scope.

A Track Selector needle appears as a fine straight line on the face of the scope. It extends to each edge of the compass rose and may be rotated manually about the center of the scope. In each problem it is set in the proper position to indicate your desired track as specified.

INSTRUCTIONS FOR EXPERIMENTAL PICTORIAL "C"

(#8)



This instrument is a visual representation of the ground for an area extending 120 miles in all directions about your own airplane. Your airplane is represented by the outline at the center of the instrument. It is fixed in position, always pointing straight ahead, as it were. The card of the compass rose is free to rotate as your plane turns, so that your present magnetic heading is always read at the arrow head of the vertical lubber line which extends from the nose of your fixed airplane outline.

The station always appears as a pip (-ǿ-) somewhere on the face of the scope. It shows the position of the station in relation to your airplane, both in terms of direction and distance. In actual flight the pip is constantly moving, thus showing at any given moment a graphic representation of the position of the station in relation to your airplane.

The scope has six concentric circles on it, representing distances from your airplane. It will not be necessary to use these in solving the problems. However, it is apparent that if you were flying toward the station, the station pip would appear directly in front of your airplane outline and would move slowly down the face of the scope toward the center; while if you were flying away from the station, the pip would appear directly behind your airplane outline and would move slowly down the face of the scope away from the center. Also if the station pip were to one side or the other of your airplane outline, as shown, it would move slowly down the face of the scope parallel to the vertical lubber line which shows your heading.

Furthermore, whenever your plane is turning in flight, the station pip will move rather rapidly about the face of the scope in the opposite direction to the direction of your turn, thus constantly showing the relationship between the direction from your plane to the station and your momentary heading. For example, if you were to make a right turn, both the compass card and the station pip would rotate to the left, that is, in a counterclockwise direction. If you were to make a left turn, the compass card and the pip would rotate to the right.

A Track Selector needle appears as a fine straight line on the face of the scope. It extends to each edge of the compass card and may be rotated manually about the center of the scope. Once it has been rotated to correspond with the heading of any desired track on the compass rose, it automatically follows that heading on the rotating compass card, no matter how the airplane may turn in flight. In each problem this Track Selector needle is set in the proper position to indicate your desired track and will turn with the compass card so that no further manipulation is necessary.

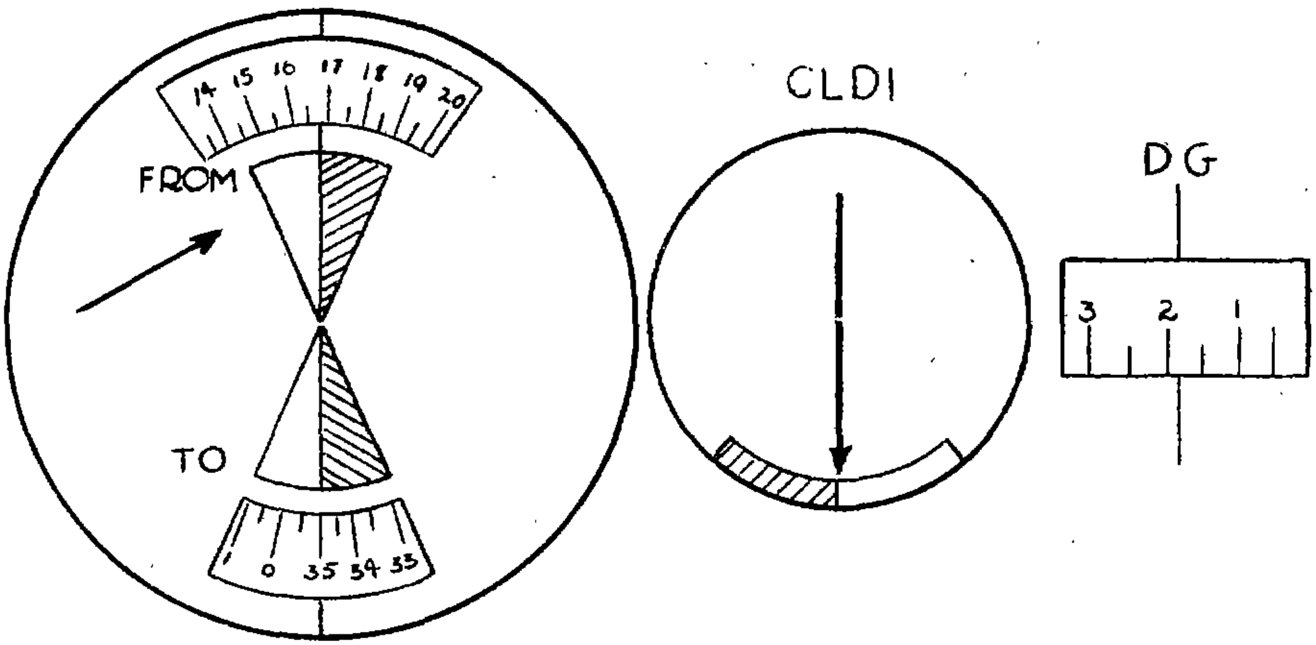
APPENDIX 2

Sample Problems: eight of the ten basic problems used in the test are shown, one problem by each of the eight displays tested. The problem is stated above each display and the double multiple choice of answers below.

The answer key for the eight sample problems is as follows:

1. I should turn right to a heading of 215 degrees.
2. I should turn right to a heading of 185 degrees.
3. I should turn right to a heading of 205 degrees.
4. I should turn right to a heading of 215 degrees.
5. I should turn left to a heading of 190 degrees.
6. I should turn left to a heading of 200 degrees.
7. I should turn left to a heading of 300 degrees.
8. I should turn right to a heading of 305 degrees.

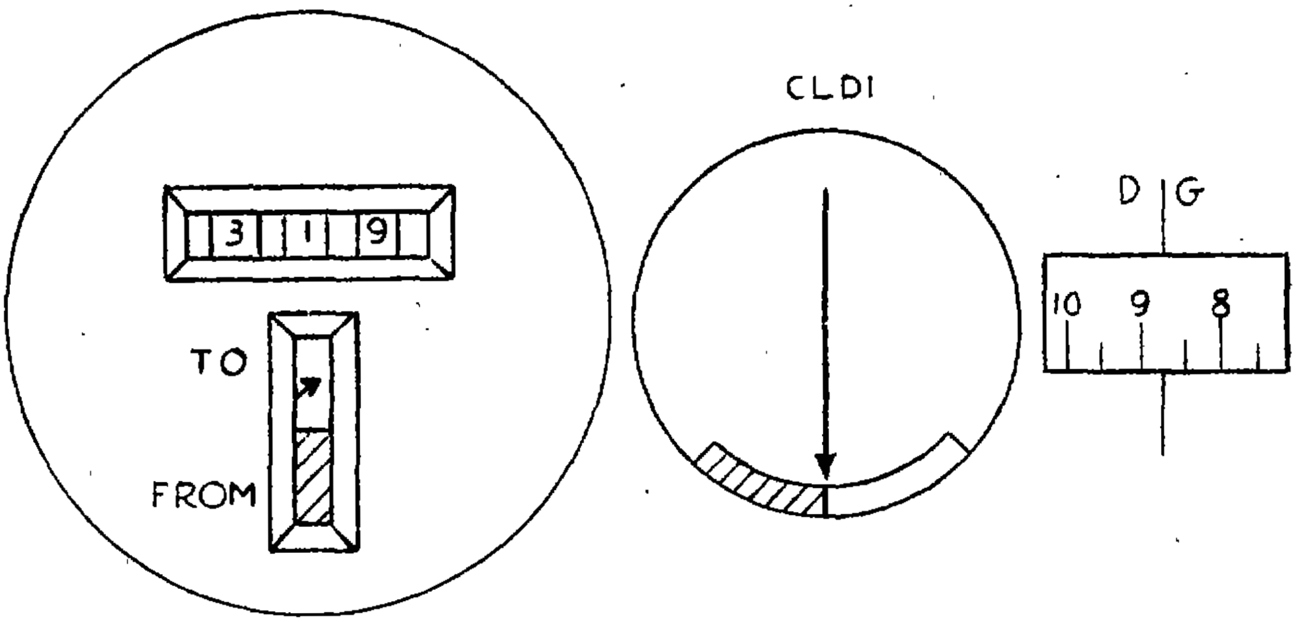
Problem: To fly directly away from the station along a track through my present position,



			168 degrees.
	turn right		215 degrees.
I should	fly straight	to/on a heading of	305 degrees.
	turn left		258 degrees.
			same as present.

PROBLEM 1

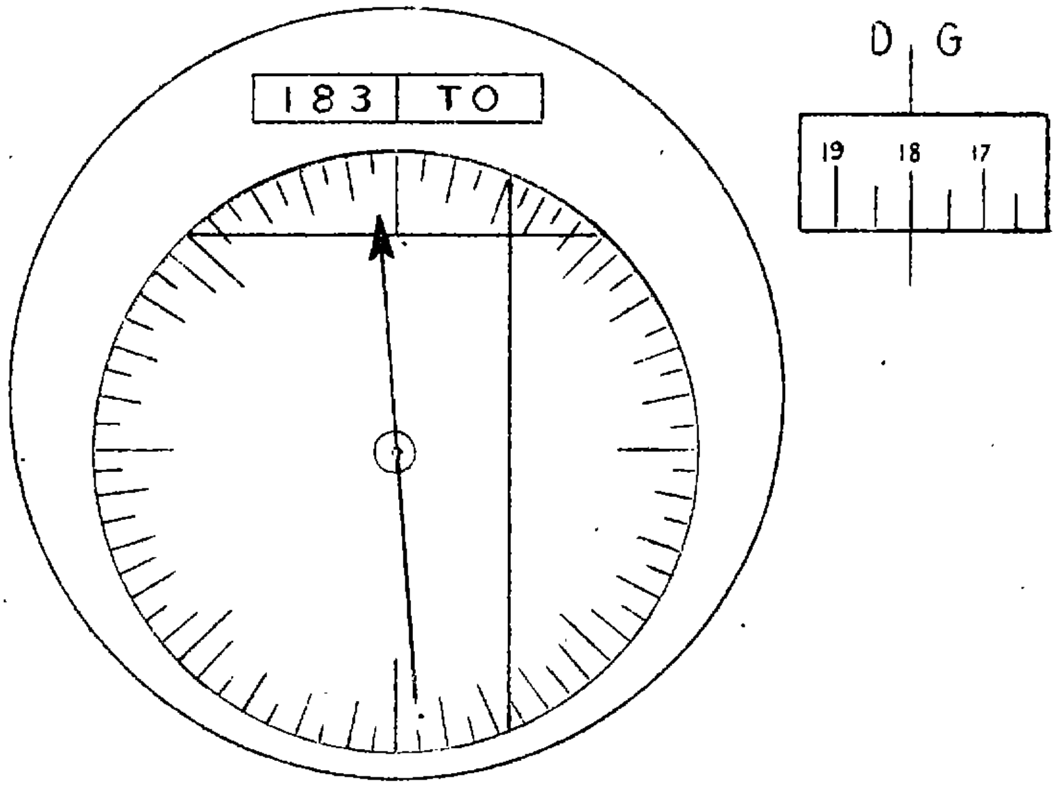
Problem: To fly away from the station along a track through my present position,



			same as present.
	turn right		275 degrees.
I should	fly straight	to/on a heading of	130 degrees.
	turn left		185 degrees.
			310 degrees.

PROBLEM 2

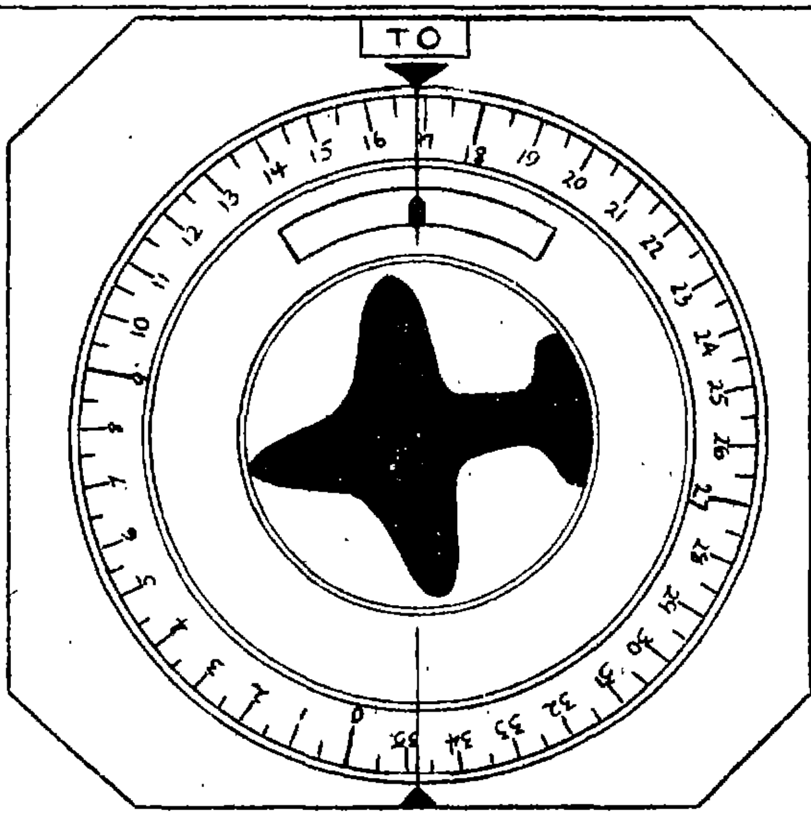
Problem: To approach the station along a track of 183 degrees,



	turn right			205 degrees.
				same as present.
I should	fly straight	to/on	a heading of	183 degrees.
	turn left			3 degrees.
				240 degrees.

PROBLEM 3

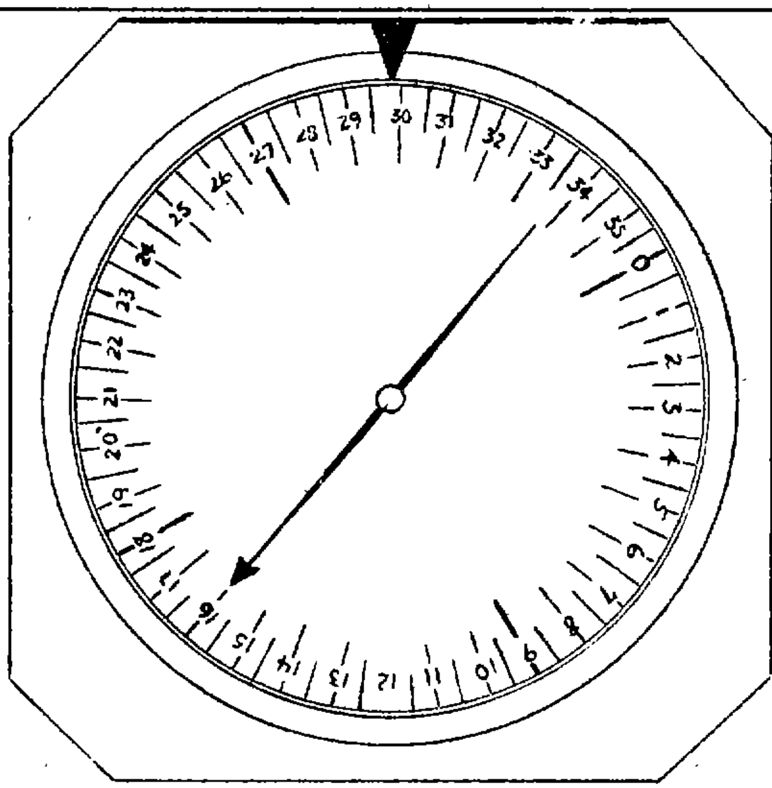
Problem: To approach the station along a track through my present position,



			346 degrees.
	turn right		305 degrees.
I should	fly straight	to/on a heading of	same as present.
	turn left		215 degrees.
			165 degrees.

PROBLEM 4

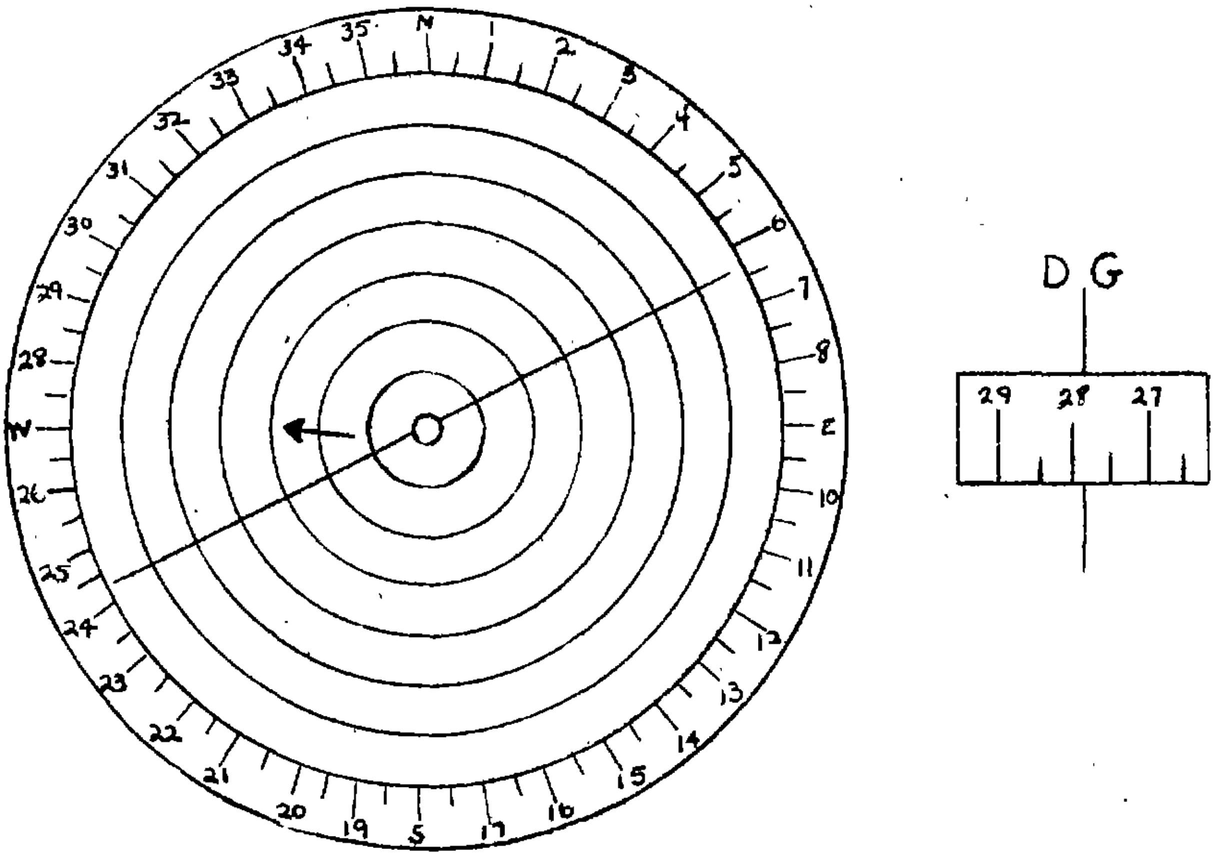
Problem: To approach the station on a track of 143 degrees,



			same as present.
	turn right		190 degrees.
I should	fly straight	to/on a heading of	100 degrees.
	turn left		55 degrees.
			280 degrees.

PROBLEM 5

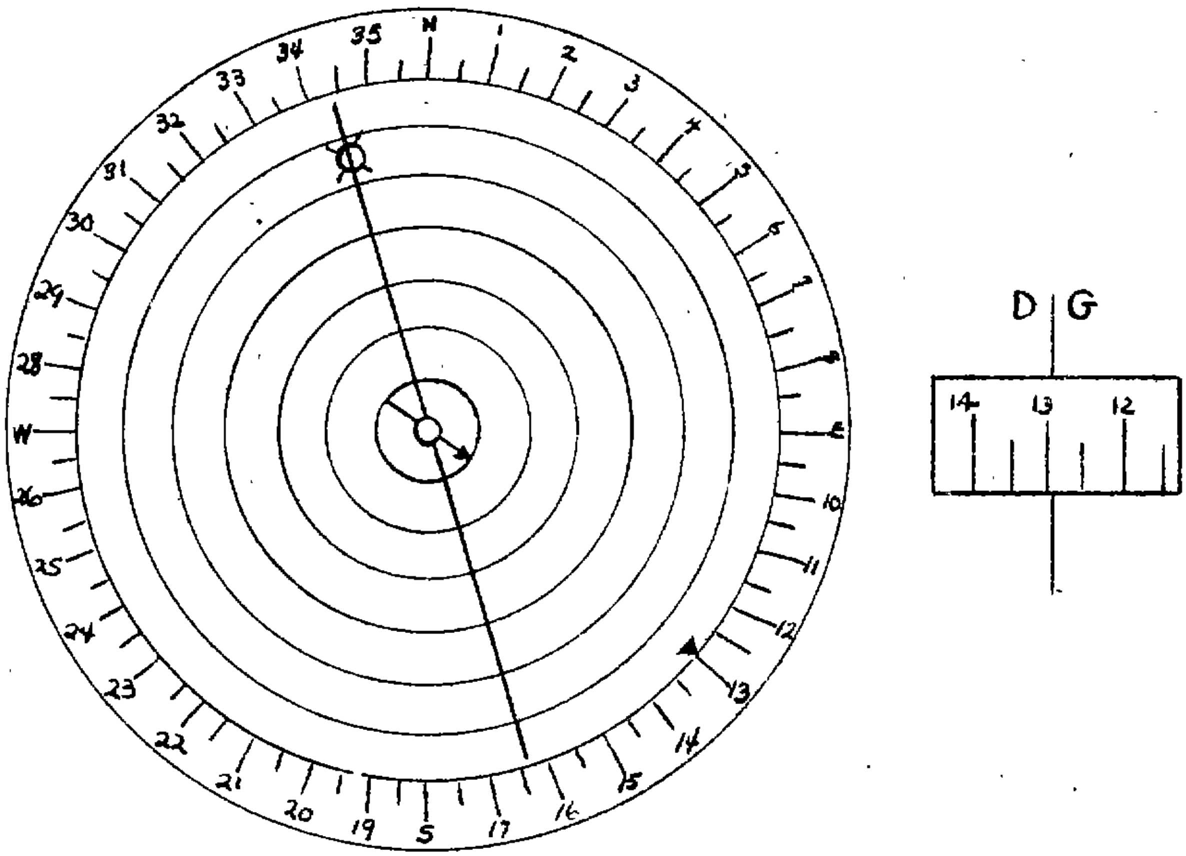
Problem: To fly away from the station on a track of 243 degrees,



			243 degrees.
	turn right		same as present.
I should	fly straight	to/on a heading of	155 degrees.
	turn left		290 degrees.
			200 degrees.

PROBLEM 6

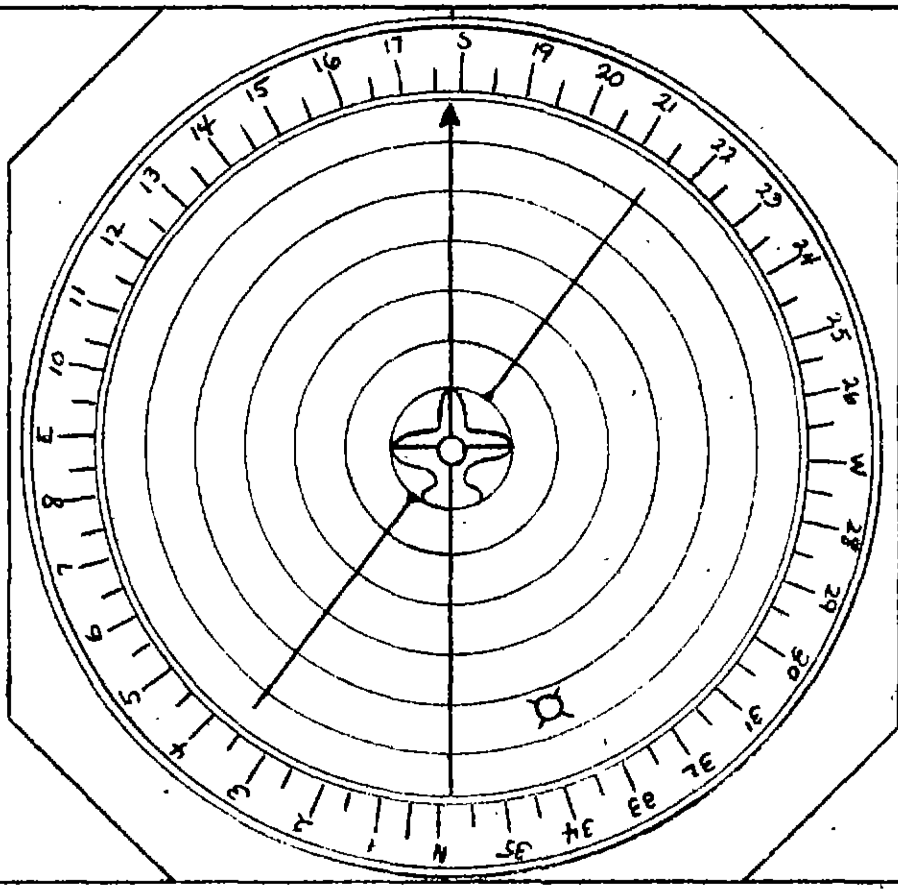
Problem: To approach the station along a track through my present position,



			65 degrees.
	turn right		same as present.
I should	fly straight	to/on a heading of	300 degrees.
	turn left		210 degrees.
			345 degrees.

PROBLEM 7

Problem: To approach the station along a track of 35 degrees,



				305 degrees.
	turn right			350 degrees.
I should	fly straight	to/on	a heading of	80 degrees.
	turn left			260 degrees.
				170 degrees.

PROBLEM 8

APPENDIX 3

Summary of the analyses of variance of the time and error scores for the three experimental groups.

APPENDIX 1

TABLE 1

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE ERROR SCORES FOR GROUP I

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between displays	211	r - 1 = 8 - 1 = 7	30.143
Within displays	699	N - r = 128 - 8 = 120	5.852
Total	910	N - 1 = 128 - 1 = 127	

F = 30.143 / 5.852 = 5.175 (F = 2.82 at 1% level for 7 and 120 degrees of freedom)

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between subjects	435	n - 1 = 16 - 1 = 15	29.000
Within subjects	475	N - n = 128 - 16 = 112	4.241
Total	910	N - 1 = 128 - 1 = 127	

F = 29.000 / 4.241 = 6.838 (F = 2.20 at 1% level for 15 and 112 degrees of freedom)

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Total	910	N - 1 = 128 - 1 = 127	
Between displays	211	r - 1 = 8 - 1 = 7	(30.143)
Between subjects	435	n - 1 = 16 - 1 = 15	(29.000)
Residual	264	(n - 1) (r - 1) = 105	2.514

The Residual Variance is less than either the Within Display Variance (5.852) or the Within Subject Variance (4.241). It is therefore insignificant.

TABLE 2

SUMMARY OF THE ANALYSIS OF VARIANCE FOR THE TIME SCORES FOR GROUP I

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between displays	2263	7	323.290
Within displays	10489	120	87.410
Total	12752	127	

F = 323.29 / 87.41 = 3.699 (F = 2.82 at 1% level)

Between subjects	5038	15	335.900
Within subjects	7714	112	68.900
Total	12752	127	

F = 335.90 / 68.90 = 4.875 (F = 2.20 at 1% level)

Total	12752	127	
Between displays	2263	7	(323.290)
Between subjects	5038	15	(335.900)
Residual	5451	105	51.900

The Residual Variance is less than either the Within Display Variance (87.41) or the Within Subject Variance (68.90). It is therefore insignificant.

TABLE 3

SUMMARY OF THE ANALYSIS OF VARIANCE OF THE
ERROR SCORES FOR GROUP II

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between displays	150	7	21.429
Within displays	604	120	5.033
Total	754	127	

F = 21.429 / 5.033 = 4.258 (F = 2.82 at 1% level)

Between subjects	344	15	22.933
Within subjects	410	112	3.661
Total	754	127	

F = 22.933 / 3.661 = 6.264 (F = 2.20 at 1% level)

Total	754	127	
Between displays	150	7	(21.429)
Between subjects	344	15	(22.993)
Residual	260	105	2.476

The Residual Variance is less than either the Within Display Variance (5.033) or the Within Subject Variance (3.661). It is therefore insignificant.

TABLE 4

SUMMARY OF THE ANALYSIS OF VARIANCE OF THE TIME SCORES FOR GROUP II

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between displays	3510	7	501.429
Within displays	5414	120	45.117
Total	8924	127	

F = 501.429 / 45.117 = 11.114 (F = 2.82 at 1% level)

Between subjects	1416	15	94.400
Within subjects	7508	112	67.036
Total	8924	127	

F = 94.400 / 67.036 = 1.408 (not significant; F = 1.76 at 5% level)

Total	8924	127	
Between Displays	3510	7	501.429
Between subjects	1416	15	94.400
Residual	3998	105	38.076

The Residual Variance is less than either the Within Display Variance (45.117) or the Within Subject Variance (67.036). It is therefore insignificant.

TABLE 5

SUMMARY OF THE ANALYSIS OF VARIANCE OF THE ERROR SCORES FOR GROUP III

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between displays	200	7	28.571
Within displays	542	120	4.517
Total	742	127	

F = 28.571 / 4.517 = 6.325 (F = 2.82 at 1% level)

Between subjects	294.25	15	19.617
Within subjects	447.75	112	3.998
Total	742	127	

F = 19.617 / 3.998 = 4.907 (F = 2.20 at 1% level)

Total	742	127	
Between displays	200	7	(28.571)
Between subjects	294.25	15	(19.617)
Residual	247.75	105	1.360

The Residual Variance is less than either the Within Display Variance (4.517) or the Within Subject Variance (3.998). It is therefore insignificant.

TABLE 6

SUMMARY OF THE ANALYSIS OF VARIANCE OF THE TIME SCORES FOR GROUP III

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between displays	2737.69	7	391.100
Within displays	5233.31	120	43.600
Total	7971.00	127	

F = 391.1 / 43.6 = 8.97 (F = 2.82 at 1% level)

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Between subjects	2009.89	15	133.990
Within subjects	5961.11	112	53.220
Total	7971.00	127	

F = 133.99 / 53.22 = 2.52 (F = 2.20 at 1% level)

Source of Variance	Sum of Squares	Degrees of Freedom	Estimate of Variance
Total	7971.00	127	
Between displays	2737.69	7	(391.100)
Between subjects	2009.89	15	(133.990)
Residual	3223.42	105	30.700

The Residual Variance is less than either the Within Display Variance (43.600) or the Within Subject Variance (53.220). It is therefore insignificant.