PSYCHOLOGICAL PROBLEMS IN COCKPIT INSTRUMENTATION FOR THE OMNI-DIRECTIONAL RANGE (ODR) AND DISTANCE MEASURING EQUIPMENT (DME)

by

Arthur W. Melton

A report on research conducted at The Ohio State University, Columbus, Ohio, under the auspices of the National Research Council Committee on Aviation Psychology, from funds provided by the Civil Aeronautics Administration.

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Committee on Aviation Psychology

Executive Subcommittee

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National Research Council

1948

LETTER OF TRANSMITTAL

NATIONAL RESEARCH COUNCIL

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

Committee on Aviation Psychology

April 5, 1948

Dr. Dean R. Brimhall
Assistant to the Administrator
for Research
Civil Aeronautics Administration
Room 5217, Commerce Building
Washington 25, D. C.

Dear Dr. Brimhall:

Attached is a report entitled Psychological Problems in Cockpit Instrumentation for the Omni-Directional Range (ODR) and Distance Measuring Equipment (DME), by Arthur W. Melton. This report 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 survey described in the report was undertaken: (1) to determine what was being done in the way of evaluating the Omni-Directional Range and Distance Measuring instruments and equipment; (2) to find out what was being planned in the way of research by interested individuals and agencies on the human factors involved in the presentation and use of such instruments; (3) to analyze the basic problems involved in the presentation and use of such instruments; and (4) to suggest profitable avenues of research which could lead to the most effective use of such instruments in terms of airline safety.

The survey has pointed to the necessity and potential fruitfulness of research on specific problems and such research is now being undertaken by the Committee on Aviation Psychology.

Sincerely yours,

MSViteles

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

MSV:rm

EDITORIAL FOREWORD

The Omni-Directional Range (ODR) and Distance Measuring Equipment (DME) now under development will represent marked advances in air navigation instrumentation. Maximum advantage can be taken of these advances, however, only if the presentation on the instrument panel of the information which the equipment yields is in such form as to be readily interpretable by the pilot. This is particularly true since these instruments will be incorporated into the already overcrowded panel.

Because of the importance of the ODR and DME developments, and in recognition of the general need for basic research on the psychological problems of instrumentation, the Civil Aeronautics Administration requested that the National Research Council Committee on Aviation Psychology undertake a preliminary survey of the psychological problems in cockpit instrumentation relative to the Omni-Directional Range and Distance Measuring Equipment. This survey, under the auspices of the Committee, was conducted by Dr. Arthur W. Melton, of The Ohio State University.

The limited nature of the investigation prevented a complete survey of the thinking and activities of all agencies associated with development of this equipment. Nevertheless, the coverage was representative and the orientation obtained with respect to both the general problem and the isolation of several typical specific problems provides an approach to the psychological problems presented by the instruments under consideration.

The results of the survey emphasize the need for basic research on the psychological aspects of aircraft equipment design. Even though research of this type is being supported by various agencies, particularly military groups, the psychological problems are so numerous and varied that a cooperative effort of many research organizations will be required if progress in such research is to overtake the technical aspects of instrumentation and to keep pace with it thereafter.

In the belief that there is a special need for a civilian research organization devoted to the psychological problems which could serve, in part, as liaison between the psychological and the technical or operational groups, it has been suggested that:

1. facilities be established through which information regarding psychological research on aircraft instrument problems could be disseminated to interested groups.

2. provisions be made for extending research which would include not only investigations of immediate practical value but also research on basic problems of instrumentation.

3. working liaison be established between the civilian research group and those concerned with the design and construction of aircraft instruments in order to permit the prompt application of research findings to the design and construction of the instruments.

M. S. Viteles, Chairman
Committee on Aviation Psychology

February 24, 1948

CONTENTS

INTRODUCTION

In compliance with a request of the Committee on Aviation Psychology of the National Research Council, a preliminary survey has been made of the psychological problems involved in cockpit instrumentation for a new air navigation system which involves the Omni-Directional Range (ODR) and Distance Measuring Equipment (DME). The primary purpose has been to define research problems or procedures which would further the psychological adequacy of the cockpit instrumentation for ODR, DME, and associated equipment.

It soon became apparent that a complete survey of the thought and contemplated action of agencies interested in this problem was impossible under the terms of the request. It was equally apparent that the interested agencies were by no means in agreement regarding instrumentation problems. Therefore, the sampling technique that was employed for orientation to the problems may have led to over-emphasis on some problems or instruments, and under-emphasis or lack of information on other problems or instruments. The groups and individuals who were consulted are as follows:

1. The Psychology Branch, Aero Medical Laboratory, USAF Material Command, Wright Field, Ohio, where the psychological problems involved in cockpit instrumentation for the ODR and DME, as well as all other types of cockpit displays, are under consideration. The representatives consulted were Dr. Paul M. Fitts, Dr. Walter F. Grether, and Dr. Glen Finch.

2. The Electronics Subdivision, Communications and Navigation Laboratory, USAF Materiel Command, Wright Field, Ohio, where the primary interest is in the development of cockpit instrumentation suitable for military aircraft, and for military operational use. The representatives consulted were Mr. N. Braverman and Mr. A. G. Wedin.

3. The CAA Experimental Station, Municipal Airport, Indianapolis, Indiana, where the primary interest is in the technical aspects of equipment for ODR and DME, and in the development of cockpit instrumentation which will be suitable for privately owned aircraft and within the price range attractive to the private owner. However, work is also going forward with types of equipment which would be suitable for air-line or large aircraft use. The representatives consulted were Mr. Joseph C. Hromada, Mr. William B. Jackson, and Mr. R. E. McCormack. Mr. Hromada and Mr. Jackson also arranged a special flight demonstration of ODR, DME, and course computer mechanisms and instruments which was eminently successful and instructive.

4. Aeronautical Radio, Incorporated, 1108 16th Street, N.W., Washington, D.C., where the primary interest is in the equipment which will be used by the scheduled airlines. This organization, which is a

cooperative of the airlines, has the function of seeing that the policies and requirements laid down by the Radio Technical Commission for Aeronautics are accomplished before the purchase of the equipment by the airlines. Aeronautical Radio, Inc. (Arinc) has published the only comprehensive treatise on ODR and DME in a manual entitled, "ARINC OMNI-DIRECTIONAL RADIO RANGE SYSTEM MANUAL," January, 1947.

5. The Radio Technical Commission for Aeronautics has headquarters in the Department of State, 17th Street and Pennsylvania Ave., N.W., Washington, D.C., and is interested in the over-all problems of the use of the navigational aids under consideration. Reports of RTCA committees which might be helpful on the ODR-DME instrumentation problem were made available. Two technical reports on DME equipment were supplied but reports of two committees of RTCA which are at present engaged in studies of ODR and cockpit instrumentation were unavailable, since reports had not yet been prepared. The committees involved are SC31, under the joint chairmanship of Colonel J. B. Duckworth, USAF, and Captain A. S. Born, USN; and SC17, under the chairmanship of Admiral F. E. Cleaves of Collins Radio Company. Another RTCA committee, SC24, has been concerned with navigation nomenclature. A copy of the final report of committee SC24 has been supplied in which many terms employed in discussions of ODR and DME are defined and the preferred nomenclature is indicated.

6. The intent of the Civil Aeronautics Administration in the development and installation of ODR and DME has been surveyed in conference with Mr. C. I. Stanton, Deputy Administrator, Dr. Dean Brimhall, Assistant to the Administrator for Research, and Dr. Morris S. Viteles, Chairman, NRC Committee on Aviation Psychology.

No attempt has been made to consult the interested individuals in the Navy or to go beyond the Electronics Subdivision, Communications and Navigation Laboratory, in the Air Force. In addition, no attempt has been made to consult the numerous aircraft instrument companies regarding proposed designs and production plans.

PSYCHOLOGICAL PROBLEMS IN COCKPIT INSTRUMENTATION FOR THE OMNI-DIRECTIONAL RANGE (ODR) AND DISTANCE MEASURING EQUIPMENT (DME)

THE NATURE AND STATUS OF ODR AND DME EQUIPMENT

In the development of the new navigation equipment three stages may be defined: (a) the development of the ODR, (b) the development of DME, and (c) the development of course computers based on ODR and DME. All three are a reality at the present time, although extensive research and equipment development will be required before they can be employed routinely by either the airlines or private pilots. In addition to these technological stages there is an overlapping and concurrent phase of the whole development which may be called the instrumentation phase. What the whole system is to be depends on the uses and this in turn should be reflected in the cockpit instrumentation.

In the ODR system the ground station transmits signals which may be analyzed by a receiver in the aircraft to indicate visually the bearing of the airplane from the station with magnetic north as the reference point. It may also provide immediate information regarding the bearing of the station from the airplane. At the present time, this indication, in angular degrees, has an error of approximately ± 1.70, and there are certain irregularities (although not considered serious) in the radial lines which result from reflections and occlusions. RTCA specifications call for an error of not more than ± .75°, and it is believed that this can be achieved. The effective limit of the ODR station is approximately 100 miles, and varies with altitude, since the transmitted impulses operate on a line-of-sight principle.

At the present time, there is still much research to be done to determine (a) the most effective type and position of the aerial on the aircraft, (b) the most accurate and reliable receiving system, (c) the most effective transmitting aerial and the effects of geographic location of the transmitting aerial.

With reference to the latter point, it is important to note that the transmitting station will frequently not be located at the airfield, and it may, because of terrain considerations, be located several miles from the airfield. In spite of these technical problems, several aircraft instrument companies are carrying through intensive development and production schedules[1] on receivers and other equipment for the ODR. The use of ODR has been approved by the Air Transport Association, and specifications for the equipment have been set up by RTCA. General use of the equipment must await installation of ground stations (of which there are only about 12 at present) by the CAA, but it is anticipated that the equipment will be in use in the next 18 to 24 months. It is also recognized that there must be a relatively long transition period in the adoption of ODR, although it is hoped that eventually the A-N Radio Ranges may be abandoned

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[1]Especially Federal Telephone and Radio Corp. and Collins Radio Co.

Distance Measuring Equipment (DME) is a combination of ground and air equipment which permits the pilot to determine the slant distance, in miles, of the aircraft from the selected DME transmitting station. It is essentially a radar system in which there is an unique relationship between the aircraft and the ground system. Very few DME ground stations have been installed as yet, and it is generally considered that routine use of DME will be one or more years later than routine use of ODR. The DME ground station has limitations similar to those of the ODR ground stations as related to the use of VHF line-of-sight transmission. DME stations, incidentally, may not be located immediately adjacent to ODR stations.[2]

Course computers for the integration of ODR and DME information in such a manner as to permit the flying of off-set courses (e.g., a course parallel to a radial to a station but displaced by five miles, ten miles, etc.) are still further in the future. It depends, in the first place, on the final development of ODR and DME equipment, and in the second place on the development of a computer mechanism which will integrate these two sources of information as to the position of the airplane. One model of such a computer has been constructed by the Minneapolis-Honeywell Company for the CAA Experimental Station at Indianapolis, and is currently in experimental use. The computer is judged to be accurate within reasonable limits. Other models are in preparation, on contracts let by the CAA and the USAF. The problems involved in the construction of these computers are judged to be relatively simple, and it is not anticipated that the development of adequate computers will lag much behind the final development of adequate DME. There will, however, be no computers (and, hence, no routine use of off-set flight courses) before adequate DME equipment is available and installed.

Before considering the details of proposed cockpit instrumentation for the ODR and DME, the potentialities of the system for air navigation should be explicitly stated. On the one hand, since the ODR gives complete and accurate information regarding the magnetic bearing of a station from the airplane, it may be used for "homing" on a station with much greater ease and less possibility of confusion than the present A-N Radio Range. This fact may, however, blind one to the still more important fact that, properly used, the ODR and DME, may permit the fixing of the position of the airplane in space with an exactitude which has never before been possible. In effect, with this system it becomes possible for the aerial navigator to define his position, within the area served by an ODR-DME network, with reference to a system of coordinates analogous to those employed by the mariner. This latter use of the ODR-DME system is the primary intent of the CAA, and for that reason great care has been taken in the planning of the locations of the ODR stations, so that when the installation of the stations is complete for the continental United States, a complete grid system will have been approximated.

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[2]An active DME station is located at the CAA Experimental Station, Indianapolis Municipal Airport.

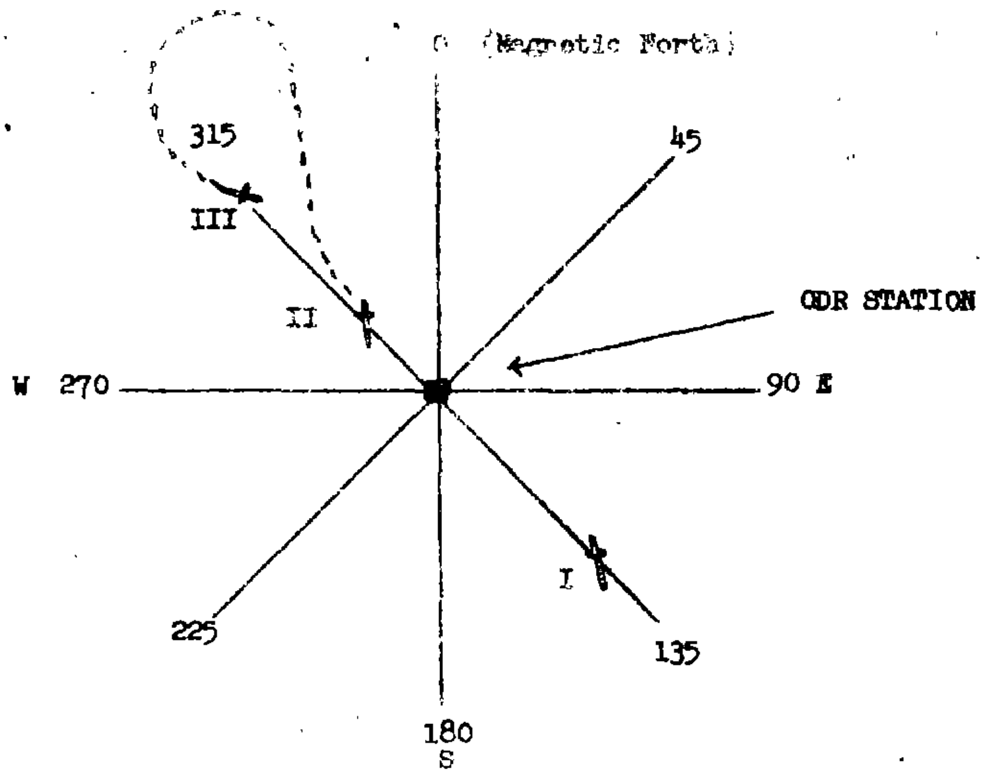
Of importance at this time is the fact that emphasis upon the ODR-DME as a method for exact location of the airplane in space leads to emphasis on <u>bearing from a station</u> in the cockpit instrumentation; whereas, emphasis on the use of ODR-DME for "homing" leads to emphasis on <u>bearing to a station</u> in the cockpit instrumentation. Although both functions may easily be realized by the use of appropriate instrumentation, it is a reasonable prophecy that interpretational errors of pilots and navigators will be affected by which emphasis is permitted to dominate the design and labelling of the cockpit instruments. The CAA, through Mr. C. I. Stanton, strongly urges that all basic instruments be designed so that they indicate <u>bearing from a station</u>, on the ground that this is the more basic information in air navigation. It is this information which will be required for use of the R-Theta system of polar coordinates to permit (a) determining the position of the airplane at any point in space, (b) determining the coordinates of any other point in space which is selected as a destination, (c) determining the course to fly, and (d) reporting position for the purpose of air traffic control. On the other hand, as will be noted in the discussion of the proposed instrumentation, emphasis is frequently on the reciprocal of the bearing from a station, i.e., <u>bearing to a station</u>. The psychological problem involved in this possible source of confusion will be discussed in a concluding section of this report.

BASIC COCKPIT INSTRUMENTATION AND USES OF ODR, DME, AND R-THETA COMPUTERS

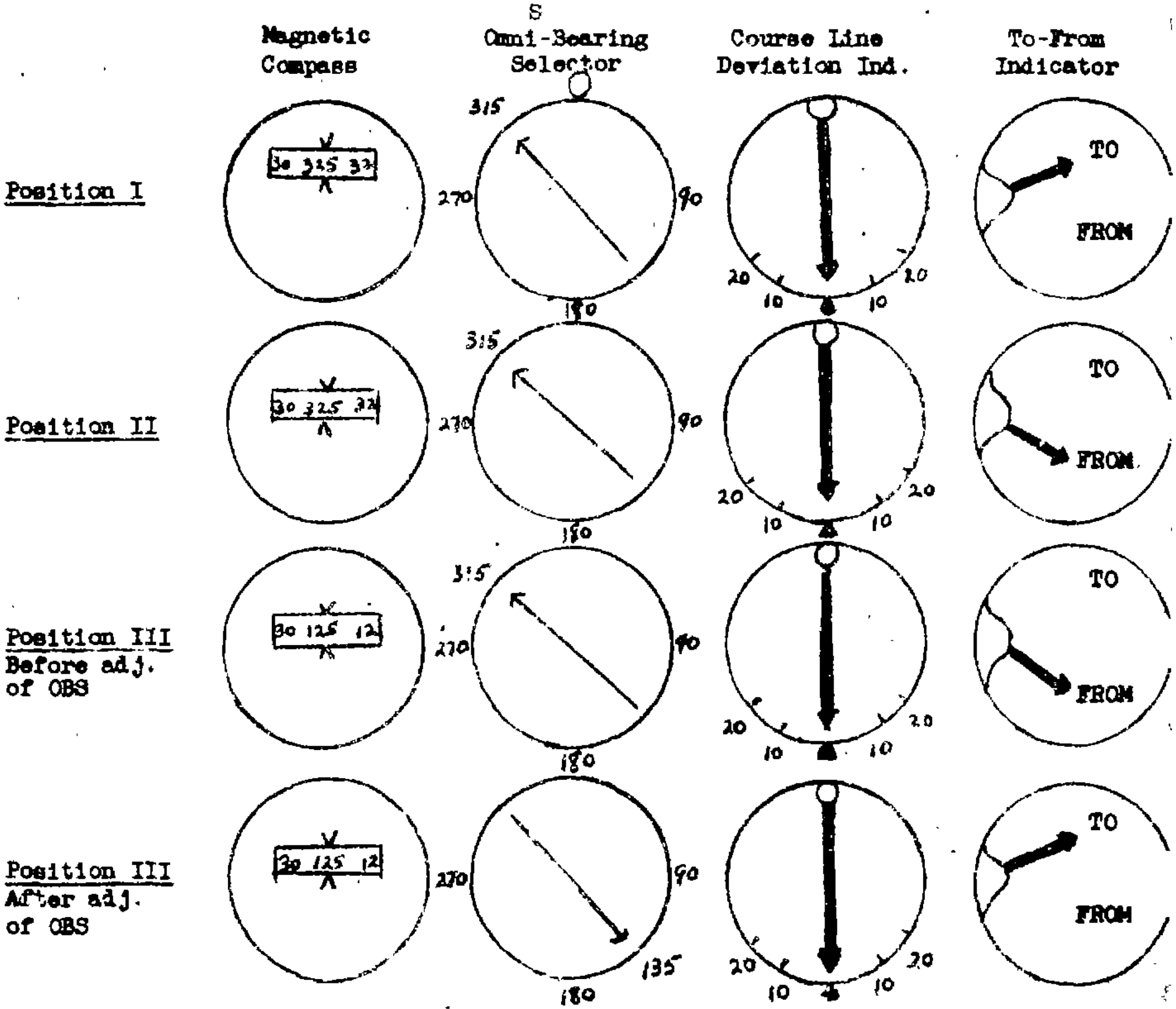
As remarked previously, the combined use of ODR and DME for navigation with R-Theta Computers will probably follow an interim use of ODR alone. Nevertheless, it is important that the cockpit instruments for use in the interim period be psychologically congruent with the most efficient instrumentation of ODR when DME and R-Theta Computers are available. This point requires emphasis only because there is an inherent ambiguity in the ODR system which can only be resolved by an "Ambiguity Indicator" and a convention regarding the meanings of its indications. It is necessary to make certain that the convention adopted for the interpretation of this indicator during the interim period is appropriate to the use of the entire system when R-Theta Computers are available.

The ambiguity referred to may best be illustrated by a description of the use of the ODR for navigation to a station. In Figure 1 are shown three positions of an airplane with respect to an ODR station and the instruments required to inform the pilot. For the purposes of this exposition the Ambiguity Indicator is pictured as a "To-From Indicator," although this is only one of the suggested conventions for resolving the ambiguity of the ODR.

If the pilot does not know (and wishes to determine) his position, he tunes his VHF receiver to the frequency of a station (between 108 and 122 mc). This tuner will probably not be on the instrument panel. After tuning, the pilot then searches for the radial on which the airplane is located by using the Omni-Bearing Selector in conjunction with an Ambiguity Indicator and a Course Line Deviation Indicator. These instruments are shown schematically in Figure 1. The search involves the movement of the pointer of the Omni Bearing Selector until the Course Line Deviation



0 (Magnetic North)
315
45
III
II
ODR STATION
W 270
90 E
I
225
135
180
S



Magnetic Compass
Omni-Bearing Selector
Course Line Deviation Ind.
To-From Indicator
Position I
Position II
Position III
Before adj. of OBS
Position III
After adj. of OBS
315
270
90
180
135
20
10
TO
FROM

Indicator shows no deviation from zero. If, when this occurs, the Ambiguity Indicator shows "From," the pilot knows that his magnetic bearing <u>from</u> the station is shown by the pointer of the Omni-Bearing Selector (e.g., 135°) If the pilot were reporting his position this would be the information required. Without DME, a complete "fix" could be obtained by tuning another ODR station and adjusting the Omni-Bearing Selector until the Course Deviation Indicator was again centered and the Ambiguity Indicator again indicated "From." On the other hand, if the pilot wished to know the magnetic bearing he should fly to the first ODR station he would either (a) compute the reciprocal of the bearing from the station, (i.e., 135° + 180° = 315°) or (b) reset his Omni-Bearing Selector manually until the Course Deviation Indicator again shows no deviation from zero and the Ambiguity Indicator shows "To," which will occur when the pointer on the Omni-Bearing Selector shows 315°

In this connection, it is important to note that <u>two</u> positions of the pointer on the Omni-Bearing Selector give no deviation of the Course Line Deviation Indicator, but in one case the indication is the magnetic bearing of the airplane FROM the station (Ambiguity Indicator shows "FROM") and in the other case the indication is the magnetic bearing of the station from the airplane. (Ambiguity Indicator shows "TO") It is also important to note that the ODR instrumentation gives no information regarding the heading being flown by the pilot at the moment, but merely the magnetic bearing to or from the station. If, for example, he were flying a course due north, and located 30 miles due east from the station to which he desired to fly, he would necessarily make successive adjustments of the Omni-Bearing Selector to center the Course Line Deviation Indicator. In actual practice, the pilot will use the Magnetic Compass to assist in his orientation, since (as will be seen later) the sensing of the Course Line Deviation Indicator is "proper," i.e., the pilot flies "to the needle," only when the Magnetic Compass and the Omni-Bearing Selector are in agreement except for a drift factor. In that event, the Ambiguity Indicator shows the pilot whether the station is in front of him or behind him on the course he is flying.

<u>Position I</u> In Position I (see Figure 1) the heading of the airplane is 325° as determined from the Magnetic Compass, and the pilot discovers that the bearing of the station from him is 315°, since the Ambiguity Indicator shows "TO" when the Course Line Deviation Indicator is centered. Without drift, the pilot is informed that he should fly a course line of 315° to pass over the ODR station. Since there is a 10° difference between the course of the airplane and the heading, and as a consequence of the drift factor, the pilot would fly with a magnetic heading of 325° to pass directly over the station. The Course Line Deviation Indicator has the "proper" sensing in this case, so that the pilot could fly theoretically the Course Line Deviation Indicator to the station without further concern with the Magnetic Compass.

<u>Position II</u>. In Position II the airplane has passed over the station In passing over the station, the pilot would have noted several rapid fluctuations of the needle of the Ambiguity Indicator. When flying at relatively low altitude (3500 feet) the duration of these fluctuations of the Ambiguity Indicator, which correspond to the "cone of silence" in the present A-N Radio Range stations, would be relatively short. At high

altitudes, this period of ambiguity might be fairly long. In either event, the pilot must fly the Magnetic Compass (or Directional Gyro) during this time in order to continue on his course without error, since the Course Line Deviation Indicator is also subject to rapid fluctuations as the plane goes through the "cone of silence." (There is some uncertainty at the present time whether installation of a blinker light as a "positive indicator of the cone of silence" can be justified in view of the heavy expense involved in such an addition to the ODR ground station.)

After the pilot passes over the station (as in Position II, Figure 1), he should still be continuing on the 315° course line. Assuming that no manual adjustments have been made his Omni-Bearing Selector will still be set at 315° and he will continue to fly to the needle (i.e., "proper sensing") on the Course Line Deviation Indicator. But the Ambiguity Indicator now shows "FROM" which means that he is now flying away from the station and his bearing from the station is 315°. As long as his Magnetic Compass is in essential agreement, except for the drift factor, with the pointer on the Omni-Bearing Selector, his position with reference to the station is unambiguous and the sensing of the Course Line Deviation Indicator is correct.

Position III. In Position III (see Figure 1) the pilot has made a procedure turn (180°) and is flying in toward the station. He is now flying a course line of 135°, and the Magnetic Compass shows a heading of 125° in order to correct for the drift angle. However, the Omni-Bearing Selector still reads 315° and the Ambiguity Indicator still reads "FROM." That is, the Omni-Bearing Selector is continuing to indicate the magnetic bearing of the airplane from the station. Furthermore, the sensing of the Course Line Deviation Indicator is now reversed, and the pilot must change his Omni-Bearing Selector to read the bearing of the station from him. As he moves the Omni-Bearing Selector to 135°, the Ambiguity Indicator will shift from "FROM" to "TO" and the Course Line Deviation Indicator will resume its proper sensing. This need for immediate shift of the Omni-Bearing Selector so that it shows the bearing to the station, in order to obtain the proper sensing of the Course Line Deviation Indicator, is generally recognized, and has been considered in the design of the instruments.

From this description, it should be clear that the meaning of the indications on the Omni-Bearing Selector and the Course Line Deviation Indicator is a function of the indications of the Ambiguity Indicator. This ambiguity may be resolved by two rules:

1. When the chief concern is with the location of the airplane with reference to an ODR station (or stations, when determining a "fix"), "FROM" on the Ambiguity Indicator means that the Omni-Bearing Selector indicates the magnetic bearing of the airplane from the station, "TO" on the Ambiguity Indicator means that the Omni-Bearing Selector indicates the magnetic bearing of the station from the airplane.

2. When the Omni-Bearing Selector is being employed to determine a flight course to or from a station (and the sensing of the Course Line Deviation Indicator is to be "proper" at all times) the "TO" and "FROM" of the Ambiguity Indicator must be congruent with the direction of motion

of the airplane (except for heading differences due to a drift factor), as determined from a Magnetic Compass or its equivalent. This does not, of course, conflict with the basic meanings of "TO" and "FROM" presented in (1) above, but merely formulates the conditions under which "bearing to" a station means "inbound" and "bearing from" a station means "outbound." The psychological difference may, however, be quite important, since in the first instance the station (or the system of polar coordinates it represents) is taken as the frame of reference, and in the second instance the airplane and its direction of motion is taken as the frame of reference.

So far the description has been restricted to a relatively simple problem involving a single ODR station, with ODR instruments alone. It should be apparent that the addition of DME would permit the pilot to fix his position with reference to a single ODR station, both as regards bearing from that station and distance. Without DME, two ODR stations can provide an exact "fix" from which distance to either station can be determined by triangulation. Although an airplane with a single ODR receiver can make such "fixes," the instrumentation for ODR in large planes envisages the use of two ODR receivers. As a consequence, those receivers can provide simultaneous bearings of the airplane from (or to) two ODR stations and "fixes" may be determined continuously.

Flying "off-set" courses to way points which do not coincide with ODR stations will be routine procedure when computers, which combine ODR and DME information, are available. In Figure 2 is illustrated a simple problem which could be readily solved by a computer. The airplane is located 55 miles West of the station (bearing from the station = 270°), and it is desired to proceed to a way point which is 55 miles Southeast of the station (bearing from the station = 135°). The required instrument panel includes an ADF (or Radio-Magnetic Indicator), a Course Line Deviation Indicator, a continuous reading Omni-Bearing Indicator which shows bearing of the airplane <u>from</u> the ODR station, and two DME indicators, one for distance of the airplane from the station and one for distance of the airplane from the selected way point. The information which must be set into the computer is (a) the bearing of the way point from the ODR station, (b) the distance of the way point from the ODR station, and (c) the magnetic course it is desired to fly (112° or any reasonable approximation).

After this information has been set into the computer, the pilot may fly the Course Line Deviation Indicator with proper sensing to the way point. He will be continuously informed regarding (a) his bearing from the ODR station, (b) his distance from the ODR station, and (c) his distance from the way point. It is noteworthy that in the use of the computer the pilot is concerned primarily with the bearing of the way point <u>from</u> the station relative to his bearing <u>from</u> the station, and that he must approximate the magnetic bearing of the way point from him. These knowledges are congruent only if the pilot works entirely within a frame of reference in which he is the moving object in a system of fixed points.

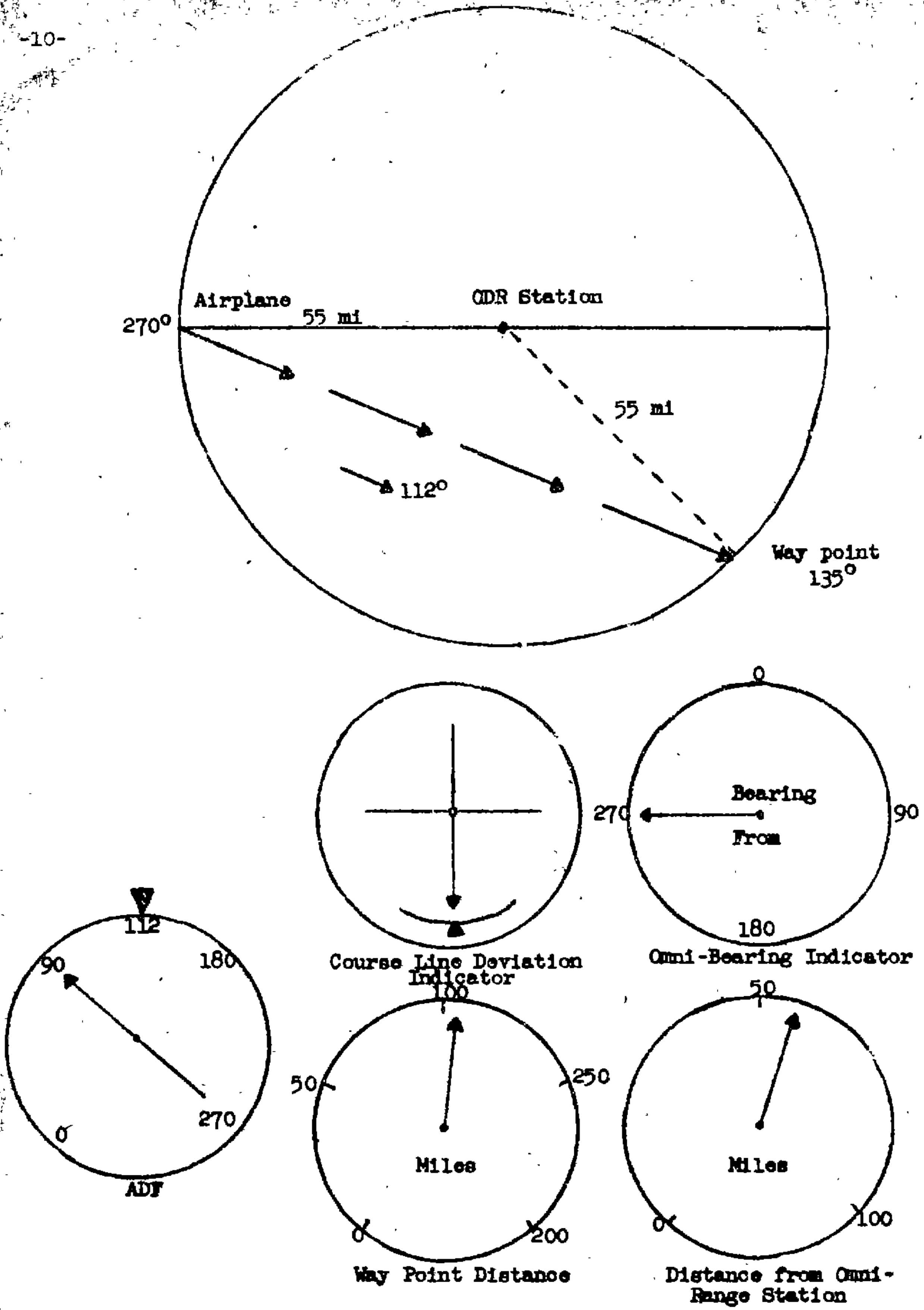

Airplane
ODR Station
270°
55 mi
55 mi
112°
Way point
135°
0
270
90
Bearing
From
180
Course Line Deviation Indicator
Omni-Bearing Indicator
112
90
180
270
0
ADF
100
50
250
Miles
0
200
Way Point Distance
50
Miles
0
100
Distance from Omni-Range Station

FIGURE 2

SUGGESTED ODR INSTRUMENTS

Omni-Bearing Selector and Ambiguity Indicator. As indicated in the preceding section, the manner of interpretation of the Ambiguity Indicator and the indications of the Omni-Bearing Selector is the major potential source of confusion in the use of the ODR system. If emphasis is placed upon locating the position of the airplane with reference to a station, the Omni-Bearing Selector must be adjusted until the Ambiguity Indicator shows that the Selector refers to "bearing of the airplane from the station." This emphasis seems particularly defensible in terms of the manner of interpretation required when R-Theta computers are available. On the other hand, if emphasis is placed on the use of the instruments, especially the Course Line Deviation Indicator, for the purpose of flying to or from a station, the Omni-Bearing Selector must be adjusted until the Ambiguity Indicator shows that the motion of the airplane is inbound or outbound with respect to the station, a matter which must be judged with the aid of a Magnetic Compass or substitute device. Ideally, the Omni-Bearing Selector and Ambiguity Indicator should be so combined that the instruments could be used for either of these purposes without confusion.

Another consideration in the design of these instruments must be the type of aircraft for which the instruments are designed. Somewhat different requirements have been set up by Aeronautical Radio, Inc. and by the CAA Experimental Station. The differences are related to the primary interest of the former in the problem of the airlines, and the primary interest of the latter in the design of equipment for the small private airplane. Space on the panel is a much more serious consideration in the case of the airlines and cost of the equipment is a much more serious consideration in the case of the private pilot. The only ODR instrumentation now offered to the private pilot is produced by the Aircraft Radio Corporation, Boonton, New Jersey, (Indicator Unit, Type G-11) and is reputed to cost approximately $2,000, installed.

The indicator currently favored by Aeronautical Radio, Inc. is shown schematically in Figure 3. It may be seen that this instrument is a combination Omni-Bearing Selector and To-From Indicator in which the selected bearing is shown in a counter-type display. In addition, there is a simple device for selecting immediately the reciprocal of the radial originally selected. The lever which moves the shutter in front of the numerals also shifts the To-From Indicator and the sensing of the Course Line Deviation Indicator. Thus, during a procedure turn after Position II in Figure 1, the pilot needs merely to throw a lever on the indicator in order to present the new bearing to fly TO the station with correct sensing of the Course Line Deviation Indicator.[3]

The obvious advantage of this instrument, other than its use in the turn, is that it should reduce the time required to determine the proper bearing to fly TO or FROM a station in the course of an initial search (Position I, Figure 1). The Omni-Bearing Selector would be manipulated

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[3]This type of instrument has been seen in operation in the experimental airplane of the Collins Radio Company.

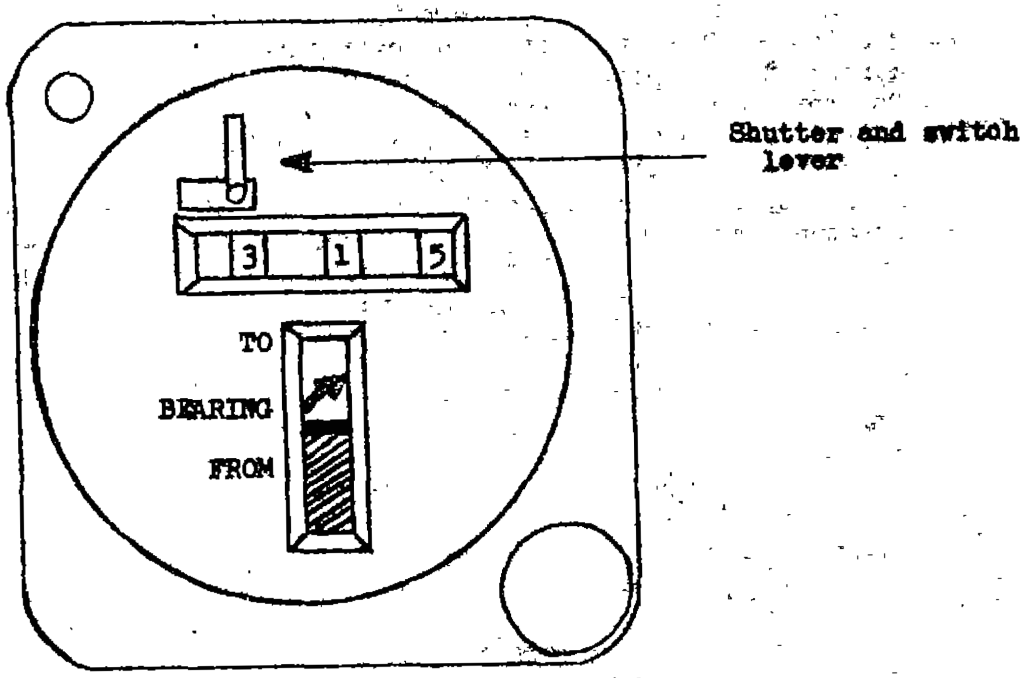

FIGURE 3

COMBINATION TO-FROM INDICATOR AND OMNI-BEARING SELECTOR
WITH MANUAL SWITCH FOR RECIPROCAL BEARING

until the Course Line Deviation Indicator is in the zero position. Then, if the selected bearing is in conformity with the direction of motion of the airplane as indicated by the Magnetic Compass, the pilot immediately knows that the To-From Indicator shows the station to be in front of ("TO") or behind ("FROM") the airplane. If, however, the selected bearing is the reciprocal of the direction of motion of the airplane, the proper meanings of the To-From Indicator and the proper sensing of the Course Line Deviation Indicator can be obtained immediately by shifting the lever on the instrument.

Similar suggestions for the Omni-Bearing Selector and To-From Indicator have come from the CAA Experimental Station, where the interest is primarily in small airplane installations. It is believed that the Omni-Bearing Selector described above is too expensive for small airplanes, and that the need for conservation of panel space is not nearly so acute. In Figure 4 is shown one of the earliest forms of Omni-Bearing Selector and To-From Indicator combinations. This is the one which has been produced by the Aircraft Radio Corporation. The presentation of the To-From Indicator is straight-forward. The Omni-Bearing Selector is a simple pointer and card arrangement in which the primary end of the pointer refers to the bearing to which the To-From Indicator refers, and the secondary end of the pointer can be used to determine the reciprocal bearing. Although the indication of the reciprocal bearing might be considered an aid to the pilot, it may be a source of confusion since the To-From Indicator and the Course Line Deviation Indicator are improperly interpreted unless the direction of motion of the airplane agrees with the bearing indication at the primary end of the pointer.

A form of the Omni-Bearing Selector which has been recently suggested to the CAA Experimental Station by a manufacturer, because of the low cost involved in its production, is shown in Figure 5. In this indicator, no attempt is made to maintain the symmetry of compass directions in the card markings, since there is a "dead" space on the dial. It is clear that the pilot would not be tempted to read the reciprocal bearing directly from the position of the pointer. The instrument would, presumably, be employed with a To-From Indicator similar to the one shown in Figure 4. It should be remarked that this Omni-Bearing Selector has not yet received serious consideration, but is merely one proposal of a manufacturer.

In the instruments discussed above, the primary emphasis seems to be on the use of ODR for flying to or from certain stations, in view of the use of "To" and "From" on the Ambiguity Indicator. In effect, the emphasis is on defining the position of the station with reference to the aircraft, rather than on the position of the aircraft with reference to the station. That is, the pilot must reflect, when presented with "To" that the Omni-Bearing Selector indicates the proper bearing to fly to the station if that is what he chooses to do, or when presented with "From," that the Omni-Bearing Selector indicates the proper bearing to fly from the station. The essential information regarding his present magnetic bearing <u>from</u> the station is likely to be lost or confused as a consequence of this effort to give him directions for his future actions, rather than merely information regarding his present position.

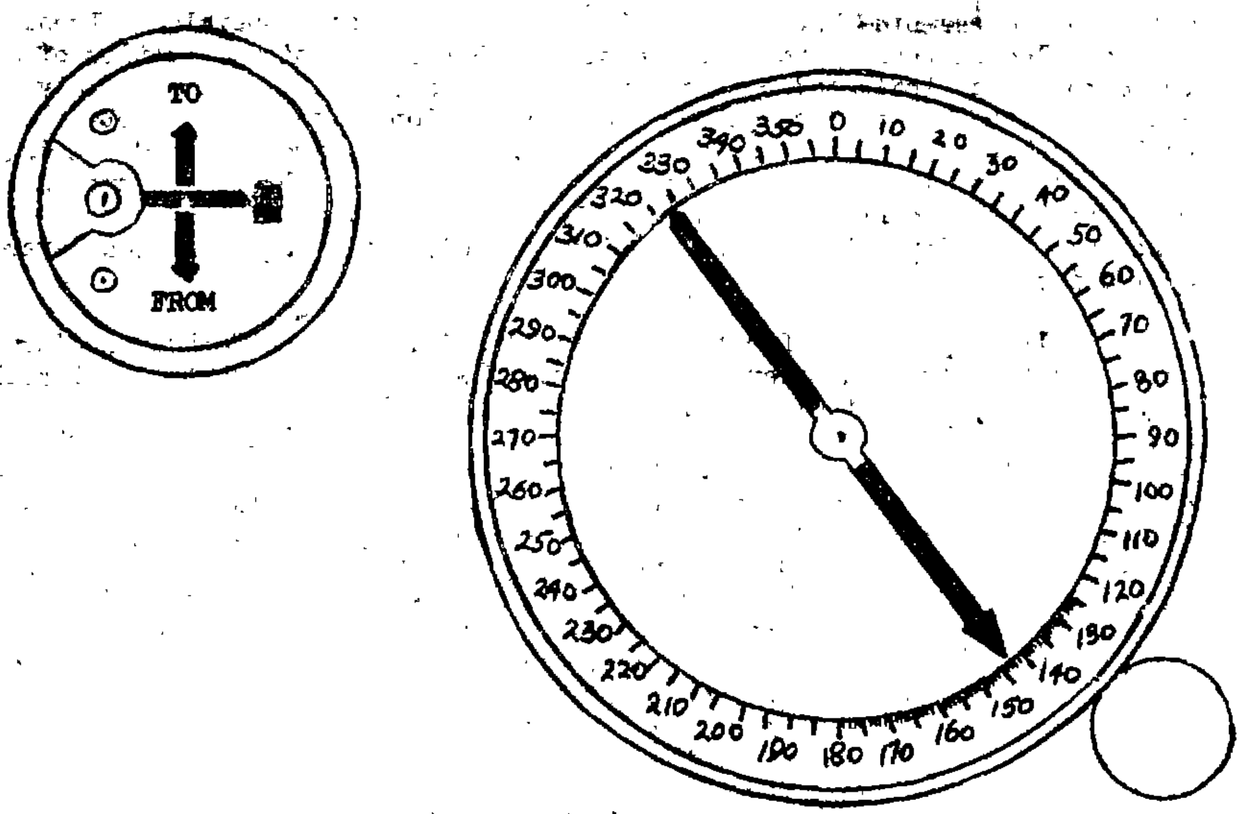

FIGURE 4

TO-FROM INDICATOR AND OMNI-BEARING SELECTOR

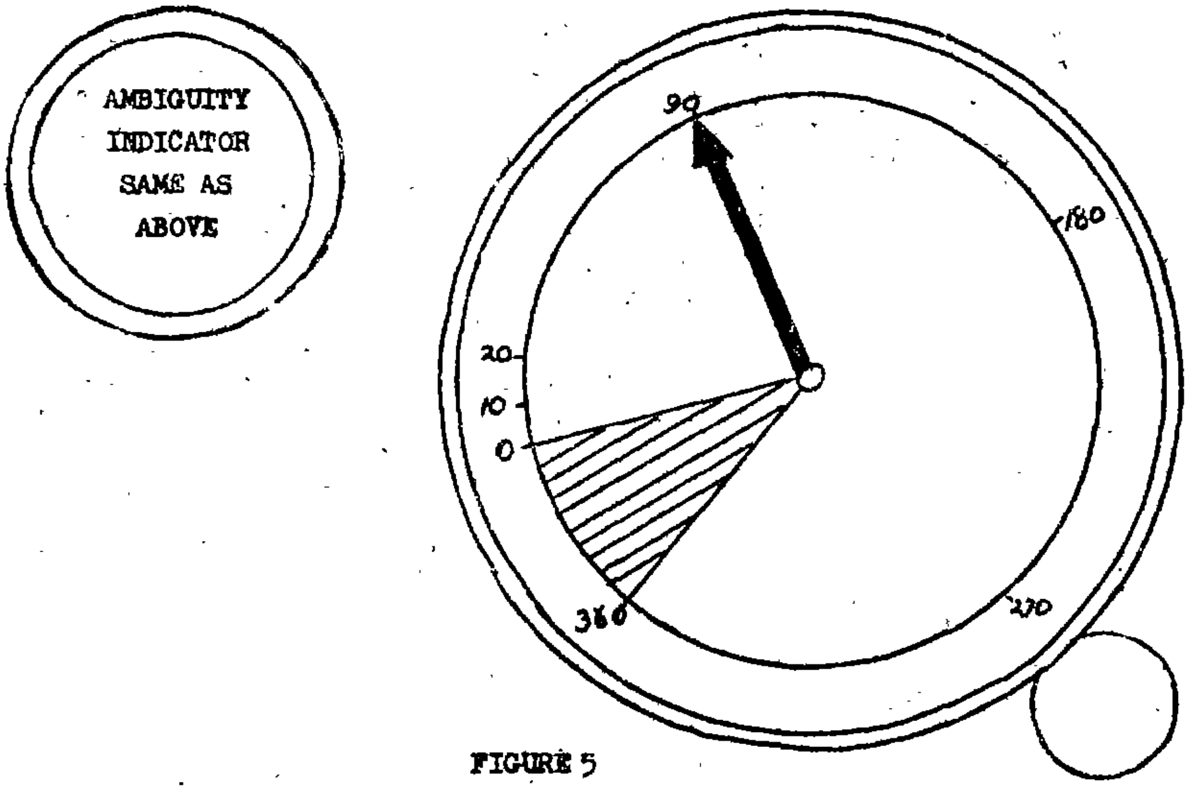

FIGURE 5

OMNI-BEARING SELECTOR

An attempt has been made to combine without confusion these two types of information in an instrument designed by the CAA Experimental Station, and pictured in Figure 6. Here the Ambiguity Indicator is combined with the Omni-Bearing Selector, and the movement of the selector knob results in the movement of the card underneath a lubber line, rather than the movement of a pointer over a stationary card. An aperture in the lower part of the instrument permits the direct reading of the reciprocal bearing. In following through the pictorial representation of the geographical positions of the airplane and the ODR station, the "inbound" or "TO" indication of the Ambiguity Indicator is now in a "down" position and the "outbound" or "FROM" indication is in an "up" position. It is clear that this instrument integrates the information as to present position and the instructions for future action. Thus, if the Course Line Deviation Indicator is centered with the indications as shown in Figure 6, it is clear that the bearing of the airplane from the station is 90° and that the proper bearing to fly away from the station is 90°. If the Ambiguity Indicator had pointed to "inbound" it would have been equally clear that the magnetic bearing of the airplane from the station was 270°, but that a bearing of 90° should be flown to approach the station. In short, this instrument forces the acceptance of the ODR station as the basic point of reference at all times.

Course Line Deviation Indicator. The purpose of the Course Line Deviation Indicator is to give the pilot information as to his lateral position relative to the bearing he has selected as his course line to or from an ODR station. It is used during the initial search with the Omni-Bearing Selector to indicate when the proper bearing has been selected, and, after assumption of the desired course, it may then be used as a course indicator in much the same manner as the Automatic Direction Finder is now used. The latter purpose is also served by the Omni-Bearing Indicator and the Radio Magnetic Indicator, using VHF omni-bearing data. These will be described in a later section.

There is apparently general agreement that large airplanes which are now equipped with the Flight Path Deviation Indicator of the ILS will employ the localizer needle of this instrument as the Course Line Deviation Indicator. The instrument is shown in Figure 7. This is the newer type instrument (Type ID-48) which includes "flag alarms" to warn that indication is unreliable. Deviations of the localizer needle to the left indicate that a correction must be made to the left, and vise versa, i.e., the pilot flies to the needle. This holds, of course, only when the Magnetic heading and the selected bearing are in essential agreement and the To-From Indicator shows the actual direction of motion with respect to the ODR station. The localizer needle can be tied into the Automatic Pilot so that the flight along the selected bearing is completely automatic. Since the localizer needle is also used in following the flight path during instrument landing, it is very sensitive to course line deviations. There is some question whether this instrument will be used for manual flying in aircraft equipped with the Radio Magnetic Indicator or Automatic Direction Finder. It should be noted, however, that when the localizer needle is flown as a Course Line Deviation Indicator, it is necessary that the airplane be made to assume the necessary drift angle and heading to make good the course line.

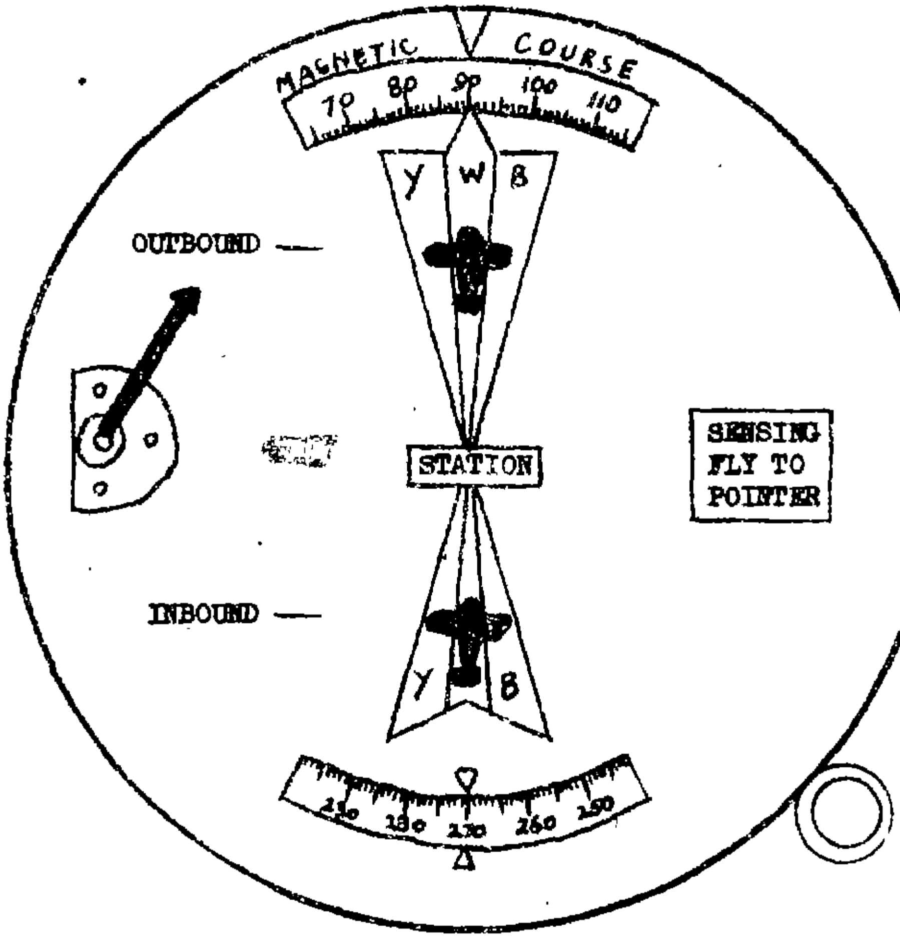

FIGURE 6

COMBINATION TO-FROM INDICATOR AND OMNI-BEARING SELECTOR
DESIGNED BY CAA EXPERIMENTAL STATION

The Electronics Subdivision, Communication and Navigation Laboratory, Wright Field, has designed a combination Flight Path Deviation Indicator which incorporates an indication of drift angle. In fact, this instrument combines relative magnetic heading indication, course line deviation indication, the Omni-Bearing Selector, and the Ambiguity Indicator. A schematic diagram of one form of the instrument is shown in Figure 8. The selected bearing is shown in a counter type mechanism at the top of the instrument, and the Ambiguity Indicator is immediately adjacent. The difference between the magnetic bearing of the station and the magnetic heading of the aircraft is indicated by the needle which is pivoted in the center of the instrument.

In order to make room for this indication, the pivoting of the localizer and glide path needles of the indicator has been changed so that the two needles move in a coordinate system (right-left, up-down) throughout the extent of their visible excursions. In flying this instrument, the localizer needle should be centered and the drift angle may then be read directly from the scale of the small needle, after the drift has been "killed." For example, in Position I, Figure 1, the localizer needle would be centered when the Omni-Bearing Selector was set for 315°, and the drift angle needle would indicate a 10 degree positive difference between the bearing and the heading.

It is noteworthy that this instrument does not include the device for instantaneously exposing the reciprocal of the selected bearing and for switching the Ambiguity Indicator and the sensing of the localizer needle. Instead, it is assumed that the pilot would make no manual adjustment during the procedure turn, but would fly the localizer needle with reverse sensing and read the bottom scale for the heading indication.

A possible advantage of this system might be realized in procedure turns in which the pilot turned at a rate which would make the heading needle rotate smoothly between the initial drift angle and the terminal drift angle. It has even been suggested that a "pacing" light could move around the rim of the instrument at such a speed that the turn would be completed in exactly the required number of seconds or minutes. However, the extent to which the reverse sensing would be productive of pilot error should, on a priori grounds, be a matter of some concern. Also, the effects of combining so many indications in a single instrument should be determined through research.

To date, there apparently has been no commitment regarding the characteristics of the Course Line Deviation Indicator which would be developed for use in aircraft not already equipped with the Flight Path Deviation Indicator. In the ODR indicator unit now available through the Aircraft Radio Corporation a Flight Path Deviation Indicator without flag alarms is used. The glide path (horizontal) needle remains in the instrument, but is not used. It would seem that there is a real possibility of enabling this instrument to be designed in terms of basic instrumentation research. Accordingly, the design of this instrument for small airplanes offers immediate opportunity for the application of research findings.

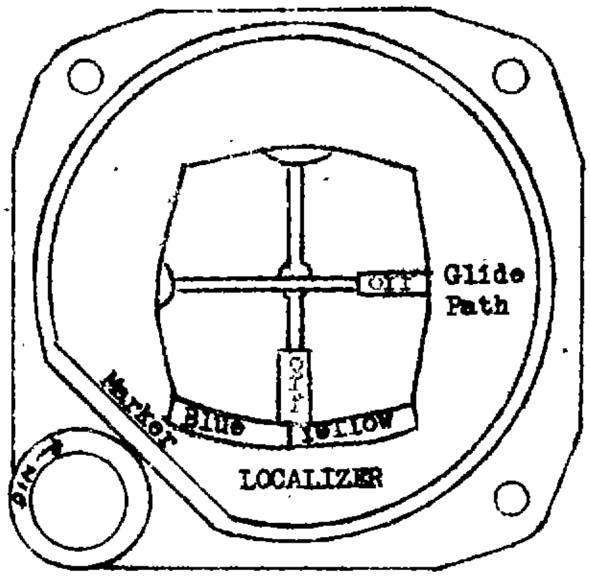

FIGURE 7

GLIDE PATH DEVIATION INDICATOR (TYPE ID-48)

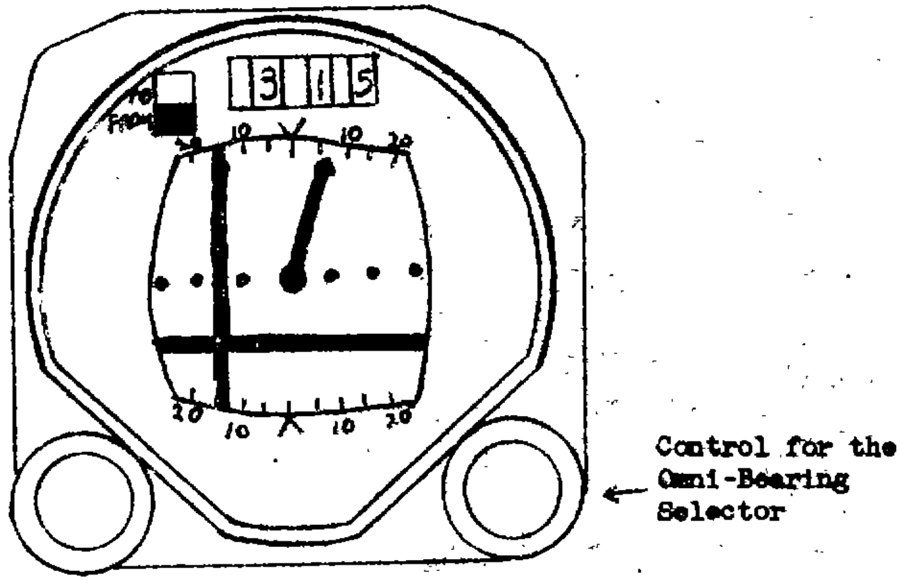

FIGURE 8

COMBINATION TO-FROM INDICATOR, OMNI-BEARING SELECTOR, COURSE LINE DEVIATION INDICATOR, GLIDE PATH DEVIATION INDICATOR AND DRIFT ANGLE INDICATOR, AS DESIGNED BY ELECTRONICS SUBDIVISION, C & N LABORATORY, USAF MATERIEL COMMAND

Omni-Bearing Indicator and Radio Magnetic Indicator. As previously indicated (p.15), instruments are available for continuous automatic indication of the bearing of an ODR station or stations from the aircraft. One simple Omni-Bearing Indicator is shown in Figure 9. In this instrument, which is produced by Pioneer, the bearing of the ODR station FROM the aircraft is shown directly on a card which rotates behind a lubber line. In view of the earlier discussion of the use of R-Theta Computers, it would seem that this instrument would be most useful if it indicated the bearing of the airplane from the ODR station. This instrument is intended only for bearing information, and, therefore, may be used in lieu of or simultaneously with the Omni-Bearing Selector, but is not intended to replace the Course Line Deviation Indicator. However, it could be used roughly for that purpose.

The Radio Magnetic Indicator is a combination of one or more Omni-Bearing Indicators and a magnetic heading indicator. It can be used only in those aircraft equipped with a remote reading gyro stabilized magnetic compass. The instrument is already in use in place of the ADF in some aircraft, since it may be used with low frequency stations as well as with VHF ODR stations. All RMI's have the same basic design, although they may differ in scale markings, pointer differentiation, etc. One type is shown in Figure 10. The marked card rotates in response to the magnetic heading of the airplane, as determined by the gyro compass. Each of the needles is continuously oriented toward a selected ODR station. They at all times indicate the magnetic bearing of the stations from the geographical location of the airplane, which may be read from the card.[4]

Thus, after tuning to an ODR station and centering the Course Line Deviation Indicator, if the pilot notes that the magnetic bearing of the station and the magnetic heading of the aircraft are identical (needle is pointing to the lubber line) he knows that he is making good a course to the station without drift. If, on the other hand, the magnetic bearing of the station is 315° and the magnetic heading of the aircraft is 325°, he knows that he is making good the course to the station, but with a 10 degree drift angle of the aircraft. The RMI thus provides an indicator (of somewhat less sensitivity than the Localizer Needle on the Localizer Glide Path Indicator) which may be used to make good a course with immediate graphical and numerical indication of the drift angle. In addition, simultaneous presentation of the bearings of two ODR stations has obvious advantages in the determination of a "fix" in terms of which the exact position of the plane can be computed.

It will be noted that the RMI is a combination of a continuously indicating Omni-Bearing Converter and the magnetic compass. Although, it is possible that the pilot may "fly" the ODR needle, it is more likely that he will fly the "card" after having determined the proper heading to make good his course to the station. In that event, he will turn

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[4]This is accomplished by feeding the output of the magnetic compass transmitter into a differential in an Omni-Bearing Converter such that the difference between the ODR bearing and the magnetic heading is determined. It is this difference which is imposed on the needles of the RMI.

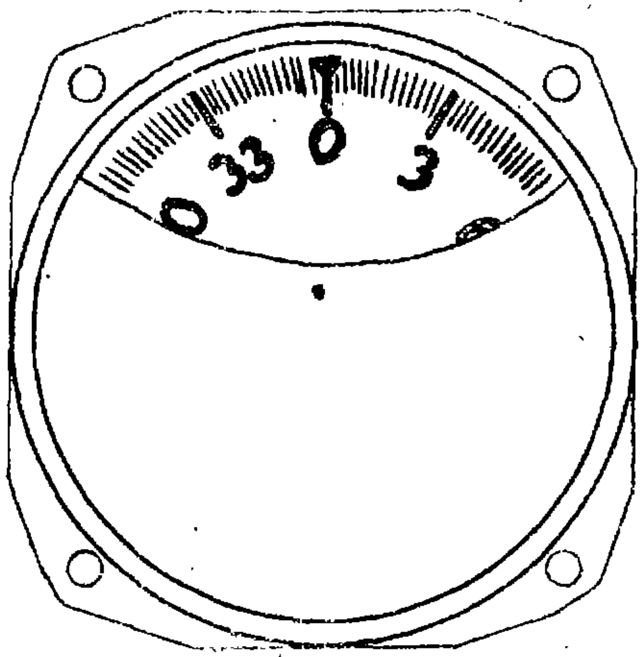

FIGURE 9

OMNI-BEARING INDICATOR

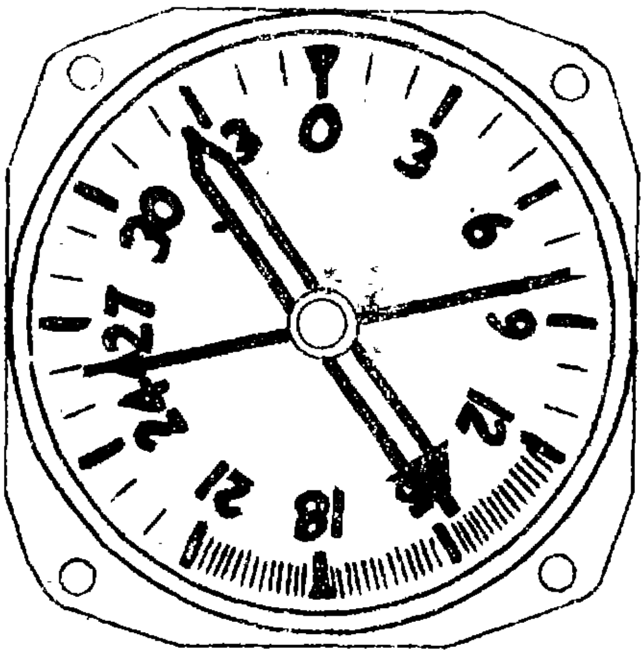

FIGURE 10

RADIO MAGNETIC INDICATOR

to the left to correct for a deviation of that heading to the left (counter-clock wise) on the card. Some competent instrument pilots maintain that they will prefer to "fly" the RMI, rather than the Course Line Deviation Indicator.

SUGGESTED DME INSTRUMENTS

Instrumentation for the Distance Measuring Equipment is essentially simple. The number of miles from the aircraft to the DME station is the only information required. This is usually indicated on a dial which has a maximum indication of 120 miles. It is desirable that distance indications be made as fine as 1/5 mile, although the readings are not now accurate to better than ± 1 mile. Two types of DME instruments which have been seen are shown in Figure 11. In the first, which is currently employed by the CAA Experimental Station, the gross scale extends from 0 to 120 miles, and a fine scale, covering the same extent of the instrument face, extends from 0 to 12 miles. After the pilot has come within the 12 mile range, he manually switches the instrument to the fine scale. In the second, which is currently employed in a C-47 owned by the Collins Radio Company, the same fineness of reading is obtained for all distances up to 120 miles by using one hand for ten mile steps and a second hand for one mile steps. This double hand system brings to mind the research of the Aero Medical Laboratory on the accuracy of readings of standard altimeters, in which it has been shown that the double hand system produces an excess of erroneous interpretations when the large unit hand is in the nine to eleven o'clock position.

SUGGESTED INSTRUMENTATION FOR ODR-DME COURSE COMPUTERS

Automatic course computers for the definition of off-set course lines based on an integration of ODR and DME data are now in a very early stage of development. It is anticipated that these off-set courses will be fed into the Course Line Deviation Indicator and will be used by the pilot or the auto-pilot in exactly the same way that it is used for "homing" on a station. Likewise, the course computer will permit the measurement of distance to any point on the off-set course line of the airplane. This information will presumably be given to the pilot in the same type of instrument employed for the direct-to-station DME. A complete appreciation of the problems inherent in such instrumentation will certainly depend on the variety of off-set courses which the computer can define, and also on the uses to which such equipment is put in the control of air traffic.[5] Following the discussion in an earlier section (see p. 5) it may be suggested that the indication of bearing of the airplane or other object from a station will be the primary orientation datum in the use of R-Theta Course Computers.

[5] Some suggestions along these lines are contained in a publication of the Air Navigation Traffic Control Group of the Air Transport Association of America, entitled "Recommendations for Safe Control of Expanding Air Traffic: Part 1," February, 1947.

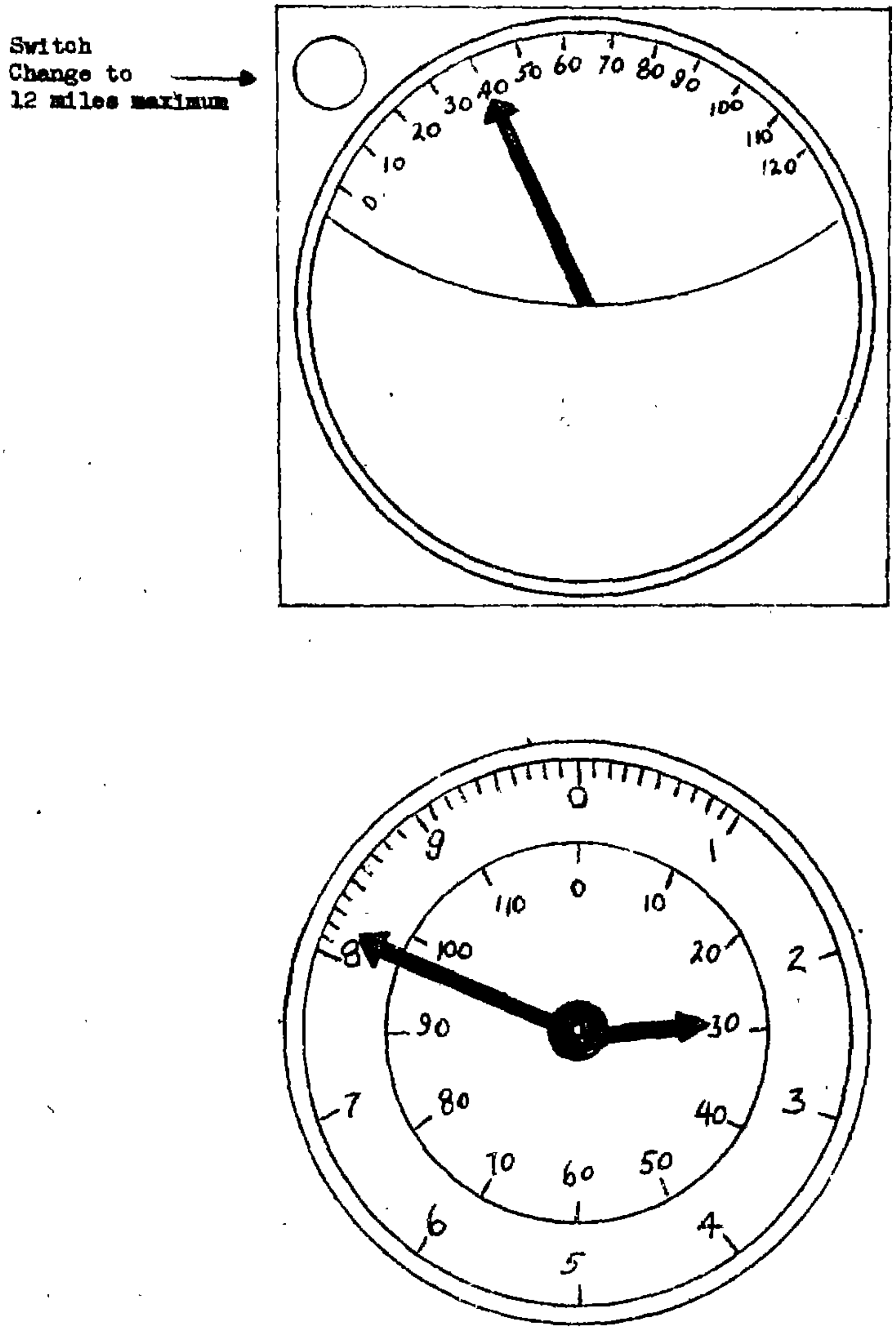

FIGURE 11

TWO TYPES OF DISTANCE INDICATORS FOR USE WITH DME

PSYCHOLOGICAL PROBLEMS IN ODR-DME INSTRUMENTATION

It would appear that the major psychological problem in the design cockpit instruments for the use of ODR, DME, and R-Theta Computers is the frame of reference to be given primary emphasis. Although this problem involves particularly the design of the Omni-Bearing Selector and its associated Ambiguity Indicator, it is also involved in the design of accessory equipment such as the Omni-Bearing Indicator and the Radio Magnetic Indicator. On the one hand the design and labelling of some Omni-Bearing Selectors and Ambiguity Indicators appear to emphasize instructions to the pilot regarding the proper course line to follow in approaching a station or going away from a station. This is epitomized in the labelling of the Ambiguity Indicator as a "To-From Indicator," and the consequent equal emphasis on "bearing from an airplane to a station" and "bearing of an airplane from a station." This emphasis is, of course, understandable when it is remembered that the Course Line Deviation Indicator has the proper sensing only when the actual course line of the airplane is congruent with the indications on the To-From Indicator.

On the other hand, it is possible that this emphasis may lead to confusion when the intent of the pilot is merely to determine and state his position with reference to a station, stations, or a system of polar coordinates, in which case he should uniformly state his position in terms of his magnetic bearing from a station or stations. Such confusion could easily lead to misstatement of position for purposes of traffic control. It is noteworthy that such misstatements of position, in response to queries from traffic control operators, would have no immediate consequences which would call the error to the attention of the pilot; whereas, if "bearing from a station" should ever be misunderstood in the planning of the course of action of the airplane, there are numerous sources of information within the cockpit which would indicate the need for correction. Among these are the reverse sensing of the Course Line Deviation Indicator and the lack of agreement between the various heading indicators (with drift angle considered) and the Omni-Bearing Selector and Ambiguity Indicator.

It would seem, as a consequence of these considerations that investigations are required to determine the advantages and disadvantages of the Omni-Bearing Selectors and Ambiguity Indicators which depend heavily on the pilot's conceptualization of his problem and those, like the one shown in Figure 6, in which an attempt is made to combine in a pictorial presentation the position and course of action of the airplane. The same problem should, of course, be considered in the design of the Omni-Bearing Indicator and the Radio-Magnetic Indicator; although in these cases there may be the special problem of the effects of prior use of the ADF. In fact, since the psychological problem, as stated, is one which is involved in the design of all the established orientation instruments, such as the Magnetic Compass, the Directional Gyro, and the ADF, it is proper that such investigations encompass the entire problem of the most effective modes of display of bearing and heading information. Important methods of evaluation would be in terms of the difficulty of training to a certain standard of accuracy and the frequency of errors of interpretation after standard amounts of [illegible].

A secondary problem in the design of such instruments, although undoubtedly an important one, is the determination of the specific manner of indication which is least likely to result in error. As may be seen from the description of the proposed Omni-Bearing Selectors, there seems to be no current information which would lead one to reject an instrument in which the card turns beneath a lubber line, in favor of an instrument in which a pointer moves over the face of a stationary card, or vice versa. Nor is there any certainty that the simple numerical indication of bearing by a counter type instrument is necessarily superior or inferior to the dial type of indicator in which there is at least some similarity to other "earth orientation" instruments and perhaps some aid to visualisation of the position and flight course of the airplane.

In the design of the Course Line Deviation Indicator, it is clear that thought has been molded by the already present Flight Path Deviation Indicator. However, in this case there is widespread criticism of that Indicator, chiefly because it seems more natural to present the deviation of the airplane from the intended line of flight than to indicate the deviation of the intended line of flight from the airplane. In the former case, one would fly to the right to bring the symbol of the airplane back to the center line, which represents the intended line of flight; in the latter and standard case, one flies to the left to move the center line, which represents the aircraft, over to the intended line of flight. The same type of problem is, of course, present in the design of the Attitude Indicator. With the present interest of CAA in the extension of ODR instrumentation to all aircraft, both large and small, perhaps the moment is propitious to apply psychological principles in the design of the basic flight instruments.

A third general problem of some moment is the matter of combinations of indicators. The combinations which have been proposed in connection with the ODR seem, for the most part, to be reasonable and probably productive of more efficient performance. The necessary psychological interdependence of the Ambiguity Indicator and the Omni-Bearing Selector strongly argues for these being combined into a single indicator. Again, the RMI seems to be a productive combination of information, in that heading and omni-bearing data are integrated in a way which relieves the pilot of certain computations and minimizes his division of attention. On the other hand, the composite instrument proposed by the USAF (Figure 8) may conceivably result in a decrement in efficiency under some circumstances. The most favorable condition of its use would probably be when the pilot was homing on the station to which the Omni-Bearing Selector was tuned. But a disturbance of performance might occur during the use of the instrument for an ILS landing, or when the flight course being followed on the localizer needle is an off-set course set up by a course computer, and not the course defined by the Omni-Bearing Selector.

SUMMARY OF PROBLEMS

Although recognizing that the psychological problems pertaining to ODR and DME equipment are broad in nature, and demand basic research on the psychological aspects of aircraft equipment design, it may be of interest, in recapitulation, to list, as follows, certain of the specific problems involving the human element which this preliminary survey has uncovered with regard to these instruments.

1. What "frame of reference" in terms of orientation to the station should be given primary emphasis in the design of cockpit instruments for the use of ODR, DME, and R-Theta Computers?

2. What is the relative tendency for error in interpretation and action in various characteristic flight situations when the components of ODR navigation are in separate instruments or combined in a single instrument?

3. Is there any difference in the interpretability of bearing and heading instruments in which the card turns beneath a "lubber line" and instruments in which a pointer moves around a circular card?

4. What differences in effectiveness are there between instruments which present information through a counter type of display as compared with instruments employing dial type display and/or what types of information can most effectively be presented by each of these respective methods?

5. What are the psychological problems involved in interpreting and/or adjusting the ODR instruments following a 180° procedure turn?

6. Should the Course Line Deviation Indicator give a representation of the direction of the proper course line from the aircraft, or the direction of the aircraft from the proper course line (i.e., should the pilot be required to fly "from the needle" or "to the needle")?

7. What type of "Course Line Deviation Indicator" is most applicable for small-plane installation in which ILS instrumentation is not already present or contemplated?

8. Should the DME indications be presented in terms of a clock-face dial (similar to the standard altimeters), or in terms of a scale of the type illustrated in Figure 11, or some other type?

9. How fine should be the division marks on the Radio Magnetic Indicator and what differentiation of the two pointers will be least productive of confusion between them?

10. What are the advantages and disadvantages of specific prototype instruments already designed, such as the CAA Experimental Station's proposed Omni-Bearing Selector (Figure 6) and the USAF combination of the ILS and ODR indicators (Figure 8)?

11. What specific training problems are important in the indoctrination of pilots in the use of ODR and DME equipment?

It should be emphasized, of course, that due to the limited nature of the present survey, the above list of problems cannot be considered definitive. The problems are, however, representative of the type which will demand solution, either through direct attack, or on the basis of implications drawn from fundamental research on instrument problems

A number of the general problems listed above are being studied in connection with existing engineering psychology research projects at several laboratories. While none of this research is concerned exclusively with the Omni-Directional Range presentation problem, results should contribute to this particular problem.

An extensive research program on instrument display problems is under way at the Aero Medical Laboratory, Wright Field, Ohio. This program has been concerned particularly with instrument comprehension problems and with discovery of psychological principles pertinent to the design of new instruments. Emphasis has been placed on problems faced by the pilot when he has to shift rapidly between a number of different instruments, synthesizing the indications from all of them. The general objective has been to discover general principles that can be applied to all panel instruments, thus reducing "transition time" between instruments. The program includes both surveys and job analysis studies on the one hand and laboratory and air experiments on the other.

The Department of Psychology at the University of Washington has been conducting experiments under contract with the Aero Medical Laboratory on orientation problems relating to instrument design, particularly heading indication. The Department of Psychology, University of Illinois, has been working under contract with the Office of Naval Research on the study of psychological problems connected with the design of aircraft instruments.[6]

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[6]A selected list of research reports and bibliographies prepared by these activities is given below. While none of these reports deals directly with the Omni-Range, many of the findings and principles are applicable to this particular problem.

Fitts, Paul M. (Ed.) Psychological Research on Equipment Design. Government Printing Office, 1947, pp. XII-246

Fitts, Paul M., and Jones, R. E. Psychological aspects of instrument display. I. Analysis of 270 "pilot error" experiences in reading and interpreting aircraft instruments. AMC Engineering Division Memorandum Report No. TSEAA-694-12a, 1 October, 1947.

that studies involving the gyrohorizon have indicated that interpretation of this instrument was more efficient when the moving horizontal bars were indicative of the plane's attitude (the representation of the horizon remaining stationary) than when the representation of the horizon turned around a stationary model plane.[7,8] This, together with results of work in Great Britain indicating that fewer errors are made when the movement of an indicator and the "expected direction" of associated control movement are the same,[9] might suggest, with reference to the Course Line Deviation Indicator, that display in terms of direction of indication of the plane's position from the course line would prove superior to the currently standard procedure of indicating the direction of the proper course line from the plane. (In other words, flying "from" the needle rather than "to" the needle might be indicated.) Additional, and more direct experimental evidence on this point would, of course, be desirable.[10]

Moreover, with reference to the two types of indicators suggested for the Distance Measuring Equipment, the results of work on altimeters[11] would suggest (as noted previously) that the dial-type display in Figure 11 might well be conducive to error in reading.

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[7]Loucks, Roger Brown. An experimental evaluation of the interpretability of various types of aircraft attitude indicators. Psychological Research in Equipment Design, Army Air Forces Aviation Psychology Program, Research Report No. 19. Washington, D.C.: U. S. Government Printing Office, 1947, pp. 111-135.

[8]Browne, R. C. Comparative trials of two attitude indicators. Great Brit. FPRC Reports 661 and 661a as abstracted in Annotated Bibliography on Human Factors in Engineering Design. Washington, D.C.: Aviation Branch, Research Division, Bureau of Medicine and Surgery, Navy Department, February, 1946.

[9]Vince, M. A. Direction of movement of machine controls. Great Brit. FPRC Report No. 637 (as cited in Grether, Walter F. Efficiency of several types of control movements in the performance of a simple compensatory pursuit task. Psychological Research in Equipment Design, Army Air Forces Aviation Psychology Program, Research Report No. 19, Washington, D.C.: U. S. Government Printing Office, 1947, pp. 227-239.

[10]It should be recognized, of course, that any apparent advantage in favor of altered methods of indication might be offset by confusion resulting from interference with established habit patterns of experienced pilots. This, too, would be a matter for experimental determination.

[11]Grether, Walter F. The effect of variations in indicator design upon speed and accuracy of altitude readings. Memorandum report TSEAA-694-14, Hdqtrs. Air Materiel Command, Eng. Division, 2 September, 1947.

DIRECTION OF SUBSEQUENT INQUIRY

As noted previously, the psychological problems associated with the ODR and DME equipment are not altogether unique. Many of the problems are common to other types of instrument display, and can be resolved on the basis of implications from results of the fundamental research on instrumentation in general, or on the basis of research on other instruments. Other problems are more specific, and may accordingly demand research treatment oriented toward specific ODR and DME equipment.

In considering the avenues by means of which attack on the instrument problems associated with this equipment can be furthered, a number of methods of action present themselves.

1. The results of current research on instrument problems should be thoroughly investigated to determine the implications of such research for ODR and DME display problems.

2. A program of basic research might well be outlined, integrated with other instrument research being at present conducted by various agencies, and oriented toward ODR, DME and Course-Computer problems, although also having pertinence to general and theoretical problems in instrument display.

3. Research on problems unique to ODR and associated equipment should be instituted, based in part on the results of "basic" and more general investigations.

4. Investigation should be conducted to determine the basic training requirements for indoctrination in ODR procedures.

With reference to item 1, above, (the pertinence of research on other instruments to ODR instrumentation problems), it might be noted for example,

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6 (Continued)
Grether, Walter F. Discussion of pictorial versus symbolic aircraft instrument displays. AMC Engineering Division Memorandum Report No. TSEAA-694-8b, 4 August, 1947.

Hermans, T. G., and Loucks, Roger Brown. Annotated bibliography on the psychological aspects of orientation as they relate to aviation. AMC Engineering Division Memorandum Report No. 694-16a, 1 December, 1947.

Smith, W. M., and Kappauf, W. E. Studies pertaining to the design and use of visual displays for aircraft instruments, computers, maps, charts, and tables: a bibliography. AMC Engineering Division Memorandum Report No. TSEAA-694-1g, May, 1947.

With reference to item 4, page 27, (training requirements for indoctrination in the use of the ODR indicators) it should be apparent that the ODR instrumentation involves potential sources of confusion and error. Although it is frequently asserted that "pilots have no difficulty in learning to use the ODR," nothing apparently has yet been done to determine the rate of adjustment of pilots to such new equipment. Cooperation between a research agency and the airlines might well have merit in connection with the institution of ODR training programs. In addition, it is possible that studies of learning to interpret and use ODR instruments, employing non-pilots or pilots without instrument training, would yield important information bearing on potential training problems, as well as serving as a method of evaluating different types of instrumentation.

Finally, the importance of establishing adequate liaison between investigators in this field of applied psychology, and technical and operational groups should be emphasized. In the course of the present survey it was repeatedly evident that those civilian agencies primarily concerned with ODR and other aircraft instruments had had no opportunity to be informed regarding recent psychological research on instrument problems. It may well be that this situation also prevails among aircraft instrument designers in commercial organizations. Such liaison could perhaps best be accomplished through some civilian agency.