A TUNED-REED COURSE INDICATOR FOR THE 4 AND 12 COURSE AIRCRAFT RADIO RANGE

By F. W. Dunmore

ABSTRACT

For the 12-course radio range system, in which three modulation frequencies are used, a type of reed indicator has been developed to indicate when the aircraft is on any one of the 12 courses, and if off, approximately how many degrees and whether to the right or left, and, in addition, indicates to the pilot, in case he becomes lost, which course he is nearest, how to turn to get on it, and which way he is flying on it. This is accomplished by the use of three reeds in the visual indicator, each reed being tuned to one of the modulation frequencies sent out by the radio range, namely, 65, 86.7, and 108.3 cycles. Unequal amplitudes of vibration of the reeds indicate the plane is off the course to the side of the reed having the greatest amplitude. A simple shutter with windows, in front of the vibrating reeds, exposes any two at a time. The correct two for a given course is determined by a color system which is exposed by the window to correspond to the color of the particular radio range route marked on the map. A second shutter and color system is provided so that the rule, "Longest reed indicates side off course," may be made to hold regardless of the course being flown or the direction of flight.

The 4-course indicator is the same as the 2-course indicator with the exception of a shutter and color system on its face to adapt it to any one of the four courses.

A pilot using these indicators may hold a plane in a given radio range course with an accuracy of approximately $\pm 1°$.

CONTENTS

I. INTRODUCTION

The tuned-reed type of visual indicator is used to give a pilot a visual indication as to whether or not he is flying on a specified double-modulation radio range course, and, if not, to which side and how much he has deviated. The indication is given continuously by two vibrating reeds, the relative amplitudes of which indicate the position of the airplane with respect to the radio-range course. In order to observe the reed vibration, each reed carries a white tab on its free end.

These two tabs produce two adjacent white lines when the reeds vibrate. It is the relative length of these two lines which the pilot observes. Each reed is tuned to one of the frequencies of modulation used at the radio range. The course is a zone in space where the strengths of the radio-range modulation frequencies are equal, each zone being indicated to the pilot by equality of amplitude of vibration of the two reeds. A deviation from the course is indicated by an increase in that reed amplitude on the side to which the airplane has deviated, and an equivalent decrease in the other reed amplitude.

A tuned-reed indicator designated as type F for the double-modulation (2-course) radio range has been described in a previous issue of this publication.[1] There has recently been developed a 12-course radio range system [2] in which three modulation frequencies are used and which gives 12 courses spaced about 30° apart. This requires a tuned-reed indicator useful on any one of the 12 courses. This paper describes such an indicator, which when used in conjunction with this radio range serves to give a pilot the following information: (*a*) Indicates when he is on any of the 12 courses; (*b*) indicates when off the course and approximately by how many degrees and whether to the right or left, and (*c*) indicates in case he becomes lost (which is hardly possible when using the radio range), which course he is nearest, how to turn to get to it, and which way he is flying on it; that is, whether "to" or "from" the radio range.

A 4-course indicator which was designed to meet the requirements of the 4-course radio range, which uses two modulation frequencies but produces four courses which may be oriented at will, is also described in this paper.[3] These requirements, while not as difficult to meet as those of the 12-course radio range, did necessitate, however, the use of new features on the face of the 2-course reed box in order to adapt it to any one of the four courses.

II. THE 12-COURSE REED INDICATOR

1. DETAILS OF DESIGN

(*a*) *Reeds and driving elements.*—This indicator, shown in Figures 2, 4, 5, 6, and 7, contains three reeds tuned to frequencies of 86.7, 108.3, and 65 cycles, respectively, the three frequencies of modulation used at the radio range. These reeds are made of elinvar, which makes their natural period of vibration independent of temperature. Steel reeds may be used, in which case a weighted bimetallic compensation strip should be fastened to their free end. This strip, when bending because of a temperature change, moves the weight on its end a sufficient amount to change the tuning of the reed by an amount which compensates for the change in its tuning due to the effect of temperature on its elastic constant. Each reed is polarized by a set of permanent magnets, *T* and *U* (fig. 4), common to all reeds. *D* is a soft iron yoke connecting two like poles of the magnets. Each reed has a separate set of driving electromagnets, *C*, similar to those used in telephone receivers, the windings of which are all connected in series in the proper polarity to operate the polarized reeds. The

[1] F. W. Dunmore, Design of Tuned-Reed Course Indicators for Aircraft Radiobeacon, B. S. Jour. Research, 1, pp. 751–769; November, 1928. Reprinted as Research Paper No. 28.

[2] H. Diamond and F. G. Kear, A 12-Course Radio Range for Guiding Aircraft With Tuned-Reed Visual Indication, B. S. Jour. Research, 4, p. 351; March, 1930. Reprint as Research Paper No. 154.

[3] H. Diamond, Applying the Visual Double-Modulation Type Radio Range to the Airways, B. S. Jour. Research, 4, p. 265; February, 1930. Reprint as Research Paper No. 148.

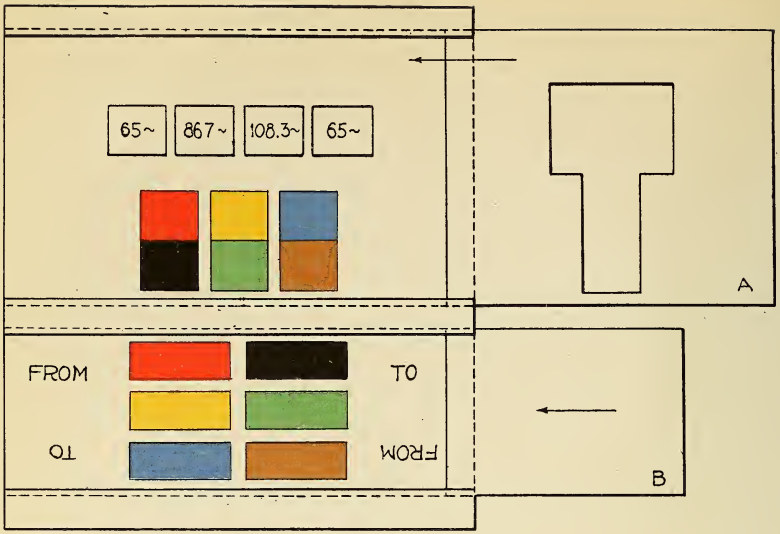

FIGURE 1.—*Face of 12-course reed indicator showing shutters removed to expose color system, and whitened tabs attached to the reeds*

FIGURE 2.—*Tuned-reed course indicator for use on any course of the 12-course aircraft radio range*

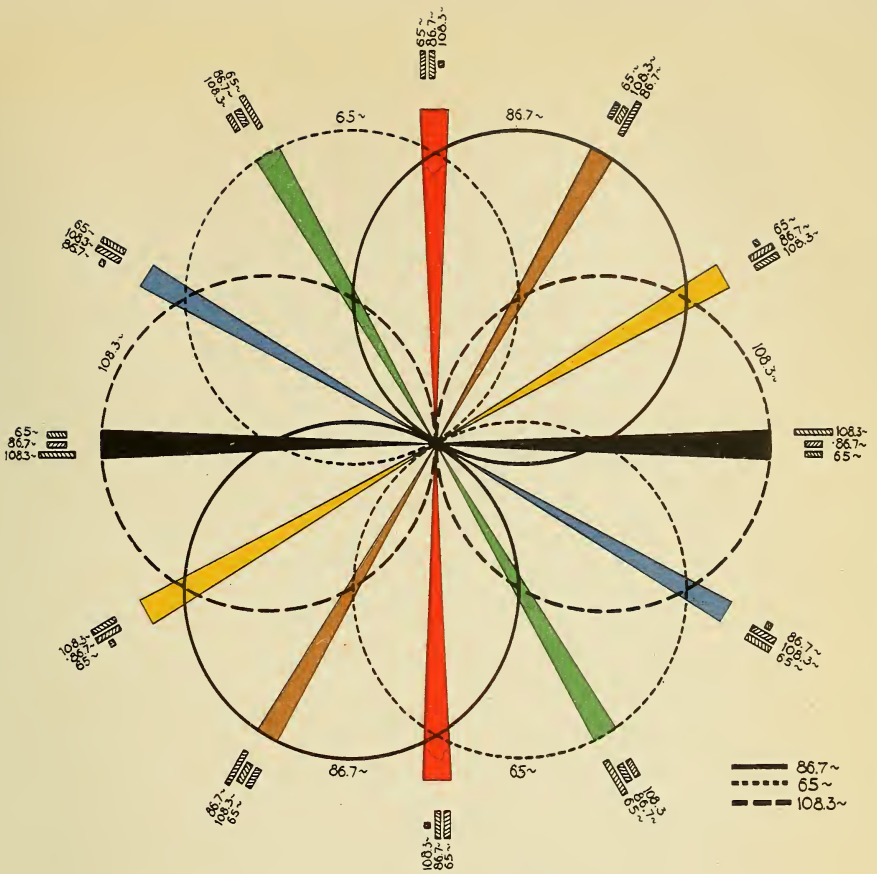

FIGURE 3.—*The 12-course radio range transmission characteristic*
The colors indicate courses where the two modulation frequencies are of equal strength and the reeds tuned to these frequencies vibrate with equal amplitude.

DESCRIPTION

The indicator contains three reeds tuned to the three modulation frequencies used at the beacon. Whitened reed tips, when reeds are vibrating, due to beacon signal, produce adjacent vertical white lines. The proper set of two adjacent lines to be observed for a given course is determined by shutter *A*, which, when adjusted to show the proper color, exposes the correct two lines. Equal lengths of these lines indicate airplane is on beacon course. Unequal lengths indicate airplane is off course to side of line having the greatest amplitude. This rule — longest line shows side off course—is made to hold for all courses and directions of flight by exposing the proper color with shutter *B*.

The radiobeacon courses on the airways strip map may be colored to correspond to colors shown in Figure 3, depending on the two frequencies of modulation used on a given course.

To use the reed indicator shown in Figures 1 and 2 for flying on any given course:

1. Set shutters *A* and *B* to show the color, according to the map, of the airway to be flown.
2. Rotate reed box in its holder to show "FROM" or "TO" right side up depending upon whether the direction of flight is *from* or *to* the radio range.
3. Longest line shows side off course.

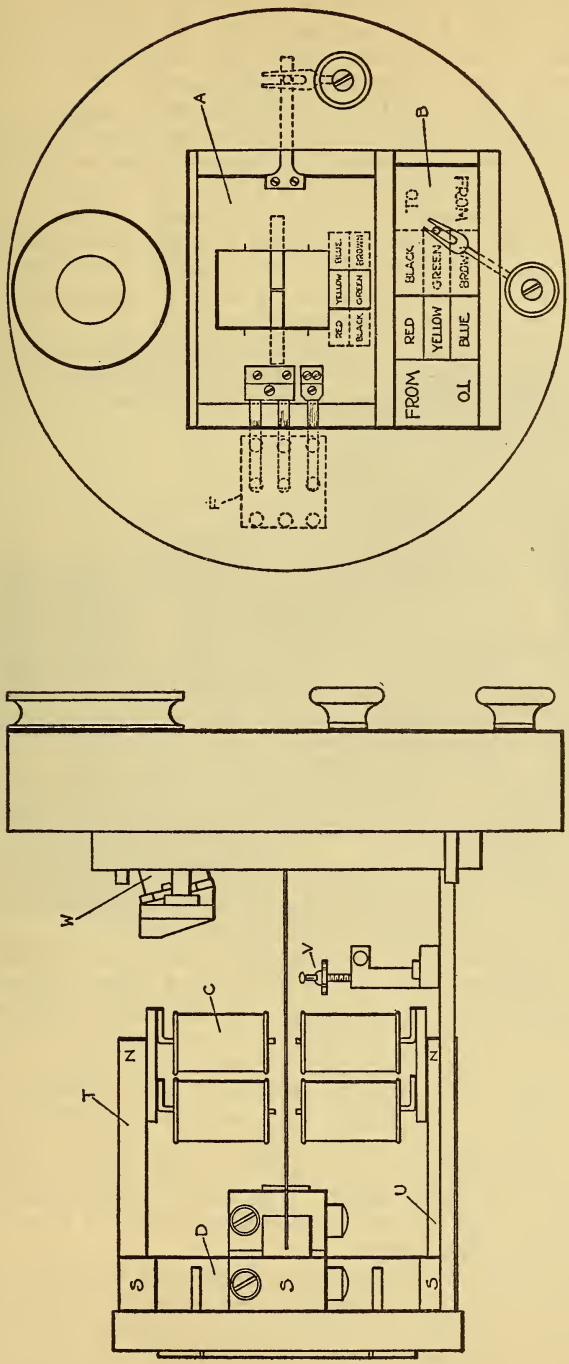

FIGURE 4.—*Tuned-reed course indicator for the 12-course radio range*

terminals of these electromagnets are connected to the output of the radio-range receiving set. The housing, *W*, contains a lamp for illuminating the reeds; *V* is a bumper to hold the reed vibration within bounds; *A* and *B* are shutters over the reeds and color system. Figure 5 is a plan view of a portion of Figure 4.

For each course the vibration of adjacent reeds must be observed. The 108.3-cycle reed is placed between the 86.7 and 65 cycle reeds. For one set of courses, therefore, in order to observe the 86.7-cycle reed adjacent to the 65-cycle reed, a light arm extension, *K* (fig. 5), is fastened to the free end of the 65-cycle reed. This arm carries a white tab, *L*, on the further end, which tab vibrates adjacent to the tab, *O*, on the upturned front end of the damper, *H*, on the 86.7-cycle reed. The other two air dampers, *I* and *J*, also have upturned whitened ends or tabs, as shown at *N* and *M*. *L O N M* is an end view of the reeds or tabs as the pilot would see them with the shutter removed. There are three sets of reed combinations which go to make up the 12-course indications. For one set of courses, tabs

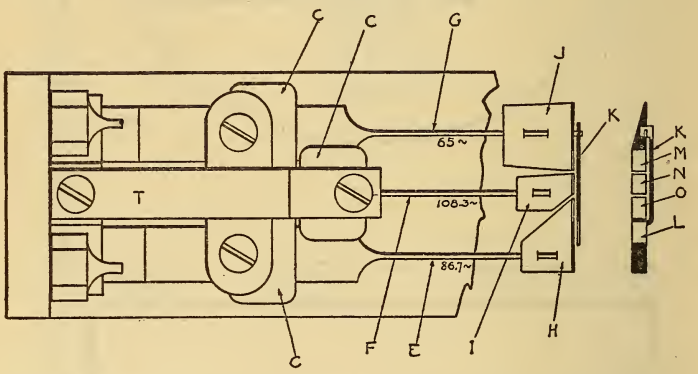

FIGURE 5.—*Plan view of 12-course indicator showing reeds, dampers, extension arm on 65-cycle reed, and whitened tabs*

M and *N* are observed; for another, tabs *N* and *O;* for a third, tabs *O* and *L*. As previously stated, tabs *L* and *M* both vibrate with the 65-cycle reed, *G*.

(*b*) *Shutter and color system.*—Since it is necessary to observe any two adjacent whitened tabs on the reeds for a given course, without seeing the others, a shutter, *A* (figs. 1 and 4), with a window, is provided. This window may be moved to expose any two adjacent tabs depending on what radio-range course is to be flown. This same window also exposes two different colors at each setting in order to facilitate the choice of the proper two reeds for a given course.

Another shutter, *B*, is provided with a color system to simplify the operation of the indicator in connection with its use when flying "to" or "from" the radio range. The use of both of these shutters will be explained in more detail under Application of Reed Indicator to the 12-Course Radio Range.

(*c*) *Cylindrical type of indicator and shock-proof mounting.*—Since it is not necessary to plug in different indicators for different radio-range courses with the 12-course indicator, the one indicator serving all courses, this instrument and mounting may be made more in keeping with the rest of the aircraft instruments. A cylindrical shape for the indicator and mounting, as shown in Figures 2, 6, and 7 may,

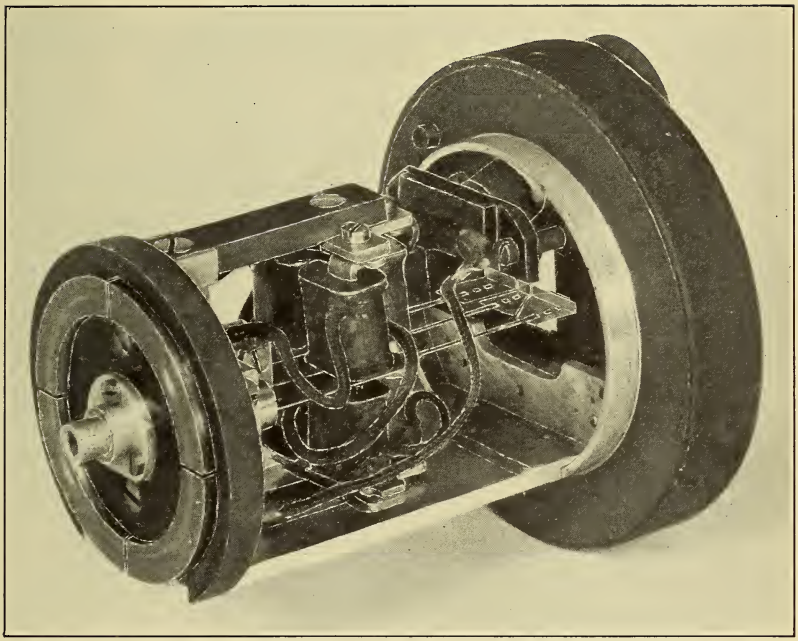

FIGURE 6.—*Rear inside view of tuned reed 12-course indicator shown in Figure 2*

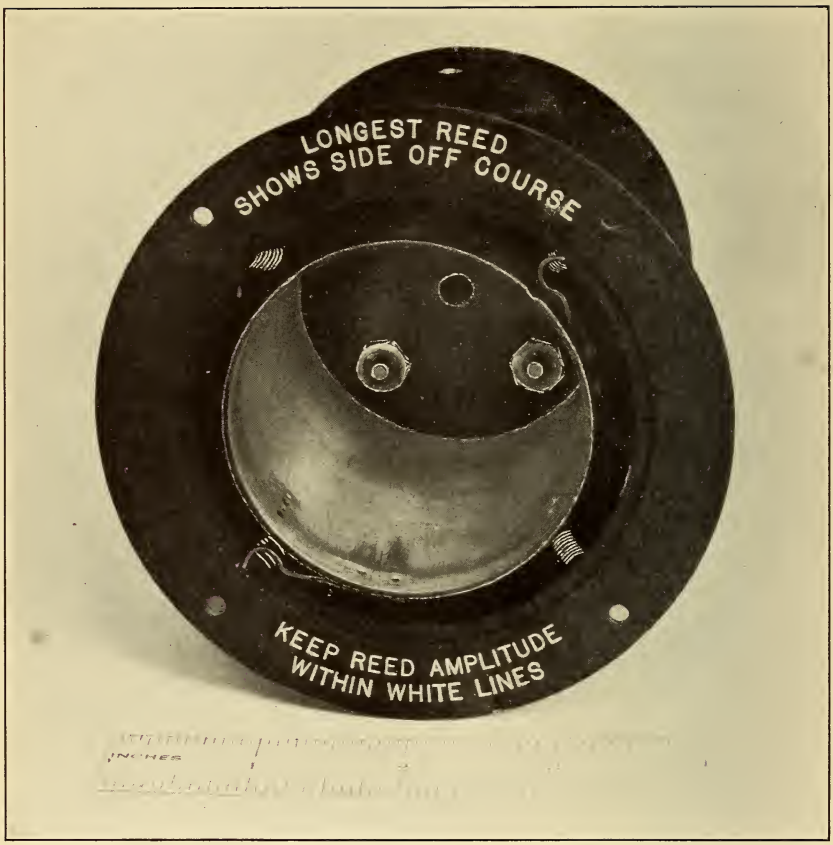

FIGURE 7.—*Cylindrical type of shock-proof mounting for 12-course tuned reed indicator shown in Figure 6*

therefore, be adopted. The reed unit shown in Figure 6 is designed to rotate within the inner cylinder shown in Figure 7, this cylinder being held within an outer cylinder by means of eight springs. This outer cylinder is fastened to the instrument board. The spring mounting is necessary to prevent the mechanical vibration from the airplane from operating the reeds at certain engine speeds. Slip rings shown in Figure 6, on the rear of the indicator and brushes on the rear of the inner cylinder, serve to carry the current for operating the reeds and the light for illuminating them.

To show the words "To" and "From" on the indicator the proper side up, the reed unit shown in Figure 6, is turned through 180° by revolving it in its mounting. A covering with a glass window is placed over the reeds, shutter, and color system, to protect them from

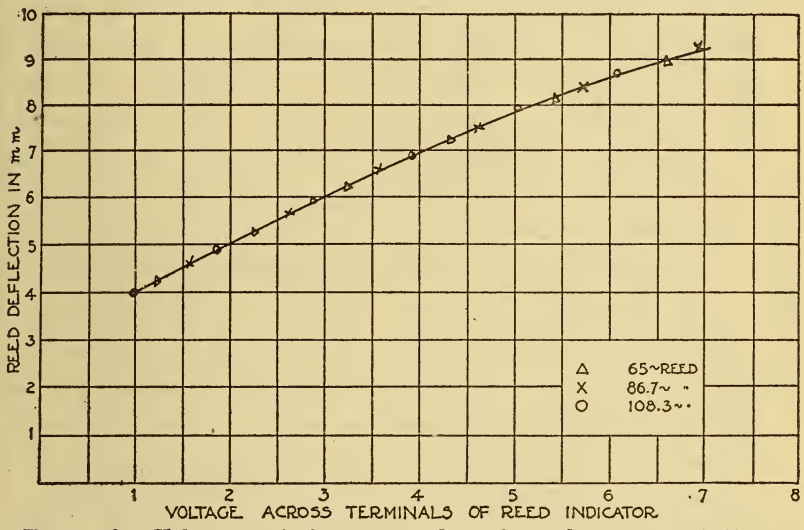

FIGURE 8.—*Voltage required to operate the reeds on the 12-course indicator*

the dirt and rain. Two knobs extending through this cover provide means for operating the shutters. A front view of the instrument, as seen by the pilot, is shown in Figure 2. The indicator and mounting shown in Figures 2, 6, and 7 weighs about 1¾ pounds. It is 3½ inches in diameter and 5 inches long.

2. OPERATING CHARACTERISTICS

(*a*) *Sensitivity.*—The three reeds are adjusted to be equisensitive by changing the air gap between the electromagnet pole pieces for each reed. Figure 8 shows the reed deflections in millimeters, as seen by an observer, plotted against the voltage applied to the terminals of the reed indicator. At the amplitudes of vibration normally used, that is, 4 to 9 mm, it will be noted that essentially a straight-line relation exists between the deflection and applied voltage, which is quite necessary in order to prevent any apparent shift in course with adjustment of volume control on the receiving set operating the reeds. At the normal deflection of 8 mm the current in the driving coils is 1.4 ma. This sensitivity has been obtained by means of a switch *F* (fig. 4) operated by shutter *A*, which short-circuits the two

driving coils for whichever reed is not in use. Additional sensitivity may be obtained over that shown in Figure 8 by the use of a large 1-piece permanent magnet.

(*b*) *Selectivity.*—Like the 2-course indicator the reeds in the 12-course indicator are insensitive to any frequency other than their natural frequency. This is a very valuable feature, since it practically eliminates the effects of interfering signals unless these signals are of such a very severe nature as to block the tubes in the receiving set, or unless they are very near the same frequency to which the reeds are tuned. This interference may come from many sources, such,

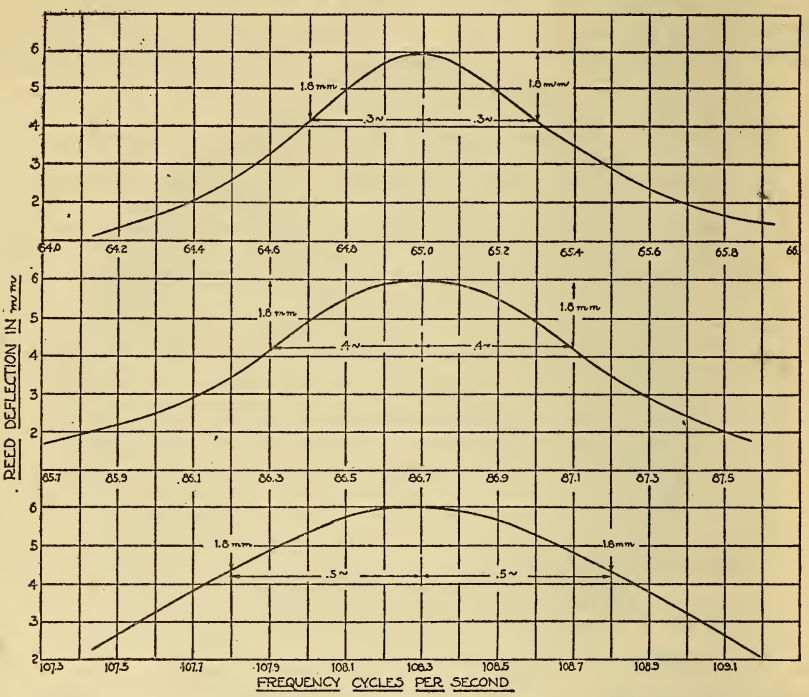

FIGURE 9.—*Resonance curves for the three reeds in the 12-course indicator, showing effect of correctly proportioning the damping to keep reed amplitudes the same, relatively, as frequency changes*

for example, as engine ignition and atmospheric disturbances, marine beacon signals, and radio range signals of the aural type. In many cases it was found that where the radiotelephone signals were coming in stronger than the aural radio range signals the latter were entirely unintelligible on account of interference, while under the same conditions the reeds functioned satisfactorily.

(*c*) *Effect of damping the reeds.*—Light aluminum air dampers, *J*, *H*, *I* (fig. 5), are placed on the end of each reed in order to broaden the tuning, to prevent any appreciable change in reed amplitude should the modulation frequency shift by as much as 0.3 per cent. The damping is so proportioned that the relative reed amplitude will not change appreciably even though the frequency varies by as much as 0.5 per cent. The resonance curves for the three reeds are shown in Figure 9. Since the three frequencies of modulation at the radio

range are obtained from three generators with 6, 8, and 10 poles with shafts directly connected, the three frequencies must vary in this fixed ratio so that, if, for example, a 0.3-cycle variation occurs in the 65-cycle frequency, a 0.4-cycle variation will occur in the 86.7-cycle frequency, and a 0.5-cycle variation will occur in the 108.3-cycle frequency. From the curves in Figure 9 it will be seen that for such a variation in each frequency the reeds will all drop in amplitude approximately the same amount, that is, 1.8 mm. Since the relative amplitudes of the reeds do not change, an apparent shift in the course is therefore not obtained.

Since the data for the curves shown in Figure 9 were obtained means have become available for holding the modulation frequencies to the correct values with greater accuracy, so that it is possible to

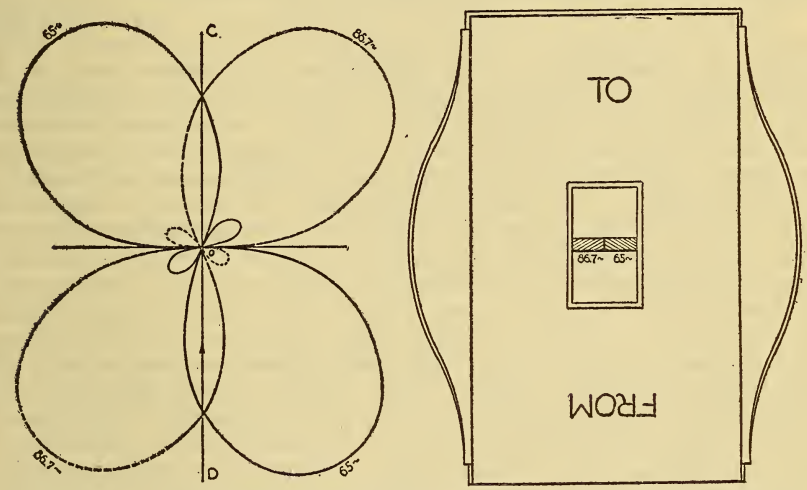

FIGURE 10.—*Radio range transmission characteristic and face of reed indicator, showing necessity for turning the unit upside down when reversing the direction of flight*

use less damping on the reeds. This not only increases their sensitivity but also their selectivity, making them even less subject to interfering signals of frequencies near that to which they are tuned.

3. APPLICATION OF THE REED INDICATOR TO THE 12 COURSES

One of the features which simplifies the use of the 2-course reed indicator is the one simple rule which the pilot must remember; that is, "Longest reed shows side off course." For example, if the right-hand reed vibrates with greater amplitude than the left-hand reed, the plane has drifted off the course to the right. In order that this rule will hold regardless of the direction of flight, the reed box is used as follows:

Referring to Figure 10, which shows a typical radiation characteristic of the double modulation radio range and also the front of the 2-course reed box, when the pilot is on the course flying in a certain direction, say *toward* the radio range located at *O*, along the line *DO*, the zone of greatest 65-cycle modulation is on his right and the zone of greatest 86.7-cycle modulation on his left. When drifting off

the course to the right, therefore, the 65-cycle reed would vibrate with greater amplitude. This reed should, therefore, be on the pilot's right, since the one rule should hold, "Longest reed shows side off course." The words "To" and "From" are so engraved on the face of the reed box as shown, that, when the word "To" is right side up, the 65-cycle reed is on the pilot's right. Should the pilot make a 180° turn and fly *from* the radio range, the location of the zones of greatest 65 and 86.7 cycle modulation reverses with respect to his right and left. This is also true if he passes over the radio range and flies from it along the line *OC*. It is therefore necessary to turn the reed box upside down; that is, so the word "From" is right side up. This reverses the reed locations and places the 86.7-cycle reed on his right, in accordance with the reversal of the zones of modulation with respect to the pilot's right and left.

With the 12-course indicator the problem of maintaining this simple rule becomes more difficult, as will be seen by Figure 3, which shows the distribution of the modulation frequencies used at the radio range for the different courses. The three figures-of-eight show the radiation characteristics of the 12-course radio range for each of the three frequencies of modulation. The colors indicate the courses or zones where two of the frequencies of modulation are present in equal amounts. This color combination was chosen to match the color system on the face of the reed box in order to simplify the operation of the reed indicator, as shown in Figure 1, where two colors appear for each setting of a window *A*, and three colors for each setting of window *B*. The pilot's map has the radio range courses in color so if he wishes to fly on a red radio range course, as shown by the map, the shutter *A* on the face of the reed indicator is set to show red through part of the window. This exposes the 65 and 86.7 cycle reeds which, from Figure 3, are the two frequencies of modulation used on the red radio range course. A black course could also be flown with this same shutter setting. It will be noted when flying on a black course *from* the radio range (it being located at the intersection of all lines) that the 86.7-cycle signal is on the pilot's left, while it is on his right when flying *from* the radio range on the red airway. This reversal is true of all the 90° courses and upsets the fundamental rule for using the reed indicator; that is, "Longest reed indicates side off course." To overcome this, a second shutter, *B*, and color scheme (fig. 1) are provided on the face of the indicator. This shutter reverses the "To" and "From," as shown, to compensate for the reversal of the location of the frequencies of modulation with respect to the pilot's right and left on the 90° courses. The shutter system operates as follows: The pilot observes on his map the color of the radio range airway course he desires to fly and which way he desires to fly on it; that is, whether "to" or "from" the radio range. If he chooses a red course, he sets both shutter *A* and *B* to show red. This exposes the 65 and 86.7 cycle reeds, which are the correct ones for the red course, as shown on Figure 3. The lower shutter exposes the words "From" and "To," one of which is upside down. If he desires to fly "from" the radio range, he rotates the indicator unit in its mounting so the word "From" is right side up (when the red is exposed by both shutters). This puts the 86.7-cycle reed on his right and the 65-cycle reed on his left. From a glance at Figure 3, on the red course, it will be noted that the 86.7-cycle modulation is

on the pilot's right when flying "from" the radio range, the 65-cycle on his left, so the rule will hold, since if he turns to the right the 86.7-cycle signal will become stronger and the 65-cycle signal weaker; therefore, the 86.7-cycle reed indication will appear longer and the 65-cycle reed indication will appear shorter. A similar test may be made, using Figures 1 and 3, on any one of the 12 courses, and it will always be found, if the reed box is rotated to have the correct side up, that the longest reed will always indicate the side off course.

The pilot's instructions for operating the indicator may be condensed to the following:

1. Set both shutters to show the color, according to the map, of the airway to be flown.
2. Turn reed box to show "From" or "To" right side up, depending upon whether the desired direction of flight is *from* or *to* the radio range.
3. Longest reed indicates side off course.

A further application of this type of reed indicator is its use by a pilot when lost in fog, to guide him in the right direction to the nearest radio range. There are many instances when a pilot navigating by magnetic compass in fog without radio-range facilities has been completely lost. With the 12-course reed indicator used in conjunction with the 12-course type of radio range, a pilot should have no occasion to become lost; but if he should, it is a rather simple matter for him to "find himself"; that is, he is able to get on a radio range course and determine definitely which way he is flying along that course.

This feature is made possible by the fact, as will be seen from Figure 3, that the courses alternate in their relative signal strength; that is, there are six courses of given signal strength and six more between these of 58 per cent of the signal strength. The amplitudes of vibration of the three reeds for each course are shown opposite each course in Figure 3. A pilot, therefore, if lost, may make use of his third reed to determine what course he is on, in the following manner: First, he moves shutter *A* (fig. 1) and finds the two adjacent reeds which are nearest equal, and navigates until they are equal. This places the airplane on one of four courses, say, either of the two red or black courses, since from Figure 3 it will be seen that a given course, its 180° course, and the two 90° courses have the same modulation frequencies, which would cause the same two reeds to vibrate. Two of the courses may be eliminated by observing the third reed; that is, the reed adjacent to the two equal reeds. If this reed is vibrating with greater amplitude than the two equal reeds, then, as seen from Figure 3, the airplane is on one of the black courses, since the 108.3-cycle signal is nearly twice the 86.7 and 65-cycle signal operating the two equal reeds. Should the airplane have been on a red course, the third reed would have had zero amplitude. Having determined that the airplane is on one of the black courses, the shutters *A* and *B* (fig. 1) are set to show black. There still remains the ambiguity as to which of the black courses the airplane is on, and as to the direction of flight. Assume the black courses extend in a north and south direction as shown in Figure 11. The airplane is flown by means of the magnet compass in one of these directions, say, north, and flown off course to the right. The reed box is turned in its mounting so that the right-hand reed is longest when off course to the right. If the word

"From" exposed by shutter *B* is right side up, the airplane is flying north *from* the radio range on the northern black route *OD*. It can not fly north *to* the radio range along this line. If the word "To" exposed by shutter *B* is right side up, the airplane is flying north *to* the radio range on the southern black route *OC*. It can not fly north *from* the radio range along this line. Thus a pilot may definitely establish his location with respect to the radio range. The above system of procedure may be condensed into a few simple rules for the pilot to follow without any technical knowledge on his part of the radio range system. These rules, which a pilot should seldom find necessary to use, are as follows:

1. Move shutter *A* to show the two reeds of nearest equal amplitude and navigate airplane until they are equal.
2. Note amplitude of reed adjacent to the two equal reeds.

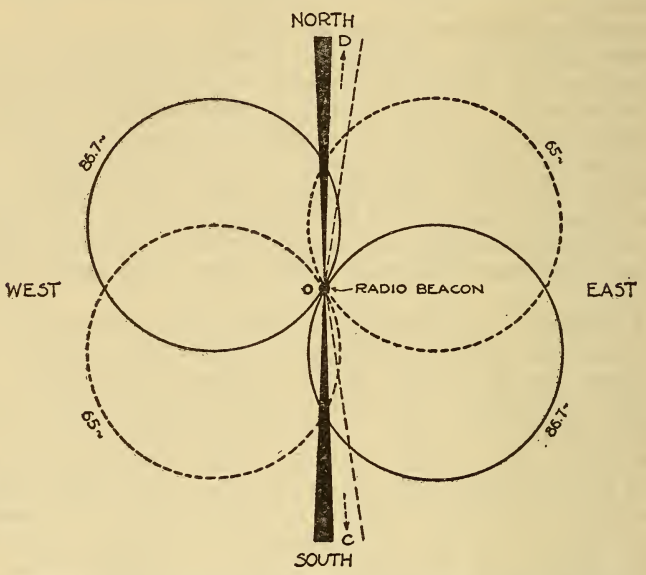

FIGURE 11.—*Chart showing method of determining the direction of flight relative to the radio range when such direction is unknown*

3. If amplitude of this reed is greater than that of the two equal reeds, set shutter *B* to show black, green, and brown; if less, set it to show red, yellow, and blue.
4. Then the common color exposed by both shutters is the course being flown.
5. Note the directions of this course on the map and fly according to the magnetic compass in one of these directions, deviating to the right until the equal reeds become unequal.
6. Turn reed box so that the longest reed is on the right; then, whichever of the words "To" or "From" is right side up indicates the general direction of flight relative to the radio range, and the magnetic compass indicates the absolute direction.

A single 12-course indicator may be used on any number of 12-course radio ranges, since neighboring radio ranges operate on the same modulation frequencies, but on a slightly different carrier fre-

quency. A change in tuning of the receiving set, therefore, is all that is necessary to cause the indicator to operate from signals from another radio range. This tuning should be done when the plane reaches a point approximately midway between the two radio ranges being used. The courses of two neighboring radio ranges are oriented where possible so that courses with the same modulation frequencies will be in a straight line. In this case the reed box need only be turned upside down to show "To" instead of "From" at the mid-point between the two radio ranges when the receiving set is tuned to the radio range being approached.

The 12-course reed indicator gives a continuous indication to the pilot as to the position of his airplane with respect to the radio range course. This feature is of great advantage when used to guide an object moving as fast as a modern airplane. This is especially true when approaching a radio range located on a landing field. As the airplane nears the radio range, any slight movement of the airplane from one side to the other is immediately noticed with only a glance at the reeds. In fact, when over the field the indication is sharp enough so that a pilot is able to keep the airplane within the width of the average runway if the course is oriented down the center of it.

III. THE 4-COURSE REED INDICATOR

1. DETAILS OF DESIGN

(*a*) *Reeds and driving elements.*—These features of the 4-course indicator are identical to those of the type F 2-course indicator referred to in the introduction.

(*b*) *Shutter and color system.*—It is the addition of a shutter with a color system that changes the 2-course indicator to the 4-course indicator. This shutter is the same as shutter *B* (figs. 1 and 4), except only two colors are used, one for each position of the shutter. Shutter *A* and its color system are not used, as there are but two reeds in this indicator. Figure 12 shows the indicator with mounting.

(*c*) *Shock-proof mounting.*—Since it is necessary to plug in a different indicator of this type, if radio range courses using different modulation frequencies are to be used, the shock-proof mounting is made the same as that used with the type F, 2-course indicator.

2. APPLICATION OF THE REED INDICATOR TO THE 4-COURSE RADIO RANGE

A typical radiation characteristic for the 4-course radio range and the face of the 4-course reed box with shutter *B* are shown in Figure 13. The purpose of this shutter is the same as the similar shutter used on the 12-course reed box; that is, it reverses the "To" and "From," so the rule, "Longest reed shows side off course," will hold, regardless of the course being flown and direction of flight. In other words, it compensates for the reversal of the location of the frequencies of modulation with respect to the pilot's right and left on the 90° courses.

To adjust the reed box for use on a given course the pilot merely sets the shutter to show the color of the radio range course he is to fly as shown on his map, and plugs the indicator into its holder the proper side up to show the "To" or "From" right side up, depending

upon whether he is flying "to" or "from" the radio range. In Figure 13 the shutter is set for a black airway, and the reed box is in a position for flying "from" the radio range.

3. APPLICATION OF 4-COURSE REED BOX TO THE 12-COURSE RADIO RANGE

Aside from its use with the 4-course radio range, the 4-course red indicator may be used with the 12-course radio range. For example, the 4-course indicator described above with 65 and 86.7 cycle reeds may be used on the two black and two red courses of the 12-course radio range. With the two reeds in the 4-course indicator tuned to 65 and 108.3 cycles and a brown and blue color scheme used on its face, this indicator may be used on the two brown and two blue courses of the 12-course radio range. When the reeds are tuned to

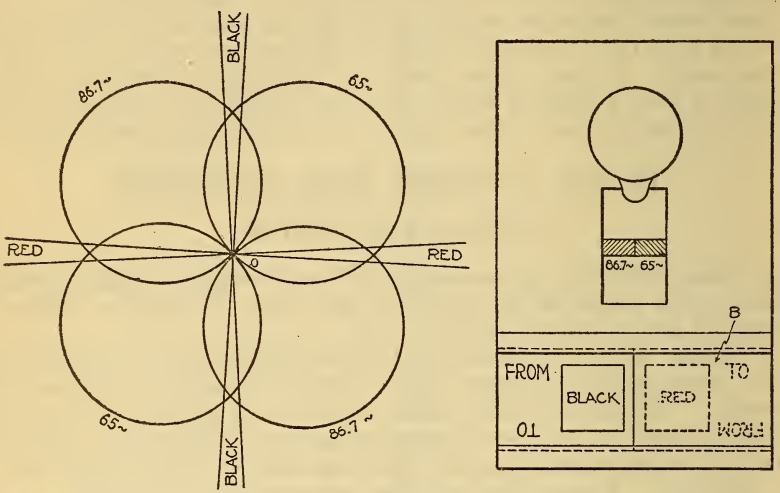

FIGURE 13.—*The 4-course radio range transmission characteristic and face of reed indicator for use on any one of the four courses*

108.3 and 86.7 cycles and the colors green and yellow used, the remaining courses of the 12-course radio range may be utilized.

Thus a pilot chooses the reed box having the same color as the radio range course to be flown and uses it for flights on those courses.

In some instances, therefore, when an airplane flying on a 12-course radio range is used on a fixed route, as is often the case with mail airplanes, a 4-course reed box may be used in place of the 12-course indicator.

The 4-course indicator plugs into its mounting so that another may be quickly substituted for use on another set of four courses. Thus three 4-course reed boxes may be used in place of one 12-course reed box in case of necessity.

With a 4-course indicator with reed-driving coils shunted by a potentiometer which changes the relative sensitivity of the two reeds, a single radio range course may be made effective over an angle of 30° or more; that is, a course may be flown with equal reed deflections along any line making an angle of up to 15° on either side of the true course.

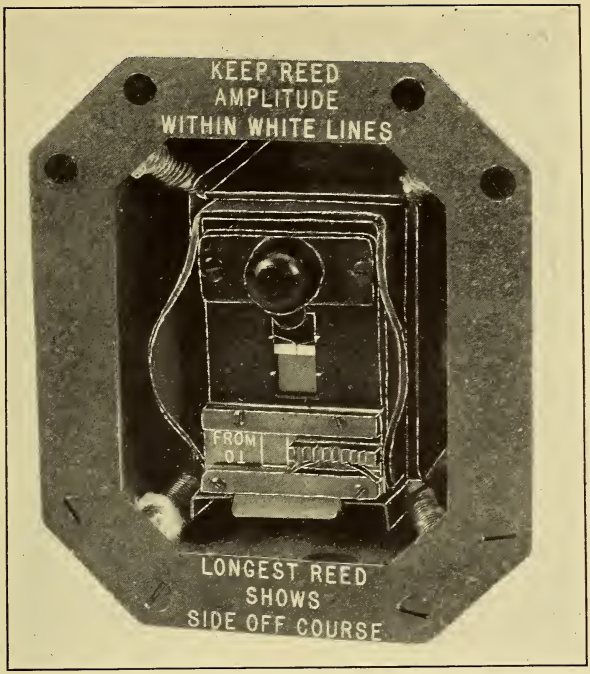

FIGURE 12.—*The 4-course tuned reed indicator and shock-proof mounting*

FIGURE 15.—*The deviometer or course-shifting device used with the reed indicator to enable a pilot to fly off the course with equal reed deflections*

In this way of using three 4-course indicators with shunting potentiometer the 12-course radio range becomes effective over practically the full 360°, that is, a course may be held with equal reed deflections at any angle of flight toward or away from the radio range.

A 10,000-ohm potentiometer is connected to the reed-driving coils, *U*, *V*, *W*, and *X*, of the 4-course indicator, as shown in Figure 14. A front view of this course deviometer with uncalibrated scales is shown in Figure 15.

As the direction of movement of the sliding contact on the potentiometer reverses for the 90° courses, a color system with a double pointer is again used. In this way the pointer which is over the correct color scale is moved to the right or left, depending upon which side of the course the pilot desires to fly. The scales may be calibrated approximately in degrees deviation from the course. When calibrated for the 12-course radio range, the lower scale is calibrated for the black, brown, and green courses, while the upper scale is calibrated for the yellow, blue, and red courses. (See fig. 3.)

The deviometer may be used with the 12-course indicator, in which case shutter *A* (fig. 1) may be made to operate a second switch, connecting the moving contact of the deviometer to the center connection between the two sets of driving coils in circuit for the particular sitting of shutter *A*.

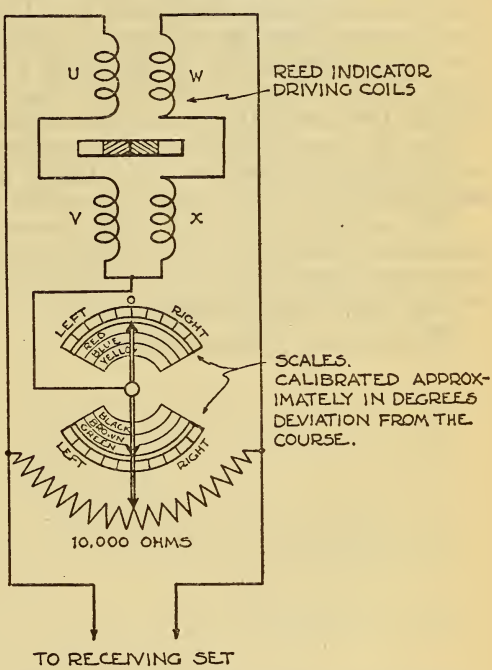

FIGURE 14.—*Circuit diagram for the deviometer or course-shifting device for use with the 2 or 4 course tuned-reed indicators*

IV. CONCLUSION

The 12-course reed indicator described herein contains three reeds tuned to the three frequencies of modulation used in a 12-course radio range. It has been so designed as to permit the guiding of an airplane along any one of the 12 courses without confusion.

The relative amplitude of vibration of any two adjacent reeds indicates continuously the position of the airplane with respect to a given course. Equal amplitudes of vibration indicate that the airplane is on the course. Unequal amplitudes of vibration of the reeds indicate that the airplane is off the course to the side of the reed having the greater amplitude. A simple shutter with windows, in front of the vibrating reeds, exposes any two at a time. The correct two for a given course is determined by a color system which is exposed by the window to correspond to the color of the particular radio

range route marked on the map. A second shutter and color system is provided so that the rule, "Longest reed indicates side off course," may be made to hold regardless of the course being flown or the direction of flight.

The 4-course indicator is the same as the 2-course indicator with the exception of a shutter and color system on its face to adapt it to any one of the four courses. The 4-course indicator may be used on the 12-course radio range, three such indicators being necessary to cover all 12 courses, each indicator having reeds tuned to match the frequency of modulation of the different courses.

A pilot using these indicators may hold an airplane in a given radio range course with an accuracy of approximately $\pm 1°$. By changing the relative sensitivity of the reeds with shunt resistances, a given radio range course may be made effective over an angle of 30°, thus greatly increasing the service area of the radio range.

The 12-course indicator and mounting weighs about 1¾ pounds and is 3½ inches in diameter and 5 inches long. The 4-course indicator and mounting weighs about 1½ pounds and is 3½ by 2¾ by 4½ inches.

The author is indebted to H. Diamond for helpful suggestions in connection with the design of these indicators and to R. R. Gessford for constructing the indicator models and for suggestions pertaining to their mechanical design.

Washington, October 4, 1929.