THE CAA-RTCA INSTRUMENT LANDING SYSTEM TESTS AND MODIFICATIONS

PART II

By

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FOREWORD

The author wishes to express appreciation for the cooperation by the engineers of the International Telephone Development Company, Inc on this project

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THE CAA-RTCA INSTRUMENT LANDING SYSTEM
PART II - TESTS AND MODIFICATIONS

SUMMARY

This report describes the development work carried out by the Technical Development Division, Civil Aeronautics Administration, in cooperation with the International Telephone Development Company, Inc , to make the instrument landing system at Indianapolis comply, in so far as practicable, with the standards set up by the Radio Technical Commission for Aeronautics at its meeting of September 15, 1939 It also describes the general operation of the system and the receiving equipment in various aircraft

The work has resulted in

1 A localizer whose course is free of bends and sharp enough to permit proper localizing for a standard-width runway

2 A glide path which is essentially straight from 1,700 feet altitude to 200 feet altitude, and which below this point becomes nearly parabolic to reduce the angle of contact The average rate of descent along the glide path is 500 feet per minute for a 90 mile per hour airspeed

3 A receiving antenna which is free of the detuning effect of rain

4 The development of technique essential to the success of the ultra-high-frequency program in fields co-related to instrument landing

INTRODUCTION

Under contract, the International Telephone Development Company manufactured and installed the instrument landing system at the CAA Experimental Station at Indianapolis, Ind The Radio Technical Commission for Aeronautics, after carefully inspecting and flight testing the system in September 1939, set up specifications for a glide path and a localizer course that would be acceptable for a national installation for pilot training These specifications may be summarized

1 Localizers

(a) Equipment may be combined with or separate from glide path transmitters

(b) Straightness of the course shall be such that no bends or multiple courses are perceptible to a pilot flying in still air

(c) Localizer needle deflection - the vertical needle of the cross pointer indicator shall give a deflection of not less than 10° for a 1 9° angular deviation from the center line of the runway The meter scale shall be uniformly compressed from center to the stop pin at each side The Civil Aeronautics Administration shall provide for test at least two meters having different rates of scale compression The rate of scale compression desired is tentatively as follows

Meter Indication	Deg. Off-Course
10°	1 9°
Full Scale	6-8°

The meter indications shall be completely free from lag It is further recommended that experiments be conducted to check the possibility of providing definite "advance" or rate-of-change indications. The designation "advance" applied to an indicator is a term adopted by the RTCA to describe an indicator which has a dynamic characteristic causing it to exaggerate the changing position of the airplane with respect to the course Only during gradual changes of position would such a meter correctly indicate position Rapid rates of change of position would cause the indicator to overshoot, thereby providing, in effect, a lead in the indicator over the position of the airplane Thus, suppose an airplane off-course is headed toward the course The meter indicates this movement of the airplane toward the course but at a greater rate than the changing position of the airplane would normally require, so that the meter pointer indicates that a position on-course has been reached before the airplane actually arrives in this position

(d) Localizer courses - either a one- or two-course runway localizer will be considered satisfactory

Four-course localizers are definitely not recommended

(e) Localizer course length - a usable runway localizer course shall be provided for a distance of 15 miles at 2,000 feet

2 Glide Path

(a) A smooth glide path shall be provided, i e , one which is free from interference pattern effects perceptible to the pilot when on the localizer course

(b) Viewed head on, it is most desirable that the glide path shall rise to either side of the localizer course, in any event, the dip down on either side shall not exceed an angle of 3°

(c) The glide path shape, when on the localizer course, shall be as follows:

(1) A glide path intersection shall be obtained at 1,500 feet altitude at a distance of 6 miles from the transmitter end of the runway

(2) The point of contact shall be not less than 3,000 feet from the far end of the runway At the point of contact the glide path shall have an angle with the runway of not less than 1° and not more than 2° The glide path shall pass through the following points: not less than 500 feet or more than 700 feet altitude at a distance of 3 miles from the far end of the runway, and 1,500 feet altitude at 6 miles

(3) The rate of descent shall not exceed 800 feet per minute at any point

With this definite commitment as to actual desired performance, work was started at once to modify the glide path and localizer stations of the northeast approach The work was carried out jointly by the International Telephone Development Company, Inc , and the CAA Experimental Station

The localizer station was modified to operate with an auxiliary antenna which, in effect, produced a null of radiation toward the airport Administration Building and simultaneously increased the course sharpness These changes reduced the bends in the course to a negligible or imperceptible value

The glide path station was modified to operate with an auxiliary antenna The main radiator was also modified and installed within the glide path station building The final radiation pattern gave essentially the desired path and permitted some freedom in selection of the point of contact

After completion of the changes, many flight observations were made by the Civil Aeronautics Administration, the Army, the Navy, and various airlines The Administration's airline inspectors were trained in airplane NC-11, a 247-D Boeing, during May 1940

TESTS AND RESULTS

Localizer

The original radiation pattern of the northeast localizer is shown in figure 1, curve A This pattern was produced by five loop radiators, two of which were mounted in wing extensions of the original building (see fig 2) and parasitically excited The connections between transmitter and antenna and the spacings of the loop radiators are given in figure 3

Figures 2 and 3 also show the auxiliary antenna used in the final arrangement This antenna is excited with side band energy derived from the outer radiator circuit of the localizer antenna system It consists of two loop radiators spaced one-half wavelength and excited in-phase so as to produce, by itself, a dumbbell-shaped pattern the maximum of which is in the direction of the course The phase of the radiation from the auxiliary antenna is adjusted in the control unit shown in figure 4 so as to give resultant front and rear courses that are exactly reciprocal The control unit also provides for adjustment of current amplitude in the auxiliary antenna This amplitude is set at a value which will give the desired depth of null in the chosen direction

The position of the auxiliary antenna is determined by the direction of the desired course and the desired direction of the resulting null For a given direction of course, as established by the original localizer station, the auxiliary antenna is placed to the side and moved forward or backward until the resultant course is parallel to the original course The rear course is made reciprocal in each instance by phase adjustment The distance between the auxiliary antenna and the center of the main station is determined by the direction desired for the null For example, for a null at β degrees from course,

$$d = \frac{270}{\sin \beta} \text{ degrees}$$

where d is the distance in degrees and 270 is the amount of phase change (in degrees) required for the auxiliary antenna component of radiation from the direction of on-course to the direction of the null

The following characteristics, illustrated diagrammatically in figure 5, are exhibited by the auxiliary antenna:

(a) Its distance A from the main array determines the direction β of the null and the amount of course sharpness

(b) Its position B ahead of or behind the line of main radiators determines the alignment ϕ of the course

(c) The relative phase of excitation determines the bend 2α between the rear course and the forward course

(d) The magnitude of its radiation determines the depth of the null and, to some extent, the course sharpness

(e) The resultant course is parallel to the original course out displaced a distance C toward the auxiliary antenna in proportion to the value of auxiliary antenna current and inversely proportional to the main array current

The radiation pattern, as finally used on the northeast localizer, is shown in figure 1, curve B This pattern was taken at a radius of 300 feet from the station using the field detector unit described in a previous report[1] The patterns A and B, figure 1, are obtained by stopping the modulator motor and placing a short-circuiting bar on the modulated section of the modulator When one section is shunted, thereby preventing passage of power through it, one of the beam patterns is obtained The other is obtained when the other section is shunted These patterns represent static conditions and are referred to as "static" patterns The actual course produced by the station when operating normally may be different from that position indicated by the overlap of the static beam patterns This can be attributed to the difference in modulation percentage between the static short circuit and the simulated short circuit produced during modulation by the coupled modulating sections

Both receiving and transmitting equipments are provided with adjustments for setting the course It was found impractical to set the receiver adjustment in the laboratory with a standard modulated signal generator and use the receiver as a measure of the transmitter setting The best method was to use a wave analyzer and a flat-response localizer receiver located somewhere on the proposed course and vary the adjustment of the transmitter until the 90- and 150-cycle components on-course were equal

The auxiliary antenna is connected to the main radiating system by a shielded balanced transmission line This line was operated for a considerable time at atmospheric pressure, although it was arranged for ultimate sealing and filling with dry nitrogen During the operation without nitrogen, slow variations from day to day of about plus and minus 10 minutes of arc were observed in the course at the point of contact Comparison of this course location with the other localizer courses established at the airport indicated that these variations were not in the receiving equipment Dry nitrogen gas was applied under pressure to all lines of the northeast localizer station Immediately upon application of the gas there was a course shift counter-clockwise corresponding to a phase delay in the auxiliary antenna current A curve was plotted of course variation versus gas pressure (fig 6) which indicated the need for operating the gas at relatively low pressure and of regulating this pressure A pressure of 5 pounds per square inch is used It is possible, through expansion, for the pressure to rise from 5 pounds to about 12 pounds, since the regulator does not provide for relief of excess pressure However, the change in course resulting thereby is in the order of 2 feet (about 2 minutes angle) at the point of contact and is insignificant

There have since been variations, totaling about 6 feet, in the position of the course at the point of contact These variations represent the combined errors of receiver, transmitter, and observer The course has always appeared to be in satisfactory alignment with the runway when viewed from the 6-mile and outer marker positions The inherent small variations may be due to phase changes imposed by line expansion and contraction during weather changes, although no correlation has been apparent These difficulties may be avoided by a different design contemplated for future localizers which will utilize a symmetrically disposed auxiliary antenna

Flight records of the localizer before and after the installation of the auxiliary antenna are shown in figure 7 Figure 7A shows the relative variation of the course from the centerline of the runway during an approach, and figure 7B shows the cross-course flights at the southwest outer marker The increased course sharpness is obvious The gain of the receiver and recording amplifier was essentially the same for all flights It will be noted that while there was still evidence of interference near the point of contact, as shown in the curves of figure 7A, this amounted to even less variation of the actual course in degrees because of the increase in sharpness

Preliminary observations made by transit at night indicated that the pilot was able to keep the airplane, a Waco Model N, within plus or minus 10 minutes of the correct course The actual course accuracy is obviously greater than this

<u>Glide Path</u>

The development of a glide path to meet the RTCA requirements was not a simple task It involved first, the difficult problem of determining the exact shape of the horizontal radiation pattern required, and second, the design of the antenna to produce it Accurate determination of the required pattern was difficult because of variations in the pattern of the aircraft receiving antenna and inherent inaccuracy in flight position and altitude observations Flights were made over the 6-mile point (6 miles southwest of the localizer end of the southwest-northeast runway) at the altitude (1,500 feet) prescribed by the RTCA for this point When the airplane was exactly over this point, the glide path station antenna current was adjusted until normal glide path signal was observed in the airplane The airplane was headed toward the station over this point to preclude the possibility of error to receiving antenna characteristics Similar flights were then made over other points along the course at altitudes prescribed by the RTCA for these points, the transmitter being adjusted to give normal receiver output for each Having determined the required transmitter current to give the correct glide path for each position, and knowing the relative horizontal angle of each position with respect to the station, it was therefore possible to plot the required horizontal pattern of the station From these data an analysis was made of the possible arrays which would provide the desired pattern The antenna array which was finally adopted produced the pattern shown in figure 8 (curve A) It will be observed that the resultant pattern A is produced by a main radiator pattern B and an auxiliary radiator pattern C The phase and current of the auxiliary radiation is controlled in a unit similar to that shown for the localizer

[1] F I Metz, Technical Development Report, "The CAA-RTCA Instrument Landing System Part I - Development and Installation"

The schematic arrangement of the main and auxiliary arrays is shown in figure 9 The main and auxiliary stations are shown in figure 10, and the main array and reflecting screen are shown in figure 11

The shape of the radiation pattern (fig 8) from plus 10° to plus 50° (i e , in the direction of the runway) is essentially circular, giving a practically parabolic path in the vicinity of the point of contact to bring about reduction in the rate of descent of the aircraft prior to contact

The shape of path produced by the radiation pattern of figure 8 is shown in curve B of figure 12 Curve A of figure 12 shows the conventional parabolic path An advantageous characteristic of the CAA-RTCA glide path, curve B, is the low altitude at the 6-mile point This permits orientation at the safe altitude of 1,600 to 1,700 feet and entrance into the actual approach farther from the field without excessive or rapidly changing rate of descent

The term "tilt angle" has been applied to define the slope of the intersection of the constant intensity surface of the glide path and a plane perpendicular to the course It is the angle between the curved line thus defined and the horizontal Obviously the smaller this angle is the better, because if it is small (or zero) there is no serious change in height of the glide path for positions off the localizer course Unfortunately, this feature must be given secondary consideration To produce a low tilt angle and the CAA-RTCA type path simultaneously, the transmitting station would have to be removed a great distance from the runway This would require greater transmitter power and would impose possible variables between the station and the airport, seriously affecting the glide path The tilt angle of the present system is approximately 9° at the 6-mile point and 6° at the outer marker

A "one, two" flight technique has been used, requiring the pilot first to establish his localizer course and second, to get on the glide path The glide path indication is always disregarded unless the localizer indicator is within the scale limits, i e , 1 5° from the center of the localizer course In test flights conducted by a large number of pilots there has been no difficulty with the 9° "tilt angle"

Some investigation has been undertaken on glide path stability Figure 13 illustrates the variation of the point of contact for change in transmitter output The same curve applies for equivalent change in receiver sensitivity It should be noted that when the radiation pattern from the CAA-RTCA glide path is arranged to cause flattening of the path near the point of contact, the position of the point of contact is more susceptible to variation The greater the angle of descent near the point of contact, the greater will be the stability of the point of contact The present stability, however, is satisfactory because the point of contact is, in extreme cases, well back on the runway There is a rapid increase in field strength several hundred feet after the point of contact (see curve A of figure 8) which precludes the possibility of failing to contact because of change in path

The glide path signal gradients at the outer marker and 6-mile points are given in figure 14 These gradients are independent of the glide path shape or station pattern Except for effects of the vertical plane pattern of the receiving antenna, the gradients (in percent altitude change) are the same everywhere along the course This feature makes the path indication less sensitive at the distant points and consequently easier to follow The sensitivity and stability of the indications increase as the runway is approached The apparent gradient can be altered by using square law detection in the receiver This was done at one time but eventually was abandoned because it increased the difficulty of flying the path near the point of contact, exaggerated the small irregularities of the path, and decreased the stability of the receiving equipment

In connection with irregularities along the glide path, it is interesting to note the recordings of figure 15 These are actual flight check records but are not intended to show the pilot's ability to follow the path Sudden changes in attitude were avoided in order to make the records more reliable The variations shown are amplified approximately four times the value they normally have on the cross pointer instrument for purpose of study The scale is indicated While both records show satisfactory smoothness, there is evidence of greater irregularity on the RTCA path as compared to the parabolic path These irregularities are not apparent in normal flight

Receiving Antenna

An improvement in the receiving antenna for localizer and glide path signal reception is illustrated in figures 16, 17, and 18 These are views of a DC-3 type hatch cover equipped with a receiving loop hermetically sealed in lucite tubing There is no observable variation in the glide path receiver output when this antenna is subjected to direct water spray The previously used exposed loop antennas were unstable in rain or spray, the glide path in one instance changing from 600 feet to 1,000 feet at the outer marker The antenna became detuned in rain but not in heavy icing conditions The new antenna gave no change in path when flown in heavy rain The type of enclosed loop shown was constructed and mounted on hatch covers for DC-3 and DC-2 Douglas aircraft and for 247-D Boeings for experimental use

A development model of an improved tuning unit is illustrated in figure 19 This is being used in airplane NC-17 and is mounted directly at the base of the antenna, in the ceiling of the airplane cabin This unit tunes and balances the 93 9- and 109 9-megacycle channels and requires only two single coaxial cables for connection, one to each receiver

Horizontal patterns of the DC-3 loop, both in free space and on the airplane, are shown on figure 20 The patterns were made at the same place on the runway, the free space pattern being made with the loop mounted on a wooden box inside of which were the receiver and battery The loop height was 7 feet On the DC-3 it is $16\frac{1}{2}$ feet The distortion caused by the mass of the ship is evident

The attitude of the airplane in flying the glide path has some effect on the height of the path The effect was studied on the runway by raising and lowering the ship on special wooden ramps The results are as shown in figure 21 Curve B shows the results with the lucite-enclosed loop which, when installed, was tilted 6° from the former position in an effort to reduce the effect Position (A) gave results superior to those with the loop tilted downward Attitude effect is generally noticed at positions beyond the outer marker (3 miles) Under normal conditions, however, it is of no serious consequence because the path is essentially straight and extreme attitude changes can and should be avoided on instrument approaches

Localizer Operation

Only one of the four localizer transmitters has failed in $1\frac{1}{2}$ years operation This failure was caused by breakage of the lead on a plate supply r-f choke coil The fact that the localizer transmitters have not been operated at their full rated output probably accounts for the absence of tube failures

Glide Path Operation

Except for the short life of power amplifier tubes, there have been no difficulties in the operation of the glide path transmitters The RTCA glide path transmitter must be operated at its maximum output, and under this condition the present type of power amplifier tube does not have satisfactory life The failure is evidently due to loss of emission and unbalance

One failure of the CAA-RTCA glide path station resulted from slippage of the conductors inside a transmission line, causing the line to become grounded at a corner junction box. Flanged beads to prevent slippage are now used

Marker Operation

The operation of the eight marker transmitters has been reliable except for one radio failure where a defective contact existed on an interstage coupling condenser Failure of keyer motors has been observed on most of the stations These motors are of standard design, modified only with regard to the type of lubricating oil to withstand specified temperatures of minus 40° to plus 60° C The long record of this type of motor in marine service and its excellent speed regulation under temperature change were the particular reasons why it was selected for marker service However, it is operated here in the cathode circuit of vacuum tubes and its operating voltage is brought up gradually instead of being applied instantly This probably accounts for most of the reported starting failures However, correct operation has always been obtained immediately after flipping the control switch so as to apply a surge for starting the armature

Receiver Operation

The Type RUK localizer receivers have given excellent service Three were procured on the instrument landing system contract. One of these, serial #2, was sealed in October 1939 and has been in continuous service as a "standard" without failure or observed instability of calibration The other two receivers appeared to be equally stable, however, they were used in experimental work and a record of their stability of calibration was not kept No tube replacements have been required in any localizer receiver

The Type RUJ glide path receivers have failed on several occasions and in addition have been found to have a "warm-up" characteristic that is not sufficiently corrected by the compensating devices in the receivers This characteristic causes their sensitivity to decrease slightly during the first 30 minutes of operation Of the direct failures, two were caused by tubes suddenly becoming inoperative On two other occasions aged tubes had to be replaced to regain normal sensitivity and to obtain normal stability under change of battery voltage One failure, manifesting itself by occasional decrease in sensitivity (of 20 db or more), was found to be caused by a small spiral brass shaving on top of an intermediate-frequency tuning condenser The intermediate-frequency transformer cases have since been sealed to protect them against entrance of foreign particles. Oil-filled by-pass condensers have leaked in all three glide path receivers under temperature and pressure changes incident to flying the system

In each case of glide path receiver failure, the failure has been either so complete or so insignificant as not to endanger the aircraft In the former case the trouble was evident to the pilot at or before reaching the outer marker, prior to attempting the landing. In the latter case the glide path remained within normal tolerance

Two marker receiver (Type RUG) failures were observed, one caused by "frequency flipping" of the receiver crystal, and the other caused by power pack heating. In the second case, the failure was indirectly caused by low battery voltage, the airplane battery having been accidentally left on over night with the marker receiver operating. It is believed that as the battery voltage became low, the vibrator stopped, causing steady current below fuse rating to flow through the power transformer The resultant heating boiled the compound out of the transformer and ruined its windings The vibrator was not damaged

Monitor and Control Unit Operation

Operation of the monitor and control unit has disclosed several design features which should be revised in future installations For example, the recording and alarm circuits should be entirely independent of each other, that is, they should be non-reactive on each other to facilitate control adjustment setting There should be no reaction between these and the monitor instrument circuit for the same reason In this present installation where the normal chart speed is 3 inches per minute during normal operation of the system, and 3 inches per hour when the system is not operating, the charts should last between 5-1/2 and 330 hours, depending upon the amount of system operation Maintenance therefore requires special attention

Aircraft Installations

Figure 22 shows the installation of the cross pointer instrument and marker signal lamps in an American Airlines Douglas DC-3 airplane The associated receiver installation was made in a baggage compartment, as shown in figure 23

The lucite-encased loop installation on airplane NC-17 is shown in figure 24 Although this antenna is not suitable for regular airline operation, it has proved to be entirely satisfactory for test flights pending the development of one having better aerodynamic structure and a broad band frequency characteristic

The installation of the equipment in DC-2's, DC-3's, and 247-D Boeing airplanes was facilitated by making complete antenna units pretuned on appropriate hatch covers, by having the receivers available with mountings, and by having battery and instrument cables prearranged Except for difficulties sometimes encountered in rearranging the instrument panel to make room for the cross pointer instrument, the entire test installation could be made in less than an hour

Special Demonstration

On February 13, 1940, the Air Transport Association of America, representing in general the operations personnel of all the major airlines, met at the Experimental Station to inspect and fly the instrument landing system, as modified A description of the installation was presented by the Administration in bulletin form, a copy of which is included in the appendix The general layout of the airport and a proposed procedure for approach were illustrated on a colored map with the bulletin The bulletin also contained a questionnaire which was used to obtain constructive criticism The general reaction was favorable toward the performance of the instrument landing system The results of the questionnaire are included in the appendix

CONCLUSION

The following accomplishments resulted from the further development of the CAA-RTCA instrument landing system

1 The engineering, operating, and flying techniques incident to instrument landing were considerably advanced

2 A localizer was developed and operated which, amid surrounding reflecting objects, produced a course substantially free of bends with a course sharpness of 4 7 db per $1\frac{1}{2}^{\circ}$ off-course

3 A glide path that is essentially straight from 1,700 feet to 200 feet altitude, and which below this point becomes nearly parabolic to reduce the angle of contact, was developed The average rate of descent on normal approach is approximately 500 feet per minute at 90 miles per hour

4 A receiving antenna encased in lucite was developed which is free of detuning effects of rain

5 The system has been extremely useful from an educational viewpoint It has been demonstrated to approximately 250 officially interested persons Among these, about 100 pilots have flown the system in several types of aircraft, including Douglas DC-3's, DC-2's, Boeing 247-D's, and a Waco N Approximately 4,000 instrument approaches have been made, of which about 10 percent were completed landings or contacts simulating landings From this experience and from the comments, questions, and discussions that resulted, a definite advance toward the ultimate general acceptance of instrument landing has been made

From the data contained in the questionnaires submitted by members of the Air Transport Association of America, the following conclusions were reached

1 A satisfactory method of determining position with respect to the localizer course was developed, using a chart colored in red on one side of the localizer course and green on the other side[2]

2 The method of "flying" the miniature airplane in the center of the instrument face toward the intersection of the instrument needles when making a landing is superior to the older method where the reverse procedure was used This sensing is similar to the Sperry Horizon and permits the eventual grouping of all essential indications into one instrument, such as the Metcalf three-spot indicator or the Sperry Flightray

[2]These colors have subsequently been changed from red and green to yellow and blue, respectively Since the instrument has coloring similar to the coloring of the map, an easy method is provided for determining position without the confusion of switches previously required

3 An instrument sensitivity of 17.5° of instrument pointer deflection for 0.7° off-course is required to make consistent landings on a narrow runway (105 feet at Indianapolis). This sensitivity permits faster bracketing of the localizer course, thus reducing the time required to make an instrument approach. The instrument sensitivities tried were 17.5°, 13.1°, and 8.75° of pointer deflection per 0.7° off-course for sensitivities A, B, and C, respectively.

4 Sensitivity controls should not be provided on the localizer indicator.

5 A linear detector should be used in the glide path receiver to give the preferred instrument sensitivity.

6 Both the localizer and glide path indicators should have high-speed pointers with critical damping and should have linear response over the entire scale.

7 The present markers are entirely satisfactory both in operation and location.

8 A two-course localizer is preferred to either the one- or four-course variety.

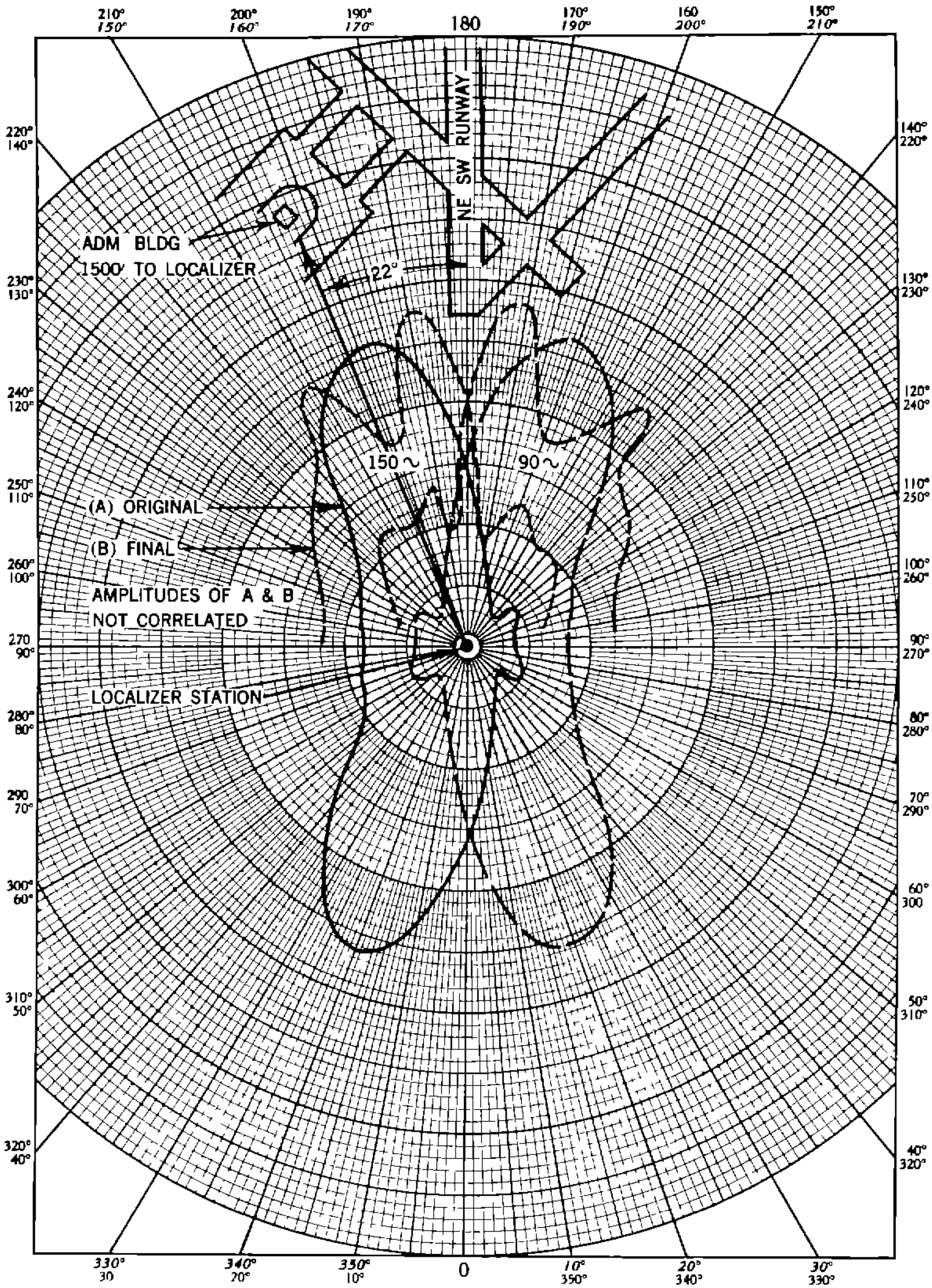
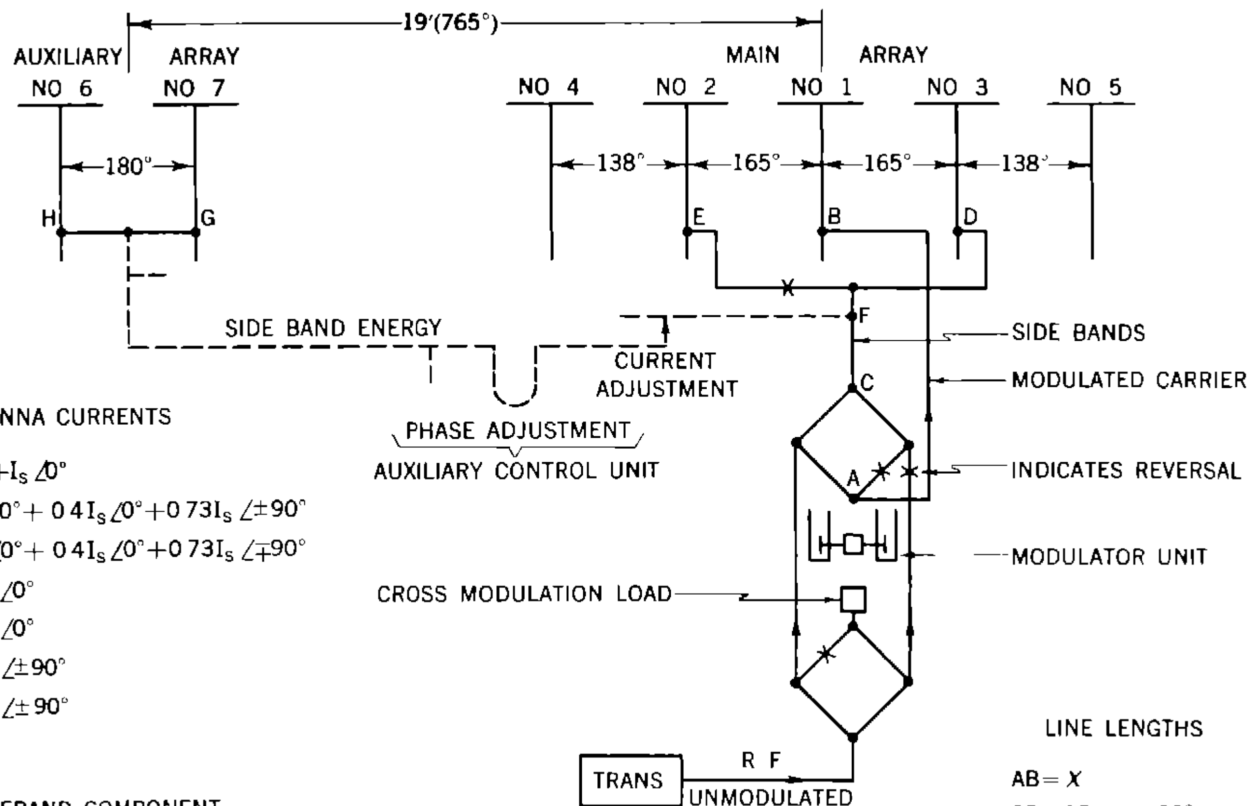


FIGURE 1 Ground Patterns of Northeast Localizer

FIGURE 2. Northeast Localizer Station with Auxiliary Antenna.



RELATIVE ANTENNA CURRENTS

ANTENNA NO 1 – $I_1 = I_o \angle 0° + I_S \angle 0°$

ANTENNA NO 2 – $I_2 = 0.4 I_o \angle 0° + 0.4 I_S \angle 0° + 0.73 I_S \angle \pm 90°$

ANTENNA NO 3 – $I_3 = 0.4 I_o \angle 0° + 0.4 I_S \angle 0° + 0.73 I_S \angle \mp 90°$

ANTENNA NO 4 – $I_4 = 0.23 I_2 \angle 0°$

ANTENNA NO 5 – $I_5 = 0.23 I_3 \angle 0°$

ANTENNA NO 6 – $I_6 = 0.33 I_S \angle \pm 90°$

ANTENNA NO 7 – $I_7 = 0.33 I_S \angle \pm 90°$

I_o = CARRIER COMPONENT

I_S = 90 AND 150 CYCLE SIDEBAND COMPONENT

LINE LENGTHS

AB = X

CD = CE = $X + 90°$

CG = CH = $X + n\lambda + 90°$

OBSERVED RELATIVE ANTENNA CURRENTS
UNDER NORMAL OPERATING CONDITIONS

ANTENNA NO 1 = 110 ANTENNA NO 4 = 15
ANTENNA NO 2 = 66 ANTENNA NO 5 = 15
ANTENNA NO 3 = 66 ANTENNA NO 6 = 26
ANTENNA NO 7 = 26

FIGURE 3 Northeast Localizer

FIGURE 4. Phase and Current Control Unit for Auxiliary Antenna.

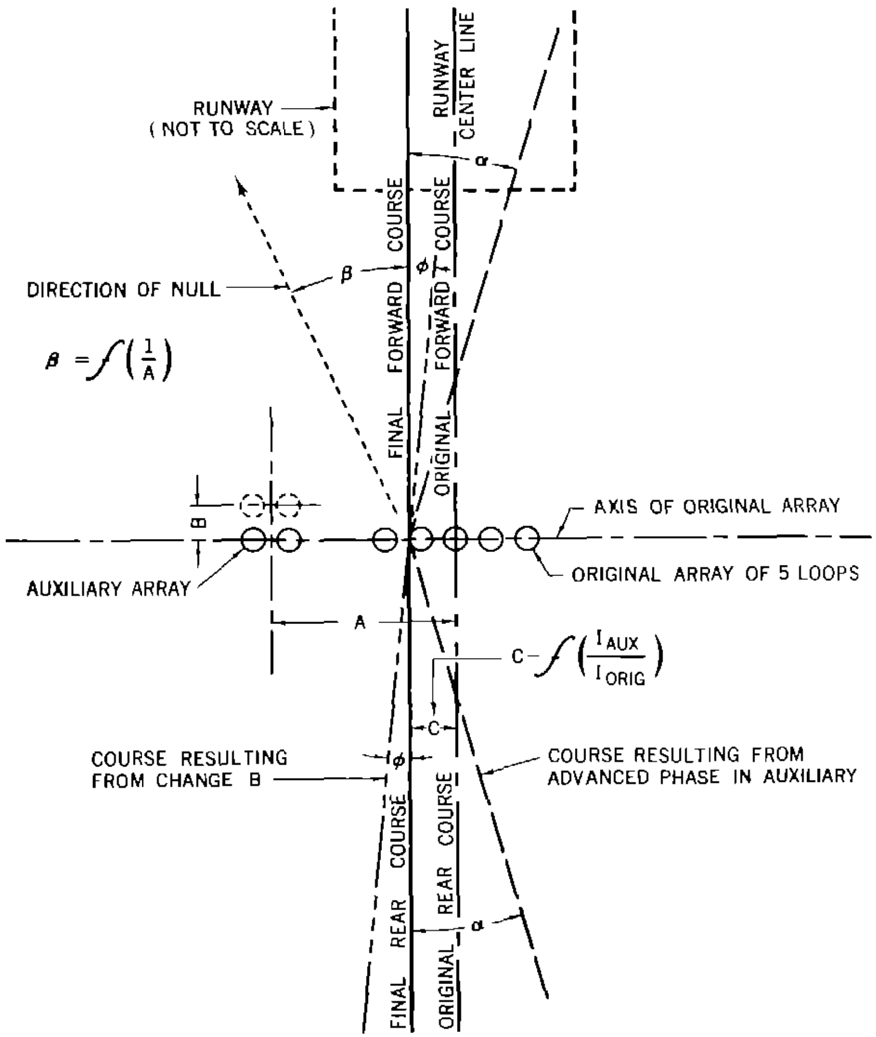


FIGURE 5   Effects of the Auxiliary Array

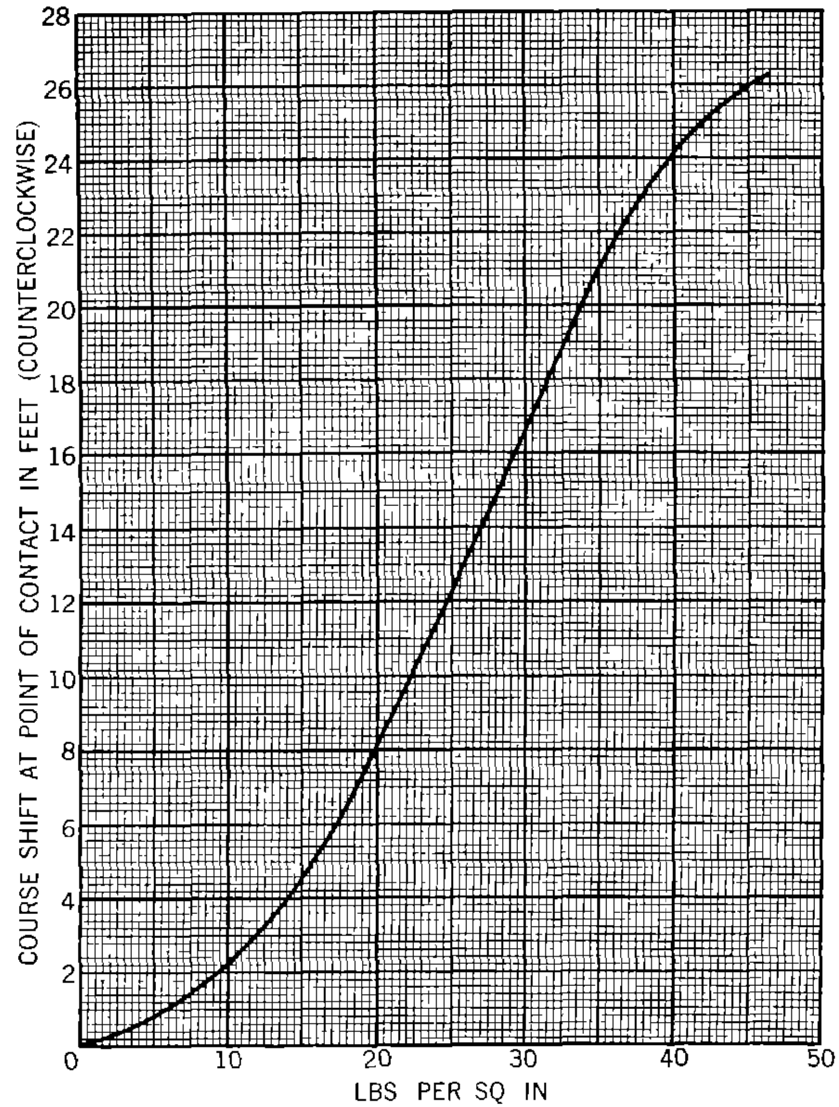


FIGURE 6   Course Variation vs Line Gas Pressure

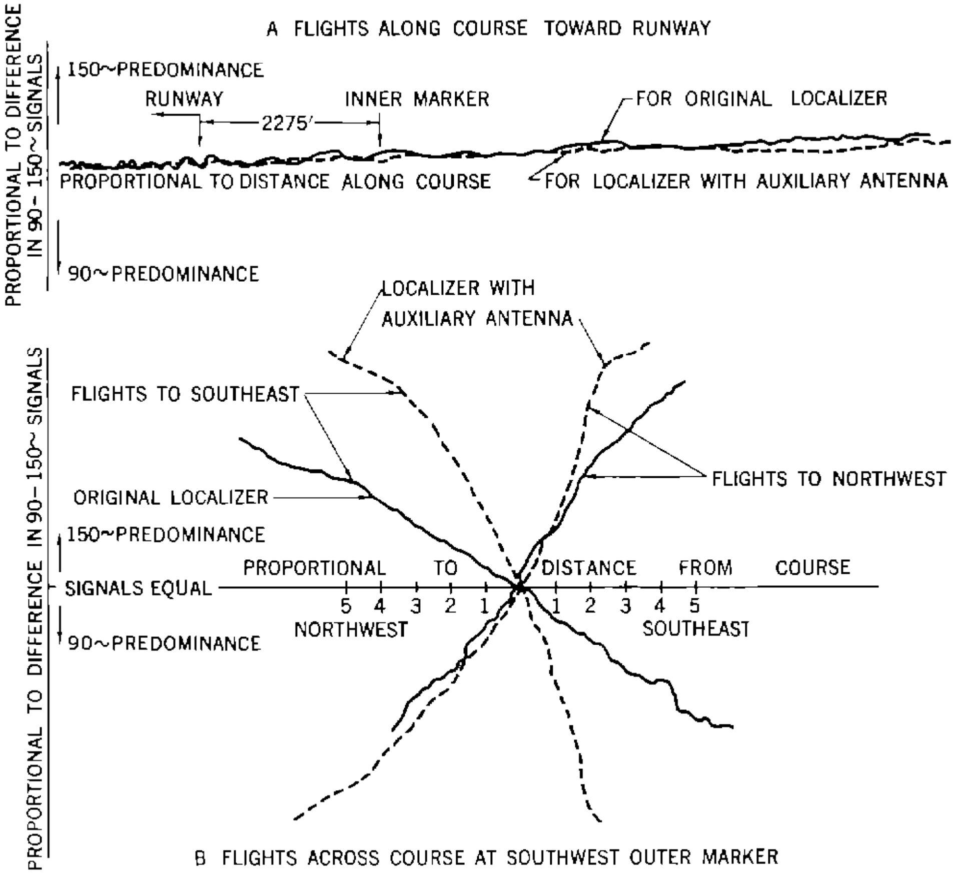


FIGURE 7 Recordings of Localizer Courses

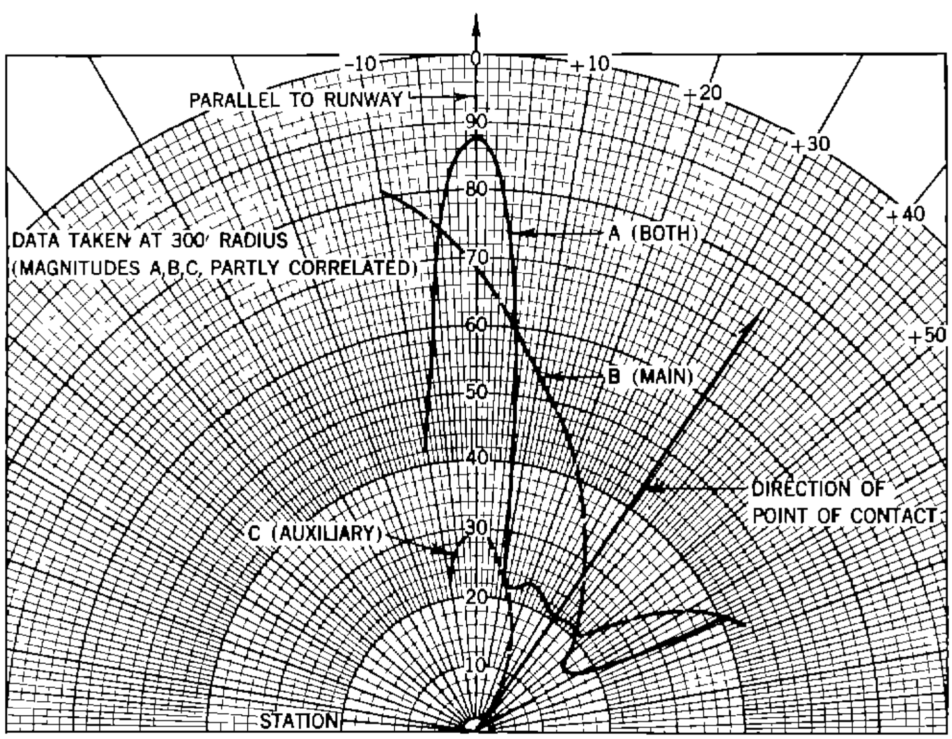


FIGURE 8 Ground Patterns of CAA-RTCA Glide Path

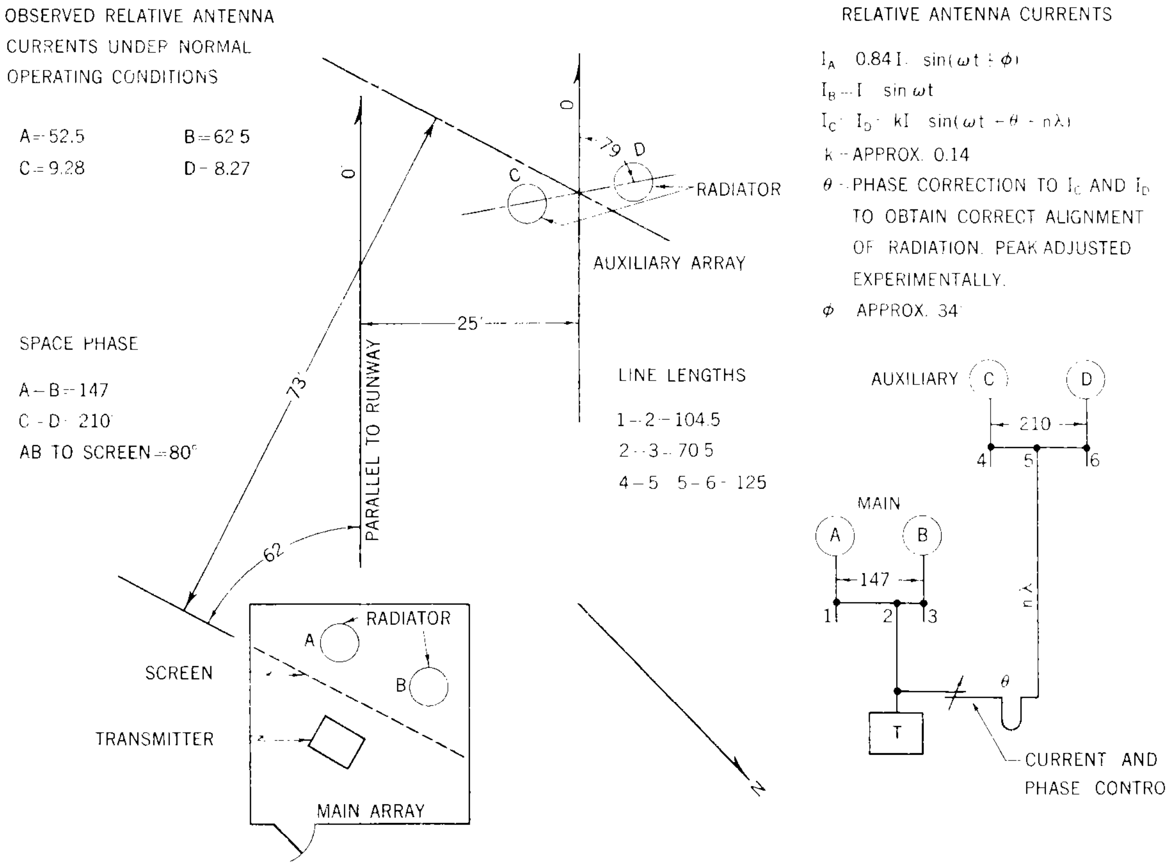


FIGURE 9. Arrangement of CAA-RTCA Glide Path.

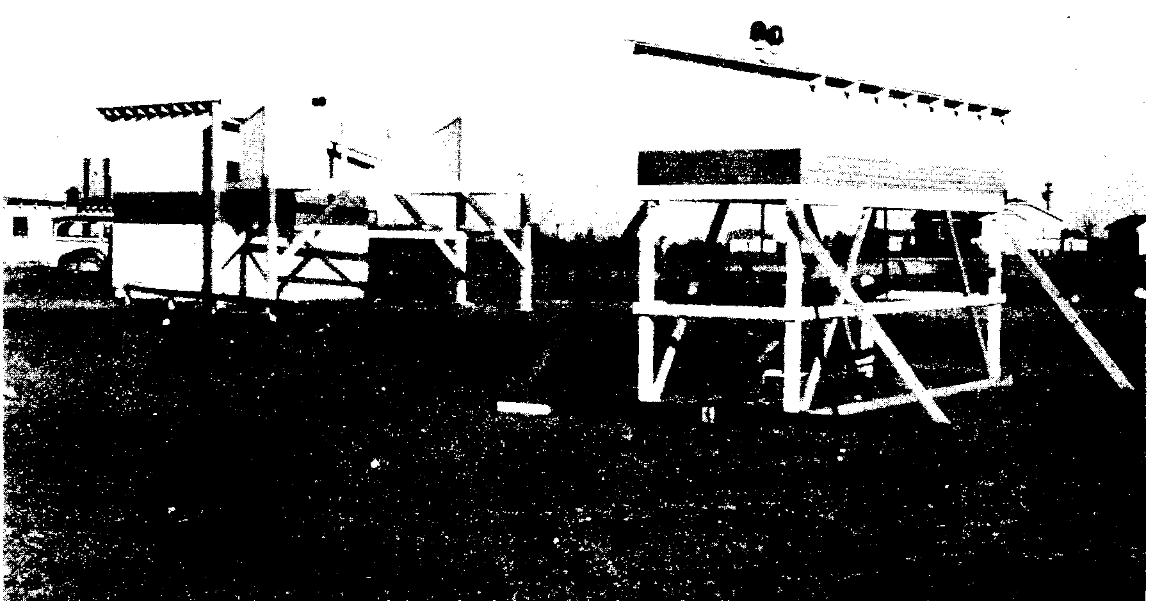


FIGURE 10. CAA-RTCA Glide Path Station.

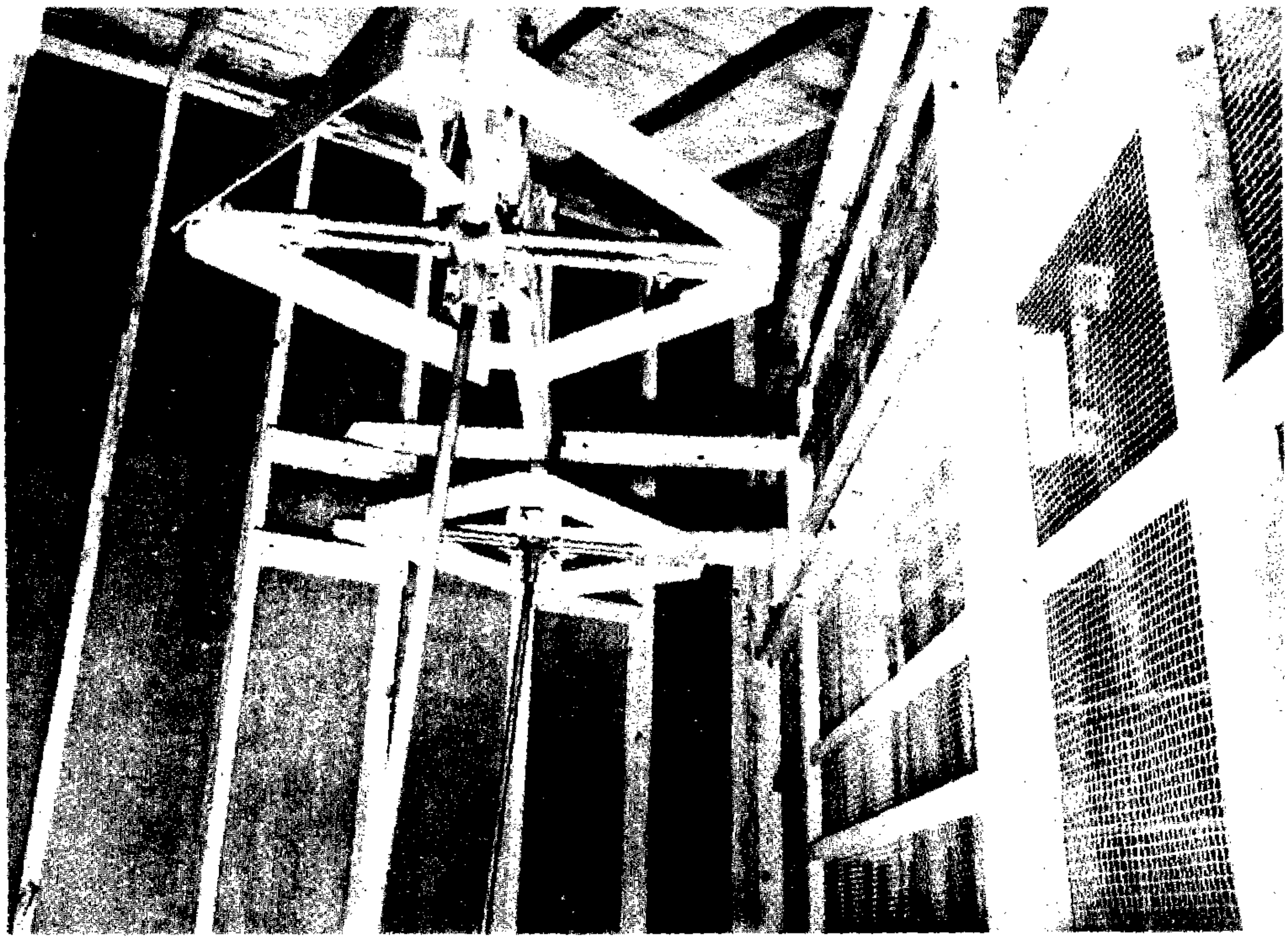


FIGURE 11. Main Radiators and Screen - CAA-RTCA Glide Path.

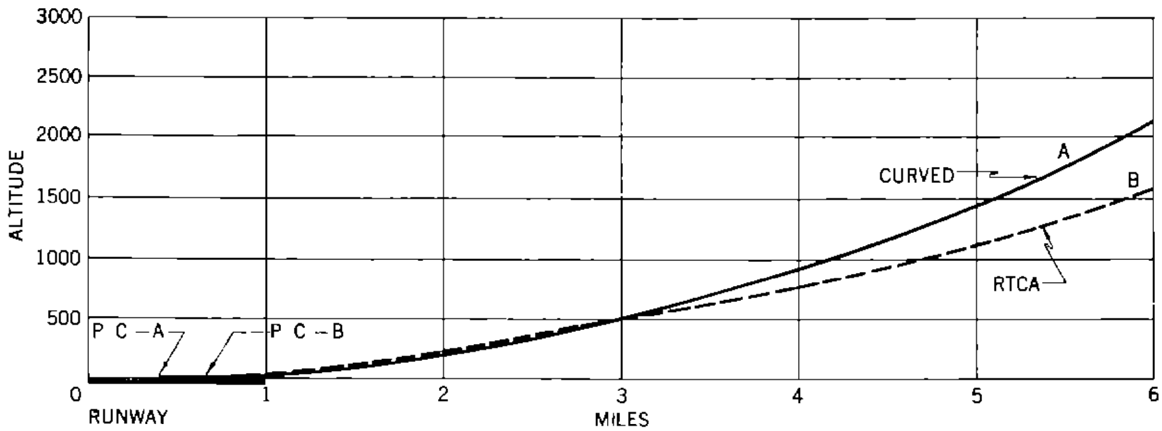


FIGURE 12 Comparison of Glide Paths

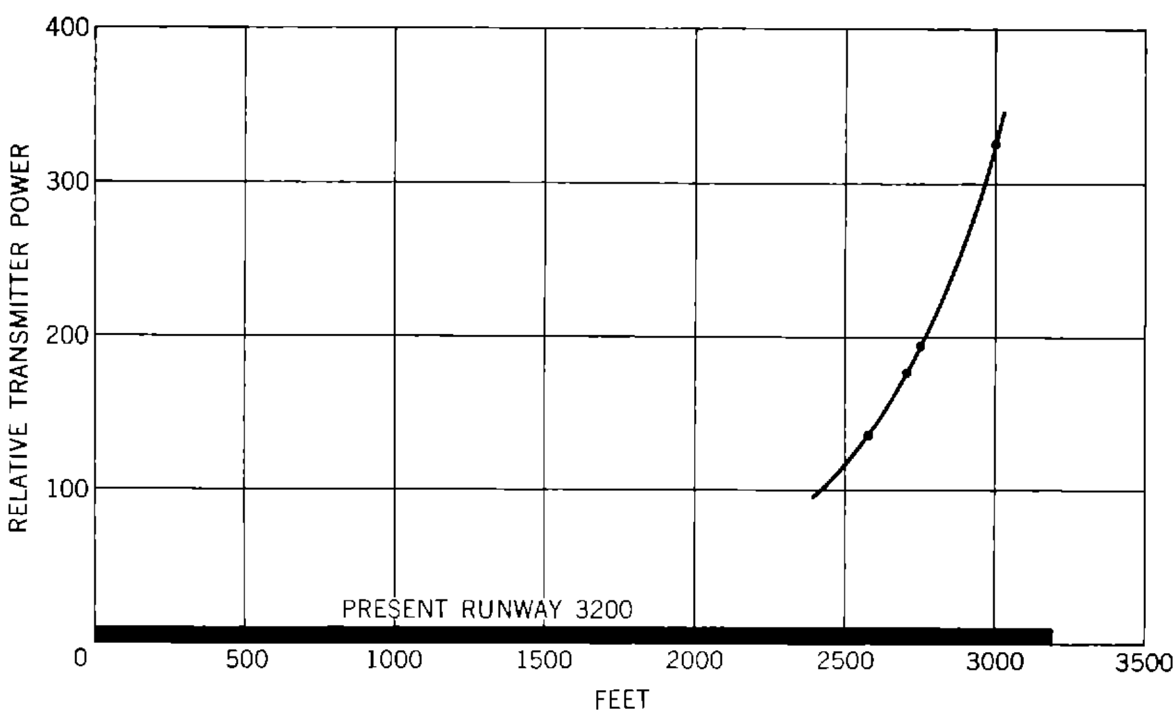


FIGURE 13 Point of Contact vs Transmitter Output- CAA-RTCA Glide Path

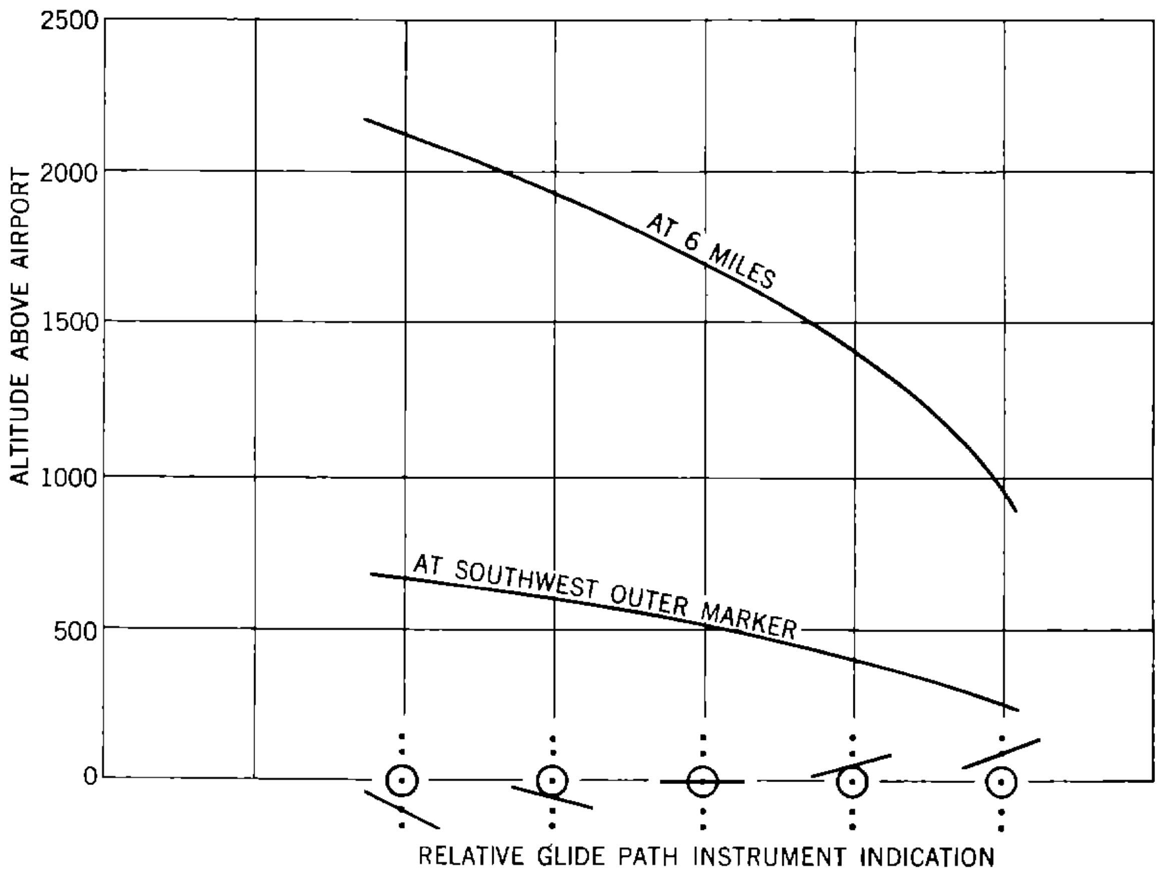


FIGURE 14 Signal Gradients on CAA-RTCA Glide Path

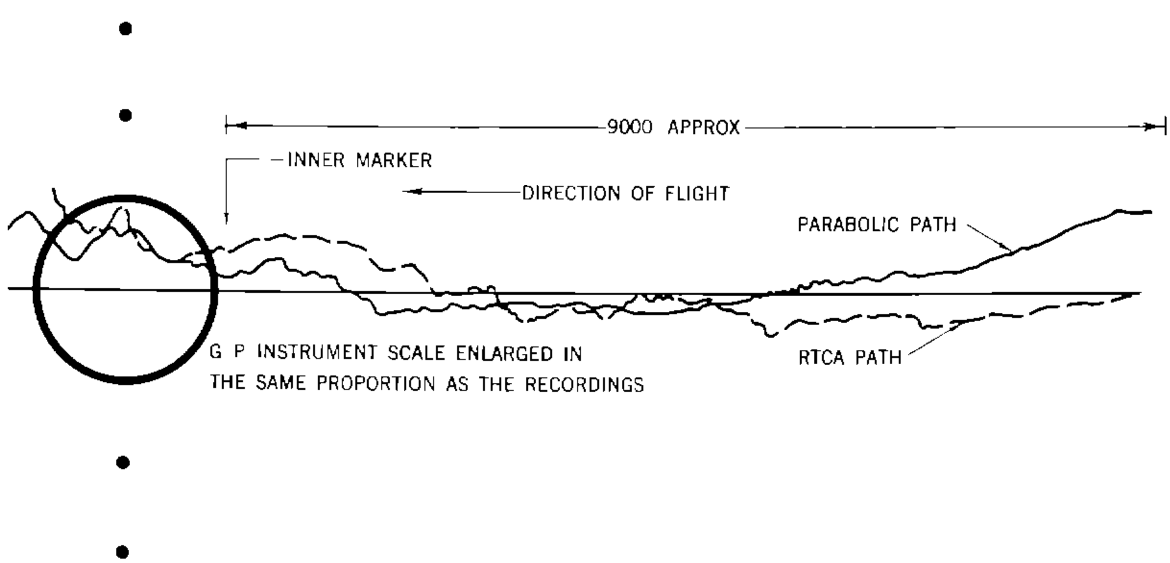


FIGURE 15 Recordings of Glide Path Irregularities

FIGURE 16. DC-3 Airliner with New Receiving Loop.

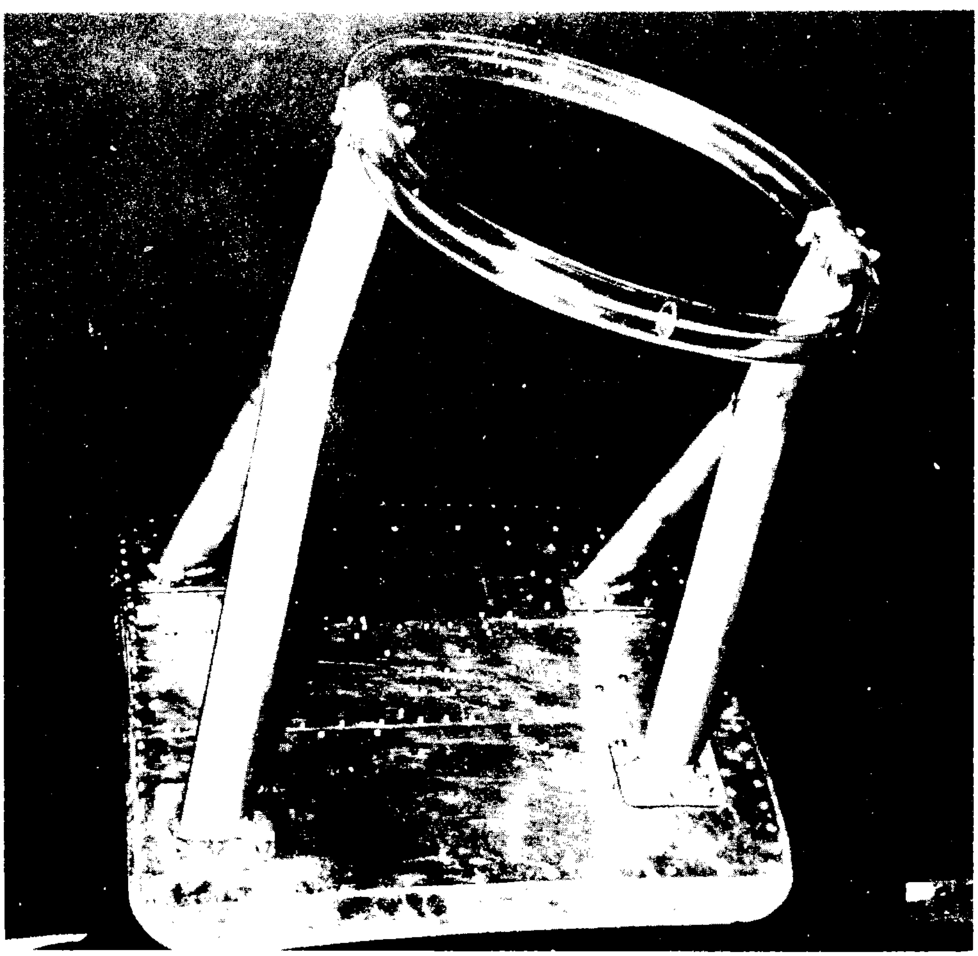


FIGURE 17. Close-Up of DC-3 Hatch Cover and Loop.

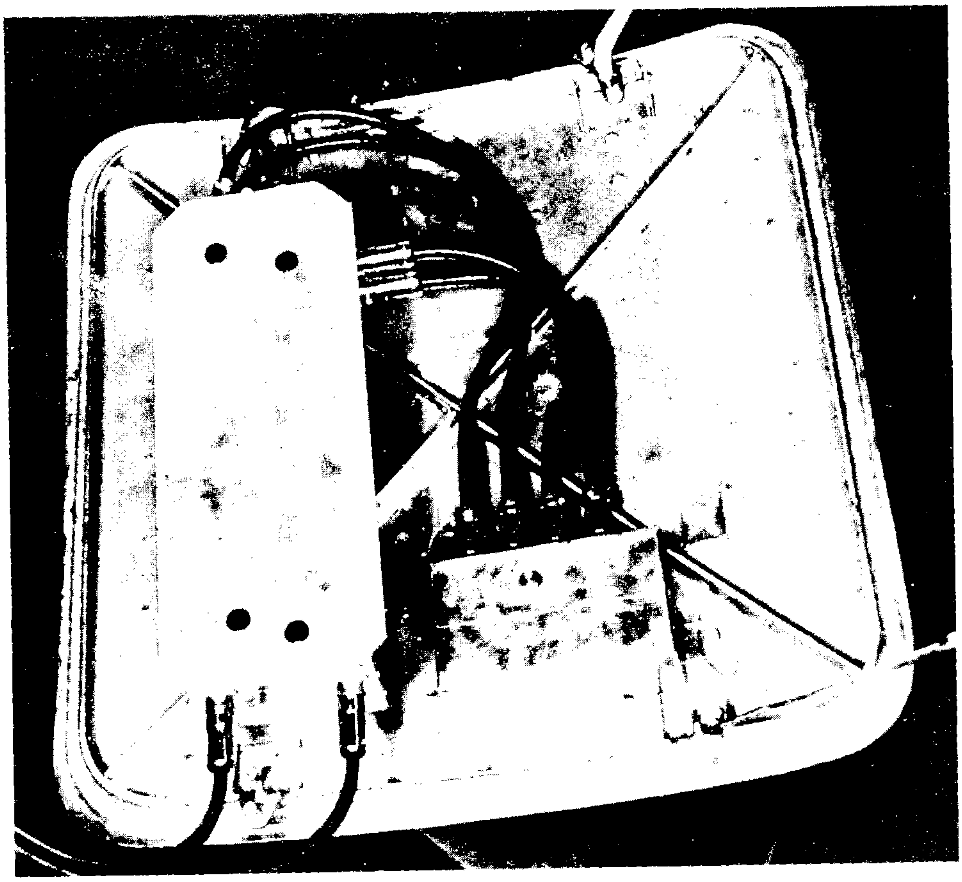


FIGURE 18. Bottom View of DC-3 Hatch Cover Showing Tuning Units.

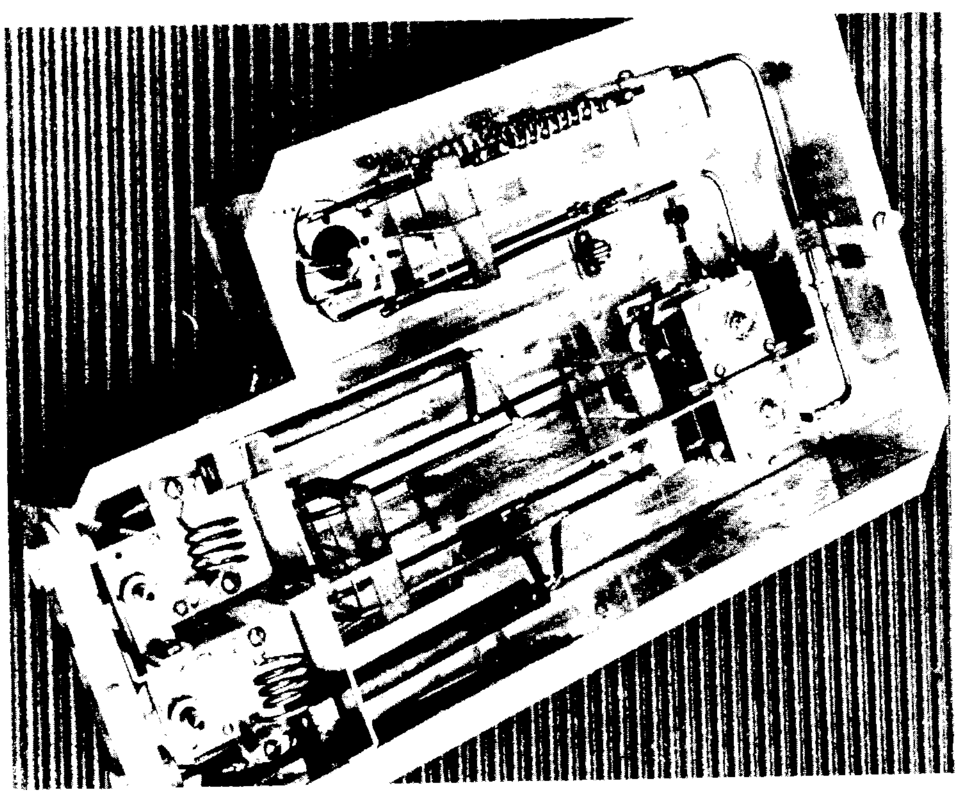


FIGURE 19. NC-17 Loop Tuning Unit.

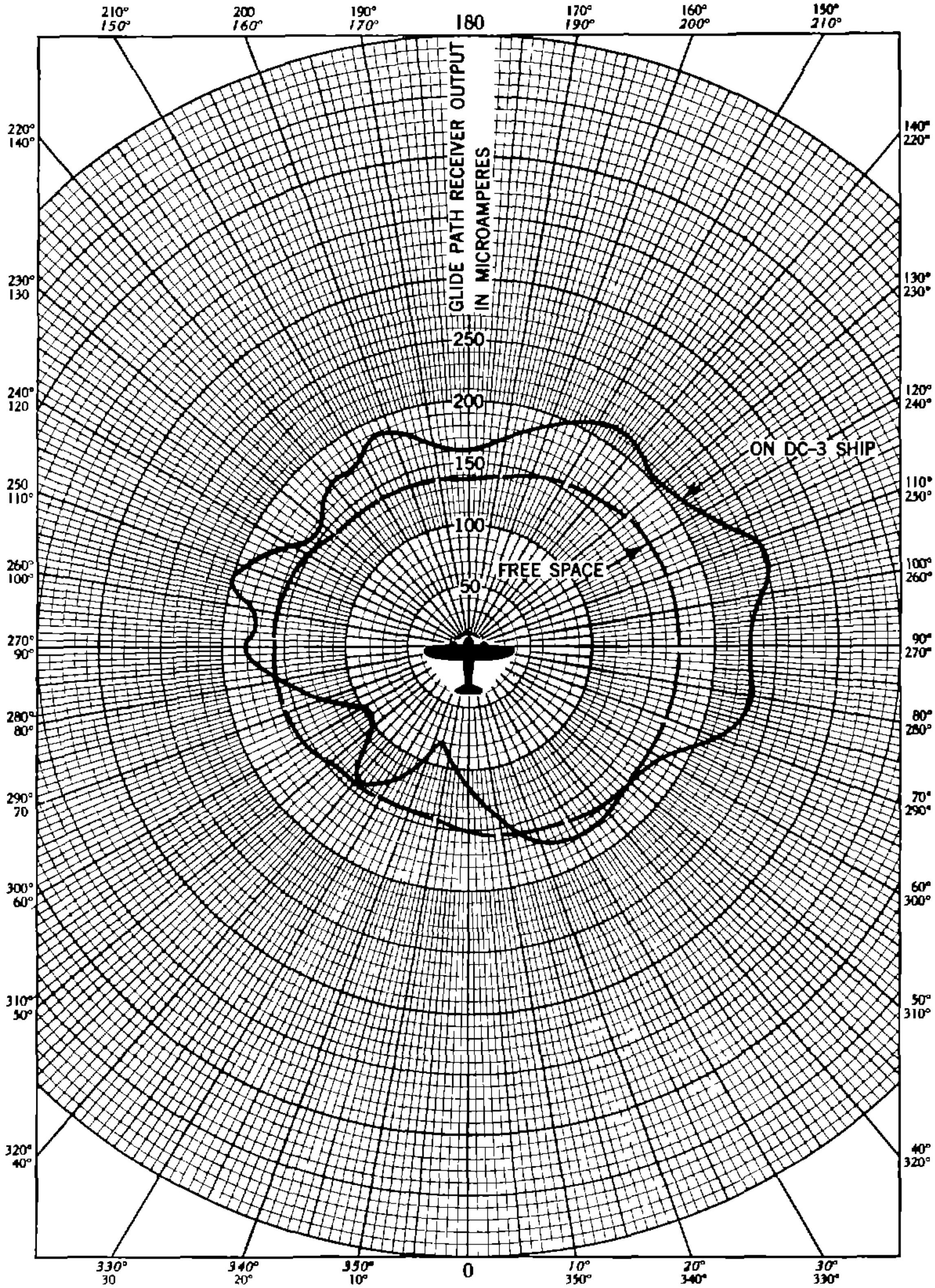


FIGURE 20 Patterns of DC-3 Receiving Loop

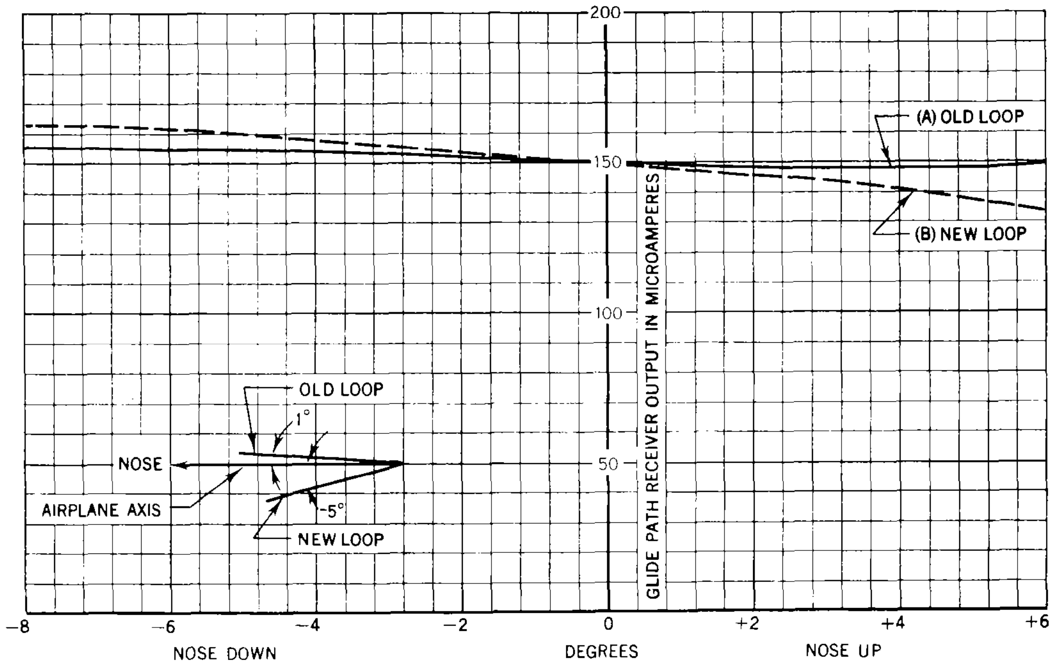


FIGURE 21. Attitude Tests of Two Receiving Loops on NC-17.

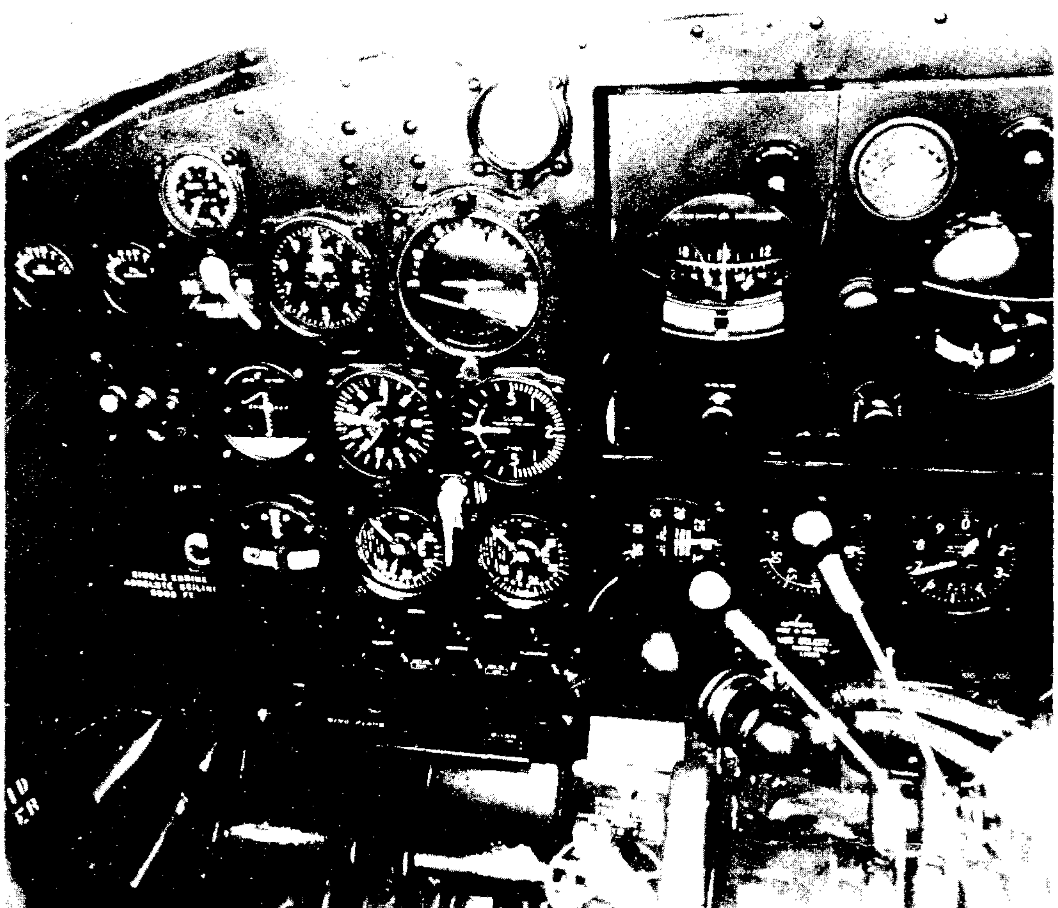


FIGURE 22. Cross Pointer Instrument and Marker Signal Lamps in DC-3 Airliner.

FIGURE 23. Receiver Installation in DC-3 Airliner.

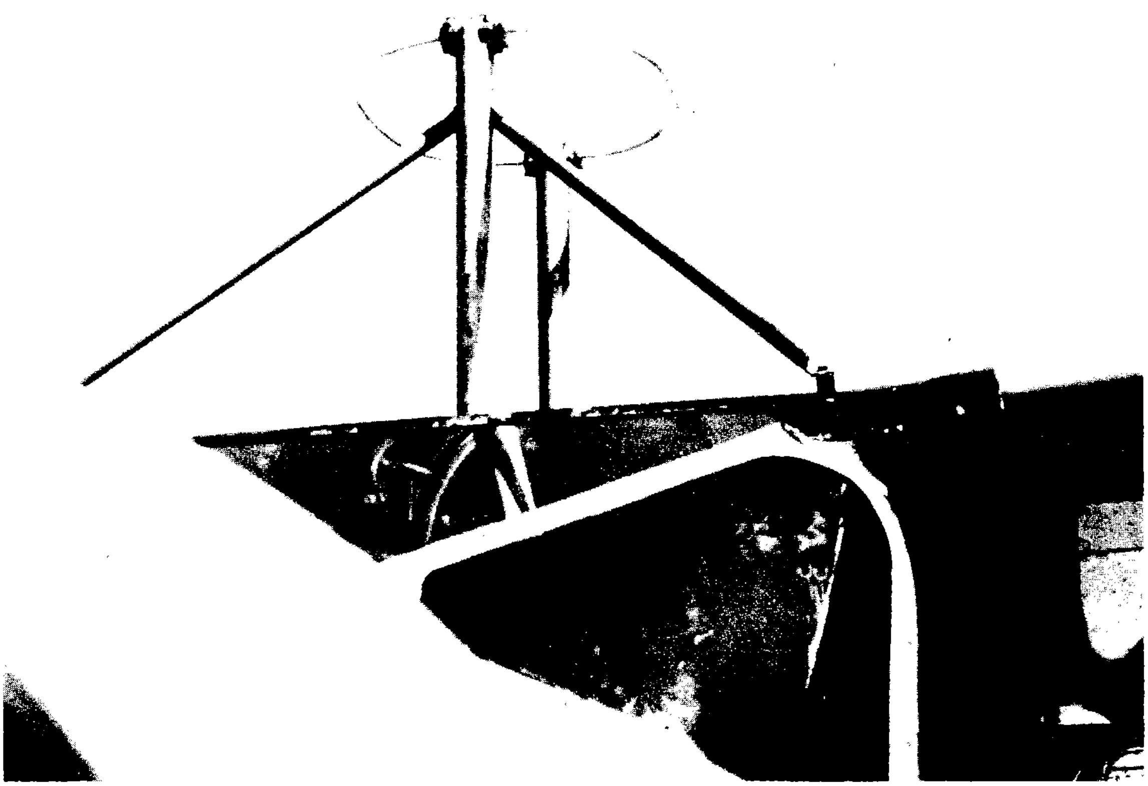


FIGURE 24. New Receiving Loop on NC-17.

APPENDIX

DESCRIPTION AND QUESTIONS CONCERNING INSTRUMENT LANDING INSTALLATION AT CAA EXPERIMENTAL STATION, INDIANAPOLIS, IND

General Description

The radio instrument landing system at Indianapolis comprises four elements, namely, the localizer (visual type two-course radio range), the glide path, an inner marker, and an outer marker The localizer is located 1150 feet northeast of the northeast-southwest runway The glide path building is approximately 1300 feet to the right of the runway and 950 feet forward from the far end of the northeast runway The inner marker is located 2275 feet on the approach side of the runway The outer marker is located approximately 2-1/8 miles from the inner marker

The localizer transmitter produces a visual radio range course along the center of the runway and a reciprocal course northeast of the transmitter Referring to the attached instrument landing chart showing the radio layout, it will be noted that the entire area southeast of the localizer range course is colored green The entire area to the northwest of the course is colored red Referring to the attached sketch, you will observe a drawing of an instrument which is the cross pointer instrument used in the airplane At the bottom of the scale, you will notice a sector which is split in the middle Green appears on the left and red appears on the right Whenever the vertical needle (localizer indicator), that is, the one hanging from the pivot at the top, points to the green sector at the bottom of the indicator, the pilot may be assured that he is in the green area indicated on the map If the vertical needle points to the red sector on the meter, he can be assured that he is in the red area If, on the other hand, the pointer is in the vertical position which bisects the green and red sectors, the pilot can be assured that he is on the bisector of the runway, <u>regardless of the heading of the ship</u>

In the center of the instrument you will observe a small miniature airplane in white The procedure to remember is that <u>when flying in a northeasterly direction</u>, that is, the proper direction for making an instrument approach, <u>the airplane should be flown toward the needle in order to fly toward the course</u> This is true regardless of whether the airplane is southwest of the localizer building or northeast of the localizer building However, <u>when flying in a southwesterly direction, the airplane is flown away from the needle in order to approach the course</u> This holds true regardless of whether the airplane is northeast of the localizer building or southwest of the localizer building

The glide path needle is pivoted on the lefthand side of the instrument When approaching the field for an instrument landing, if the needle is above the airplane, the airplane is lower than the glide path If the needle is below the airplane, the airplane is above the glide path If the needle is horizontal, then the airplane is on the glide path

The average height at which the aircraft will approach over the outer marker is approximately 510 feet The <u>outer marker</u> will operate the purple light continuously at a rate of two dashes per second for a period of 8 seconds The pilot will hear the 400-cycle marker signals about 1 second before the light comes on

The <u>inner marker</u> will flash an amber light for approximately 1-1/2 seconds when the plane passes over it at an altitude of 45 feet This tone is 1300 cycles and keys continuous dots at the rate of six dots per second

Procedure

The standard orientation procedure should be used in case of an emergency to locate the Z marker of the 260-kilocycle Indianapolis range All operations will be made at 1500 feet above the field (2300 feet sea level) After the pilot passes through the cone-of-silence Z marker, he should follow a compass course of 82° directly toward the municipal airport The pilot will either hear the inner marker tone or observe the amber light as he approaches the airport As he flies along this course, he will note that the localizer needle is indicating that he is definitely in the red area Approximately two minutes is required to fly from the Z marker to the localizer course when flying at 120 miles per hour Immediately after the inner marker is passed, the localizer needle will rapidly cross from the red area to the green area This indicates that the localizer course has been crossed At this point, the airplane should be put into a procedure turn to the right, continuing until the compass reads 270° At this point, the airplane should be flown at 270° until the localizer needle crosses from the green area to the on-course position with a heading of approximately 225° At this point, the localizer course will be flown Shortly thereafter, the outer marker beacon will operate the purple light When the purple light goes out, the pilot should continue to fly on the localizer course away from the field for 2-1/2 minutes at 120 miles an hour, or for 5 miles At this point, still maintaining an altitude of 1500 feet above the field, a 45° turn is executed to the left As soon as the gyro reads 180°, this course is flown for a period of approximately 40 seconds, depending on particular wind conditions The airplane is next put into a procedure turn to the right until the course is intercepted As soon as the course is intercepted, a gyro course is established which will maintain the localizer needle on course The glide path needle will gradually drop from the top of the scale as the airport is approached, and as soon as the needle drops to the top of the circle in the center of the indicator, the throttle should be partially closed and the plane gradually flown into and down the glide path, keeping the localizer pointer on course Particular care should be taken to maintain the airplane in a level or slightly gliding attitude as indicated by the horizon bar Excessive variations in attitude should be minimized in order to obtain best results At an altitude of 1200 feet the glide path needle should be horizontal, and from this point on down to contact, every effort should be made to hold the needle either in this position or slightly below the miniature airplane This is a safety precaution which will maintain the aircraft either on or slightly above the glide path At an altitude of 510 feet, the outer marker purple light will operate for approximately 8 seconds A careful check of the altitude should be made at this point to make certain that the transmitting and receiving equipments are operating properly If the purple light comes on at any altitude between 450 and 700 feet, when the glide path needle is horizontal, a normal instrument landing can be made The inner marker light will operate at an altitude of 45 feet (The Kolsman altimeter will usually indicate an altitude considerably higher than 45 feet due to the lag in the instrument Usually it will read from 60 to 80 feet) The inner marker will operate the amber light for approximately 1-1/2 seconds The end of the runway is approximately 2250 feet beyond the inner marker Contact with the runway will be made between 2700 and 3200 feet from the far end of the runway, depending on the height of the antenna on the aircraft and the sensitivity of the glide path receiver

Suggested Rules

Experience gained from flights already made on this system indicates that the following simple rules are beneficial in flying the radio instrument landing system

(1) Set the gyro to the same reading as the magnetic compass

(2) When the airplane is headed toward the field for an instrument approach, the area to the right of the localizer course is green and that to the left is red, similar to the navigation lights

(3) The colors on the map never change

(4) When the airplane is headed toward the field for an instrument landing, the small airplane on the indicator is always flown toward the localizer needle and toward the glide path needle, similar to the sensing of the radio compass and the artificial horizon bar

(5) When flying in the opposite direction, the airplane is flown away from the localizer needle in order to approach the course

(6) Variations in attitude of the airplane should be reduced to a minimum in order to obtain best results

(7) Skidding should be avoided and the ball should always be kept in the center

(8) The localizer pointer should always be coordinated with the gyro heading in order to know what gyro course should be flown

(9) When descending, allowance should always be made for variations in the gyro heading to take care of varying wind velocities with altitude, varying wind directions with altitude and precession (This may best be done by continually keeping the localizer pointer as near on-course as possible)

(10) When flying the glide path below 1200 feet, plan on flying the airplane either exactly on the glide path or slightly above the glide path

The attached sheet shows various positions of the needles of the instrument landing indicator and explains the relative position of the airplane with respect to the localizer course and glide path when making an instrument approach

FLIGHT TESTS OF RADIO INSTRUMENT LANDING SYSTEM
AT INDIANAPOLIS MUNICIPAL AIRPORT

Date 2-12 to 2-19-40

Organization or Company

American Airlines, Pan American Airways, Transcontinental & Western Air Lines, and United Air Lines

Aircraft Make 80% Douglas 20% Waco Model DC-2 and Model N

Captain ______ First Officer ______

Total hours flown on this radio instrument landing system ______

In order to assist the CAA in improving the instrument landing system, it is requested that you conscientiously fill out your replies to the questions outlined below

1 Do you like the color scheme for sector identification on the map and on the instrument?
83-1/3% - Yes 16-2/3% - Not Sure

2 If you do not like it, how would you suggest improving it? One suggested slightly brighter color on map

3 Do you like the instrument sensing? 83-1/3% - Yes 16-2/3% - Not Sure

4 If you do not like it, how would you change it? Explain why One suggested sooner indications of on-course for both localizer and glide path

5 Which localizer sharpness do you like best for instrument approaches?
Sensitivity A (maximum sensitivity) 50% - Yes
Sensitivity B (moderate sensitivity) 16-2/3% - Yes
Sensitivity C (low sensitivity) ______

6 Why do you like it best at the particular sensitivity you mentioned? 50% liked A sensitivity because it permitted faster bracketing of the localizer course, was comparable with other instrument sensitivity and provided better runway alignment. 16-2/3% liked B because they felt A was too sensitive in rough air. 33-1/3% made no comment.

7 Do you believe that a sensitivity control should be standard equipment on the localizer indicator?
50% - No 16-2/3% - Perhaps 33-1/3% - No Comment

8 Should the glide path pointer be more sensitive? 83-1/3% - No 16-2/3% - No Comment

9 If yes, why? ______

10 When intercepting the glide path at 1500 feet altitude above the field and following the glide path down to the field, at what altitude do you prefer to be when the outer marker light comes on?
33-1/3% - 500, 16-2/3% - 550, 16-2/3% - 500 to 800, 16-2/3% - 700, 16-2/3% - No Answer

11 Do you like the operation of the inner and outer markers? 100% - Yes

12 At what distance from the boundary of the field would you prefer to have the outer marker?
66-2/3% - 2 miles (present distance) 16-2/3% - 2 to 3 miles, 16-2/3% - No Comment

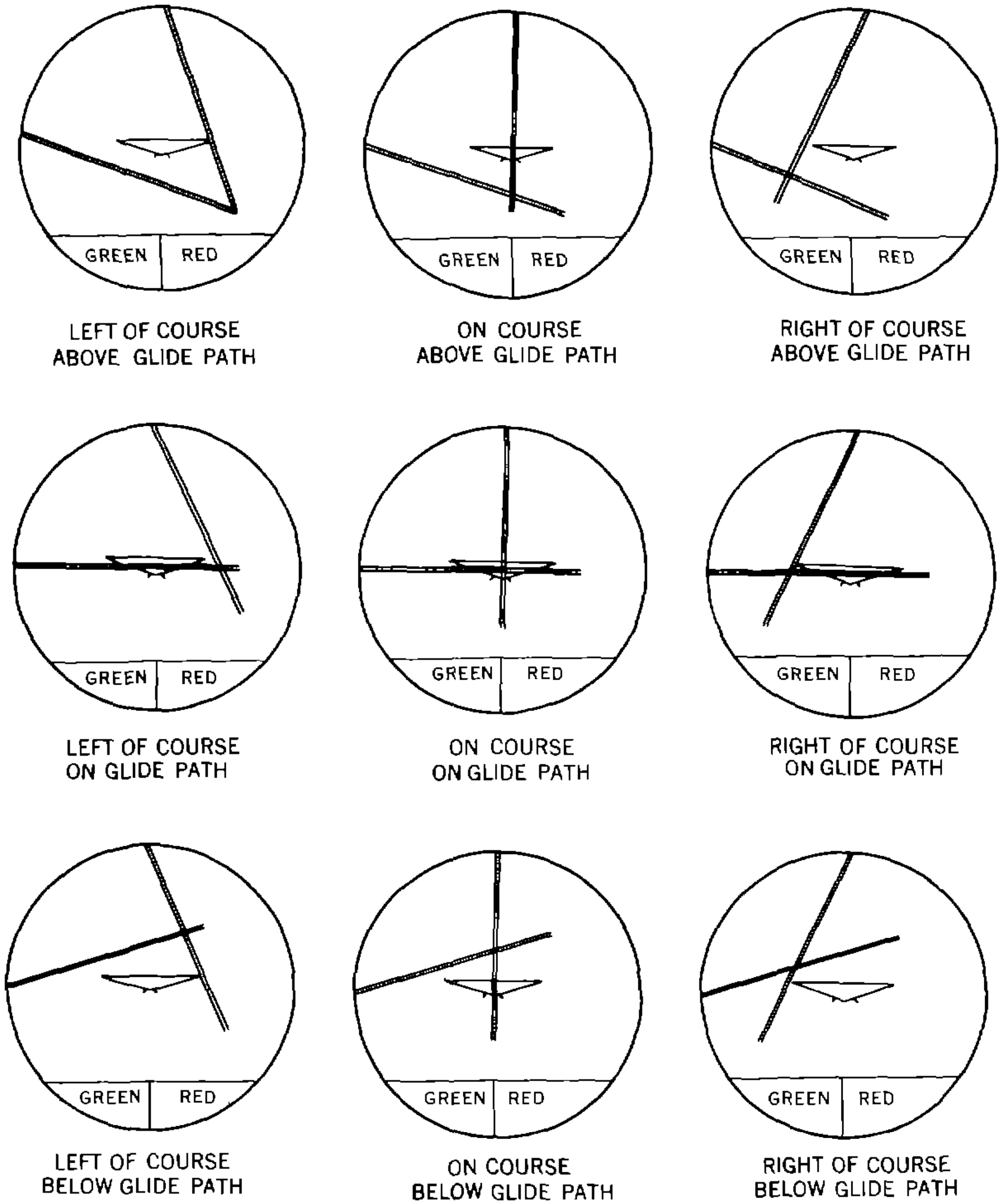
13 Do you have any suggestions for improving the markers? 83-1/3% - No 16-2/3% - No Comment

14 How would you improve the shape of the glide path? 66-2/3% - OK as is, 16-2/3% - desired linear path extended, 16-2/3% - no comment

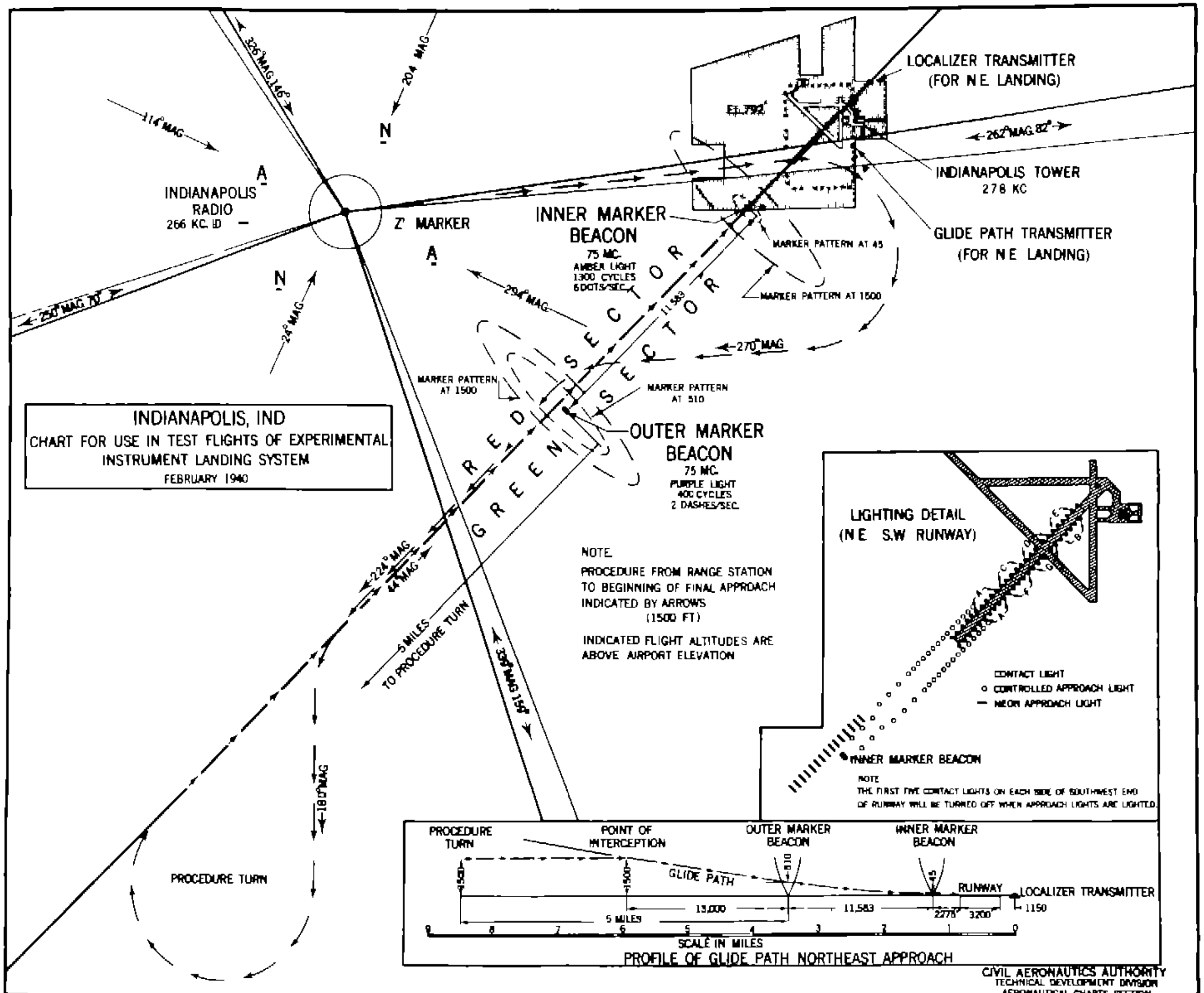
15 Do you like the two-course localizer? 100% - Yes

16 How would you improve the localizer? 83-1/3% - No Comment, 16-2/3% - suggested addition of quadrant identification later if practicable

17 Do you have any further suggestions as to how the system can be improved? 83-1/3% - No, 16-2/3% - suggested more markers to prevent stacking and delay



LOCALIZER AND GLIDE PATH INDICATIONS DURING APPROACH


INDIANAPOLIS, IND
CHART FOR USE IN TEST FLIGHTS OF EXPERIMENTAL INSTRUMENT LANDING SYSTEM
FEBRUARY 1940
LOCALIZER TRANSMITTER
(FOR N.E. LANDING)
INDIANAPOLIS TOWER
278 KC
GLIDE PATH TRANSMITTER
(FOR N.E. LANDING)
INDIANAPOLIS
RADIO
266 KC. ID
Z' MARKER
INNER MARKER
BEACON
75 MC.
AMBER LIGHT
1300 CYCLES
6 DOTS/SEC.
OUTER MARKER
BEACON
75 MC.
PURPLE LIGHT
400 CYCLES
2 DASHES/SEC.
RED SECTOR
GREEN SECTOR
MARKER PATTERN AT 45
MARKER PATTERN AT 1500
MARKER PATTERN AT 510
114° MAG
204° MAG
326° MAG 146°
262° MAG 82°
294° MAG
270° MAG
250° MAG 70°
24° MAG
224° MAG
44° MAG
180° MAG
5 MILES TO PROCEDURE TURN
PROCEDURE TURN
NOTE
PROCEDURE FROM RANGE STATION TO BEGINNING OF FINAL APPROACH INDICATED BY ARROWS (1500 FT)
INDICATED FLIGHT ALTITUDES ARE ABOVE AIRPORT ELEVATION
LIGHTING DETAIL
(N.E. S.W. RUNWAY)
CONTACT LIGHT
CONTROLLED APPROACH LIGHT
NEON APPROACH LIGHT
INNER MARKER BEACON
NOTE
THE FIRST FIVE CONTACT LIGHTS ON EACH SIDE OF SOUTHWEST END OF RUNWAY WILL BE TURNED OFF WHEN APPROACH LIGHTS ARE LIGHTED.
PROCEDURE TURN
POINT OF INTERCEPTION
OUTER MARKER BEACON
INNER MARKER BEACON
GLIDE PATH
RUNWAY
LOCALIZER TRANSMITTER
13,000
11,583
5 MILES
SCALE IN MILES
PROFILE OF GLIDE PATH NORTHEAST APPROACH
CIVIL AERONAUTICS AUTHORITY
TECHNICAL DEVELOPMENT DIVISION
AERONAUTICAL CHARTS SECTION