TECHNICAL DEVELOPMENT REPORT NO. 331

# EVALUATION OF QUADRADAR

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November 1957

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INDIANAPOLIS 21, INDIANA

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## SUMMARY

This report describes the operational and technical evaluation of a Quadradar radar set to determine its applicability to the present air traffic control system.

The tests indicated that the airport surveillance radar (ASR) function of Quadradar could not be used for separating aircraft in the same way that other radar equipment presently operated by the CAA is used. The ASR presentation is not available if one of the other functions is in use. The comparatively narrow vertical width of the azimuth antenna pattern, and the fact that the antenna can be tilted by the operator, can result easily in the loss of targets.

The precision approach radar (PAR) function of Quadradar proved to be its most useful feature, with performance similar to that of other types of PAR equipment. The Quadradar equipment has several advantages.

1 It can be used for long straight-in precision approaches starting from maximum radar range

2. The azimuth antenna scans a 30° horizontal angle, rather than the 20° scan of the PAR-1 radar

3 The elevation cursor can be adjusted so as to form a steep glide path for helicopter approaches

4 If a suitable site is available, it can cover the approach paths to four different runways. The azimuth and elevation cursors can be prealigned to permit four different precision approaches, which may be any combination of the four runways and high or low glide-path angles to the same or different runways.

The height-finder function would be of little value for air traffic control purposes. However, it might be useful in some types of aircraft emergencies, or for estimating the heights of the bases and tops of cloud buildups

It was determined that the relatively slow rate of antenna rotation, and lack of resolution in the airport surface detection equipment (ASDE) function make accurate direction of taxiing aircraft extremely difficult.

The accuracy and resolution of the surveillance and precision approach functions were within the limits specified in the instruction literature supplied by the manufacturer. The cursor accuracy was not within the specified tolerances at close ranges. It was not possible to investigate cursor accuracy in greater detail because of time limitations.

Information obtained during the flight tests indicates that present CAA flight-checking procedures are not adequate for checking this type of equipment. Recommendations relative to desired improvements in flight-checking procedures are included in this report.

Test equipment supplied with the Quadradar was not adequate for maintenance purposes. The individual units are accessible and have sufficient test points for maintenance work. Maintenance of the antenna system, transmitter, and receiver would be very difficult under adverse weather conditions unless the equipment is placed in a building.

## INTRODUCTION

In July, 1957, the CAA Office of Air Navigation Facilities advised the Technical Development Center (TDC) that a Quadradar being delivered to the Army Signal Corps could be diverted to TDC for a period of 30 days, and requested that an evaluation be conducted. A 50-kilowatt (kw) system, with 500 feet of remoting cable, was subsequently received on July 19, 1957.

The Quadradar is manufactured by Gilfillan Bros., Inc., and operates in the X band between 9,000 and 9,160 megacycles (Mc). This equipment has a military nomenclature of "Radar Set AN/FPN-33" and was designed to be set up quickly and placed in operation by a minimum of personnel, and to be transported by surface or air. As the name implies, this equipment is intended to perform four radar functions: surveillance (ASR), precision approach (PAR), height-finding, and taxi (ASDE).

Installation of the Quadradar was made at the operating location by TDC and Gilfillan personnel. The installation of a control-tower coordination interphone, air/ground and point-to-point transmitting and receiving equipment, etc., was completed, and operating controls familiarization was begun on July 30.

The 50-kw system was operated until August 5, 1957, at which time the 50-kw components were replaced by 150-kw components. Shipping commitments dictated the discontinuance of evaluation of the Quadradar on August 14, 1957.

## EVALUATION OBJECTIVES

The evaluation was conducted for the purpose of observing:

1. Accuracy and other performance characteristics.

2. Equipment reliability and stability.

3. Maintenance requirements.

4. Flight-checking procedures.

5. The feasibility of shifting from one function to another, such as ASR to PAR.

6. Difficulties encountered in attempting to control more than one aircraft at one time and possible application at airports having only limited radar requirements.

7. Whether monitoring provisions are adequate.

## EQUIPMENT DESCRIPTION

The Quadradar antenna system consists of two parabolic antennas mounted on a rotatable pedestal, which in turn is mounted atop the transmitter-receiver case as shown in Fig. 1. Rotation of the common pedestal permits height-finding or precision-approach operations in any desired direction. Each parabolic antenna has a scan function of its own, which is derived from a common scan motor and appropriate mechanical linkage. One antenna is horizontal and may rotate throughout 360° at 15 revolutions per minute (rpm) for taxi or surveillance operation, or it may swing back and forth through a 30° sector for the azimuth portion of the precision approach function. The other antenna is vertical and rocks vertically through a 7° or 31° sector to provide height-finding and the elevation portion of the precision approach.

The elevation antenna has a vertical beam width of approximately 0.85° and a horizontal beam width of approximately 2.5°, while the azimuth antenna has a horizontal beam width of approximately 0.95° and a vertical beamwidth of 3° cosecant squared to approximately 30°. Each of the parabolic antennas is illuminated by a horn similar to the one used on the CPN-4 radar. Horizontal polarization is used on the azimuth antenna and vertical polarization is used on the elevation antenna. However, circular polarization may be used on either antenna by turning a small knob on the respective horn.

The transmitter-receiver group may be one of two types. In one type the nominal transmitter power is 50 kw, whereas the power of the other type is 150 kw. The components are interchangeable. Because the 150-kw unit gave improved performance over the 50-kw unit, it was used for most of the tests.

The transmitter uses a Type 4J50T fixed-tuned, X-band magnetron, which supplies a peak power of 150 kw. The modulator consists of a 5C22 hydrogen thyratron switch tube utilizing a linear line-type pulser. This system uses a 0.5-microsecond pulse at 1,500 pulses per second for all functions except taxi operation. When the unit is switched to taxi operation, the pulse length is reduced automatically to 0.18 microsecond.

Physically, the receiver is located at the duplexer, eliminating the need for the remotely located preamplifier. The signal mixer consists of 1N21-C and 1N21-B crystals balanced to cancel local oscillator noise. A Type 2K25 klystron is used in the local oscillator circuit, which has no provisions for automatic frequency control. However, the repeller voltage may be adjusted at the indicator console for optimum tuning on each of the precision-approach scan functions. The resulting 30-Mc signal drives an i-f strip, which has a gain exceeding 100 decibels (db) and a bandwidth of 4 Mc. An exception to this is noted in taxi operation, when the gain becomes 94 db with a bandwidth of 11.6 Mc. The receiver has sensitivity-time-control (STC) and fast-time-constant (FTC) circuitry, any combination of which may be selected by the operator. Moving-target-indicator (MTI) provisions were not included in the receiver.

A highly modified CPN-4 indicator displays the selected data in a form suitable for interpretation. Figure 2 is a photograph of the indicator unit. Although the servo-amplifier has been reconstructed for simplified operation, the original CPN-4 type of PPI still is maintained. In order to provide for a precision approach display, the direction-finding circuitry was replaced with a new deflection system, which displays vertical and azimuth data versus range on a beta-type scan.

The control-indicator group measures 24 inches in depth, 22 inches in width, and 43 1/2 inches in height. When placed upon the power supply group the over-all height is increased to 59 inches.

Operationally, the Quadradar differs materially in several significant respects from radar equipment presently used by CAA.

1. All of the controls necessary for alignment are on the face of the indicator unit, and are available to the operator.

2 The precision-approach function takes the form of a beta-scan presentation on the face of the cathode ray tube in which the elevation and azimuth displays are presented respectively on the upper and lower halves of the tube face in the usual manner, but in which the time base sweep extends horizontally and moves vertically rather than angularly across the display. See Fig. 3.

3. The elevation and azimuth cursors appear as logarithmically progressive curves, rather than straight lines, and have correspondingly greater expansion. See Fig. 3.

4. The PAR presentation is usable throughout the full 40-mile range of the equipment, and a 2-, 10-, 20-, or 40-mile display may be selected at the discretion of the operator. The 10-mile range is exponentially expanded.

5. If proper siting is provided, the PAR function can be used for approaches to four runways, the selection of runway being controlled from the operating position.

6. The entire antenna mount, including both antennas, is rotatable in both a clockwise or counterclockwise direction through 385°, and this rotation is controllable from the operating position. See Fig. 4.

7. The direction faced by the antenna mount is indicated during the ASR presentation by a strobe line on the face of the cathode ray tube, and during the PAR presentation by a compass rose in the upper left corner of the indicator unit.

8. Regardless of the function selected, the degree of azimuth antenna tilt is controllable from the operating position, from the surface to 25° above, with the degree of tilt indicated on a calibrated instrument in the upper right corner of the indicator unit.

9. The elevation antenna provides a sweep of 7° of vertical arc during the PAR function and of 31° of vertical arc during the height-finder function.

10. The height-finder function utilizes the elevation portion of the PAR presentation but employs a different cursor. See Fig. 3.

The controls and indicators of the Quadradar differ in some respects from those found on radar equipment now in use by CAA and include several controls normally available to the operators of the latter equipment. See Figs. 6 and 7. From the top of the control-indicator group downward, the controls and indicators requiring attention from the operator are:

| Power Distribution Panel | Figure 5A |
|---|---|
| 1. XMTR EQUIP OVERHEAT Indicator Lamp | Lights when transmitter equipment has overheated, indicating maintenance attention is required. |
| 2. SCAN Switch | ON position starts scanning action of the antennas, throw to OFF position to stop the antennas for fine tuning. |
| 3. LO TUNE EL Control | Controls fine tuning of the elevation antenna returns. |
| 4. LO TUNE AZ Control | Controls fine tuning of the azimuth elevation antenna returns. |
| 5. TRANSMITTER HV OFF Switch | Push to turn off the high voltage to the transmitter. |
| 6 TRANSMITTER HV ON Indicator Lamp | Lights to indicate that the transmitter high voltage is on. |
| 7. TRANSMITTER POWER Switch | Controls the 117-volt a-c supply at the transmitter case. |
| 8. TRANSMITTER HV RESET | Push to turn the transmitter high voltage on after it has been turned off. |
| 9. STC Switch | Maintains target brilliance as the range varies. |

| Azimuth-Elevation-Range Indicator Panel | Figure 5B |
|---|---|
| 1. MOUNT POSITION INDICATOR | During the PAR presentation indicates the antenna mount position with respect to magnetic north. |
| 2. AZ TILT Meter | During all functions of the Quadradar indicates the vertical tilt of the azimuth antenna. |

| | |
|---|---|
| 3. VIDEO GAIN Control (Screw Driver Adjustment) | Controls the gain of the incoming video signal |
| 4. CATHODE RAY TUBE | Displays visual information concerning range, bearing, and altitude of the radar returns. |
| 5. COMPASS LIGHT Control | Controls the brilliance of the compass rose lights around the cathode ray tube (CRT). |
| 6. NAV HEAD LIGHT Control | Controls the brilliance of the lighting of the rotatable navigation head. |
| 7. FOCUS Control | Controls the sharpness of the display on the CRT. |
| 8. INTENSITY Control | Controls the brilliance of the display on the CRT. |
| 9. NAV HEAD | Rotates to align the grids in the desired direction across the CRT. |
| 10. MOUNT POSITION STROBE LINE | Indicates the direction the antenna mount is facing. |
| 11. AZIMUTH and ELEVATION ANTENNA STROBE LINES | Indicates the positions of the antennas. |
| 12. HEIGHT-FINDER CURSORS | Used during the height-finder functions. |
| 13. ELEVATION and AZIMUTH CURSORS | Provide glide-path and track guidance to the operator in the PAR function. |

| Indicator Function Control Panel | Figure 6A |
|---|---|
| 1. FTC Switch | In ON position, reduces the size of targets on the CRT. |
| 2. FINAL APPROACH-SURVEILLANCE-HEIGHT-FINDER Switch (SCAN SELECT Switch) | Selects the PAR, ASR, or HEIGHT-FINDER functions. |

3. EL CURSOR Switch — When the scan select switch is in the FINAL APPROACH position, throw to HEIGHT-FINDER position to display the HEIGHT-FINDER CURSOR and to GLIDE PATH position to display the ELEVATION CURSOR.

4. MOUNT POS Switch — Throw to the CW position to rotate the antenna mount clockwise, and to the CCW position to rotate the antenna mount counterclockwise.

5. IF GAIN Control (AZ and EL) — Controls the brilliance of the returns on the precision displays.

6. CURSOR ALIGN Switch — When positioning the antennas in the PAR function, push to obtain a sweep trace on the CRT showing the center of the scan area of the elevation and azimuth antennas.

7. EL STROBE Switch — Push to obtain the ELEVATION ANTENNA STROBE LINE on the azimuth portion of the PAR display.

8. EL ANT LEFT-RIGHT Control — Controls (servoes) the horizontal (azimuth) position of the elevation antenna.

9. AZ ANT UP-DOWN Control — Controls (servoes) the vertical tilt of the azimuth antenna.

10. HEIGHT-FINDER Control — Selects the HEIGHT-FINDER or the GLIDE PATH CURSOR for presentation on the elevation portion of the display in the FINAL APPROACH or HEIGHT-FINDER function.

11. HEIGHT Indicators — When operating in the PAR function (SCAN SELECT switch) with the HEIGHT-FINDER cursor selected (EL CURSOR switch), left indicator shows altitude of aircraft from 0 to 5,000 feet, when operating in HEIGHT-FINDER function (SCAN SELECT switch), the right indicator shows the altitude of the aircraft from 5,000 to 50,000 feet.

| | |
|---|---|
| 12. RUNWAY 1-2-3-4 Indicator | Indicates the runway and corresponding cursor selected by the CURSOR SELECT switch on the computer front panel. |
| **Electronic Marker Generator Panel** | **Figure 6B** |
| 1. R M GAIN Control | Controls the intensity of the range marks on the CRT. |
| 2. R M RATIO Control (Screw Driver Adjustment) | Controls the intensity of the alternate 1-mile range marks on either PAR or ASR function when a range of not more than 10 miles is selected. |
| 3. OFF-CENTERING ON-OFF Switch | Throw to the OFF position to off-center the ASR or TAXI sweep on the CRT. |
| 4. VERT OFF-CENTERING Control | Controls the position of the sweep vertically on the CRT. |
| 5. HOR OFF-CENTERING Control | Controls the position of the sweep horizontally on the CRT. |
| 6. RANGE NAUTICAL MILES Switch | Selects PREC ranges of 1-3, 10, 20, or 40 nautical miles for display on the CRT when operating in the PAR function (SCAN SELECT switch), or SEARCH ranges of 1-2.5 (TAXI), 5, 10, 20, or 40 nautical miles for display on the CRT when operating in the ASR function. |
| 7. I5801 and I5802 Indicators | Light to indicate blown fuses. |
| **Cursor Alignment Control Panel** | **Figure 6C** |
| 1. CURSOR SELECT Switch | Selects the AZIMUTH and ELEVATION CURSORS for one of four runways. |
| 2. Groups 1, 2, 3, and 4 | Controls for prealignment of the azimuth and elevation cursors for each of four runways. |

The remainder of the controls also are available to the operator, but are not required for the actual operation of the equipment, and normally would be used by maintenance personnel.

## EQUIPMENT INSTALLATION

The Quadradar antenna system, transmitter, receiver, and case together comprise one unit which was located near the center of the west boundary of Weir Cook Municipal Airport at Indianapolis, Indiana. The control-indicator group, which includes the indicator power supply, scope, and all controls necessary for alignment of the equipment and for interpretation of the radar information received, was placed in a permanent-type building along the west edge of the airport. See Fig. 7.

The selection of a site for this installation was fairly well fixed by 500 feet of remoting cable, location of a suitable building with communications, and space for the indicator unit and limited access to certain runways as a result of runway construction. The following steps describe the exact installation procedure which was used.

1. A fork lift was used to set the transmitter on the selected site and the indicator was installed in a building located 500 feet away.

2. Interconnecting power and control cables were installed and the two units were checked for proper electrical operation.

3. The north-south and east-west runways were surveyed and corner reflectors were placed as indicated in Fig. 7. The reflector identified as CLA was located at the point of touchdown and offset a distance equal to the right-angle distance from the runway centerline to the radar site. The remaining two reflectors were bracketing reflectors which located the corresponding runway approach on the radar display.

4. The transmitter-receiver pedestal was leveled by adjusting jacks located in each tripod leg while observing two fixed levels mounted atop the pedestal.

5. A gun sight was placed in position on the common pedestal and the pedestal then was revolved until the cross hair in the gun sight split the south CLA corner reflector. The differential selsyn on the common pedestal then was orientated until the strobe on the surveillance display pointed south.

6. The precision-approach function then was aligned for operation on either runway 27 or 36. After placing the first reference range mark on the touchdown reflector, the cursor was placed between the runway bracket reflectors by adjusting the runway potentiometer. By adjusting the angle potentiometer, the strobe also passed through the point at which the 20-mile range mark intersected the center of scan strobe. The elevation display was aligned by adjusting the touchdown potentiometer until the cursor passed below the touchdown reflector and, by adjustment of the angle potentiometer, the cursor crossed the six-mile range mark at the point of intersection with the center of scan strobe. The glide path used was 2.5°, which is the same as the center of scan strobe used in the above alignment. Each of the above adjustments may interact and may require readjustment.

7. To align the height-finder, it was necessary to place the first range mark at the main bang. The 31° height-finder function was aligned first, as it involves the only zero adjustment. To determine proper settings of the counters, the altitudes at 5, 10, and 15 miles were calculated for the center of scan, or 14.5°. The first adjustment was made at five miles by adjusting the strobe counter until the calculated value for five miles was indicated. The origin of the sweep was set with the zero-adjust potentiometer, and the 30° calibrate potentiometer was adjusted so that the cursor intersected the five-mile range mark at the center of sweep strobe. The counter then was set to the calculated value for 15 miles and the 30° angle potentiometer was adjusted to intersect the cursor with the center of sweep strobe and the 15-mile range mark.

The unit then was switched to the 7° height-finder position which covers the 0 to 5,000-foot altitude. At a range of five miles, the calculated center of scan height, which in this instance would be (6080 X 5 X sin 2.5°), was transferred to the counter. Next, by adjustment of the 7° calibrate potentiometer, the cursor was made to touch the center of scan strobe at the point of intersection of the 5-mile range mark. A similar adjustment was made on the 15-mile range by adjustment of the 7° angle potentiometer. A check then was run at 10 miles.

After proper alignment of the cursors, the counters have provisions for slipping, which permits setting the counter zero to the field elevation. At this location, 800 feet was used as zero or the elevation above mean sea level.

## TEST PROCEDURES

It was determined that, insofar as possible, all four functions of the Quadradar should be tested and that the tests should be conducted with a multiengine metal-skin aircraft, and with a single-engine fabric-covered light aircraft. A DC-3 and a Piper Tri-Pacer equipped with a gyro-compass were used. Both aircraft were flown by TDC pilots experienced in this type of operation. The equipment was operated continuously during the test period.

Surveillance (ASR) Function and Coverage.

While antenna-coverage and pattern tests were being flown for the technical evaluation, the personnel making the operational evaluation performed the air/ground communications functions, and observed the range, coverage, and character of the radar returns. With the 50-kw components installed, two circles having a radius of 30 statute miles from the antenna were flown to examine shielding effects at low angles. One circle was flown at an altitude of 3,800 feet mean sea level (MSL), and the other at 4,800 feet MSL. The elevation of the airport is approximately 800 feet MSL, and for both circles the azimuth antenna of the Quadradar was tilted an indicated 3° above horizontal. In addition to the circles, eight runs were made at 1,000-foot intervals from 1,800 feet to 8,800 feet MSL on an outbound track of 305° from, and on inbound track of 125° to, the antenna. These runs also were made with a 3° antenna tilt. An additional eight runs were made in a similar manner using circular polarization.

After the 150-kw components were installed, two more circles were flown as before. Runs were made at 1,800, 8,800, and 9,800 feet MSL from 5 miles out in order to determine vertical coverage. Because of ground clutter, one run at 9,800 feet MSL was made on a track of 210°. These circles and runs all were flown in the DC-3. This aircraft also was used in locating several known ground targets.

Height-Finder Function.

Two runs were made with the DC-3 in order to observe the height-finder function of the Quadradar. The first was begun from a point 22 nautical miles northwest of the antenna at an altitude of 9,800 feet MSL. The aircraft then descended on a track of 130° with the pilot reporting each 1,000 feet of descent. The corresponding altitude was noted on the Quadradar indicator at each report. The aircraft reached 4,800 feet MSL 1 mile from the antenna, at which point a turn was made and the 2,800- and 1,800-foot MSL altitude reports were made on an outbound track of 320°. Because of wide variations between the reported altitudes and those indicated on the Quadradar, the height-finder test was discontinued pending realignment of the equipment by the Gilfillan representatives.

After realignment of the height-finder function, the second run was made beginning at a point 2 nautical miles south of the antenna at an altitude of 1,800 feet MSL. The aircraft then climbed on an outbound track of 180° to an altitude of 8,800 feet MSL, which was reached 24.5 nautical miles south of the antenna. The reporting procedure used during the first run also was used during the second run.

Taxi (ASDE) Function.

Because of the results obtained from a previous evaluation of the Airport Surface Detection Equipment (ASDE), which was made from approximately the same location,[1] it was anticipated that only a cursory test of the Quadradar ASDE function could be conducted. This proved to be the case. However, random vehicular and aircraft traffic was observed on most portions of the airport. In addition, four taxi runs were made on runway 36, which was closed to other traffic because of construction work, and which was most nearly visible on the scope in its entirety. These runs were made with the DC-3 airplane.

Precision (PAR) Function.

A total of 105 approaches were flown, all of which were conducted under VFR conditions. Of this number, 4 were surveillance approaches and 100 were precision approaches. One of the latter was a long, straight-in approach starting at 22 miles from touchdown.

Of the 100 precision approaches, 24 were controlled by 5 operators who were not participating directly in the evaluation. All of these personnel were experienced air traffic controllers. However, one had no previous radar experience, one had previous PAR and ASR experience, and three had previous ASR experience only. None of the five operators had observed a Quadradar in operation previously, and had only a very brief period for observation prior to these approaches. All operators required varying degrees of assistance in control manipulation because of lack of familiarization.

Resolution.

Azimuth resolution was checked for both the surveillance and precision-approach functions by means of corner reflectors at the 1,000- and 5,000-foot ranges. Range resolution was examined in a similar manner, however, the corner reflectors were separated by distances at the 1,000- and

[1] E. M. Blount, S. L. Kades, H. A. Kay, and R. E. McCormick, "Evaluation of Airport Surface Detection Equipment Model AN/MPN-7 (XW-1), Part I, Technical Evaluation," Technical Development Report No. 175, June 1952, pp. 3 and 4.

5,000-foot ranges to take into consideration the shorter pulse length used on the 150-kw taxi function. The tests were made to verify values in equipment specifications and no attempt was made to determine absolute values.

Accuracy

Azimuth and range accuracies for the surveillance function were examined by location and identification of fixed ground targets. In addition, a corner reflector was placed at the range of one mile to check the accuracy of the first range mark.

The only accuracy test performed on the precision-approach function was that of cursor positioning. To do this, a theodolite was positioned on an appropriate runway and readings were taken at each one-mile interval of an aircraft making an approach. As each of these theodolite readings was taken, a photograph of the precision scope was taken simultaneously. The time allotted for these tests did not permit working out the details of the photo-grid-marker technique.

TEST RESULTS

Controls and Operation.

The number of controls requiring attention of the operator at some point during normal operation of the equipment is greater than that found on other radar equipment operated by CAA if all four functions of the Quadradar are utilized on one CONTROL-INDICATOR GROUP. However, in a function-by-function comparison, the number of controls necessary for the use of each function is approximately the same. Detailed information concerning actions required of the operator is included in Appendix I.

Coverage.

Figures 8 and 9 show the results of coverage tests with the 50-kw and 150-kw units installed. Coverage with circular polarization and with the 50-kw units installed is shown by Fig. 10. The use of circular polarization reduced the range approximately 25 per cent. Generally speaking, the patterns are well defined and the level top of the pattern shown in Fig. 8 indicates that the recommended 3° azimuth antenna tilt is proper. However, there is some indication that this tilt was too great when the 150-kw units were used.

With the antenna tilt the same as for previous tests, azimuth patterns at 30 statute miles and altitudes of 3,800 and 4,800 feet MSL for both the 50-kw and 150-kw units were made. The results of these flights showed considerable shadowing effects, which were expected at this location.

Benefits of increased power were apparent, because at 3,800 feet altitude the 50-kw equipment was unusable while target returns were rated at 2 or more when the 150-kw units were installed.

Resolution.

To determine resolution, corner reflectors were set at the range and azimuth distances corresponding to the respective equipment specifications. In the case of the 50-kw unit, the resolution at 1,000 feet is 1°, or a separation of 17.5 feet in azimuth and 174 feet in range. At 1,000 feet the surveillance display was incapable of resolving the targets because of clutter. The three targets circled on the photographs of Fig. 11 show the range and azimuthal resolution at 1,000 feet of the 50-kw and 150-kw precision-approach functions. Three test targets are circled on the photographs of Fig. 12 which show range separation of 150 feet and azimuthal separation of 3/4°, or 65.5 feet at 5,000 feet. It is noted in Fig. 12 that one of the azimuth targets is partially hidden by a block. This was a tree about 160 feet in front of the faint target. The surveillance display, Fig. 12, indicates that the limit of azimuthal resolution has been approached.

Accuracy.

Fixed ground targets were used for testing the accuracy of the surveillance radar function. The azimuth of each target under consideration was obtained by servoing the common mount until the precision mount strobe bisected the target, and gave the value directly on the compass rose. Range data were obtained directly from the range marks. Table I lists the fixed targets which were identified and used for checking radar accuracies.

TABLE I

RANGE AND AZIMUTH ACCURACY TESTS

| Target | Target No. | Radar Bearing (deg.) | True Bearing (deg.) | Error (deg.) | Radar Range (n.m.) | Map Range (n.m.) | Error (per cent) |
|---|---|---|---|---|---|---|---|
| Gas Tank | 1 | 71 | 70.2 | +0.8 | 6.125 | | |
| Power Plant | 2 | 104 | 103.6 | +0.4 | 4.5 | | |
| Water Tank | 3 | 343 | 343.8 | -0.8 | 5.5 | 5.4 | +0.1 |
| TV Tower | 4 | 70 | 70.6 | -0.6 | 6.5 | 6.46 | +0.04 |
| TV Tower | 5 | 82 | 82.8 | -0.8 | 13.1 | 13.25 | -0.15 |
| Water Tank | 6 | 323 | 323.5 | -0.5 | 8.4 | 8.37 | +0.03 |
| TV Tower | 7 | 22 | 22.4 | -0.4 | 11.0 | 10.9 | +0.1 |
| Microwave Tower | 8 | 287 | 287.8 | -0.8 | 13.7 | 13.6 | +0.1 |
| Test Tower | 9 | 360 | 0.2 | -0.2 | 6.8 | 6.56 | +0.24 |

Performance specifications furnished with this radar state that slant ranges shall be within 1.0 per cent of actual ranges and the indicated bearing shall be within plus or minus 2.0° of actual bearing. Results are acceptable for all targets except No. 9, for which the range error is excessive. At certain beam tilts, targets were picked up which later were lost as the antenna tilt was changed. Examination of the area which contained these targets failed to disclose any unusual buildup of terrain. This effect may be the result of varying propagation effects at various azimuths as the antenna tilt is changed.

Accuracy checks of the precision-approach function were limited to verification of cursor position accuracy. Alignment is accomplished by servoing the common mount until the mount position strobe bisects the touchdown reflector of the desired runway. The cursor align pushbutton then is pressed and the azimuth of the elevation antenna is adjusted to bisect the touchdown reflector.

If previous maintenance alignments are correct, the azimuth cursor passes between runway reflectors B and C and terminates at the touchdown point as shown in Fig. 13. The elevation cursor, which in this instance was set for a 2.5° glide path, terminates at the touchdown reflector A of the elevation display. Table II shows elevation cursor position errors obtained from Fig. 14, and Table III shows azimuth cursor position errors obtained from Fig. 15.

TABLE II

ELEVATION CURSOR ACCURACY TESTS

| Range Nautical Miles | Aircraft Elevation (degrees) | Calculated Cursor Angle (degrees) | Calculated Error (feet) |
|---|---|---|---|
| 7 | 2.85 | 2.67 | 127 high |
| 6 | 2.75 | 2.43 | 36 low |
| 5 | 2.82 | 2.52 | 9 high |
| 4 | 2.94 | 2.7 | 92 high |
| 3 | 2.75 | 2.59 | 27 high |
| 2 | 2.95 | 2.96 | 97 high |
| 1 | 3.0 | 3.2 | 60 high |

TABLE III

AZIMUTH CURSOR ACCURACY TESTS

| Range Nautical Miles | Aircraft Azimuth (degrees) | Calculated Cursor Azimuth (degrees) | Calculated Error from Approach Path (feet) |
|---|---|---|---|
| 5 | 269.6 | 269.6 | 212 right |
| 4 | 269.7 | 269.7 | 121 right |
| 3 | 269.85 | 269.85 | 55 right |
| 2 | 270.15 | 270.4 | 85 left |
| 1 | 270.1 | 271.0 | 61 left |

These errors were calculated in the following manner a scale with 100 divisions per inch was used to measure the aircraft position on the display picture and by using the corresponding theodolite reading, a factor of K divisions per degree was established. The cursor position then was measured and established in degrees. This measured value then was compared with the desired 2.5° glide path in the vertical and to the correct position in the azimuth to establish the error. Instruction books obtained with this equipment indicate that the elevation cursor is accurate to within 0.3 per cent of true range plus or minus 20 feet, and the azimuth cursor is accurate to within 0.4 per cent of the true range plus or minus 20 feet. Elevation errors at one and two miles were greater than these limits. This probably results from the use of a simplified cursor alignment procedure. Azimuth errors also exceed equipment limits at one and two miles, and this may be the result of failure of the radar operators to position the cursor between the bracket reflectors properly.

Surveillance (ASR) Function.

During the course of the tests it was determined that, in the ASR function, the operation of the controls and the appearance of the CRT were essentially the same as other radar equipment presently used by the CAA with one outstanding exception. The aircraft returns were small, but were comparable to those appearing on CPN-18 type equipment

The exception was the tilting-antenna feature, the control of which was found to be very similar to the control of the antenna servo of the PAR-1. Operationally, the azimuth antenna-tilt feature of the Quadradar serves two purposes. First, it can be tilted so that no returns are received from ground targets, thereby eliminating ground clutter from the CRT presentation. Second, it permits extended coverage by tilting the antenna downward toward the horizon.

The feature that enables this equipment to perform the dual purpose outlined above also compromises its use in accomplishing those purposes. The vertical coverage of the Quadradar azimuth antenna is comparatively narrow, approximately 8,000 feet, and the beam is sharply defined on both the top and bottom. During each rotation the antenna is scanning a segment of air-space of relatively narrow vertical cross section. It then would be possible to have three aircraft at altitudes of 12,000, 8,000, and 4,000 feet MSL, with only one of the three aircraft presenting a usable return on the CRT display.

Depending upon the distance from the antenna and the degree of tilt of the azimuth antenna, it is possible for aircraft at 12,000 and 4,000 feet to be in the upper and lower edges of the antenna beam. Under such conditions a solid return should be received from an aircraft at 8,000 feet, while the returns from the other two would be intermittent at best. If the antenna tilt is increased so that solid returns are received from two aircraft at 8,000 and 12,000 feet, the return from an aircraft at 4,000 feet will be degraded. Conversely, degradation of the return from an aircraft at 12,000 feet will result if the antenna tilt is decreased from its original position. The effects of these and similar situations upon the radar returns may be empirically determined by reference to Fig. 16.

One of the existing standards for positive identification of radar targets is observation of a departing aircraft within one mile of the end of the runway, and this is particularly useful in the operation of departure-control radar. It is theoretically possible to accomplish such identification by the use of the tilting-antenna feature of the Quadradar. However, several attempts to do this were almost completely unsuccessful, and seemed to be dependent upon the rate of climb of the aircraft, the most success being achieved during a rapid climb-out. At best, only an intermittent target could be seen and almost constant tilting of the antenna was necessary through a range of approximately 3° to 5° in order to maintain an optimum balance between the target and the ground clutter, requiring the undivided attention of the operator. Figures 17 and 18 show the actual appearance of the display at the 3.2° and 5° tilts. Figure 17 has a surveyed target circled at a range of 6,115 feet, which is 8 feet below the antenna horizon. At the 3.2° tilt shown, this target is visible; however, at a tilt of 3.3° it disappears. Figure 18 illustrates coverage for a tilt of 5°. It will be noted that the landing aircraft become invisible at one mile.

It should be noted that an unexpected characteristic was observed in connection with the tilting-antenna feature when the 150-kw components were in use. While the antenna pattern appeared comparable to the published performance data when the 50-kw components were in use, this was not always true of the 150-kw components. For example, in the latter case the DC-3 airplane was tracked to a point nearly over the antenna at an altitude of 9,800 feet MSL, using an antenna tilt of 3°, whereas the same aircraft could not be observed consistently at altitudes of 1,000 to 2,000 feet MSL within 1 mile of the antenna using an antenna tilt of 3° to 5°.

Precision (PAR) Function.

The PAR function of the Quadradar was found to be very similar, basically, to that of other precision-approach radars. The Quadradar, however, has several unique characteristics.

The most obvious difference is the appearance of the azimuth and elevation cursors, which are presented on the display as curved lines, and which are a product of the beta-scan feature of the Quadradar. The curved cursors actually represent straight lines, and it was anticipated that some difficulty might be encountered by operators accustomed to the straight cursors of other radar equipment. It was found, however, that the curved cursors presented no special problems to operators, either with or without previous PAR experience, even though at some points in the approach the antenna strobe lines appear to be straight extensions of the cursors. See Fig. 3.

One characteristic of the curved cursors was noted; viz., when a target began to drift off course or off the glide path, in the direction of the curve, such a drift was not observed by the operator as quickly as a drift in a direction away from, or tangential to, the curve. It is probable that thorough familiarization or experience on the part of the operator would tend to reduce or eliminate this effect.

The most distinctive characteristic of the Quadradar PAR function, as in the ASR function, is associated with the capability of the azimuth and elevation antennas to be moved in two planes. This is illustrated by Fig. 4.

The azimuth antenna scans a 30° horizontal sector during precision operation, and in addition, it may be controlled by the operator to tilt upward or downward through a 25° arc. The elevation antenna scans a vertical sector of either 7° or 31° and may be controlled to move to the right or to the left while scanning. The position of the center of the scan, with respect to the on-course and glide-path cursors, is indicated by strobe lines extending horizontally across both the azimuth and the elevation portions of the display. The degree of tilt of the azimuth antenna also is indicated by a calibrated meter adjacent to the upper right quadrant of the CRT. Any tilting movement of the azimuth antenna is reflected in a corresponding movement upward or downward of the strobe line on the elevation portion of the display. Similarly, any movement to the right or left of the elevation antenna is reflected in a corresponding movement upward or downward of the strobe line on the azimuth portion of the display. This movement on the azimuth display is, in reality, movement to the right or left as viewed by the pilot during an approach. The movement of the two antennas is controlled by means of the EL ANT LEFT-RIGHT, and the AZ ANT UP-DOWN controls, which are combined in one servo control handle.

After the necessary actions have been completed for changing to the PAR function, the operator must move the elevation antenna to the right or left by means of the servo control so that the strobe line appears near the side of the azimuth display where the aircraft blip will enter. This must be done to align approximately the center of the elevation antenna scan with the aircraft so that a return from the aircraft will appear on the elevation portion of the display.

In a similar manner, the azimuth antenna must be tilted up or down by means of the servo control so that the strobe line appears on the elevation portion of the display at approximately the level at which the aircraft blip will appear. The approximate level may be judged quite closely by reference to the glide-path cursor. This must be done so that a return from the aircraft will appear on the azimuth portion of the display. This adjustment is considerably less critical than that of the elevation antenna because of the greater area covered by the azimuth antenna.

Another factor which must be considered in this connection is that, as in the ASR function, tilting the azimuth antenna downward increases the ground clutter. Therefore, a compromise may be necessary between a position yielding optimum radar returns, and a position which yields better radar returns for a portion of the approach, but which increases ground clutter to such an extent that aircraft returns in some areas of the approach are blocked. These factors will vary at different locations. Also, they will be dependent, to a certain extent, on individual operator preference. It was found at this site that an initial position of the strobe line slightly below the point at which the aircraft blip would intercept the glide path sufficed for normal precision approaches, and that only slight additional adjustment was necessary during the last mile of the approach in order to retain a satisfactory target with a minimum of ground clutter.

The horizontal coverage of the elevation antenna is much less than the vertical coverage of the azimuth antenna. Because of the wide-angle coverage necessary during aircraft approaches, considerably more movement of the elevation antenna to the right or left is required. This is particularly true as the curve of the azimuth cursor increases at an accelerated rate. The movement of the antenna is controlled by the servo control, and the rate of movement is a function of the rate at which the angle between the aircraft and the antenna is increasing. When the antennas are closer to the runway, the angle between the aircraft and the antenna will increase at a slower rate, and less movement of the antenna will be required. At the test site, almost constant attention to the azimuth position of the elevation antenna was required during the final two miles of an approach and it was necessary to move the antenna almost continuously during the final mile. Failure to do so resulted in partial or complete loss of target on the elevation portion of the display as the aircraft flew out of the antenna beam. However, recovery always was possible within one to three antenna sweeps.

As might be expected, adeptness in the use of the servo control proved to be much more difficult to acquire than an equal dexterity in the manipulation of the other controls, and during the approaches controlled by personnel not familiar with the equipment, the servo control was operated for them. It appeared that the time required to develop proficiency in the use of this control would not exceed that ordinarily required to develop proficiency in controlling PAR approaches.

Six approaches were made with two aircraft on final approach at the same time. It was found that the timing and spacing of the aircraft under such conditions was very critical, particularly if turns onto final approach are made from a normal base leg five to six miles from touchdown. In order to have both aircraft on the display at all times so that identification could be maintained during both the surveillance and precision portions of the approach, it was necessary to use parallel base legs for both aircraft spaced a distance equal to that desired for their separation during the initial portion of the final approach.

It was extremely difficult to keep both aircraft on the azimuth and elevation portions of the display during the initial portions of the approaches, and after the first aircraft had reached a point approximately two miles from touchdown, it was impossible to retain a return from the second aircraft on the elevation display because of the movement of the elevation antenna. Although it was not difficult to go back and pick up the second aircraft, since the glide path was intercepted at a point four miles from touchdown, unless the timing was very precise, the second aircraft already would be above the glide path.

When the turn onto final approach was made at a point eight to ten miles from touchdown while still on surveillance function, and the change to precision function made subsequent to the turn, it was somewhat easier to keep both aircraft on both the azimuth and elevation displays. However, after the first aircraft had reached a point approximately three miles from touchdown, the same difficulties were encountered as before.

Another distinguishing feature of the Quadradar is the long range of the precision function, which is usable out to the maximum range of the equipment. One straight-in approach was made beginning at a point 22 miles from touchdown, and appeared to differ little from a normal precision approach other than in length. The azimuth and elevation cursors extend to only 20 miles. However, at that point the curve is sufficiently flat that extrapolation, or use of the antenna strobe lines, over the remaining 20 miles is sufficiently accurate to permit use over the entire range.

It also is possible to change to the TAXI range during the precision function. This range affords slightly more than 1 1/2 miles of coverage. Attempts were made to use this range during the final portions of several approaches. A different pulse width is transmitted when the TAXI range is used, necessitating the readjustment of several controls at the beginning of the most critical portion of the approach. It never was possible to obtain consistently usable returns at this range.

The elevation cursor may be adjusted during the PAR prealignment to represent a glide path of less than 5° for approaches by fixed-wing type aircraft, or one of more than 5° to enable precision approaches to be made by helicopters.

Alignment of the equipment for the precision function is comparatively simple, and can be performed by the operator after very little instruction. All of the controls and adjustment points necessary are located on the front of the CONTROL-INDICATOR GROUP.

The Quadradar appeared to be very stable in operation. When it was properly aligned, it was capable of operating for at least an eight-hour period with no indication of drift, and with no further adjustment of the cursor controls even though it was changed frequently through all four functions. It must be noted in this connection, however, that whenever the antenna mount is moved after the sweep trace has been positioned through the center of the runway parallel-line corner reflector, the sweep trace must be repositioned. Otherwise, the course-line cursor may not be properly aligned with the runway centerline, and the accuracy of the approach will be impaired.

Height-Finder Function.

The height-finder function of the Quadradar operates in two positions of the SCAN SELECT switch. In the HEIGHT-FINDER position, a very small movement of the HEIGHT-FINDER CURSOR produces a relatively large change on the HEIGHT INDICATOR dial. The height-finder function in the FINAL APPROACH position is, in effect, an expansion of the HEIGHT-FINDER position, and a relatively large movement of the HEIGHT-FINDER CURSOR produces little change on the HEIGHT INDICATOR dial. A separate cursor is employed in each of the two positions, the cursor in the FINAL APPROACH position operates through 5,000 feet, and the cursor in the HEIGHT-FINDER position operates from 5,000 through 50,000 feet. The cursors may be adjusted so that the figures on the HEIGHT INDICATOR dial will indicate either feet above mean sea level or feet above the airport or antenna, and the alignment of the cursors is made independently in each range.

During the first of the two runs made to observe the height-finder operation, the differences between the reported altitudes of the aircraft and the indicated altitudes varied from plus 600 feet to minus 1,200 feet. The cursors were realigned, and in the second run the differences were approximately 70 feet in the FINAL APPROACH position (5,000 feet and below), and varied from 2,300 feet to 3,400 feet in the HEIGHT-FINDER position (5,000 to 50,000 feet).

It was determined later than an error had been made in the alignment of the cursor in the HEIGHT-FINDER position. However, time limitations necessitated the abandonment of the tests at this point. In addition to cursor alignment, the accuracy of the height-finder function also is dependent upon the ability of the operator to bisect the target with the cursor.

Other random observations of the heights of cloud bases and tops and of aircraft were made. However, since direct contact was not established with the aircraft, and the actual altitudes were not known, the results were inconclusive.

Taxi (ASDE) Function.

As explained under the equipment-installation section, terrain restrictions severely limited observation of the TAXI function of the Quadradar. The outlines of fences and buildings could be identified on the display, and random-vehicle and aircraft targets were visible over the area of the airport which was displayed. However, only portions of the surface of the runways were visible at various points on the landing area and considerable smearing of returns due to insufficient resolution was noted on the display. Figure 12 is a photograph of the PPI showing the TAXI presentation.

By monitoring the tower frequencies from the test site it was possible to follow the movement of taxiing aircraft on the airport. In addition, two runs were made in each direction on Runway 18-36 by the DC-3 aircraft. It was determined that, while the rate of rotation of the azimuth antenna was adequate for locating fixed or moving targets on the airport, it was too slow to permit accurate direction of a moving vehicle or aircraft by the operator. The lack of resolution previously mentioned also contributed to this limitation.

Circular Polarization.

The circular-polarization feature of the Quadradar was not remotely controlled from the CONTROL-INDICATOR GROUP. In order to circularly polarize the antennas it is necessary to go to the antenna site and manually rotate both wave guides by means of a knob on each antenna horn.

The limited occurrence of precipitation during the test period restricted observation of the effect of circular polarization on precipitation clutter. However, on two occasions it was possible to observe the effect during moderate to heavy rain in the vicinity of the airport. Figure 19 shows the display under heavy rain conditions with and without circular polarization. Circular polarization plus the use of FTC made it possible to track aircraft through moderate rain. It was not possible to track the small targets displayed by the Quadradar through the heavy rain returns which still remained on the display. Circular polarization reduced the range of the Quadradar by approximately 25 per cent and reduced the area of the displayed returns from cloud buildups.

Maintenance.

After the equipment was placed in operation it was run continuously for the entire test period. Although during this period there were no basic radar failures, the following mechanical difficulties were observed: one of the antenna microswitches operated intermittently, the antenna tilt meter was erratic, and the azimuth pedestal leaked some oil. The first two difficulties were corrected during the test period; since the third did not affect the results of the test, no corrective action was taken.

Measurements of basic radar performance were made with a TS-147 A/UP test set, and are shown in Table IV.

TABLE IV

QUADRADAR PERFORMANCE MEASUREMENTS

| Function | 50-Kilowatt Unit Trans. Power (kw) | Trans. Frequency (Mc) | Receiver Sensitivity (dbm) | 150-Kilowatt Unit Trans. Power (kw) | Trans. Frequency (Mc) | Receiver Sensitivity (dbm) |
|---|---|---|---|---|---|---|
| Surveillance | 92.0 | 9072 | -109 | 232.0 | 9085.3 | |
| Precision Az. | | | | 232.0 | 9085.3 | |
| Precision El. | | | | 227.0 | 9085.0 | |
| Taxi | 92.0 | | -109 | 115.0 | 9085.3 | -109 |

The test equipment necessary for making these measurements was not included as a part of the Quadradar. However, a small A scope included with this radar is suitable for limited monitoring and maintenance work.

The subchassis are quite accessible and have a sufficient number of test points for ease of maintenance. The cursor-generator probably will present the most difficult maintenance problem. The cursor-generator embodies demodulators, multivibrators, sawtooth generator, delay network, and comparison d-c amplifiers. By means of the above circuitry and appropriate alignment controls the cursor-generator provides four sets of cursors for use on four different runways. Because of the short period of operation, it was considered more important to continue other phases of the investigation. In order to examine the maintenance problem in more detail, an operating log for a Quadradar should be obtained.

## CONCLUSIONS

Equipment.

From an operational standpoint, the Quadradar has several commendable features. The four functions, plus the fact that it is possible to conduct four separate approaches from one site, make it a versatile piece of equipment. The Quadradar also is relatively simple to operate, despite the large number of controls available to the operator. It must be recognized that adjustment of only some of the controls is required each time a change of function is made. For example, several consecutive precision approaches to one runway were made in which the associated changes between the ASR and PAR functions were accomplished by the operation of the following controls: the SCAN SELECT switch, the RANGE NAUTICAL MILES switch, the EL ANT LEFT-RIGHT and AZ ANT UP-DOWN control (antenna servo controls), and the AZ EL IF GAIN control.

From time to time during the tests, interference was noted on various portions of the display. This interference ranged in intensity from very light to moderate. While the source was not determined, it is possible that its origin was airborne X-band radar, since no ground-based X-band radar was known to be in operation in the vicinity. The effect of this interference was of little consequence during the tests, which were conducted almost entirely in VFR conditions. However, if airborne weather radar was the source, the increased use of such radar during IFR conditions could present a serious problem.

The accuracy and resolution during operation as a surveillance or precision approach radar were satisfactory. It was not possible to determine long-term stability of operation because of time limitations. It was necessary to retune the local oscillator three to four times each eight-hour period. Otherwise, no adjustments were necessary.

Reliability of the equipment during the test period was satisfactory. An A scope at the transmitter-receiver unit was the only means provided for monitoring the performance characteristics of the equipment. It is possible to procure test equipment to improve monitoring which also will be useful for maintenance purposes. The various subchassis are accessible and have test points sufficient for maintenance purposes. Maintenance of the antennas, transmitter, and receiver would be extremely difficult under adverse weather conditions when the equipment is needed the most since this equipment is not sheltered.

The operating frequency of the equipment is not favorable for air traffic control purposes since precipitation attenuates the radar returns and clutters the display so that targets are not discernible in the cluttered areas. While circular polarization reduces display clutter, it may not reduce the clutter sufficiently under some precipitation conditions.

From the results obtained during the test period, it is concluded that the 150-kw system is superior to the 50-kw system for air traffic control.

Surveillance (ASR) Function.

The present minimum separation standards require that aircraft being vectored by means of radar within 40 miles be separated from other IFR traffic by at least 3 miles. On several occasions the pilots of the two aircraft used in the tests reported that other aircraft, which were not observed on the display, were within three miles of their position at approximately the same altitude. The majority of these reports were received from the Tri-Pacer, which was presenting a strong return on the display at the time, and concerned larger aircraft, thereby eliminating target size as a factor. All of the sightings occurred in areas in which shadowing due to ground objects should not have occurred, nor could resolution have been a factor because of the distance separating the two aircraft. It had been noted previously that changing the tilt of the azimuth antenna sometimes resulted in the gain or loss of targets on the display. It is possible that the lack of a second target in the reported sightings was directly related to the tilt of the antenna.

In order to insure effective and expeditious separation of aircraft by means of surveillance radar, it is necessary that continuous coverage be provided from the surface to the highest usable altitude. In addition to the limitations imposed by the necessity for varying the tilt of the antenna, the Quadradar also loses this capability when a change is made from the surveillance function to one of the other functions. In the case of the Quadradar, it is not possible to overcome this restricted use by the addition of repeater scopes because changing the function also alters the antenna movement, necessitating complete duplication of equipment in order to operate two functions simultaneously. Similarly, it is not practicable to use repeater scopes on one function because of the antenna-tilt problem, which would make it difficult to establish one antenna position capable of meeting the requirements of all operating positions.

It is possible that the Quadradar would have some application in situations involving only a limited number of aircraft and under conditions when most of the aircraft appear over the same point within a limited range of altitudes. Also, it is possible that special procedures could be established which afford a combination of ANC and radar separation, and which would permit utilization of the surveillance function for the spacing of aircraft.

Precision (PAR) Function.

The precision function of the Quadradar was effective. The accuracy and the stability of alignment appeared to be very good. The long- range and high glide-path features provide flexibility of operation; the former would be applicable at locations where long straight-in precision approaches are possible, and the latter enables helicopter IFR precision approaches to be made. It was not possible to test the equipment in the control of helicopters, but it is presumed that the accuracy of the high glide path would equal that of the low glide path since the alignment procedures are the same. The high glide path can be set up on any of the four cursor positions so that precision approaches can be made by both helicopter and fixed-wing aircraft to either the same or different runways.

Although it was not possible to perform an adequate test of the capacity of the Quadradar PAR function, it is probable that it would equal that of any other precision radar. Although the longer range of the PAR function theoretically would accommodate more aircraft on the display simultaneously than is the case with other types of precision radar, the application of this feature, using only one scope, still would be limited by communications capabilities and runway acceptance rate.

Height-Finder Function.

The height-finder function of the Quadradar would be of little value in the control of air traffic because of its limited accuracy. The specified accuracy for the 7° scan is 0.3 per cent of the aircraft range plus or minus 10 per cent of the actual altitude. For the 31° scan the specified accuracy is 0.4 per cent of the aircraft range plus or minus 10 per cent of the aircraft altitude. Although it might prove useful in the case of an aircraft having a malfunctioning altimeter or radio, its greatest application during the tests was in making three-dimensional measurements of cloud buildups.

Taxi (ASDE) Function.

As explained previously, a thorough test of the taxi function could not be conducted because of siting limitations. It is possible that suitable siting would produce a display of better quality. It was determined, however, that the resolution was insufficient, and the rate of antenna rotation too slow to permit other than cursory direction of taxiing aircraft.

## RECOMMENDATIONS

Should the use of the surveillance function of Quadradar be contemplated, it is recommended that coverage be determined after installation for several degrees of antenna tilt, and that charts or tables be established indicating the expected coverage and the degrees of tilt that should be used.

It is urged that any consideration given the use of Quadradar be limited to units equipped with 150-kw components.

The vertically mounted CRT was too high for comfortable use over long periods of time, particularly by operators of comparatively short stature, or if overlays are used. Because of the limited use of the height-finder function, and because the use of this function is associated with the upper half of the CRT, it is recommended that the CRT component be lowered three to five inches into the area now occupied by the HEIGHT indicator and control, and that these components be removed to the space vacated above the new location of the CRT. This also will have the effect of bringing the CRT into closer relationship with the most frequently used controls.

It also is recommended that the VIDEO GAIN, INTENSITY, and R M RATIO controls be provided with knob, rather than screw driver, adjustments.

It is further recommended that a guard be placed over the transmitter power switch on the power distribution panel so that it is not possible to turn off the power to the transmitter inadvertently.

It is strongly recommended that the circular polarization controls be remoted to the operating position.

It is recommended that any equipments used for air traffic control be housed in a suitable shelter to facilitate maintenance.

ACKNOWLEDGMENT

The assistance of the Army Signal Corps in loaning the Quadradar to the Technical Development Center and the assistance of Messrs. James K. Johnston and Cecil Morgan of Gilfillan Bros., Inc., in explaining the equipment operation, and in assisting in setting up, adjusting, and dismantling this equipment, is gratefully acknowledged.

The authors also wish to acknowledge the cooperation extended by the Indianapolis control tower personnel who already were operating under difficult circumstances because of airport construction work in progress.

# APPENDIX I

## OPERATION OF QUADRADAR CONTROLS

The following actions are required of the operator in order to use each of the four functions of the equipment. It is not necessary that they be followed in the order listed, although the order indicated is that deemed most practical as a result of the tests.

The location of each control is indicated by reference to the figure on which it appears. In all cases it has been assumed that the equipment has been turned on, is in operation, and the VIDEO GAIN and INTENSITY controls, Fig. 5B, Nos. 3 and 8, the FOCUS control, Fig. 5B, No. 7, and the LO TUNE AZ and EL controls, Fig. 5A, Nos. 3 and 4, have been adjusted so that the actions required are essentially those of changing from one function to another.

<u>Actions Common to Two or More Functions:</u> (These will be referred to only by number in the SURVEILLANCE, PRECISION, TAXI, and HEIGHT-FINDER sections which follow.)

1. Operate the AZ ANT UP-DOWN control (Fig. 6A, No. 9) as necessary to obtain the optimum vertical tilt of the azimuth antenna.

2. Rotate the AZ IF GAIN control (Fig. 6A, No. 5) as necessary to obtain the most usable display on the CRT.

3. Rotate the R M GAIN control (Fig. 6B, No. 1) as necessary to obtain the desired intensity of the range marks on the display.

4. Adjust the R M RATIO control (Fig. 6B, No. 2) so as to obtain or eliminate, as desired, the alternate one-mile range marks on the display. (This item applies only if the TAXI, 5- or 10 mile range has been selected in the SURVEILLANCE function, or the 10-mile range in the FINAL APPROACH function.)

5. Operate the STC switch (Fig. 5A, No. 9) and the FTC switch (Fig. 6A, No. 1) to either the ON or OFF positions, as necessary, to obtain the best display on the CRT.

6. Operate the OFF-CENTERING ON-OFF switch (Fig. 6B, No. 3) to the OFF position if it is desired to off-center the sweep on the CRT, and rotate

the VERT OFF-CENTERING control (Fig. 6B, No. 4) and the HOR OFF-CENTERING control (Fig. 6B, No. 5) to position the sweep in the desired position on the CRT. (Applies to the SURVEILLANCE and TAXI functions only.)

7. Rotate the NAV HEAD (Fig. 5B, No. 9) if necessary to position the grid lines in the desired direction across the CRT.

8. Rotate the COMPASS LIGHT control (Fig. 5B, No. 5) and the NAV HEAD LIGHT control (Fig. 5B, No. 6) to adjust the compass rose lights and the navigation head lights to the desired level of brilliance.

To Change to Surveillance (ASR) Function:

1 Rotate the SCAN SELECT switch (Fig. 6A, No. 2) to the SURVEILLANCE position.

2. Rotate the RANGE NAUTICAL MILES switch (Fig. 6B, No. 6) to the desired range on the SEARCH scale.

3. Execute, as necessary, Items 1-2-3-4-5-6-7 and 8 of the COMMON ACTIONS group.

To Change to Precision Approach (PAR) Function:

1. Operate the MOUNT POS switch (Fig. 6A, No. 4) to either the CW or CCW position, depending upon the direction of rotation desired, so as to rotate the antenna mount, as indicated by the MOUNT POSITION STROBE LINE (Fig. 6, No. 10) to the magnetic bearing of the extended centerline of the runway to which the approach will be made.

2. Rotate the SCAN SELECT switch (Fig. 6A, No. 2) to the FINAL APPROACH position.

Alternate Method:

1. Rotate the SCAN SELECT switch to the FINAL APPPOACH position.

2. Operate the MOUNT POS switch to either the CW or CCW position, depending upon the direction of rotation desired, so as to rotate the antenna mount, as indicated by the MOUNT POSITION indicator (Fig. 5A, No. 1), to the magnetic bearing of the extended centerline of the runway to which the approach will be made.

NOTE: In the first method, step 1 may be executed at any time during the period the ASR function is in use, while the use of the ASR function must be discontinued in order to accomplish the alternate method.

3. Note which position of the RUNWAY 1-2-3-4 indicator (Fig. 6A, No. 12) is lighted.

4. If the light in step 3 appears in a position other than that assigned to the runway to which the approach will be made, rotate the CURSOR SELECT switch (Fig. 6C, No. 1) to the numbered position which corresponds to the cursors previously aligned for the runway to which the approach will be made. Observe that the RUNWAY indicator light now appears in the position assigned to the desired runway.

5. If the HEIGHT-FINDER CURSOR is appearing on the elevation portion of the display, operate the EL CURSOR switch (Fig. 6A, No. 3) to the GLIDE PATH position.

6. Rotate the RANGE NAUTICAL MILES switch (Fig. 6B, No. 6) to the TAXI position.

7. Operate the STC switch (Fig. 5A, No. 9) to the OFF position.

8. Depress the CURSOR ALIGN switch (Fig. 6A, No. 6) to check the azimuth alignment of the elevation antenna.

9. Operate the MOUNT POS switch (step 1 or 2 above) as necessary, so as to position the sweep trace through the center of the angle reflector return on the CRT. Repeat steps 8 and 9 if necessary.

10. Check that the ELEVATION and AZIMUTH CURSORS (Fig. 5B, No. 13) are properly positioned with respect to the touchdown and bracketing reflector returns.

11. Rotate the RANGE NAUTICAL MILES switch to the desired range on the PREC scale.

12. Operate the EL ANT LEFT-RIGHT control (Fig. 6A, No. 8) as indicated by the position of the ELEVATION ANTENNA STROBE LINE (Fig. 5B, No. 11) on the azimuth portion of the display, so that a return from the desired aircraft is obtained on the elevation portion of the display.

13. Operate the AZ ANT UP-DOWN control (Fig. 6A, No. 9) as indicated by the position of the AZIMUTH ANTENNA STROBE LINE (Fig. 5B, No. 11) on the elevation portion of the display, so that a return from the desired aircraft is obtained on the azimuth portion of the display.

14. Execute, as necessary, items 2-3-4-5-7 and 8 of the *COMMON ACTIONS* group.

To Change to Taxi (ASDE) Function:

1. Rotate the SCAN SELECT switch (Fig. 6A, No. 2) to the SURVEILLANCE position.

2. Rotate the RANGE NAUTICAL MILES switch (Fig. 6B, No. 6) to the TAXI position.

3. Operate the AZ ANT UP-DOWN control (Fig. 6A, No. 9) to the DOWN position until the AZ TILT meter (Fig. 5B, No. 2) registers 0.

4. Execute, as necessary, items 2-3-4-5-6-7 and 8 of the COMMON ACTIONS group.

To Change to Height-Finder Function:

If the CONTROL-INDICATOR GROUP already is adjusted for the SURVEILLANCE FUNCTION:

1. Operate the MOUNT POS switch (Fig. 6A, No. 4) to either the CW or CCW position, depending upon the direction of rotation desired, in order to rotate the antenna mount to the approximate position of the desired aircraft return on the CRT display as indicated by the MOUNT POSITION STROBE LINE (Fig. 17).

If the CONTROL-INDICATOR GROUP already is adjusted for the PRECISION APPROACH FUNCTION:

1. Operate the MOUNT POS switch to either the CW or CCW position, depending upon the direction of rotation desired in order to rotate the antenna mount so that the bearing of the center of the antenna scan as indicated by the MOUNT POSITION indicator (Fig. 5B, No. 1) will be within 15° of the bearing to the desired aircraft.

2. Operate the EL CURSOR switch (Fig. 6A, No. 3) to the *HEIGHT-FINDER* position.

If the subject aircraft is believed to be at an altitude of 5,000 feet or below:

3. Rotate the SCAN SELECT switch (Fig. 6A, No. 2) to the FINAL APPROACH position. In addition to function selection, this action also will illuminate the left portion of the HEIGHT indicator (Fig. 6A, No. 11).

NOTE: If the CONTROL-INDICATOR GROUP already is adjusted for the PRECISION APPROACH FUNCTION, this step already will have been completed.

If the subject aircraft is believed to be at an altitude above 5,000 feet.

4. Rotate the SCAN SELECT switch to the HEIGHT-FINDER position. In addition to function selection, this action also will illuminate the right portion of the HEIGHT indicator.

5. Rotate the RANGE NAUTICAL MILES switch (Fig. 6B, No. 6) to the desired range on the PREC scale.

6. Operate the EL ANT LEFT-RIGHT control (Fig. 6A, No. 8) as indicated by the position of the ELEVATION ANTENNA STROBE LINE (Fig. 5B, No. 11) on the azimuth portion of the display, so that a return from the desired aircraft is obtained on the elevation portion of the display.

7. Execute, as necessary, items 1-2-3-4-5-7 and 8 of the COMMON ACTIONS group.

8. Rotate the HEIGHT-FINDER control (Fig. 6A, No. 10) so as to bisect the aircraft return on the elevation display with the HEIGHT-FINDER CURSOR (Fig. 5B, No. 12).

9. Read the altitude of the aircraft on either the left or the right HEIGHT indicator as selected in step 3.

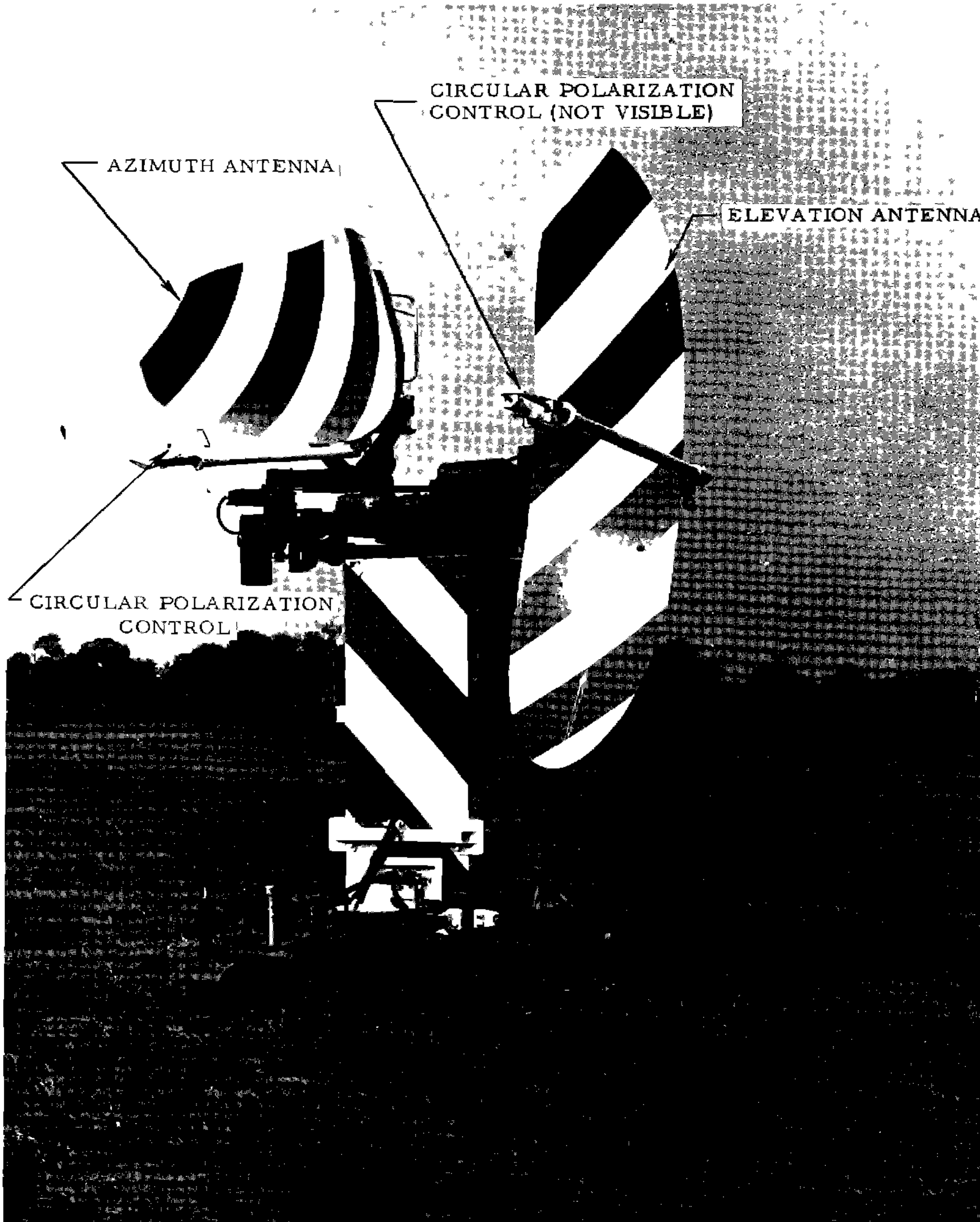
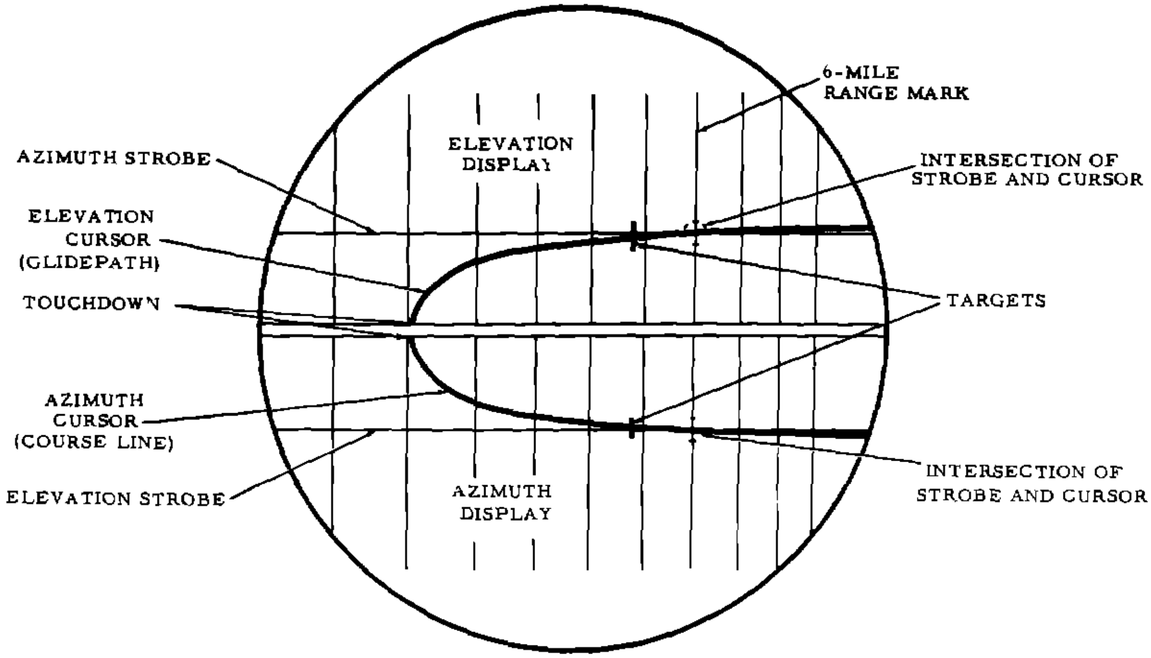


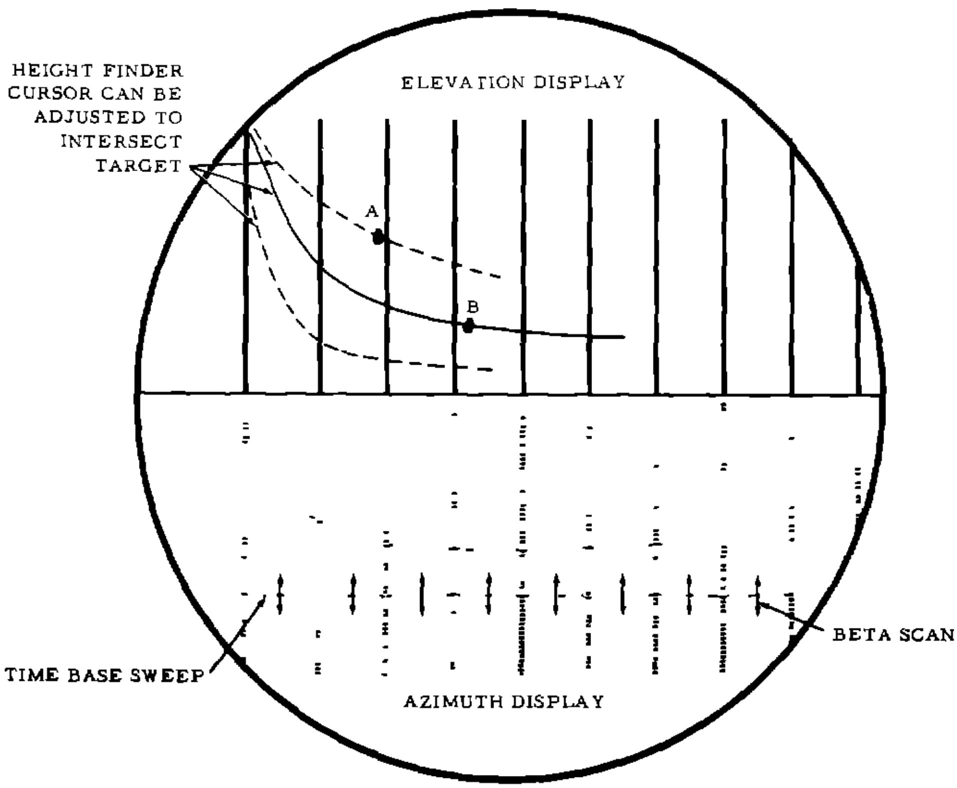

FIG 1 QUADRADAR ANTENNA SYSTEM AND TRANSMITTER-RECEIVER CASE

FIG. 2 QUADRADAR INDICATOR AND CONTROL PANELS



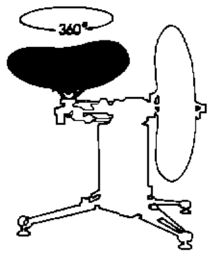

PRECISION APPROACH DISPLAY

NOTE WHEN THE TARGETS HAVE REACHED APPROXIMATELY THE POSITION INDICATED (WITH RESPECT TO THE ELEVATION AND AZIMUTH STROBES) IT IS NECESSARY TO OPERATE THE ANTENNA UP-DOWN LEFT-RIGHT CONTROL SO AS TO MAINTAIN THE ELEVATION STROBE ON OR SLIGHTLY AHEAD OF THE AZIMUTH TARGET AND TO MAINTAIN AN OPTIMUM BALANCE BETWEEN THE ELEVATION TARGET AND GROUND CLUTTER

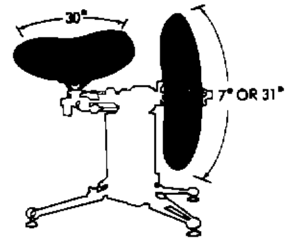



HEIGHT FINDER DISPLAY

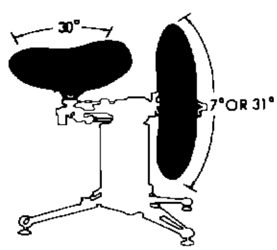
FIG 3 BETA SCAN DEPICTING PRECISION APPROACH AND HEIGHT FINDER OPERATION



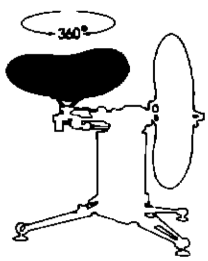

ACTION DURING SEARCH OPERATION
AZIMUTH ANTENNA ROTATES 360 AT 15 RPM
ELEVATION ANTENNA STATIONARY



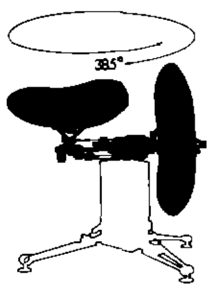

ACTION DURING PRECISION OPERATION
AZIMUTH ANTENNA SCANS A 30° HORIZONTAL SECTOR
ELEVATION ANTENNA SCANS A 7 OR 31 VERTICAL SECTOR
15 EITHER SIDE OF AZIMUTH CENTERLINE



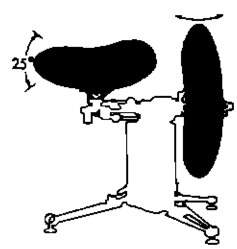

ACTION DURING HEIGHT FINDING OPERATION
AZIMUTH ANTENNA SCANS A 30 HORIZONTAL SECTOR
ELEVATION ANTENNA SCANS A 7 OR 31 VERTICAL
SECTOR 15 EITHER SIDE OF AZIMUTH CENTERLINE




ACTION DURING AIRPORT TAXI OPERATION
AZIMUTH ANTENNA ROTATES 360 AT 15 RPM
ELEVATION ANTENNA STATIONARY

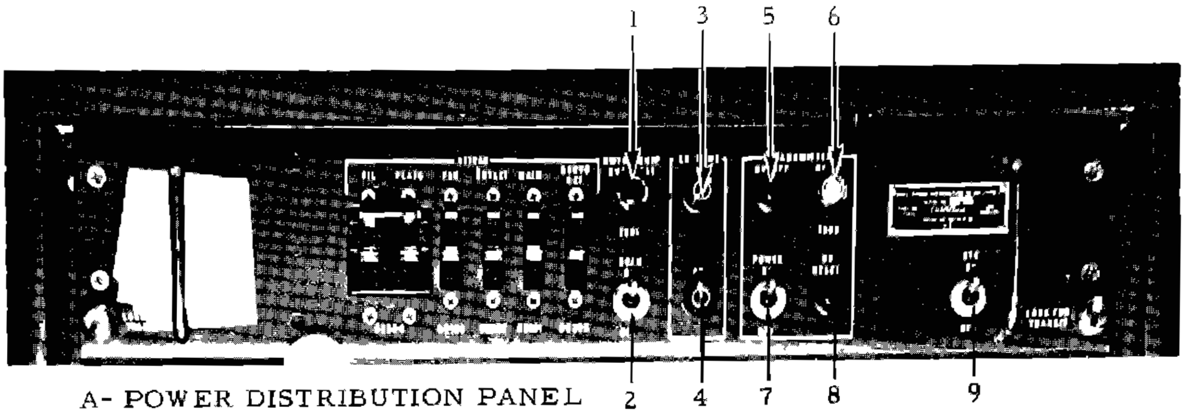



ACTION DURING PRECISION OPERATION TO
CHANGE RUNWAYS
AS AN AIRCRAFT HEIGHT FINDING SYSTEM
TO TRACK IN AZIMUTH
ANTENNA MOUNT ROTATES THROUGH
385 IN EITHER DIRECTION AT 12
PER SECOND

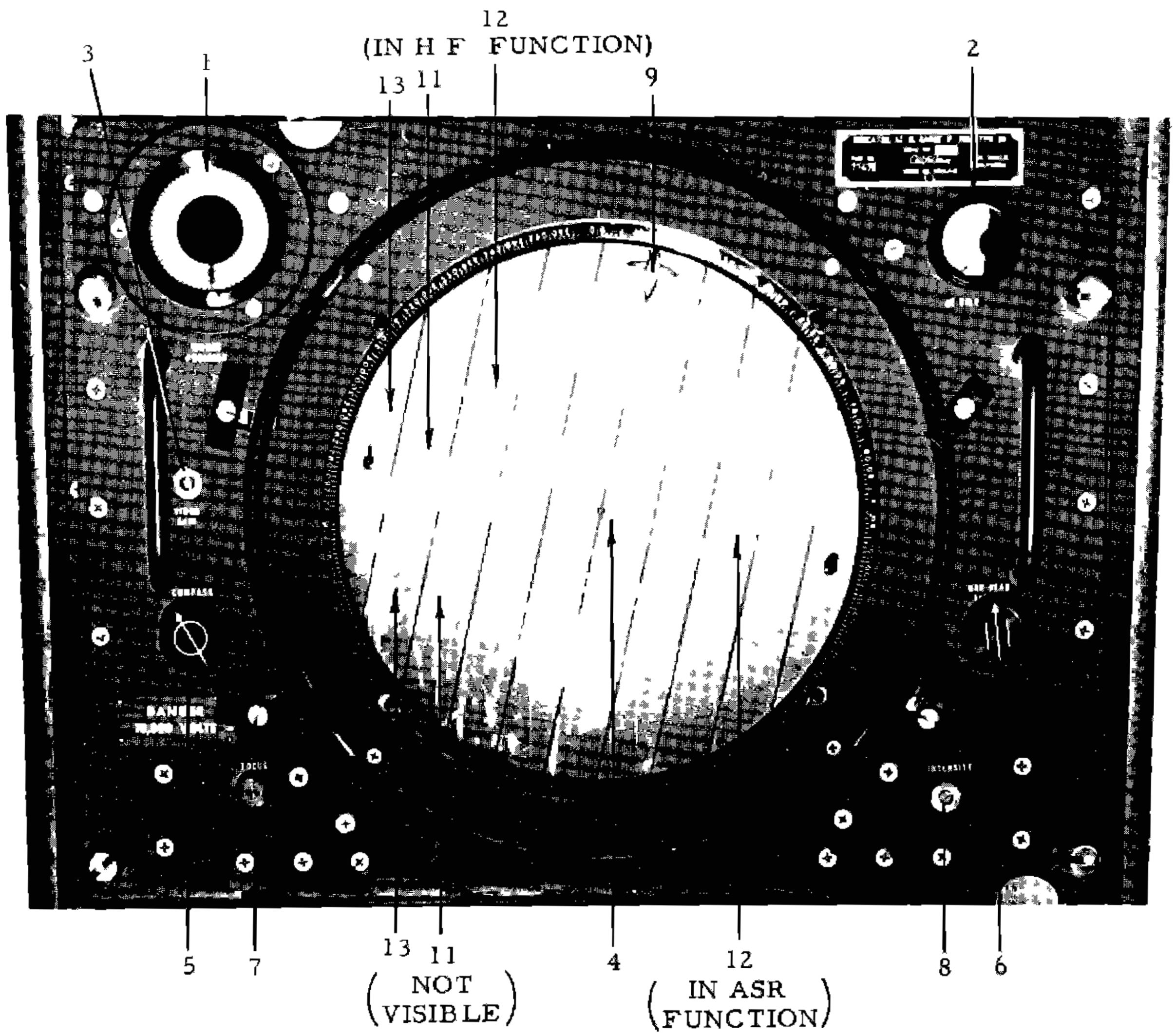



AZIMUTH ANTENNA TILT
ELEVATION ANTENNA MOVEMENT
AZIMUTH ANTENNA CAN BE TILTED (SERVOED)
FROM 0 TO 25
ELEVATION ANTENNA CAN BE ROTATED (SERVOED)
TO LEFT OR RIGHT

FIG 4 FUNCTIONS OF ANTENNA SYSTEM

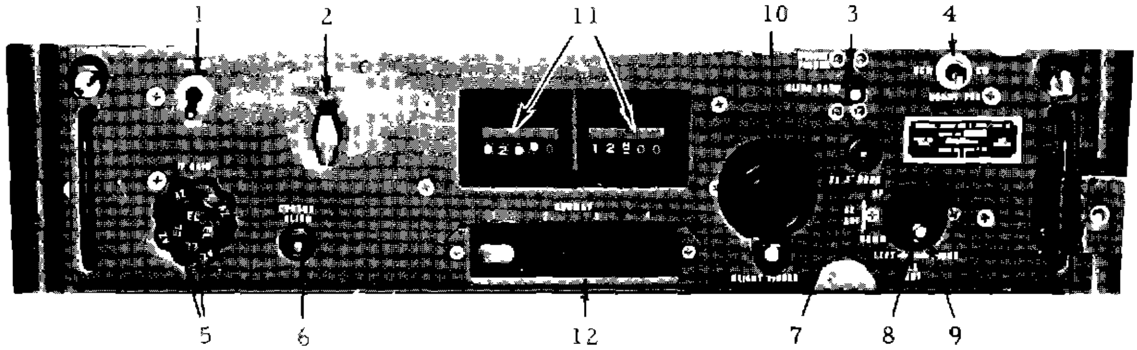



A- POWER DISTRIBUTION PANEL

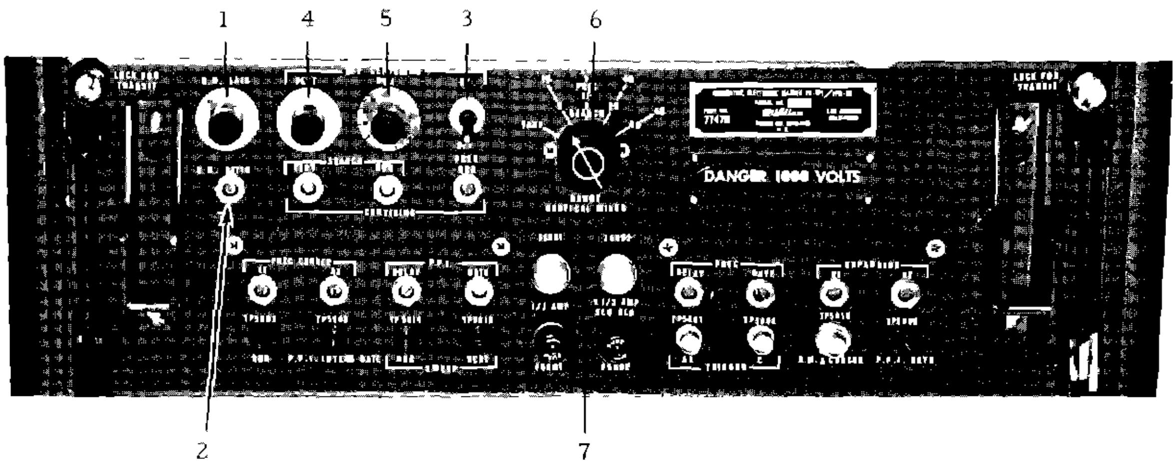



B - AZ EL RANGE INDICATOR

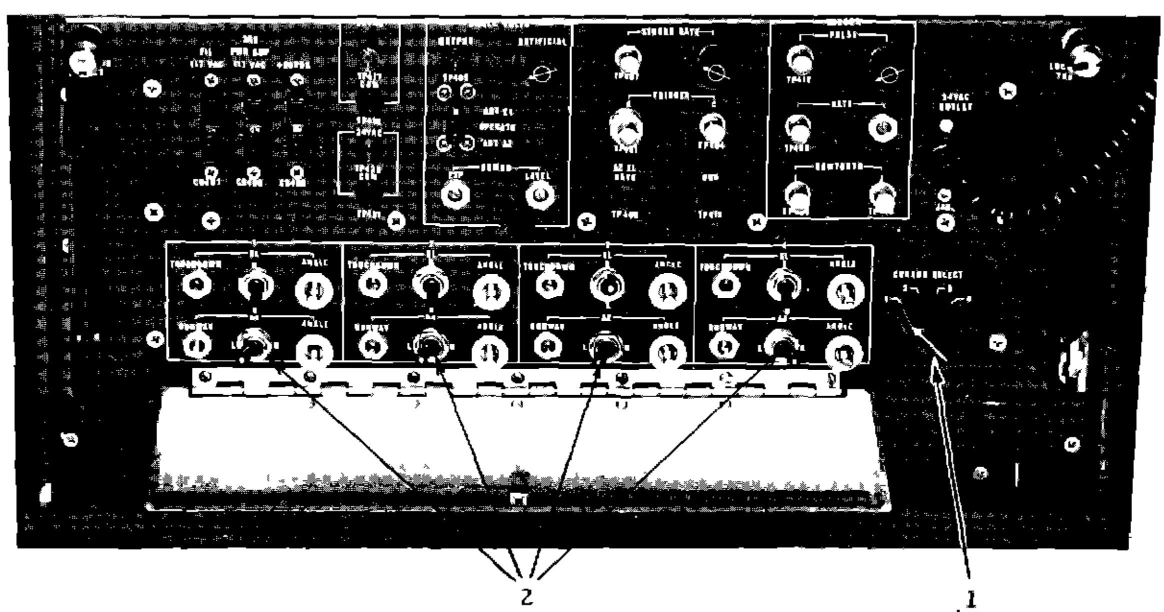
FIG 5 INDICATOR AND POWER DISTRIBUTION PANEL



A - INDICATOR FUNCTION CONTROL PANEL



B - ELECTRONIC MARKER GENERATOR



C - CURSOR ALIGNMENT CONTROL PANEL

FIG 6 OPERATOR CONTROLS

CAA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS INDIANA

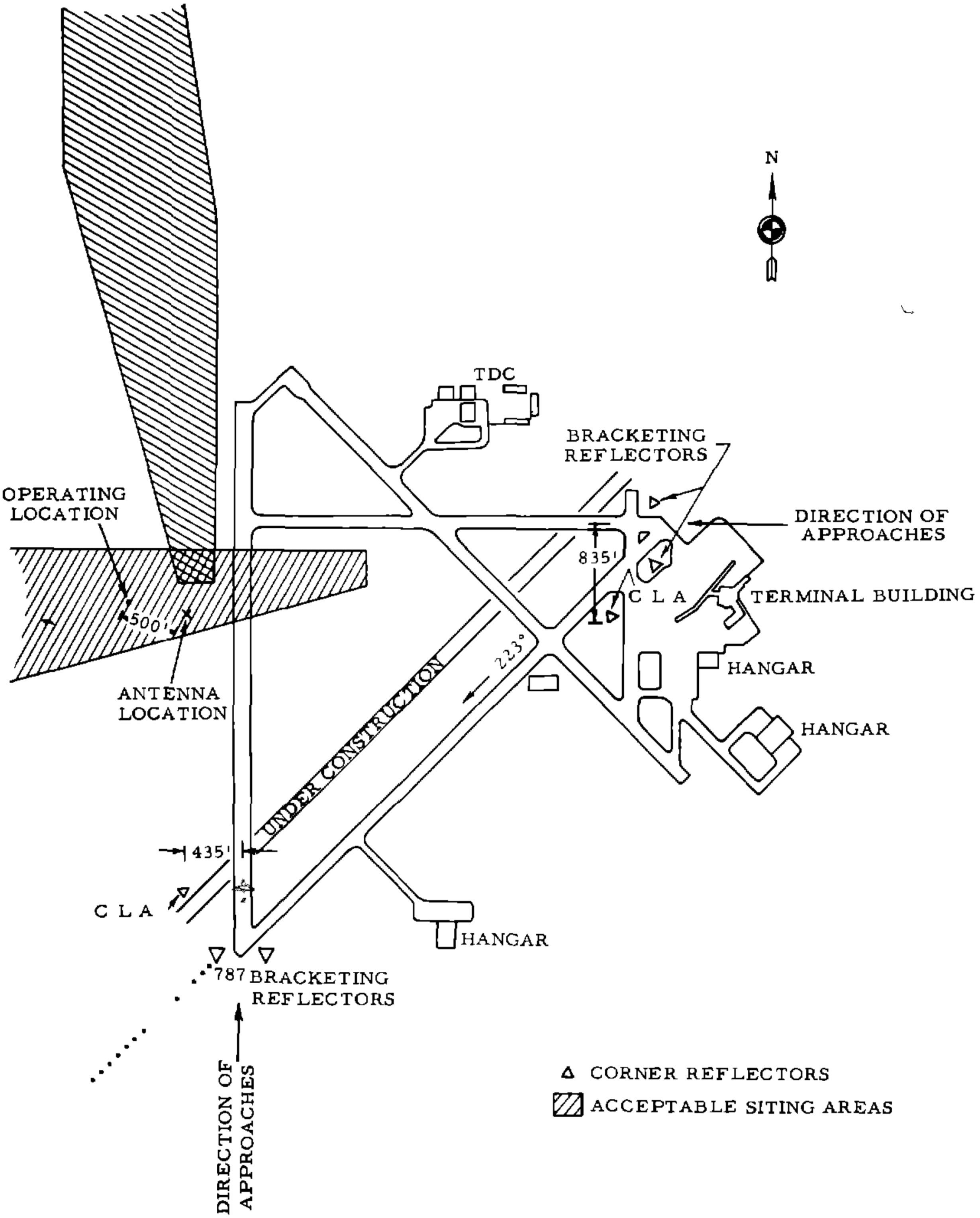



FIG 7 SITING OF QUADRADAR AND LOCATION OF ALIGNMENT REFLECTORS
INDIANAPOLIS AIRPORT

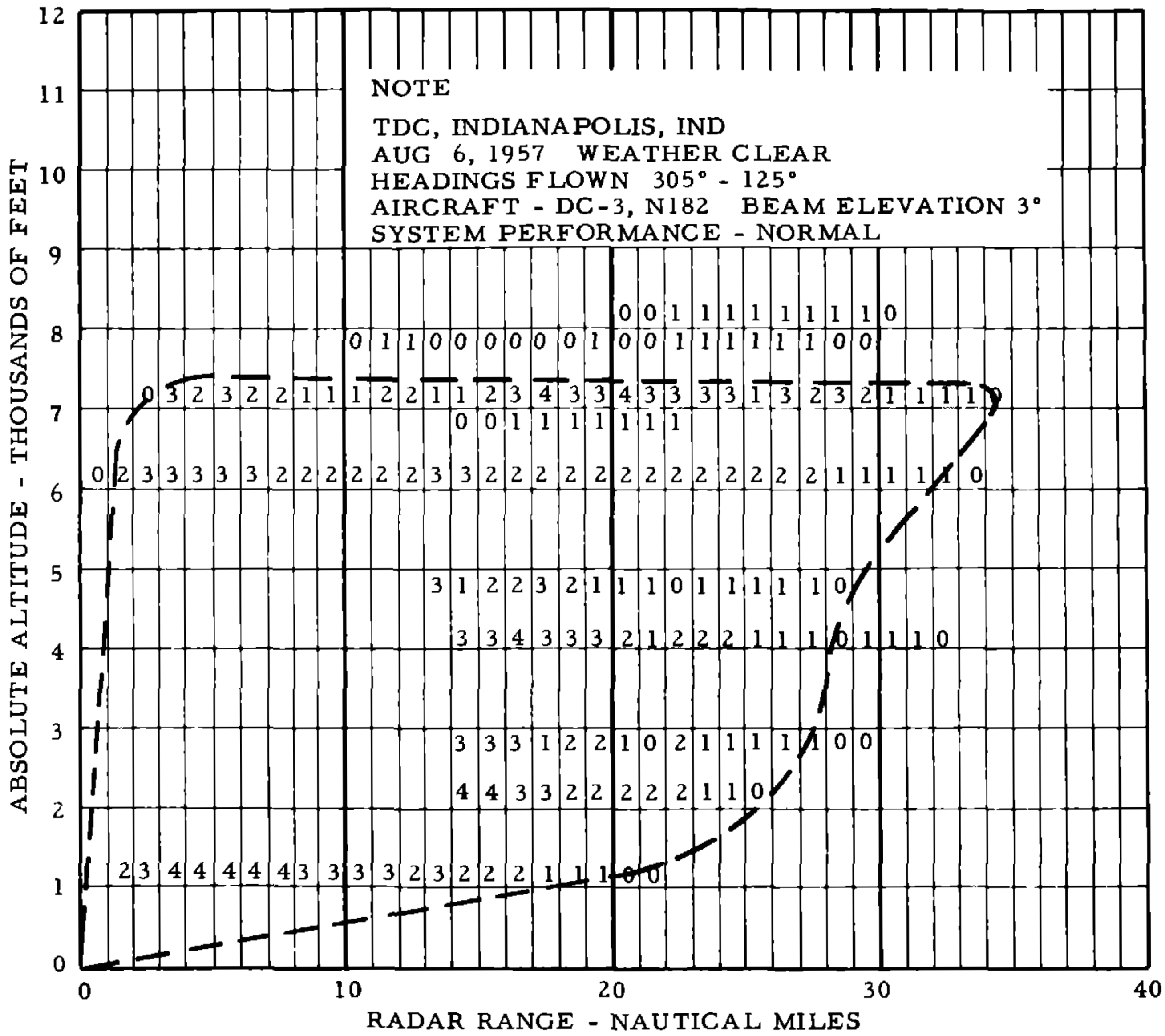



FIG 8 50 KILOWATT SURVEILLANCE RADAR ELEVATION PATTERN
(LINEAR POLARIZATION)

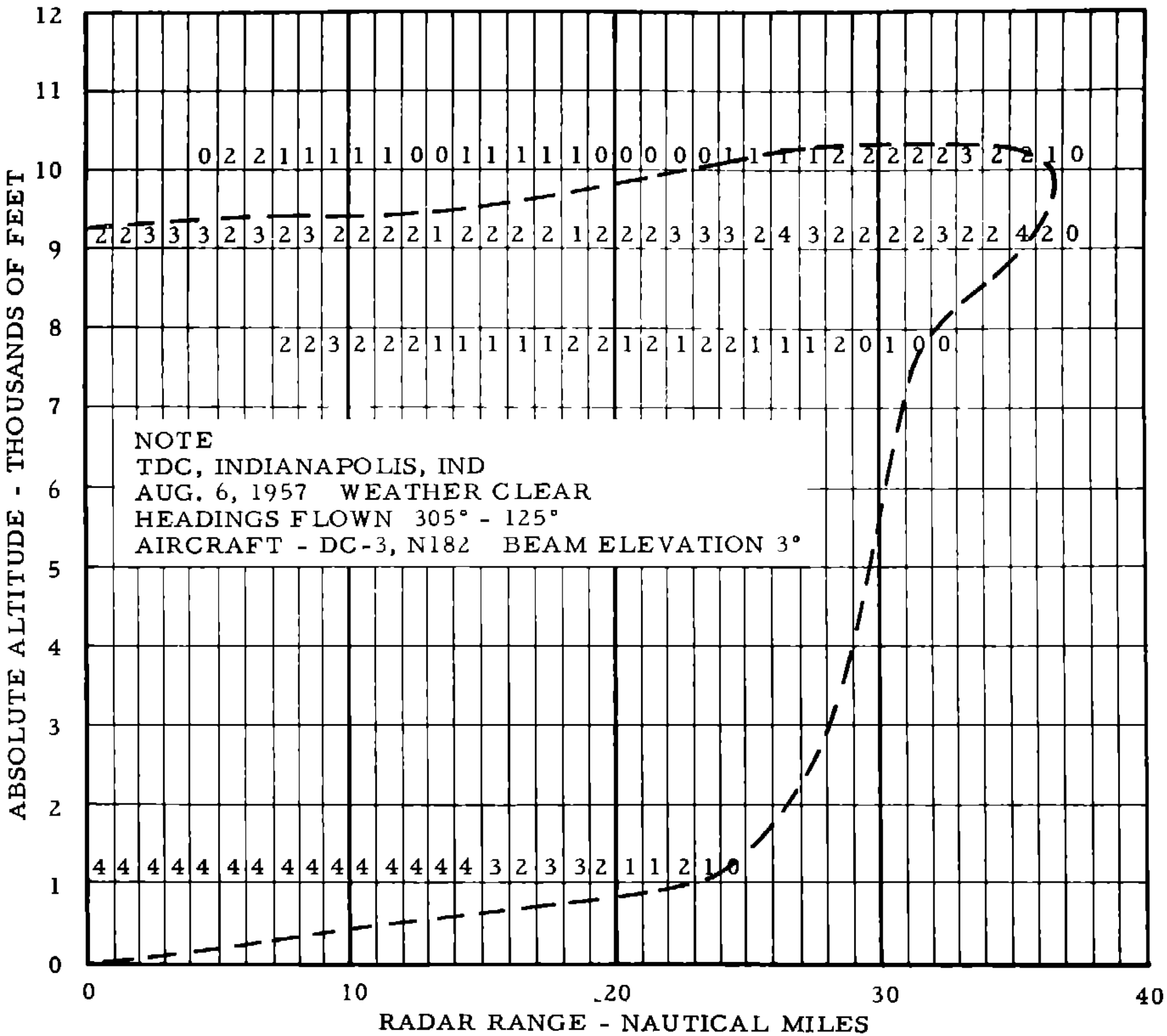



FIG 9 150 KILOWATT SURVEILLANCE RADAR ELEVATION PATTERN (LINEAR POLARIZATION)

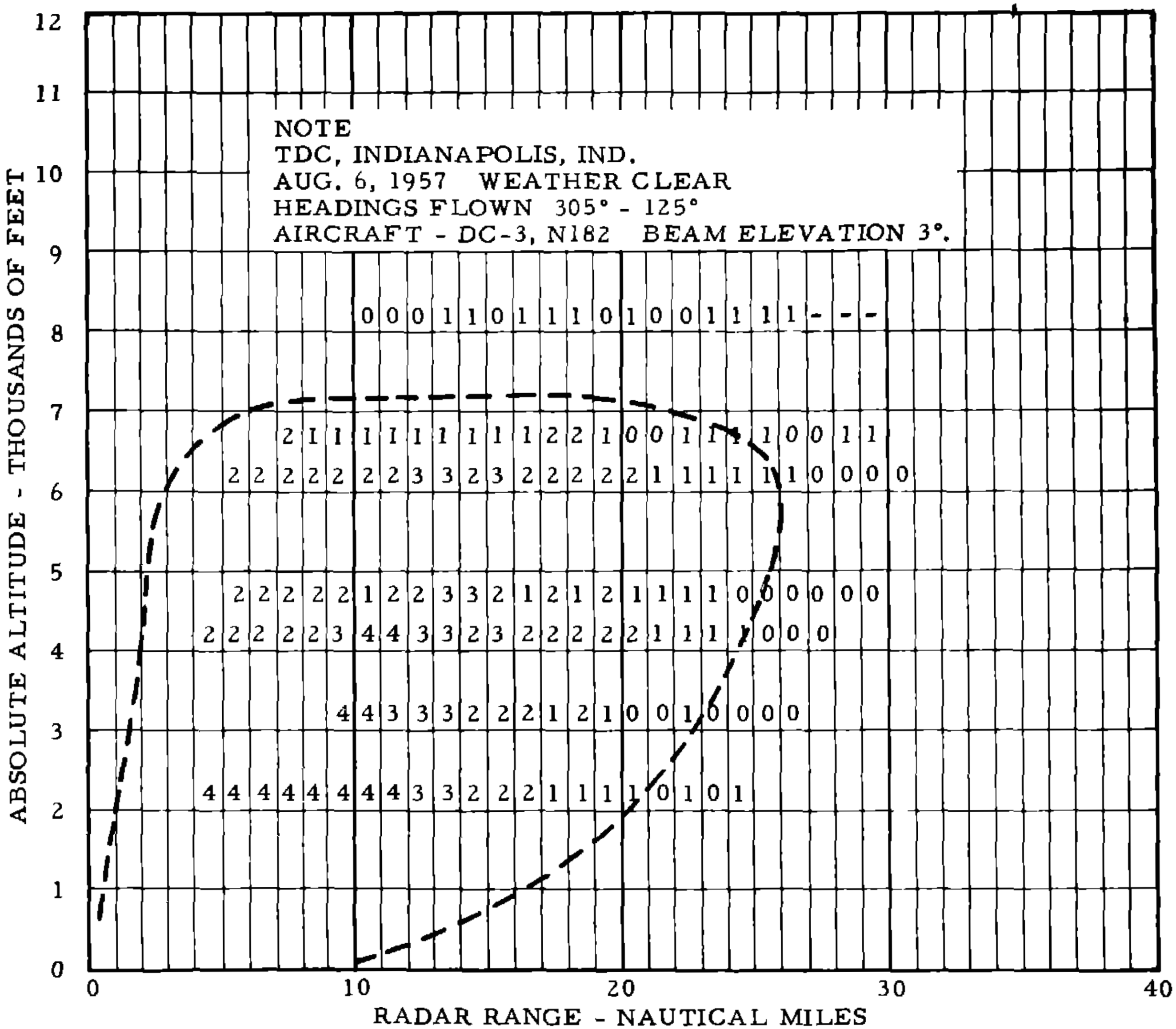
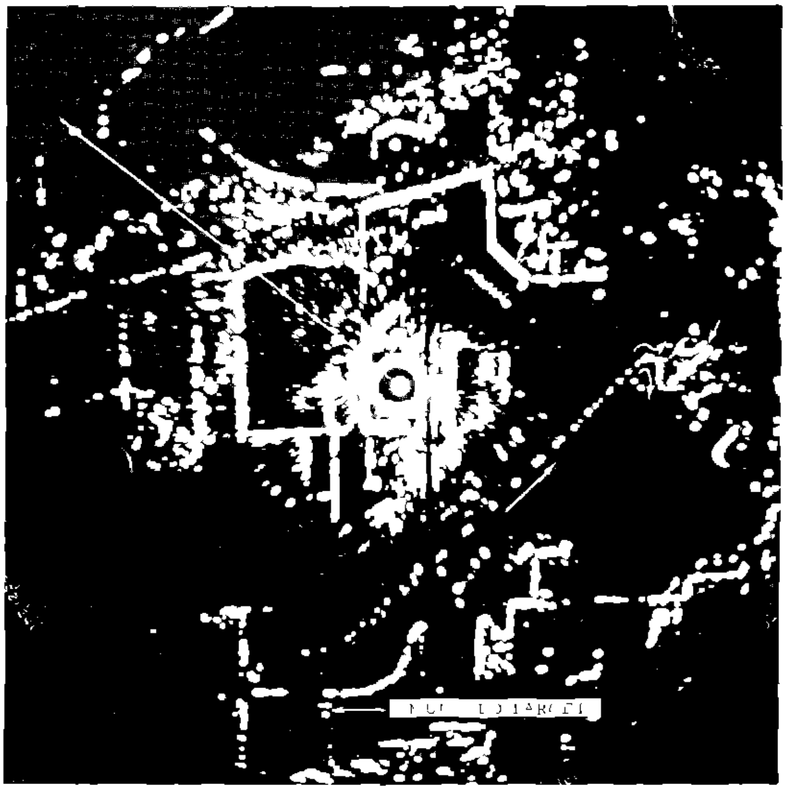
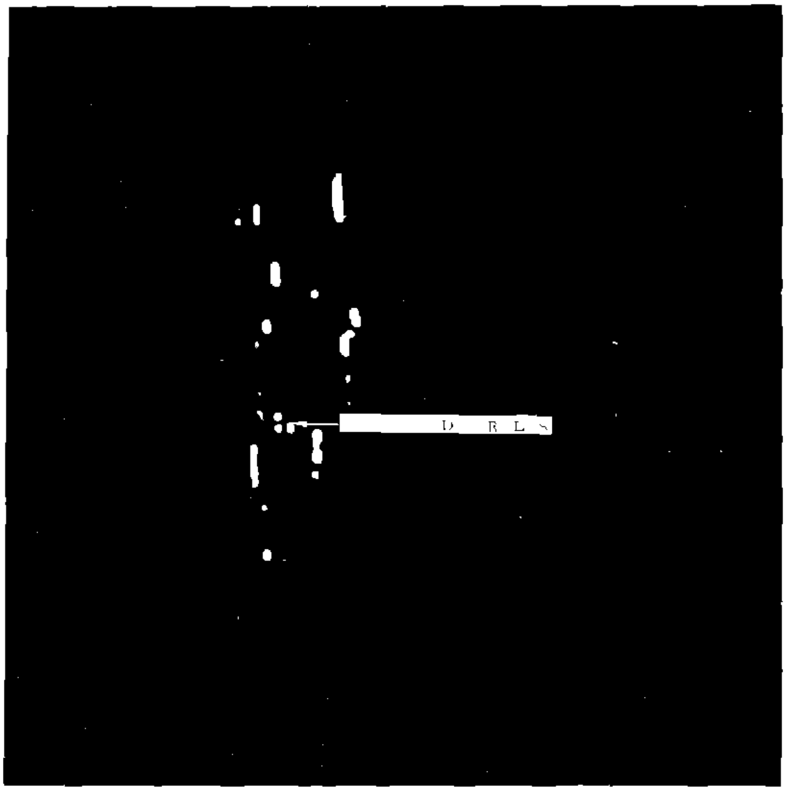



FIG 10 50 KILOWATT SURVEILLANCE RADAR ELEVATION PATTERN
(CIRCULAR POLARIZATION)



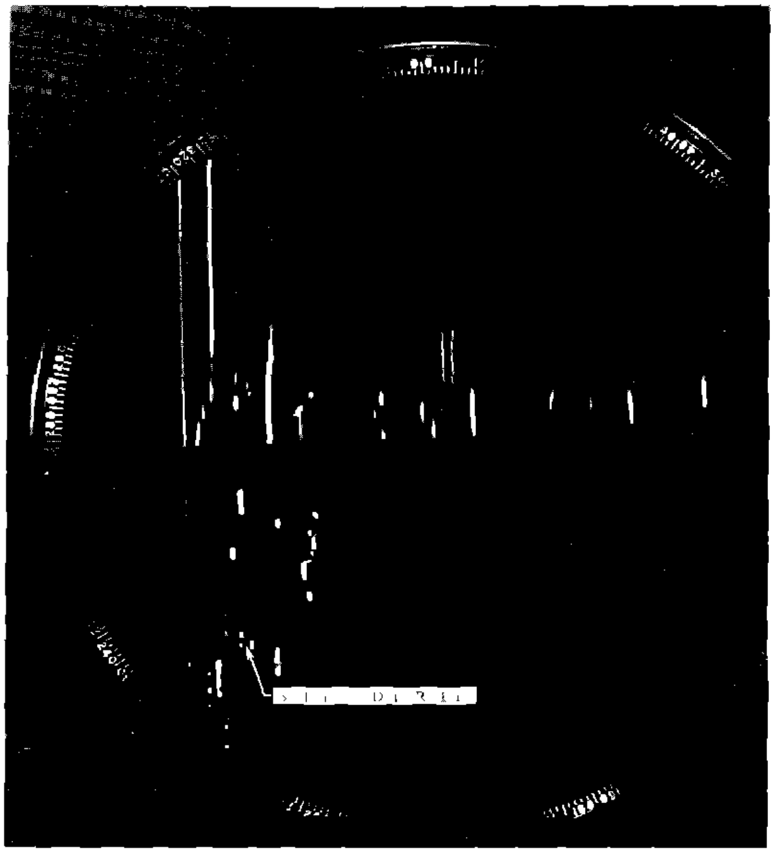
50 KILOWATT TAXI FUNCTION



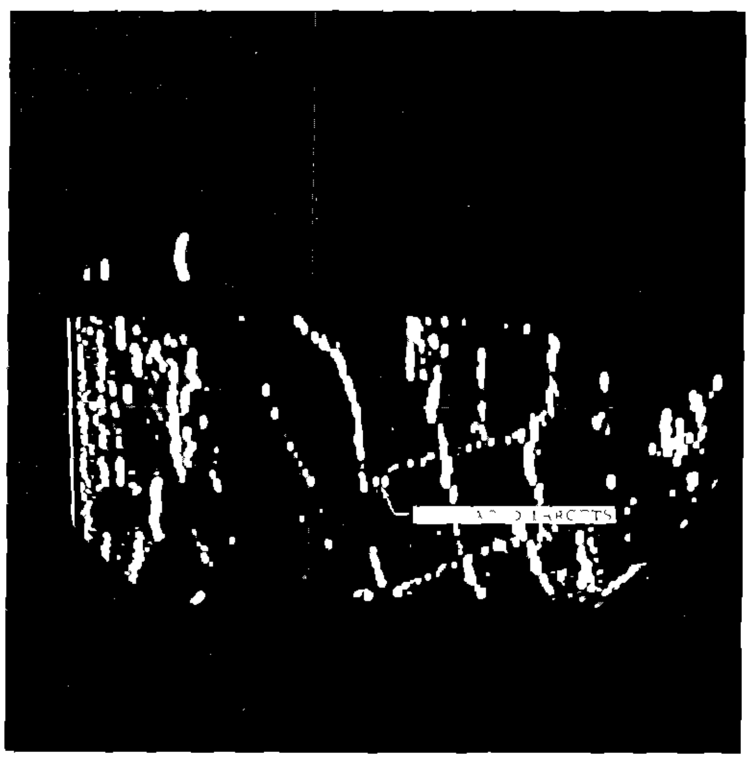
50 KILOWATT PRECISION APPROACH FUNCTION

FIG. 13 QUADRADAR RESOLUTION AT 1000 FEET

CAA TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA



K[illegible] WATT PRECISION APPROACH FUNCTION



150 KILOWATT PRECISION APPROACH FUNCTION

FIG 12 QUADRADAR RESOLUTION AT 5 000 FEET

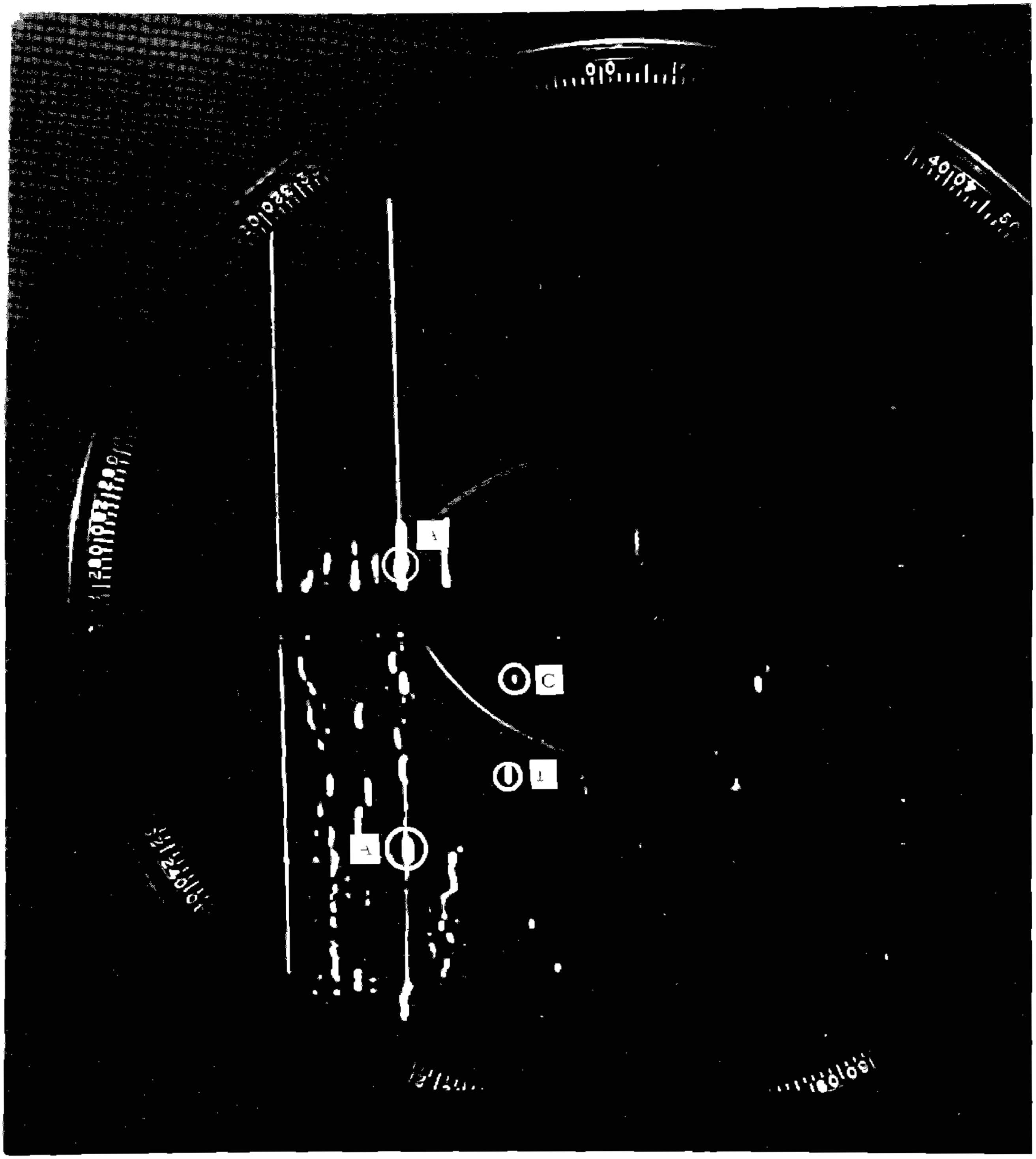


FIG 13 PRECISION APPROACH CURSOR ALIGNMENT

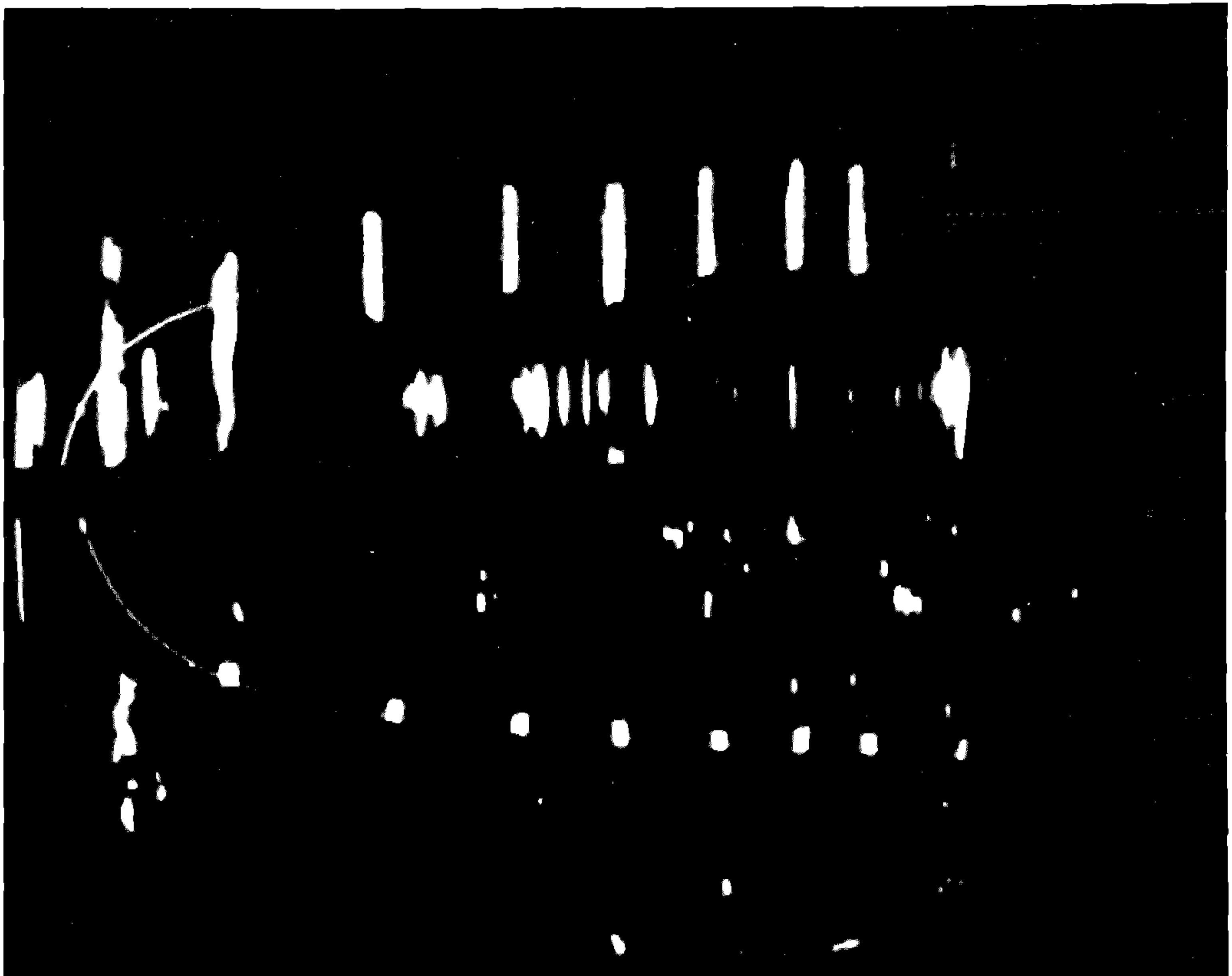


FIG. 14 PRECISION APPROACH ELEVATION ERRORS

CAA TECHNICAL DEVELOPMENT CENTER INDIANAPOLIS INDIANA

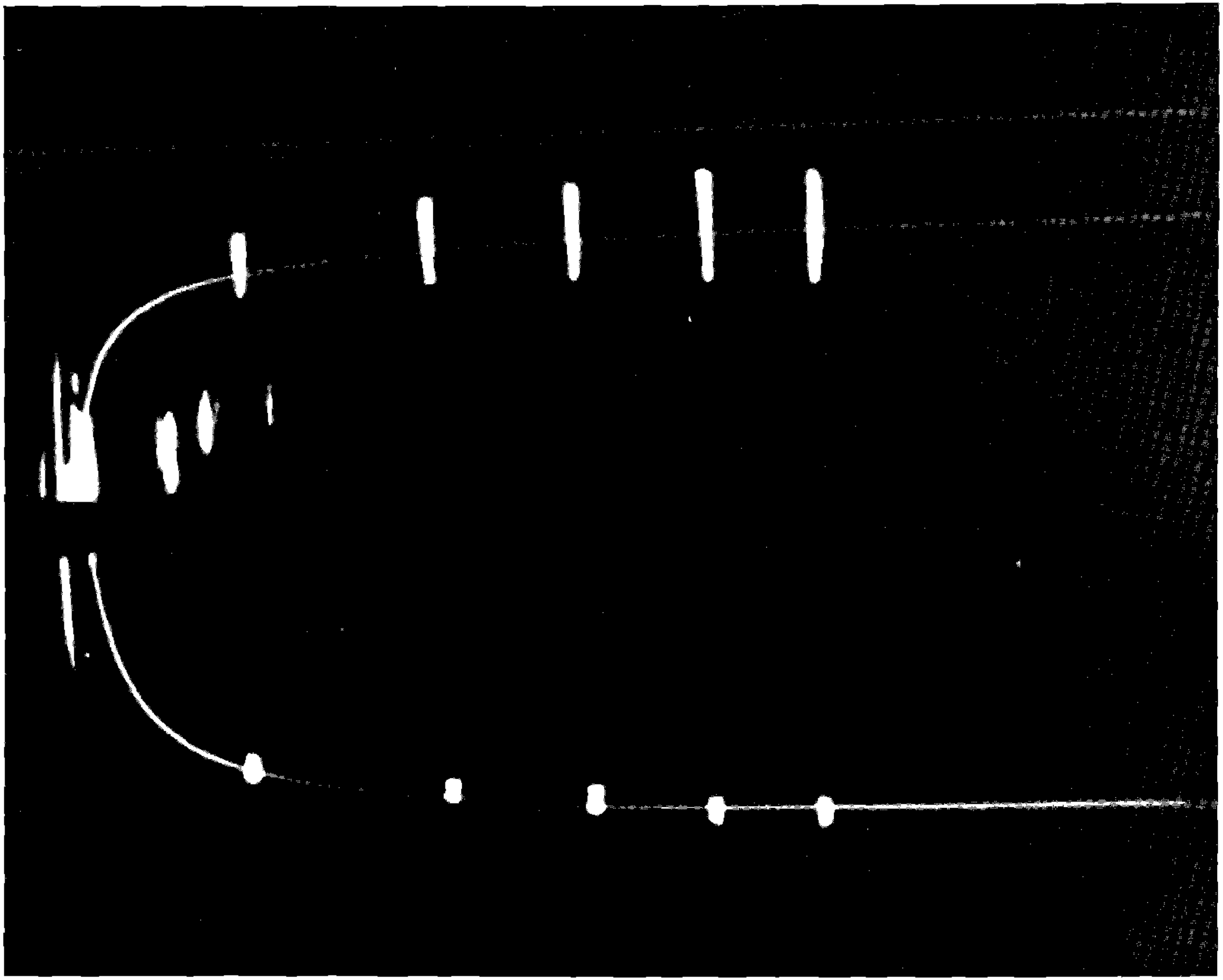


FIG 15 PRECISION APPROACH AZIMUTH ERRORS

CAA TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA

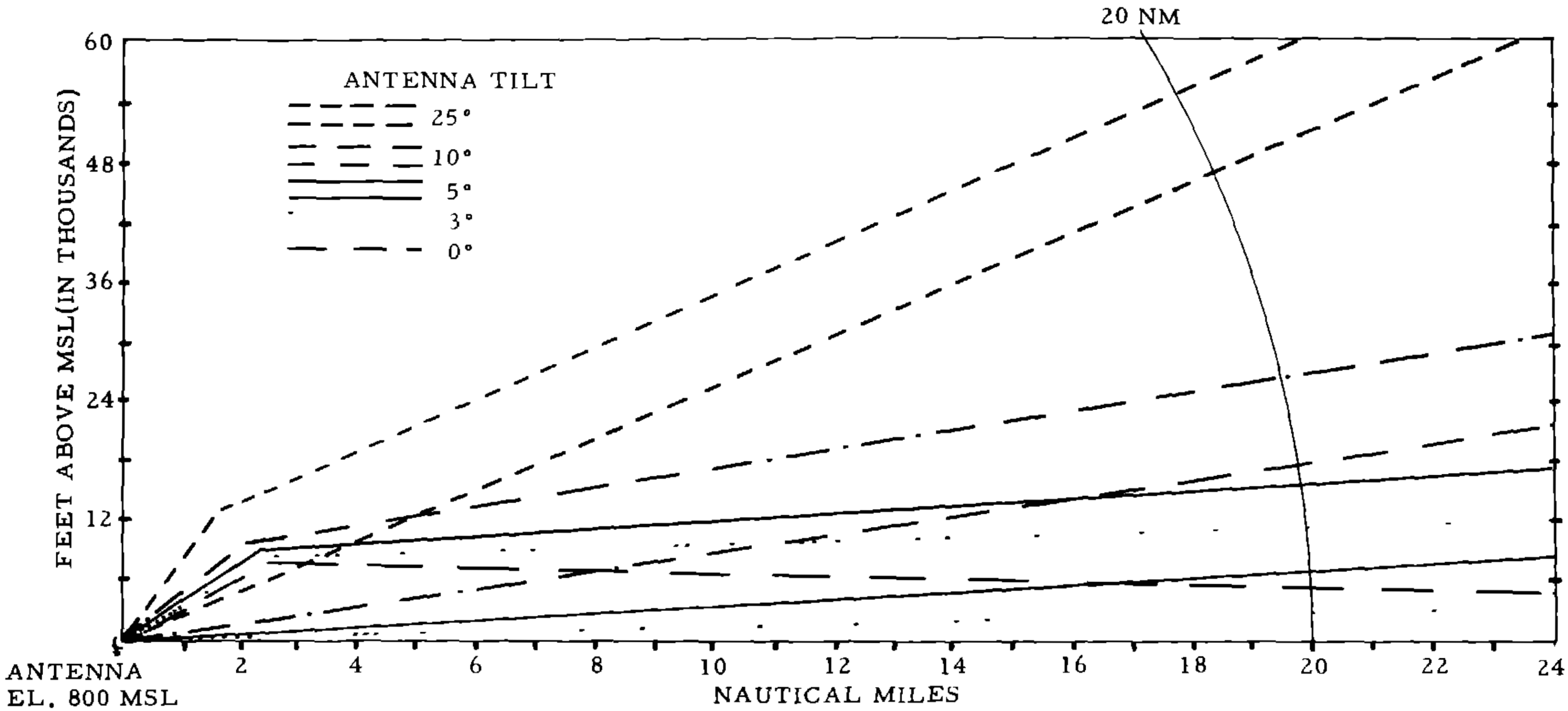



FIG 16 APPROXIMATE VERTICAL COVERAGE OF COSECANTED PATTERN

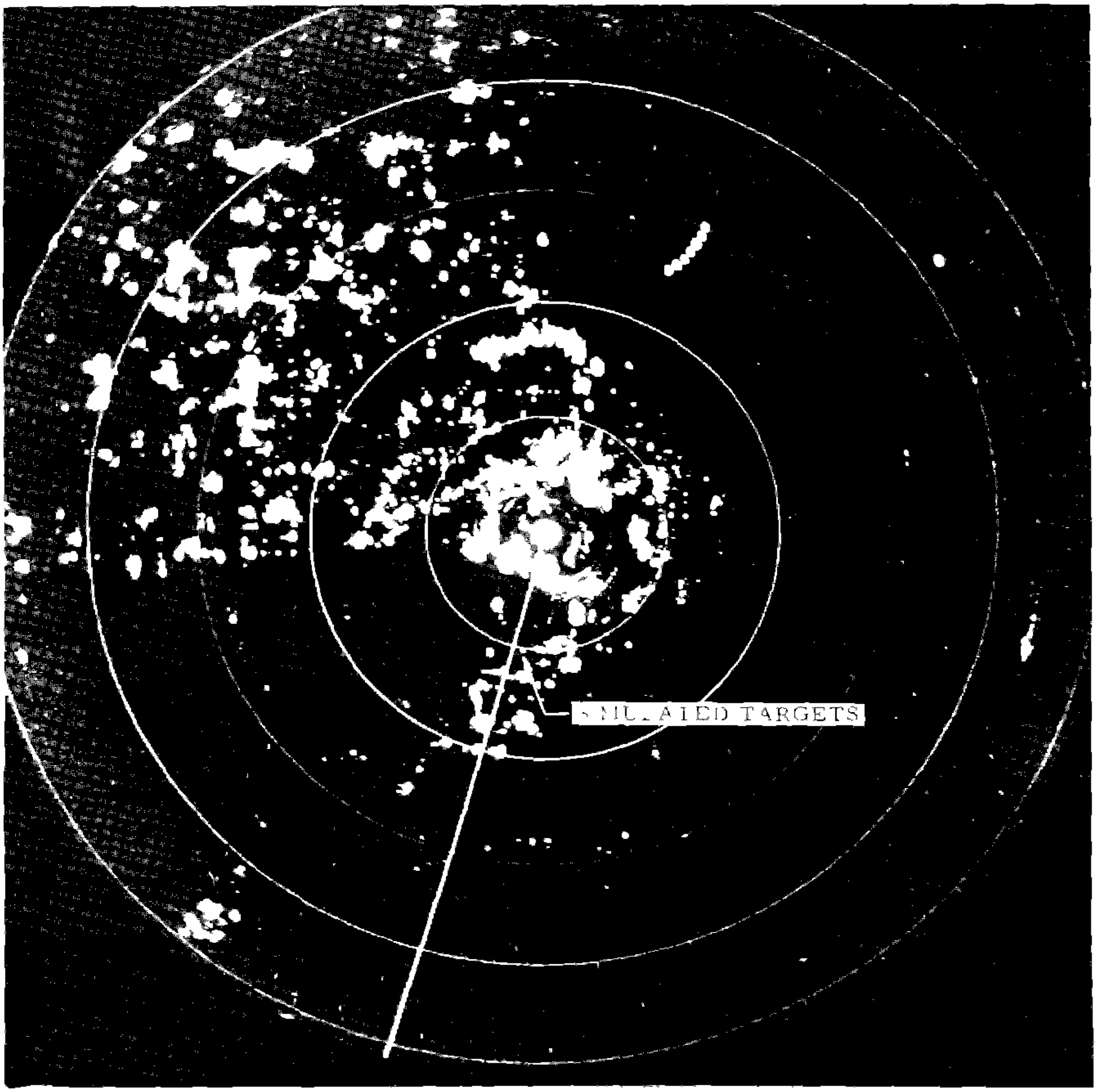



FIG 17 QUADRADAR SURVEILLANCE 10 MILES AT 3 2 DEGREE ANTENNA TILT

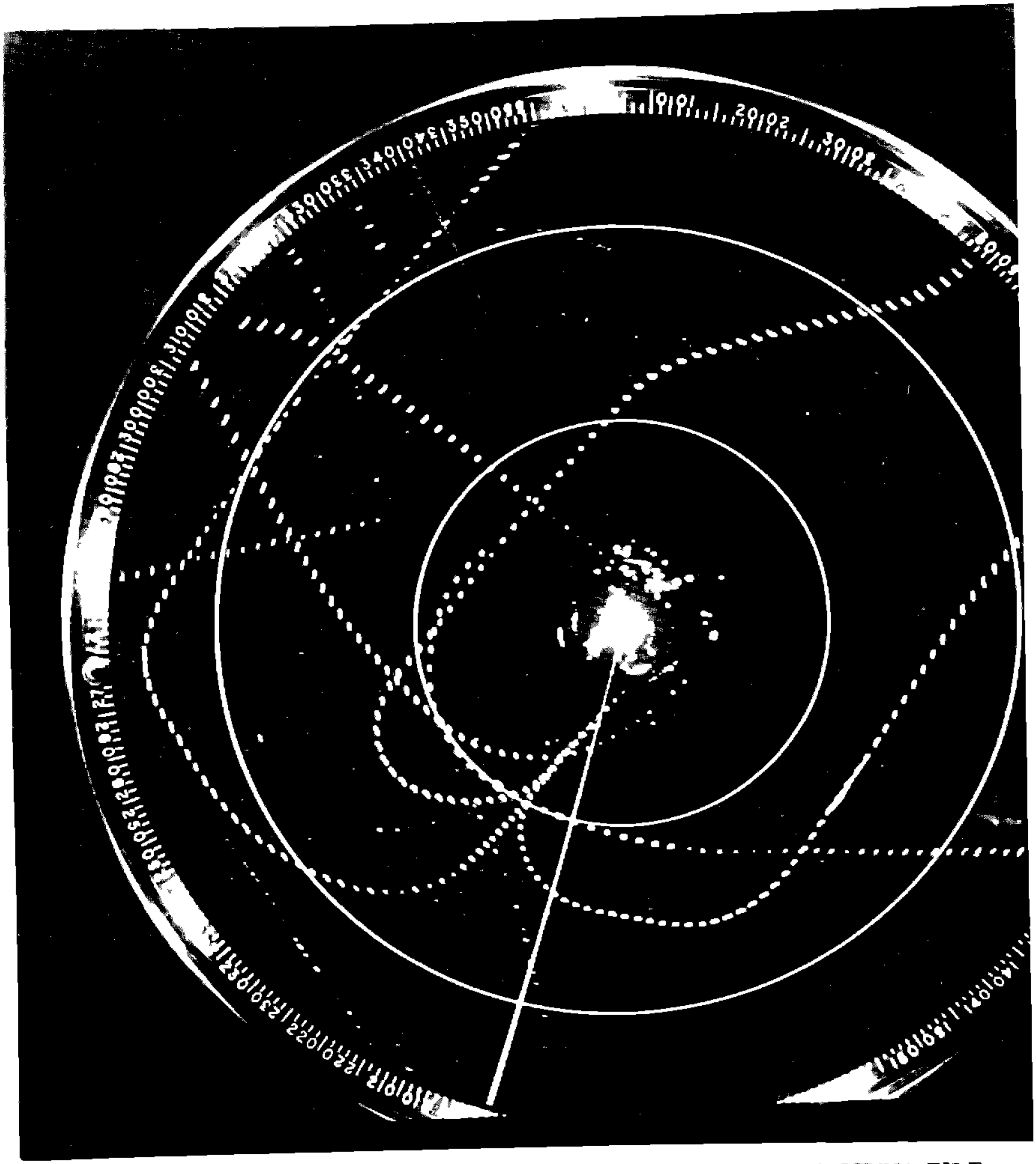
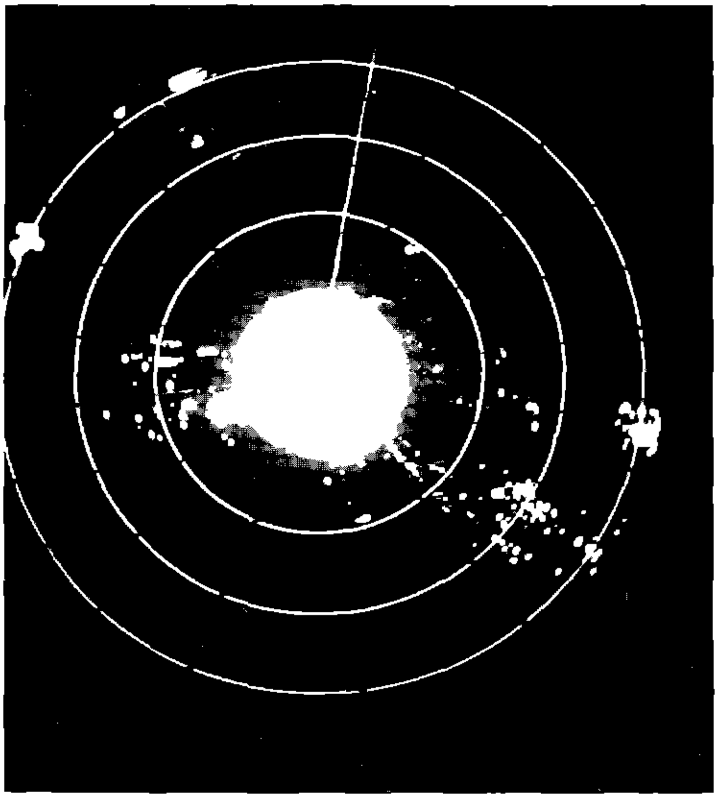
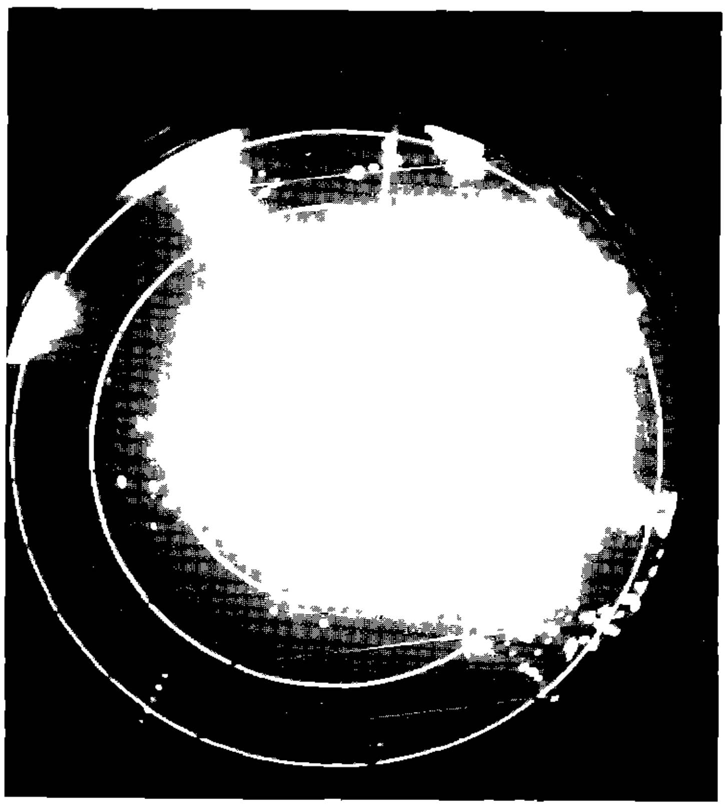


FIG 18 QUADRADAR SURVEILLANCE 10 MILES AT 5 DEGREE ANTENNA TILT

CAA TECHNICAL
DEVELOPMENT CENTER
INDIANAPOLIS INDIANA



[illegible]



LINEAR POLARIZATION

FIG 19 50 KILOWATT PPI DISPLAY DURING HEAVY RAIN