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REPORT ON COMPARATIVE TESTS OF EXISTING TERRAIN CLEARANCE INDICATORS

by

R. C. Borden and H. A. Kay

Radio Development Division

Technical Development

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REPORT ON COMPARATIVE TESTS OF EXISTING TERRAIN CLEARANCE INDICATORS

SUMMARY

This report describes the results of a number of flight tests conducted in an effort to obtain relative evaluations of the so-called Hughes radar type of terrain clearance indicator and the FM type of radio altimeter. These tests were conducted in the vicinity of Indianapolis, Indiana, and in the Smoky Mountains near Knoxville, Tennessee. Pertinent data are included, as well as a discussion of equipment limitations.

EQUIPMENT

The AVQ-6 radio altimeter which was used during these tests is manufactured by the Radio Corporation of America and is very nearly the same equipment as the APN-1 radio altimeter which was employed extensively by the armed services during the war. This device supplies continuous altitude information to the pilot through means of a d-c meter mounted on the instrument panel. Two altitude ranges are available, 0-400 feet and 400-4000 feet. Altitude measurement is accomplished by transmitting a frequency modulated carrier which varies between 420 and 460 megacycles. A portion of the energy striking the ground is reflected back to the airplane where it is received by a separate antenna. Since a finite time is required for this energy to travel to the ground and return, the return signal will be at a slightly different frequency than that of the transmitted carrier at the time of arrival of the return signal. The difference between these two frequencies is a measure of the distance to the reflecting surface and is in the audio range. A suitable detector is used to measure this frequency difference, and following detection, this audio wave form is shaped into a limited square wave for counting by conventional circuits, which in turn drive the indicating meter. The AVQ-6 radio altimeter weighs approximately 30 pounds including all accessories. It is contained in one box 19 1/16 x 7 9/64 x 7 1/16 inches and is shock mounted. There are 14 tubes in the equipment, and the power consumption is 70 watts at 27 volts d-c. Space is required on the aircraft instrument panel for a three-inch indicator, a three-inch limit switch, and three indicator lights. The complete equipment is shown in Fig. 1. Fig. 2 shows the indicator, limit switch, and indicator lights as mounted on the instrument panel, and Fig 3 shows the location of the two antennas.

The Hughes radar is a modification of the APS-13 tail-warning radar which was employed during the war for detecting the presence of hostile aircraft within a limited range behind APS-13 equipped planes. The principle of operation is that of conventional radar; however, there is no oscilloscope indicator. In the case of the Hughes radar an echo returning from an object within 500 or 2000 feet (depending on the range scale selected) will operate an indicator light in the cockpit. A red light is used for 500-foot warning and an amber light for 2000-foot warning. If desired, an audio warning device, such as a horn, might also be operated. The basis of this indication is the fact that the radar receiver is made incapable of operation except for a period of time equal to that of a round trip radio path of 2000 or 500 feet, whichever the case may be. This time interval is measured from the instant of pulse transmission.

The Hughes radar weighs approximately 16 pounds, complete with antenna and cables. It is contained in one shock-mounted box 15 7/32 x 7 25/32 x 8 15/32 inches. There are 17 tubes in the equipment. The power consumption is 90 watts at 27 volts d-c. The space required on tre aircraft instrument panel for the indicator lights and control switches is approximately 5x 4 inches.

The complete equipment is shown in Fig. 4, while Fig. 5 shows the indicator and control box on the instrument panel, and Fig. 6 shows the antenna.

RESULTS

Preliminary flight tests were conducted in the vicinity of Indianapolis to ascertain that both equipments were in proper operating condition and to check the accuracy of calibrations. These tests showed that the indicated accuracy of each was quite good. In the case of the Hughes radar the 500-foot warning did not appear to be independent of gain adjustment, since widening of the gate was evidenced as the gain was increased. The 2000-foot gate was not affected. The so-called "500-foot gain control" of the Hughes radar is not truly a receiver gain control, but controls the amplitude of the 500-foot gate supplied to the receiver. Since this gate is not square, but more nearly sinusoidal in shape, a change in amplitude is accompanied by a change in gate width, and consequently a change in the operating point of the red warning light.

The spread available with this control is in the neighborhood of 100 feet. If set to the proper operating point, there is no reason why it should not remain there for as long a time as would normally be assigned between routine checks for such equipment if placed in commercial operation.

Another bad feature of the red light indication is apparent as the aircraft approaches the ground. At approximately 100 feet altitude or less, the red warning light may, and usually does, go out. This is due to the fact that the receiver is blocked during the time of the transmitted pulse and is incapable of reception during this short period of time. If echoes are received from objects other than the closest ground point at ranges greater than 100 feet but less than 500 feet, the warning light may remain on throughout the landing procedure and on the ground. In short, operation of the red light indicator at absolute altitudes of less than 100 feet is erratic.

The 2000-foot gate is independent of tube aging, as far as accuracy of the indication is concerned. Calibration of the radio altimeter is, to some extent, dependent upon emission capabilities of the tubes and will change with tube aging, although if the period between routine calibration checks were not made excessive, this would not present too serious a drawback. On the initial flight check of the Hughes radar it was found that the amber light remained on well above 2000 feet. It was discovered that internal receiver noise and external interference noise was triggering the relay tube which operates the light. By reducing the gain to a suitable level, this trouble was cleared up. There appears to be plenty of sensitivity under this lowered gain condition, since the gain control can be reduced to the position of lowest gain, and there is still adequate signal when at 2000 feet to operate the light. It is of interest to note that should the equipment malfunction because of excessive noise, the malfunctioning would be "safe" since the yellow light would be on. A more dangerous possibility would be a gradual reduction of receiver sensitivity, or power output, to the point where insufficient signal would be received at 2000 feet to operate the light. In this case no light would be indicated until the aircraft was close enough to the ground to receive a return signal of the threshold amplitude. This altitude might well be dangerously low.

Following these local flights, more extensive flights were made over relatively rugged terrain in the Smoky Mountains near Knoxville. The purpose of the first flight was to determine the utility of the Hughes radar 2000-foot warning light. Mt. Guyot, a peak in excess of 6600 feet, was approached from a point about nine miles west, at an altitude of 2000 feet above the ground. Naturally, the yellow signal was lighted at this time, and the pilot was instructed to continue flight toward the peak but to climb until the signal was cleared. Upon clearing the light, the pilot leveled off until the warning was again received, then repeated the procedure outlined above. These tactics resulted in a comfortable margin of clearance over the mountain peak. During this flight, rates of climb of 2000 feet per minute and greater were observed on the rate-of-climb indicator. It was also observed during this flight that the radio altimeter appeared to be indicating clearances in excess of those actually maintained. Fig. 7 shows a contour of Mt. Guyot for the approach flown and indicates how it might be cleared by successive climbs as warning signals are received. The aircraft path sketched thereon is not necessarily that which was described during this particular flight (such data are nearly impossible to obtain) but is the ascent path recommended by promoters of the Hughes radar. This ascent procedure specifically dictates a 900-foot climb for the first mile following the yellow indication, and 500 feet for each succeeding mile until a 2000-foot climb has been accomplished or until the yellow light has been cleared, whichever is later.

In order to examine the ability of the altimeter to accurately indicate rapid changes in terrain elevation a flight path having this characteristic was selected. The flight path selected is about 8 1/2 miles in length and has the contour profile shown in Fig. 8. This contour was plotted from data appearing on Quadrangle Charts of the U. S. Geological Survey. The particular charts involved were the Wear Cove and Walden Creek Quadrangles which cover an area extending from 35°37'30" S to 35°52'30" S in latitude, and from 83°37'30" W to 83°45' W in longitude. The flight path extends from the northernmost point of a bend in the Chapman Highway (near the Zion Hill School on the Walden Creek Quadrangle) to the peak of Benson Mountain (Wear Cove Quadrangle). A slight dog-leg was involved in flying the course in order to have the aircraft pass over the summit of Chilhowee Mountain (elevation 3069 feet). This peak is located approximately midway between the two end points. All three of these check points were readily identifiable from the air. Four passes were made over this track, two each at Kollsman altimeter readings of 4000 and 3600 feet. At each altitude both a north-south and a south-north pass were made. The instantaneous readings of the radio altimeter were recorded by means of a d-c recorder (Esterline-Angus) connected in series with the indicating meter. The recorder was equipped with a shorting switch so that it could be alternately cut in or out of the altimeter circuit. It was observed that operation of this switch resulted in a momentary flicker of the indicator needle followed by a return to the previously indicated altitude. In other words insertion of the recorder is held to have negligible effect on the altimeter reading. After plotting the clearance contour recorded by the altimeter and comparing it with the actual clearance contour (obtained by subtracting the elevations shown in Fig. 8 from the appropriate Kollsman value for each pass), it was discovered that unusually large errors, up to 1000 feet, between the two curves were indicated. Subsequent laboratory tests of the recorder revealed that its response to rapidly changing currents was rather poor, though by no means poor enough to justify the magnitude of the errors observed between actual and indicated clearance. However, in order to eliminate the recorder contribution to the actual errors, it was decided to repeat the above tests taking visual readings of the altimeter indicator at five-second intervals. In order to eliminate observational error insofar as possible, a total of 22 passes were made, 11 in each direction, with 16 of the total being made at a barometric altitude of 4000 feet, and the remaining six at 3500 feet.

After plotting the data thus taken, it was found that separate runs in the same direction, and at equal Kollsman altitudes, repeated themselves rather well. This is evidenced by Fig. 9 which is a comparison of runs 18, 20, and 22 all on a south-north course, with runs 17, 19, and 21 all on a north-south course, and with the actual clearance contour.

A study of Fig. 9 reveals that appreciable error exists between the actual and recorded clearance values, this error being particularly severe at the center peak. The error appears to be made up of two components. The actual minimum values recorded by the altimeter show a discrepancy of 250-300 feet when compared with the actual clearance existent over the peak. This error is in the same direction in all cases, the recorded clearance always being greater than the actual clearance. In addition it should be observed that there is a linear displacement between the actual clearance curve and the recorded curves. The actual peak lies nearly symmetrically between the two recorded peaks. By noting the directions of flight in each case, it is seen that a lag exists in recording changes in clearance. This lag introduces additional error in the instantaneous altimeter readings. Totaling both errors, it was found that instantaneous discrepancy of 400-600 feet exists in the case of the south-north passes and 550-1000 feet in the case of the north-south passes. Again these errors take the form of greater indicated clearance than actual clearance. A large portion of the error can be assigned simply to the electrical lag inherent in the altimeter, but a not insignificant portion can be laid to the effect of spurious reflections. Spurious reflections are those which are returned from terrain surfaces other than those surfaces closest to the aircraft. Due to the nature of the measuring and counting circuits within the altimeter, the current supplied to the indicator is determined by a general average of reflections, and consequently of different audio frequencies. Thus, the reading of the indicator can quite conceivably be greater than the shortest distance to the ground. In the ideal case over flat and level terrain, or over smooth water, all but the reflections from directly beneath the aircraft will be insignificant because of the lack of normal incidence. Over mountainous areas, cases of normal and near normal incidence of the transmitted energy become quite numerous and consequently there is an increasing number of spurious reflections of sufficient strength to affect the operation of the measuring circuits. This is due largely to the broad antenna pattern employed.

The particular altimeter amployed was properly calibrated and had been checked over flat and level terrain before making the approaches to the peak.

Fig. 10 is a chart similar to Fig. 3, except that the recorded curves in this case were plotted from data obtained during passes at a constantly maintained Kollsman altitude of 4000 feet (runs 11-16). The information contained on this chart sübstantiates that appearing in Fig. 3 with respect to the altimeter lag. In addition it should be noted that the errors between the recorded and actual clearance values are noticeably greater in Fig. 4 throughout the run. This is believed, in part, due to the greater ground area covered by the antenna pattern at the higher altitude, and consequently the increased cases of normal incidence of the transmitted carrier.

The 12 passes shown on Figs. 9 and 10 were all made within a one-hour period on the same afternoon. They are representative of a total of 26 passes made during the period of the tests.

The averaging effect of spurious reflections does not affect the Hughes radar since the indication is a simple light which will operate if there is <u>any</u> signal return from within 2000 feet regardless of direction.

Following the flights in the Smoky Mountain area, some extensive flight testing was conducted over Lake Michigan. The purpose of these flights was to observe various operational characteristics of the two equipments which could best be determined by flight over a flat and level area of considerable expanse.

One purpose of the above test was to determine the accuracy of the Hughes radar indications (both 2000-foot and 500-foot).

The elevation of Lake Michigan is 581 feet above sea level. The pilot was instructed to climb to 2580 feet and level off for a few miles in order to insure that the barometric altimeter reached a steady state. After this had been accomplished, level flight was continued with the operation of the 2000-foot light being recorded. Examination of the recording made reveals that the light was intermittent, being "on" approximately 50 percent of the time. This procedure was repeated at barometric altitudes of 2680 feet and 2480 feet. In the former case the yellow warning light was off for the entire run, and in the latter case it was "on" for the entire run. Admittedly, it is not possible to hold an aircraft closely at a prescribed altitude, nor can the barometric altimeter be depended upon more accurately than a few tens of feet, however, it is believed that the accuracy of the test was sufficient to show that operation of the yellow warning light was reliable. This test also indicates a transition period from "warning" to "no warning" of approximately 100 feet.

The above procedure was repeated for the 500-foot warning at suitable altitudes above the lake. Results indicated the transition period for the red light also to be about 100 feet, centered around 500 feet.

In an attempt to determine the effect of aircraft bank on the radio altimeter reading, the test airplane executed a 30-degree bank at constant altitude (turning) for one minute. The recording showed no fluctuations of the altimeter indicator during this time.

An interesting observation was made while flying from the water normal to and across an 80-foot bank. As the aircraft crossed the bank, the altimeter reading increased by 150 feet. This approach was repeated at a different point along the bank with the same results. After crossing the bank a second time, the course was reversed so that the airplane crossed the bank from shore to water. In this case the altimeter reading decreased by over 100 feet. In all instances the altimeter was set on the 4000-foot range. An effort was made to duplicate this phenomenon on the 400-foot range, but the equipment appeared to give the reverse, or correct, indication in each of these cases. Visual observations made on an earlier date indicated that the same thing was happening on the 400-foot range, but unfortunately, at that time there was no recorder in the circuit.

On completion of these over-water flights, the downtown section of Chicago was approached at a barometric altitude of 2900 feet. This was equivalent to approximately 2300 feet of actual clearance from the ground. The Hughes radar was set for 2000-foot warning, and the yellow warning light was off and on intermittently as the aircraft passed over the taller buildings in the city. There was no visible fluctuation of the radio altimeter pointer.

The ability of the Hughes radar to detect other aircraft has also been examined. It has been found that both red and yellow indications are obtainable from various types of aircraft ranging in size from small personal planes to DC-3 transports. It appears that there is sufficient strength of signal return to cause such indications only under ideal conditions, and the equipment could not be depended upon to give advance warning in all cases. It is believed that even intermittent warnings would serve the useful purpose of alerting the pilot and on some occasions might conceivably avert a mid-air collision.

During a series of flights in Clark County, Indiana, recordings of flights at various altitudes were made over a relatively low range of hills. The purpose of these flights was to check the consistency of the Hughes radar 2000-foot warning indication. Fig. 11 is a chart showing the actual clearance along the flight path, together with the condition of the yellow warning light for four runs at the same barometric altitude.

CONCLUSION

A number of important facts have been brought to light by this series of comparative tests. Perhaps the most significant are the following:

1) The radio altimeter can be counted on to read accurately over water or reasonably level terrain only.
2) When there is an error due to spurious reflections, the reading will indicate a clearance greater than that which actually exists.
3) Under certain conditions, there is the possibility of a lag in the radio altimeter which can also result in greater indicated than actual clearance.
4) Over flat, level terrain, or over water, the radio altimeter appears to operate satisfactorily when properly calibrated.
5) The Hughes radar 500-foot warning indication is not too reliable because of an unstable gate width, and because of possible failure of the indication below 100 feet.
6) The Hughes radar 2000-foot warning indication appears to be accurate and independent of terrain contour.
7) The Hughes radar employs a so-called "check" switch which permits the pilot to determine if the equipment is in operating condition. The circuitry employed does not permit a 100 percent check; however a large majority of possible component failures are detectable by means of this circuit.

The primary advantage of the altimeter is the continuous indication of altitude supplied; and the primary advantage of the Hughes radar is its non-susceptibility to spurious reflections. During the period of these tests, it was necessary to recalibrate the altimeter several times, whereas the Hughes radar required no attention whatsoever.

Either equipment can be of value as an interim terrain clearance indicator, provided operating personnel are familiar with the respective limitations involved.

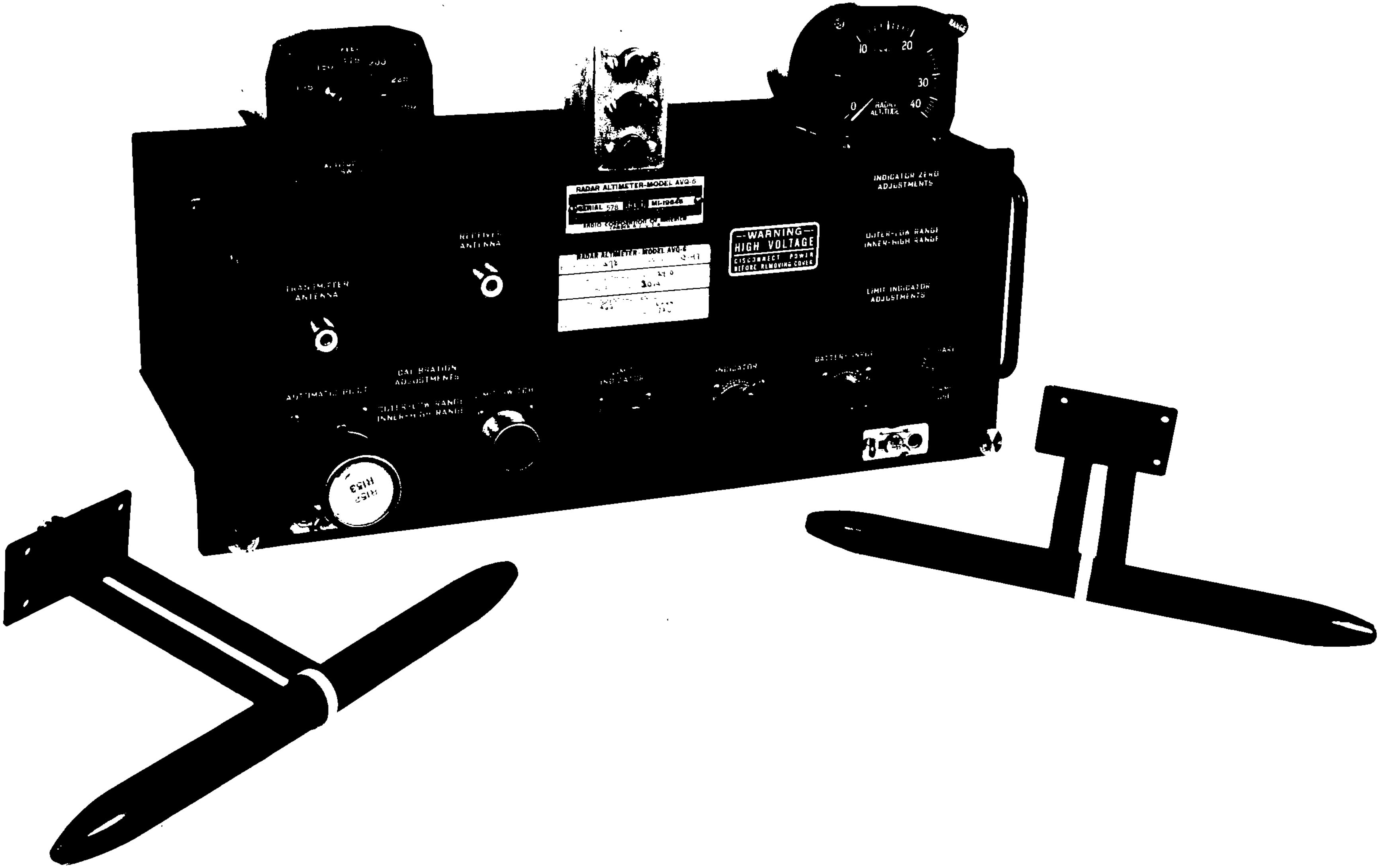

FIGURE I. RADIO ALTIMETER, UNINSTALLED

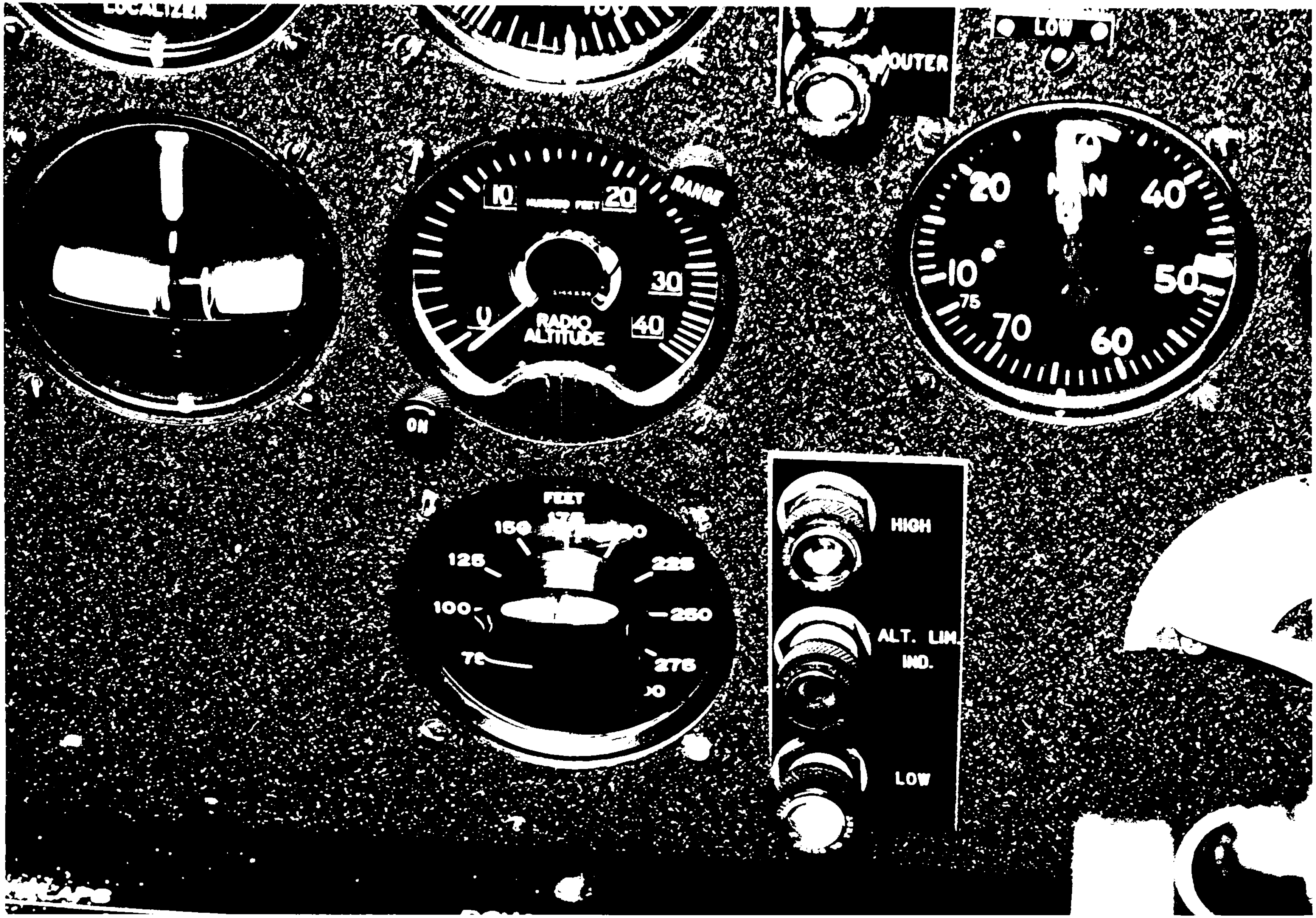

FIGURE 2. RADIO ALTIMETER COCKPIT INSTRUMENTATION

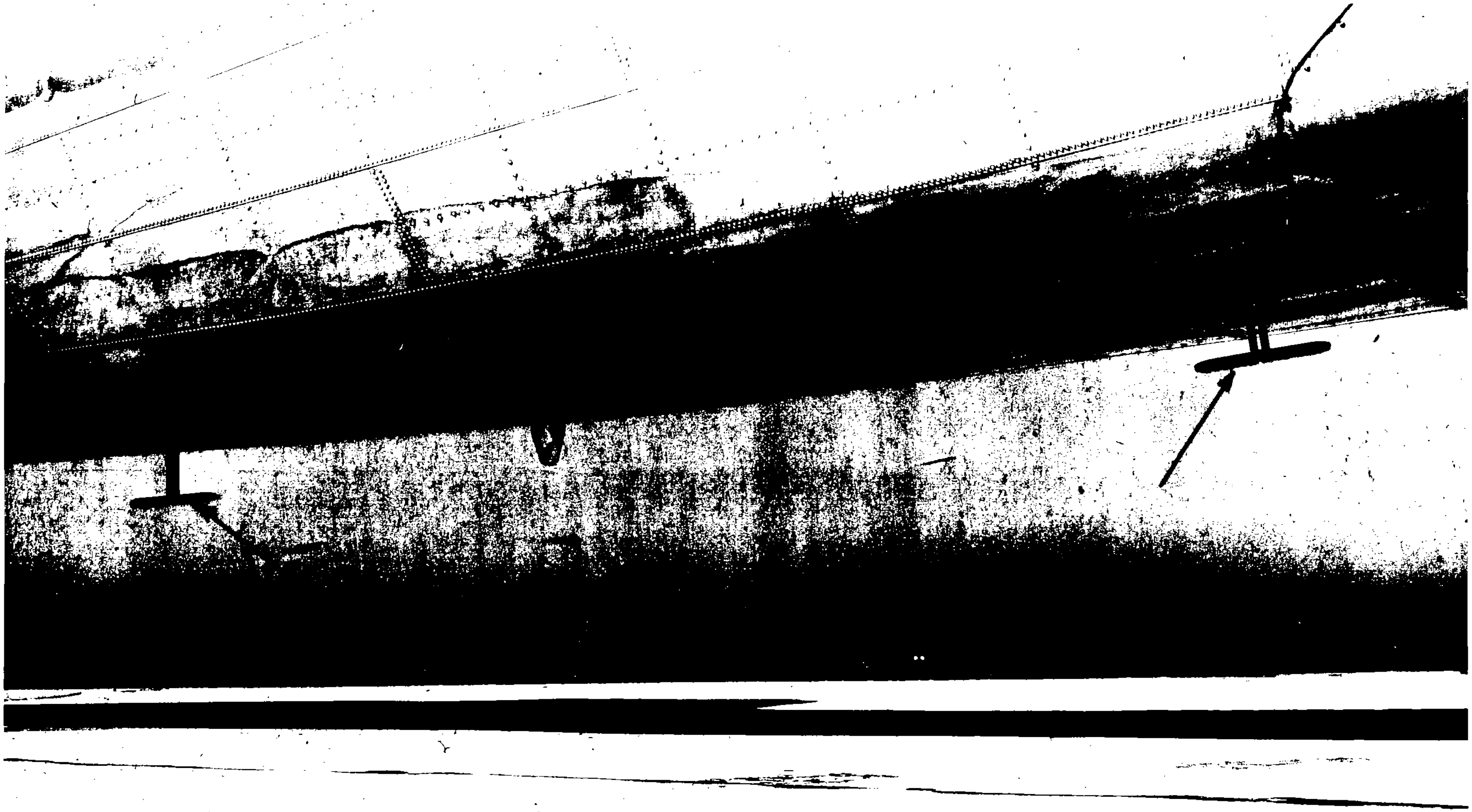

FIGURE 3. RADIO ALTIMETER ANTENNAS, INSTALLED

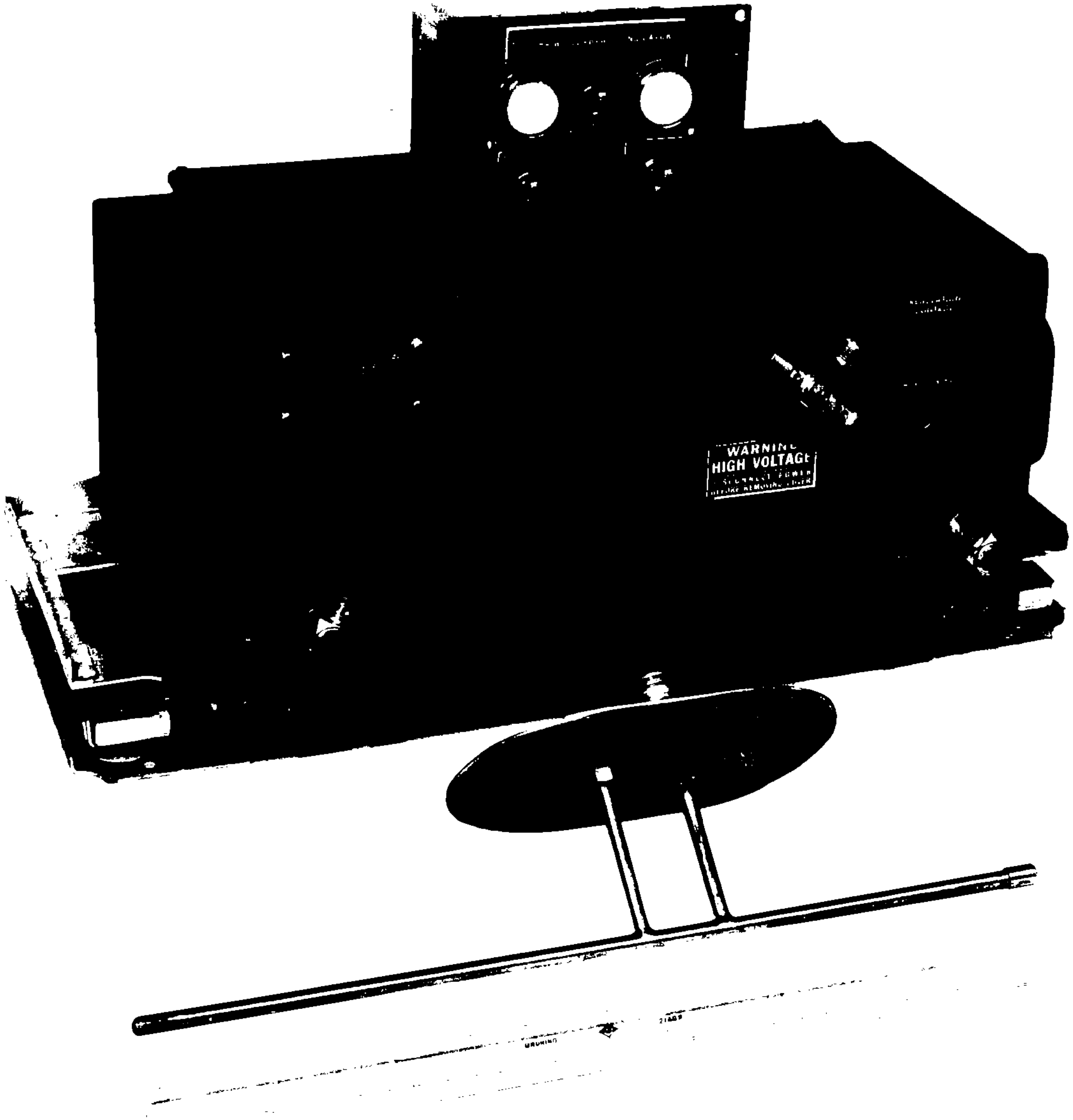

FIGURE 4. HUGHES RADAR, UNINSTALLED

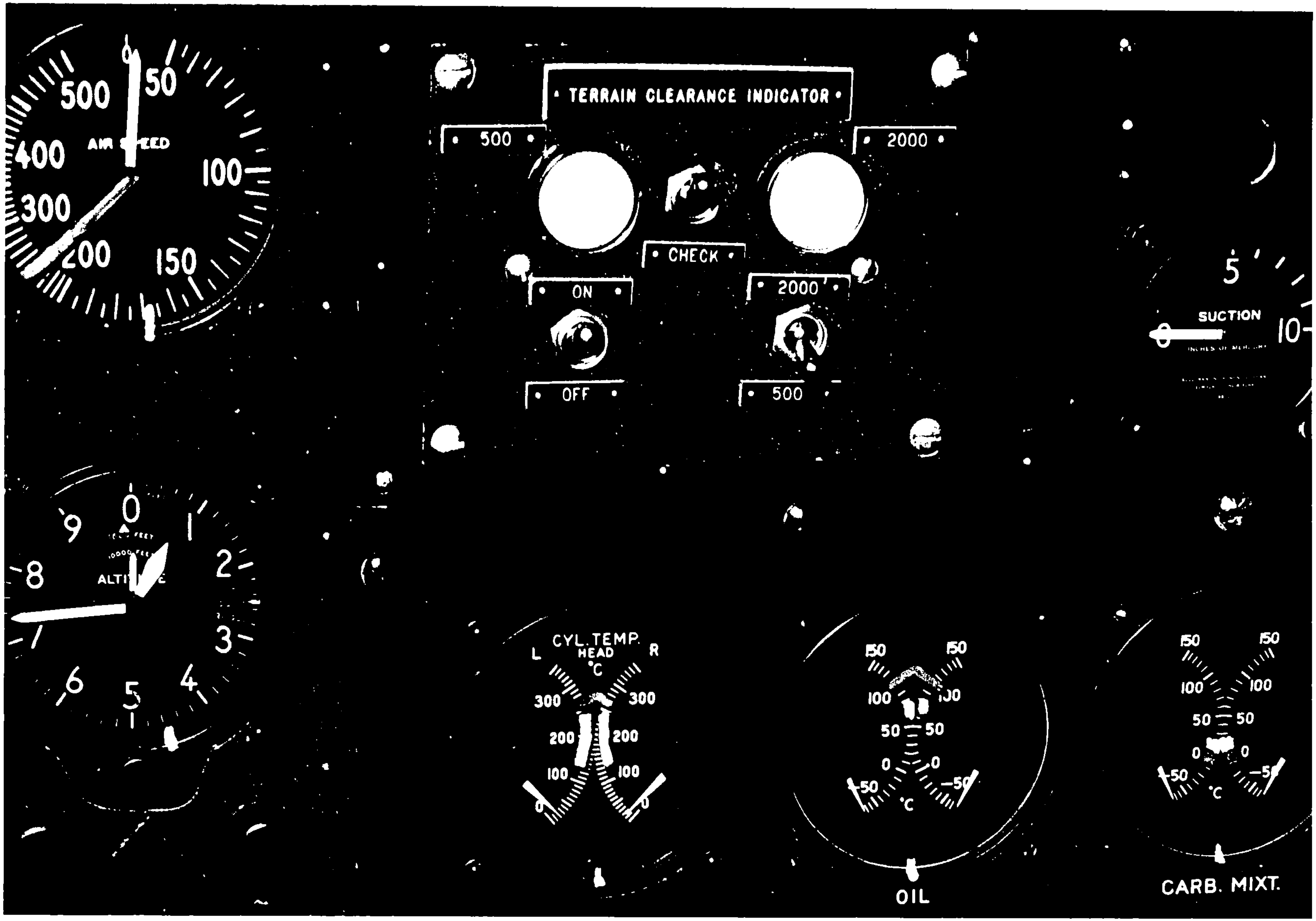

FIGURE 5. HUGHES RADAR COCKPIT INSTRUMENTATION

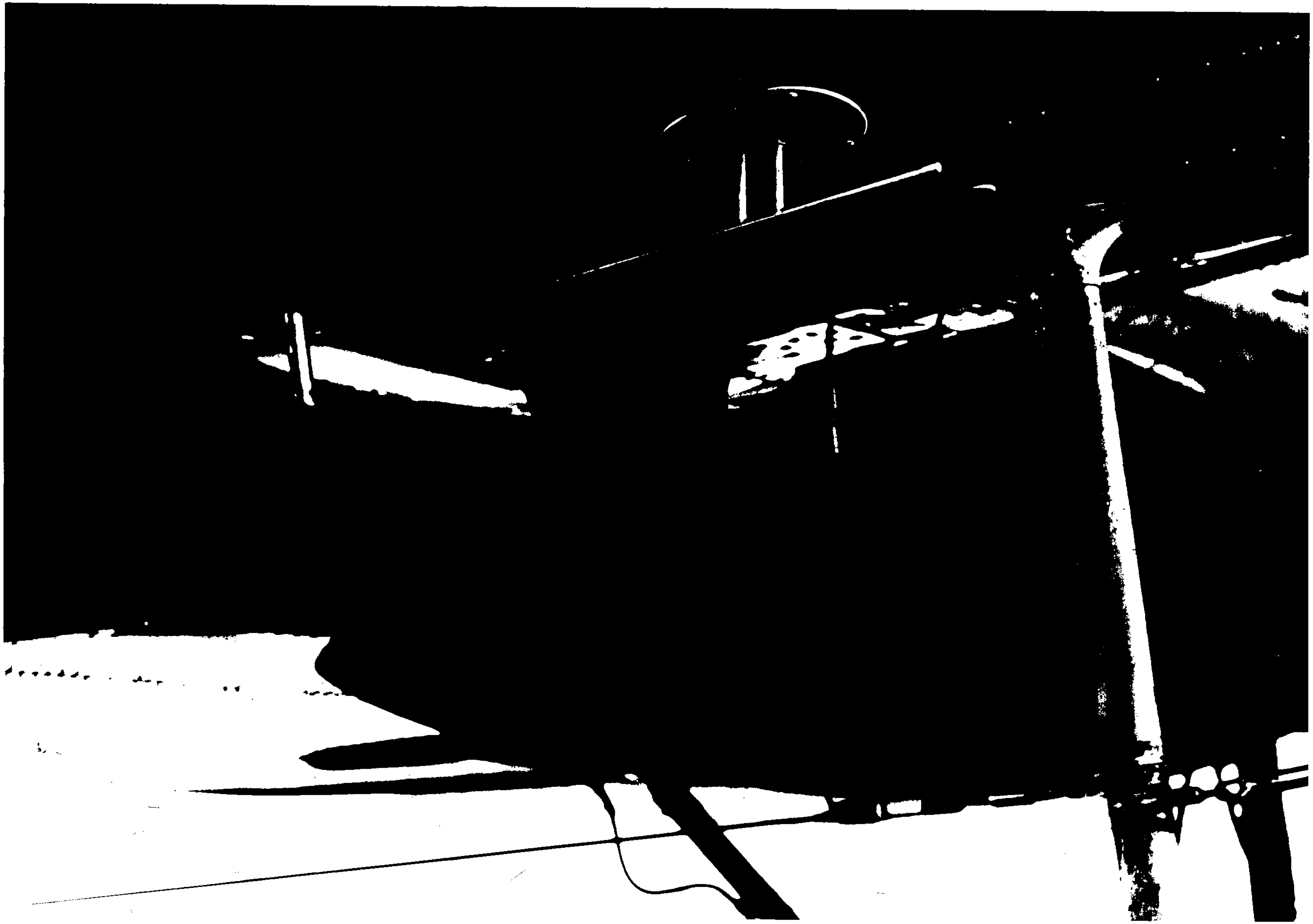

FIGURE 6. HUGHES RADAR ANTENNA, INSTALLED

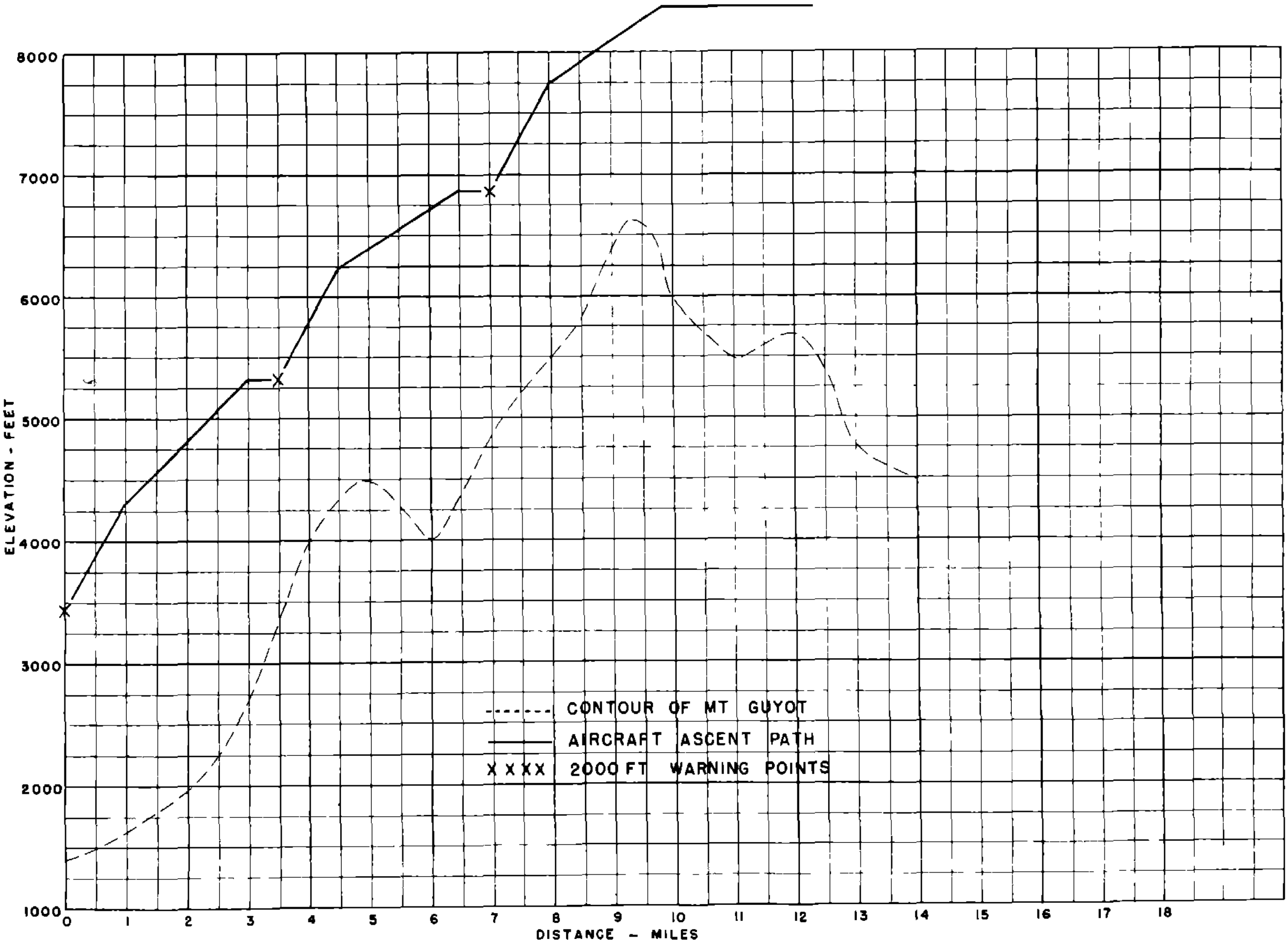

FIGURE 7 CONTOUR OF MT GUYOT SHOWING AIRCRAFT ASCENT PATH

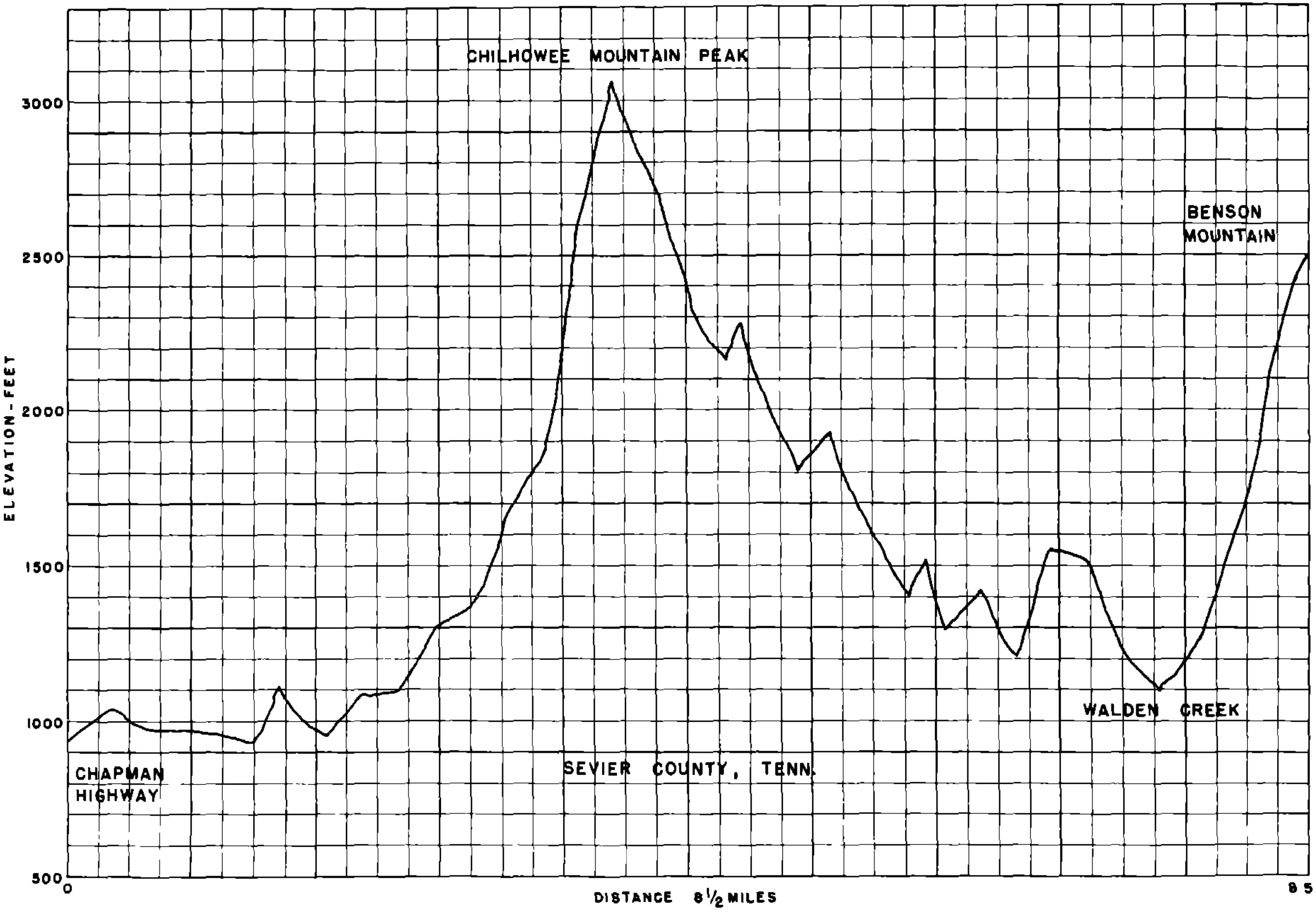

FIGURE 8 ELEVATION CONTOUR (SEVIER COUNTY, TENN)

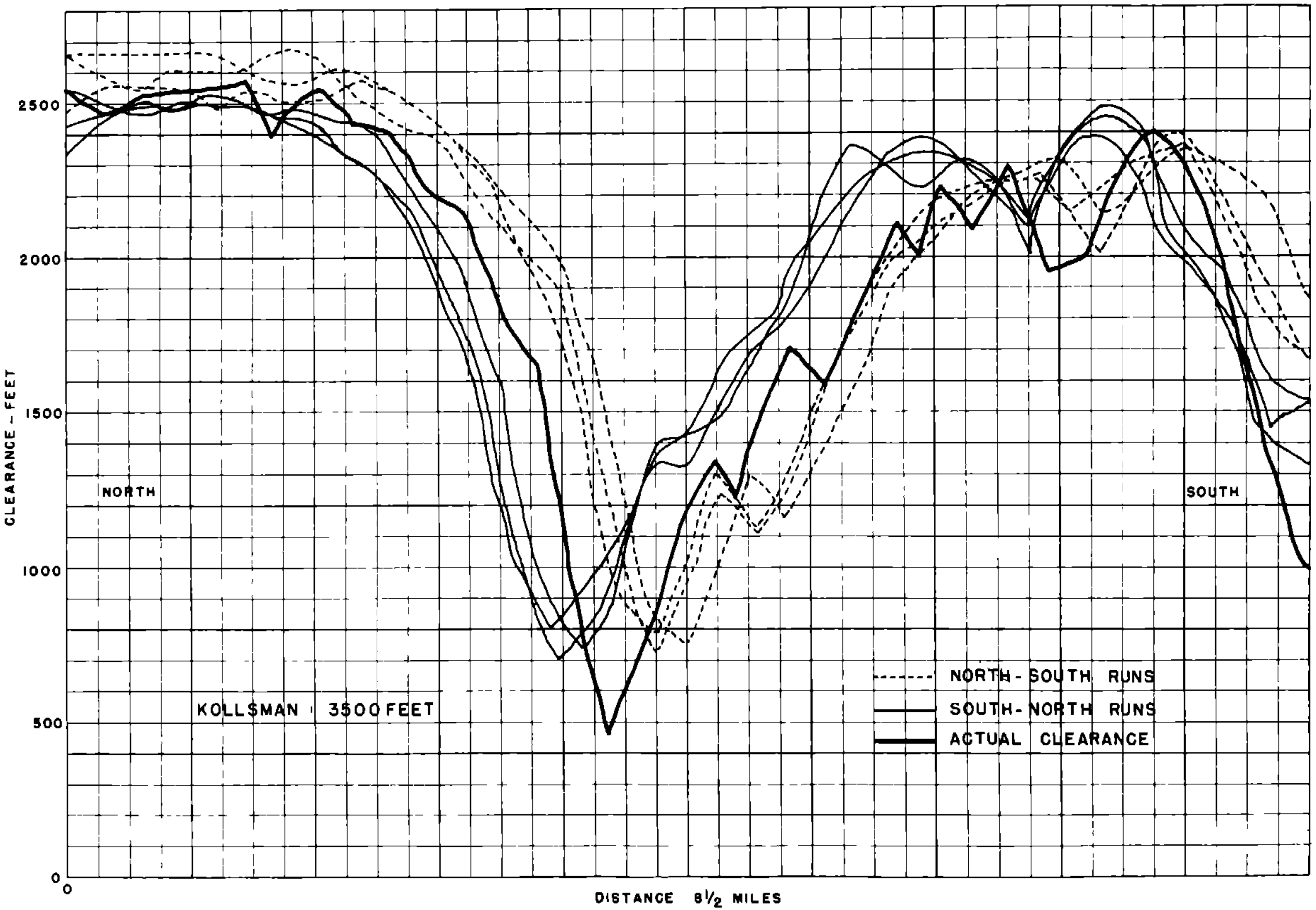

FIGURE 9 COMPARISON OF RECORDED CLEARANCES, 3500 FEET

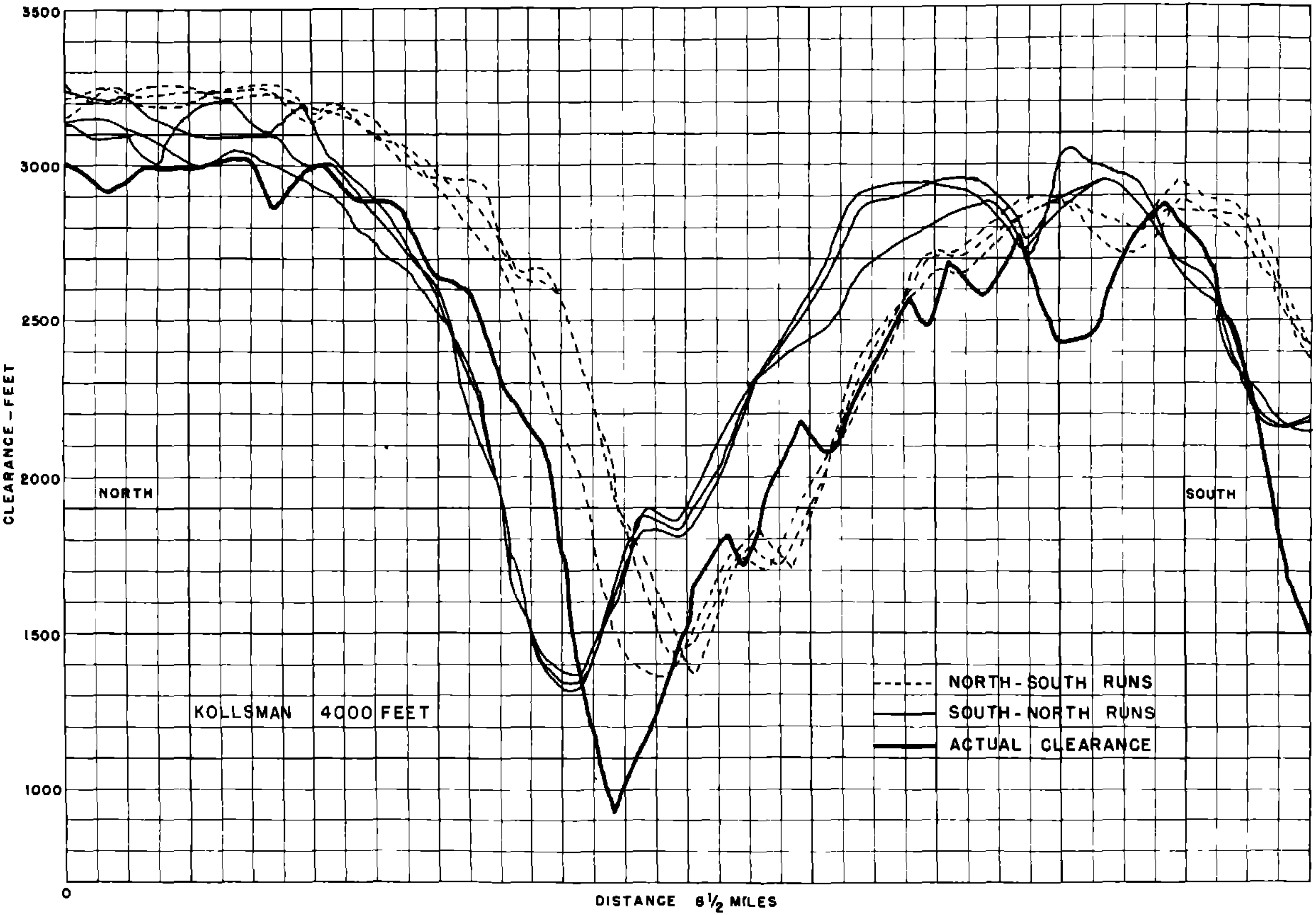

FIGURE 10 COMPARISON OF RECORDED CLEARANCES, 4000 FEET

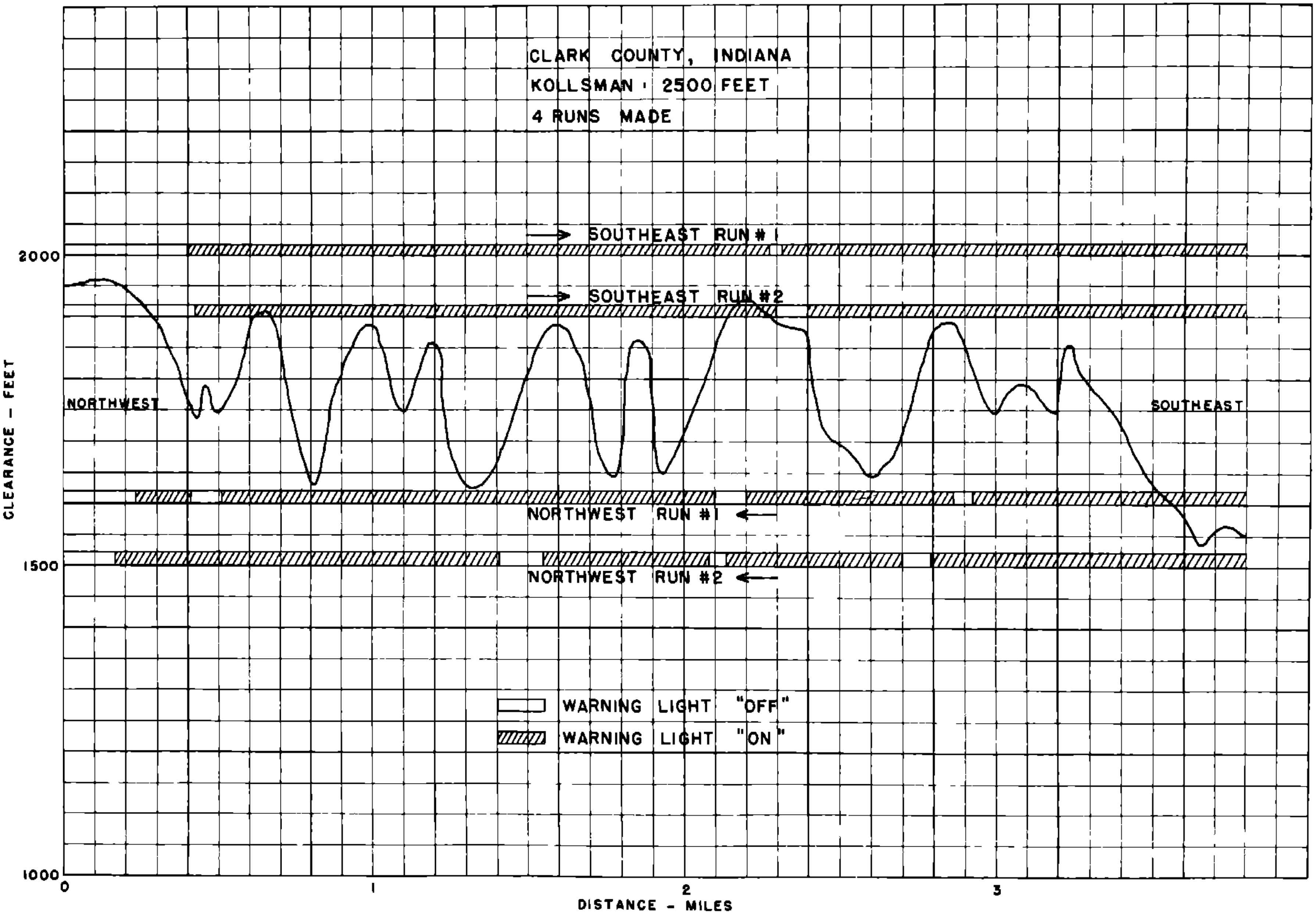

FIGURE 11 OPERATION OF HUGHES RADAR 2000-FOOT WARNING