~~RESTRICTED~~

ADVANCE COPY

TECHNICAL DEVELOPMENT REPORT NO. 61

FLIGHT TESTS OF SPERRY MICROWAVE INSTRUMENT LANDING SYSTEM

By

Francis J. Gross

Radio Development Division

Technical Development Service

March 1947

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT SERVICE
INDIANAPOLIS, INDIANA

TABLE OF CONTENTS

Page

FIGURE INDEX

FLIGHT TESTS OF SPERRY MICROWAVE INSTRUMENT LANDING SYSTEM

SUMMARY

These flight tests were conducted at the Indianapolis Airport between November 1946 and January 1947 and were primarily concerned with the indications of the cross-pointer meter as a function of the relative position of the aircraft and the transmitting antenna of either glide path or localizer. All tests were on relatively flat terrain. The localizer radiation is a beamed pattern with signal available only in a region of 67 degrees either side of the course up to a vertical angle of 4.5 degrees. Outside of this region, the signal is erratic or zero, and hence there is no back course. The localizer was located in several places where reflections affect 110 megacycle localizers; but no reflection effects were found. However, because of the concentration of energy in the beam, an inconspicuous 4" x 4" wooden post caused abnormally low clearances when within 100 feet of the antenna. The glide path suffers from a serious ground reflection effect that would seriously impair its use for glide path angles between 2 and 2.5 degrees. This might be cured by the redesign of the antenna. The equipment is well designed and reliable.

INTRODUCTION

The Sperry Microwave Instrument Landing System used in these flight tests consists essentially of a localizer transmitter, a glide path transmitter, and an airborne receiver. The receiver includes a cross-pointer similar to the conventional type except that it has "signal off" indicators of the neon type. The two transmitters are identical except for their antenna systems and frequency. Each is housed in a trailer which contains a portable power unit driven by a gasoline engine. In each transmitter all of the microwave energy radiated comes from one final power amplifier klystron stage, and this energy is equally divided between two wave guide systems which contain mechanical modulators of 900 and 600 cycles respectively. In the localizer transmitter the principle antenna is a paraboloid of revolution excited by the two wave guides and the beams are such that when the aircraft is "on course" equal amounts of 900- and 600-cycle modulated energy are fed to the receiver; but when the aircraft is off to the right side of the course, then the 900-cycle modulation will predominate; but, when it is off to the left of the course, the 600-cycle modulation will predominate. The localizer frequency is approximately 2640 megacycles. The glide path antenna is a parabolic cylinder so fed by the two wave guides that equal amounts of the 900- and 600-cycle modulated signals are fed to the receiver when the aircraft is on the glide path, but 900-cycle modulation predominates above the glide path and 600-cycle modulation predominates below the glide path. The glide path frequency is approximately 2617 megacycles.

The flight tests were conducted at the Indianapolis Airport between

November 1946 and January 1947. Experimental Station airplane NC-182, a DC-3 type, equipped with a Sperry A-12 autopilot and an automatic approach coupling unit was used. The purpose of these tests was to determine the following:

(A) The maximum reliable vertical and horizontal coverage of the localizer and the nature of the cross-pointer indications as these limits are exceeded.

(B) Course width of the localizer course in the region of cross over at various altitudes.

(C) The vertical coverage of the glide path in the region of the localizer course.

(D) Course width of the glide path course in the region of "cross over" within a limited range of azimuth angles.

(E) That the localizer equisignal plane is vertical and that the glide path equisignal plane is perpendicular to a vertical plane through the centerline of the runway.

(F) That the equisignal course is a straight line continuing down to the point of touchdown of the aircraft.

(G) Overall operation during normal approach.

(H) Effect of adjacent reflecting surfaces such as buildings, hangars, telephone lines, etc.

In the course of the tests, it was discovered that a 4" x 4" wooden post interfered noticeably with the beam pattern and part of the limited time allotted to the tests was given over to investigating the extent of the interference.

The locations occupied by the localizer during these flight tests are indicated by letters A through E on the map in Fig. 5. There was only one location F for the glide path equipment.

The localizer trailer contained a theodolite for determining azimuth angles up to 1300 mils[1] (73.1 degrees) either side of course as well as vertical angles. The glide path trailer contained a theodolite, used principally for determining vertical angles.

Mr. R. A. Von Behren, a Sperry representative, was present during most of the flight tests.

---

[1] The theodolite azimuth and elevation circles were divided up into mils instead of the usual degrees. A mil is a unit of angular measure sometimes used by field artillery. There are 6400 mils in a circle and therefore 6400 mils equal 360 degrees or one mil equals .05625 degree.

Results of Flight Tests With Localizer in Location A. Location A, shown in Fig. 5, is an ideal location for a localizer and is on the same runway as the commissioned 109.9 megacycle CAA localizer. The clearance recordings at three altitudes are reproduced in Fig. 1. The azimuth indications are those of a marker pen operated by a flight engineer who was in direct voice communication with a theodolite observer at the localizer who issued instructions. Three facts are evident from these recordings:

First, the maximum reliable horizontal coverage is approximately 65 degrees right and left of course.

Second, the low clearances at 2000 feet above the ground indicate that the maximum reliable vertical coverage is reached at a vertical angle of 4.5 degrees. Low clearances and false courses were also found at 2500 and 3000 feet, although the records are not shown here. At the extreme edges of the localizer beams, the localizer needle has an erratic behavior, and for angles much greater than these the needle is centered and the "signal off" indicators are extinguished indicating negligible microwave signal is being received.

Third, the course sharpness averages 3.7 degrees for these curves together with Figs. 7, 8, and 9. A course sharpness of 3.7 degrees means that as the cross-pointer needle moves from full scale fly right to full scale fly left when the airplane is crossing the course the theodolite reading changes by 3.7 degrees.

The recordings reproduced in Fig. 2 show the deflections of the localizer needle during two normal approaches and the level pass at 1000 feet. From a number of these records, the theodolite readings were noted each time the localizer needle was centered and were then plotted against distance in Fig. 3. Although the course bends shown here are slight, they were immediately noticed by the pilots. If the deviation off course had been plotted against vertical angle instead of distance, it would be obvious that they are due to a slight bow in the equisignal surface, and that the bends are S shaped because the aircraft passes through the same vertical angle twice on a normal approach.

The manufacturer indicates that these slight bends are due to hasty repairs made to collision damage of the antenna reflector just before this equipment was used in the PICAO demonstrations of October 1946 at Indianapolis.

Fig. 4 is a similar curve made on the commissioned 109.9 megacycle localizer for comparison.

Results of Flight Tests With Localizer in Location B. Since the principle advantage of beaming the microwave energy is the minimizing of reflections, Location B was selected as the worst reflecting condition likely to be encountered at an airport such as Indianapolis. Details of this location are shown in Fig. 6.

Before making flight tests, the aircraft was taxied to a number of positions along the taxi strip where the localizer needle showed on course.

A study of theodolite readings for these positions showed no noticeable bends. This was born out by approach recordings which were similar to those for position A. A cross course recording at 10 miles showed no scalloping which is further evidence of the absence of reflection effects on course.

Fig. 7 is a reproduction of clearance recordings for Location B. They are similar to those for Location A, except for the "shadow" effect of the buildings at the lower altitude. However, the clearance is still adequate in the shadow of the buildings at a five-mile radius.

Results of Flight Tests With Localizer in Location C. Location C was selected because of its proximity to the telephone wires which cause reflections with 110-megacycle localizers. As was expected, no effects of reflection appeared in the flight tests for this location. The absence of reflections is undoubtedly due to the absence of back course radiation from the microwave localizer.

Results of Flight Tests With Localizer in Location D. Location D was originally selected because reflections from hangars and buildings had been noticed on a 110-megacycle localizer in previous tests. No interference was noted from these sources but an inconspicuous 4" x 4" wooden post 6 feet high and 76 feet from the antenna was found to be the cause of the variations and low clearance shown on the top recording of Fig. 8. At the time of this recording, the post supported 6 feet of 1-1/4-inch lead cable, but removal of the cable had no effect on the clearance pattern. Flight recordings were made with the post at 100, 125, and 150 feet from the antenna. The effects diminished with distance. Reproduced in Fig. 8 are recordings taken with the post at distances of 75 feet and 150 feet and with the post removed. With this particular height of post, the clearances at low altitudes were the more seriously affected as shown by the recordings of Figs. 8 and 9.

The recordings for a normal approach are shown in Fig. 10, and the course straightness is shown in Fig. 11. Course shift caused by the post was less than one-quarter degree.

Results of Flight Tests in Location E. Location E was selected to obtain fundamental data on the radiation of microwave energy through trees. The data obtained in this location is expected to have no bearing on localizer problems, but may prove useful in considering siting problems of other types of microwave facilities. The clearance recordings and recording of a level pass are shown in Fig. 12. The grove of trees was approximately 500 feet from the antenna and subtended an angle of plus 11 degrees to minus 39 degrees. The highest trees were estimated to be over 40 feet high.

Results of Flight Tests on Sperry Glide Path Transmitter in Location F. Location F was the only Sperry glide path location used in these tests. It is an ideal location and, as shown in Fig. 5, it is adjacent to the standard CAA 333.8 megacycle glide path. The Sperry glide path was designed for a 2.5-degree glide path angle. With the antenna inclinometer set at this angle, three level passes were made at 1000 feet above the ground. One of these passes was on the localizer course and the other two were on radial courses 15 degrees right and 15 degrees left of this course. Analysis of the three glide path indicator records showed that the equisignal surface was perpendicular within plus or minus one mil (0.056) degrees) to a vertical plane through the centerline of the runway.

It is customary to determine the angular width of the glide path in the following manner. The aircraft flies at a constant altitude of 1000 feet above the ground and along the localizer course. The change in the vertical angle of the aircraft's position, as the glide path indicator moves from full scale fly-up to full scale fly-down, is determined. This change in vertical angle is defined as the width of the glide path. In the tests conducted with the Sperry equipment, a theodolite located in the glide path trailer was used to measure the change in vertical angle. Recordings are reproduced in Fig. 13. The curve marked G.P. 2.5 degrees in Fig. 16 is the graph of one such flight. To determine the vertical coverage of the glide path, similar passes were made at altitudes of 500, 1500, and 2000 feet above the ground, with the glide path angle at 2.5 degrees. Data for all four altitudes were found to be identical when indicator current was plotted against vertical angle. These measurements indicated a glide path width of 1.5 degrees at these altitudes. However, it was noted that all of these curves had a dip beginning at a vertical angle of approximately 2.25 degrees so that the sensitivity of the glide path needle, when the aircraft is on the glide path, was greater than a course width of 1.5 degrees would indicate.

This dip in the curve was further investigated by setting the antenna to different glide path angles with the aid of the inclinometer attached to the antenna, and flying a 1000-foot level pass for each antenna setting. This data is plotted in Fig. 16. The dip is seen to exist in all curves and begins at the same vertical angle of 2.25 degrees for all glide path angles. It is a most serious defect for glide path angles between 2.0 degrees and 2.25 degrees because it makes the sensitivity of the glide path needle very low when the aircraft is on the glide path. This condition is thought to be the result of ground reflection of 600-cycle modulated energy into the region above the glide path, which results in a decrease of the audio ratio of 900-cycle voltage to 600-cycle voltage in the receiver. A redesign of the glide path antenna is necessary to correct this defect.

In the recording at the top of Fig. 13, the first course reversal occurs near the left-hand edge at a vertical angle of approximately 6.7 degrees. In the CAA glide path the first course reversal occurs at a vertical angle of approximately 16.5 degrees.

Recordings for normal approaches on the Sperry glide path set at 1.83 degrees and 2.5 degrees are reproduced in Fig. 14. An approach recording for the CAA glide path set at 2.0 degrees is also shown in Fig. 14 for comparison.

Course softening is not used in the Sperry glide path system, but a total of approximately 12 db of softening is incorporated in the CAA glide path system. It is apparent from the approach recordings of Fig. 14 that softening improves the flyability. Near the outer marker, the cross-pointer sensitivity of the two systems is nearly the same, i.e. about 30-35 microamperes per mil, corresponding to a course width of approximately 0.5 to 0.6 degrees as measured from Fig. 16, and in Fig. 14 the excursions of the pointer are within plus or minus one dot in the vicinity of the outer marker for both systems. For the approach on the CAA glide path the excursions of the pointer remain within plus or minus one dot to the end of the runway. On the Sperry glide path, however, the excursions of the needle increased to nearly two dots at the middle marker and at one-fifth mile from the end of the runway (three-fifths mile from touchdown) the excursions of the needle become excessive. The altitude of the plane one-fifth mile from the runway is 110 feet for a 2.5 degree glide path and 80 feet for a 1.83 degree glide path.

Course straightness curves for the Sperry glide path are reproduced in Fig. 15. The glide path is straight and continues to the point of touchdown with this aircraft installation in which the antenna is mounted on top of the airplane.

CONCLUSIONS

A. The localizer beam reliably covers approximately 65 degrees of azimuth either side of course, up to a vertical angle of 4.5 degrees. At these limits, the localizer needle becomes erratic and neon signal indicators flicker on and off. Outside of the limits the localizer needle is in the zero or on-course position and the neon indicators are out.

B. The average course sharpness is 3.7 degrees.

C. The localizer equisignal plane is vertical within one-fifth degree of azimuth.

D. Beaming the localizer radiation as is done in this equipment, reduces reflection effects from buildings, etc. However, relatively small objects such as a 4" x 4" post in the concentrated beam, within 100 feet of the antenna, have a pronounced effect on the localizer needle deflections.

E. The curves of glide path needle deflection versus vertical angle show that the glide path needle is insensitive near the glide path for glide path angles near 2.15 degrees.

F. There is a course reversal of the glide path at a vertical angle of about 6.7 degrees. If this reversal could be extended up 15 to 20 degrees, there would be less opportunity for confusion.

G. The glide path is straight and the equisignal surface is perpendicular to a vertical plane through the centerline of the runway.

H. Although reliability experiments were not part of these tests, it is worthy of note that in 30 hours of flying and approximately 100 hours of ground equipment operation, only one failure occurred. This failure involved a power transformer in the glide path transmitter which was replaced in a few hours.

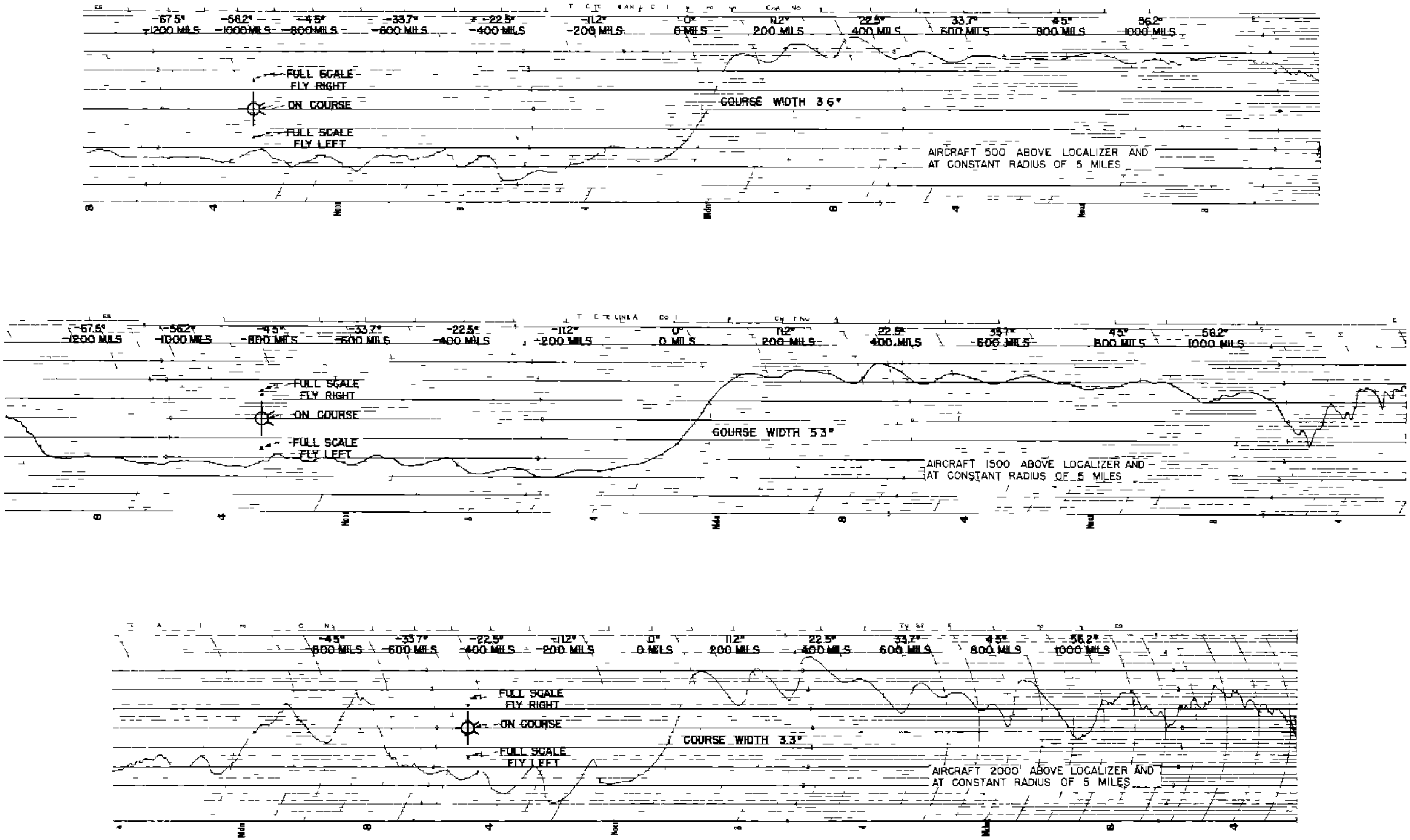

FIGURE I CLEARANCE RECORDINGS WITH SPERRY LOCALIZER IN LOCATION A

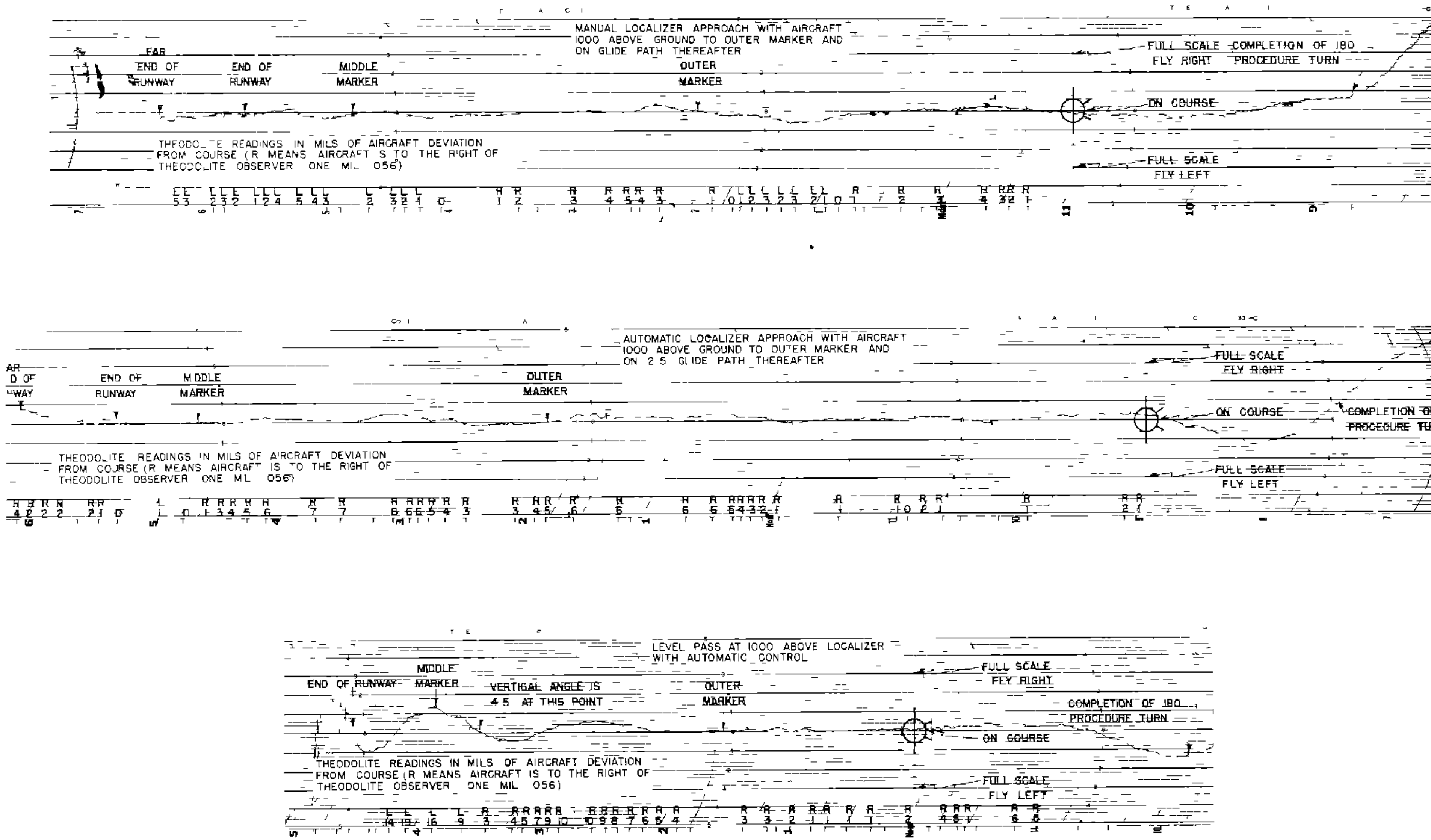

FIGURE 2 LOCALIZER APPROACH RECORDINGS WITH SPERRY LOCALIZER IN LOCATION A

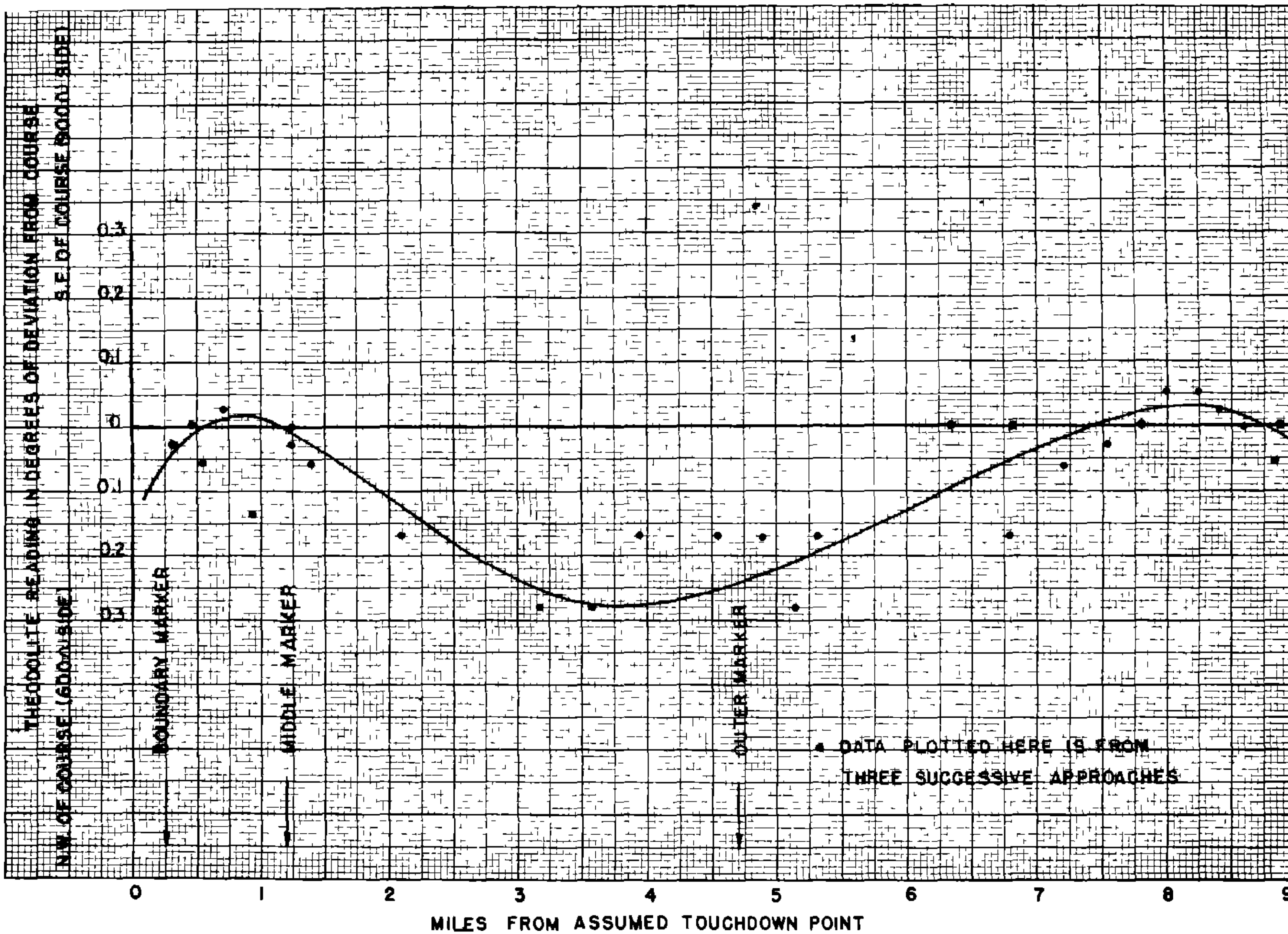

FIGURE 3 COURSE STRAIGHTNESS OF SPERRY LOCALIZER IN LOCATION "A"

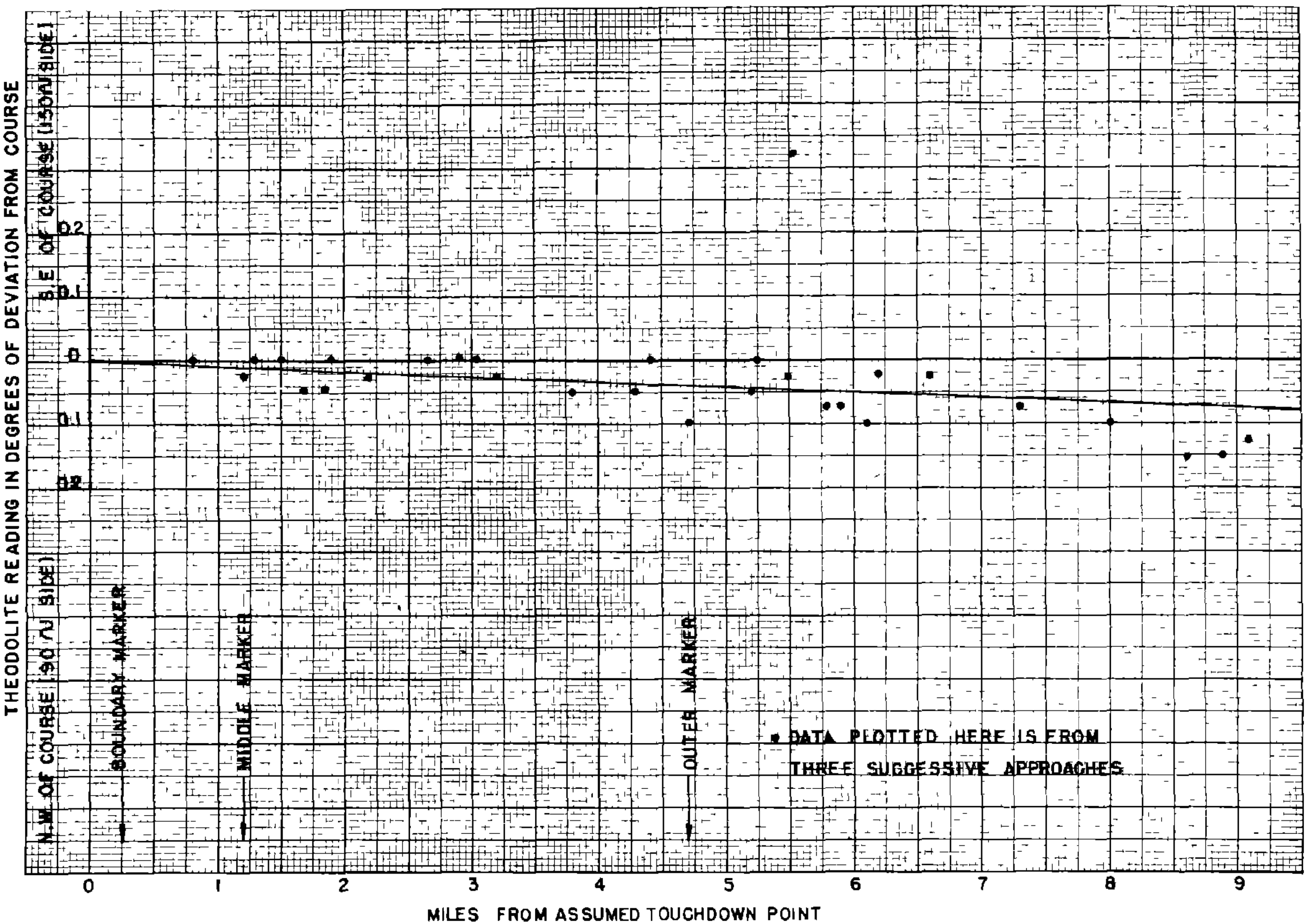

FIGURE 4 COURSE STRAIGHTNESS OF 109 9 MC C A A LOCALIZER AT INDIANAPOLIS

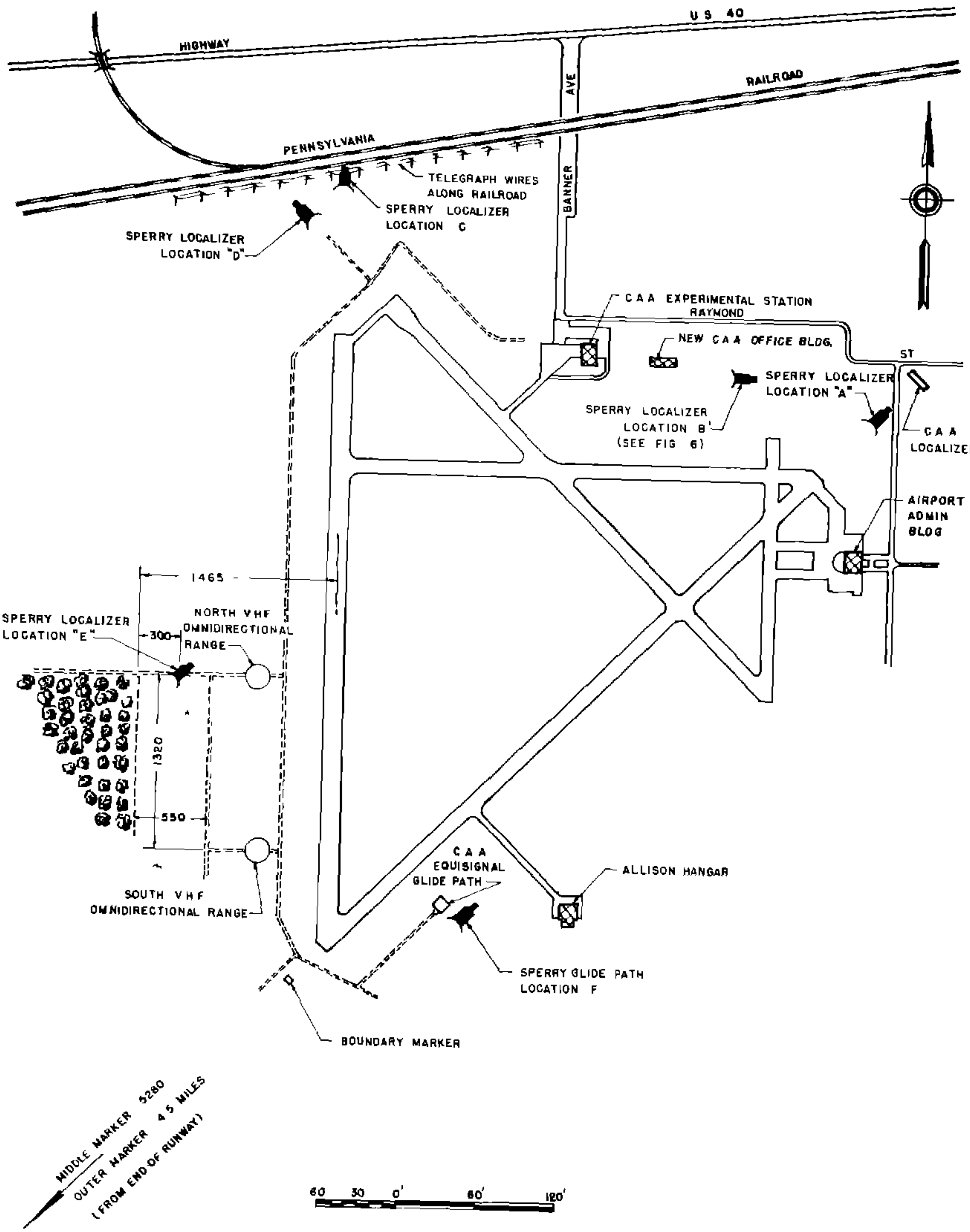

FIGURE 5 LOCATION SKETCH OF SPERRY MICROWAVE INSTRUMENT LANDING SYSTEM FOR FLIGHT TESTS AT INDIANAPOLIS

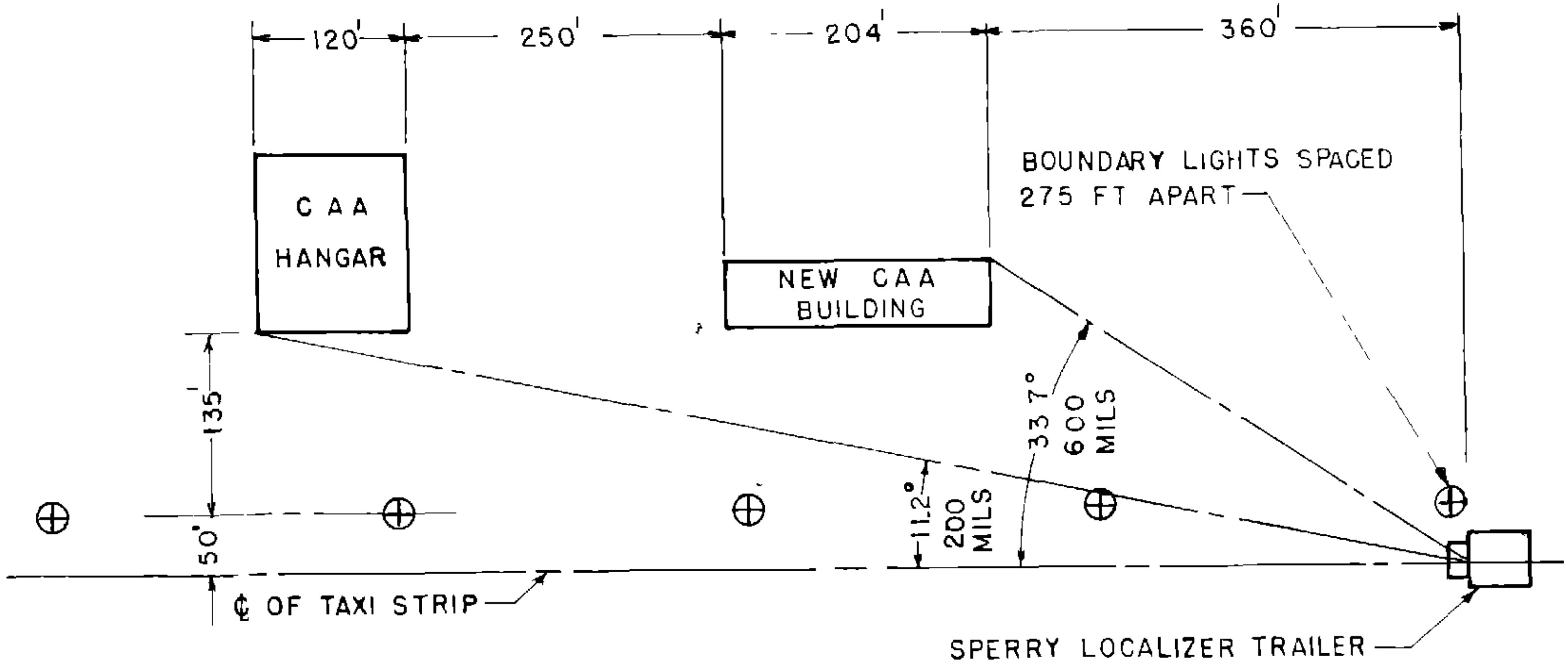

FIGURE 6 DETAILS OF LOCATION "B" OF SPERRY LOCALIZER
TRAILER FOR "REFLECTION" TESTS

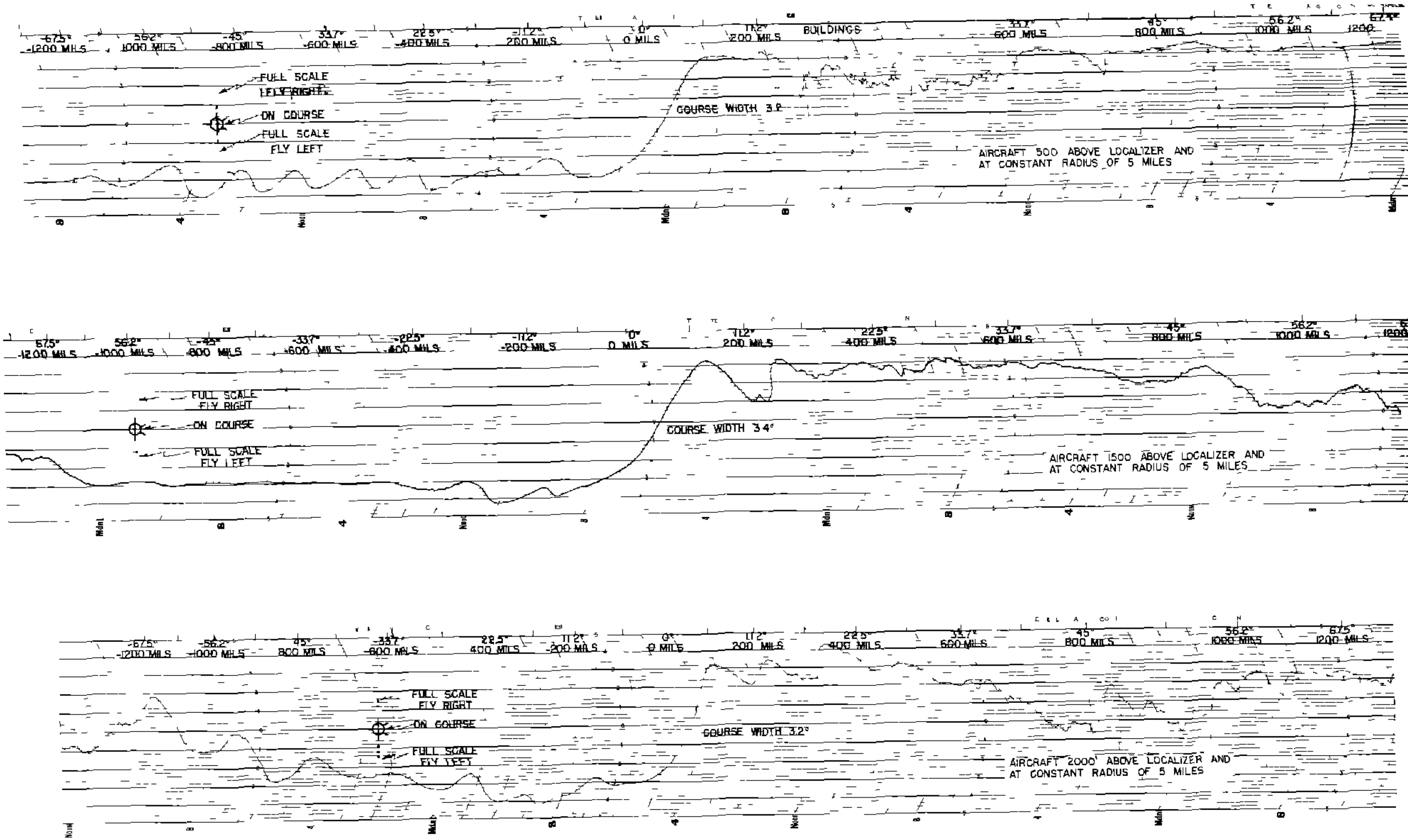

FIGURE 7 LOCALIZER CLEARANCE RECORDINGS WITH SPERRY LOCALIZER IN LOCATION B
BUILDINGS SUBTEND THE ANGLE 11° TO 33°

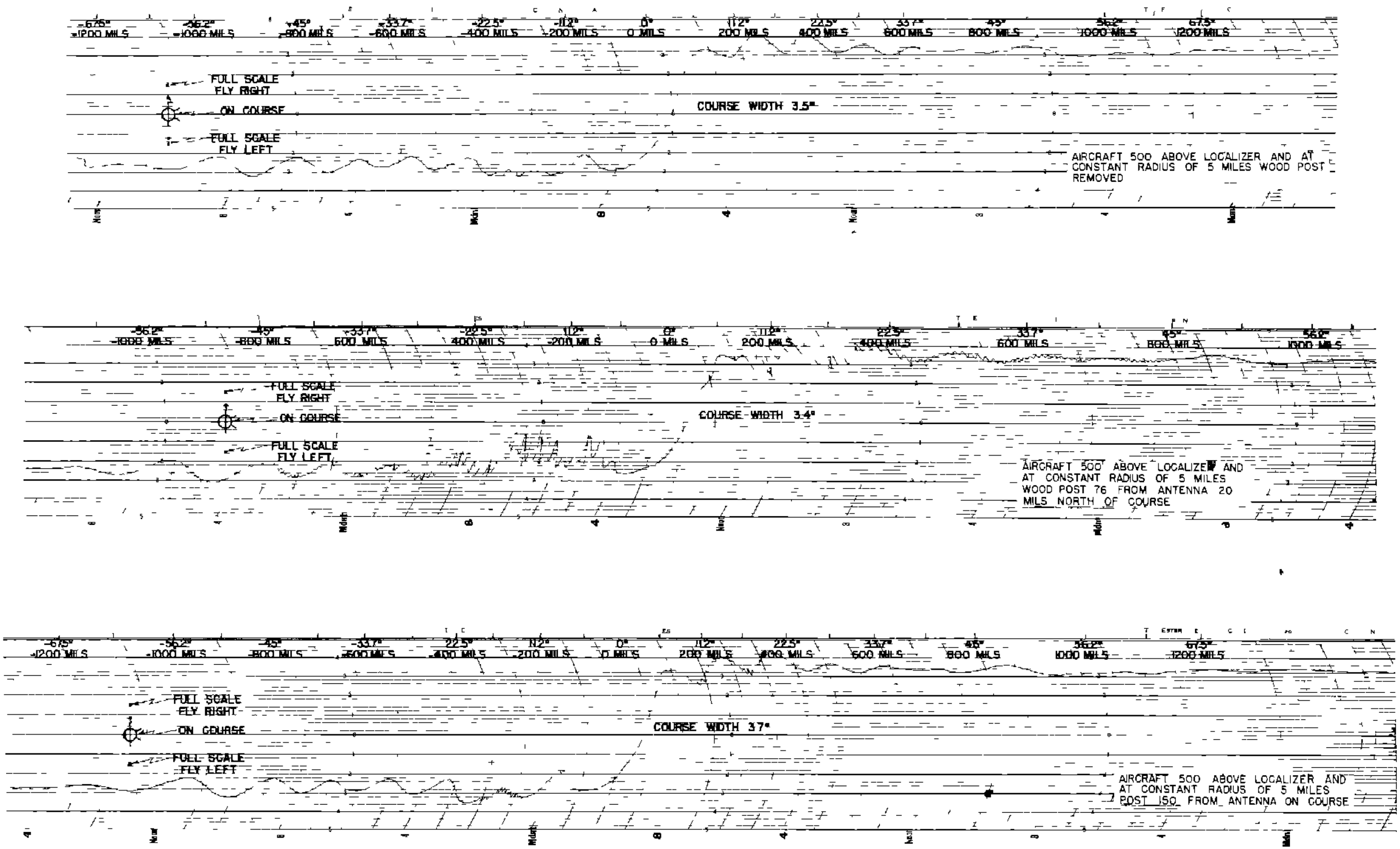

FIGURE 8 LOCALIZER CLEARANCE RECORDINGS WITH SPERRY LOCALIZER IN LOCATION D SHOWING EFFECT OF 4" × 4" WOOD POST 6' HIGH

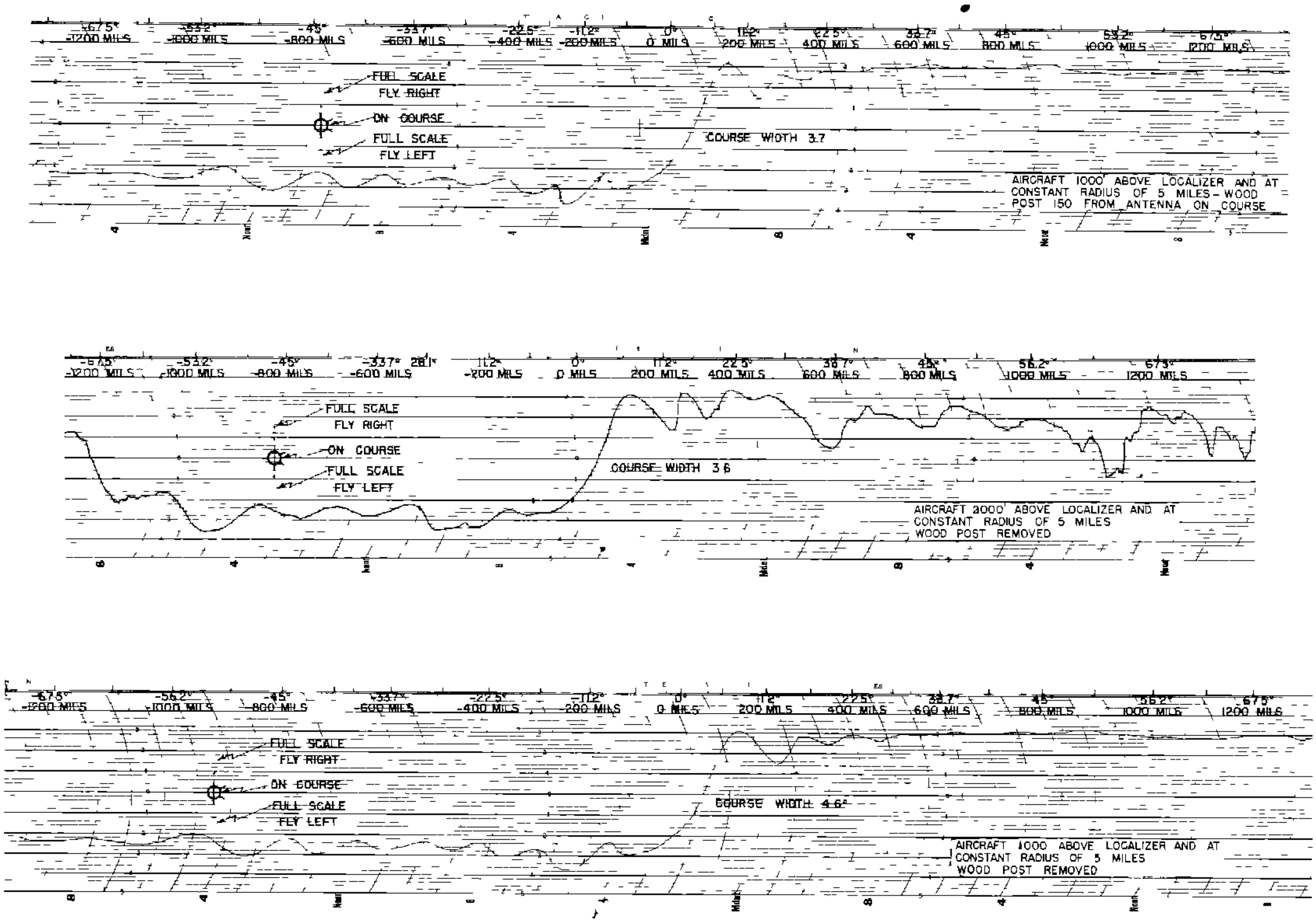

FIGURE 9 LOCALIZER CLEARANCE RECORDINGS WITH SPERRY LOCALIZER IN LOCATION D

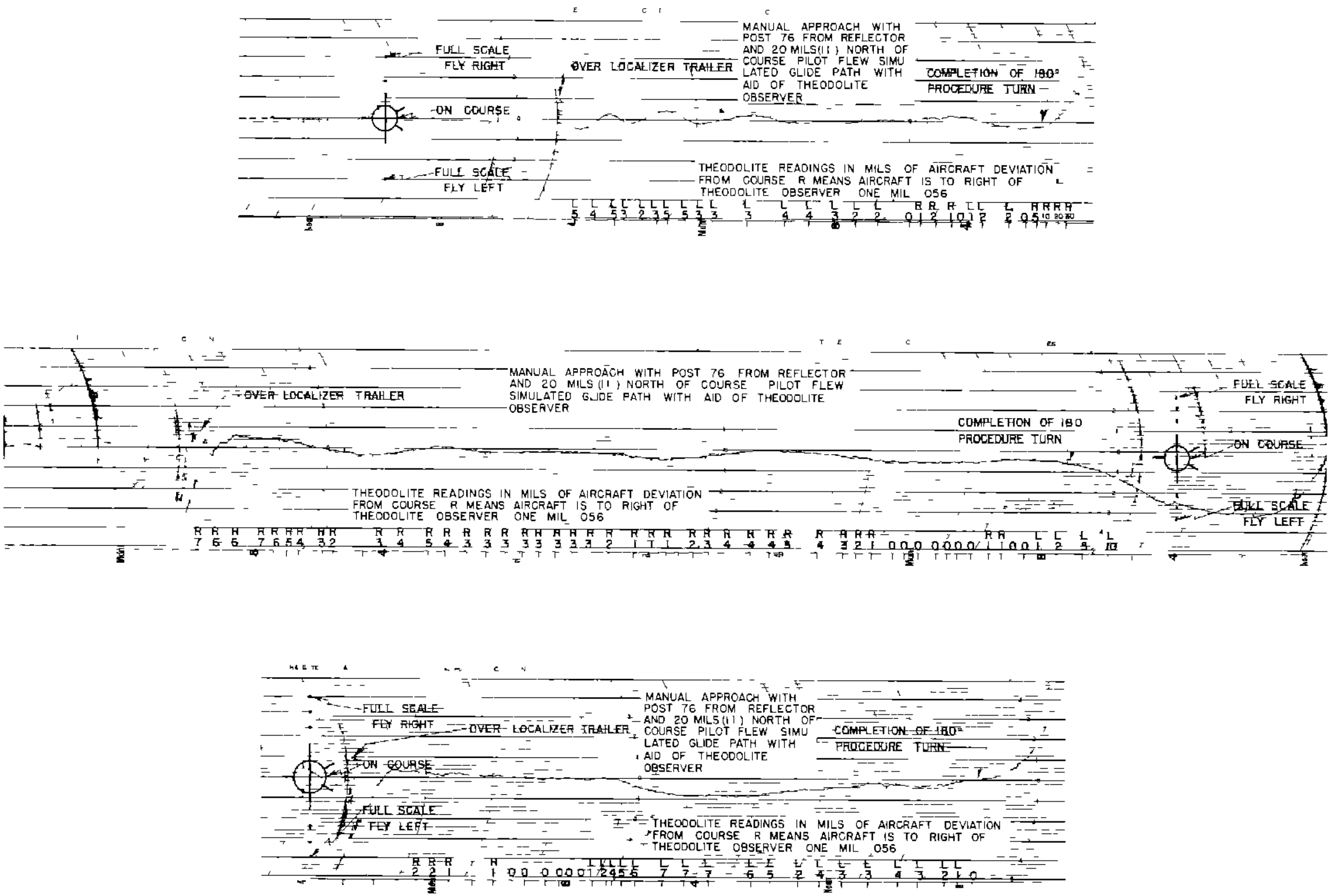

FIGURE 10 LOCALIZER APPROACH RECORDINGS WITH SPERRY LOCALIZER IN LOCATION D
NOTE POST LOCATIONS

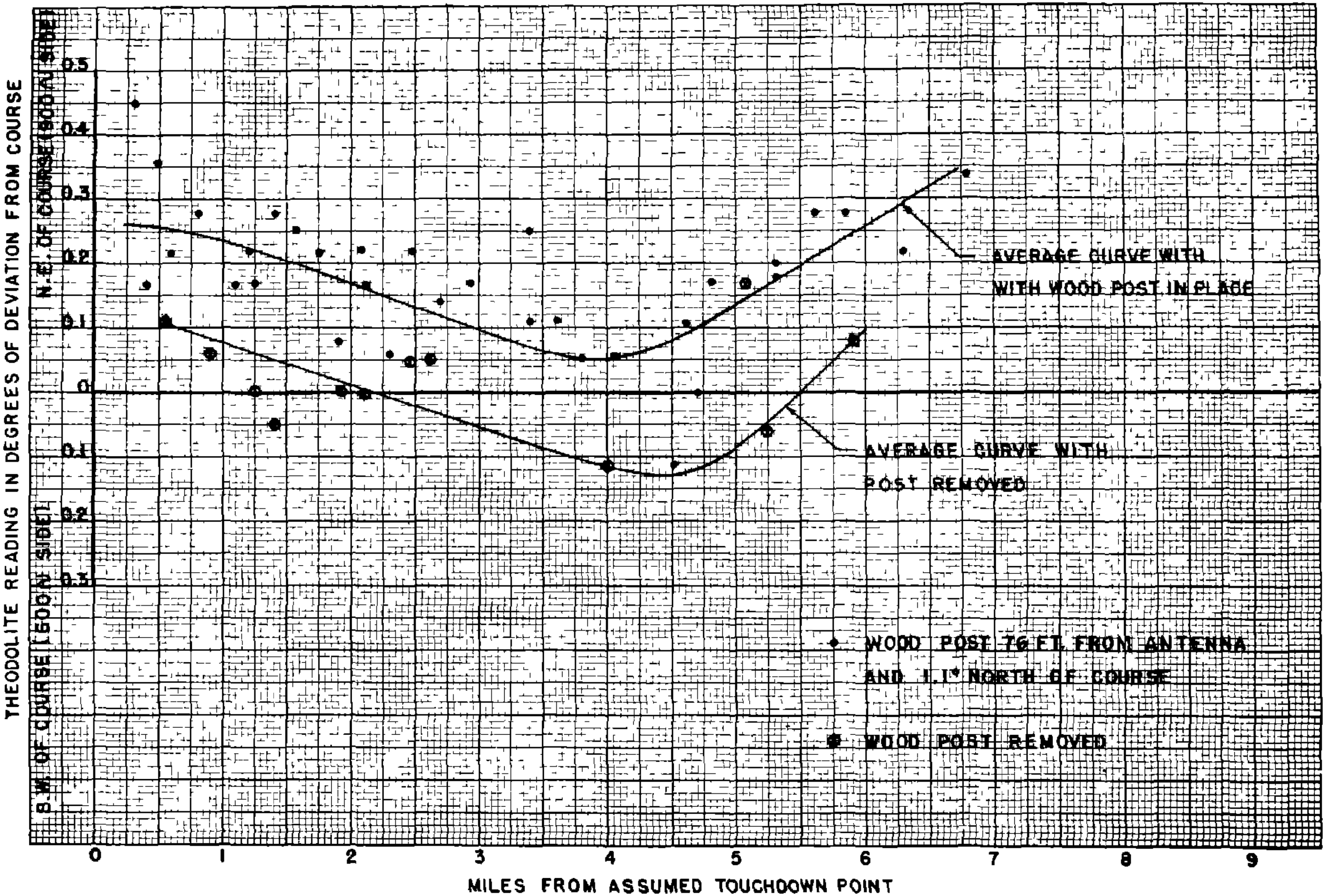

FIGURE 11 COURSE STRAIGHTNESS OF SPERRY LOCALIZER IN LOCATION "D"

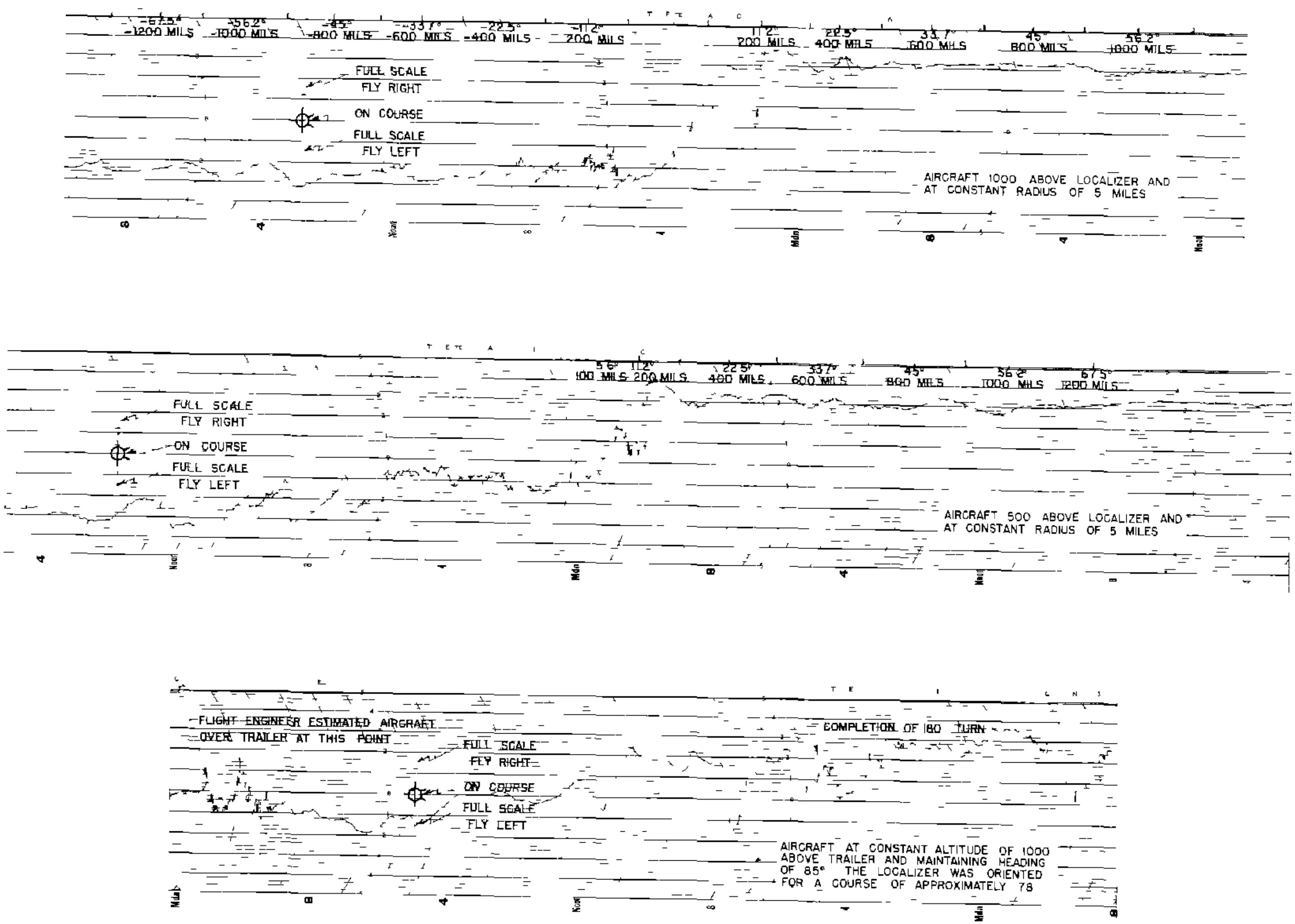

FIGURE 12 LOCALIZER RECORDINGS WITH SPERRY LOCALIZER IN LOCATION E RADIATING THROUGH TREES TREES SUBTEND THE ANGLE BETWEEN +11° & -39°

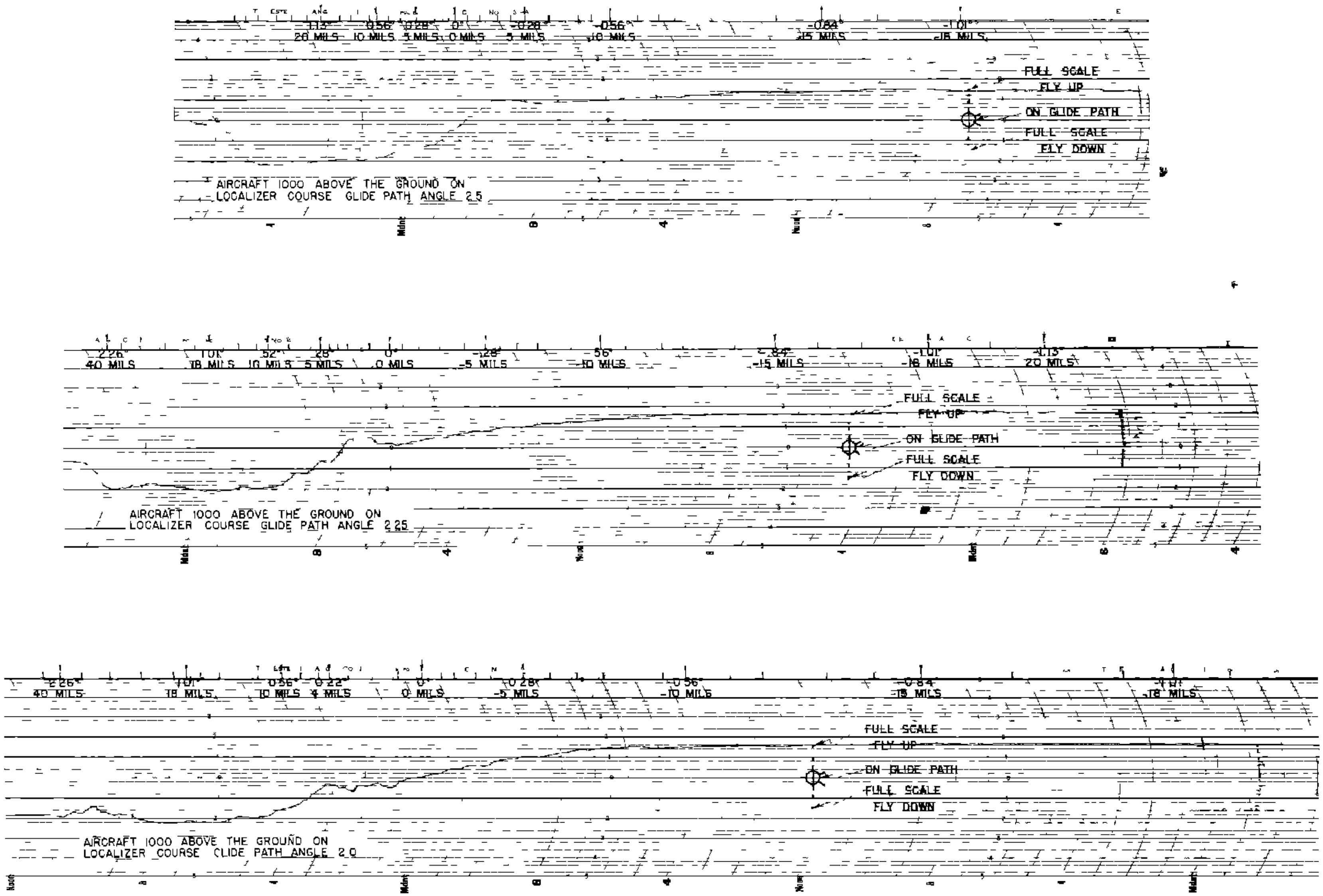

FIGURE 13 RECORDINGS OF GLIDE PATH INDICATOR DURING LEVEL PASSES

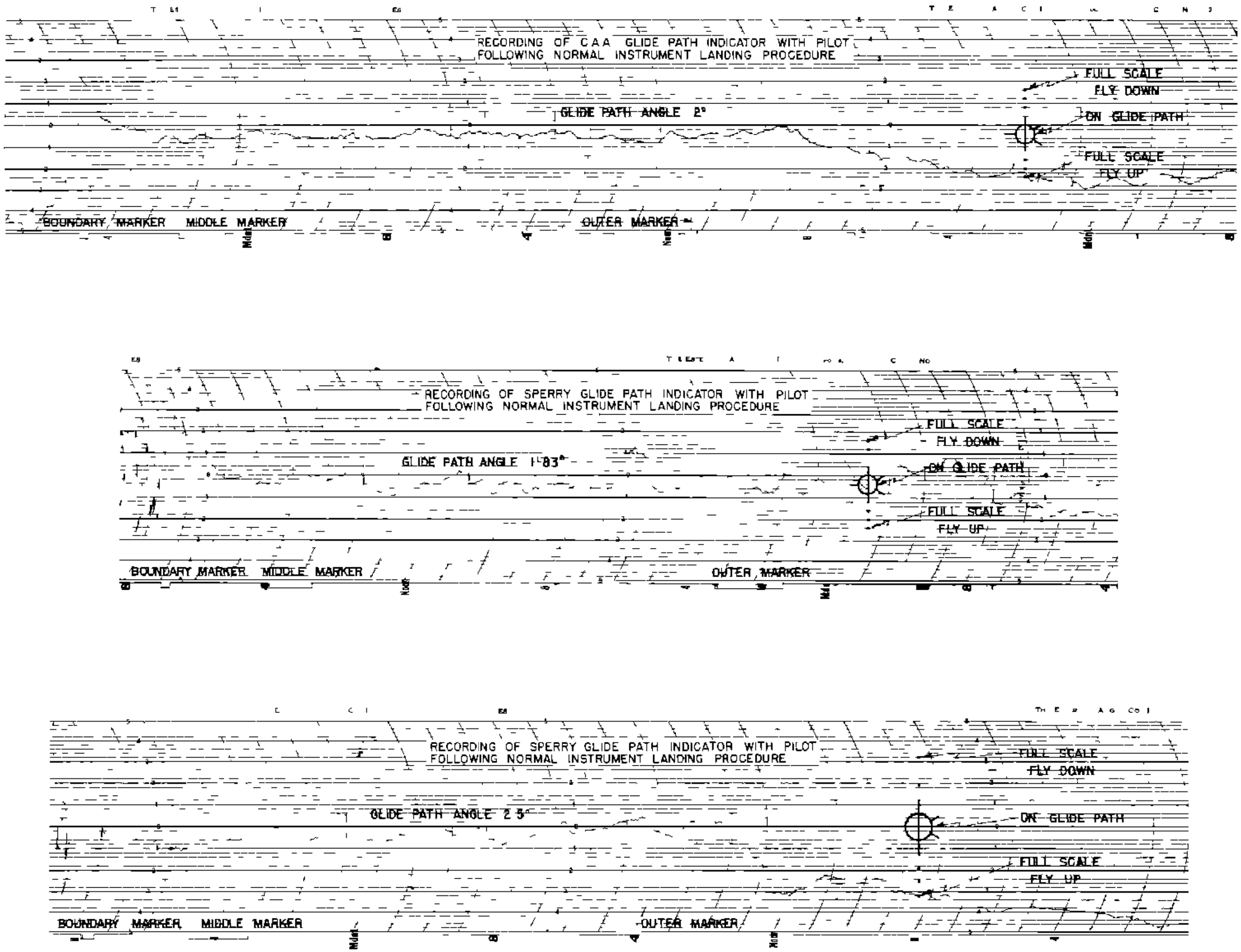

FIGURE 14 RECORDINGS OF GLIDE PATH INDICATOR ON MANUAL APPROACH

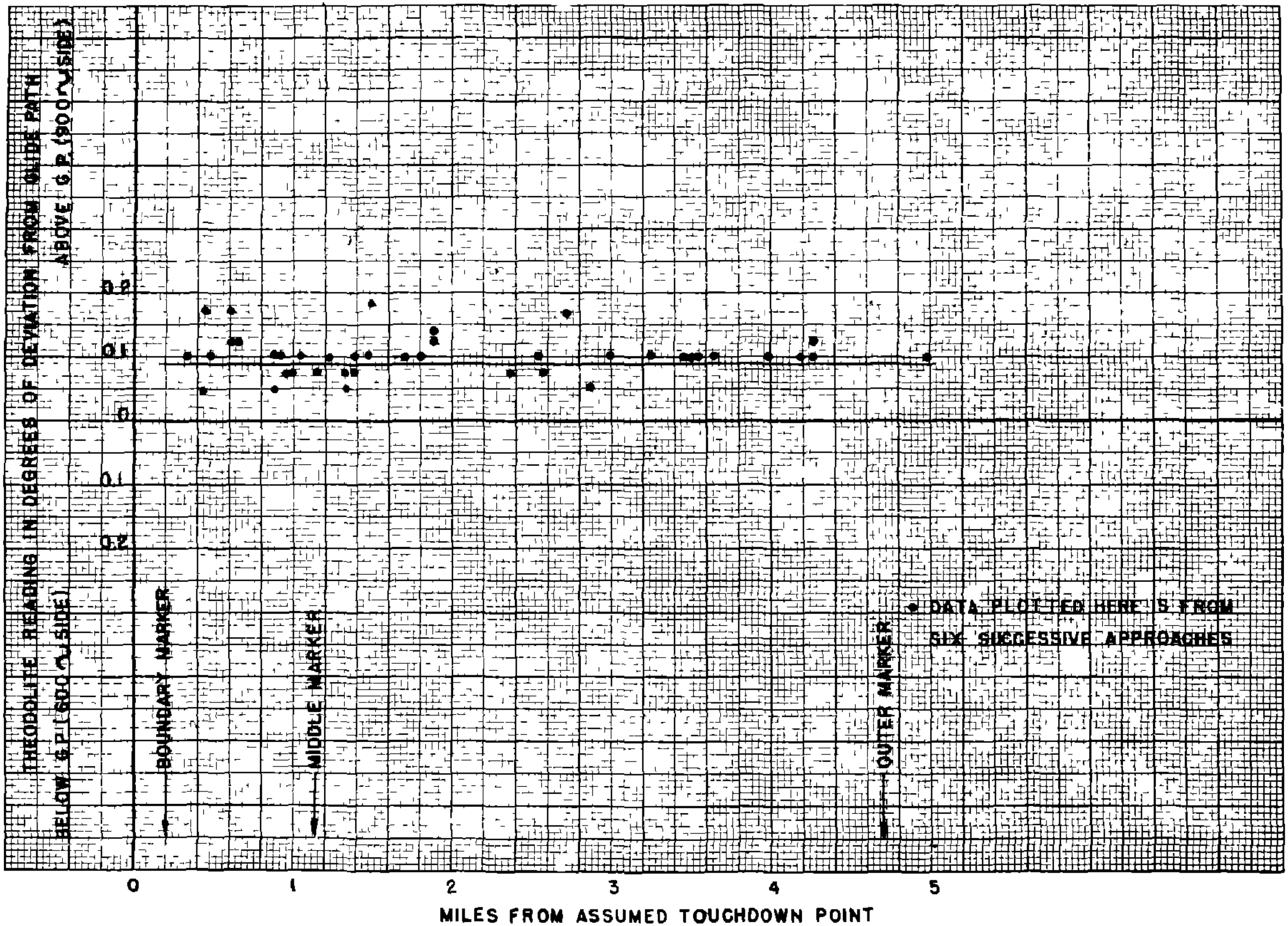

FIGURE 15 STRAIGHTNESS OF SPERRY GLIDE PATH

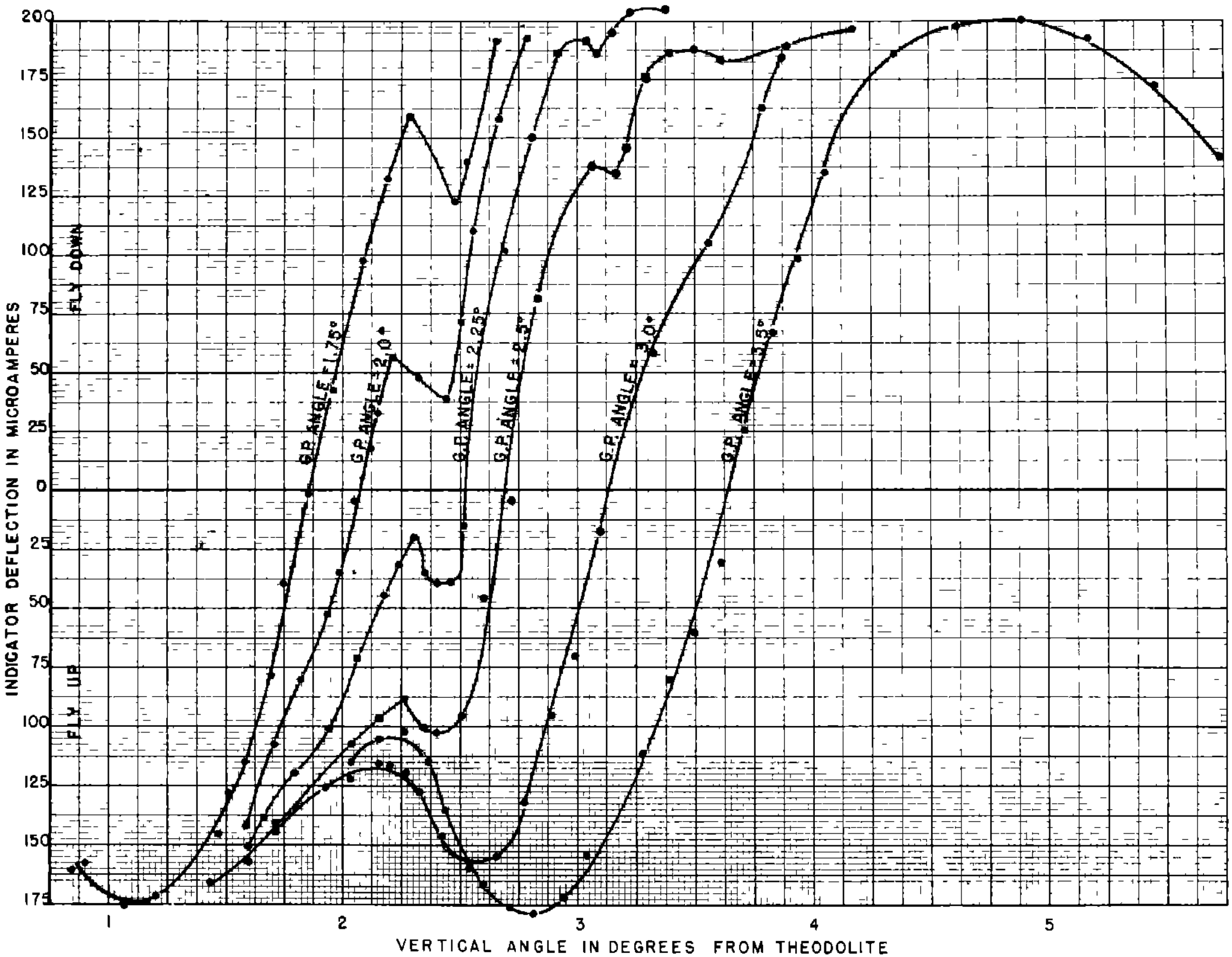

FIGURE 16 GLIDE PATH INDICATOR CURRENT VERSUS VERTICAL ANGLE READING OF THEODOLITE WITH AIRCRAFT AT 1000 ABOVE GROUND ON LOCALIZER COURSE