SOME EFFECTS OF TERRAIN ON THE NULL-REFERENCE GLIDE PATH SHAPE

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SUMMARY

Tests giving data necessary for determining the shape of the Instrument Landing System (ILS) glide path were conducted at Indianapolis, Ind, St Louis, Mo, Kansas City, Mo, and Binghamton, N. Y Results are plotted to show the angular departure of the path from a straight line An improved antenna identified as the null-reference transmitting array was utilized in the tests At St Louis, tests were also conducted with the equisignal glide path system in order to compare it to the null-reference system. A brief description of the method employed for determining the glide path shape is included

INTRODUCTION

The procurement of the null-reference transmitting equipment which includes an improved glide path[1] antenna system was initiated by CAA Previous tests verified the advantages predicted by theoretical studies of a similar null-reference system [2] The first production unit of the glide path transmitter with the improved antenna was delivered to the Technical Development and Evaluation Center for evaluation early in 1951

This report describes the path shapes which were produced when the null-reference transmitting array was installed at several sites The sites selected were Lambert Field, St Louis, Mo, Kansas City Municipal Airport, Kansas City, Mo, and Broome County Airport, Binghamton, N Y These sites are located where the terrain in the direction of the propagated path is very irregular The objective of the tests was confined to determining the shape of the paths The contour of the terrain surrounding the glide path station is related to the resulting glide path shape as shown by the data presented in this report Additional tests would be required to establish precisely which characteristics of the terrain were responsible for the departures of the glide paths from a straight line

[1] Throughout this report the term "glide path" is used in preference to the term "glide slope" to define an inclined surface of signal extending upward at an angle to the horizontal from the point of desired ground contact

[2] Chester B Watts "Theoretical Consideration of an Improved Glide Path Antenna System," Technical Development Report No 81, March 1949

TEST METHOD

The path shapes were determined by a method developed at this Center The method consists of making simultaneous recordings on Esterline-Angus recorders of the course deviation indicator (CDI) in the aircraft and of theodolite observations (taken on the ground) of the aircraft during an approach on the ILS From these two recordings a chart was prepared which accurately indicates the path shape

One recorder, located in the aircraft flying the glide path, records course deviation indications while the other recorder, located on the ground, is electrically coupled to the vertical angle control of a theodolite which is tracking the aircraft The speeds of the two recorders are carefully synchronized The theodolite recorder is adjusted to indicate zero when the theodolite is sighted on the aircraft as it is flown on course over the outer marker This establishes a straight line between the theodolite and an on-course position over the outer marker Next, the sensitivity of the ground recorder is adjusted so that any angular departure of the aircraft from the on-course position over the outer marker will show equal amplitude of deflection on both recorders

The aircraft makes a simulated approach, approximately down the glide path The CDI recording shows departure of the aircraft from the null-reference-generated glide path at the same time that the theodolite recording shows departure of the aircraft from a theoretical straight line in space established by the theodolite If the glide path has bends and if the aircraft is flown along the straight line which theoretically defines the glide path, the CDI recording will indicate path shape If the approach is made with the CDI exactly centered, the theodolite recording will correspond to path shape In any practical case the CDI is not exactly centered during the approach, and the aircraft does not follow an exact straight line In such a case, the path shape is determined by superimposing either the ground recording or the airborne recording upon each other The amplitude difference of the two recordings is a measure of the angular departure of the actual path angle from the theoretical path angle This difference is then plotted as glide path shape in terms of angular departure from the theoretical straight line versus horizontal distance in feet from the end of the runway This system has an important advantage in that the accuracy is not affected if the pilot does not keep the CDI centered

TESTS AND RESULTS

Two preliminary flight checks were made at Indianapolis The station location is indicated by Site A, Fig 1 The terrain within 500 feet of the antenna is relatively flat except for the irregularities produced by two road grades One road is perpendicular to the direction of projection, approximately 20 feet in front of the antennas, the other road grade is parallel to the direction of projection and is located between the station and the runway, approximately 100 feet east of the station, two feet above the average grade, with ditches on either side 18 inches below average grade level A row of approach lights crosses the path of projection diagonally, at a point 900 feet from the station in the direction of glide path projection

The path shape curves shown in Fig 2 were obtained from the preliminary flights They were made on different days and show close correlation A prominent deviation from a straight line occurs on both curves at approximately 12,000 feet from the end of the runway At this site there is anticipated additional work, some of which will be directed toward determining more definitely the cause of these irregularities in the path shape

In June 1951, the Type TUS system which included a transmitter and a null-reference antenna were moved to Lambert Field, St Louis, Mo The sites and the surrounding terrain are shown in Fig 3a The area immediately in front of the station (in the direction of glide path projection) was quite smoothly graded Profiles of this area are shown in Fig 3b A hill 50 feet high lay in the direction of projection and approximately 2,000 feet from the station Another hill 100 feet high lay at approximately 10,000 feet from the station in the same direction A small sheet-metal building was located 1,500 feet north of the station Fig 4b shows a cross section of the terrain along the approach path

The Type TUS equipment is designed to produce a glide path which is essentially straight, which has no flare, and which if projected would contact the runway at the intersection of the base line and the center line of the runway The slope near the bottom end of the path and the location of the touchdown point are controlled by the amount of modifier power radiated Due to the variation in height of the antenna above the wheels of the aircraft, the touchdown point has been defined as the point where the glide path is 12 feet above the center line of the runway The distance between the touchdown point and the base line is a function of the angle of the glide path The desired modifier power is defined as the power which produces a 12-foot touchdown at a specified distance from the base line

The glide path shapes shown in Fig 4a were obtained when the glide path station was located at Site A It is of interest to note that this path shape produced with power removed from the modifier antenna is considerably rougher than those produced with power applied to the modifier Further tests would be necessary to form any conclusions regarding the cause of this phenomenon

Site B produced the path shapes shown in Fig 5 These path shapes are better, in general, than those obtained when the station was located at Site A Paths produced with the station at Site A are somewhat rougher and exhibit a tendency to dive toward the runway from a point 8,000 feet from the end of the runway The important difference between the two sites is that Site B is 268 feet farther from the 50-foot hill than Site A The results of a probe of the glide path along the center line of the runway are shown in Fig 6

In September 1951, a flight check was made on a Type CRN-2 equisignal glide path station located at Site B, Lambert Field The measured glide path shapes are shown in Fig 7 In each of the three shapes shown, the angle of the path increases as it approaches the end of the runway This is the reverse of the null-reference glide path charts which show either a constant angle or a decreasing angle near the runway The paths produced by the equisignal system are no rougher than those produced by the null-reference system

In August 1951, the null-reference glide path system was installed on a new runway at Kansas City Municipal Airport

The location of the glide path station is shown in Fig 8a The ground plane sloped upward both toward the runway and in the direction of glide path projection During the first series of tests, the ground plane was uneven because of ridges of earth 18 inches high running parallel to the direction of projection and extending 500 feet out from the base of the antenna A later series of tests was made after these ridges of earth had been leveled and after some heavy earth-moving machinery and large concrete mixers had been moved several hundred feet away from the line of glide path projection Attention is directed to the railroad switch tracks shown in Fig 8a During most of the tests, long lines of freight cars stood on the switch tracks A large steel grain elevator was located to the northeast just beyond the range of the map. As the contours show, there was also a considerable discontinuity in the ground plane caused by the levee and river at the end of the runway Fig 8b is a profile of the ground plane in front of the antennas Fig 9 was obtained by probing the glide path along the center line of the runway The maximum variations from a straight line glide path are not more than one foot along this portion of the path

The glide path shapes obtained on August 9 and 11, shown in Fig 10, are insignificantly different from those obtained on September 19, shown in Fig 11a, although the terrain on the latter date had been altered as described above Hence it may be concluded that the ridges of earth and machinery did not produce significant roughness in the glide path It can also be pointed out that a 200-foot hill that is 10,000 feet from the transmitter does not produce an unflyable glide path Fig 11b shows a profile of the terrain beneath the glide path out to 30,000 feet from the end of the runway

On October 15, 1951, the null-reference glide path was moved to Broome County Airport near Binghamton, N Y This airport is in rough country with 800-foot mountains in all directions from the airport The null-reference system was tried at three sites which are indicated by A, B, and C of Fig 12 Fig 14 is the glide path shape obtained in two flights with the null-reference glide path station at Site A This figure is noteworthy because of the way that the roughness between 6,000 and 10,000 feet from the station is duplicated on a second flight There is sufficient evidence that the sharp discontinuity in the ground plane located directly in front of the station, as shown in Fig 13, is the cause of this roughness Fig 15 shows the results of probing with a telescoping mast along the center line of the runway Previous results obtained with the equisignal glide path system exhibited irregularities which made this site unacceptable

The glide path shape produced when the station was located at Site B is shown in Fig 16 This site did not produce an acceptable glide path although it was relatively smooth and straight from the outer marker to approximately 2,000 feet from the theodolite, which distance was as close as the aircraft could be accurately tracked If tracking could not be maintained to 0 1° or less, it was not considered to be sufficiently accurate It was in the region near the end of the runway that the pilots found unflyable roughness in the glide path Fig 17 shows the results of probing along the center line of the runway with a telescoping mast When the on-course indication of the glide path could no longer be reached with the probe, the bottom of the course (150 microamperes of "fly up" signal) was plotted, anticipating that the extreme roughness reported by the pilots would be evident From these results it is evident that the roughness was between 1,300 and 2,300 feet from the theodolite

When the station was located at Site C, the glide path proved acceptable when flight tested The graphs are shown in Fig 18a, while Fig 18b shows the approach area ground profile Fig 19 shows the results of probing along the runway when the glide path station was at Site C As may be seen from Fig 12, this location would require special attention for the monitor position and probably would require the closing of the taxiway which is directly in front of the station

CONCLUSIONS

From an inspection of the results of the tests made at St Louis it is concluded that, while the terrain affects the shape of the null-reference-generated path system differently than that of the equisignal system, there is no evidence that these effects are more adverse to one system than to the other

The results indicate that the rise in the terrain approximately 1,600 feet in the direction of propagation from the site does not constitute an unacceptable obstruction, however, the influence of this obstruction can be seen by noting the improvement in glide path shape when the station was moved from Site A to Site B

From the Kansas City results, it is concluded that the terrain in the direction of projection from the station and out to a distance of approximately 800 feet does not require careful grading The glide path shape produced when this area contained ridges 18 to 24 inches high was essentially the same as that produced when this area was smoothly graded It was also noted at Kansas City that heavy machinery located 1,200 feet in a direction directly ahead of the station had only negligible effect on glide path shape

The results at Binghamton indicate that when the terrain drops off sharply 500 feet in a direction of projection from the station, the glide path shape is unacceptable If a sharp drop in the terrain occurs at a distance of 1,500 feet in the direction of projection from the station, the glide path shape is negligibly affected

From the Binghamton and Kansas City tests, it appears that neither hills 200 feet high nor valleys 400 feet deep located beneath the approach path and two miles or farther from the end of the runway cause a glide path to be unacceptable

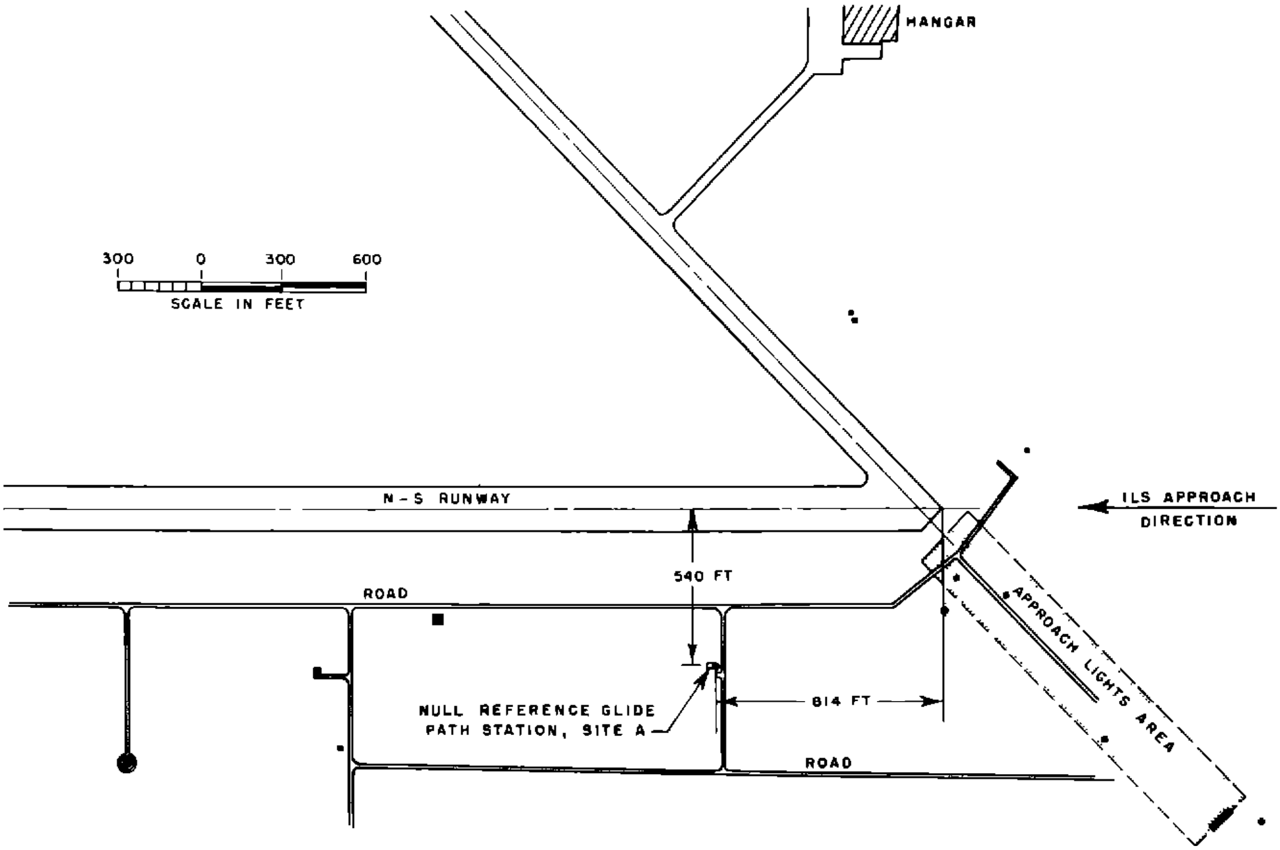

FIG 1 GLIDE PATH STATION, WEIR COOK AIRPORT, INDIANAPOLIS, INDIANA

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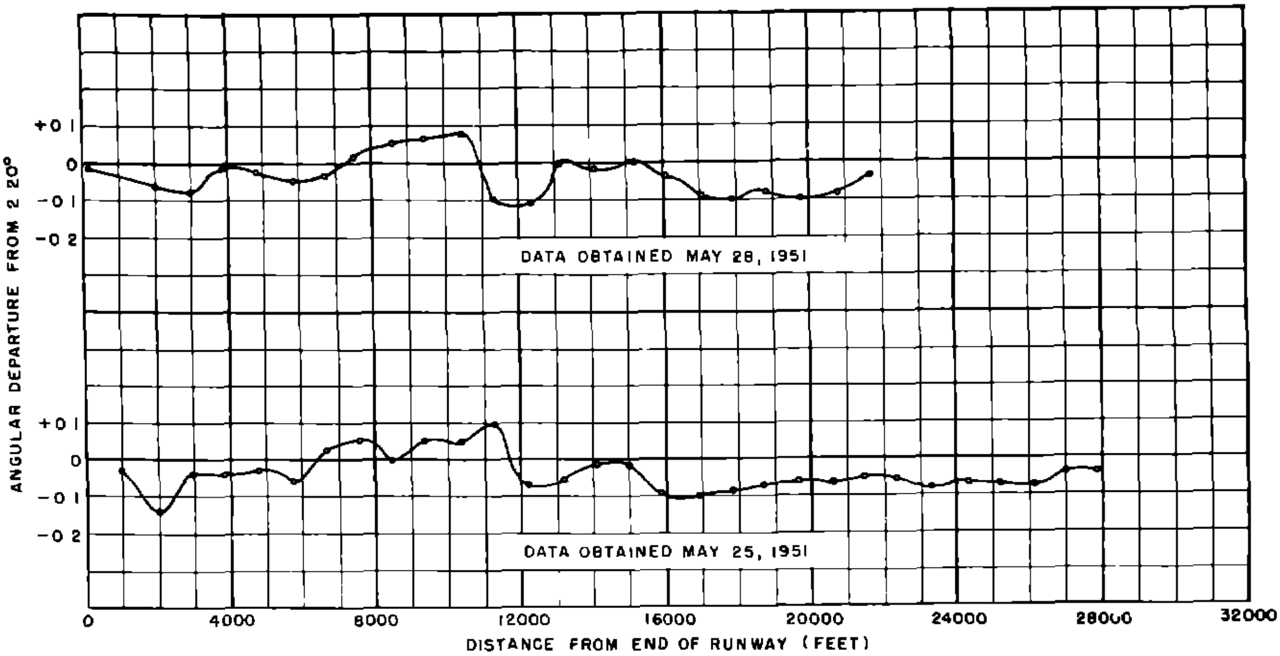

FIG 2 NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE A
WEIR COOK AIRPORT, INDIANAPOLIS, INDIANA

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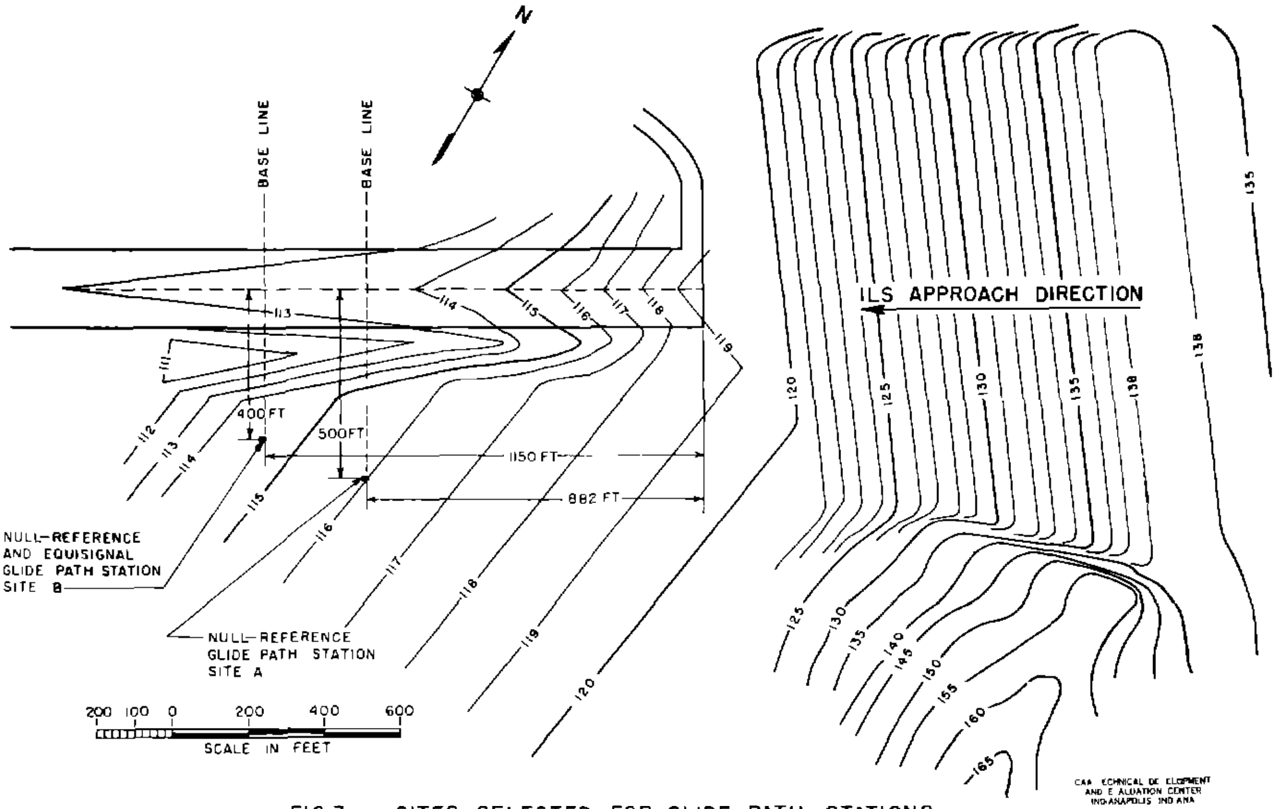

FIG 3a SITES SELECTED FOR GLIDE PATH STATIONS
LAMBERT FIELD, ST LOUIS, MISSOURI

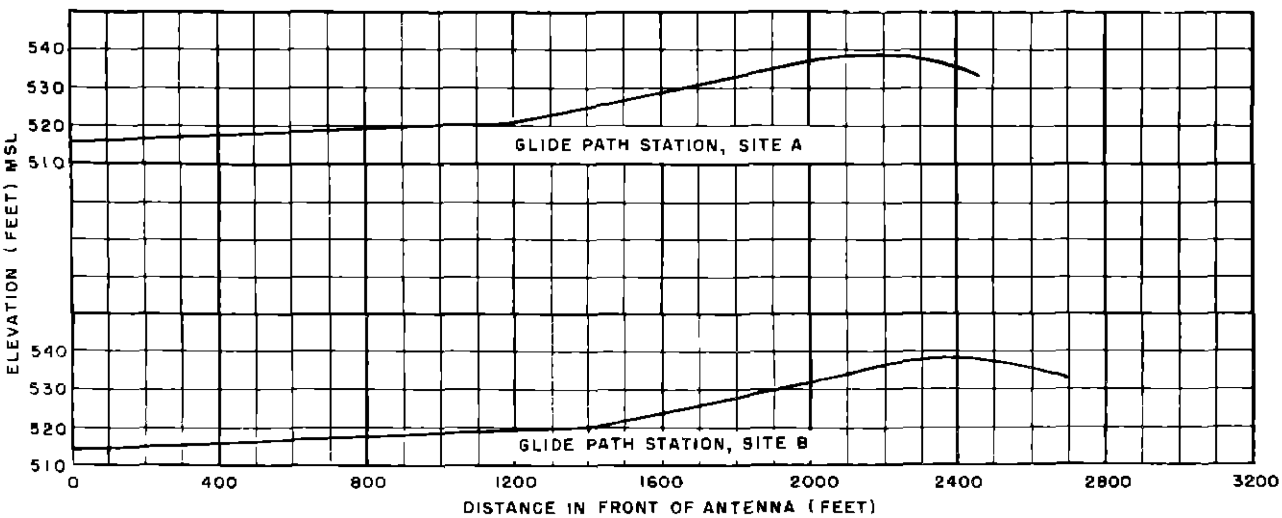

FIG 3b PROFILES OF APPROACH AREA IMMEDIATELY IN FRONT
OF STATION AT LAMBERT FIELD, ST LOUIS, MISSOURI

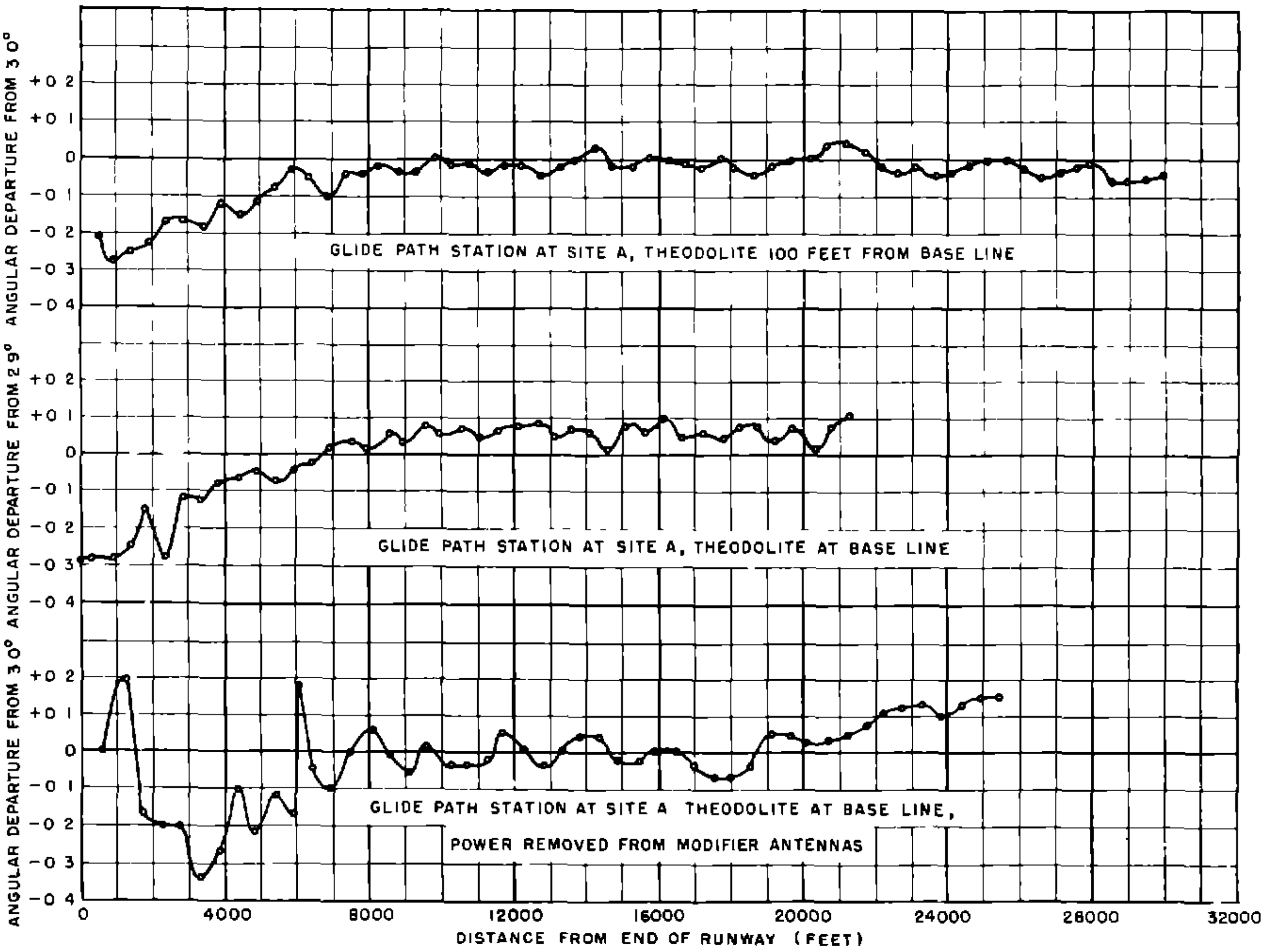

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FIG 4a NULL-REFERENCE GLIDE PATH COURSE SHAPES, LAMBERT FIELD, ST LOUIS, MISSOURI

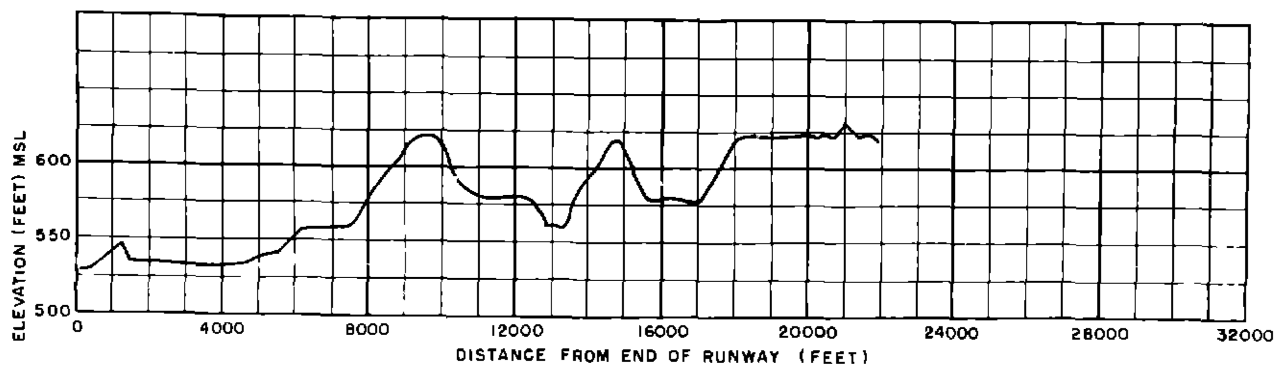

FIG 4b APPROACH AREA GROUND PROFILE, LAMBERT FIELD, ST LOUIS, MISSOURI

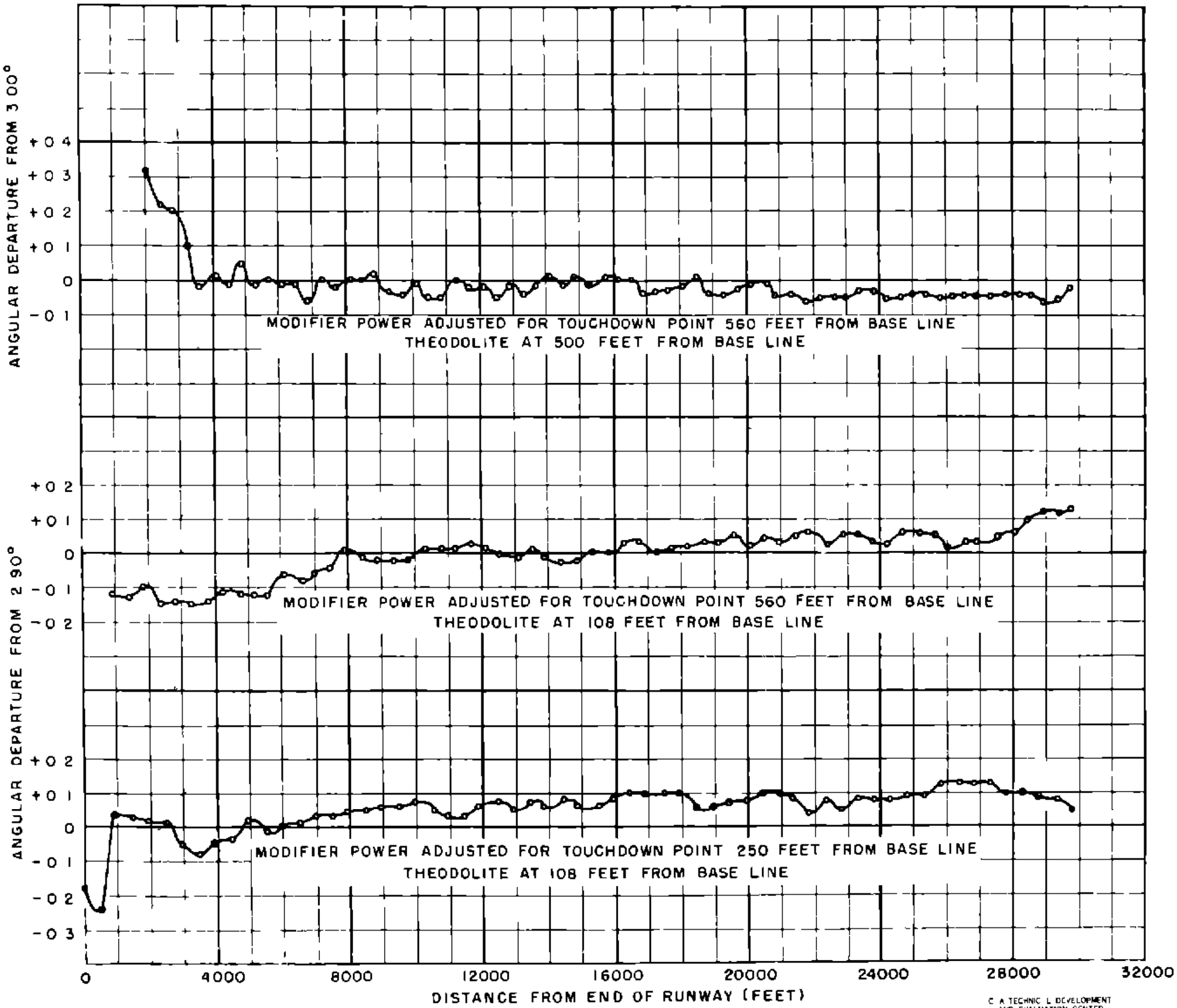

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FIG 5 NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE B
LAMBERT FIELD, ST LOUIS, MISSOURI

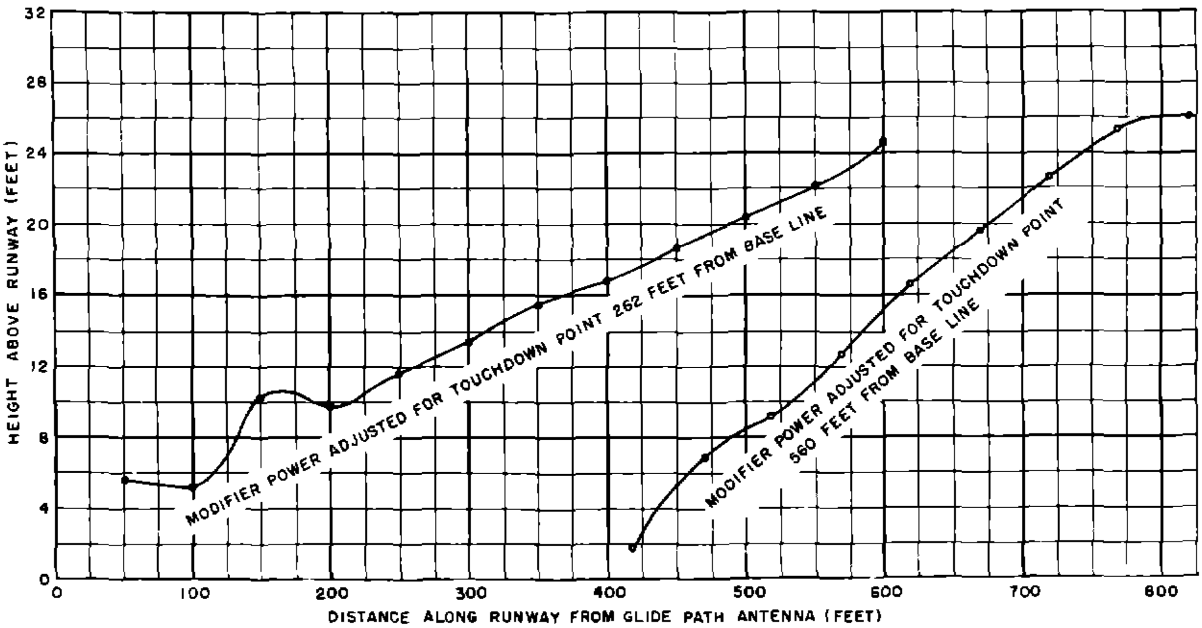

FIG 6 PROBE OF THE NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE B
LAMBERT FIELD, ST LOUIS, MISSOURI

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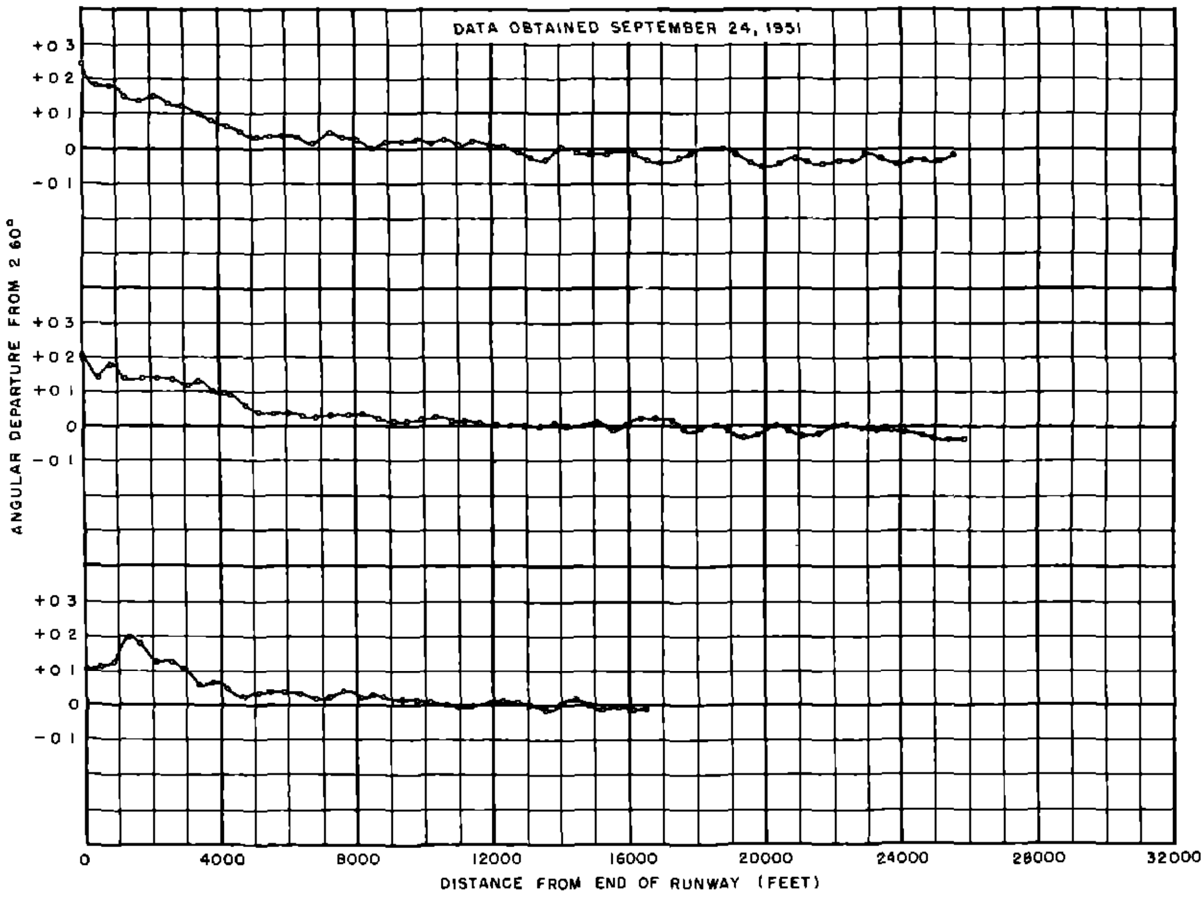

FIG 7 EQUISIGNAL GLIDE PATH COURSE SHAPES, SITE B
LAMBERT FIELD, ST LOUIS, MISSOURI

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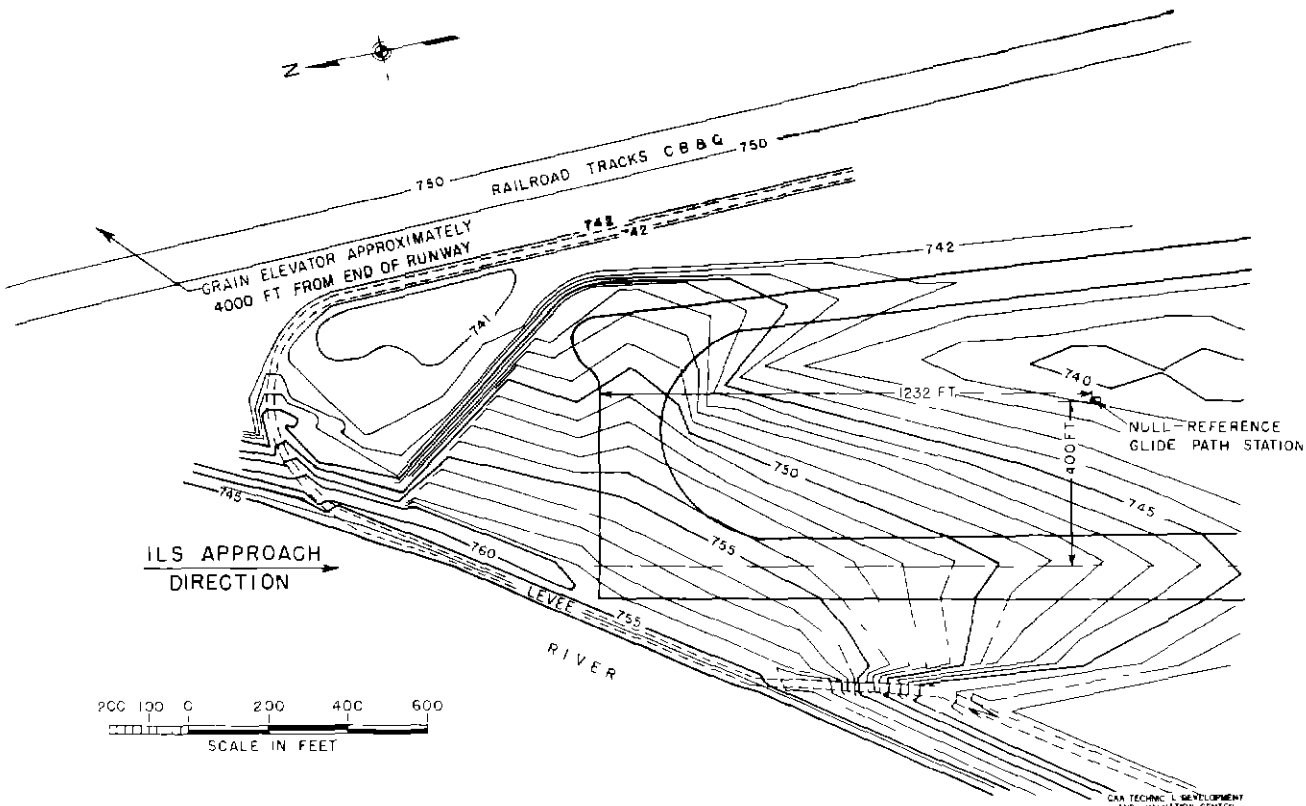

FIG 8a SITE SELECTED FOR GLIDE PATH STATION
MUNICIPAL AIRPORT, KANSAS CITY, MISSOURI

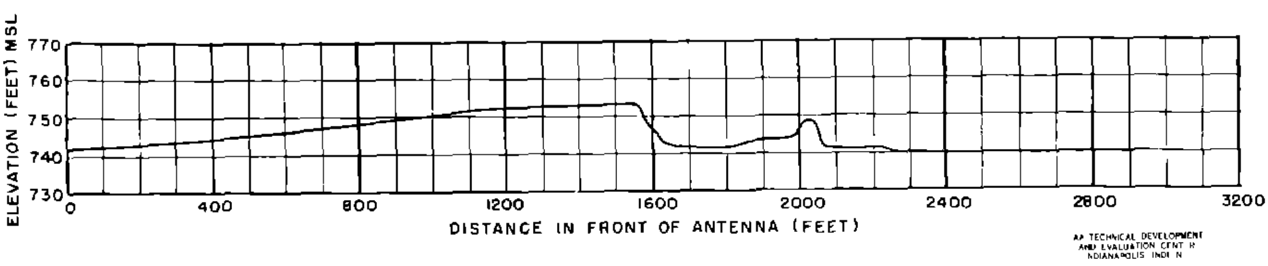

FIG 8b APPROACH AREA GROUND PROFILE IMMEDIATELY IN FRONT OF
ANTENNAS, MUNICIPAL AIRPORT, KANSAS CITY, MISSOURI

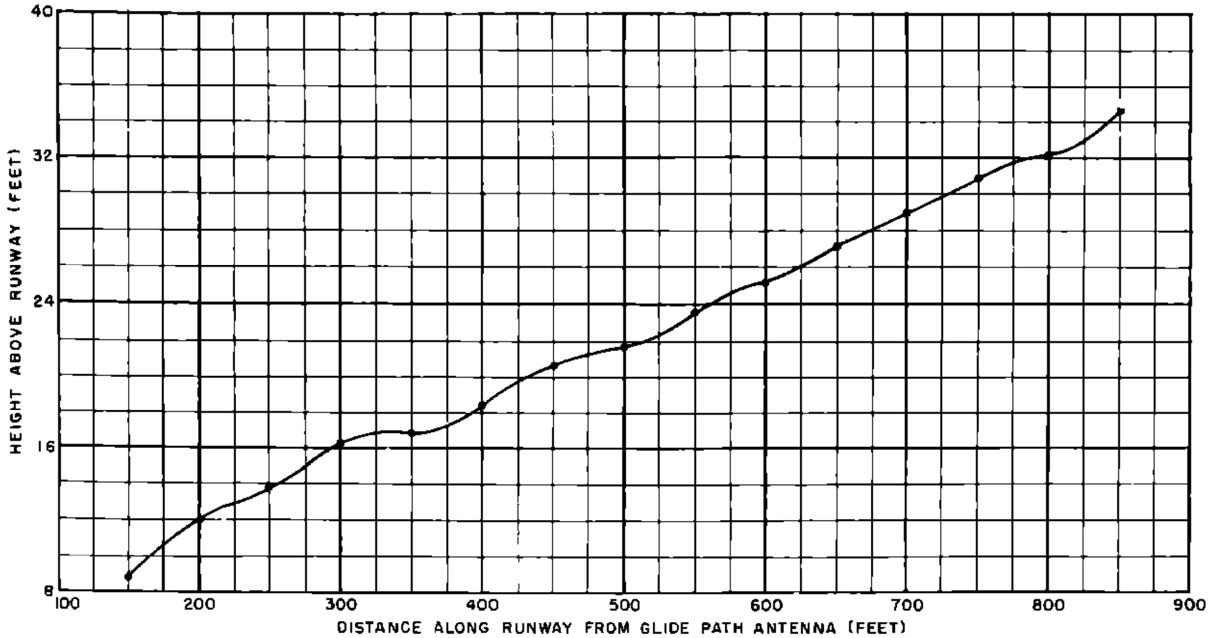

FIG 9 PROBE OF THE NULL-REFERENCE GLIDE PATH COURSE SHAPE MUNICIPAL AIRPORT, KANSAS CITY MISSOURI

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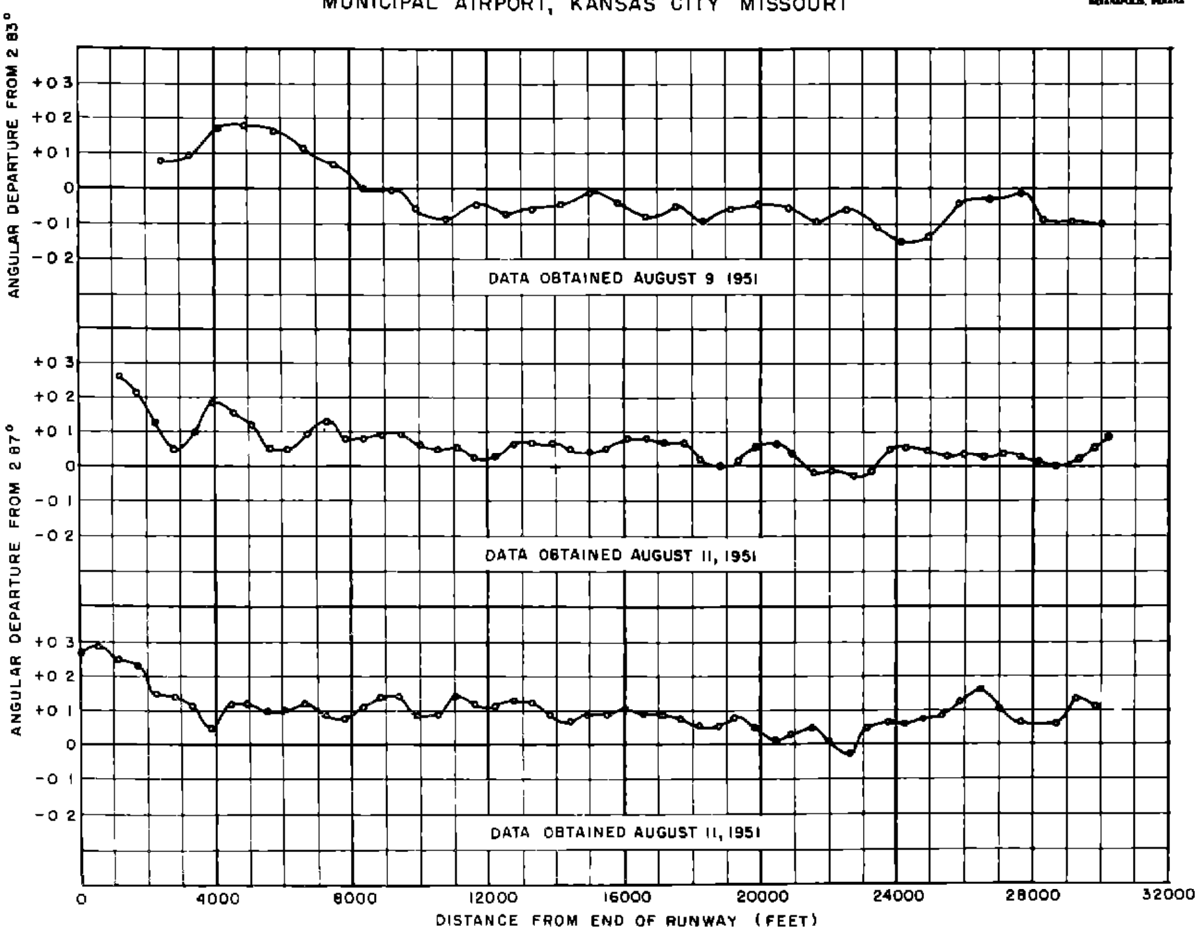

FIG 10 NULL-REFERENCE GLIDE PATH COURSE SHAPES, MUNICIPAL AIRPORT, KANSAS CITY, MISSOURI, FROM DATA COMPILED BEFORE FINAL GRADING OF APPROACH AREA WAS ACCOMPLISHED

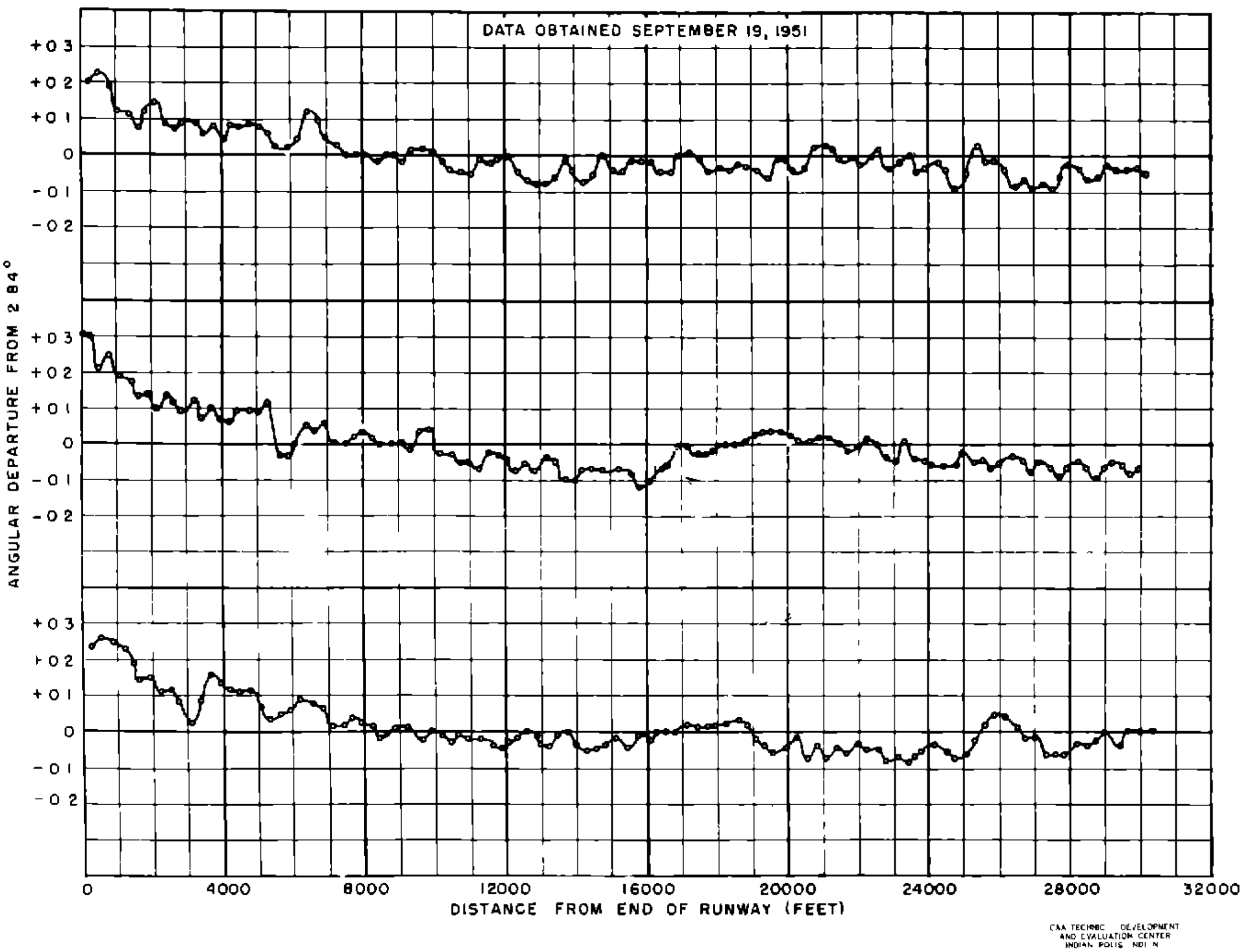

FIG 11a NULL-REFERENCE GLIDE PATH COURSE SHAPES, MUNICIPAL AIRPORT, KANSAS CITY, MISSOURI, FROM DATA COMPILED AFTER FINAL GRADING OF APPROACH AREA WAS ACCOMPLISHED

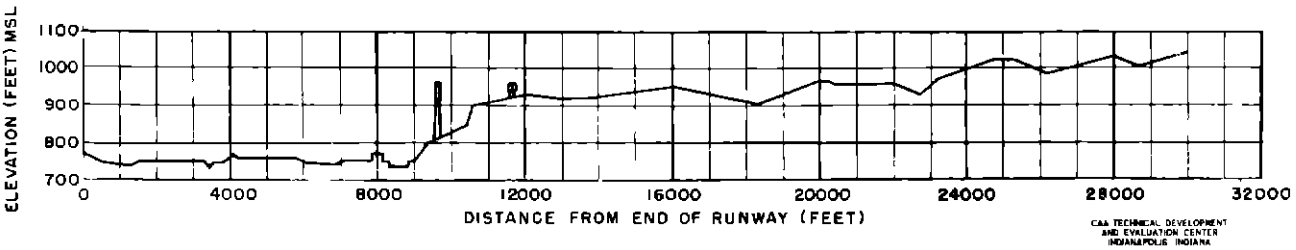

FIG 11b APPROACH AREA GROUND PROFILE, MUNICIPAL AIRPORT, KANSAS CITY, MISSOURI

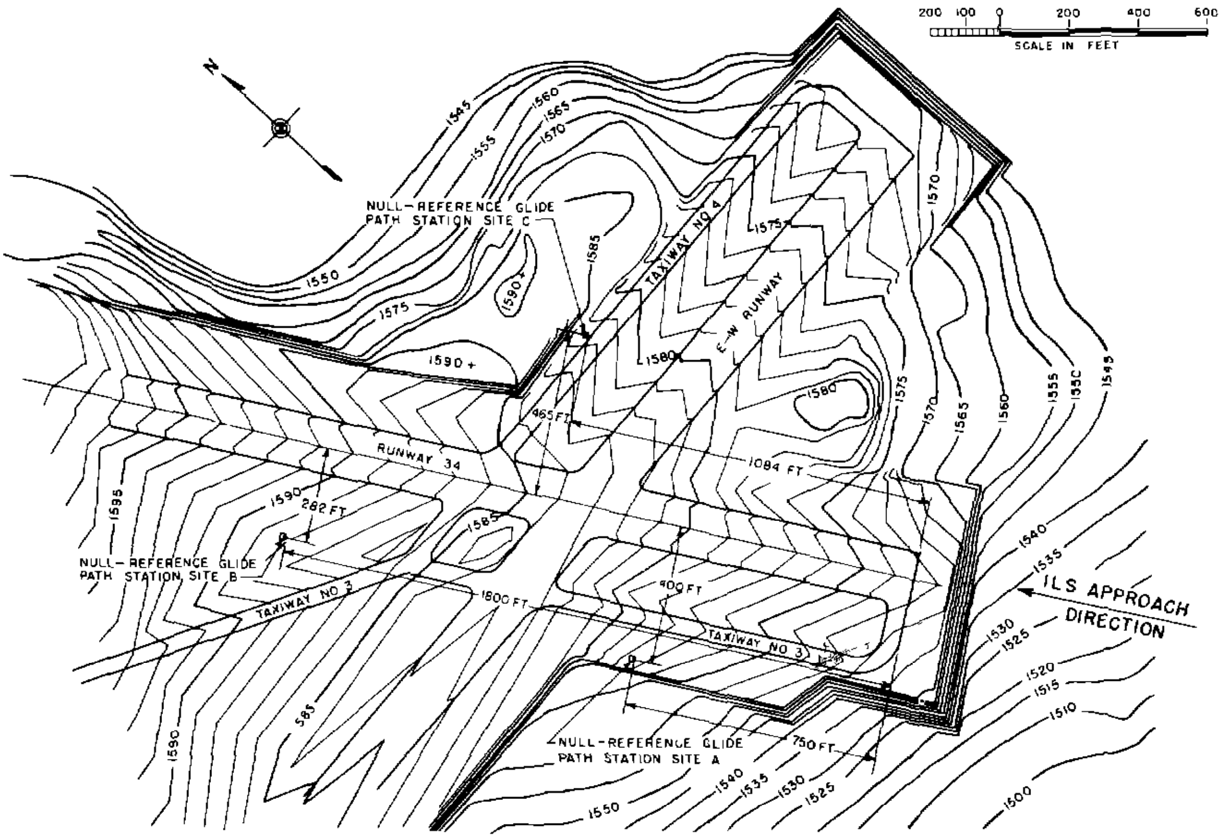

FIG 12 SITES SELECTED FOR GLIDE PATH STATIONS BROOME COUNTY AIRPORT BINGHAMTON N Y

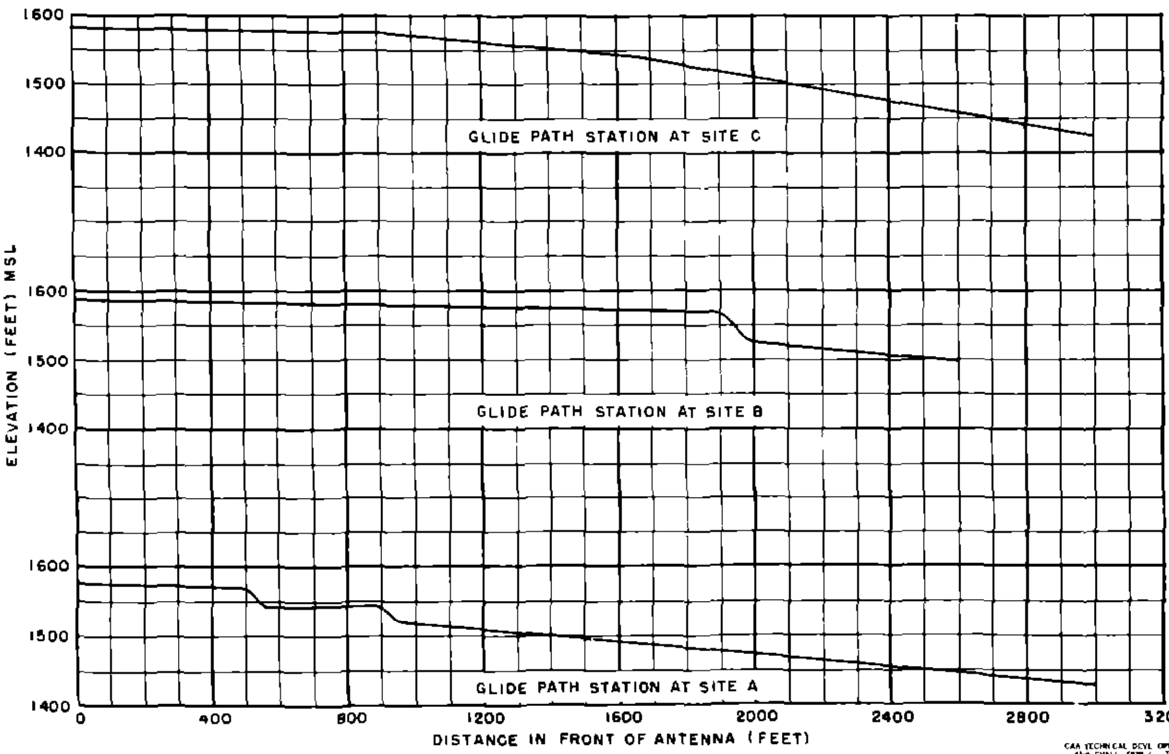

FIG 13 APPROACH AREA GROUND PROFILE IMMEDIATELY IN FRONT OF ANTENNAS, BROOME COUNTY AIRPORT, BINGHAMPTON, NEW YORK

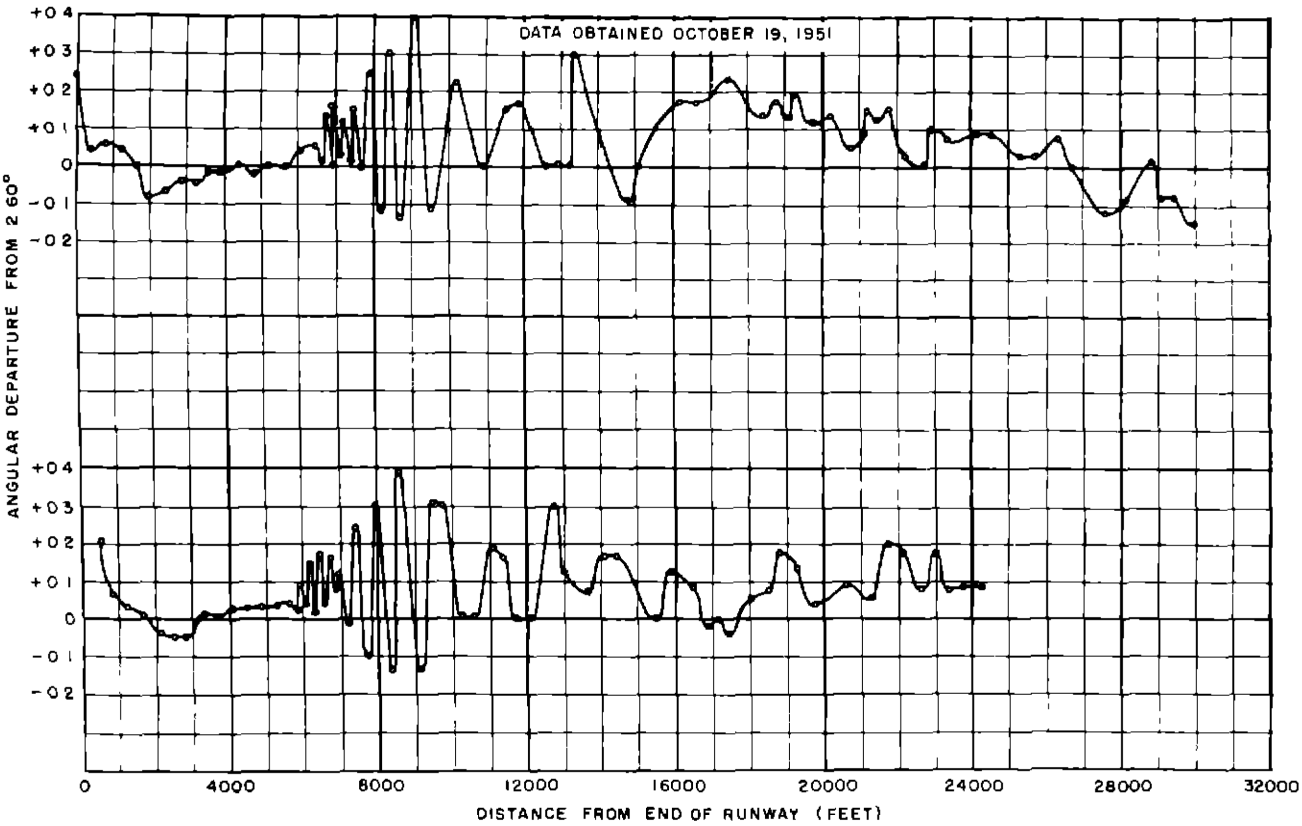

FIG 14 NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE A BROOME COUNTY AIRPORT, BINGHAMPTON, NEW YORK

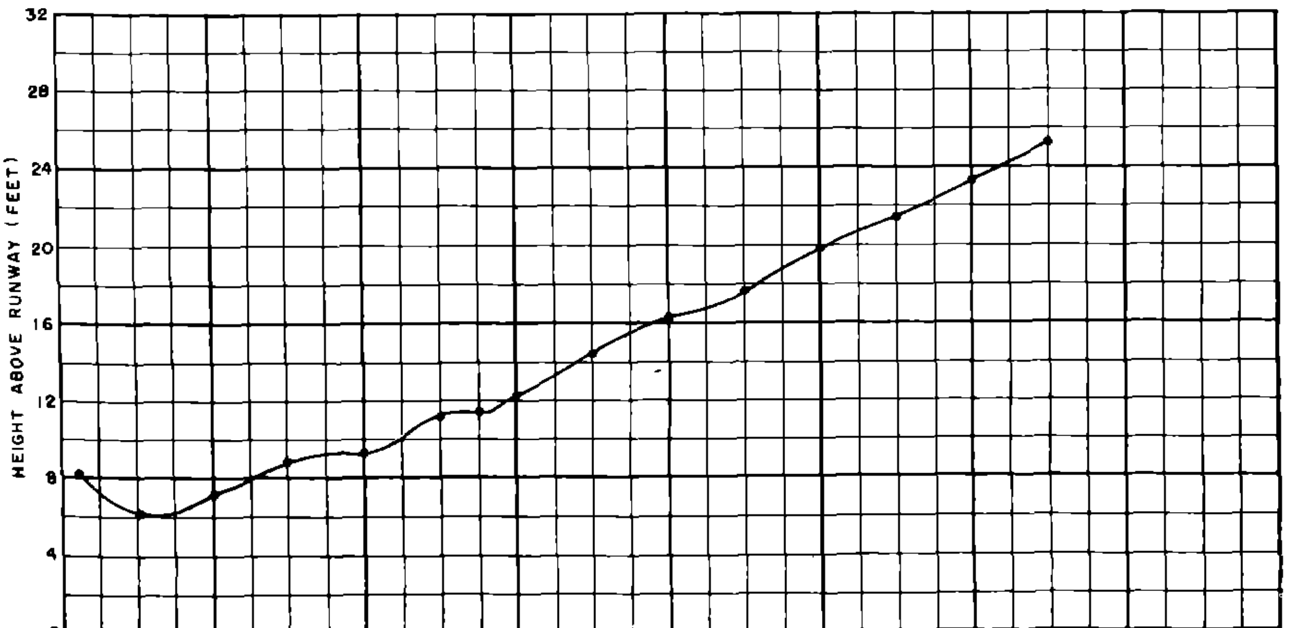

FIG 15 PROBE OF THE NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE A BROOME COUNTY AIRPORT, BINGHAMPTON, NEW YORK

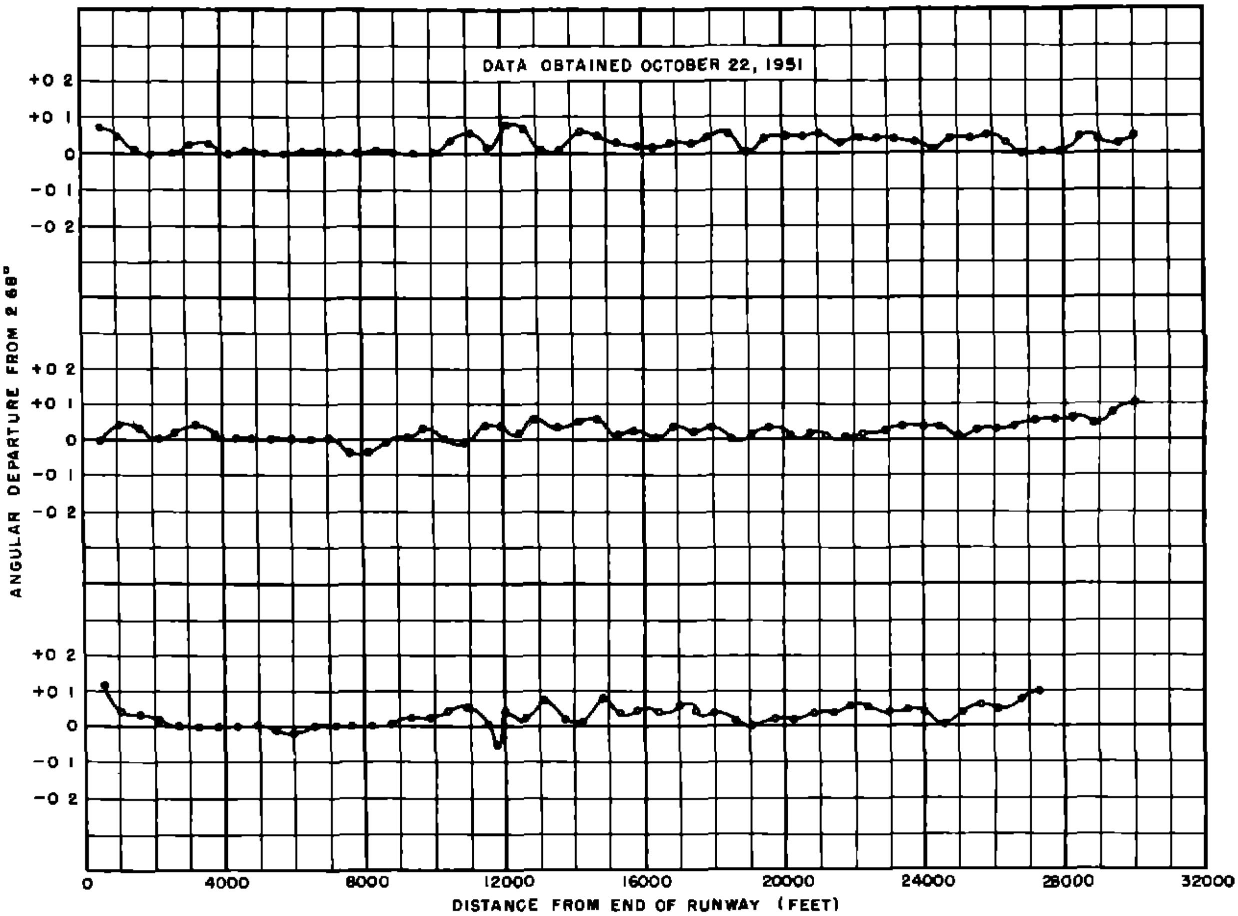

FIG 16 NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE B
BROOME COUNTY AIRPORT, BINGHAMPTON, NEW YORK

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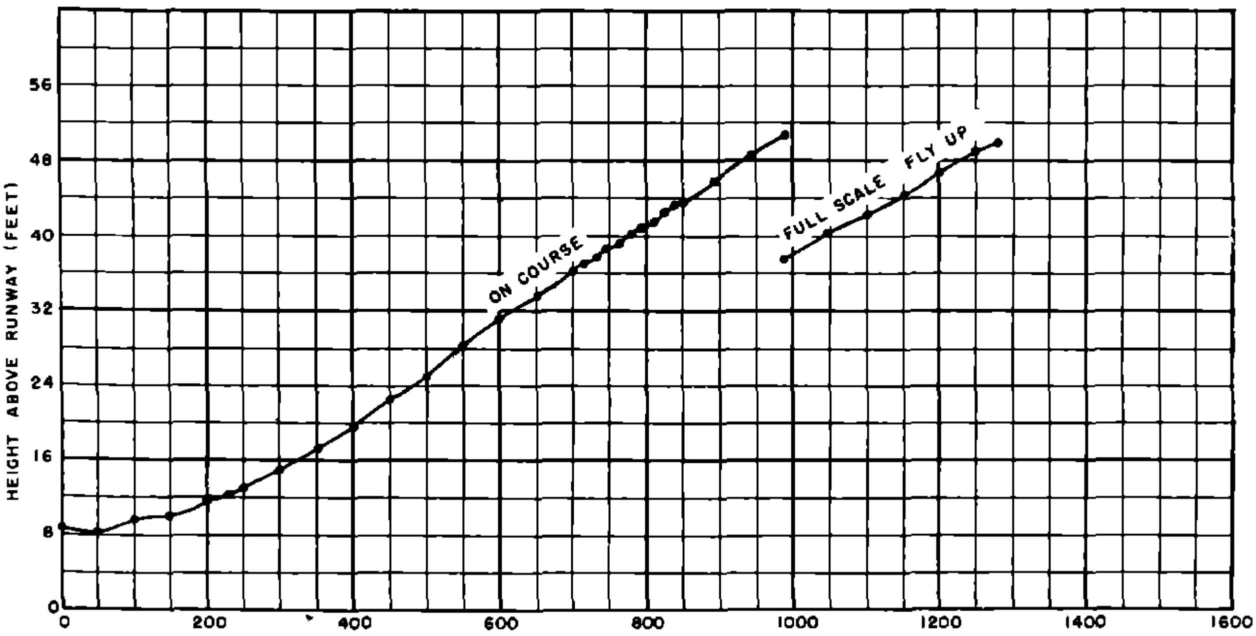

FIG 17 PROBE OF THE NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE B
BROOME COUNTY AIRPORT, BINGHAMPTON, NEW YORK

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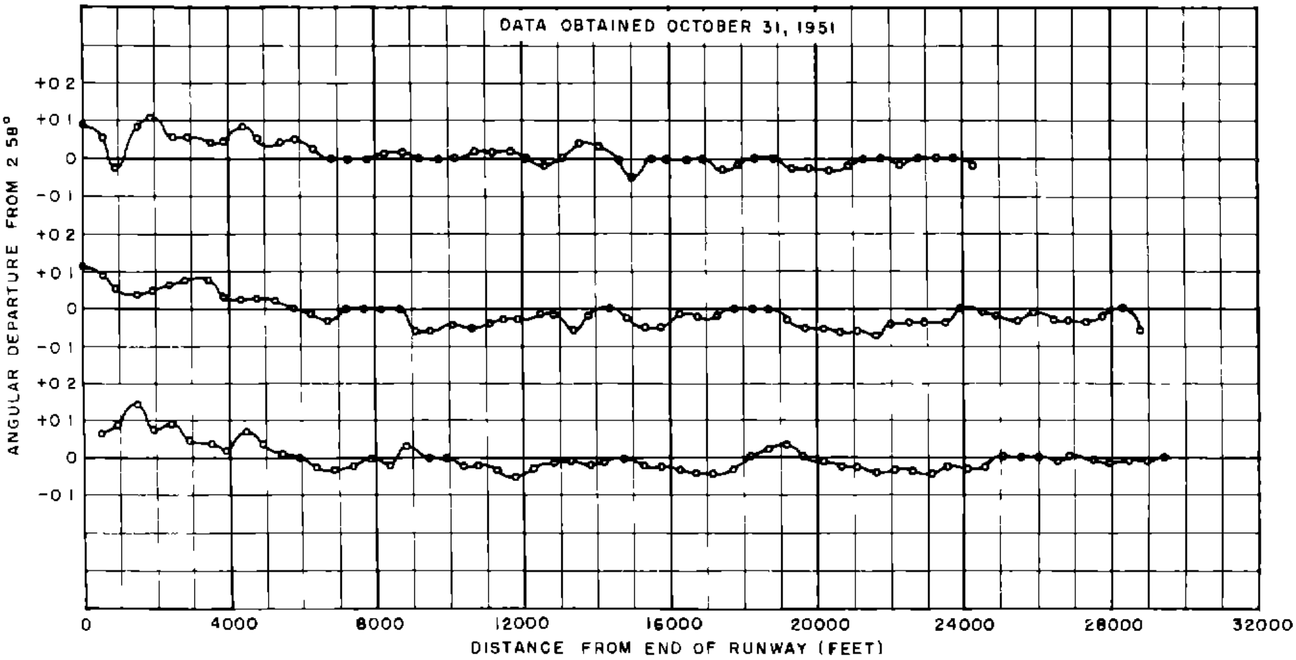

FIG 18a NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE C
BROOME COUNTY AIRPORT, BINGHAMPTON, NEW YORK

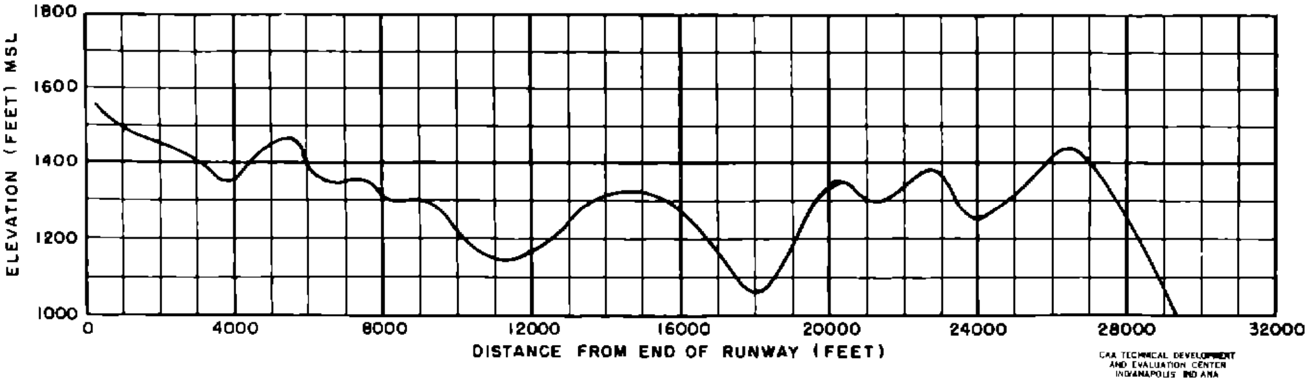

FIG 18b APPROACH AREA GROUND PROFILE, BROOME COUNTY AIRPORT, BINGHAMPTON, NEW YORK

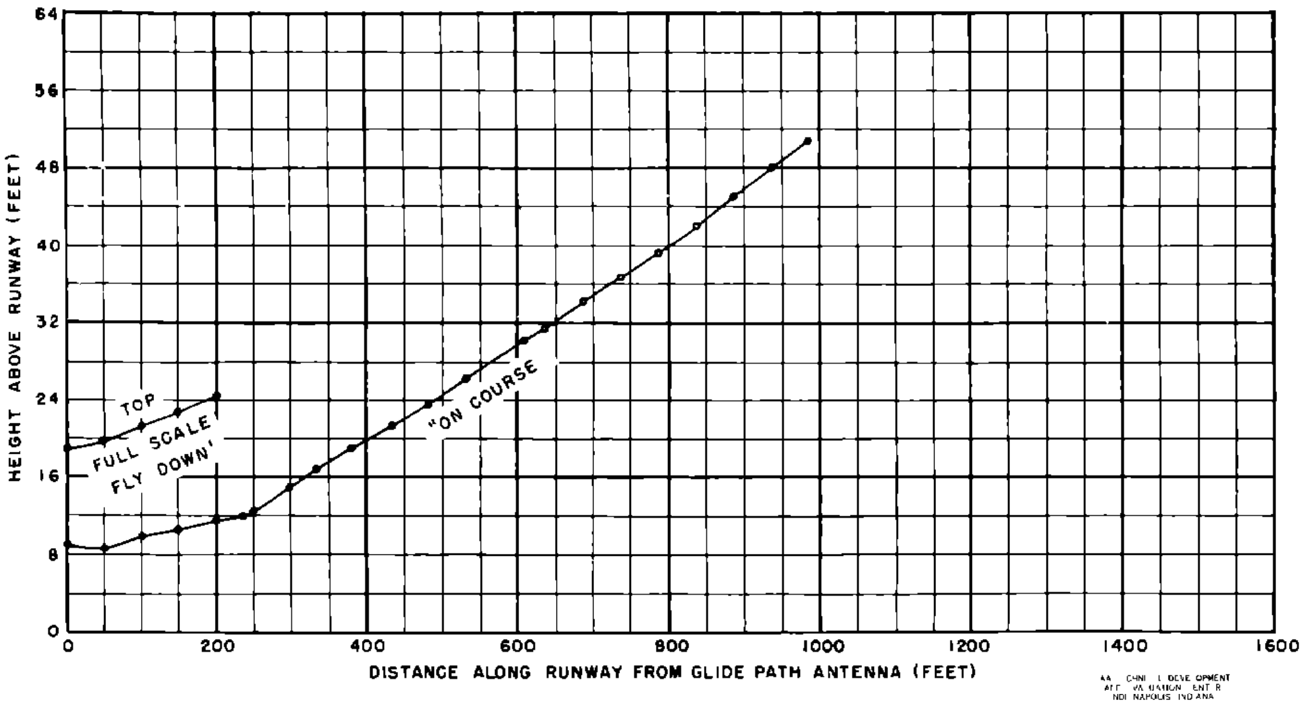

FIG 19 PROBE OF THE NULL-REFERENCE GLIDE PATH COURSE SHAPES, SITE C
BROOME COUNTY AIRPORT BINGHAMPTON NEW YORK

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