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EXPERIMENTAL VALIDATION OF BOEING 747 ILS SIGNAL SCATTERING CALCULATIONS FOR CRITICAL AREA DETERMINATION

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FINAL REPORT

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16. Abstract

Charts showing recommended designated critical areas for aircraft parking on an airdrome are presented. These have been derived from data taken from extensive mathematical modeling of the effects of the Boeing 747 on the ILS signal in space and the recently completed experimental validation of these mathematical models.

Presented also are contour charts which can be used to analyze the effects on the ILS of parking a Boeing 747 at specific locations on the airdrome.

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I. SUMMARY OF RESULTS

Following are two charts, Figure 1 concerning the localizer and Figure 2 , the glide slope. These charts show worst case critical areas* for an airdrome that, given a Boeing 747 aircraft parked at a point in the area, a maximum perturbation in the ILS on course in space will occur exceeding allowable Category I, II, and III path tolerances. Mathematical models previously developed have been used to provide the basic data for the critical area charts. Also included in the report are contour charts which indicate the maximum perturbation an aircraft will see on an ILS approach given an aircraft parked at a point on the contour. These data have been recently validated with full-scale measurements, and these details are reported.

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*A critical area for an airdrome is defined to contain points on the airdrome where a parked or taxiing Boeing 747 aircraft (or similar jumbo jet) will produce an out-of-tolerance perturbation in the ILS beam in space.

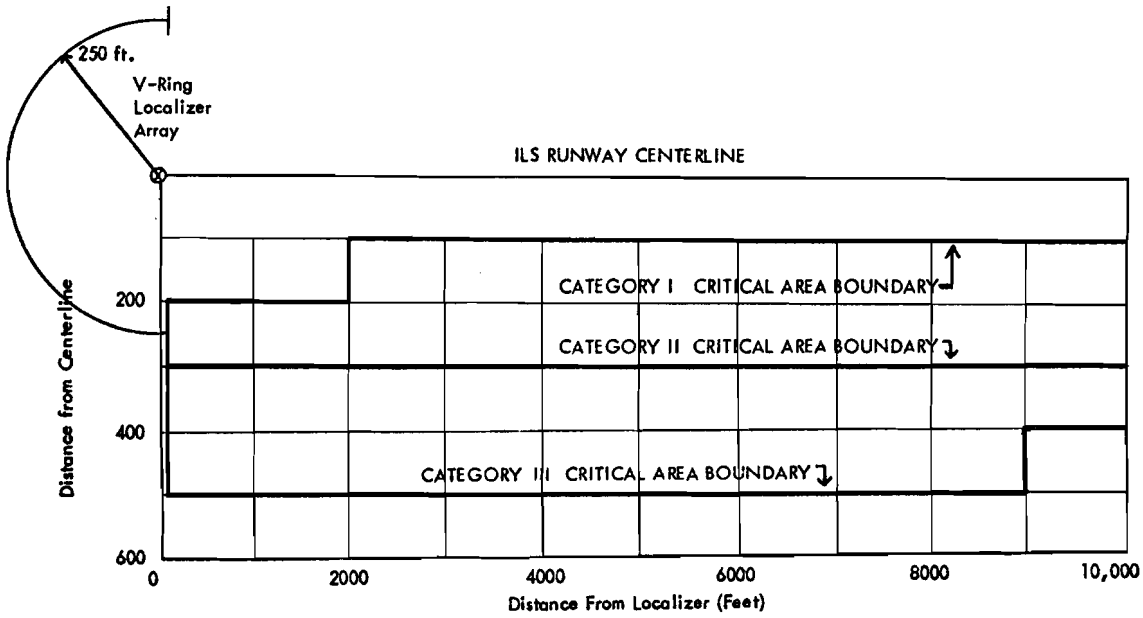


Figure 1. Worst Case - Proposed Localizer Critical Areas.

II. INTRODUCTION AND BACKGROUND

One of the major concerns in the establishment and operation of the contemporary instrument landing system has always been the effects of multipath. With the increasing population of the large, jumbo-jet type aircraft there is a high probability that such a large aircraft will be present in critical areas on taxiways and runways. These mobile reflectors provide a great range of possibilities of location and orientation. Indeed, some of these possibilities of placement even from an intuitive standpoint cause great concern as to the effects that would be produced on the ILS course structures.

With tolerances for path straightness tighter for landings under Category II and III conditions, and with some beams already suffering from considerable noise due to multipath from buildings and natural effects, the situation becomes potentially critical when the possibility of a large aircraft reflecting surface enters the picture.

In the 1960's large buildings on airports became concerns, and with the advent of high speed computers it was possible to predict theoretically in quantitative terms what course derrogation would be produced. Using similar approaches it has been possible to predict the effects of large aircraft. Because of the more complicated geometries, it has been necessary to make some simplifying assumptions concerning the aircraft being modeled, and there has naturally been a concern as to how well the assumed model met actual conditions. Further, there has been a requirement to perform great numbers of calculations because of the great number of real possibilities for placement and orientation of the large aircraft. Consequently, it has been highly desirable for economic reasons to provide the simplest calculation model for the computer operation to minimize computation time.

Results of mathematical predictions are expected to have an effect on air traffic control operations as certain areas are sterilized and hold lines are enforced. Because of this, it is obviously important that the accuracy of the predictions be checked and the mathematical model and technique be validated. To do this a series of experiments was performed which included a practical airport situation, viz. Miami International Airport, Florida with a National Airlines Boeing 747 serving as a reflector. Airborne observations were the basis for the validations. In the case of the localizer, these were supplemented by ground-based measurements made over the runway to simulate roll-out conditions.

In earlier work two theoretical models covering localizer signal derrogation were developed, one covering the reflection of localizer signals by large aircraft[1] and the other covering the diffraction of localizer signals around large aircraft.[2] These used a cylinder/trapezoid configuration for the aircraft and a geometrical optics calculation approach. The theory and results of calculations for a Boeing 747 aircraft were reported.

In view of the location of a localizer array with respect to the typical layout of an airport's runway and accompanying taxiways, a large aircraft will generally be oriented perpendicular to, or nearly perpendicular to, the runway centerline when the aircraft causes the more serious localizer course perturbations. These perturbations arise from the diffraction of signal energy around an aircraft which might be on the centerline, or up to only a

present hold lines seem to be adequate to insure no significant diffraction effects from large aircraft perpendicular to the centerline on an intersecting taxiway. However, when the taxiways and mast are on the same side of the centerline, large perturbations could appear in the glide path whenever a large aircraft enters the area in front of the mast.

Thus, as in the case of the localizer signal quality assurance, adequate critical areas must also be defined for the glide slope portion of an instrument landing system to insure the signal quality necessary for Category III operations, with particular attention given to those taxiways that cross in front of a glide slope array.

Following in this report is a detailed discussion of the experiments performed by the FAA, Ohio University, and National Airlines along with the results. These experimental results are correlated with those values predicted by the calculations and an accuracy assessment provided. As a result of the new information the experiments provided, it was possible to revise the contour map previously published (See Figure 3-6, Report RD 73-137) from solely theoretical data to give what is believed to be a highly representative picture of path derrogation. From this map critical areas may be determined given specific micro-ampere path tolerance limits. In this report both localizer and glide slope areas are considered.

It is important to note that supplementary experimental data has been used. Experiments made in England,[7] experiments using a C 5A at NAFEC, Atlantic City, New Jersey,[8] data from measurements performed by the FAA at the Seattle-Tacoma Airport in Washington,[9] and some experiments run at Dulles by the FAA[10] have all produced information against which the model could be checked. The systematic experiments at Miami have given the greatest base of information and it is on these data that most of the comparisons are based.

This report and the experimental work performed for the mathematical model validation have been accomplished in accordance with contract FA74WA3361.

III. CRITICAL AREAS

The purpose of this report is to recommend any changes that could be made in the sizes of the critical areas that are defined around the glide slope and localizer antenna sites as specified in the FAA manuals nos. 6750.15 and 6750.17. The recommended changes are based on the results of extensive mathematical modeling which is used to predict signal quality degradation caused by the presence of large aircraft located near the transmitting arrays. A discussion of the limits on the accuracy with which mathematical modeling techniques can be used to predict this signal degradation is covered in a later section where a comparison is made between theoretical results and the experimental results as obtained from the experiments performed at Miami International Airport.

A. Glide Slope Critical Areas

Figure 3a illustrates the critical and no-parking areas as they now exist around the glide slope site.[11] Points A B C D define the no-parking area, and points E F G H define

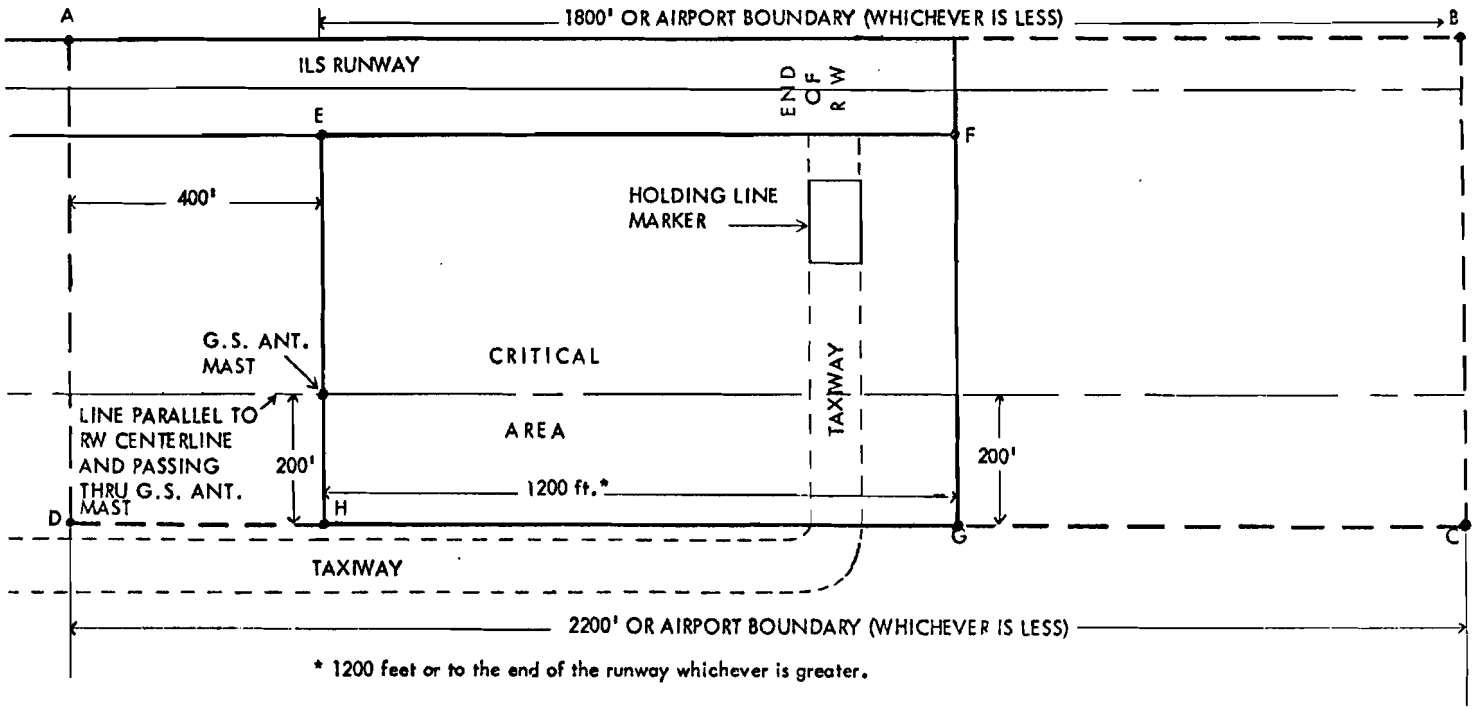


Figure 3b. Glide Slope Critical and No-Parking Areas - Proposed Boundaries.

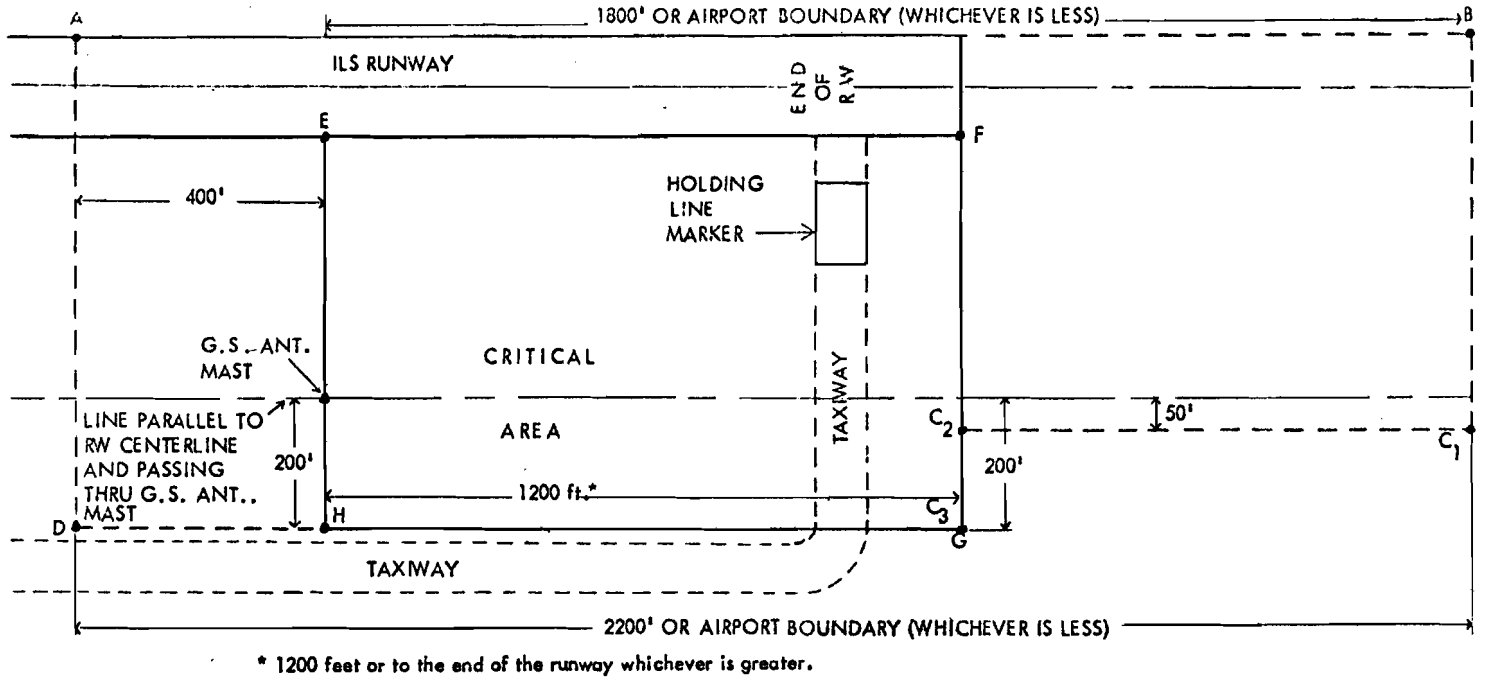


Figure 3c. Glide Slope Critical and No-Parking Areas - Proposed Boundaries for Airports Where Adequate Control over Orientation of Parked Aircraft Can Be Maintained. (See Text)

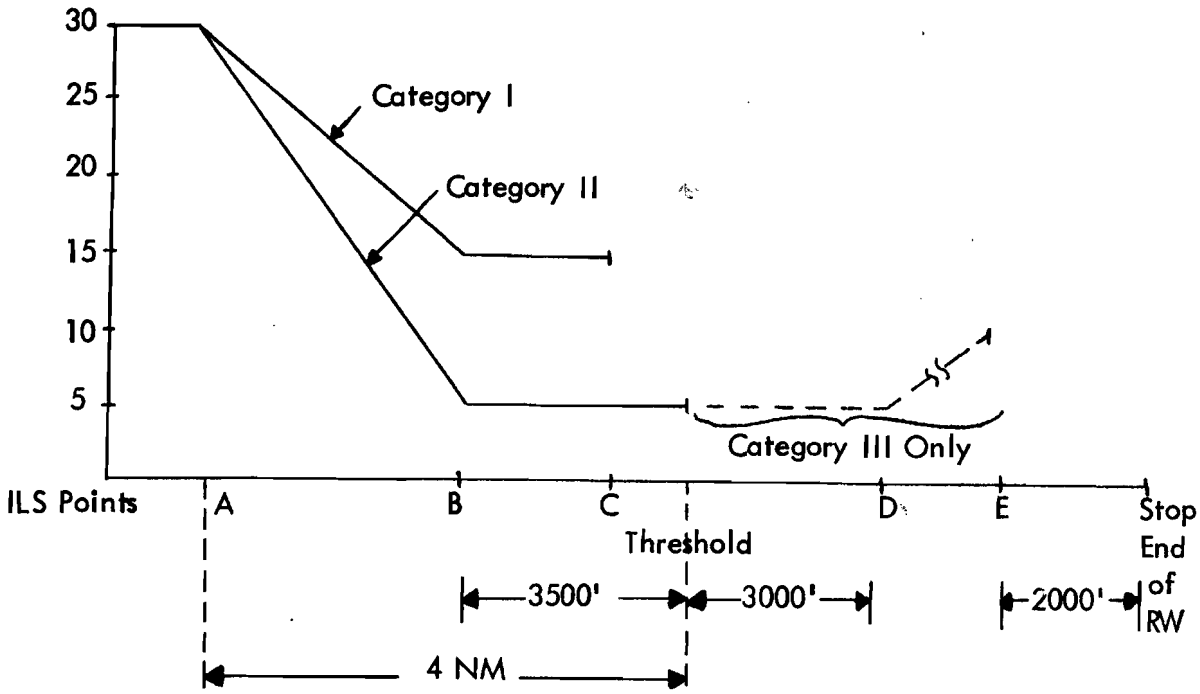


Figure 4. Localizer Course Maximum Bend Amplitude Criteria. (See References 15 and 16)

In Section IV, the CDI current contour maps shown in Figures 9, 10, and 11 give the contours of the peak disturbances, and these generally occur within 1200 feet of the location of the aircraft causing the disturbances. Consequently, except for the positions at distances of 9000 feet or more from the localizer, these peak disturbances will be inside the threshold and will affect Category III operations only. However, for aircraft positions close to the stop end of the runway, large magnitude offsets in the localizer course structure also occur which can cause out-of-tolerance conditions for the various categories of operation out into the runway approach zone. For Category II and I operations, the signal beyond the threshold must be examined using the criterion set forth in section 217.44 of the U.S. Standard Flight Inspection Manual which states: "The following procedures will govern the application of course structure tolerances:

1. Where course structure is out-of-tolerance in any region of the approach, the flight recordings will be analyzed in time intervals of 40 seconds centered about the region where the out-of-tolerance occurs. No two 40 second intervals shall overlap; where necessary to avoid this, centering the interval about the out-of-tolerance region may be disregarded.

2. If the course structure within each 40 second interval is out-of-tolerance for a period of time equal to or less than five percent of the total time of each interval (a maximum of 2 seconds), the course structure is acceptable."

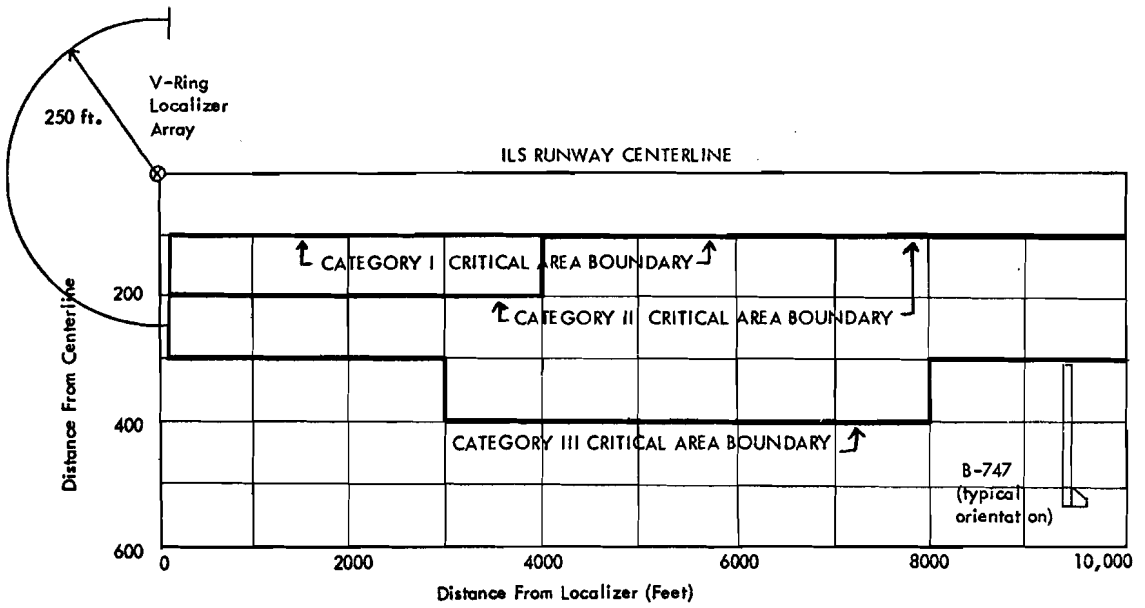


Figure 5a. Localizer Critical Areas - B-747 Perpendicular to and Heading Towards the Centerline.

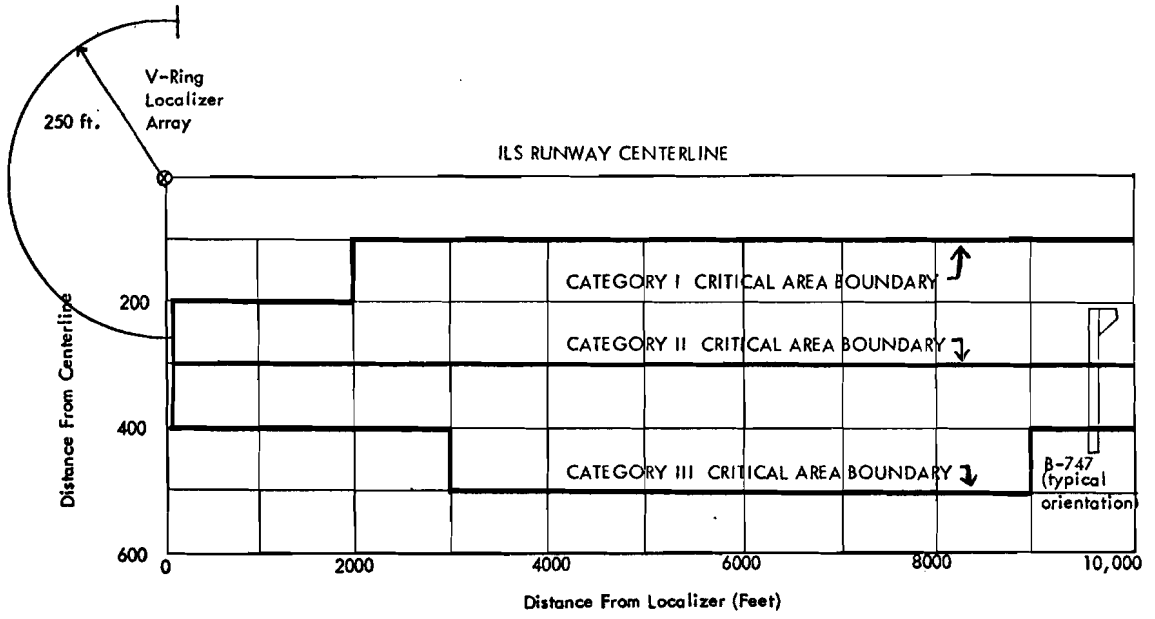


Figure 5b. Localizer Critical Areas - B-747 Perpendicular to and Heading Away from the Centerline.

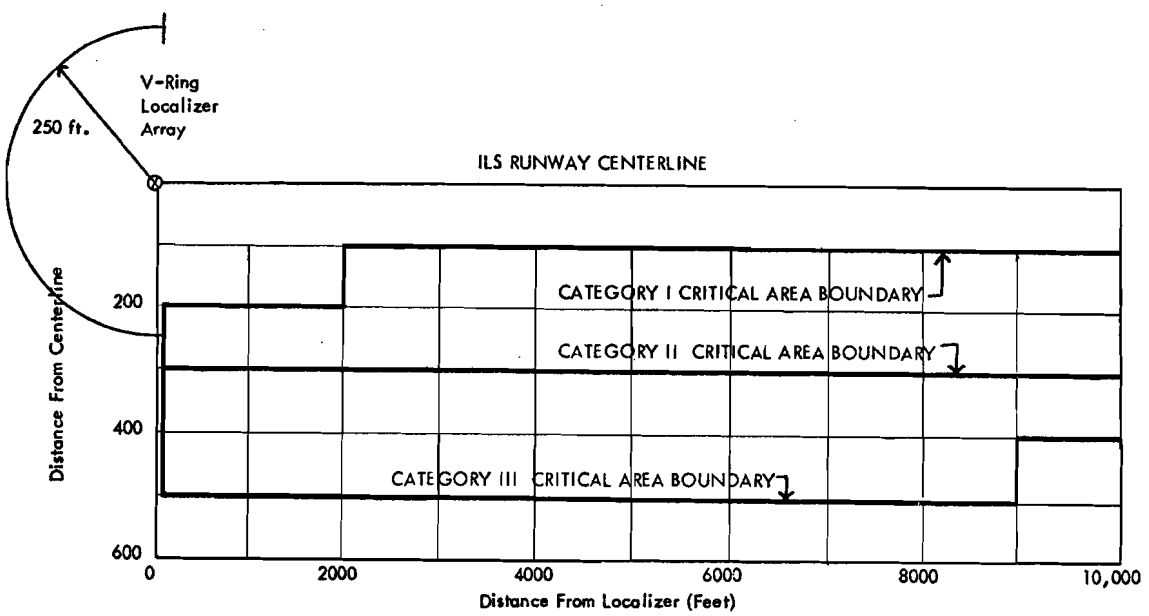


Figure 6. Worst Case- Proposed Localizer Critical Area.

In view of the size of the proposed worst case critical area for Category II operations, a closer look will now be taken at the reasons for placing the critical area boundary at a distance of 300 feet to either side of the centerline for the length of the runway. Table 1 lists the CDI current values at the threshold, and points C and B (for distances of 11,000, 12,000, and 14,500 feet respectively from the localizer array) for a number of positions of the Boeing 747 at 1000 and 9000 foot distances from the localizer array. Also listed are the areas over the extended centerline in which an out-of-tolerance signal condition exists, and the duration that the disturbance theoretically would be observed by an incoming aircraft traveling at a ground speed of 105 knots. A receiver time constant of .25 second was used in the theoretical calculations. As can be noted, three of the four positions at the 1000 foot distance are well out-of-tolerance for Category II operation and two are well beyond the Category I tolerance limits. These distrubances exist well beyond point B and thus fall into the constant offset category.

At the 9000 foot distance, the two positions with the tail fin at 280 and 290 foot distances from the centerline are out of tolerance for Category II operations. Also two other positions cause signal conditions that are close to being out-of-tolerance. Figure 7 illustrates the quality of the localizer signal showing disturbances in both CDI current and feet offset from the centerline for the position with the tail fin 280 feet from the centerline. The course is characterized by a number of path scallops with the values of the peak course bends being -6μa to +7.2μa (-14.9 to +16.9 feet about the extended centerline at a distance of 675 feet from threshold up to the threshold).

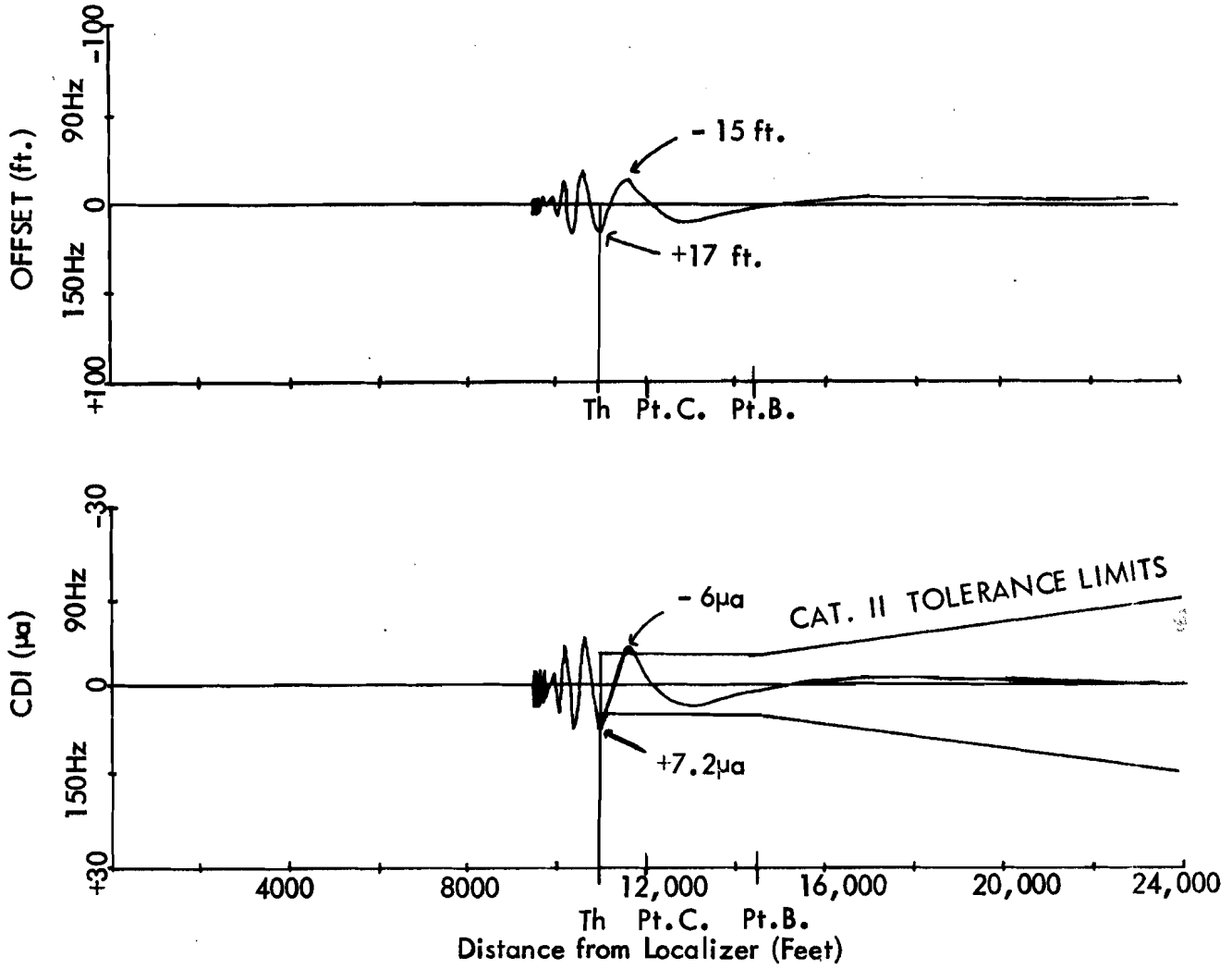


Figure 7. Localizer Course Structure with B-747 Positioned 9000 Feet from Localizer Array and 280 Feet from Centerline.

The results for the various Boeing 747 positions along taxiways which might be located at 5000, 6000, 7000, and 8000 foot distances from the localizer array are similar to those for the 9000 foot distance, that is, there is a small region along the taxiway where a parked Boeing 747 would cause signal conditions that are just out of Category II operation tolerances, and this region is bounded by a larger region in which a parked Boeing 747 would cause signal conditions that are just under Category II operation tolerances. This question of just in or just out-of-tolerance now becomes critical when various other factors are considered, namely the uncertainty in the theoretical model, the presence of other aircraft which might contribute additional degredation into the localizer course, and any inherent course bends that are due to stationary objects such as large buildings, nearby hills, etc.

Along taxiways at the 2000 to 4000 foot distances from the localizer array, the presence of a Boeing 747 parked with its tail fin closer than 300 feet from the centerline will cause the localizer signal to shift beyond the tolerance limits for Category II operations, but the disturbances will now be characterized by a course shift that is either relatively constant, or one that is slowly decaying, over distances up to and greater than 20,000 feet from the localizer array. These constant offsets are clearly evident in both the theoretical and measured results for localizer interference positions 1, 2, and 5 of the Miami International Airport tests (see Figures 17b, 17c and 17e).

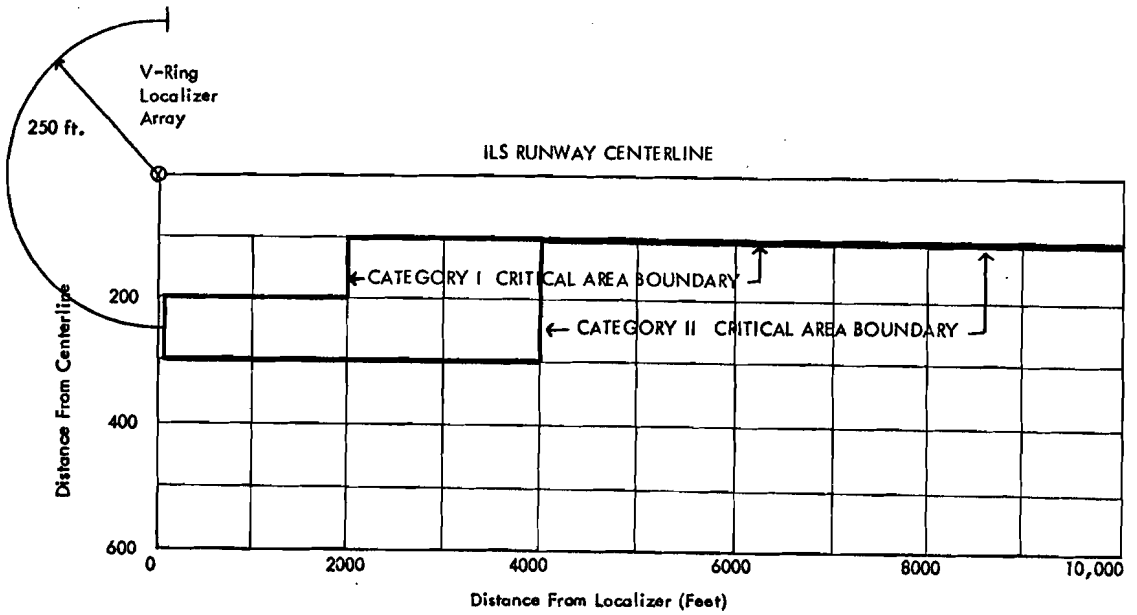


Figure 8. Worst case - Proposed Localizer Critical Areas for Aircraft the Size of the Douglass DC-10 or Smaller.

IV. DISCUSSION OF CONTOUR MAPS

To insure the integrity of the ILS signals for Category III, and in a number of cases for Category II, operations, adequate critical areas must be defined around the localizer and glide slope arrays, areas in which the presence of large aircraft would cause course bends of sufficient magnitude such as to prohibit the use of instruments for safe aircraft landing guidance. The theoretical models were used to obtain predicted course bend information for a number of aircraft locations near the localizer and glide slope arrays. This information was used to compose a series of maps showing Course Deviation Indicator current contours versus position of the aircraft causing the course disturbances. From these contour maps, adequate critical areas were defined as shown in Section III.

A. Localizer Contour Maps

One reason a large aircraft would be found inside the critical area near the localizer array is when the aircraft, having completed its landing and roll-out, turns broadside to the array while exiting the runway. During this period the aircraft causes large bends in the localizer course both over the centerline and in the approach zones. Due to the spacing between incoming flights, the perturbations in the approach zone are of major interest in that the duration of the disturbances, which depends on the time required by the taxiing aircraft to exit the runway area, will determine the minimum spacing needed for Category II or III operation.

The second reason a large aircraft would be found inside the localizer critical areas is when the aircraft is directed to cross an active runway to reach some other area of the airport. Again bends are introduced into the localizer course both above the centerline and in the approach zones. Now, for Category III the condition of the signal over the centerline must also be examined, especially when the aircraft is directed to hold on one side of the runway while an incoming flight lands and completes its roll-out.

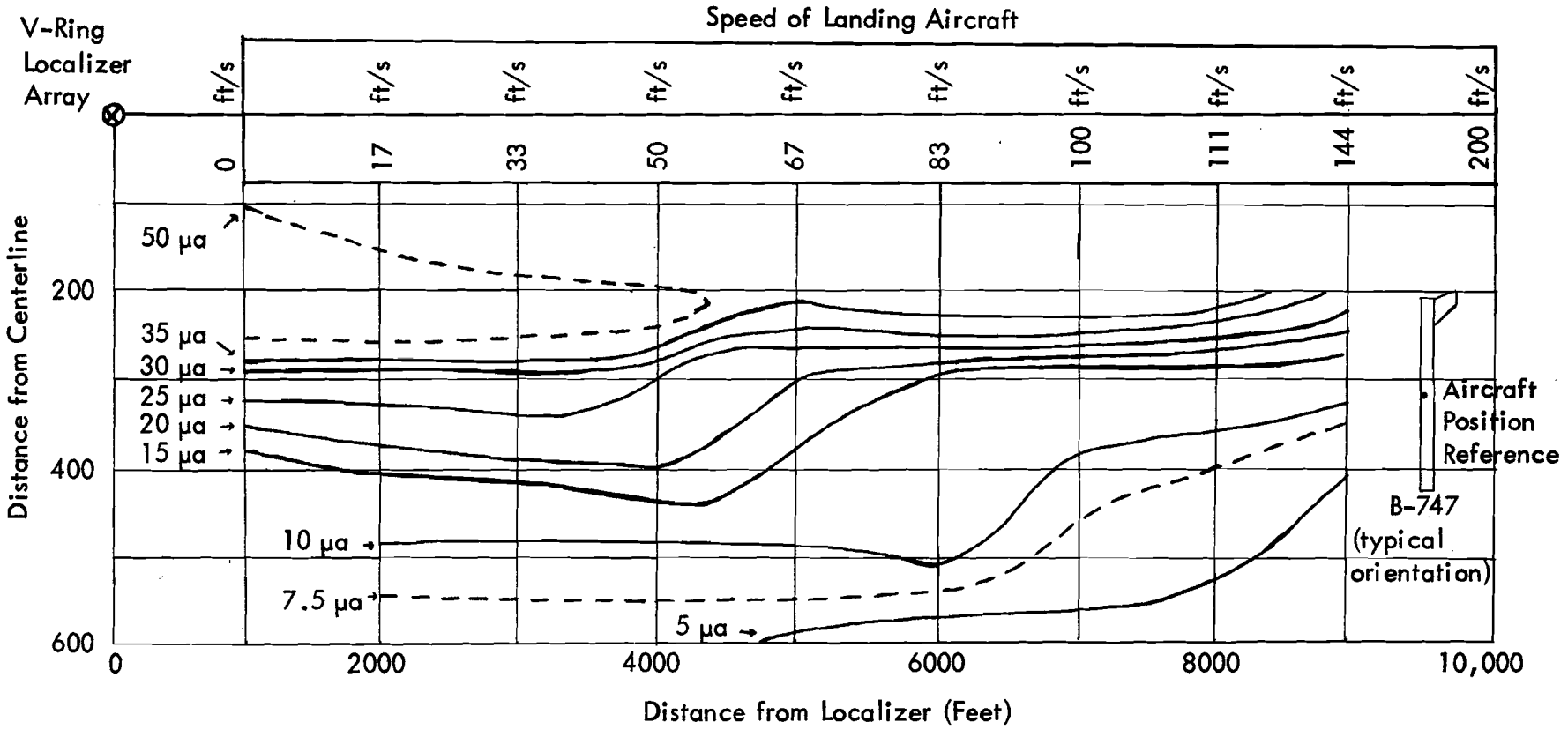


Figure 10. A Contour Map of Peak CDI Current Response Caused by the Diffraction of Signals by a B-747 Aircraft Parked Perpendicular to the Centerline. Dynamic Response for a Touchdown Speed of 120 Knots.

Here it is important to note that both theory and experiment have shown that the tail, rather than the fuselage, of a large aircraft causes the major portion of the course perturbations. Since a Boeing 747 is approximately 225 feet in length, the orientation of the aircraft with respect to the runway centerline must be considered when determining localizer critical areas. That is, a large aircraft heading towards an active runway will be more likely to be held and thereby cause disturbances of longer duration than will an aircraft that is exiting, or has already crossed, an active runway. Figures 9 and 10 are contour maps of the CDI current diffraction peaks for the two orientations of a large aircraft perpendicular to the centerline, with Figure 9 for the aircraft heading towards, and Figure 10 heading away from, the centerline. The position information is referred to the center of the aircraft with the nose and tail approximately 112 feet to either side of the position point. The effects of rotating the aircraft around a given position point from its orientation in Figure 9 to that in Figure 10, and thus moving the tail center approximately 200 feet closer to the centerline, is clearly illustrated by the approximately 200 foot shift of both the 7.5 μa and the 10 μa contour lines. When the aircraft causing the disturbance effects shown in Figure 10 turns onto a taxiway adjacent to, and thus parallel to, the centerline, the course bends are now caused by the reflection of, rather than the diffraction of, signal energy into the approach path. Figure 11 is a contour map of the CDI reflection peaks for a large aircraft parallel to the centerline, and as can be seen, the CDI current value for a given position point is significantly smaller than that shown for the corresponding point in Figure 10.

The CDI current contours shown in Figures 9, 10, and 11 are dynamic values, that is, they are the values that would be observed by an aircraft touching down 10,000 feet from the localizer at a velocity of 200 feet per second (120 knots) and coming to a stop 1000 feet from the localizer, as shown in the figures. The contours also were computed for a localizer course width of 5 degrees, which would put the threshold 8100 feet from the localizer. At facilities with longer runways, and thus narrower course widths, these figures would tend to be slightly conservative. Finally, the peak CDI current values indicated on these contour maps generally occur at distances less than 1200 feet further down the centerline from the location of the aircraft causing the disturbances. Consequently, except for the positions at 9000 feet distances from the localizer, these disturbances will be inside the threshold and will affect Category III operations only.

B. Glide Slope Contour Maps

In general, a large aircraft will be found inside the critical area near the glide slope array when that aircraft is proceeding to the end of an active runway prior to takeoff. For typical airport configurations, the parallel taxiways are at least 450 feet from the runway centerline, with the glide slope antenna mast usually located 400 feet from the centerline on the opposite side of the runway. Large aircraft located on these taxiways are sufficiently separated from the glide slope transmitting arrays so as to produce no significant interference effects to the signals in space. Similarly, for those taxiways perpendicular to the centerline but again on the opposite side of the centerline from the antenna mast and approximately 1000 feet further down the centerline, the present hold lines (200 feet or more from the centerline) seem adequate to prevent any noticeable degredation to signal quality due to a Boeing 747 aircraft parked perpendicular to the centerline. This fact is substantiated in Figure 18b which shows the negligible interference produced by a Boeing 747 aircraft parked at position 1 near the glide slope array.

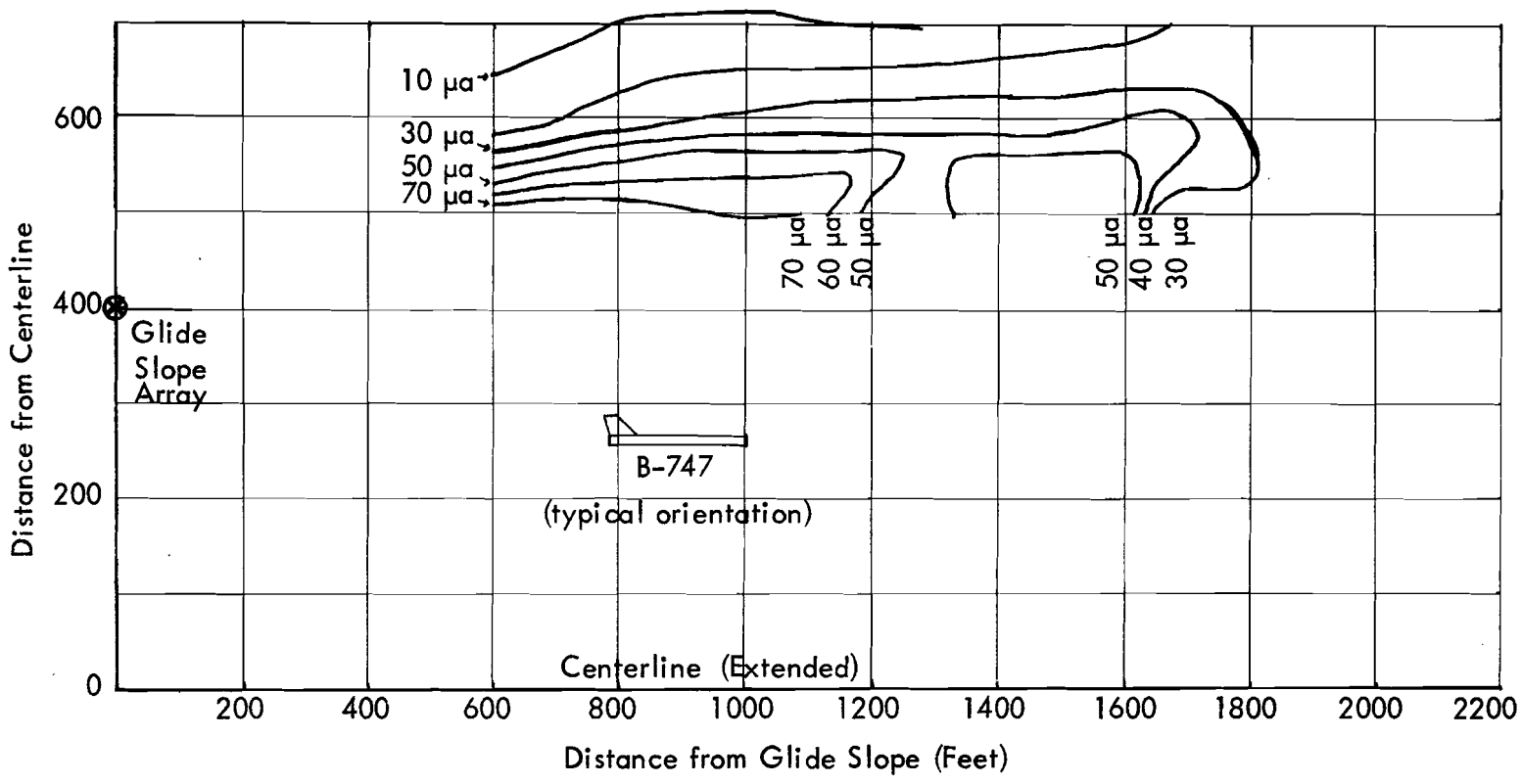


Figure 13. A Contour Map of Peak CDI Current Response Caused by the Reflection of Signals from a B-747 Aircraft Parked Parallel to the Centerline. Dynamic Response for an Approach Speed of 120 Knots.

d. The airport must have a relatively low traffic density.

e. Airport authority and FAA approvals must be available.

With respect to item d, this requirement was met by conducting the experiments in early morning hours 0400 to 0800 EDT. Fortunately these were the hours when the B-747 was available. Item e was not only met but exceeded through the gracious cooperation of the Miami Dade County Port Authority and the FAA Facilities Sector and Air Traffic Control personnel.

MIA offered another tremendous advantage as a site, that of minimizing weather problems. Inasmuch as all airborne data was taken with radio telemetering theodolite controlled approaches, it was important from the standpoint of efficiency that good visibilities exist concurrently with the availability of the B-747 and the flight test aircraft and crews.

Equipment used for the data collection was:

Douglas DC-3, N49, FAA Flight Inspection Aircraft,
Century 472 Recorder, Differential Amplifier,
Standard FAA Collins and/or Bendix Localizer,
Glide Slope, and Theodolite Receivers

Beechcraft BE35, N2179D, Ohio University-Operated Aircraft,
Honeywell Electronik 19 Recorder, Differential Amplifier,
Specially Modified Narco NAV-11 Localizer Receiver,
Narco UGR-2A Glide Slope Receiver, and Narco UGR-2
Theodolite Receiver

Ford Van, Ohio University Test Vehicle,
Honeywell Electronik 19 Recorder, Narco Nav-11
Localizer Receiver with Specially Designed Digital
Audio Processor, Precision Odometer

Reference data for the MIA facilities in the unperturbed state were made by each aircraft prior to the runs with the Boeing 747 in place. On September 26, 27, and 28 the validation data were collected.

Generally the operational plan was to tug the B-747 to a predetermined position with the aircraft then making six runs, three each. Two theodolite trackers were operating alternately on the runs so that human errors could be averaged out. Between times the

GLIDE SLOPE, RUNWAY 27-R

Glide Slope Antenna Mast — 1115' from threshold; 300' from centerline

Position Number	Perpendicular Distance of Nose to			Heading Aircraft (0°=N)
	Centerline	Threshold	Line Through Glide Pole Perp., to CL.	
1	206	204*	911*	0°
2	322	117	998	180°
3	450	305	810	90°
5	0	365	750	270°

*NOTE: That items in columns 3 and 4 add to 1115' which is distance of pole from threshold line.

GLIDE SLOPE, RUNWAY 27-L

Glide Pole — 1275' from threshold; 400' from centerline

Position Number	Perpendicular Distance of Nose to			Heading Aircraft (0°=N)
	Centerline	Threshold	Line Through Glide Pole Perp. to CL.	
6	230	651 +	624 +	298.7°
7	376	448	827	225.4°
8	130	827	448	302.4°

+NOTE: That items in columns 3 and 4 add to 1275' which is distance of pole from threshold line.

LOCALIZER, RUNWAY 27-R

Array — 800' from end of runway

Position Number	Perpendicular Distance of Nose to		Heading Aircraft (0°=N)
	Centerline	Localizer Array Axis	
1	128	958	180°
2	356	968	178.5°
4	450	1883	91°
5	332	2104	180°
7	295	3871	117.2°
8	344	5840	170°

Table 3. Position Information for B-747 at Miami International Airport.

Figure 15. View of Ground-Based and Airborne Equipment Used by Ohio University Personnel in Collecting Data on Instrument Landing Systems. The van contains localizer receiving equipment which permits recording of path information over the runway for scrutiny of guidance signals for roll-out. A radio-telemetering theodolite shown is used to track aircraft such as the Beechcraft, N2179D. Calibration equipment is shown under this aircraft wing which permits reference of the mini-lab equipment on board to nationally recognized standards. The use of a small aircraft with a telemetering theodolite has been shown to be a practical method of obtaining airborne data in an economical manner.

POSITION NUMBER	THEORY		EXPERIMENT	
	CDI (μa)	Distance from Localizer (Feet)	CDI (μa)	Distance from Localizer (Feet)
1	+ 67	2087	+ 32	2450
	0	4820	0	5000
	- 28	15000	- 20	15000
2	0	1862	0	1700
	+ 30	2112	+ 63	2000
	0	2383	0	2250
	- 27	2950	- 52	2900
	0	4272	0	4300
	+ 26	15000	+ 32	15000
4	20 (p-p)	2768	14 (p-p)	2300
	+ 10	2950	+ 50	2950
	0	15000	0	15000
5	0	2636	0	2525
	- 44	2750	- 63	2625
	0	2886	0	2700
	+ 86	3025	+ 88	2875
	0	3302	0	3150
	- 31	3825	- 43	3750
	0	5885	0	5750
	+ 11	15000	+ 13	15000

(Continued on Next Page)

Table 4. A Comparison of Theoretical and Measured Results for Localizer Course Perturbations.

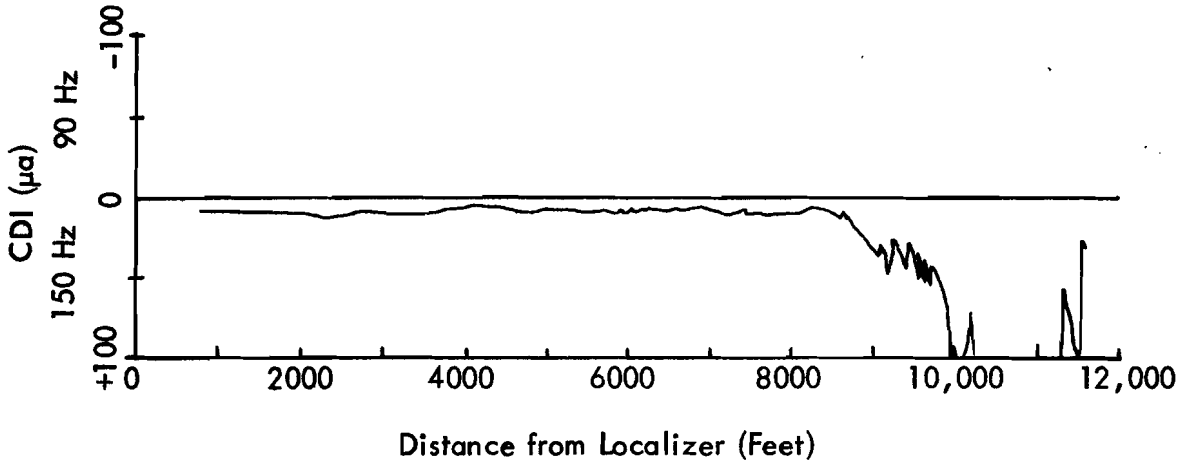


Figure 16a. Nominal Localizer Course Structure.

Note: Van localizer measurements for ranges beyond 8500 feet from the localizer array were not usable because of a radio frequency interference problem. This interference also destroyed most of the flight recordings for the region inside the threshold.

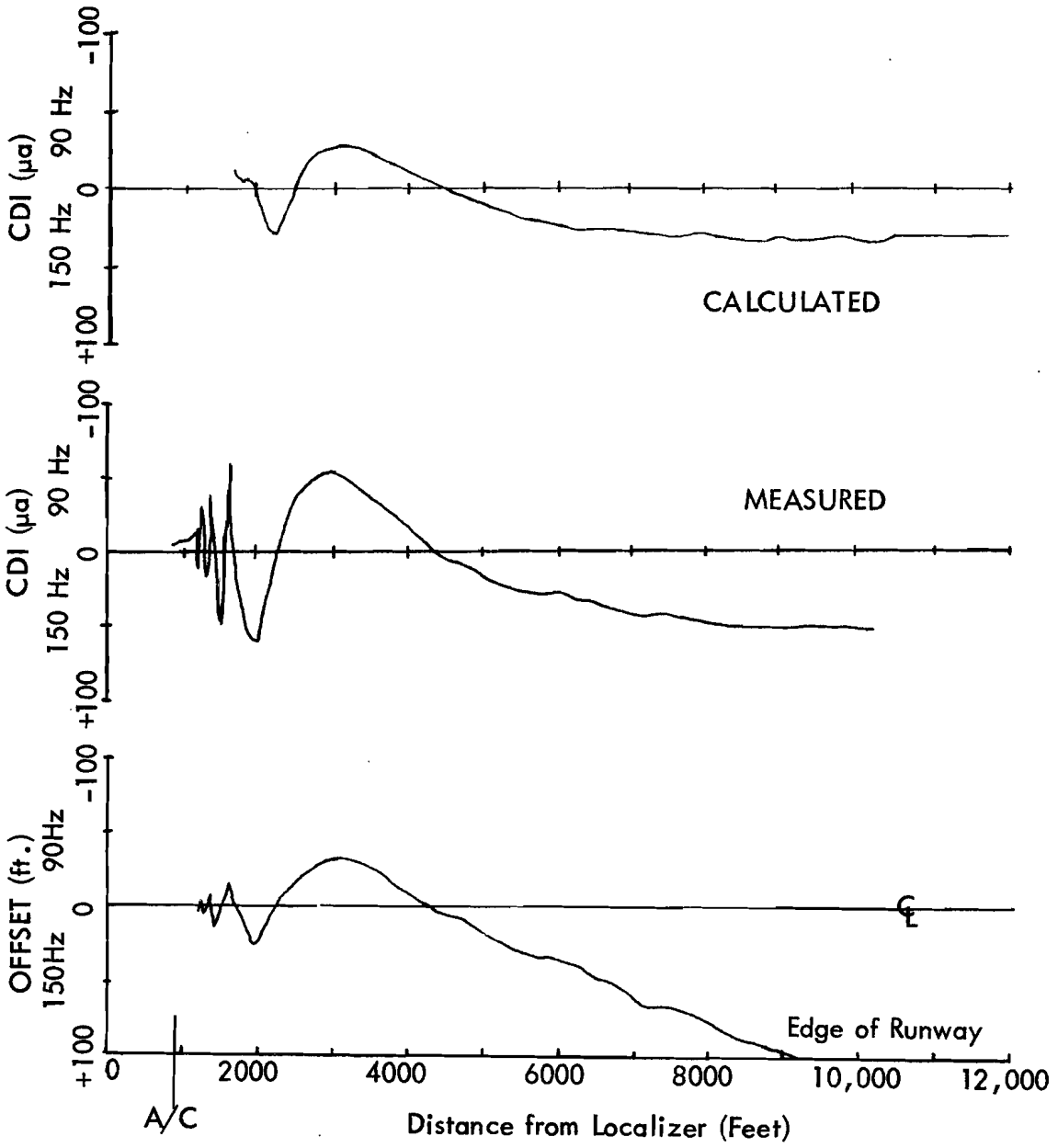


Figure 16c. Localizer Course Structure - B-747 at Position 2.

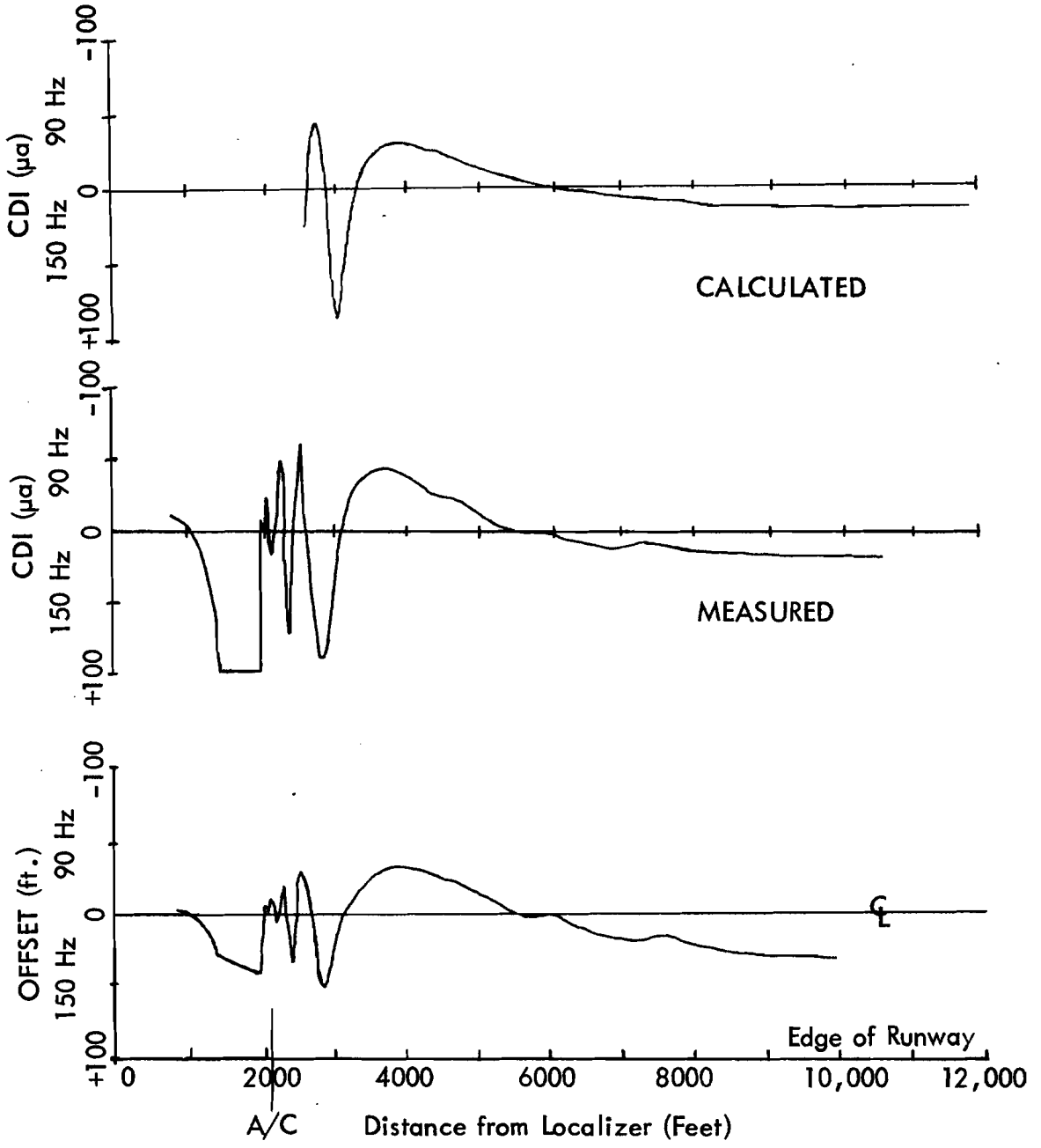


Figure 16e. Localizer Course Structure - B-747 at Position 5.

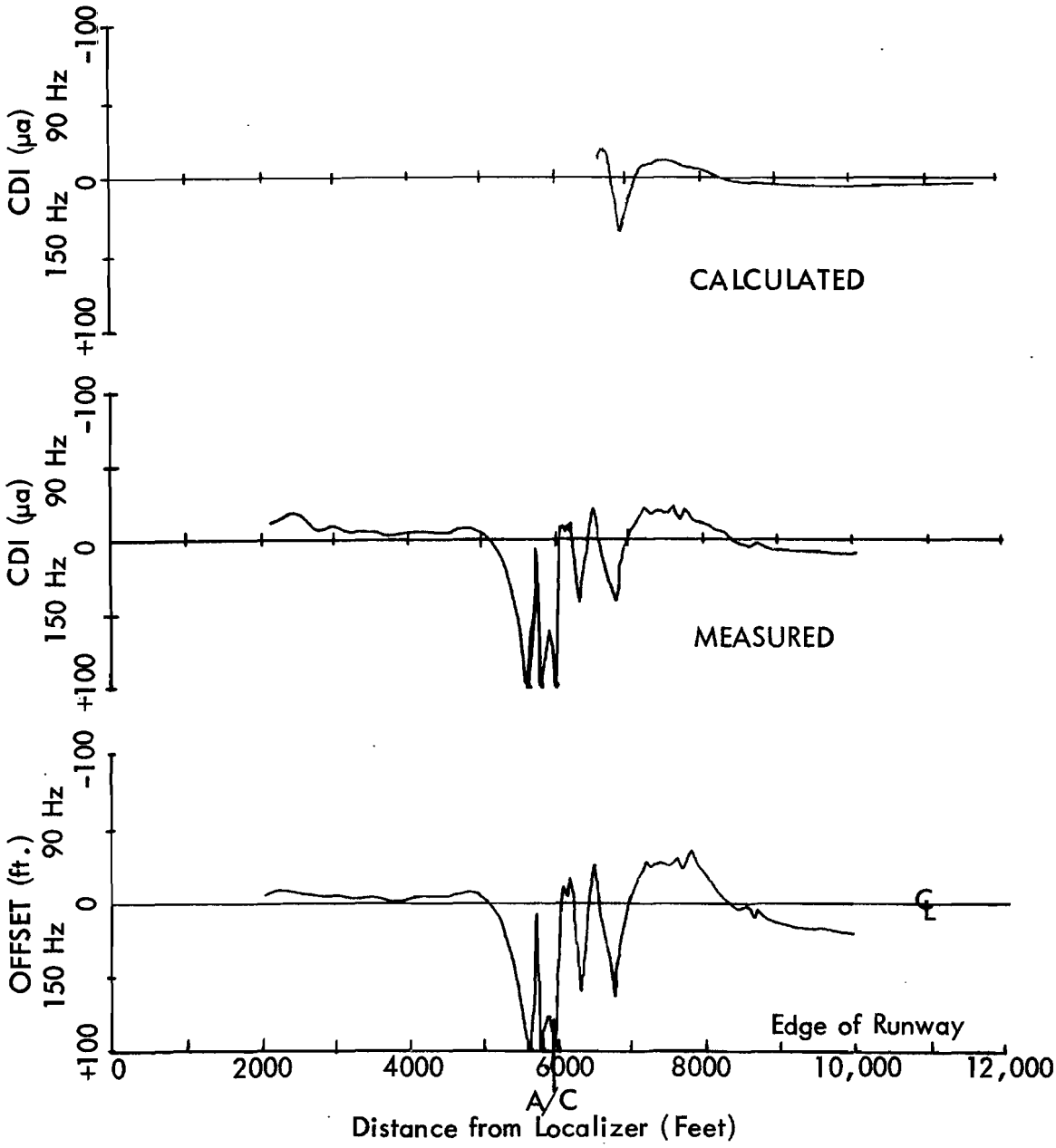


Figure 16g. Localizer Course Structure - B-747 at Position 8.

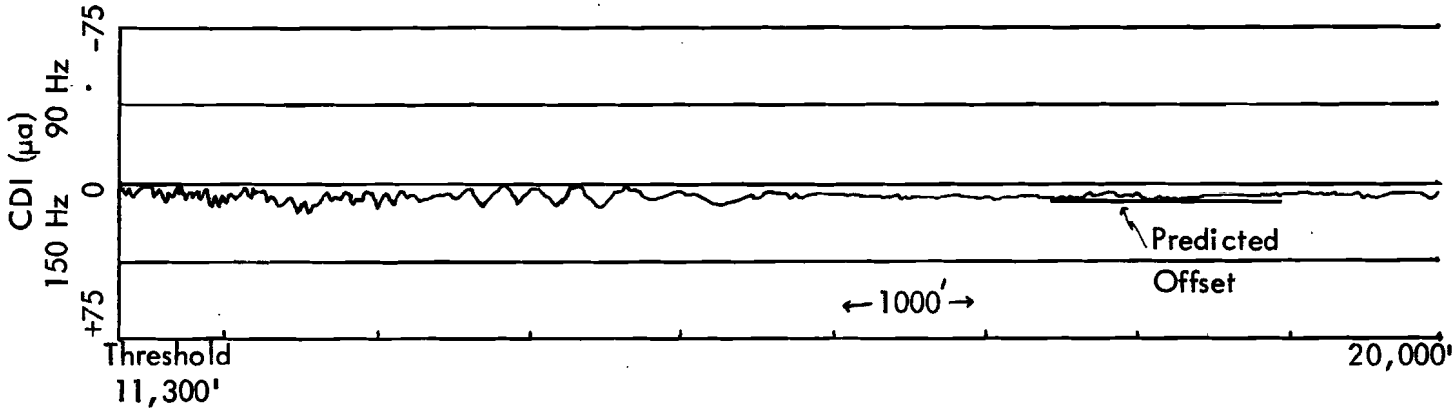


Figure 17d. Measured Localizer Course Structure - Position 4.

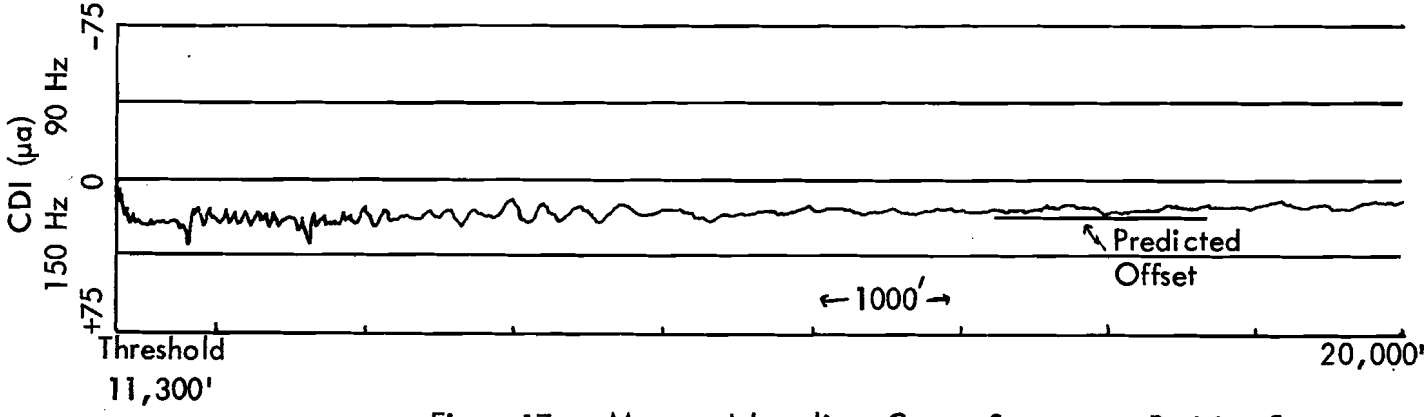


Figure 17e. Measured Localizer Course Structure - Position 5.

B. Glide Slope

A summary of results for the glide slope portion of the experiments is presented in Table 5 which lists measured and theoretical course bend information for seven positions of the Boeing 747 aircraft. Positions 1, 2, 3, and 5 are for the glide slope associated with runway 27R while positions 6, 7, and 8 are for the glide slope associated with runway 27L (See Figure 14).

Figures 18a through 18d show the computer predicted glide slope course structures over the extended centerline of runway 27R for the case of no Boeing 747 aircraft interference and for the Boeing 747 at positions 1, 2, and 3. Shown directly below each calculated curve are the measured curves obtained by the FAA flight inspection aircraft. Figure 18e shows the measured course structure only for position 5.

Figures 19a through 19d show the corresponding glide slope course structures over the extended centerline of runway 27L for positions 6, 7, and 8.

The course bends for positions 1, 2, 6, 7, and 8 are caused by the diffraction of signal energy around the Boeing 747 aircraft, and the theoretical results for these positions are obtained from the diffraction model. In view of the roughness in the nominal course, as shown in Figure 18a a qualitative analysis is difficult for positions 1 and 2 since the predicted disturbances are less than, or approximately equal to the roughness in the path. Although the nominal course for the glide slope on runway 27L is also rough (See Figure 19a), the large bends introduced into the course structure with the Boeing 747 aircraft at positions 6, 7, and 8 allows a better comparison to be made of the measured and theoretical values.

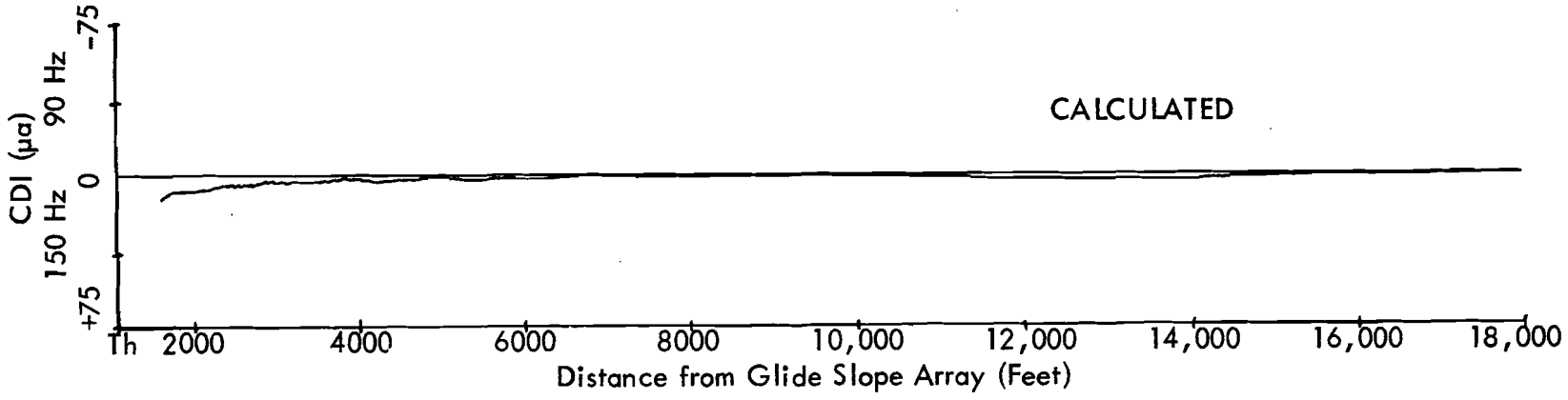
A comparison of experimental results with those predicted using the mathematical model reveals very good correlation. As in the case of the localizer, the degree of correlation increases as the point of consideration is moved further from the transmitting antennas. For position number 8, at which the center of the Boeing 747 aircraft was located only 543 feet forwards of the glide slope array, the limits of the model capabilities are being reached. At this close in range, interference effects due to the wings, engines, and stabilizers should probably be included.

The course bends for position 3 are caused by the reflection of signal energy from the Boeing 747 aircraft, and the theoretical results for this position are obtained from a second model which is based on geometrical optics techniques in contrast to the Kirchhoff diffraction method used in the previously discussed model. This method tends to be overly conservative in the regions of the specular reflection points, especially for the tail fin as is evident by the 90 microampere peak in Figure 18d but indicates no perturbation outside these regions. Neglecting the large spike due to specular reflection from the tail section, this model predicts a disturbance of about 63 microamperes peak-to-peak along the extended centerline from about 2000 to 3400 feet from the glide slope array when a simple dipole array is used. For a restricted radiation pattern (e.g. 3db for a 28° beamwidth) the above results would be reduced by a factor of approximately 22% (at position 3, the tail fin of the Boeing 747 air-

POSITION NUMBER	THEORY		EXPERIMENT	
	CDI (μa)	Distance From Glide Pole (Feet)	CDI (μa)	Distance From Glide Pole (Feet)
6	-148	4500	-64	4150
	0	9025	0	5500*
	+38	15,000	+10 Average	>10,000
7	0	3210	0	3225
	-29	3650	-38	3550
	0	3890	0	3930
	+21	4100	+30	4200
	0	4325	0	4420
	-97	5200	-75	5225
	-22	15,000	+10 Average	>15,000
8	0	2135	0	1600
	-34	2275	-48	1820
	0	2545	0	2090
	+29	2850	+27	2260
	0	3085	0	2530
	-7	3275	-11	2585
	0 Average	15,000	-10 Average	>10,000

*The location of the B-747's tail fin caused a loss of tracking over the range from approximately 5800 to 7500 feet. Thus, this position for 0 μa is not certain.

Table 5. (Continued). A Comparison of Theoretical and Measured Results for Glide Slope Course Perturbations.



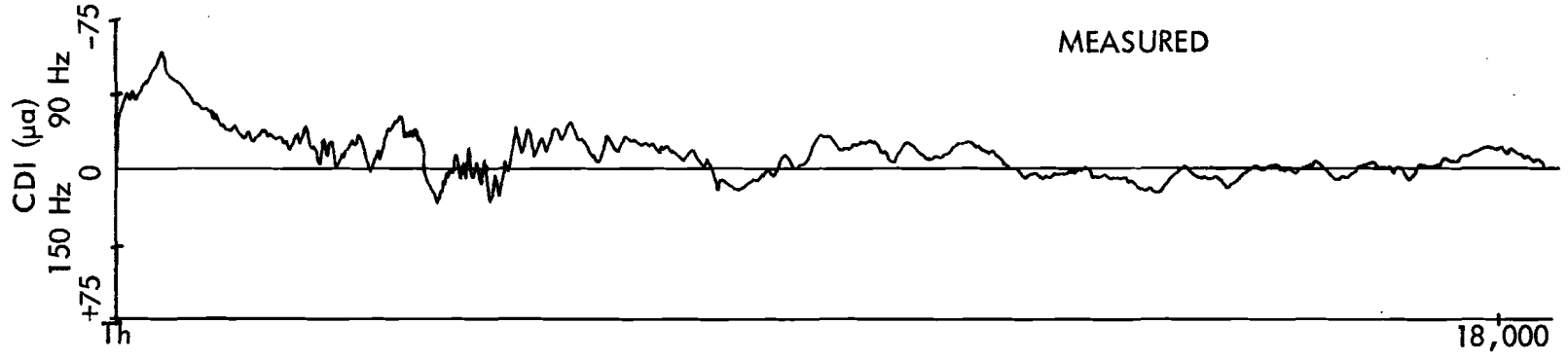


Figure 18b. Glide Slope Course Structure - B-747 at Position 1, Runway 27R.

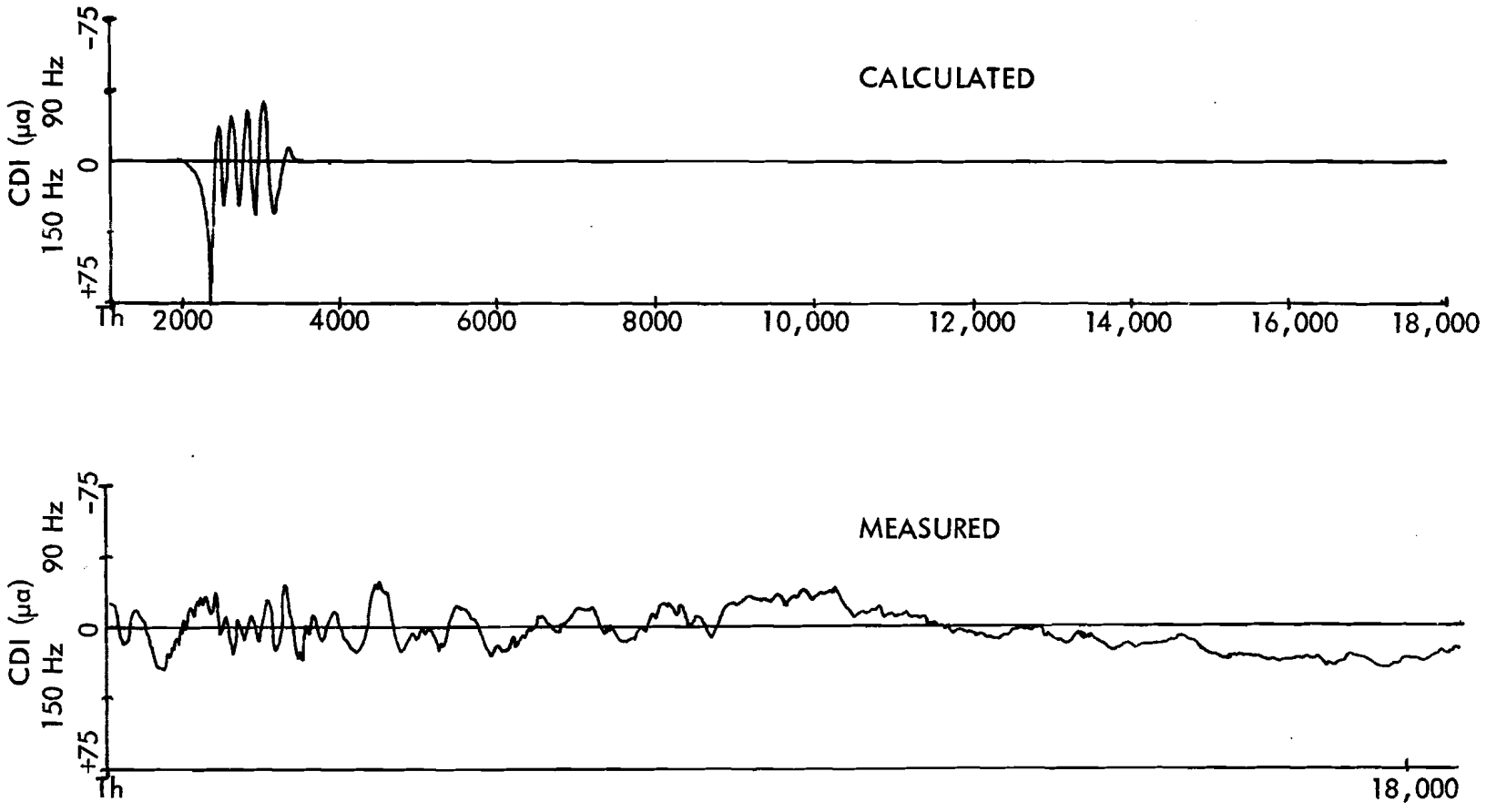


Figure 18d. Glide Slope Course Structure - B-747 at Position 3, Runway 27R.

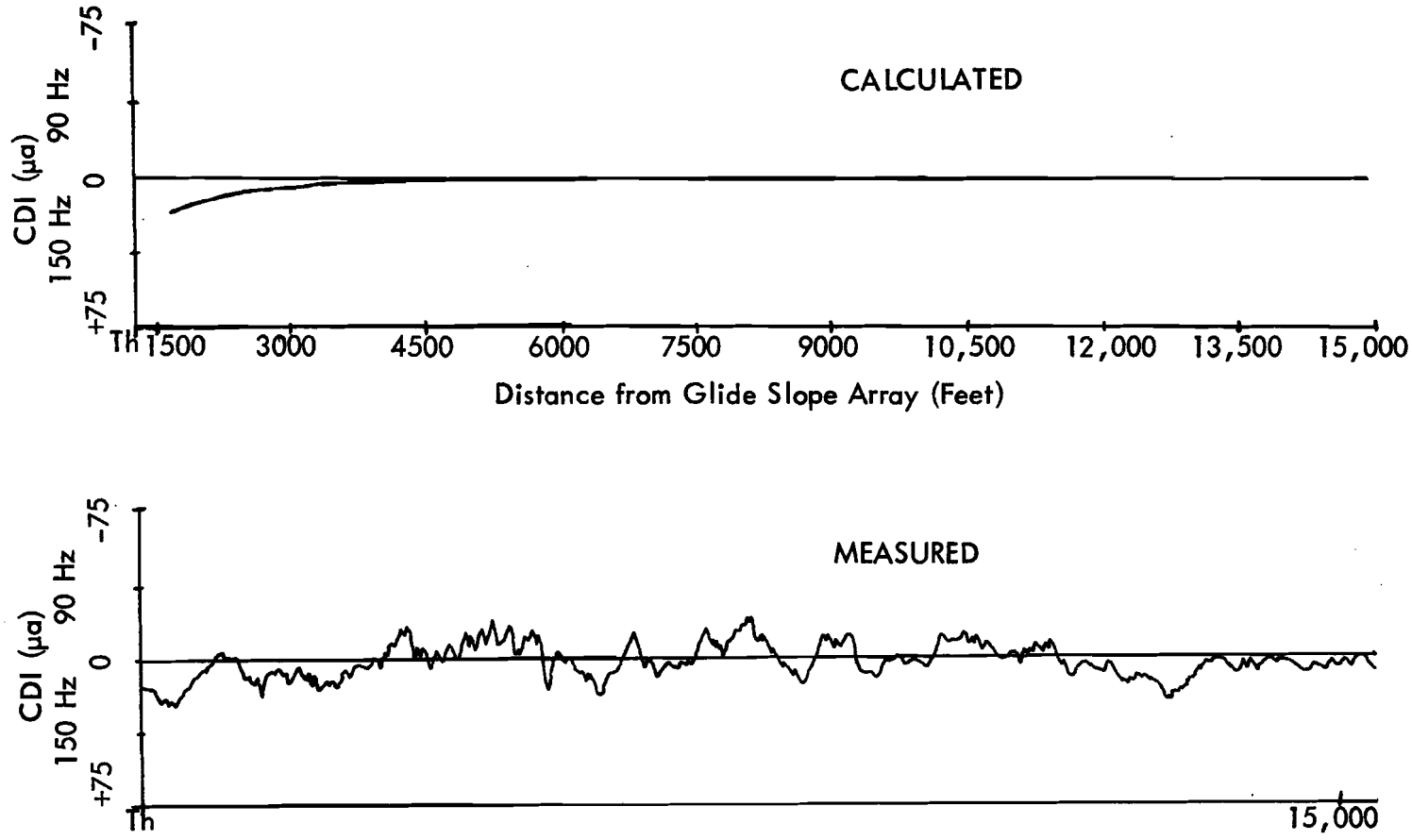


Figure 19a. Nominal Glide Slope Signal, Runway 27L.

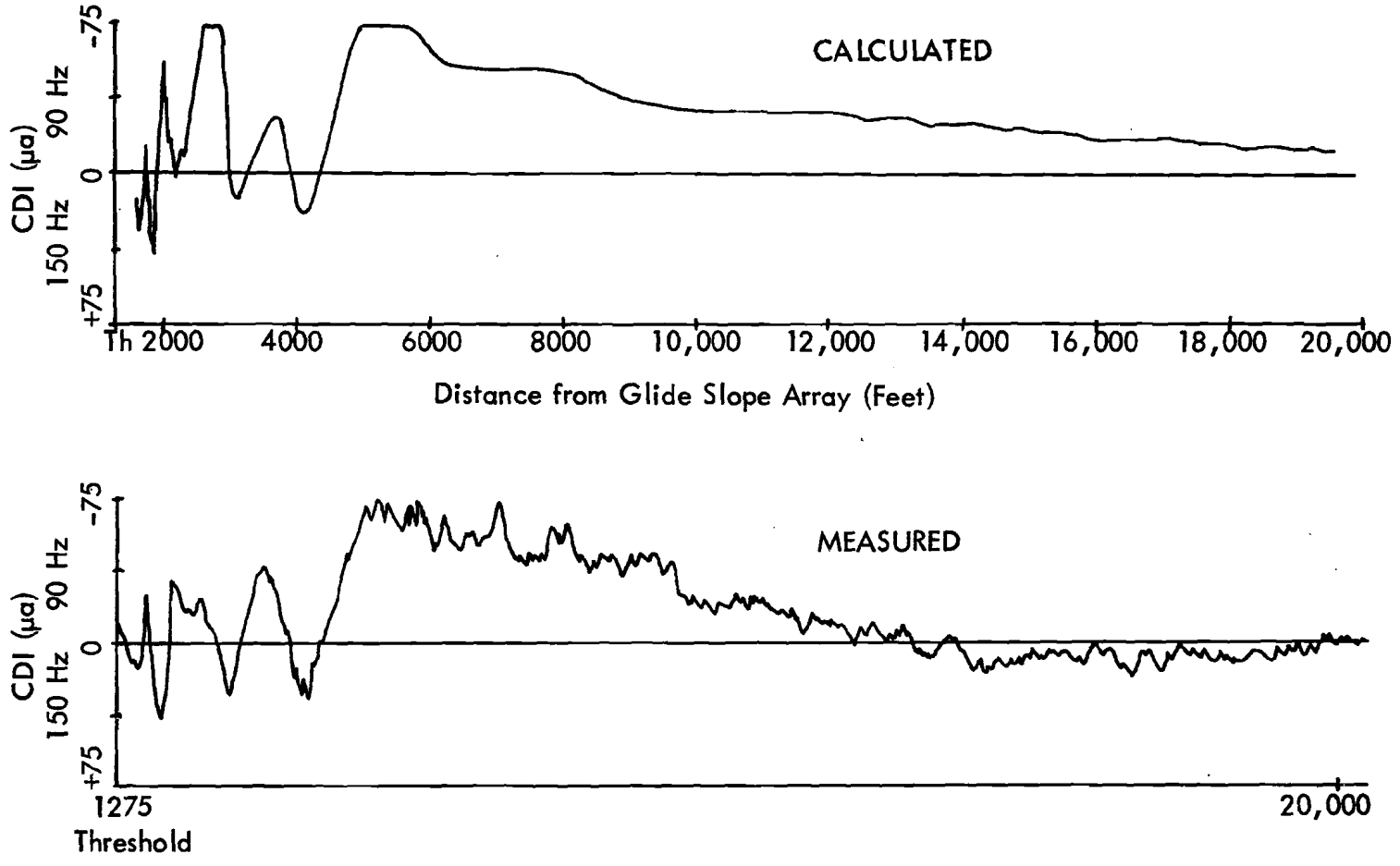


Figure 19c. Glide Slope Course Structure - B-747 at Position 7, Runway 27L.

VII. CONCLUSIONS

A comparison of the theoretical versus experimental results for the various localizer positions and glide slope positions indicates good correlation between the two sets of data, with the best correlations obtained as the interfering aircraft is positioned further from the transmitting array. As the separation between the transmitting array and the aircraft is decreased, the correlation between the peak magnitudes of the course disturbances decreases, while the general slope of the course disturbances and far-field course effects are still fairly well correlated. Since both theory and experiment show the perturbations for these close-in-positions to be well out-of-tolerance, it is felt that the models can be used to adequately predict the effects of course bending as produced by a parked Boeing 747 aircraft. To obtain any higher degree of correlation for these close-in positions would necessitate including the effects of the wings, engines and stabilizers of the 747 aircraft, effects which would be extremely difficult to model and which would require extremely long and expensive computer runs. If, for these close-in points, the disturbances were near the limits of operational tolerances, then the effects of the wings, engines and stabilizers would have to be included. But, as the results indicate that the question of 'just in' or 'just out' of tolerance occurs for those positions of the 747 aircraft which show high degrees of correlation between theory and experiment for both amplitude and shape of the course distrubances, it is felt that the above-mentioned additional modeling effort is not necessary at this time.

The following conclusions are based on an analysis of the experimental data which has been obtained during the course of this project and its correlations with calculated model results.

1. On the average, the difference between the calculated and measured offsets in the localizer signal can be expected to be approximately 5 microamperes (at approximately 15,000 feet from the array) assuming no initial course offset in the localizer. This value is mainly due to differences between the calculated and measured course offsets when the Boeing 747 is positioned less than 2500 feet from the array. As the aircraft is positioned at larger distances from the localizer array, the difference in calculated versus measured offsets is now on the order of the uncertainty of present measurement procedures, or approximately 2 microamperes (refer to the results for localizer positions 7 and 8 in Table 4). The corresponding value for the glide slope is approximately 13 microamperes.

2. Prediction of the location of concentration of scalloping for localizer disturbances can be expected to be at best within 200 feet along the course, deteriorating to 500 feet when the scattering aircraft is located 1000 feet from the transmitting array. For the glide slope the accuracy is much the same except the distance between the transmitting array and the scattering aircraft may be reduced by approximately 40%. Note that for glide slope position 8, the limits of the model capabilities are being reached. At this close position the effects of the wings, engines, and stabilizers should probably be considered also.

VIII. ACKNOWLEDGEMENTS

The rather intense data collection period which yielded the first systematic data for validating mathematical model predictions of jumbo jet effects on the ILS was successful only because of the tremendous cooperation received from a number of people representing several organizations.

First, the great contribution made by National Airlines in making their Boeing 747's available for these measurements is acknowledged. Ramp facilities for the Ohio University aircraft were also furnished by National Airlines. Without the cooperative attitude of company officials this project would not have been possible. In particular, Mr. Warren Schuling, Vice President for Maintenance, Mr. W. L. Morton, Manager of Maintenance, and Mr. Robert Vermillion, Superintendent of Line Maintenance, supported this project work in every way, and this has been greatly appreciated.

Second, this project work was possible at the Miami International Airport only through the approval of the Dade County Aviation Department. The cooperation of Mr. Charles Mauch of Dade County was very helpful in providing for the physical needs of the project.

Third and quite important was the great help that was obtained from the FAA Flight Inspection Team headed by Mr. Garland Bell, the Air Ways Facilities personnel whose sector manager is Mr. Clint Murphy, and the Air Traffic Control under the supervision of Mr. Carl Joritz. It is particularly important to note that the records used for the documentation in this report were obtained by an FAA flight crew: Jack Mitchell, Pilot; Cecil Beugnot, Airborne Panel Operator; and Carl Rainwater, Theodolite Operator.

Acknowledgment is made of Mr. Harry Hooghkirk's and Mr. Jack McDonald's part in the data collection.

[12] "Maintenance of ILS Localizer Equipment", FAA Order 6750.15, May 17, 1971, Page 4.

[13] "Criteria for Approval of Category II Landing Weather Minima", FAA Advisory Circular, AC NO: 120-20, June 6, 1966, Page A3-3.

[14] "Aeronautical Telecommunications, Annex 10", Volume I, International Civil Aviation Organization, July, 1972, Page 101.

[15] "United States Standard Flight Inspection Manual", FAA OA P 8200.1, May, 1963, Reprinted January, 1970, Pages 217.19 and 217.20.

[16] "Aeronautical Telecommunications, Annex 10", Volume I, International Civil Aviation Organization, July, 1972, Page 98.

X. APPENDICES

Appendix A. MIA Path Perturbations Taken from Routine FAA Flight Inspection Reports

RUNWAY 27 L 8 - Loop Array, Null Reference

		Zone 1*	Zone 2*	Zone 3*
LOC	TX 1	0 μa peak	0 μa peak	8 (.3 mi) μa peak
4/19/73	TX 2	0	0	5 (.3 mi)
		"	"	"
G.S.	TX 1	0	16	17 (.3 mi)
5/25/73	TX 2	0	10	15 (.2 mi)

RUNWAY 27 R V-Ring, Null Reference

		Zone 1	Zone 2	Zone 3
LOC	TX 1	0 μa peak	5 (2.5 mi) μa peak	3 (.2 mi) μa peak
6/7/73	TX 2	0	4 (2.5 mi)	3 (.2 mi)
		"	"	"
G.S.	TX 1	5 (5 mi)	10 (1.5 mi)	15 (.3 mi)
5/15/73	TX 2	5 (5.5 mi)	15 (1.0 mi)	10 .3 mi)

RUNWAY 9 L Waveguide Null Reference

		Zone 1	Zone 2	Zone 3
LOC	TX 1	0 μa peak	0 μa peak	3 (.3 mi) μa peak
6/20/73	TX 2	0	0	3 (.2 mi)
		"	"	"
G.S.	TX 1	0	30 (2 mi)	10 (.3 mi)
	TX 2	0	28 (2 mi)	8 (.3 mi)

→ moved 210' back, 325' from centerline.

*According to the U.S. Standard Flight Inspection Manual, Zone 1 is the distance from the coverage limit of the localizer/glide path to Point A (four miles from the runway threshold), and Zone 2 is the distance from Point A to Point B. Zone 3 is the distance from Point B to Point C for evaluations of Category I and Category II training systems and the distance from Point B to the runway threshold for evaluations of Category II operational systems.

Points A, B, and C referred to in the above are defined as follows:

Point A - An imaginary point on the glide path/localizer course measured along the runway centerline extended, in the approach direction, 4 nautical miles from the runway threshold.

Point B - An imaginary point on the glide path/localizer course measured along the runway centerline extended, in the approach direction, 3500 feet from the runway threshold.

Point C - A point through which the downward extended straight portion of the glide path (at the commissioned angle) passes at a height of 100 feet above the horizontal plane containing the runway threshold.

POSITION NUMBER	CDI (μa)	ANGLE (DEG.)	HALF WIDTH (DEG.)	WIDTH (DEG.)
Nominal 27R	-150	3.6869	.7084	1.4125
	0	2.9785	.7041	
	+150	2.2744		
1	-150	3.6875	.7085	1.4105
	0	2.9790	.7020	
	+150	2.2770		
2	-150	3.6701	.7000	1.4106
	0	2.9701	.7106	
	+150	2.2595		
Nominal 27L	-150	3.6294	.7149	1.4210
	0	2.9145	.7061	
	+150	2.2084		
6	-150	3.5257	1.1634	1.5187
	0	2.3623	.3553	
	+150	2.0070		
7	-150	4.3578	-	2.5076
	0	2.9852 2.4773 2.2489		
	+150	1.8502	-	
8	-150	3.5900	.6509	1.3555
	0	2.9391	.7046	
	+150	2.2345		

Table A-1. Theoretical Values of Glide Slope Course Widths.

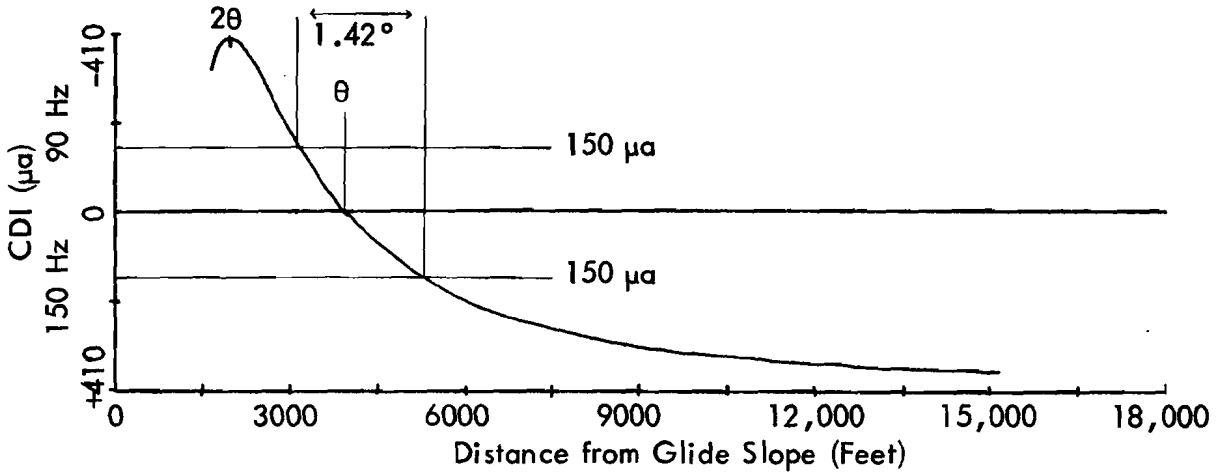


Figure A-2a. Nominal Course Width.

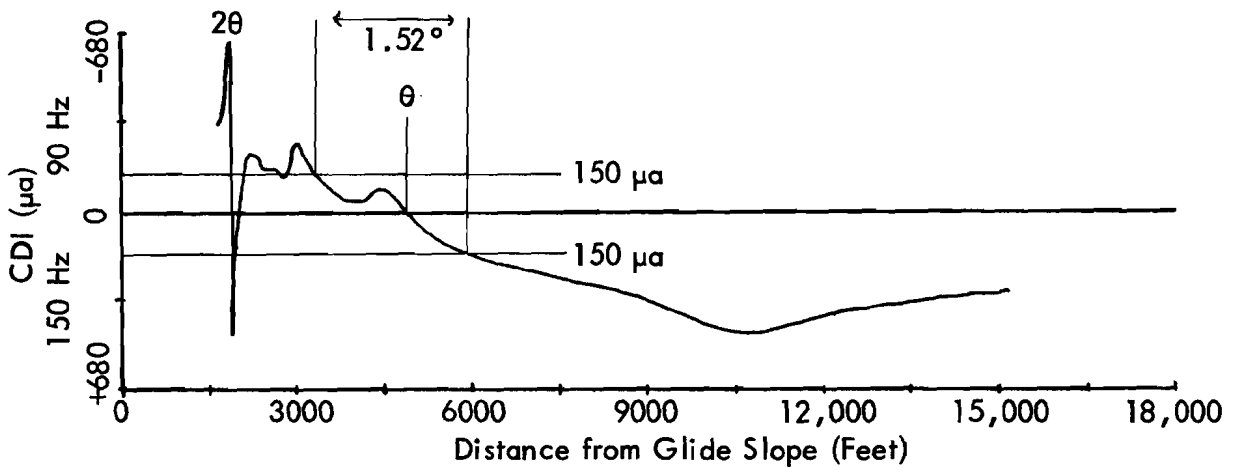


Figure A-2b. Course Width - B-747 at Position 6.

Figure A-2 a-d. Predicted Glide Slope Course Widths, Runway 27L.
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