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AIR FORCE COMMUNICATIONS COMMAND

TRACALS EVALUATION REPORT

SPECIAL REPORT

A PROCEDURE FOR RTT POSITION IMPROVEMENT
USING LINEAR REGRESSION ANALYSIS
OF GLIDE SLOPE STRUCTURE

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DEPARTMENT OF THE AIR FORCE
1866 Facility Checking Squadron
Scott AFB, Illinois

30 May 1982

SPECIAL REPORT

A PROCEDURE FOR RTT POSITION IMPROVEMENT USING LINEAR REGRESSION ANALYSIS OF GLIDE SLOPE STRUCTURE

82/66S-277

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This report presents a method to improve the position of a Radio Telemetering Theodolite (RTT) through an analysis by linear regression of the observed glide path structure of an instrument landing system. A complete derivation of the procedure is also presented, including examples testing the procedure at different glide slope facilities. These tests validated the procedure as well as revealed the limitations of its use. The procedure may be used to establish a permanent optimum RTT location for future use when commissioning new glide slope facilities exhibiting marginal performance and/or requiring Category II operation.

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1. SUMMARY

1-1. Background. Probably the most argued item in glide slope performance analysis is where to position the Radio Telemetering Theodolite (RTT) to observe the flight inspection aircraft. Attachment 1 of this report provides an explanation of RTT operation and how they are used in glide slope flight inspections. Engineers generally agree that RTT position can have some effect on the recorded structure data; consequently, there have been many techniques developed to optimally position the RTT. My involvement in RTT positioning began in April 1978, when HQ Air Force Communications Command (AFCC) tasked the 1866 Facility Checking Squadron to investigate RTT placements along the runway edge minimizing parallax tracking errors due to being offset from the runway centerline. The results of our investigations were presented in the Wright-Patterson AFB Traffic Control and Landing Systems (TRACALS) Evaluation Reports, Nos. 78/66S-135 and 79/66S-166. I found our investigation had insufficient means to fully compare results at the various RTT locations. I could only compare average angle readings, or structure in the various Solid State Instrument Landing Systems (SSILS) zones. No indication of any pattern in the RTT placement could be determined until I tried analyzing the recorded structure data using a linear regression. Then I discovered the tilt of the linear regression indicated the position of the RTT relative to the linear regression. The ensuing three years have been spent collecting data from over 16 TRACALS SSILS Evaluations to investigate this phenomenon and developing equations to determine where to reposition an RTT for optimum viewing of the glide path.

1-2. Linear Regression Versus the Present Analysis Method:

a. The primary area where glide path structure is examined is in Zone 2, which is the area of the glide slope approach from 3500 feet to four nautical miles (NM) from the runway threshold. The recorded structure in Zone 2 is significant because of three reasons. First, it is the area where most troublesome anomalies occur. Second, a qualified theodolite operator can provide minimal aircraft tracking errors through this zone. Third, Zone 2 is usually the critical sector of the the glide slope approach where transition from instrument to visual approach occurs or where missed approach procedures are initiated.

b. The present method of examining Zone 2 structure is determining the average angle. This is the algebraic sum of the RTT eyepiece angle and the angular difference between the RTT eyepiece angle and the structure (differential trace). Structure occurrences are then measured from this average angle for Zone 2. In my opinion, the average angle method of analysis is inadequate because it will not depict or account for a trend in the angle data. Because of this inadequacy, it is possible for a glide path to have a structure occurrence within Zone 2 structure tolerances measured from the average but would exceed the tolerances when measured from the data trend. Consequently, a glide path could have an unsafe condition depending on the location and severity of the structure occurrence not accounted for with average angle analysis.

c. A more suitable analysis method is to apply structure tolerances from the data trend. This data trend can be established by fitting a straight line to the data. A best fit line can be derived using a linear regression by the method of least squares. This provides an equation of the form $Y = BX + A$, where A and B are constants. By using a programmable calculator, the linear regression can be found as easily as determining the average angle. Various programs to compute linear regression are presented in Attachments 7 thru 9. A more detailed discussion on the advantages and use of linear regression for glide path structure analysis is presented in Appendix I.

1-3. RTT Position Improvement Using Linear Regression Analysis:

a. Two TRACALS evaluations of the Wright-Patterson AFB, Ohio SSILS showed that RTT position can affect the recorded structure data. Primarily, the effect concerns the trend of the data. Our evaluations show that a data trend where the slope of the recorded structure decreases as an aircraft flies toward the threshold indicates the RTT is too close to the glide slope antennas. Conversely, a data trend where the slope of the recorded structure increases as the aircraft flies toward the threshold indicates the RTT is too far from the antennas. This implies a data trend where the slope of the recorded structure remains relatively constant will indicate an optimum RTT position and provide a truer indication of the glide path performance. The average angle will also correspond to the linear regression when the slope of the data trend is constant.

b. My procedure was developed to adjust the RTT position from an initial position so the recorded data will be relatively constant. The complete reasoning and derivation of the procedure is presented in Appendix II. The steps for the procedure are as follows.

(1) Collect the following information for the calculations.

d_{off} = Offset distance of the antenna base from the runway centerline in feet

d_o = Distance along the runway centerline from the threshold to the point abeam the antenna base in feet

s = Slope in terrain from the horizontal in front of the initial origin in degrees

Θ_{eye} = RTT eyepiece angle in degrees

(2) Set up the RTT along a line between the glide slope antenna base and the runway threshold centerline such that the RTT eyepiece is backsighted to the antenna base at the desired or commissioned angle.

(3) Perform an RTT structure run, recording the differential trace through Zone 2. This can be done as a normal RTT structure run through all three zones. An extra run for repeatability is desirable.

(4) Sample points are collected as coordinates with seconds as the X-coordinate and light lines as the Y-coordinate. The seconds should start at the glide slope antenna and proceed outward to the point 4 NM from the threshold (Point A). Sample points are collected starting 3500 feet from threshold (Point B) and proceeding to Point A. Sample the recording every two seconds and determine the light line deviation of the differential trace from the recording centerline at each sample point. Light line values on the 150 Hz side of the recording are considered positive. Those on the 90 Hz side of the recording are considered negative.

(5) Up to this point, this analysis is performed during a normal flight inspection. Now, find the best fit straight line to the series of sample points using a linear regression by the method of least squares. This is done using the following equations.

For (x_i, y_i), $i = 1, \ldots, n$

$$Y = BX + A \qquad (1)$$

where

$$B = \frac{(\Sigma x_i y_i) - \frac{(\Sigma x_i)(\Sigma y_i)}{n}}{(\Sigma (x_i)^2) - \frac{(\Sigma x_i)^2}{n}} \qquad (2)$$

$$A = \frac{\Sigma y_i}{n} - B\left(\frac{\Sigma x_i}{n}\right) \qquad (3)$$

(6) The following equations determine the viewing angle to Points A and B using the light line values of the linear regression at Points A and B and the RTT eyepiece angle (Θ_{eye}). These equations assume the recording is calibrated to 150 uA and run at 75 uA.

$$\Theta_A = \Theta_{eye} + (LL_A (0.7/40)) \qquad (4)$$

$$\Theta_B = \Theta_{eye} + (LL_B (0.7/40)) \qquad (5)$$

(7) Find the linear regression angle from the following equation based on the glide slope distance offset from the runway centerline (d_{off}) and the glide slope distance to threshold parallel to the runway (d_o).

$$\theta_{lin} = \tan^{-1}\left\{\frac{\sqrt{d_{off}^{\,2} + \left[d_o + 24304\right]^2}\left[\tan\theta_A\right] - \sqrt{d_{off}^{\,2} + \left[d_o + 3500\right]^2}\left[\tan\theta_B\right]}{20804}\right\} \qquad (6)$$

(8) Determine the distance to move the RTT along the line between the antenna base and the runway threshold centerline, accounting for a terrain slope (s).

$$X = \sqrt{d_{off}^{\,2} + \left(d_o + 3500\right)^2}\left[1 - \frac{\tan\theta_B}{\tan\theta_{lin}}\right]\left[\frac{\sin\theta_{lin}}{\sin\left|\theta_{lin} - s\right|}\right] \qquad (7)$$

The first factor of Equation (7) is a reference distance for the site we are checking. The second factor relates the shift of the new RTT position based on the relationship between the angle at which we view the glide path at Point B and the linear regression angle. The third factor relates the effect of terrain slope to the new RTT position. If X is negative, move the RTT toward the antenna base. If X is positive, move the RTT toward the runway threshold centerline.

(9) Perform another RTT structure run recording the differential trace. The slope of the trace should now be more parallel to the recording centerline

than the trace recorded from the initial RTT position. The linear regression angle will be closer to the average angle as well. The representation of structure on this run will provide a truer indication of the glide path performance.

c. There are three primary assumptions to make in this procedure. First, assume the RTT is aligned between the antenna base and Point B rather than between the antenna base and the threshold centerline. This causes less than 0.01° error in the Point B viewing angle and a negligible change in the viewing angle for Point A. However, a five to seven foot error is incurred for most glide slope sites in the optimum RTT placement. Another assumption is the RTT viewing angles, the average angle, and the linear regression angle pass through the same apparent origin. For the initial RTT position, the apparent origin is the antenna base. The third assumption is the RTT will be repositioned at the same height above ground as at the initial position. Appendix III discusses in detail the inaccuracies associated with these assumptions.

1-4. Examples of RTT Repositioning. Efforts to fully investigate the validity of the procedure have been hampered in recent months by aircraft scheduling and weather. As a result, tests of the procedure at Lajes Field, MacDill AFB, Wiliams AFB, and Laughlin AFB have had to be dropped or only partially completed. Only two tests of the procedure have been performed to date, one at Myrtle Beach AFB and the other at Duke Field. Appendix IV presents a complete analysis of these tests. A summary of these test results are presented below.

a. The procedure was first tested on the Runway 35 glide slope facility at Myrtle Beach AFB in early February 1982. Structure runs were conducted with the RTT positioned at the standard initial position. Time constraints did not allow calculations to be made before the RTT was moved. The RTT was moved 50 feet forward to investigate the results from a different position. The procedure calculations made from both RTT positions indicate the same location for optimum RTT placement. The procedure indicated both positions were too far forward from the optimum location. Unfortunately, the RTT could not be set up at this optimum location to examine the improvement in the glide path structure recordings. The linear regression angle and average angle were worse at the second position than those from the first position. This agrees with the theory presented in my procedure and indicates the procedure is valid.

b. The second test occurred in March 1982 on the Runway 18 glide slope facility at Duke Field (Eglin AFB Auxilliary Field 3). Structure runs were made from the standard initial position and the calculations were used on-site to determine the new position. However, the calculations were erroneously performed resulting in positioning the RTT 40 feet forward instead of 66 feet in back of the initial position. The structure runs from the second position appear better than those from the first position, even though the RTT was moved the wrong direction. Because the RTT is much closer to the threshold and Point B, all data observed between these points appear at a higher viewing angle and effectively cancels the actual fly-down indication near threshold caused by antenna offset. On the other hand, both the linear regression and average angles improved at the second position, which theoretically should not have occurred. This may indicate the procedure is quite sensitive to the data, and therefore may not always provide an exact optimum location for the RTT. Values from the two positions show different optimum locations, although both positions show the RTT is too far forward. While the numerical values for the optimum location do not agree between the two positions, they do indicate the correct direction to move the RTT. This means the procedure will at least improve the position of the RTT, if not always relocate it at an optimum position.

2. CONCLUSIONS AND RECOMMENDATIONS

2-1. Conclusions:

a. Although there is a very limited experience with this procedure, it appears the procedure is a valid method for improving the RTT position. In some cases, the procedure appears to indicate the optimum location for viewing glide path performance.

b. As indicated during the Duke Field test, the RTT position has a definite effect on the recorded structure, particularly when near the threshold. When in Zones 1 and 2, the effect of RTT placement is not as evident.

c. The procedure appears to be sensitive to the data used in the linear regression. It may be the procedure cannot always indicate an exact optimum location for the position, although it will improve the position.

d. As the RTT position is improved, the linear regression angle and the average angle converge. This implies that once an optimum RTT location is established for a given glide slope site, the normal analysis methods in AFM 55-8 may be used and will produce the same results as linear regression analysis.

2-2. Recommendations:

a. The 1866 Facility Checking Squadron should continue to apply this procedure during all glide slope facility evaluations. As a sufficient data base is built, a more definite indication of the exact capabilities and limitiations of this procedure can be derived.

b. Based on the present knowledge of the procedure, I recommend it be used only when commissioning new Category II facilities or when examining glide slope facilities with a history of poor or marginal performance.

APPENDIX I

LINEAR REGRESSION ANALYSIS OF GLIDE SLOPE STRUCTURE

1. Present Method of Glide Slope Structure Analysis:

a. The TRACALS evaluation of a glide slope facility is concerned with the investigation of the glide path performance in the installed environment. Flight inspection of glide slope facilities includes measurement of the facility structure, defined in AFM 55-8 as "an accurate measurement of the magnitude of aberrations (roughness, scalloping, and bends) of the path from the actual path angle and the graphical average path." The structure is measured in Zones 1, 2, and 3 which are shown in Figure I-1. In Zone 1, the aircraft's distance from the RTT makes it difficult to accurately track the aircraft. The differential trace in Zone 1 usually shows little or no structure because the effect of aircraft movement at those distances is less significant. Use of structure data in Zone 3 is suspect because information there is subject to tracking errors by the RTT operator from too much aircraft movement, and parallax errors caused by being offset from the runway centerline. The data collected in Zone 2 is used for most glide slope analysis because it is far enough away to minimize tracking errors by the RTT operator and close enough to depict any glide path anomalies. Zone 2 is also usually the critical sector of the aircraft descent, where transition from instrument to visual approach is accomplished or missed approach procedures are implemented.

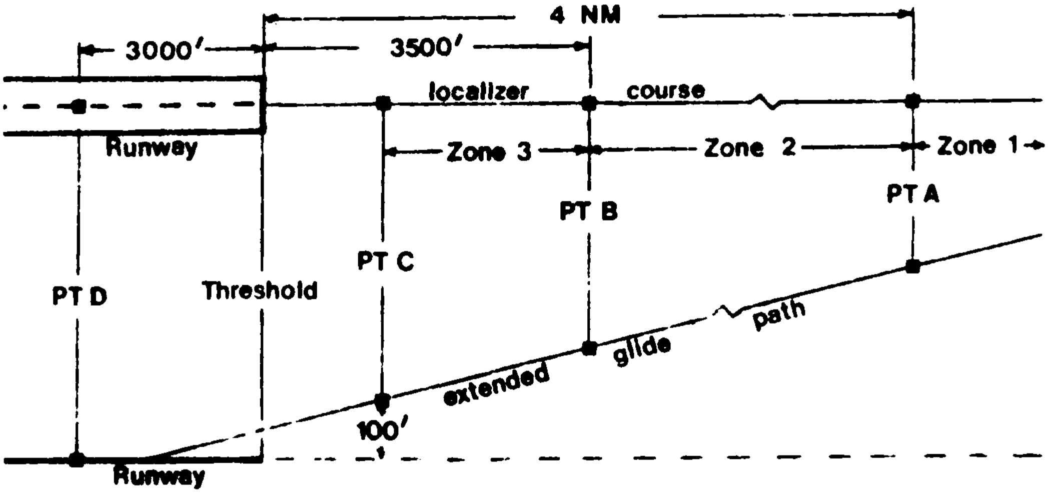


Figure I-1
ILS Reference Points and Zones

b. A sample aircraft structure recording is shown in Figure I-2. The structure information of the glide path is depicted by the differential trace. When distance marks are available on the recording, they can be converted to nautical miles from the glide slope facility or point abeam the glide slope facility on the runway centerline. Whether or not distance marks are available, the recording timing lines can be used. Using timing lines, the RTT run is sampled every two seconds between Points A and B. The panel operator determines the locations of Points A and B on the recording. The difference between the recording centerline (determined by the RTT eyepiece angle) and the trace is measured in light lines or uA. Light line values on the 150 Hz side of the centerline are read as positive values. Light line values on the 90 Hz side of the centerline are read as negative values. This is due to the method in which the differential trace is developed. The difference represents the angular difference between the RTT eyepiece angle and the differential trace. A further explanation of RTT operation is presented in Attachment 1.

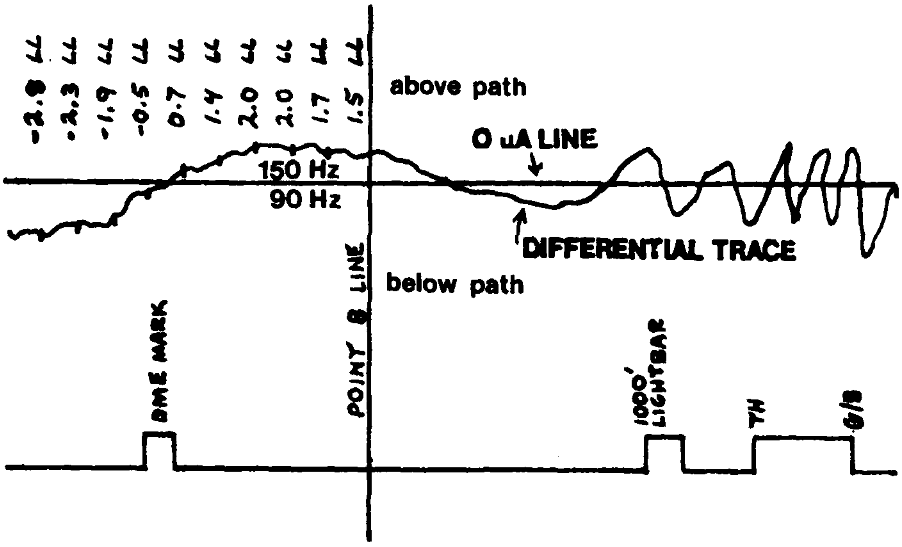


Figure I-2
Sample Aircraft Structure Recording

c. The actual, or average, angle defined in AFM 55-8 is measured in Zone 2. The average angle is the algebraic sum of the RTT eyepiece angle and the average angular difference between the RTT eyepiece angle and the differential trace. Mathematically, this can be stated as follows.

$$\Theta_{avg} = \Theta_{RTT} + \bar{X} \qquad (1)$$

where Θ_{avg} = Average angle in degrees
Θ_{RTT} = RTT eyepiece angle in degrees
$\bar{X}$ = Average difference between the differential trace and the centerline in degrees

$\bar{X}$ is defined as follows.

$$\bar{X} = \left(\frac{1}{n}\right)\sum_{i=1}^{n} (LL_i)\frac{0.7}{40} \qquad (2)$$

where (LL_i) = Light line value of the difference at each sample point i.

The factor (0.7/150) assumes a nominal path width of 0.7° set into the RTT and a recording run calibrated to 150 uA and run at 75 uA.

d. A sample structure run showing the average angle is presented in Figure I-3. Zone 2 structure is measured as the maximum excursion of the actual recorded data from the average angle. In Figure I-3, the maximum structure reading is shown as -2.9 light lines, or about 11 uA below path. If we consider the average angle as a model of the actual glide path, then the elevation (Y) of a point on the glide path above the RTT eyepiece elevation can be found at a distance (X) from the RTT by the equation $Y = X \tan(\Theta_{avg})$.

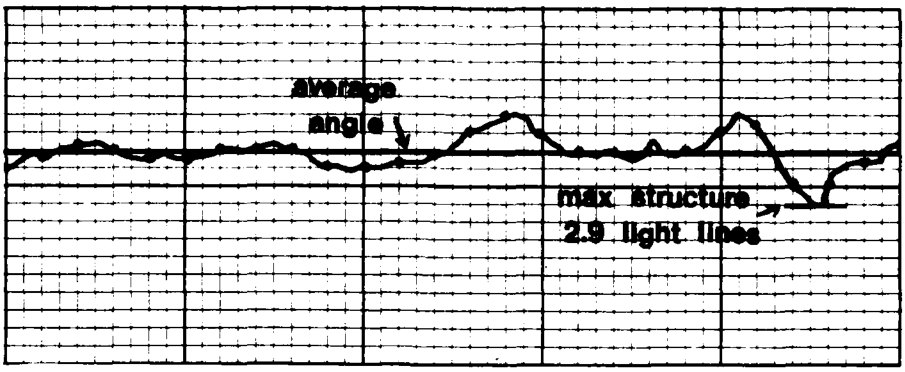


Figure I-3
Average Angle Structure Analysis

2. <u>Linear Regression of Glide Slope Structure Data.</u> Because the glide slope theoretically radiates in a straight line (in the first null of the SBO radiation pattern), the glide slope may be modeled with a linear equation of the form Y = BX + A, where A and B are constants. We can find the best fit straight line to our collection of sample points by performing a linear regression using the method of least squares. The constants A and B are then calculated from the following equations.

For (x_i, y_i), $i = 1, \ldots, n$

$$B = \frac{(\Sigma x_i y_i) - \frac{(\Sigma x_i)(\Sigma y_i)}{n}}{(\Sigma (x_i)^2) - \frac{(\Sigma x_i)^2}{n}} \qquad (3)$$

$$A = \frac{\Sigma y_i}{n} - B\left(\frac{\Sigma x_i}{n}\right) \qquad (4)$$

Such a linear regression would appear on the flight recording as shown in Figure I-4.

3. <u>Comparison of Average Angle Versus Linear Regression:</u>

a. The advantage of using the average angle is its simplicity. It is convenient to

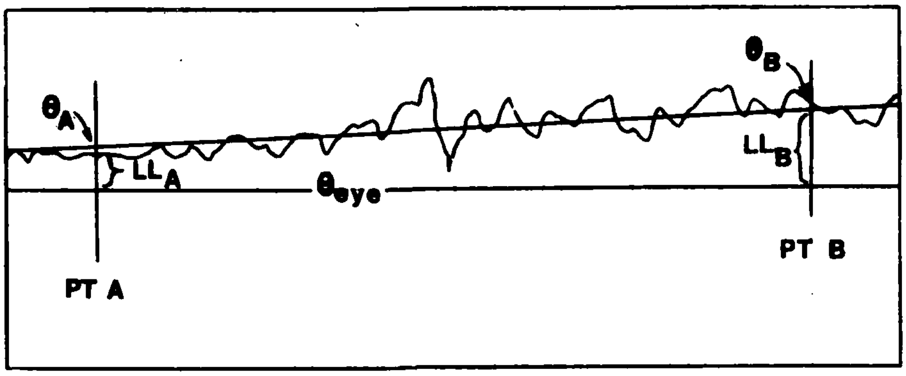


Figure I-4
Linear Regression of Flight Data

use and requires no sophisticated analysis for its derivation. The calculations can be performed quickly by the panel operator. The problem with the average angle is it does not account for any trend of the angle change. It only accounts for the average, and does not show an increasing or decreasing trend in the recorded data, as shown in Figure I-5. Additionally, the trend of the data cannot be based entirely on glide path anomalies, but may also be dependant on the RTT position. The fact that the average angle must pass through the RTT eyepiece makes it dependant on the RTT position. If the RTT is positioned below the extended glide path, the average angle will generally be higher. Conversely, if the RTT is positioned above the extended glide path, the average angle will generally be lower. This was demonstrated in eleven TRACALS evaluations on glide slope facilities conducted in the past three years. The results of these evaluations show the average angle does not allow total separation of the RTT position effects from the true glide path anomalies, and therefore may provide questionable information about the glide path performance. There is no way to tell if an RTT is optimally located from the data provided by the average angle.

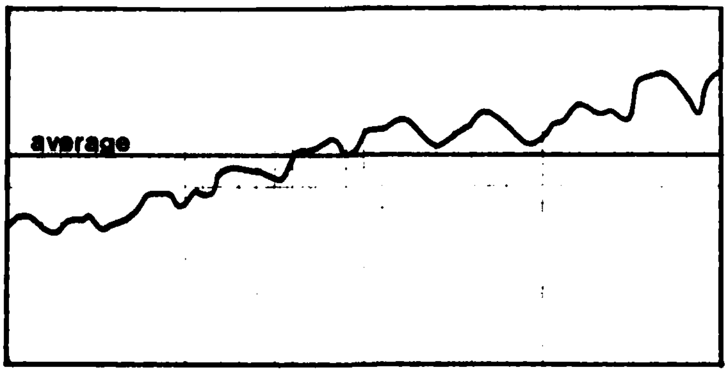


Figure I-5
Inability of Average to Show Data Trend

b. Linear regression analysis is very useful because many different topics can be investigated by its use. The major advantage of linear regression is its ability to depict the trends in the structure data.

(1) The glide path in Zone 2 can be viewed as a straight line in space in accordance with the glide slope theory of linear radiation. If a set of coordinate axes and a reference point are provided, an equation can be developed for the line. Regardless of how the line is viewed, the line is still located in the same position relative to the reference point and coordinate axes. If we assume the glide path has no bends in Zone 2, then the trend depicted by the linear equation gives an indication of the RTT position relative to the extended glide path. This application is based on data collected during the two TRACALS evaluations at Wright-Patterson AFB.

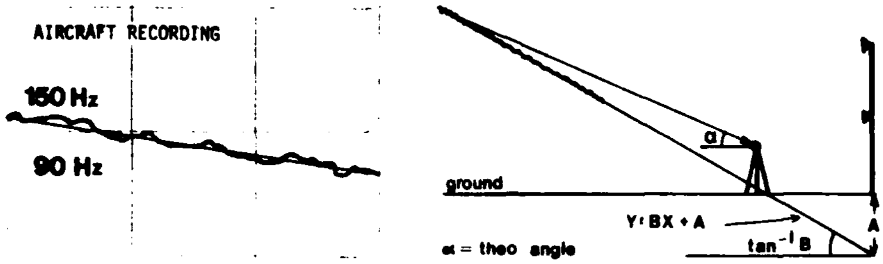
(2) Figure I-6 shows a diagram explaining the effect of RTT position on recorded structure data and the RTT position relative to the extended glide path. (RTT placement also has a slight but negligible effect on the observed glide path width and angle when measured in level runs, as explained in Attachment 3). A linear regression whose slope tends toward the 90 Hz side of the recording as the aircraft approaches threshold indicates the perceived glide angle is gradually decreasing, as shown in Figure I-6a. Assuming the glide path is straight, the perceived decrease in the glide angle implies the RTT eyepiece is above the extended glide path. Likewise, a linear regression whose slope tends toward the 150 Hz side of the recording as the aircraft approaches threshold indicates the perceived glide angle is gradually increasing, as shown in Figure I-6b. This implies the RTT is below the extended glide path.

(3) This analysis indicates the more horizontal the slope of the linear regression, the better the RTT position and the truer indication of glide path performance. The effect of an optimum RTT position and its relation to the extended glide path is shown in Figure I-6c. The ideal situation is shown in Figure I-6d, where the RTT is positioned on the extended glide path with the eyepiece at the true glide angle. Analysis of the glide path structure recordings with linear regression can be used to find the optimum RTT location at glide slope sites without permanent RTT stands, or at unusually configured glide slope sites, such as the once-operational waveguide facility at Malstrom AFB.

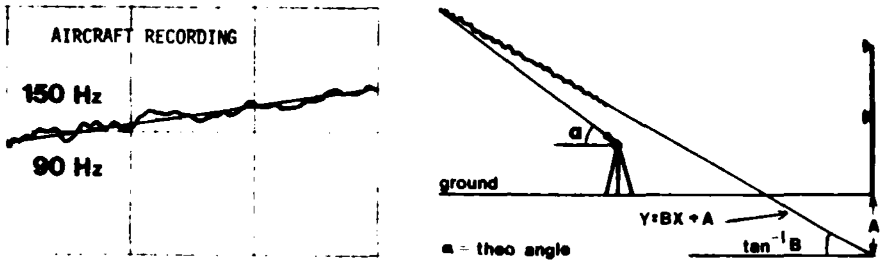
(4) Data collected at Wright-Patterson AFB demonstrated the average angles at various RTT locations had a greater dispersion than the angles found by linear regression at those RTT locations. This data is summarized in Attachments 5 and 6. The nature of a linear regression makes it relatively independant from the location of the RTT since the extension of the equation back to the origin will not pass through the RTT eyepiece except for the specific case shown in Figure I-6d. Because of this and the fact that it follows the trend of the data, linear regression provides a true indication of the actual glide angle. The true glide angle of the facility is related to the slope of the linear regression equation, namely (B). If the collection of sample points is converted to a series of coordinate points in space with both units in feet, then the true glide angle would simply be arctangent (B). Linear regression can be used to determine other glide slope parameters as explained in Attachments 2 and 4.

4. <u>Use of the Linear Regression by Flight Inspection and TRACALS Evaluation Personnel:</u>

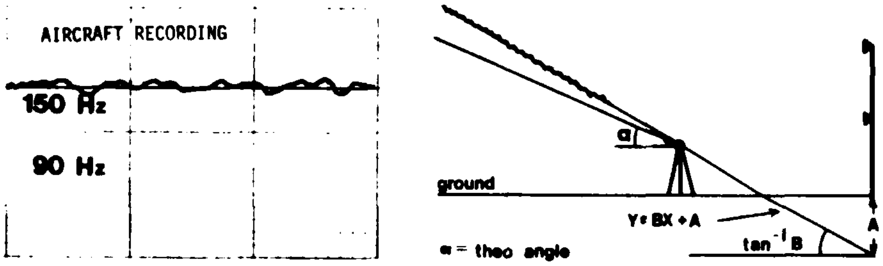
a. There are two hand-held calculators presently in the Air Force inventory used by flight inspection as well as TRACALS evaluation personnel to perform linear regression and average angle calculations during flight inspections or TRACALS evaluations. These two calculators are the Hewlett-Packard Model HP-25, NSN 7420 PHP25, and the Texas Instruments Model TI-59, NSN 7420 01 054 4382. Procedures for using the HP-25 calculator to solve linear regression and average angle are presented in Attachment 8. A program written for the TI-59 calculator to compute linear regression, new RTT placement, and average angle is presented in Attachment 9. A program is also presented in Attachment 10, written in Applesoft BASIC for an Apple computer. In addition, other programmable calculators can be used to perform linear regression and average angle calculations.



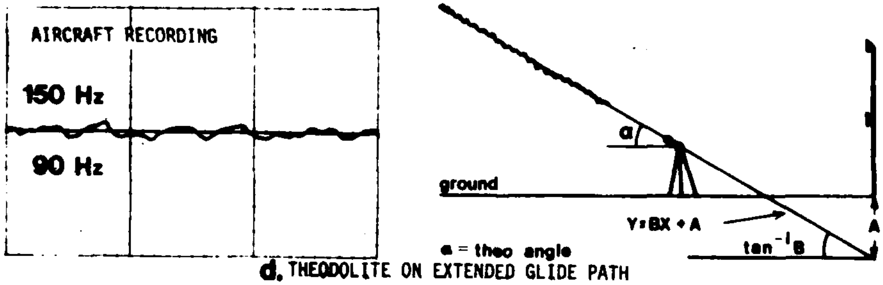
a. THEODOLITE ABOVE EXTENDED GLIDE PATH



b. THEODOLITE BELOW EXTENDED GLIDE PATH



C. THEODOLITE ON EXTENDED GLIDE PATH
WITH DIFFERENT ANGLE



d. THEODOLITE ON EXTENDED GLIDE PATH
WITH SAME ANGLE

Figure I-6
Effect of RTT Placement on Recorded Glide Path Structure

b. The primary end product for the flight inspection personnel is a line on the recording used to measure the structure and depict the glide angle. Timely computation during a flight inspection is essential to save funds and resources. As an added feature of linear regression, the units of the coordinate axes do not have to be equivalent. Data points can be read in coordinates of nautical miles and light lines or in the readily available coordinates of seconds and light lines to save more time. When using seconds as the X-coordinate, the zero reference should be the glide slope antenna and increase toward Point A. With this reference, Point B will generally occur between 10-20 seconds and Point A will occur between 60-90 seconds, depending on the speed of the aircraft. It is important to use the same reference on the recording as the data points when drawing the linear regression.

APPENDIX II

DERIVATION OF THE EQUATION FOR RTT REPOSITIONING BY LINEAR REGRESSION ANALYSIS OF GLIDE SLOPE STRUCTURE

1. General. This appendix presents a step by step development of the equation for repositioning an RTT using linear regression analysis of the glide slope structure. It also includes the reasoning behind the assumptions in the derivation and a listing of the variables used.

2. Thought Process for Position Improvement:

a. In order to correct our RTT position for optimum viewing of the glide path, we must first collect an initial set of RTT structure data and obtain a linear regression. The linear regression on the flight recording represents a linear regression in space of the glide path. The linear regression in space will have some angle to the horizontal reference plane, which we will call (Θ_{lin}). The ideal place to view this linear regression is a direct end view of the line. In other words, the line would appear as a point, with no parallax errors involved. The only time we would be able to "see" the point view of the linear regression with the RTT eyepiece is to be positioned on the runway centerline at the runway point of intercept (RPI) of the linear regression.

b. Positioning the RTT in such a manner is impractical for obvious reasons of safety, so we must position the RTT offset from the runway centerline. Let us limit ourselves to position the RTT somewhere along a line between the antenna base and the runway threshold centerline. This will coincide with existing methods and also limit our movement from the initial RTT position we used to obtain the linear regression. Our initial RTT position was such that we backsighted the antenna base at minus the commissioned or desired angle. Data collected from several TRACALS Evaluations support the premise that the linear regression angle (Θ_{lin}) will not differ much from the average angle, nor will either of these differ much from the RTT eyepiece angle if it's relatively close to being correct. Consequently, we can assume negligible change in the initial RTT position no matter which of the three angles is used to backsight to the antenna base. Therefore, we can state the initial RTT position is sufficient for acquiring the linear regression.

c. The advantage in having a sufficient initial RTT position is we can now have a reference for all our calculations. This reference is the antenna base, which appears as our initial origin of the glide slope signal. Because the linear regression does not pass through the RTT eyepiece except for one specific case, the linear regression will usually show a new apparent origin of the signal, which may either be behind or in front of our initial origin. Our desire is to reposition the RTT to align the eyepiece to backsight to the new apparent origin.

d. Before we get into the actual derivation of the RTT positioning equation, it is convenient at this point to list the variables used. These appear as follows.

Θ_{avg} = Average angle of the structure data in degrees

Θ_{lin} = Angle of the linear regression from the horizontal in degrees

Θ_{eye} = RTT eyepiece angle in degrees

Θ_A = Observed elevation angle of the linear regression at Point A in degrees

Θ_B = Observed elevation angle of the linear regression at Point B in degrees

s = Slope in terrain from the horizontal in front of the initial origin in degrees

a = Obtuse angle between the terrain slope and the line defined by the linear regression in degrees

d_{off} = Offset distance of the antenna base from the runway centerline in feet

d_o = Distance along the runway centerline from the threshold to the point abeam the antenna base in feet

d_a = Direct distance from the RTT position to Point A in feet

d_b = Direct distance from the RTT position to Point B in feet

D_A = Direct distance from the antenna base to Point A in feet

D_B = Direct distance from the antenna base to Point B in feet

D_{theo} = Horizontal distance the RTT is moved along the line between the antenna base and the runway threshold centerline in feet

LL_A = Light line value of the linear regression at Point A

LL_B = Light line value of the linear regression at Point B

X = Distance along the terrain surface the RTT is moved from the initial position to the new position in feet.

e. Let's now look at the geometry involved in my calculations. For the initial RTT position, the geometry appears as shown in Figure II-1.

$$D_A = \sqrt{{d_{off}}^2 + \left[d_o + 24304\right]^2}$$

$$D_B = \sqrt{{d_{off}}^2 + \left[d_o + 3500\right]^2}$$

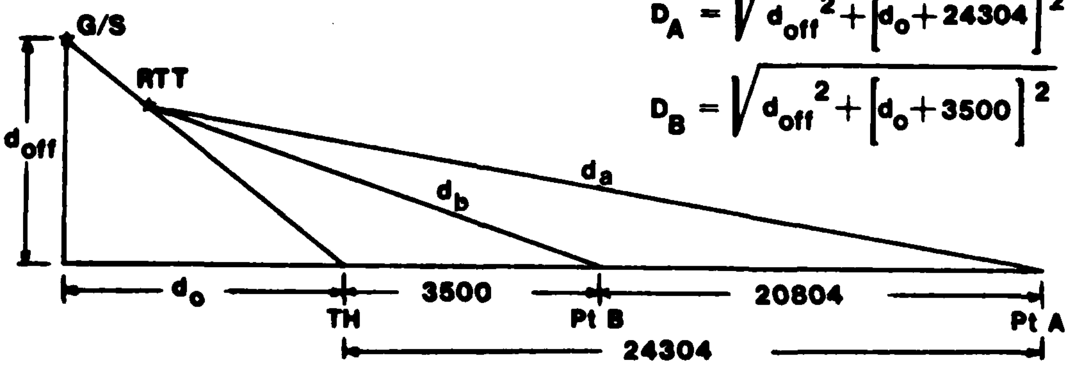


Figure II-1
RTT Position Geometry

We can see the trigonometry involved with determining all results from our initial RTT position will get somewhat difficult since the location is not in line with the antenna base and either of the points we are interested in. Therefore, I will assume (d_a) and (d_b) will not appreciably change if I envision the RTT as being placed along the line between the antenna base and Point B. This will simplify the mathematical development and the final equation later on. Figure III-1 in Appendix III shows the error in feet incurred for various combinations of (d_{off}) and (d_o) because of this assumption. Generally, we could expect about six to seven feet error in the new RTT position. Without actually moving the RTT to this new alignment, let's pursue the problem as if it were aligned between the antenna base and Point B. Our geometry for this situation would now appear as shown in Figure II-2.

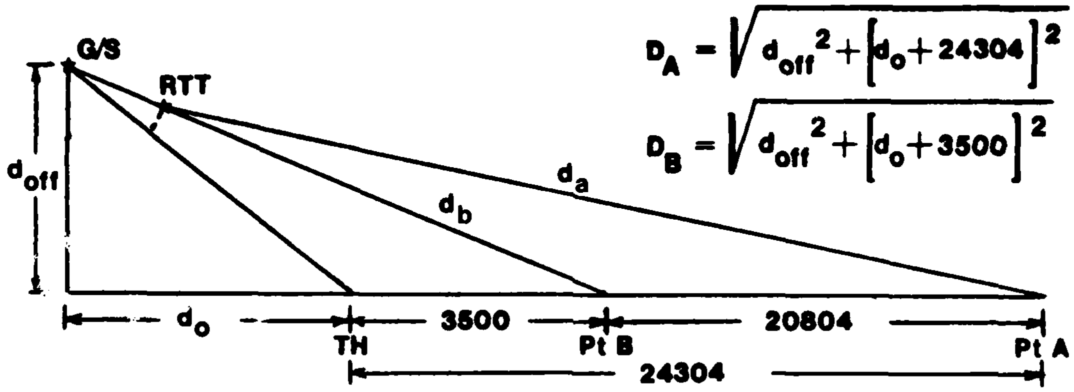


Figure II-2
Revision to RTT Position Geometry for Mathematical Simplification

f. Let's suppose the elevation angle at which we view the glide path at Point A will not noticeably change when we envision the RTT aligned to Point B, because (d_a) is large compared to the distance the RTT is moved. The nominal change in (d_a) from moving the RTT is less than 0.043%. The elevation angle at which we view the glide path at Point B is more dependant on the RTT position. The nominal change in (d_b) from moving the RTT is about 0.352%. Although this error is not particularly significant, let's move the RTT such that the eyepiece angle required to observe the glide path at Point B is the linear regression angle (Θ_{lin}). This will allow structure at Point B (which is where the structure tolerances become critical) to be observed as if we could view the glide path at the RPI of the linear regression. Remember, the angle at which we view Point A will not appreciably change when moving the RTT (if we move the RTT 150 feet toward the threshold, for example, the angle to view the glide path at Point A will change less than 0.50%). The end result is to position the RTT along the line between the antenna base and the runway threshold centerline so the linear regression data on the flight recording is seen at a constant angle. In other words, the linear regression on the flight recording is parallel to the differential trace centerline (Θ_{eye}). If (Θ_{lin}) is greater than (Θ_{eye}), we must move away from the antenna base to increase our viewing angle to the glide path at Point B. Conversely, if (Θ_{lin}) is less than (Θ_{eye}), we must move closer to the antenna base to lower our viewing angle to the glide path at Point B.

3. Derivation:

a. Once we have the linear regression, we can find the light line values of the linear regression at Points A and B. We can use these values to find our viewing angles to Points A and B from the following equations.

$$\Theta_A = \Theta_{eye} + (LL_A (0.7/40)) \qquad \text{(1a)}$$

$$\Theta_B = \Theta_{eye} + (LL_B (0.7/40)) \qquad \text{(1b)}$$

If we drew our known information on the flight recording, it would appear something like Figure II-3. We can now see how the RTT will be moved by looking at the values for (Θ_A) and (Θ_B). When (Θ_A) is greater than (Θ_B), the RTT is too close to the antenna base; conversely, when (Θ_A) is less than (Θ_B), the RTT is too far away from the antenna base.

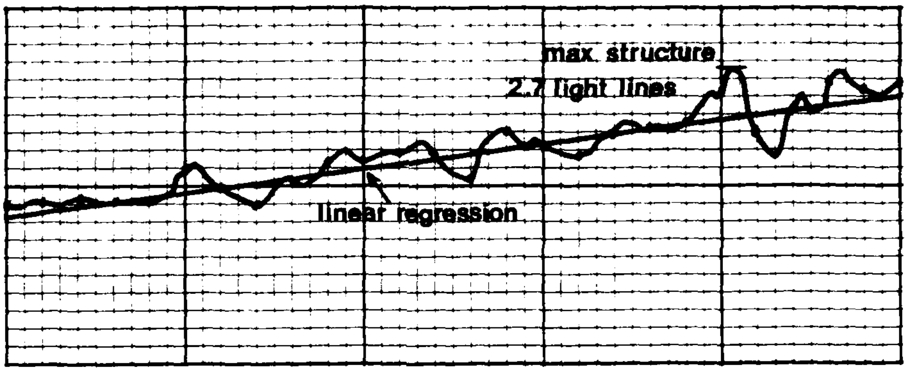


Figure II-3
RTT Structure Run Showing Linear Regression

b. *Remember* an assumption I made stating the RTT position is essentially unaffected whether we use (Θ_{lin}), (Θ_{eye}), or (Θ_{avg}) to backsight to the antenna base. Therefore, (Θ_A) and (Θ_B) also originate from the antenna base as well (for the initial RTT position). We can then make an intermediate step to calculate the heights in space of the linear regression by using the distances from the antenna base to Points A and B (D_A and D_B, respectively) in the following equations.

$$H_A = D_A \tan(\Theta_A) \qquad \text{(2a)}$$

$$H_B = D_B \tan(\Theta_B) \qquad \text{(2b)}$$

c. We can use the heights at Points A and B to find the elevation angle of the linear regression relative to the horizontal. The geometry for this calculation is shown in Figure II-4. With a simple trigonometric identity, we arrive at (Θ_{lin}) by the following equation.

$$\theta_{lin} = \tan^{-1}\left[\frac{H_A - H_B}{20804}\right] \qquad \text{(3)}$$

Now let's substitute Equations (2a) and (2b) into (3), and also have (D_A) and (D_B) in terms of (d_{off}) and (d_o) as depicted in Figure II-1. Our final equation for (Θ_{lin}) is as follows.

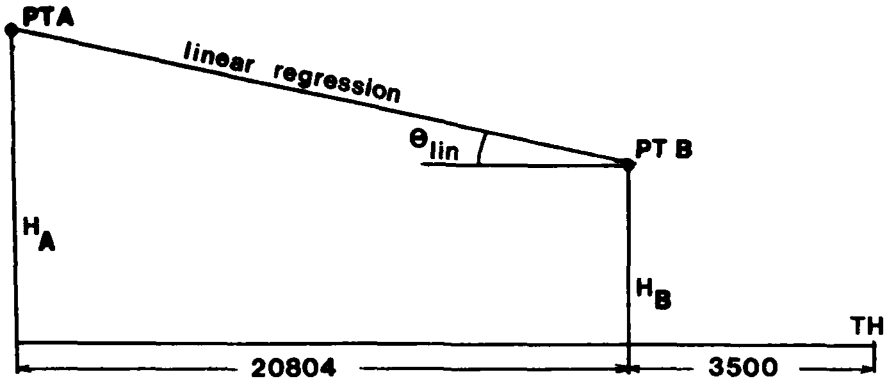


Figure II-4
Geometry for Determining Linear Regression Elevation Angle

$$\theta_{lin} = \tan^{-1}\left\{\frac{\sqrt{d_{off}^{2}+\left[d_o+24304\right]^{2}}\left[\tan\theta_A\right]-\sqrt{d_{off}^{2}+\left[d_o+3500\right]^{2}}\left[\tan\theta_B\right]}{20804}\right\} \quad (4)$$

d. We want to reposition the RTT to view Point B at (Θ_{lin}). Since (H_B) should remain unchanged, then moving the RTT will appear to align the eyepiece to some new apparent origin. The horizontal distance from Point B (at the same elevation as our initial origin, the antenna base) to the new apparent origin (D_B') is found with Equation (5).

$$D_B' = \frac{H_B}{\tan\theta_{lin}} \quad (5)$$

e. I will now make an assumption concerning the height of the RTT. Assume the RTT will be repositioned at the same height above the ground as at the initial position. This is a valid assumption because the same RTT operator will be at the site moving the RTT. It is logical to assume he will set up the RTT at the same eyepiece height for his own comfort every time. Let us also assume the terrain is flat. This means the new apparent origin is at the same elevation as the initial origin. If we make these assumptions, the distance we should move the RTT is simply the difference between (D_B) and (D_B'), shown in Equation (6).

$$D_{theo} = D_B - D_B' \quad (6)$$

Because we have (H_B) in terms of (D_B) in Equation (2b), let's substitute (2b) into (5). Then we now can substitute Equation (5) into (6) for (D_B'), and have (D_{theo}) in terms of (D_B).

$$D_{theo} = D_B - \left[\frac{D_B \tan\theta_B}{\tan\theta_{lin}}\right]$$

$$D_{theo} = D_B\left[1 - \frac{\tan\theta_B}{\tan\theta_{lin}}\right] \tag{7}$$

If we put (D_B) in terms of the more easily known distances (d_{off}) and (d_o) from Figure II-1, then our equation for RTT positioning with flat terrain in front of the antenna base is shown in Equation (8).

$$D_{theo} = \sqrt{d_{off}^2 + \left(d_o + 3500\right)^2}\left[1 - \frac{\tan\theta_B}{\tan\theta_{lin}}\right] \tag{8}$$

f. In many cases, we will not have flat terrain in front of the antenna base. We should therefore adjust Equation (8) to reflect a general case for terrain slope. Figure II-5 illustrates the geometry used to account for terrain slope. In this figure, the slope is a negative value. A similar geometric relationship can be drawn for a positive slope and for negative values of (D_{theo}). All angles and sides will have the same relationship with each other.

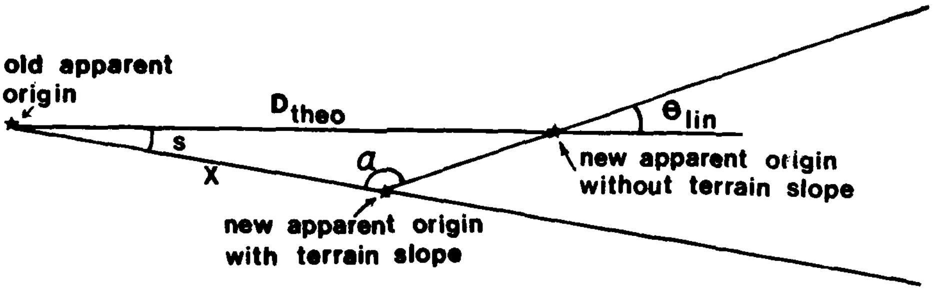


Figure II-5
Geometry for Incorporating Terrain Slope Into RTT Repositioning

Having made the assumption the RTT eyepiece will be repositioned at the same height above the terrain, then the distance to move the RTT on sloping terrain is X from Figure II-5. We can find an equation for X using the Law of Sines.

$$\frac{\sin\alpha}{D_{theo}} = \frac{\sin\theta_{lin}}{X}$$

$$X \sin\alpha = D_{theo} \sin\theta_{lin}$$

$$X = D_{theo}\left[\frac{\sin\theta_{lin}}{\sin\alpha}\right] \qquad (9)$$

The angle (α) needs to be expressed in some other terms. Let's put it in terms of (Θ_{lin}) and the terrain slope (s), as shown in Equation (10).

$$\alpha = 180 - \Theta_{lin} + s \qquad (10)$$

You will notice s is a positive term in (10) because we consider it negative in Figure II-5. We can now reduce (10) to (11) through the following process.

$$\begin{aligned} \alpha &= 180 - \Theta_{lin} + s \\ \sin\alpha &= \sin(180 - \Theta_{lin} + s) \\ \sin\alpha &= \sin(180 - (\Theta_{lin} - s)) \\ \sin\alpha &= \sin(\Theta_{lin} - s) \qquad (11) \end{aligned}$$

If we substitute (11) into (9) for ($\sin\alpha$), we get the following equation.

$$X = D_{theo}\left[\frac{\sin\theta_{lin}}{\sin|\theta_{lin} - s|}\right] \qquad (12)$$

g. Our final step is to substitute Equation (8) into (12) for (D_{theo}). We now have an equation for (X) to reposition the RTT with a slope in the terrain.

$$X = \sqrt{d_{off}^2 + \left(d_o + 3500\right)^2}\left[1 - \frac{\tan\theta_B}{\tan\theta_{lin}}\right]\left[\frac{\sin\theta_{lin}}{\sin|\theta_{lin} - s|}\right] \qquad (13)$$

Although this is a horrendous looking equation, the three terms represent specific items about the new RTT position. The first factor is a reference distance for the site we are checking. The second factor relates the shift of the new RTT position based on the relationship between the angle at which we view the glide path at Point B and the linear regression angle. The third factor relates the effect of terrain slope to the new RTT position.

APPENDIX III

ACCURACIES INVOLVED IN USING LINEAR REGRESSION ANALYSIS FOR RTT REPOSITIONING

1. General:

a. The technique which we use to measure glide path structure, that of tracking the aircraft flight with a ground based theodolite, has certain absolute errors which we are constrained by. Fortunately, these errors are small, so a high degree of accuracy can be achieved. There are three primary areas limiting the accuracy of our measurement technique.

(1) The majority of theodolites used in glide slope flight inspection have a calibrated accuracy of 0.01°. Generally, a qualified theodolite operator will be able to track the aircraft flight within 0.01° of its actual position.

(2) The RTT transmitter design also provides a small inaccuracy. The calibration procedure and meter face on most transmitters generally produce enough variance to cause a 2-3 uA error in the transmitted signal. Using normal aircraft receiver calibration, this will induce about 0.01° error in the differential trace.

(3) The recording light lines are physically about 0.1 inches apart. It is generally possible to read the differential trace to within 0.5 light lines. Using normal receiver calibration, this corresponds to less than 0.01° error in the differential trace.

(4) The cumulative error of measuring glide path angles resulting from our measurement technique is about 0.03°. This is comparable to the accuracy achieved using an automated flight inspection system.

b. In the process of developing my procedure for optimum repositioning of an RTT based on linear regression analysis of glide slope structure, I made several assumptions to help simplify the derivation. Whenever most simplifying assumptions are made, there is usually some inherent loss of accuracy associated with the assumptions. Some of the simpler assumptions I made are already discussed in Appendix II. I will now examine the more complex assumptions I made in my derivation and their associated accuracies.

2. Assuming RTT Alignment to Point B Instead of Threshold:

a. One of my major assumptions was we could envision the RTT as being placed along the line between the antenna base and Point B, to simplify the mathematics. Because we are backsighting our initial RTT position to the antenna base, the RTT will be the same distance from the antenna base when realigned to Point B. However, this will change the RTT's distance to Point B, which affects the angle at which we view the linear regression and glide path at Point B.

b. For small angles such as 3.00° or less, the tangent of the angle is simply the value of the angle in radians. Since the tangent is proportional to the distance from Point B, a change in the distance will cause a proportionate change in the angle. Figure III-1 shows the change in distance from the RTT to Point B assuming alignment to Point B. This is done for various combinations of the glide slope offset distance (d_{off}) and distance to threshold (d_o). For example, let's use a distance to thresold of 1000 feet and an offset distance of 500 feet. Figure III-1 shows the distance from the RTT to Point B

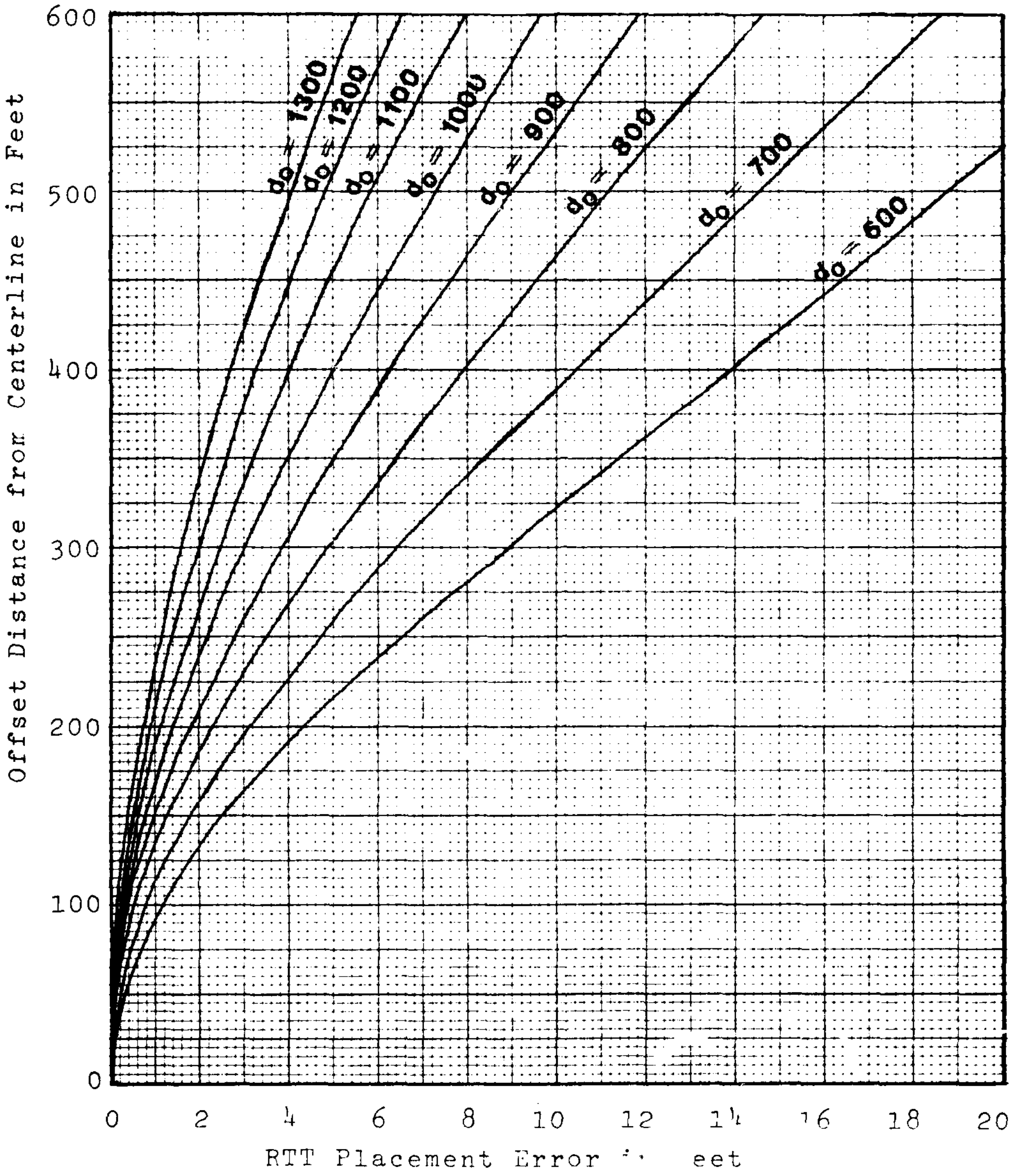


Figure III-1
RTT Placement Error Assuming Placement Between Site and Point B
Versus Site and Threshold

will be 7.3 feet different (shorter) when assuming alignment to Point B rather than the actual alignment to threshold. The RTT distance from the antenna base used in Figure III-1 is 115 feet, corresponding to an angle of about 2.75°.

c. Figure III-1 shows that as the ratio of (d_o) to (d_{off}) decreases, the change in distance will increase, and vice versa. The closer the facility is to the lower left corner of Figure III-1, the less inaccuracy is incurred in my derivation by assuming RTT alignment to Point B. In the example above (d_o = 1000, d_{off} = 500), the RTT distance to Point B is 4412.7 feet. The 7.3 feet from Figure III-1 represents an error of 0.165% in distance, or an error of less than 0.01° in the Point B viewing angle. These errors are within the limits of our measurement techniques; therefore, I can envision the RTT as being aligned to Point B for simplification of the mathematics in my derivation.

3. Absolute Error of Viewing the Linear Regression in Space From An Offset Position:

a. As I stated in Appendix II, the ideal place to view the linear regression in space is from a direct end view of the line. This means the RTT is located on the runway centerline at the RPI of the linear regression. Because we cannot do this, we incur some error by moving away from the point view. The amount of error is dependant primarily on (d_{off}) and to a lesser degree on (d_o).

b. Figure III-2 depicts the absolute accuracy of viewing a perfectly straight line from various RTT locations. The graphs were developed by sampling 20 points from a perfect linear regression at 3.00^o (coefficient of determination is 1) based on various combinations of (d_{off}) and (d_o). The value of 3.00^o is used because it will cause the largest amount of inaccuracy when varying (d_o) and (d_{off}). We can see that (d_{off}) has the major effect on the absolute percent of accuracy. Changing (d_o) affects the absolute accuracy very little because the graphs for various values of (d_o) are close together.

c. The results indicate we can expect better than 99.8% accuracy in our measurements for the majority of glide slope sites in existance, even though we have offset the RTT from the ideal viewpoint. This level of accuracy will not appreciably affect the RTT positioning procedure when the RTT is placed in its usual position along a line between the glide slope antenna base and the runway threshold centerline.

4. Assuming All Major Elevation Angles Pass Through the Same Apparent Origin:

a. Early in my derivation, I assumed that the linear regression angle, the average angle, and the eyepiece angle would not differ appreciably from each other and hence appear to pass through the same apparent origin. The position of the origin is related to the tangent of the elevation angle when the RTT is kept at a constant height above the ground. Therefore, we can get an idea of the disparity between angles that will not cause the origin to change by more than five feet. Table III-1 presents this relationship of origin distance from the RTT versus elevation angle. The RTT height for these calculations is 5.5 feet.

b. Table III-1 shows that more change in the apparent origin occurs for a change in elevation angle when the elevation angle is lower. Even at 2.50^o, a change of 0.1^o in the elevation angle will cause about 5.0 feet change in the apparent origin. This means if the eyepiece angle is 0.1^o off from the average or linear regression angles, it appears to originate only 5.0 feet from the origins of the average and linear regression angles. Our ability to measure the aircraft position in space is not accurate enough for a 5.0 feet change in the origin to cause a significant error in my procedure. Thus we can tolerate a dispersion between the eyepiece angle, the linear regression angle, and the average angle of up to 0.1^o without introducing an appreciable error in the calculations for a new RTT position.

5. Assuming a Constant RTT Eyepiece Height Above Ground. I made the assumption that when we move our RTT to the new position, it will be set up at the same height above the ground. This appears to be valid because during a given evaluation or flight inspection the same theodolite operator would be tracking the aircraft. However, the operator will probably vary the eyepiece height somewhat due to terrain or other considerations. If we keep the RTT eyepiece angle constant (2.5^o), we could vary the

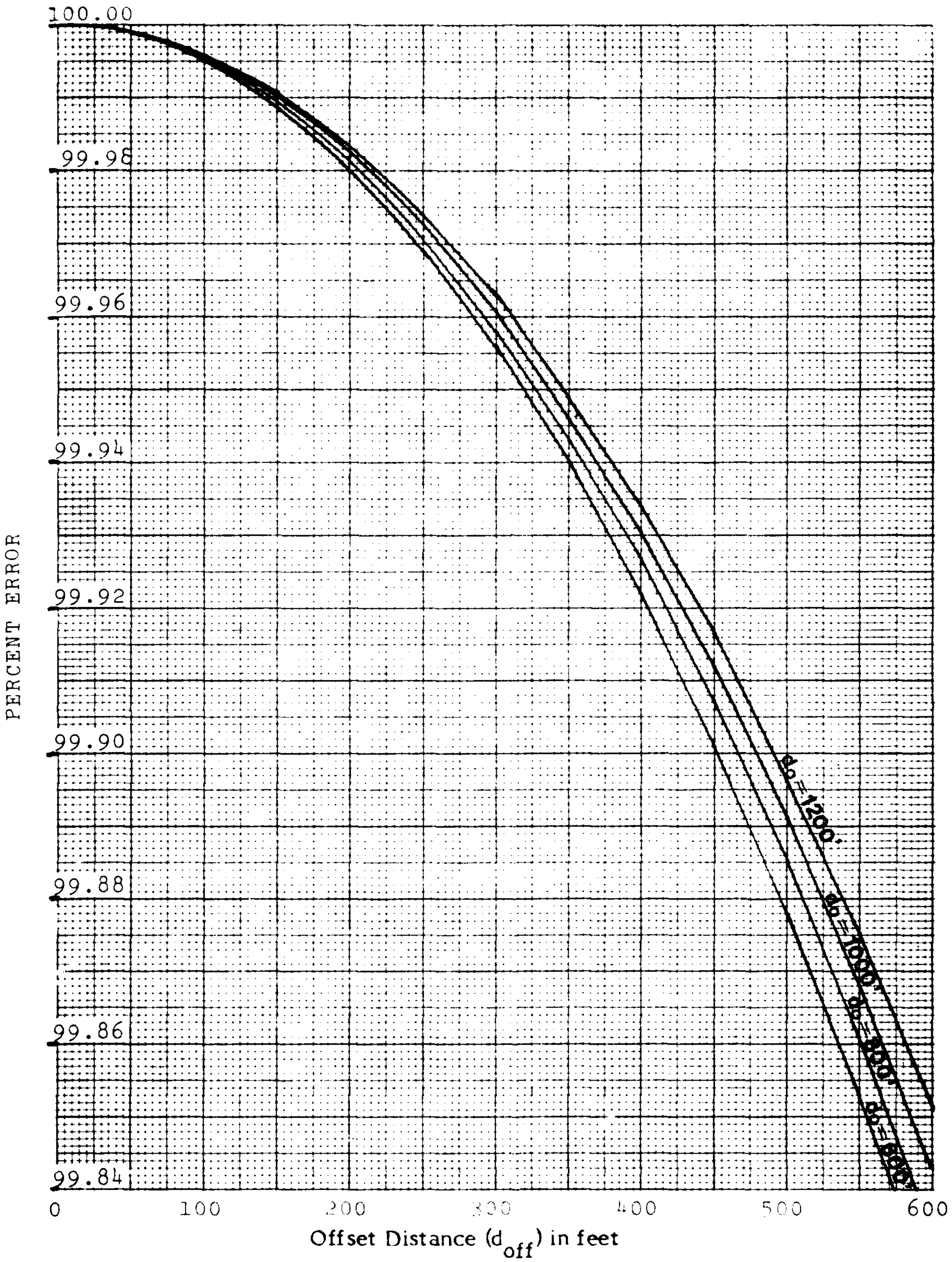


Figure III-2
Absolute Error of Viewing a Linear Regression in Space
From An Offset Position

TABLE III-1
ORIGIN DISTANCE VERSUS ELEVATION ANGLE

ELEVATION ANGLE IN DEGREES	DISTANCE FROM RTT TO ORIGIN IN FEET	CHANGE OF DISTANCE IN FEET
2.45	128.5	
2.50	126.5	2.5
2.55	123.5	2.5
2.60	121.1	2.4
2.65	118.8	2.3
2.70	116.6	2.2
2.75	114.5	2.1
2.80	112.5	2.0
2.85	110.5	2.0
2.90	108.6	1.9
2.95	106.7	1.9
3.00	104.9	1.8
3.05	103.2	1.7

TABLE III-2
DISTANCE TO ORIGIN VERSUS RTT HEIGHT FOR A CONSTANT ANGLE

EYEPIECE HEIGHT IN FEET	ORIGIN DISTANCE IN FEET	DISTANCE CHANGE IN FEET
6.0	137.4	
5.9	135.1	2.3
5.8	132.8	2.3
5.7	130.6	2.2
5.6	128.3	2.3
5.5	126.0	2.3
5.4	123.7	2.3
5.3	121.4	2.3
5.2	119.1	2.3
5.1	116.8	2.3
5.0	114.5	2.3

eyepiece height and see the change in the distance to the origin for flat terrain. The 2.5° angle will cause the largest change in the distance to the origin. The results of this analysis are summarized in Table III-2 and indicate we could tolerate an eyepiece height change of 0.2 feet (about 2.5 inches) without changing the origin distance more than 5.0 feet. A theodolite operator, while not always setting up the theodolite the same exact height every time, would most likely set his eyepiece height within 2.5 inches of his nominal comfortable value. Variances in eyepiece height from operator to operator will not affect the RTT positioning procedure because the eyepiece is actually referenced to an apparent origin through the eyepiece angle. The operator will still have to move the RTT the same amount whether his eyepiece height is 5.0 feet or 6.0 feet. The limitation to this analysis is the same operator must move and set up the RTT at the new position.

APPENDIX IV

EXAMPLES OF RTT REPOSITIONING

1. General. Opportunities to fully explore the feasability and accuracy of this procedure have rarely been available during TRACALS evaluations. As a result, I have only been able to perform the procedure at a very limited number of bases. This appendix presents examples showing how the RTT positioning procedure was used during recent TRACALS evaluations.

2. Myrtle Beach AFB, SC SSILS Evaluation. The first full use of the procedure occurred during the Myrtle Beach AFB, SC SSILS evaluation on Runway 35 from 27 January to 18 February 1982. During the course of this commissioning-evaluation, the procedure was attempted. However, because of delays due to weather and aircraft scheduling, a more thorough investigation could not be accomplished.

a. A contour study of the Runway 35 glide slope site and signal forming terrain was performed and is shown in Attachment 11. In addition, the following variables were collected for the procedure.

d_o = 1063.55 feet

d_{off} = 500.66 feet

s = -0.43^o

Θ_{eye} = 3.00^o

b. *Structure runs were conducted with the RTT at the standard initial position* (along the line between the antenna base and the runway threshold centerline such that the eyepiece backsights the antenna base at ($-\Theta_{eye}$)). Because of time constraints, the positioning calculations could not be performed before the RTT was moved. The evaluation team chief decided to move the RTT 50 feet forward to examine the effect of a different location. After moving the RTT, another series of structure runs was performed. The same pilot and RTT operator were used in both sets of runs. Afterwards, RTT positioning calculations were accomplished on all structure runs using Equations (1a), (1b), (4), and (13) from Appendix II. Graphs of the structure runs used for these calculations are shown in Attachment 12. The results of the calculations are presented in Table IV-1.

c. The Myrtle Beach AFB results support the validity of this procedure. The initial runs in Attachment 12 show the original RTT position was not far from optimum based on the slope of the linear regression. The graphs slope slightly upward from Point A to Point B indicating the RTT is too far forward. The results of the calculations agree and indicate the RTT should be moved back about 66 feet.

d. The RTT was repositioned 50 feet forward. At this position we should expect a greater slope in the linear regression line and perhaps worse structure indications on the recordings. The structure runs after the move show this to be the case. Calculations for the optimum RTT position from these runs indicate the RTT should be moved back about 110 feet. This corresponds (within 6 feet) to the indicated optimum position from the initial set of structure run calculations. Figure III-1 also indicates the calculations will have an error of about 6.6 feet for the Myrtle Beach site. Based on this information, both sets of structure runs indicate the correct position where the RTT should have been moved.

TABLE IV-1
RTT POSITIONING RESULTS AT MYRTLE BEACH AFB, SC

	POINT A VIEWING ANGLE (DEGREES)	POINT B VIEWING ANGLE (DEGREES)	LINEAR REGRESSION ANGLE (DEGREES)	AVERAGE ANGLE (DEGREES)	RTT MOVE (FEET)
INITIAL POSITION					
RUN #1	3.0160	3.0479	3.0057	3.0324	-64.6
RUN #2	3.0041	3.0377	2.9935	3.0211	-68.0
RTT MOVED +50 FEET					
RUN #1	3.0410	3.1020	3.0243	3.0717	-103.6
RUN #2	3.0426	3.1031	3.0260	3.0725	-117.2

3. Duke Field, FL SSILS Evaluation. A special glide slope evaluation was conducted on Runway 18 at Duke Field, FL (Eglin AFB Auxilliary Field 3) from 11-22 March 1982. A portion of this evaluation was dedicated to investigating the RTT positioning procedure.

a. A contour study of the glide slope site and signal forming terrain had been performed during a previous TRACALS evaluation. It is presented in Attachment 11. The following positioning variables were also collected.

d_o = 1265.0 feet

d_{off} = 500.0 feet

s = 0.17°

Θ_{eye} = 3.00°

b. A structure run was performed on each transmitter with the RTT positioned in the normal initial position. Equations (1a), (1b), (4), and (13) from Appendix II were used on-site to calculate values for the new RTT position based on both structure runs. However, an error was made during the calculations resulting in moving the RTT 40 feet forward. Structure runs were then performed on each transmitter from this new position and RTT position values were later calculated based on these runs. The same pilot and RTT operator were used throughout the measurements except for the second run from the new position, which was flown by a different pilot. Graphs of the Duke Field structure runs are shown in Attachment 12. The results of the RTT positioning analysis are presented in Table IV-2.

c. The results in Table IV-2 indicate several discrepancies. The structure in Zone 3 is vastly improved at the new position while the overall structure indications in Zone 2 remain about the same. In addition, the calculations from the two positions give different positions where to move the RTT. The most significant discrepancy is the average and linear regression angles were improved at the second position although the RTT was moved the wrong direction. The two angles are closer to each other and the linear regression shows less slope on the recording than from the initial position.

TABLE IV-2

RTT POSITIONING RESULTS AT DUKE FIELD, FL

	POINT A VIEWING ANGLE (DEGREES)	POINT B VIEWING ANGLE (DEGREES)	LINEAR REGRESSION ANGLE (DEGREES)	AVERAGE ANGLE (DEGREES)	RTT MOVE (FEET)
INITIAL POSITION					
RUN #1	2.9497	2.9981	2.9355	2.9734	-108.7
RUN #2	2.9525	2.9993	2.9388	2.9754	-105.0
RTT MOVED +40 FEET					
RUN #1	2.9663	3.0094	2.9534	2.9879	-96.7
RUN #2	2.9736	3.0078	2.9627	2.9906	-77.2

d. The apparent improvement in Zone 3 structure from the new RTT position can be easily explained because the RTT is grossly misplaced at the new position. The position is much closer to the threshold and Point B; consequently, everything in Zone 3 will appear at a higher viewing angle. The effect is to cancel the original fly-down indication caused by antenna offset and make it appear improved by following the general trend of the linear regression. This is a very good example of the effect of RTT position on the recorded structure data.

e. The individual runs from the new position indicate about 20 feet difference in the calculations for the optimum RTT position. The only significant factor differing from these two runs is a different pilot. Pilot technique should not be an important factor in the procedure, but these results indicate it may play a larger role than expected. Examining the raw data recorded during these runs revealed the differences in reference marks had a slight effect on the resultant differential trace. Normally, one pilot flies the glide slope while the other provides event marks for the recording, looking out the window and marking the 1000 foot light bar, the threshold, and the antenna as the aircraft passes. A pilot providing reference marks with the glide slope on his side of the aircraft will mark with greater accuracy than when the glide slope is on the opposite side of the aircraft, although when the same pilot is used on all runs, the event marks are consistent and no analytical errors are introduced. However, by changing pilots between runs it is possible to change the relative locations of the event marks on the recording. The middle marker trace was recorded on each run, and it can be seen there are some differences in the distance references on the recordings because of the event marks. The actual flight technique differences between pilots have a negligible effect on the recordings because the RTT compensates for the aircraft not being on the glide path. As a result, it appears the differences in RTT indications between the two RTT positions and between the two runs at the new position are probably indicating the procedure is quite sensitive to the data. This may indicate it is not always possible for the procedure to provide an exact optimum location for the RTT.

f. The one positive result from Duke Field is both positions do indicate the correct direction to move the RTT. Averaging the two values from the new position, there is about 60 feet difference in the actual location of the "optimum" RTT location between the two positions used in the test. Assuming the procedure is indeed valid, the actual optimum RTT position probably lies somewhere between these two locations. In any case, the procedure indicates the RTT was placed too far forward at both positions. This means the procedure will at least improve the position of the RTT, if not relocate it at an optimum location.

ATTACHMENT 1

TM(N)-24

TECH MEMO

TITLE: THE RADIO TELEMETERING THEODOLITE AND USE OF ITS DATA

PURPOSE: The purpose of this tech memo is to show how the Radio Telemetering Theodolite (RTT) basically works, and what data is used from the recording for glide slope structure analysis.

NARRATIVE: The flight inspection of a glide slope facility is accomplished to verify the radiated signal meets the specified tolerances in the United States Standard Flight Inspection Manual, AFM 55-8. Various checks of the signal are made. Ultimately, however, the primary feature which determines the adequacy of the radiated signal is the condition, or structure, of the on-path signal. A smooth structure may allow instrument approaches to be made closer to the runway, either by autopilot or manually. A rough structure, however, may restrict a facility to manual approaches only, or to a certain altitude or distance past which the signal is unreliable.

The best way to examine glide path structure is through the use of an RTT. The basic purpose of an RTT is to set up another "glide path," at a frequency of 329.0 MHz (a special frequency allocated specifically for flight inspections). This glide path, however, is "perfect." The eyepiece of the RTT is set at the expected glide angle of the facility being inspected. The RTT itself is normally positioned so the eyepiece angle is aligned with the glide path origin, which is considered to be the base of the antenna tower. The RTT's 90 Hz and 150 Hz signals are adjusted so they are balanced symmetrically around the eyepiece angle. The width of the RTT "glide path" is also adjusted to the expected width of the facility being inspected.

When the aircraft flies the real glide path, the RTT operator tracks the aircraft movement with the RTT eyepiece. The RTT sends the aircraft a signal to show where the aircraft should be if it were flying a perfect glide path. A differential receiver in the aircraft compares the RTT signal with the signal of the real glide path. The algebraic difference between the two shows the deviation of the actual glide path from the "perfect" glide path produced by the RTT. The major advantage of using the RTT is the aircraft does not always have to be exactly on-path. When the aircraft deviates from on-path, the RTT tells the aircraft differential receiver the aircraft is deviating, effectively cancelling the aircraft movement in the differential trace.

As an analogy, think of the RTT signal as a "string" positioned at the glide angle as depicted in Figure 1. As the aircraft slides down the string, it records the difference between the "string" and the actual glide path. The "string" (the centerline of the differential trace) provides the reference from which we can analyze the structure of the actual glide path.

The flight inspection of glide slope facilities includes measurement of structure in Zones 1, 2, and 3, as shown in Figure 2. In Zone 1, the aircraft's distance from the site makes it difficult to accurately track the aircraft with the RTT eyepiece. The differential trace in Zone 1 usually has little or no structure indications which can be representative of the true glide path. Use of Zone 3 is undesirable because the information there is subject to tracking errors by the RTT operator from too much aircraft movement. The data collected in Zone 2 is used for most glide slope analysis because it is far enough out to minimize tracking errors but close enough in to depict any

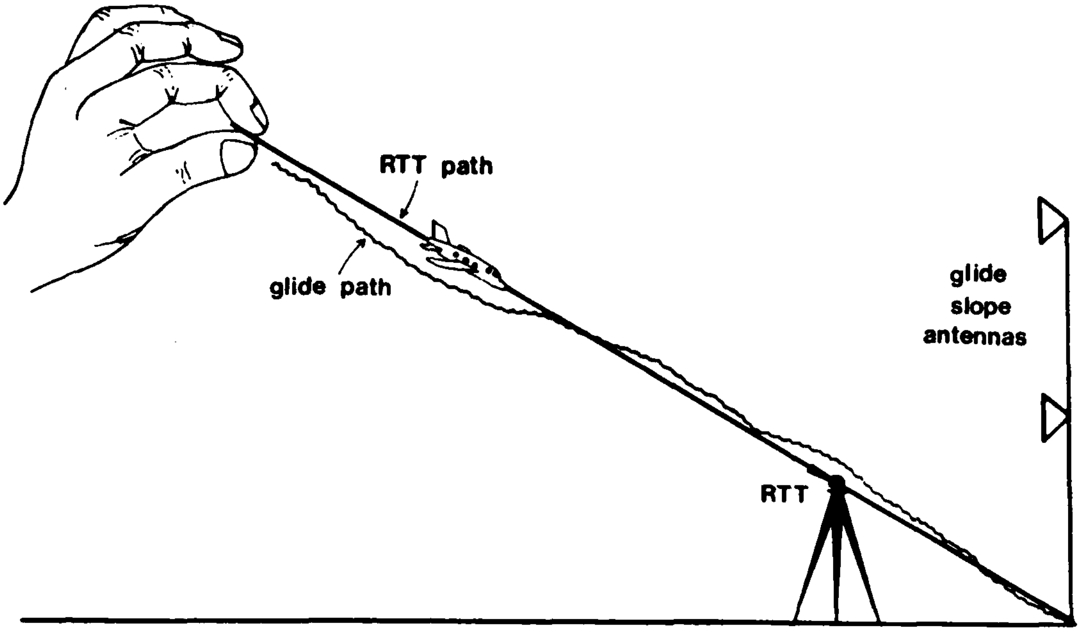


Figure 1
RTT Analogy

glide path anomalies. Zone 2 is also the critical sector of the aircraft descent, where transition from instrument to visual approach is usually accomplished or missed approach procedures are implemented.

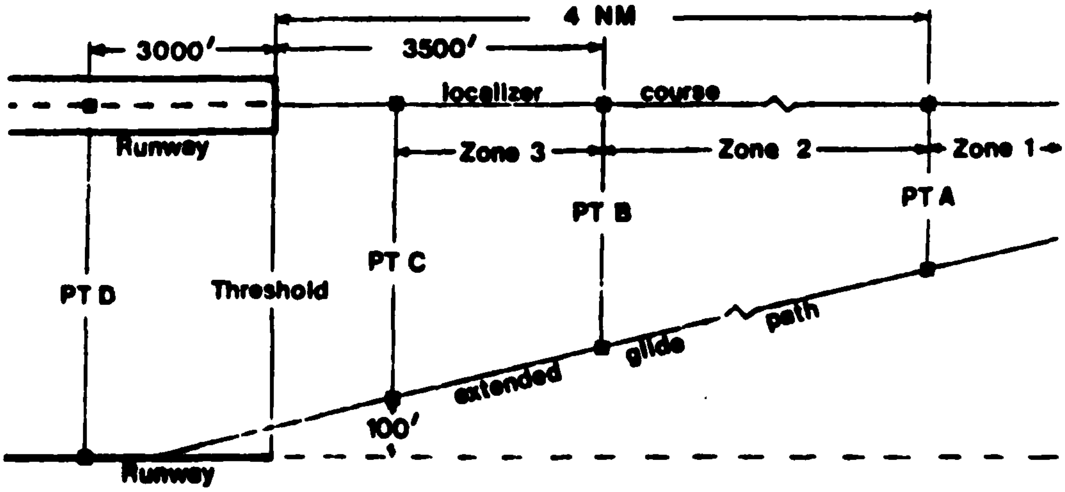


Figure 2
ILS Reference Points and Zones

ATTACHMENT 1

Use of an RTT for glide slope structure runs provides a constant stream of recorded information from which we can sample data. A sample aircraft structure recording is shown in Figure 3. The structure data shown by the differential trace is sampled at regular intervals in Zone 2. If distance marks are available on the recording, they can be converted to nautical miles from the glide slope facility. If distance marks are unavailable, the timing lines can be used with the aircraft speed to find distances. Procedures for establishing distance scales on glide slope structure recordings are presented in TM(N)-20. Where the differential trace is sampled, the difference between the recording centerline (eyepiece angle) and the trace is measured to determine the structure of the facility.

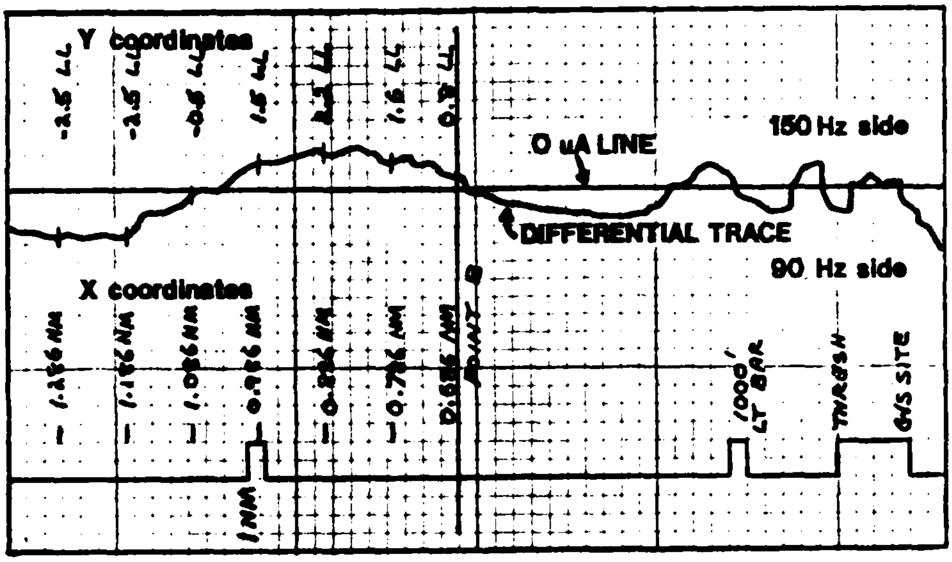


Figure 3
Sample Aircraft Structure Recording

Submitted By: 1866 FCS/TE, 1Lt Leister
30 May 1981

ATTACHMENT 2

TM(N)-21

TECH MEMO

TITLE: DETERMINING TCH USING THE HEIGHTS OF POINTS A AND B

PURPOSE: The purpose of this tech memo is to demonstrate how to arrive at a value for TCH using the heights of a model or actual glide path data at Points A and B.

NARRATIVE: TCH is defined in AFM 55-8 as the straight line extension of the glide path projected above the runway threshold. If we establish the straight line portion of the glide path, either for actual data or through the use of a model, then simple trigonometric relationships can be used to find a value for TCH. Two convenient points to use in establishing the straight line glide path are Points A and B. These points and the other ILS reference points and zones are shown in Figure 1.

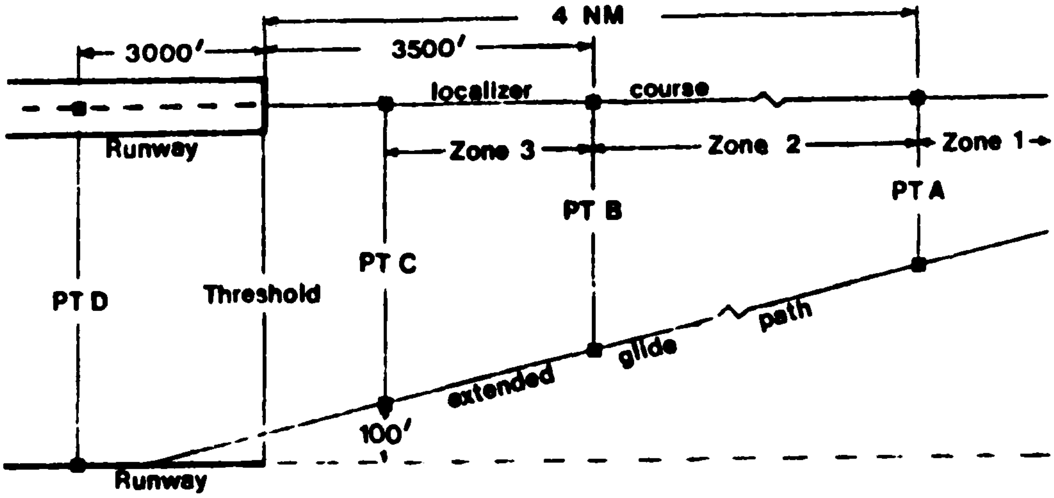


Figure 1
ILS Reference Points and Zones

There is little disagreement that Point A is located in the linear portion of the glide path. Point B, however, is located in the area where the glide path is beginning to flare. How much error in the height of Point B is produced by glide path flare? This can be demonstrated by calculating the height at Point B, first using the distance from the point on the runway centerline abeam the glide slope site, and then the diagonal distance from the glide slope site, which takes into account the offset distance of the glide slope facility from the runway centerline. For a 3.0° glide angle, an offset distance of 500 feet, and a distance to threshold of 1200 feet, the error in the height of Point B caused by glide path flare is about 1.4 feet, or less than 1 %. Therefore, we can assume the height of Point B is in the linear portion of the glide path and can be used to calculate a value for TCH.

ATTACHMENT 2

The heights at Points A and B are found in two ways. The first and simplest method is through the use of the GSSTAT Program, which automatically calculates the heights of various glide path models at Points A and B. The second method is to use the structure recording, determine the location of Points A and B on the recording, and measure the light line values of the differential trace (See TM(N)-20 for this procedure). However, the RTT must be verified to be optimally placed before structure recording data can be used. The heights at Points A and B (or any point along the glide path) can be found by the following equation:

$$H_i = D_i \tan(\theta + (LL_i)(W/40))$$

Where D_i = Horizontal distance of the point from the glide slope in feet.
θ = Center eyepiece angle of the RTT in degrees.
LL_i = Light line value of the differential trace at the point being evaluated.
W = Path width set into the RTT in degrees.

The heights of Points A and B in the GSSTAT Program are also computed in this manner. Remember, these heights are referenced from the elevation of the antenna tower base because the RTT eyepiece is backsighted to this point.

Once we have the heights at Points A and B, we can use the diagram in Figure 2 and some simple trigonometric relationships to derive an equation for calculating TCH.

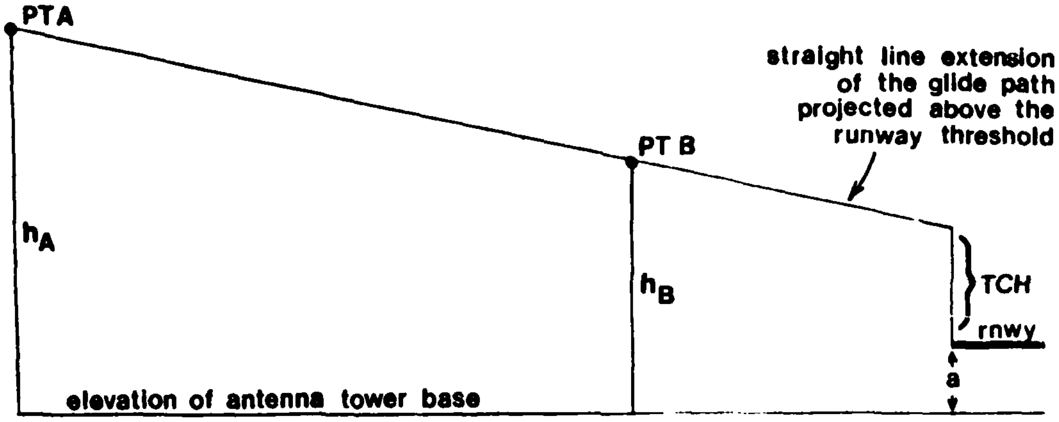


Figure 2
Determination of TCH with Heights of Points A and B

The equation for finding TCH from the heights of Points A and B is derived below:

$$\frac{h_A - (TCH + a)}{24304} = \frac{h_B - (TCH + a)}{3500}$$

ATTACHMENT 2

$$3500h_A - 3500(TCH + a) = 24304h_B - 24304(TCH + a)$$

$$20804(TCH + a) = 24304h_B - 3500h_A$$

$$\boxed{TCH = \frac{24304h_B - 3500h_A}{20804} - a}$$

Where h_A = Height at Point A in feet
h_B = Height at Point B in feet
a = Threshold elevation - antenna pad elevation in feet

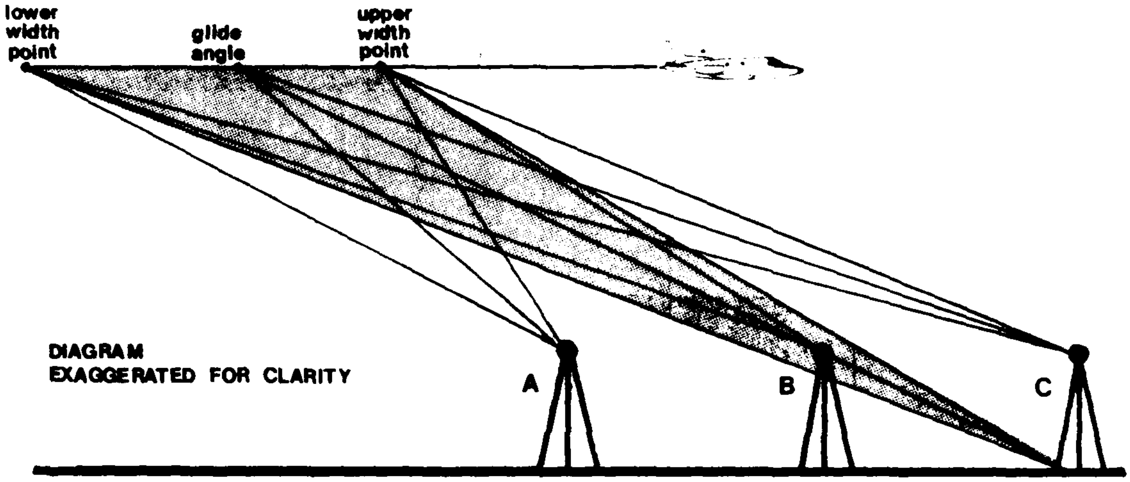
Because the heights are referenced from the elevation of the antenna tower base, the elevation difference between the glide slope site and the threshold must be accounted for. (Hence, the constant "a" in the above equation).

Submitted by: 1866 FCS/TE, Lt Leister
15 May 1980

TITLE:

EFFECT OF THEODOLITE PLACEMENT ON WIDTH AND ANGLE RUNS

The placement of the theodolite has a slight effect on the data collected during a width and angle run. For example, assume the aircraft makes a level run at 1000 feet AGL. With a constant radiation pattern, the width and angle points will always be in the same place, as shown in the diagram below. Now let's choose three theodolite locations A, B, and C. A is positioned 100 feet in front of the extended glide path, B is positioned on the extended glide path, and C is positioned 100 feet behind the extended glide path. The theodolites are 5.24 feet high. Using geometry, we can calculate the effects of the different viewpoints (theodolite locations) on the angles of the width and angle points. Assume the glide angle is 3.00°. The results are shown in the table below.



	ACTUAL GLIDE PATH	VIEWED FROM LOCATION A	VIEWED FROM LOCATION B	VIEWED FROM LOCATION C
LOWER WIDTH POINT	2.650°	2.661°	2.649°	2.637°
UPPER WIDTH POINT	3.350°	3.373°	3.353°	3.333°
GLIDE PATH ANGLE	3.000°	3.017°	3.001°	2.985°
PATH WIDTH	0.700°	0.712°	0.704°	0.696°
SYMMETRY	50%/50%	50%/50%	50%/50%	50%/50%

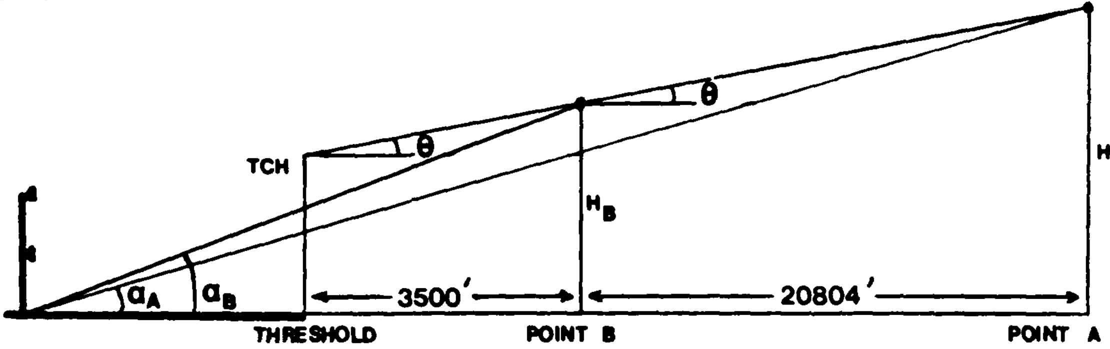
The results indicate that a theodolite position in front of (or below) the extended glide path will have a tendency to increase the angle and width. Conversely, a theodolite position behind (or above) the extended glide path will have a tendency to decrease the angle and width. The symmetry remains unaffected by the theodolite position. Terrain effects can also play a role in affecting the observed angle and width. The magnitude of these changes, however, even with the amount of theodolite misplacement shown here, is hardly measurable on the flight inspection recordings and not reportable on flight inspection reports.

ATTACHMENT 4

TITLE:

FLIGHT RECORDING ANALYSIS WITH LINEAR REGRESSION

Linear regression on glide slope structure recordings can be accomplished with most any combination of coordinate units. X coordinates can be in feet, nautical miles, or in seconds. Y coordinates can be in uA, feet, light-lines, or degrees. The most common and easiest to use is seconds and light-lines because these are readily available on the recording. When seconds are used, the starting point is not critical as long as the linear regression is drawn based on the same starting point. For uniformity, Point B can be used as the starting point. Then the seconds can be incremented toward Point A. With equal units the glide angle is readily found as the arctangent of the slope of the linear regression. With unequal units, however, the glide angle cannot be determined from the linear regression. This problem can be overcome using the following diagram and procedure.



1. Determine the value of the linear regression in light lines at Point A and Point B. Convert these light line values to degrees (α_A and α_B, respectively).

2. The height of the glide path at Points A and B can be calculated from the equation below.

$$H = D \tan\alpha$$

where H = height of glide path at each point
D = distance from the glide slope site to each point
α = degree value of the linear regression at each point

3. The glide angle for the facility is found from the following equation.

$$\theta = \arctan\left(\frac{H_A - H_B}{20804}\right)$$

The distance from the glide slope can be used because we originally set the RTT to backsight the antenna base at minus the commissioned or desired glide angle. We can therefore treat our viewpoint of the linear regression as the antenna base without incurring appreciable error. The antenna base location is easily found in the facility data sheets. If we convert H_A and H_B using step (2), and in terms of the facility offset distance (d_{off}) and distance to threshold (d_o), we get the following equation for the glide angle.

$$\theta = \tan^{-1}\left\{\frac{\sqrt{d_{off}^{\,2}+\left[d_o+24304\right]^2}\left[\tan\alpha_A\right]-\sqrt{d_{off}^{\,2}+\left[d_o+3500\right]^2}\left[\tan\alpha_B\right]}{20804}\right\}$$

ATTACHMENT 5

TITLE:

RTT POSITIONING ANALYSIS SUMMARY

LOCATION

Wright-Patterson AFB

DATE

July 1978

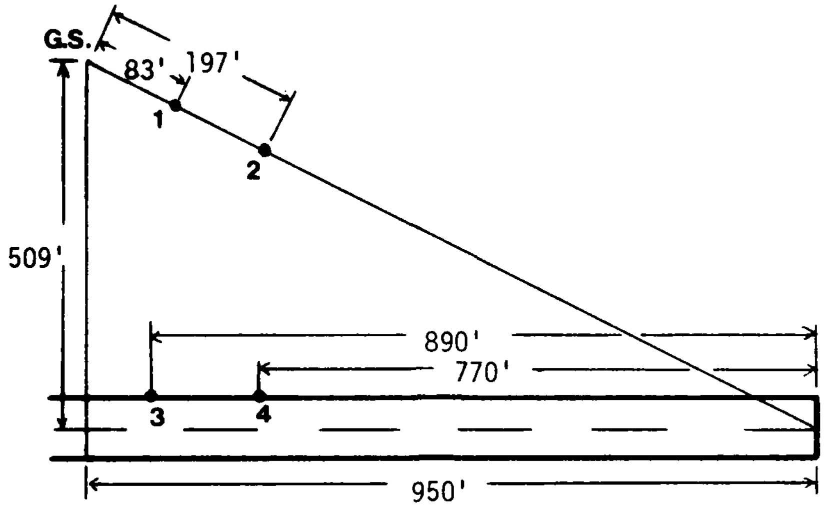


Diagram of RTT placement on runway 05
Diagram is not drawn to scale.

	POSITION 1	POSITION 2	POSITION 3	POSITION 4
AVERAGE ANGLE	3.06°	3.07°	3.02°	3.06°
STRUCTURE ZONE 1	8uA/5.8NM	7uA/4.9NM	9uA/5.3NM	8uA/5.9NM
STRUCTURE ZONE 2	19uA/2.1NM	15uA/2.1NM	15uA/2.5NM	17uA/2.9NM
STRUCTURE ZONE 3	23uA/0.6NM	15uA/0.9NM	12uA/0.8NM	12uA/0.8NM
TRUE GLIDE ANGLE	3.04°	3.05°	3.02°	3.03°

AVERAGE OF AVERAGE ANGLES:	3.05°
STANDARD DEVIATION:	0.022
AVERAGE OF TRUE GLIDE ANGLES:	3.04°
STANDARD DEVIATION:	0.019

The true glide angle values are more closely grouped than those for the average angle, based on the standard deviations. The values for true glide angle are a better indication of the actual glide angle.

REMARKS

ATTACHMENT 5

TITLE:

RTT POSITIONING ANALYSIS SUMMARY

LOCATION: Wright-Patterson AFB

DATE: April 1979

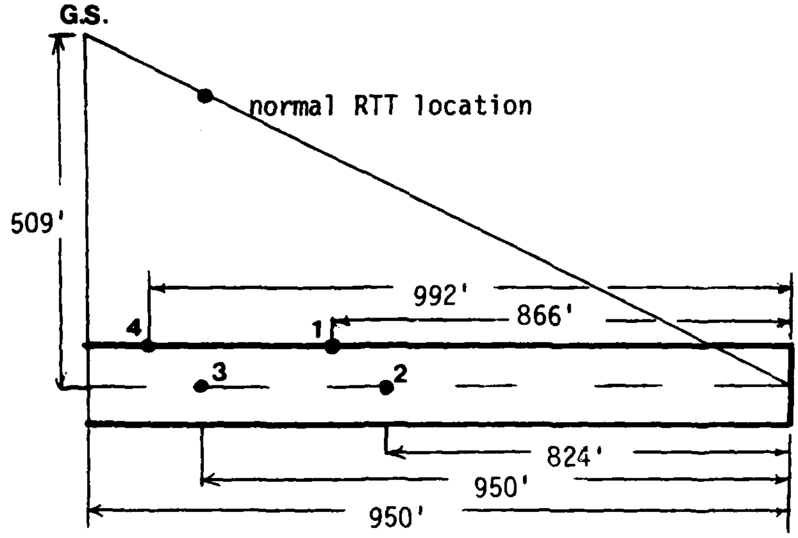


Diagram of RTT placement on runway 05
Diagram is not drawn to scale.

	THEO PAD	POSITION 1	POSITION 2	POSITION 3	POSITION 4
AVERAGE ANGLE	3.04°	3.09°	3.08°	3.05°	3.07°
STRUCTURE ZONE 1	4uA/7.0NM	3uA/5.1NM	4uA/5.0NM	1uA/4.1NM	8uA/4.1NM
STRUCTURE ZONE 2	11uA/4.1NM	19uA/0.7NM	11uA/2.6NM	12uA/1.8NM	18uA/0.6NM
STRUCTURE ZONE 3	12uA/0.3NM	10uA/0.2NM	10uA/0.3NM	9uA/0.3NM	19uA/0.3NM
TRUE GLIDE ANGLE	3.07°	3.09°	3.09°	3.10°	3.11°

AVERAGE OF AVERAGE ANGLES: 3.07°
STANDARD DEVIATION: 0.021

AVERAGE OF TRUE GLIDE ANGLES: 3.09°
STANDARD DEVIATION: 0.015

The true glide angle values are more closely grouped than those for the average angle, based on the standard deviations. The values for the true glide angle are a better indication of the actual glide angle.

REMARKS

ATTACHMENT 6

TITLE

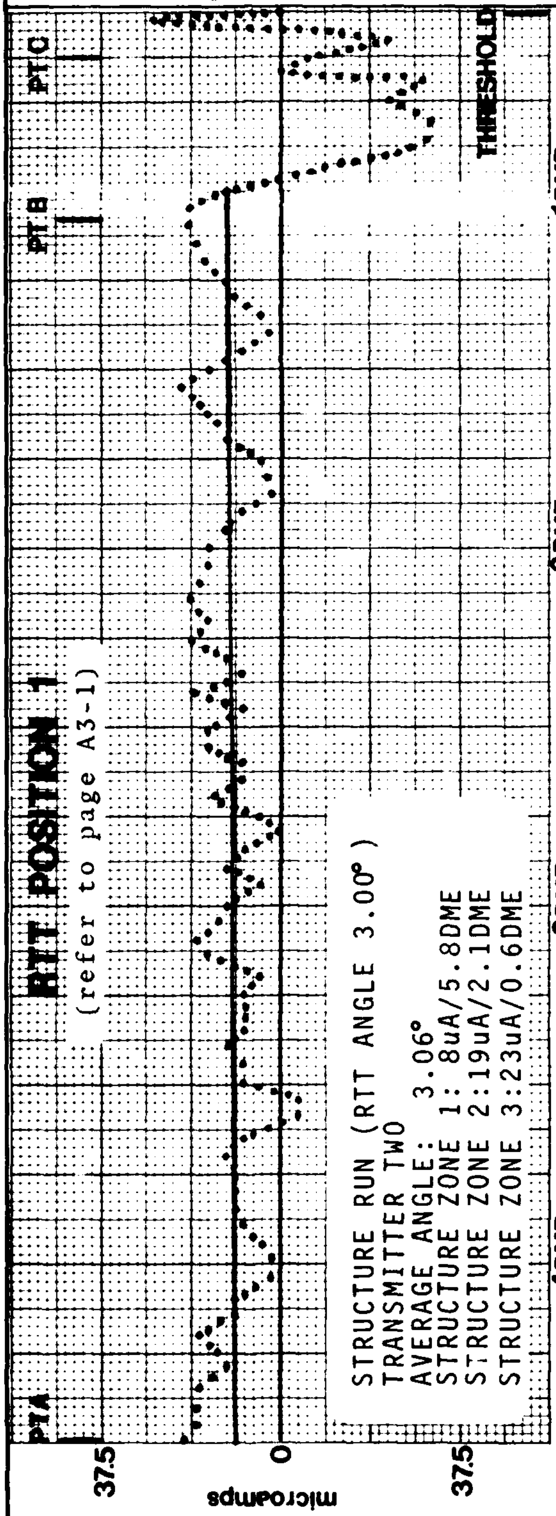
RTT POSITIONING STRUCTURE RUNS

LOCATION

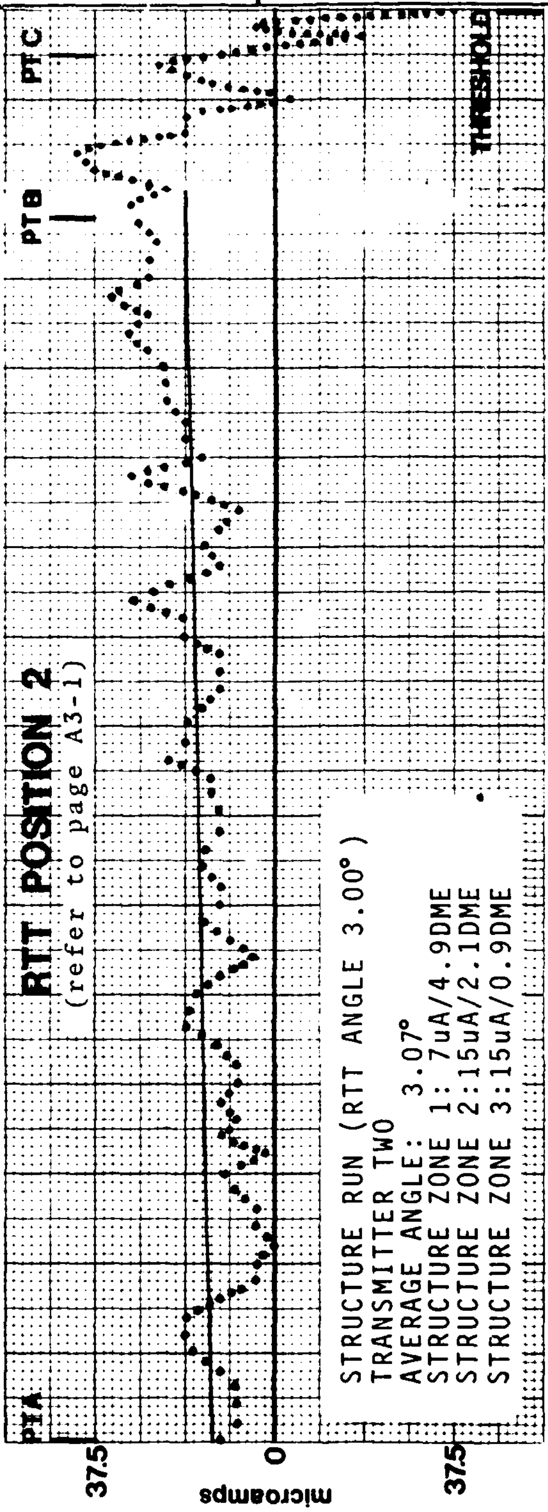
Wright-Patterson AFB

DATE

18 July 1978


RTT POSITION 1
(refer to page A3-1)

STRUCTURE RUN (RTT ANGLE 3.00°)
TRANSMITTER TWO
AVERAGE ANGLE: 3.06°
STRUCTURE ZONE 1: 8uA/5.8DME
STRUCTURE ZONE 2:19uA/2.1DME
STRUCTURE ZONE 3:23uA/0.6DME


RTT POSITION 2
(refer to page A3-1)

STRUCTURE RUN (RTT ANGLE 3.00°)
TRANSMITTER TWO
AVERAGE ANGLE: 3.07°
STRUCTURE ZONE 1: 7uA/4.9DME
STRUCTURE ZONE 2:15uA/2.1DME
STRUCTURE ZONE 3:15uA/0.9DME

REMARKS

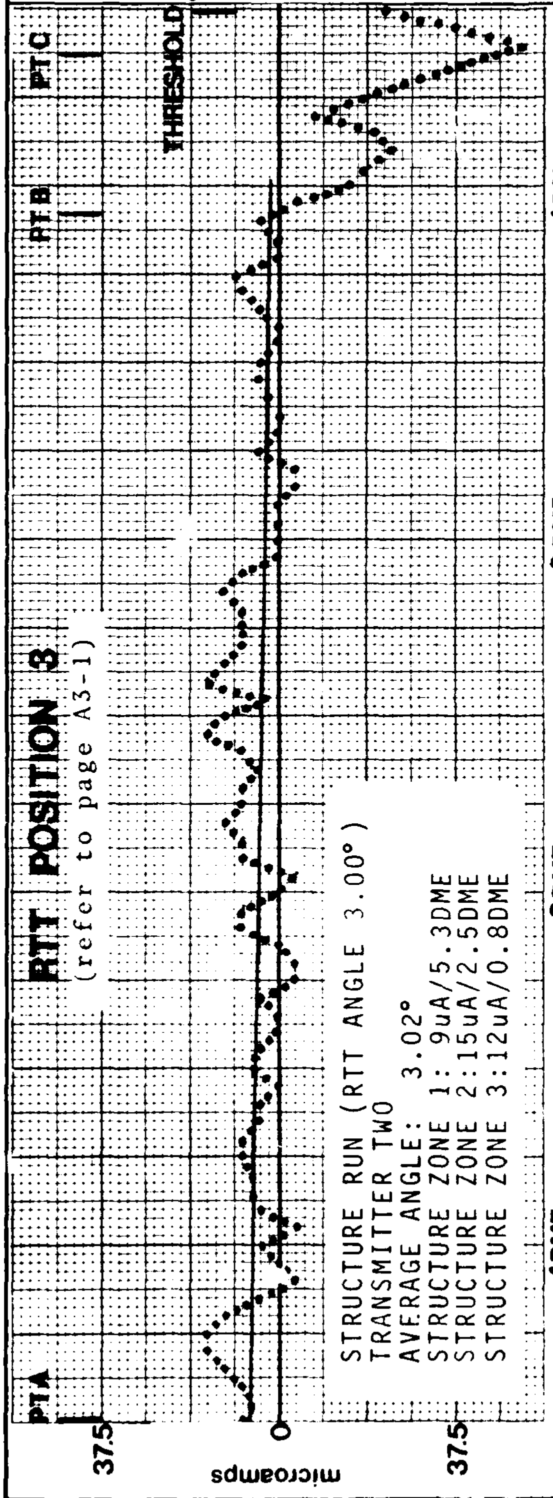
••••••• Aircraft recording(Differential trace)
——— Straight line approximation, method of least squares

ATTACHMENT 6

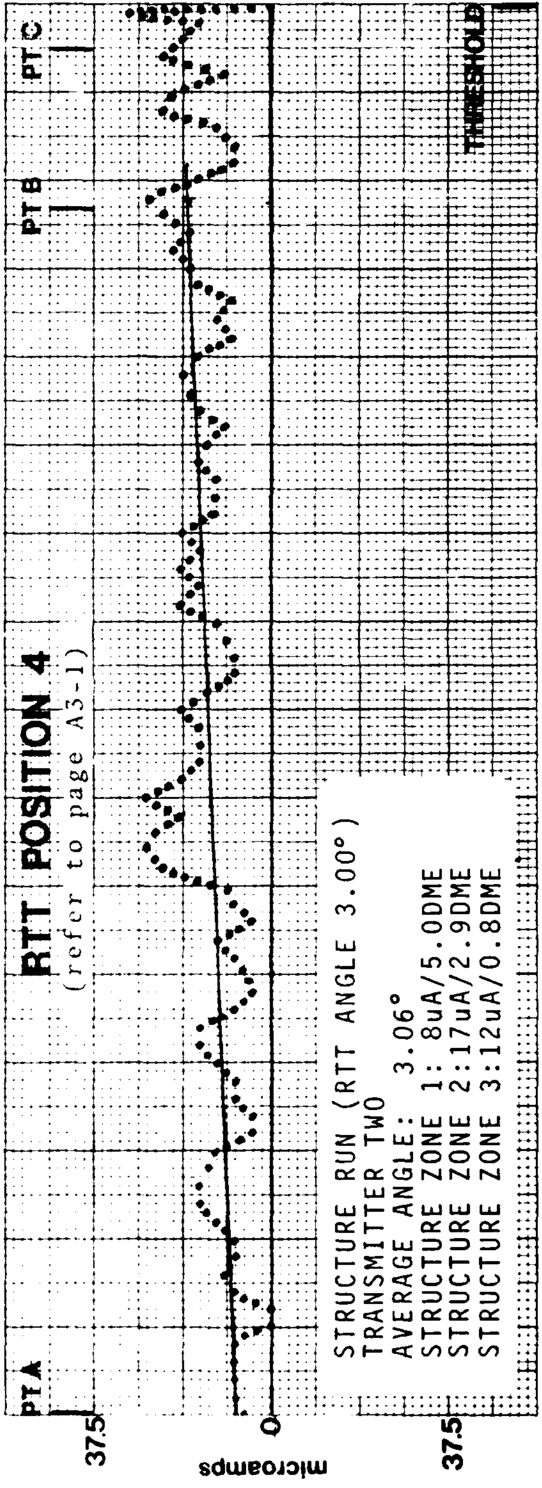
TITLE

RTT POSITIONING STRUCTURE RUNS

LOCATION	DATE
Wright-Patterson AFB	19 July 1978


RTT POSITION 3
(refer to page A3-1)

STRUCTURE RUN (RTT ANGLE 3.00°)
TRANSMITTER TWO
AVERAGE ANGLE: 3.02°
STRUCTURE ZONE 1: 9uA/5.3DME
STRUCTURE ZONE 2:15uA/2.5DME
STRUCTURE ZONE 3:12uA/0.8DME


RTT POSITION 4
(refer to page A3-1)

STRUCTURE RUN (RTT ANGLE 3.00°)
TRANSMITTER TWO
AVERAGE ANGLE: 3.06°
STRUCTURE ZONE 1: 8uA/5.0DME
STRUCTURE ZONE 2:17uA/2.9DME
STRUCTURE ZONE 3:12uA/0.8DME

REMARKS

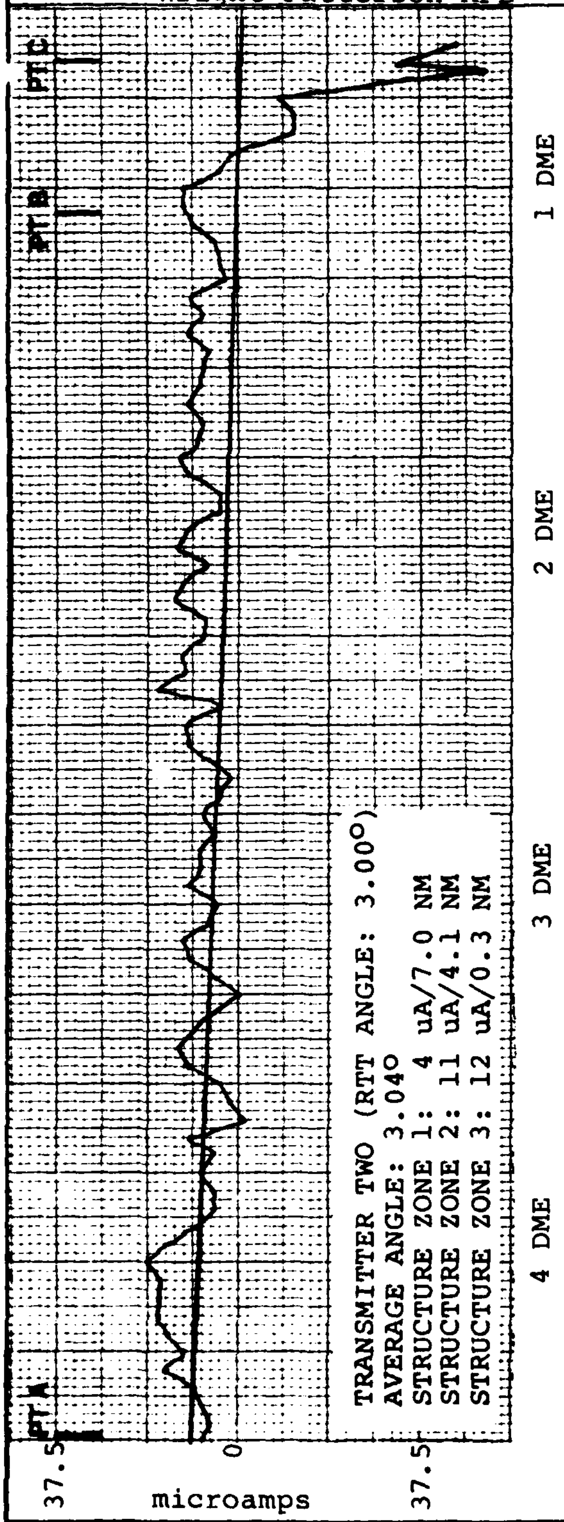
•••••• Aircraft recording (Differential trace)
—— Straight line approximation, method of least squares

ATTACHMENT 6

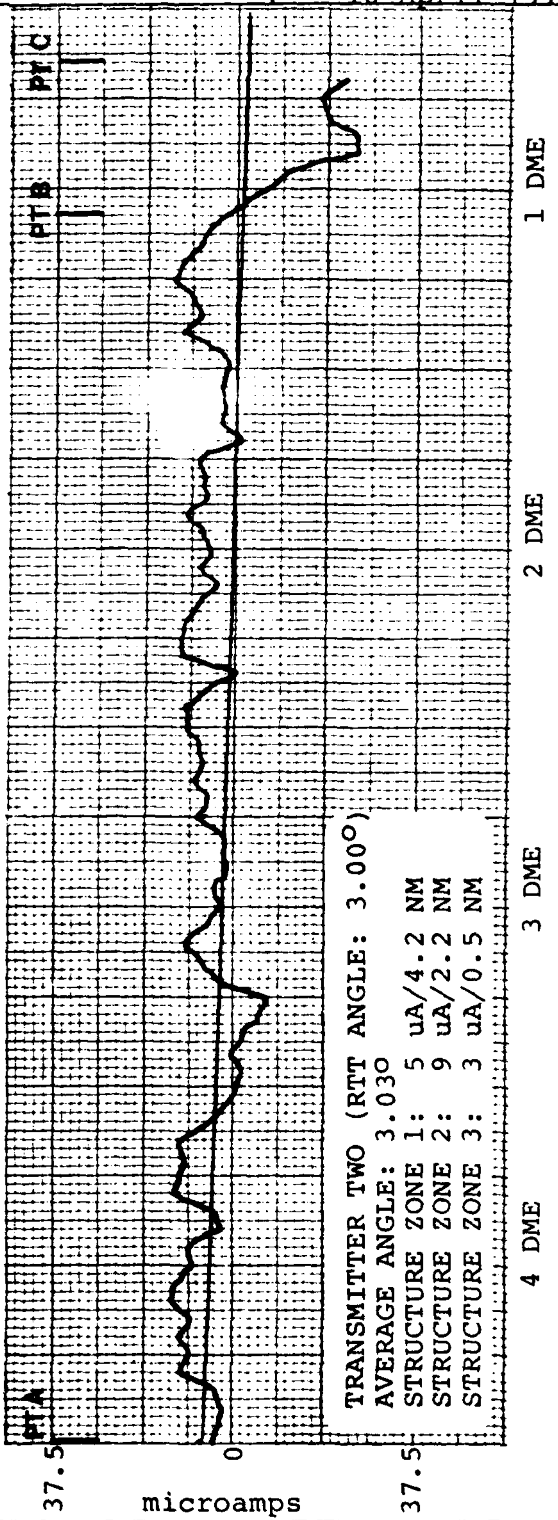
TITLE

RTT POSITIONING STRUCTURE RUNS

LOCATION	DATE
Wright-Patterson AFB	18 April 1979



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.04°
STRUCTURE ZONE 1: 4 uA/7.0 NM
STRUCTURE ZONE 2: 11 uA/4.1 NM
STRUCTURE ZONE 3: 12 uA/0.3 NM



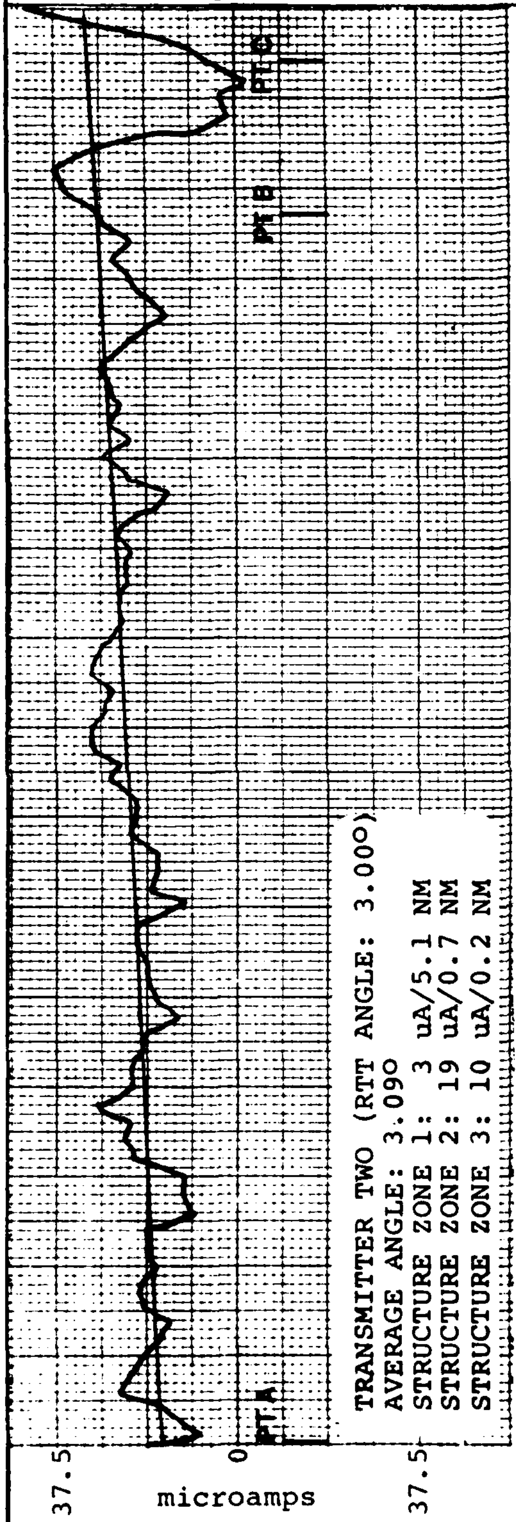
TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.03°
STRUCTURE ZONE 1: 5 uA/4.2 NM
STRUCTURE ZONE 2: 9 uA/2.2 NM
STRUCTURE ZONE 3: 3 uA/0.5 NM

REMARKS theodolite positioned at theo pad (refer to page A5-2)

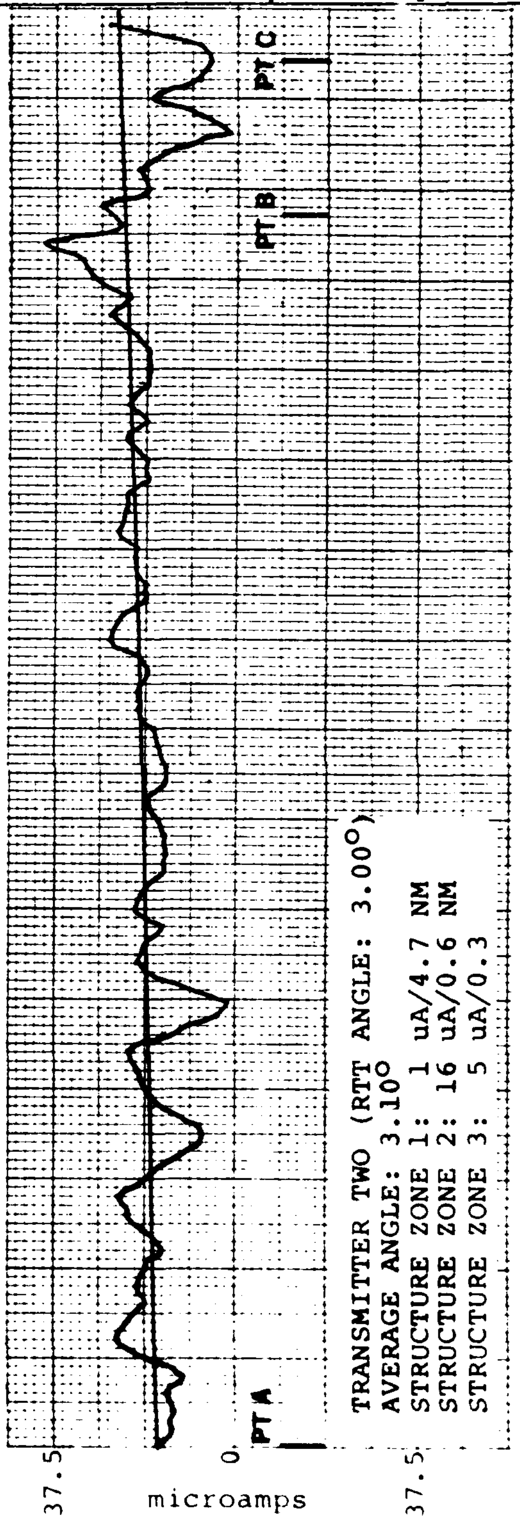
AFCS FORM MAY 73 926

ATTACHMENT 6

TITLE RTT POSITIONING STRUCTURE RUNS	
LOCATION Wright-Patterson AFB	DATE 18 April 1979



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.09°
STRUCTURE ZONE 1: 3 uA/5.1 NM
STRUCTURE ZONE 2: 19 uA/0.7 NM
STRUCTURE ZONE 3: 10 uA/0.2 NM



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.10°
STRUCTURE ZONE 1: 1 uA/4.7 NM
STRUCTURE ZONE 2: 16 uA/0.6 NM
STRUCTURE ZONE 3: 5 uA/0.3

REMARKS theodolite backsighted to Position I (refer to page A5-2)

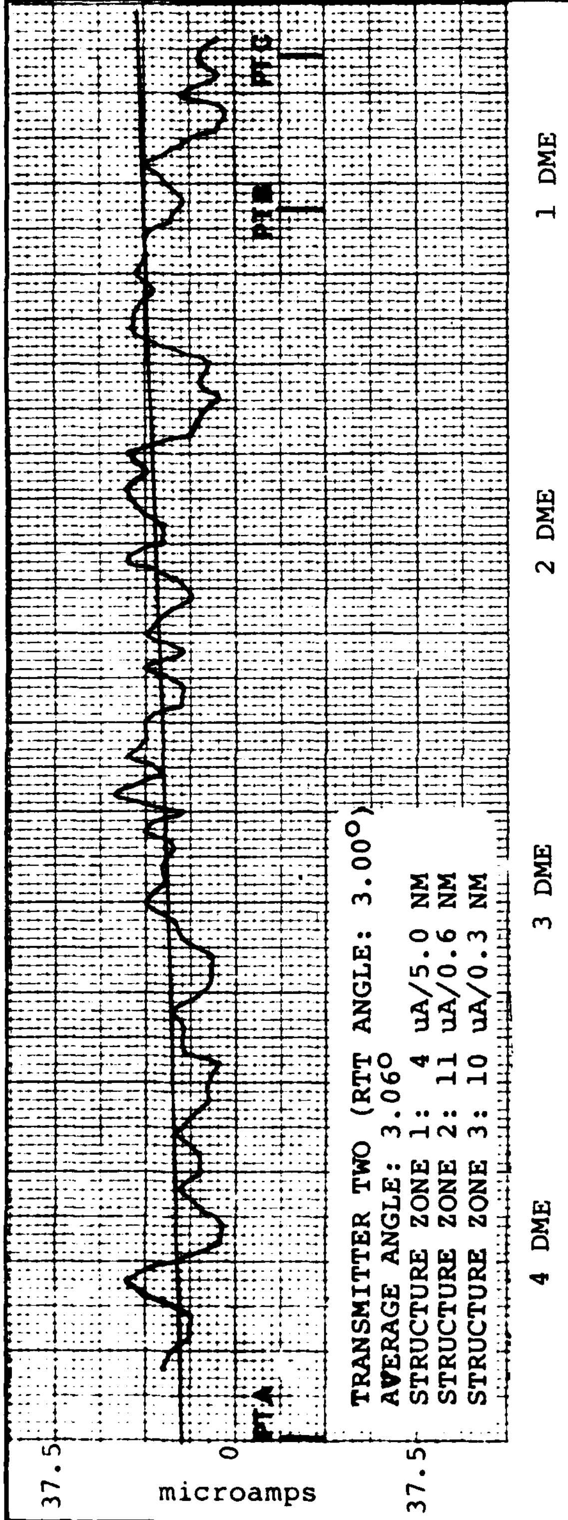
AFCS FORM MAY [illegible] 526

ATTACHMENT 6

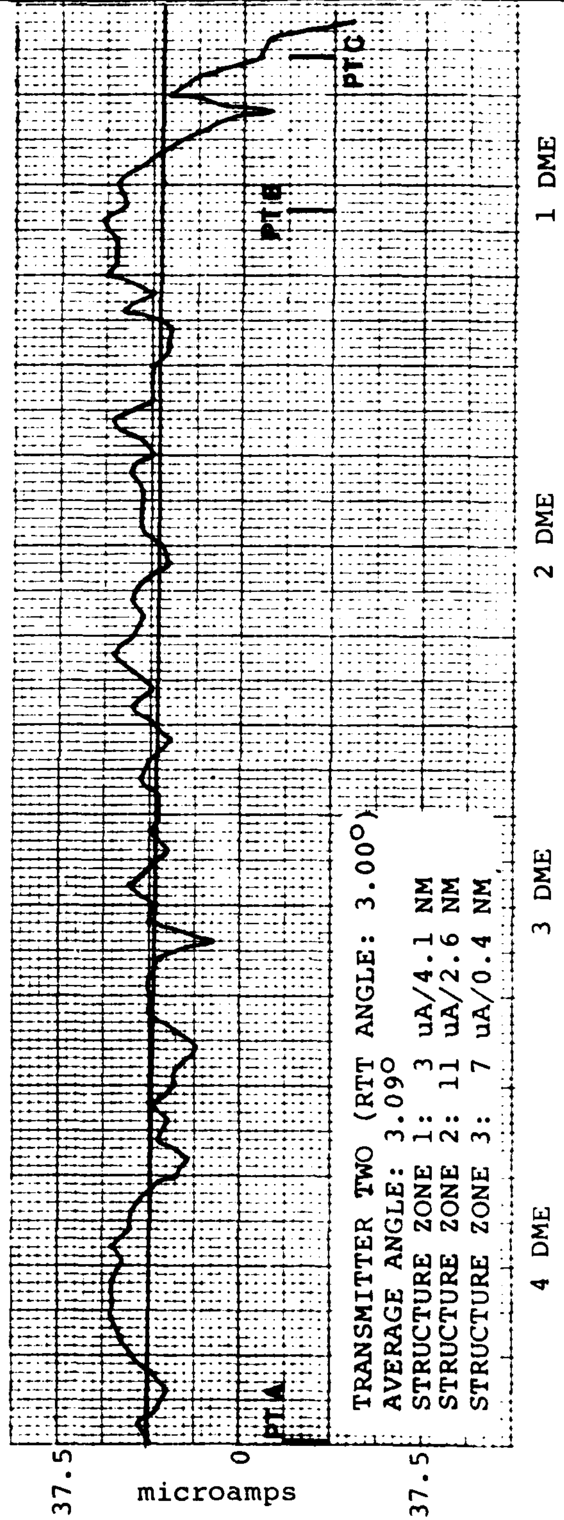
TITLE

RTT POSITIONING STRUCTURE RUNS

LOCATION	DATE
Wright-Patterson AFB	18 April 1979



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.06°
STRUCTURE ZONE 1: 4 uA/5.0 NM
STRUCTURE ZONE 2: 11 uA/0.6 NM
STRUCTURE ZONE 3: 10 uA/0.3 NM



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.09°
STRUCTURE ZONE 1: 3 uA/4.1 NM
STRUCTURE ZONE 2: 11 uA/2.6 NM
STRUCTURE ZONE 3: 7 uA/0.4 NM

REMARKS

theodolite backsighted to Position II (refer to page A6-2)

ATTACHMENT 6

TITLE

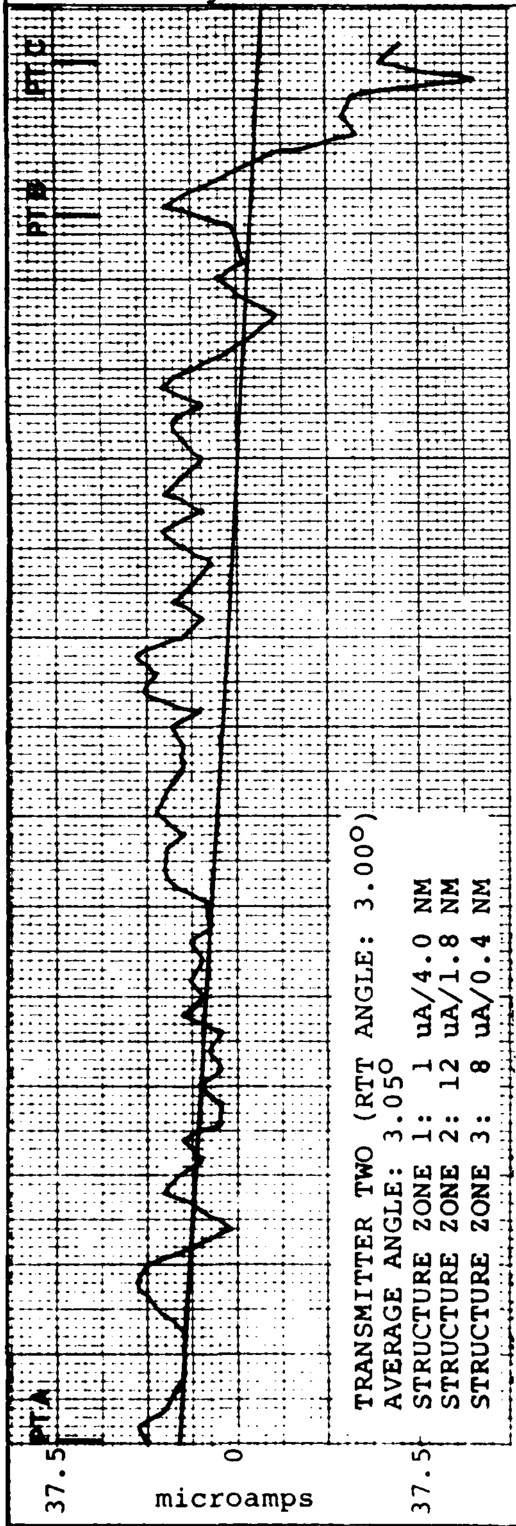
RTT POSITIONING STRUCTURE RUNS

LOCATION

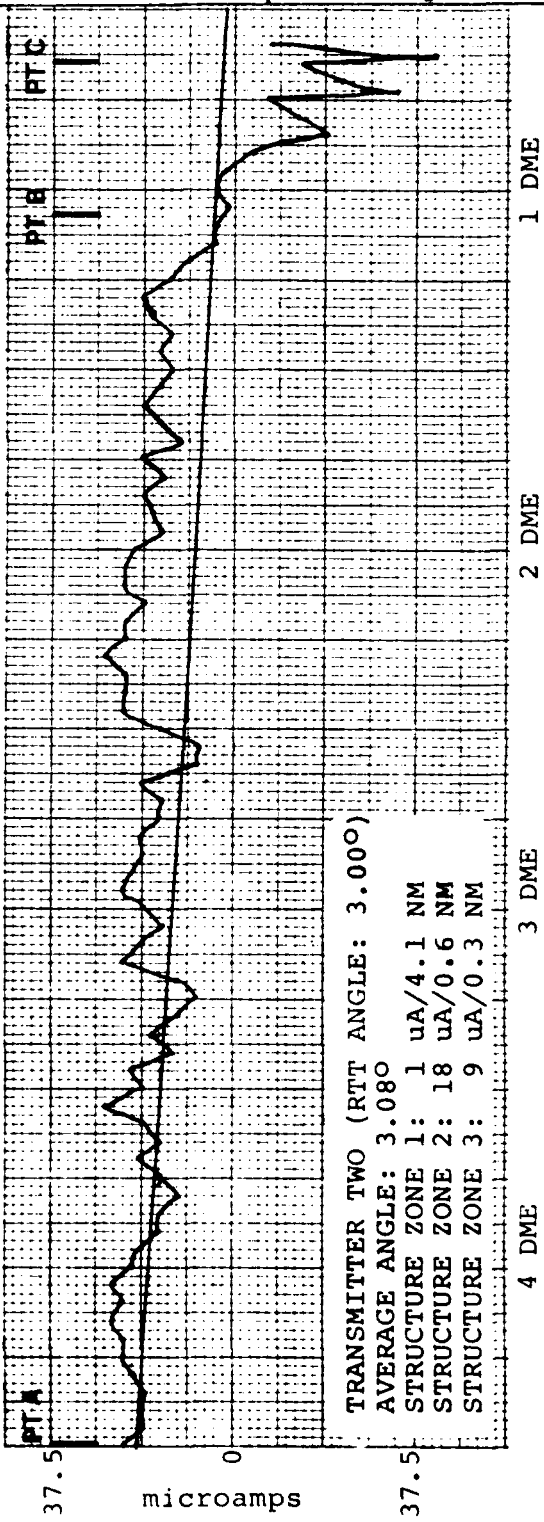
Wright-Patterson AFB

DATE

18 April 1979



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.05°
STRUCTURE ZONE 1: 1 uA/4.0 NM
STRUCTURE ZONE 2: 12 uA/1.8 NM
STRUCTURE ZONE 3: 8 uA/0.4 NM



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.08°
STRUCTURE ZONE 1: 1 uA/4.1 NM
STRUCTURE ZONE 2: 18 uA/0.6 NM
STRUCTURE ZONE 3: 9 uA/0.3 NM

REMARKS

theodolite backsighted to Position III (refer to page A6-2)

ATTACHMENT 6

TITLE

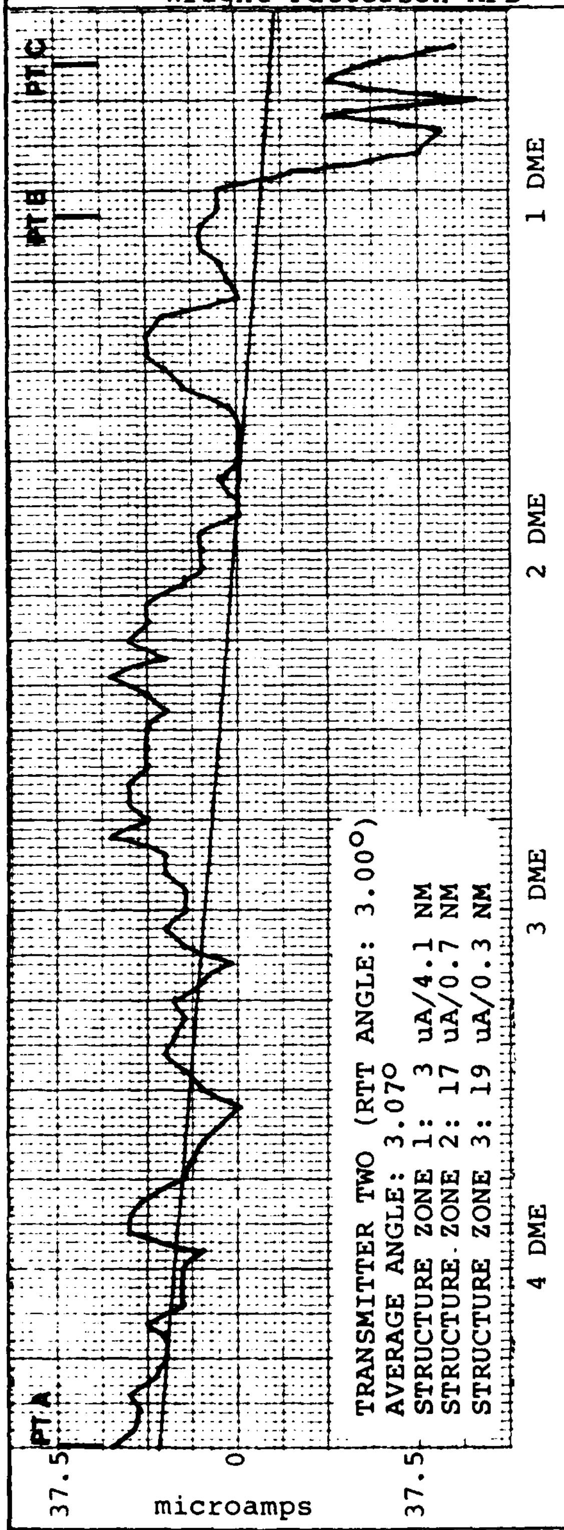
RTT POSITIONING STRUCTURE RUNS

LOCATION

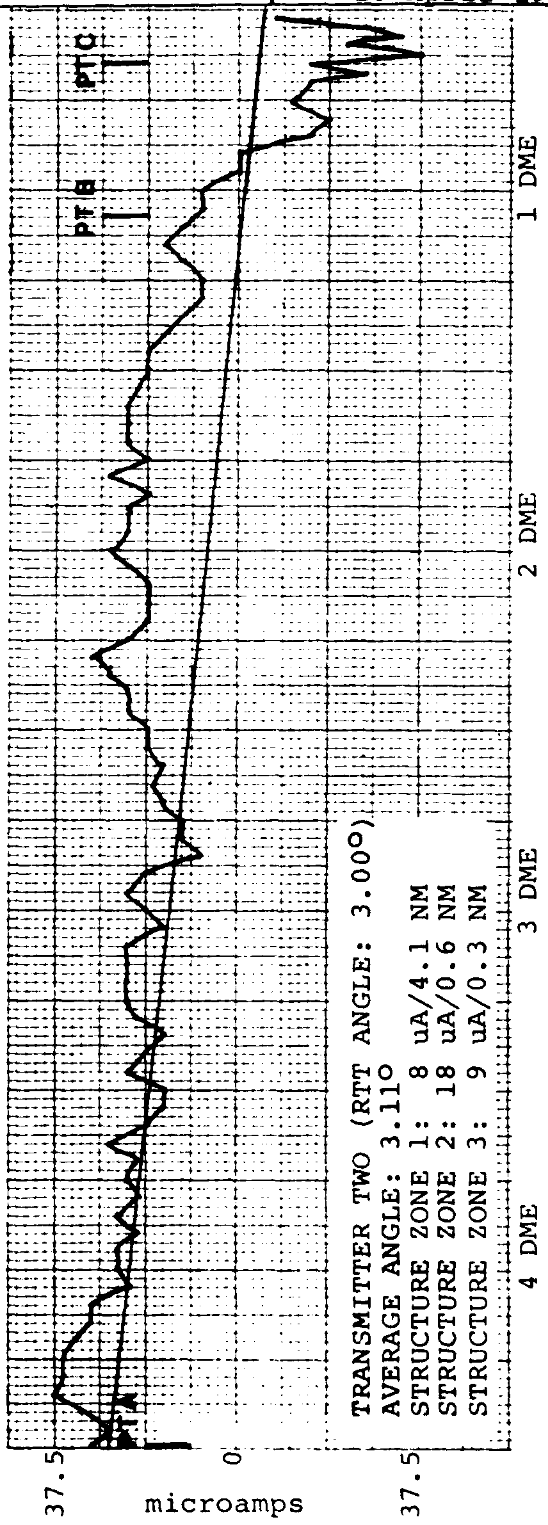
Wright-Patterson AFB

DATE

18 April 1979



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.07°
STRUCTURE ZONE 1: 3 uA/4.1 NM
STRUCTURE ZONE 2: 17 uA/0.7 NM
STRUCTURE ZONE 3: 19 uA/0.3 NM



TRANSMITTER TWO (RTT ANGLE: 3.00°)
AVERAGE ANGLE: 3.11°
STRUCTURE ZONE 1: 8 uA/4.1 NM
STRUCTURE ZONE 2: 18 uA/0.6 NM
STRUCTURE ZONE 3: 9 uA/0.3 NM

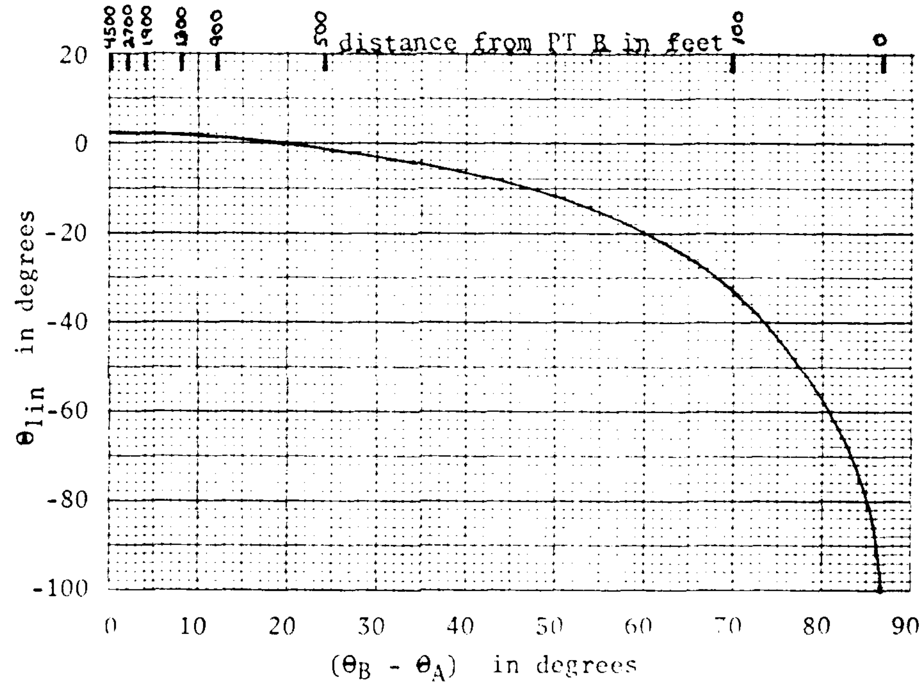
REMARKS

theodolite backsighted to Position IV (refer to page A5-2)

ATTACHMENT 7

THE EFFECT OF VIEWPOINT ON LINEAR REGRESSION ANGLE CALCULATIONS

The graph below illustrates the effect of viewpoint proximity to the linear regression as used in this procedure. The linear regression is considered to be a straight line between Points A and B at an angle of 3.00° from the horizontal. The projection of the linear regression intersects the reference plane at a point 1000 feet from the runway threshold (the "origin"), or 4500 feet from Point B. As we move the viewpoint along the runway centerline to Point B, we examine the viewing angles to Points A and B, as well as the value for the linear regression angle produced by the procedure. The linear regression angle (θ_{lin}) is plotted against the difference between the viewing angles ($\theta_B - \theta_A$). The distance from Point B is marked along the top of the graph.



The graph shows the procedure becomes increasingly inaccurate as the viewpoint becomes closer to Point B. When the viewpoint is directly under Point B (θ_B = 90°), the linear regression angle goes to negative infinity. However, when the viewpoint is in the vicinity of the apparent origin, the linear regression angle remains very near its actual value of 3.00°. The distance scale becomes extremely compressed at this point as well, which indicates that as long as the initial viewpoint is in the vicinity of the apparent origin, the procedure will evaluate the correct linear regression angle and therefore be valid.

ATTACHMENT 8

TITLE

HP-25 PROGRAM FOR LINEAR REGRESSION

This program is based on the Hewlett-Packard HP-25 program for linear regression. It has been slightly modified to compute the average light line value as well as the regression constants a_1 and a_0, based on the following equation.

$$Y = a_1(X) + a_0$$

Y is the value in light lines of the recording data point, and X is the distance from the glide slope. The distance can be in any units, as long as the linear regression is drawn on the flight recording in the same units. For use on the flight recordings, data points should be taken at least every two seconds, and if time permits, every second.

Below is the key sequence for the program itself. The next page provides instructions for using the program. It is assumed the user is familiar with the operation of the HP-25 programmable calculator.

DISPLAY		KEY		DISPLAY		KEY	
LINE	CODE	ENTRY	COMMENTS	LINE	CODE	ENTRY	COMMENTS
00			Steps 1 thru 7 for summation	25	32	CHS	
01	31	↑		26	24 04	RCL 4	
02	15 02	g X^2		27	51	+	
03	23 51 02	STO+2		28	24 03	RCL 3	
04	22	R↓		29	71	÷	
05	21	X⇆Y		30	23 00	STO 0	
06	25	Σ+		31	74	R/S	Halt to display A_0
07	13 00	GTO 00		32	24 01	RCL 1	
08	24 05	RCL 5		33	74	R/S	Halt to display A_1
09	24 07	RCL 7		34	21	X⇆Y	
10	24 04	RCL 4		35	22	R↓	
11	61	X		36	61	X	
12	24 03	RCL 3		37	24 02	RCL 2	
13	71	÷		38	24 04	RCL 4	
14	41	-		39	15 02	g X^2	
15	24 06	RCL 6		40	24 03	RCL 3	
16	24 07	RCL 7		41	71	÷	
17	15 02	g X^2		42	41	-	
18	24 03	RCL 3		43	71	÷	
19	71	÷		44	74	R/S	Display r^2
20	41	-		45	24 04	RCL 4	Coefficient of determination
21	71	÷		46	24 03	RCL 3	
22	23 01	STO 1		47	71	÷	
23	24 07	RCL 7		48	13 00	GTO 00	Display average Y's
24	61	X					

MEMORY REGISTERS

$R_0 = a_0$ $R_4 = \Sigma Y$
$R_1 = a_1$ $R_5 = \Sigma XY$
$R_2 = \Sigma Y^2$ $R_6 = \Sigma X^2$
$R_3 = n$ $R_7 = \Sigma X$

REMARKS: The value on line 14 is also needed near the end of the program to find the coefficient of determination. Since all registers are in use, the only place to store this value is in the stack. Because of its presence, do not disturb the stack.

TITLE

HP-25 PROGRAM FOR LINEAR REGRESSION

The following is a set of instructions and keystrokes to use with the program on the preceding page. Once the program is entered and initialized, the user inputs the paired values of data (X_i, Y_i), $i = 1, \ldots, n$. When all the data points have been entered, the regression constants a_1 and a_0 may be calculated.

A third value, the coefficient of determination (r^2) is also found. The value of r^2 will lie between 0 and 1, and will indicate how closely the equation fits the data; the closer r^2 is to 1, the better the fit. When the equation is solved with coordinates such as light lines and nautical miles, r^2 will not be close to 1 because the units disagree. If the time is taken to convert the coordinates to the same units, such as feet, then r^2 will be greatly improved. This is not necessary, however, since the linear regression is the best fit equation no matter what r^2 is.

STEP	INSTRUCTIONS	INPUT	KEYS				OUTPUT
1	Key in the program						
2	Initialize program		f	Rec	f	PRG	
3	Perform for i=1,...,n	X_i	↑				
		Y_i	R/S				i
4	Compute regression constants		GTO	08	R/S		a_0
			R/S				a_1
5	Compute coefficient of determination		R/S				r^2
6	Compute average of Y's		R/S				$\frac{\Sigma Y}{n}$
7	To find Y, input X	X	RCL	1	X	RCL	
			0	+			Y
8	Perform step 7 as needed						
9	For new case, go to 2.						

If X coordinates are taken every second, Step 3 can be simplified somewhat. Choose the first data point and call X = 0. Punch the ENTER↑ key. Enter the Y value and punch R/S. The display will show 1. Now punch ENTER↑ key again. Enter next Y value and punch R/S. Now the display shows 2. Continue this process for all the data points. This allows the program to use the data point number to increment the X coordinate. The data points can be entered much quicker and time is saved in computing the X coordinates.

Attachment 9

PROGRAM RECORD

	CALCULATOR TYPE TI-59 with PC 100A/C	**PAGE** 1 **OF** 1
	PROGRAMMER 1Lt M. K. McCullough	**DATE** June 1981

PROGRAM TITLE TI-59 Program for Optimum RTT Placement

PARTITIONING (OP 17) 4 7 9 5 9 **CARD NUMBER(S)** 1 / MASTER Library Module

PROGRAM DESCRIPTION

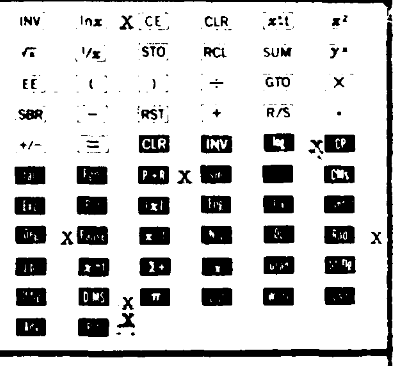
The Optimum RTT Position program provides the team chief/ engineer with a rapid method for the evaluation of the placement location of the radio telemetry theodolite (RTT). From information off of the flight recording of an RTT run, the engineer can assess the trend of the crosspointer trace and determine statistically whether the RTT is in front of, behind, or on the correct position to properly track the flight inspection aircraft.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Initialize the program after reading card.	CLR or 0	2nd	E'		0
2	Enter the G/S to threshold distance d0.	distance ft	2nd	A'		d0
3	Enter the G/S offset distance doff.	distance ft	2nd	B'		dB
4	Enter the RTT eyepiece angle. θeye.	angle deg	2nd	C'		θeye
5	Enter the terrain slope S.	slope deg	2nd	D'		S
6	Enter the number of seconds to Point A	time sec	C			Pt A
7	Enter the number of seconds to Point B	time sec	D			Pt B
8	Enter 999 for auto X or first X-value.	999 or val	A			0 or value
9	Enter Y (light line) value.	value	B			summation indx
10	Repeat 8 & 9 or 9 depending on mode (automatic X-value or manual X-value entry). Repeat until all data points are entered into the calculator.					
11	Calculate θA, θB, θlin, avg ang, Dtheo and RTT move. If the linear regression is desired to be printed enter one, else 0	1 or 0	E			RTT move ft
12	Reinitialize the program for another analysis		2nd	E'		

USER DEFINED KEYS	DATA REGISTERS (INV [illegible])	
A X-value input	10 Pt A in sec	20 Theta A (θA)
B Y-value input	11 Pt B in sec	21 Theta B (θB)
C Seconds to Pt A	12 d0 in feet	22 Theta lin (θlin)
D Seconds to Pt B	13 doff in feet	23 Avg angle
E Execute	14 dB in feet	24 Dtheo
A' d0 input	15 θ eye	25 RTT move
B' doff input	16 terrain slope	26 temp storage
C' θeye input	17 X manual buffer	27
D' Slope input	18 x auto indx buffr	08 11 to deg factor
E' Initialization	19 Y input buffer	09 temp buffer

LABELS (OP 08)



FLAGS

0	1	2	3	4	5	6	7	8	9
Auto X	LinRegPrt								

AFCC FORM FEB 81 943

Attachment 9

LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS	LOC	CODE	KEY	COMMENTS
000	76	LBL	Y-value	055	67	EQ	Check for	110	42	STO	
001	12	B	input	056	88	DMS	999 input	111	09	09	
002	42	STO		057	04	4	to flag	112	01	1	
003	19	19		058	04	4	Auto X	113	06	6	
004	87	IFF	check for	059	71	SBR		114	00	0	
005	01	01	auto X	060	99	PRT		115	01	1	
006	23	LNX		061	91	R/S		116	71	SBR	
007	43	RCL		062	76	LBL		117	99	PRT	
008	17	17		063	88	DMS		118	91	R/S	
009	32	X:T		064	86	STF	Set flag	119	76	LBL	
010	61	GTO		065	01	01	for Auto X	120	17	B'	deff input
011	60	DEG		066	43	RCL		121	42	STO	
012	76	LBL		067	11	11		122	13	13	
013	23	LNX		068	75	-		123	42	STO	
014	02	2	Auto X-in	069	02	2		124	09	09	
015	44	SUM	index sec	070	95	=		125	01	1	
016	18	18		071	42	STO		126	05	6	
017	43	RCL		072	18	18		127	03	3	
018	18	18		073	25	CLR		128	02	2	
019	42	STO		074	91	R/S		129	02	2	
020	09	09		075	76	LBL		130	01	1	
021	32	X:T		076	99	PRT	Printer	131	02	2	
022	04	4		077	69	OP	output	132	01	1	
023	04	4		078	04	04	subroutine	133	71	SBR	
024	71	SBR	Print 'X'	079	43	RCL		134	99	PRT	
025	99	PRT		080	09	09		135	33	X²	calculate
026	76	LBL		081	69	OP		136	85	+	distance
027	60	DEG		082	06	06		137	53	(	from RTT
028	43	RCL		083	92	RTN		138	43	RCL	to Pt B
029	19	19		084	76	LBL	nitializat	139	12	12	
030	42	STO		085	10	E'	sequence	140	85	+	
031	09	09		086	36	PGM		141	03	3	
032	04	4		087	01	01		142	05	5	
033	05	5		088	71	SBR		143	00	0	
034	71	SBR	Print 'Y'	089	25	CLR		144	00	0	
035	99	PRT		090	93	.	light line	145	54	)	
036	78	Σ+	Sum to lin	091	00	0	to degree	146	33	X²	
037	43	RCL	reg array	092	01	1	muitiplctn	147	95	=	
038	03	03		093	07	7	factor	148	34	√X	
039	91	R/S		094	05	5		149	42	STO	
040	76	LBL		095	42	STO		150	14	14	
041	11	A	X- value	096	08	08		151	42	STO	
042	42	STO	input	097	22	INV		152	09	09	
043	17	17		098	86	STF		153	01	1	
044	42	STO		099	01	01		154	06	6	
045	09	09		100	22	INV		155	01	1	
046	87	IFF	error trap	101	86	STF		156	04	4	
047	01	01	for auto X	102	02	02		157	71	SBR	
048	12	B		103	98	ADV		158	99	PRT	
049	09	9		104	25	CLR		159	91	R/S	
050	09	9		105	91	R/S					
051	09	9		106	76	LBL					
052	32	X:T		107	16	A'	d0 input				
053	43	RCL		108	42	STO					
054	09	09		109	12	12					

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

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Attachment 9

LOC	CODE	KEY	COMMENTS
160	76	LBL	
161	18	C'	θeye input
162	42	STO	
163	15	15	
164	42	STO	
165	09	09	
166	03	3	
167	07	7	
168	02	2	
169	03	3	
170	05	5	
171	04	4	
172	71	SBR	
173	99	PRT	
174	91	R/S	
175	76	LBL	
176	19	D'	slope input
177	42	STO	
178	16	16	
179	42	STO	
180	09	09	
181	03	3	
182	06	6	
183	02	2	
184	07	7	
185	03	3	
186	03	3	
187	71	SBR	
188	99	PRT	
189	98	ADV	
190	91	R/S	
191	76	LBL	
192	13	C	
193	42	STO	Seconds to Point A in
194	10	10	
195	42	STO	
196	09	09	
197	03	3	
198	03	3	
199	03	3	
200	07	7	
201	00	0	
202	00	0	
203	01	1	
204	03	3	
205	71	SBR	
206	99	PRT	
207	98	ADV	
208	91	R/S	
209	76	LBL	Seconds to Point B in
210	14	D	
211	42	STO	
212	11	11	
213	42	STO	
214	09	09	

LOC	CODE	KEY	COMMENTS
215	03	3	
216	03	3	
217	03	3	
218	07	7	
219	00	0	
220	00	0	
221	01	1	
222	04	4	
223	71	SBR	
224	99	PRT	
225	98	ADV	
226	91	R/S	
227	76	LBL	
228	15	E	Execute Calculations
229	32	X⇌T	
230	01	1	
231	67	EQ	Check for desire for lin reg print out
232	70	RAD	
233	43	RCL	
234	10	10	
235	69	OP	
236	14	14	
237	65	×	Calc θA
238	43	RCL	
239	08	08	
240	95	=	
241	85	+	
242	43	RCL	
243	15	15	
244	95	=	
245	42	STO	
246	20	20	
247	42	STO	
248	09	09	
249	03	3	
250	07	7	
251	02	2	
252	03	3	
253	01	1	
254	03	3	
255	71	SBR	
256	99	PRT	
257	66	PAU	
258	43	RCL	
259	11	11	Calc θB
260	69	OP	
261	14	14	
262	65	×	
263	43	RCL	
264	08	08	
265	95	=	
266	85	+	
267	43	RCL	
268	15	15	
269	95	=	

LOC	CODE	KEY	COMMENTS
270	42	STO	
271	21	21	
272	42	STO	
273	09	09	
274	03	3	
275	07	7	
276	02	2	
277	03	3	
278	01	1	
279	04	4	
280	71	SBR	
281	99	PRT	
282	66	PAU	
283	43	RCL	Calc θlin
284	14	14	
285	65	×	
286	43	RCL	
287	21	21	
288	30	TAN	
289	95	=	
290	94	+/-	
291	42	STO	
292	09	09	
293	43	RCL	
294	12	12	
295	85	+	
296	02	2	
297	04	4	
298	03	3	
299	00	0	
300	04	4	
301	95	=	
302	33	X²	
303	85	+	
304	43	RCL	
305	13	13	
306	33	X²	
307	95	=	
308	34	√X	
309	65	×	
310	43	RCL	
311	20	20	
312	30	TAN	
313	95	=	
314	85	+	
315	43	RCL	
316	09	09	
317	95	=	
318	55	÷	
319	02	2	

MERGED CODES

62 Pgm Ind	72 STO Ind	83 GTO Ind
63 Exc Ind	73 RCL Ind	84 Op Ind
64 Prd Ind	74 SUM Ind	92 INV SBR

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LOC	CODE	KEY	COMMENTS
320	00	0	
321	08	8	
322	00	0	
323	04	4	
324	95	=	
325	22	INV	
326	30	TAN	
327	95	=	
328	42	STO	
329	22	22	
330	42	STO	
331	09	09	
332	03	3	
333	07	7	
334	02	2	
335	07	7	
336	02	2	
337	04	4	
338	03	3	
339	01	1	
340	71	SBR	
341	99	PRT	
342	66	PAU	
343	79	x̄	Average Angle Calc
344	65	×	
345	43	RCL	
346	08	08	
347	85	+	
348	43	RCL	
349	15	15	
350	95	=	
351	42	STO	
352	23	23	
353	42	STO	
354	09	09	
355	06	6	
356	07	7	
357	01	1	
358	03	3	
359	03	3	
360	01	1	
361	02	2	
362	02	2	
363	71	SBR	
364	99	PRT	
365	66	PAU	
366	98	ADV	
367	43	RCL	Dtheo calc
368	21	21	
369	30	TAN	
370	55	÷	
371	43	RCL	
372	22	22	
373	30	TAN	
374	95	=	
375	94	+/-	
376	85	+	
377	01	1	
378	95	=	
379	65	×	
380	43	RCL	
381	14	14	
382	95	=	
383	42	STO	
384	24	24	
385	42	STO	
386	09	09	
387	01	1	
388	06	6	
389	03	3	
390	07	7	
391	02	2	
392	03	3	
393	03	3	
394	02	2	
395	71	SBR	
396	99	PRT	
397	66	PAU	
398	43	RCL	RTT move calculatio
399	22	22	
400	38	SIN	
401	55	÷	
402	53	(	
403	53	(	
404	43	RCL	
405	22	22	
406	75	-	
407	43	RCL	
408	16	16	
409	54	)	
410	38	SIN	
411	54	)	
412	95	=	
413	65	×	
414	43	RCL	
415	24	24	
416	95	=	
417	42	STO	
418	25	25	
419	42	STO	
420	09	09	
421	03	3	
422	00	0	
423	03	3	
424	02	2	
425	04	4	
426	02	2	
427	01	1	
428	07	7	
429	71	SBR	
430	99	PRT	
431	98	ADV	
432	98	ADV	
433	87	IFF	
434	02	02	Test for lin reg prt
435	28	LOG	
436	91	R/S	
437	76	LBL	
438	70	RAD	Set flag for lin reg print out
439	86	STF	
440	02	02	
441	25	CLR	
442	98	ADV	
443	15	E	
444	76	LBL	
445	28	LOG	linear regression print out subroutine
446	43	RCL	
447	11	11	
448	42	STO	
449	26	26	
450	76	LBL	
451	37	P/R	
452	43	RCL	
453	26	26	
454	42	STO	
455	09	09	
456	04	4	
457	04	4	
458	71	SBR	
459	99	PRT	
460	69	OP	
461	14	14	
462	42	STO	
463	09	09	
464	04	4	
465	05	5	
466	71	SBR	
467	99	PRT	
468	02	2	
469	44	SUM	
470	26	26	
471	43	RCL	
472	10	10	
473	32	X:T	
474	43	RCL	
475	26	26	
476	77	GE	
477	10	E'	
478	61	GTO	
479	37	P/R	

MERGED CODES

62 ■ ■
63 ■ ■
64 ■ ■
72 STO ■
73 RCL ■
74 SUM ■
83 GTO ■
84 ■ ■
92 INV SBR

PAGE 4 **OF** 4

ATTACHMENT 9

TI-59 Program for Optimum RTT Placement

INTRODUCTION

This guide contains the information necessary to run the program for the Leister Method of RTT Placement written for the TI-59 calculator. The program can be run on the calculator alone or on the calculator/printer combination. The program is enhanced for use with the PC-100/A or C printers.

DESCRIPTION

The RTT Method program provides the Team Chief/Engineer with a rapid method for evaluating the placement location for the radio telemetry theodolite (RTT). From information off of the flight recording of an RTT run, the engineer can assess the trend of the crosspointer trace and determine statistically whether the RTT is in front of, behind, or on the correct position to properly track the flight inspection aircraft. Data needed to input into the program include:

1. The distance in feet the glide slope antenna is from the servicing runway's threshold -- this is symbolized as DO
2. The distance in feet the glideslope antenna is from the servicing runway's centerline -- Doff
3. The general terrain slope in degrees from in front of the glide slope antenna to 200 feet out -- S
4. The RTT eyepiece angle in degrees -- θeye
5. The time in seconds it took the aircraft to fly from Point A to the glide slope antenna -- for θA calculation.
6. The time in seconds it took the aircraft to fly from Point B to the glide slope antenna -- for θB calculation.
7. The light line value of the crosspointer at some time increment -- y
8. Finally, the time in seconds from the glide slope antenna each light line value was taken off of the flight recording -- x.

The program uses linear regression to find the trend of the light line values (y) over time (x) in between Point A and Point B -- the straight-line portion of the glide path. The origin of the linear regression line is extrapolated to the runway centerline abeam the glide slope antenna base. The program then computes the trend line angle (θlin) from the data parameters in 1, 2, 6, and 7 above.

USER INSTRUCTIONS

After both sides of the TI-59 magnetic storage program card are read into the calculator, the program must be initialized. Simply press the E' key (2nd E key). The program is now initialized.

Next, the user needs to enter the parameters described in 1 through 6 above. D0 is entered through A', Doff is entered through B', -Oeye is entered through C', S is entered through D', the number of seconds from the glide slope antenna to Point A is entered through C, (the glide slope antenna is the time origin; the time count starts at zero there and increases to Point A. Thus, x can be thought of as time to go until the aircraft reaches the point abeam the glide slope antenna), and finally, the time in seconds to Point B is entered through D. If the printer is being used, each of these values entered are printed out and identified for verification.

The user is now ready to input the linear regression data points. The flight inspection recording is held so that the light line values are entered as positive if the trace is on the 150-Hz side of the zero crosspointer line and negative if the trace is on the 90-Hz side of the zero crosspointer line. This usually means that the glide slope antenna mark on the recording will be at the user's right and the Point A mark will be at the user's left. The program can be operated in two different modes. One mode is for the program to automatically provide the time increment (x) for the linear regression. This default time increment is two seconds. The user simply inputs the flight inspection recording light line value (y) at this default value from Point B to Point A.

The second mode the program can be run in is for the user to provide the values of the time (x) when the light line value (y) is measured. This allows the user the freedom to utilize this program when an RTT run is not possible, but barrel runs are. Since the theodolite operator's on call marks are generally not consistant over time, the user can input the y-value and x-value of the on call marks and construct the linear regression from these.

Therefore, if the user desires the program to default the x-values, simply enter the number 999 through the A key. This causes the program to be flagged for automatic x-value entry. Thereafter, only the y-values have to be entered in the program through the B key. There is an error trap in case mistake is made and the A key is accidently hit when entering a y-value. The y-value will be entered as if the B key was pressed.

If the user wishes to enter both of the data values then the x-value is entered through the A key followed by the y-value through the B key.

This key sequence is continued in either case until all of the data points are entered. The display of the calculator will show a counter increment of how many data points have been entered into the program. If the printer is being used, the values are printed out and are identified as x values or y-values. If a mistake is made in data point entry, it can be removed by using the trend data point removal instructions in the TI-59 handbook or the little booklet provided with the solid-state library module.

Once the linear regression data is entered, the formula computations can begin. The program will compute θA, θB, θlin, the average angle, Dtheo, and X -- the final resultant move for the theodolite. The program again has two modes at this point. If the user is using the printer and wants the values of the linear regression to be printed out; press the 1 key and then the E key. If it is not desired to have this extra information, then press the 0 key or the CLR key and then the E key.

Finally, the moment of triumph! The calculated theodolite move is displayed and also printed if you are using the printer. Remember, if the value is positive then move the theodllite forward toward the threshold. If it is negative, then move it back. If the distance to move the theodolite is computed to be less than 15 feet, the move should be considered to be insignificant.

If the user wishes to keep the facility data, simply save it onto another magnetic card by writing side 4 on the card. The information in the memories is listed below:

Register Location	Register Contents
00 thru 07	used as linear regression array
08	light-line to degrees factor
09	temporary storage buffer
10	time to Point A in seconds
11	time to Point B in seconds
12	d0 in feet
13	doff in feet
14	dB in feet
15	θeye in degrees
16	terrain slope in degrees
17	x-value manual input buffer
18	x-value automatic index buffer
19	y-value input buffer
20	θA resultant storage
21	θB resultant storage
22	θlin resultant storage
23	average angle resultant storage
24	Dtheo resultant storage
25	Theodolite move storage

To compute another RTT run, simply re-initialize the program and re-enter the facility data and the new recording data in the mode desired.

ATTACHMENT 10

```
]LIST

10  DIM DX(100): DIM DY(100)
20  REM  START THE GRAPHICS FOR OPTIMUM RTT POSITION.
30  HOME : GR
40  COLOR= 6: PLOT 3,10: PLOT 15,15: PLOT 36,15: PLOT 19,10
50  COLOR= 13: PLOT 13,30: PLOT 3,35: PLOT 26,33: PLOT 35,34
60  COLOR= 12: PLOT 12,20: PLOT 12,22: PLOT 25,25: PLOT 17,20
70  COLOR= 6: PLOT 8,15: PLOT 21,15: PLOT 30,10: PLOT 27,10
80  COLOR= 13: PLOT 11,30: PLOT 14,30: PLOT 22.30: PLOT 18,33
90  COLOR= 6: PLOT 6,15: PLOT 11,11: PLOT 36.10: PLOT 27,10
100  COLOR= 12: PLOT 15,25: PLOT 19,23: PLOT 27,20: PLOT 23,20
110  COLOR= 13: PLOT 6,31: PLOT 28.30: PLOT 28,35: PLOT 36,30
120  COLOR= 6: PLOT 32,10: PLOT 34.14: PLOT 30,15: PLOT 15,10
130  COLOR= 13: PLOT 16,35: PLOT 36.35: PLOT 26,30: PLOT 13.33
140  COLOR= 12: PLOT 12,25: PLOT 19,25: PLOT 21,20: PLOT 25,22
150  COLOR= 6: PLOT 27,15: PLOT 25,10: PLOT 19,15: PLOT 6,12
160  COLOR= 13: PLOT 3,30: PLOT 22.35: PLOT 33,33: PLOT 6.31
170  COLOR= 12: PLOT 12,25: PLOT 14.23: PLOT 19,24: PLOT 26,20
180  COLOR= 6: PLOT 3,15: PLOT 10.13: PLOT 22,12: PLOT 25,14
190  COLOR= 13: PLOT 10,35: PLOT 11,32: PLOT 16,30: PLOT 34.31
200  COLOR= 6: PLOT 8,10: PLOT 13,10: PLOT 23.15: PLOT 33,12
210  COLOR= 13: PLOT 33,35: PLOT 26,34: PLOT 31,32: PLOT 24.30
220  COLOR= 6: PLOT 15,14: PLOT 24,13: PLOT 30,10: PLOT 32,15
230  COLOR= 13: PLOT 3.33: PLOT 18,31: PLOT 36,32: PLOT 31,35
240  COLOR= 6: PLOT 3,12: PLOT 21,10: PLOT 27.13: PLOT 36,12
250  COLOR= 12: PLOT 15,21: PLOT 13,23: PLOT 19,21: PLOT 15,24
260  COLOR= 6: PLOT 4,10: PLOT 19,12: PLOT 33,13: PLOT 25,11
270  COLOR= 13: PLOT 16,30: PLOT 34,32: PLOT 29,30: PLOT 5,33
280  COLOR= 6: PLOT 17,10: PLOT 11,12: PLOT 23,14: PLOT 30,11
290  COLOR= 13: PLOT 11,35: PLOT 13,35: PLOT 20,30: PLOT 28,32
300  COLOR= 6: PLOT 15.11: PLOT 21,13: PLOT 32,11: PLOT 34,15
310  COLOR= 13: PLOT 35,33: PLOT 22.31: PLOT 8,33: PLOT 15,30
320  COLOR= 6: PLOT 8,13: PLOT 27,11: PLOT 32,13: PLOT 19,13
330  COLOR= 12: PLOT 25,21: PLOT 18.20: PLOT 15,22: PLOT 25,24
340  COLOR= 13: PLOT 9,30: PLOT 14.33: PLOT 26,35: PLOT 36,34
350  COLOR= 6: PLOT 6.10: PLOT 10,10: PLOT 30,13: PLOT 21,12
360  COLOR= 13: PLOT 5,30: PLOT 18,35: PLOT 31,30: PLOT 22,34
370  COLOR= 6: PLOT 3,14: PLOT 24,12: PLOT 29,15: PLOT 35,13
380  COLOR= 13: PLOT 33,30: PLOT 23,30: PLOT 13,31: PLOT 6,32
390  COLOR= 12: PLOT 12,23: PLOT 19,20: PLOT 25,20: PLOT 14,20
400  COLOR= 6: PLOT 6,14: PLOT 25,13: PLOT 36,11: PLOT 8,12
410  COLOR= 13: PLOT 3,31: PLOT 11,33: PLOT 28,33: PLOT 33,31
420  COLOR= 6: PLOT 15,12: PLOT 35.12: PLOT 16,10: PLOT 5,15
430  COLOR= 13: PLOT 30,35: PLOT 26.31: PLOT 18,30: PLOT 10,30
440  COLOR= 6: PLOT 3.11: PLOT 22,13: PLOT 36,14: PLOT 27,14
450  COLOR= 13: PLOT 9,35: PLOT 14.35: PLOT 31.31: PLOT 36,33
460  COLOR= 6: PLOT 6,11: PLOT 25,15: PLOT 30,14: PLOT 9,13
470  COLOR= 13: PLOT 11,31: PLOT 16,34: PLOT 31,34: PLOT 33,34
480  COLOR= 12: PLOT 12,24: PLOT 20,20: PLOT 25,23: PLOT 13,20
490  COLOR= 13: PLOT 29,35: PLOT 4.33: PLOT 22.32: PLOT 8,30
500  COLOR= 6: PLOT 19,14: PLOT 32,12: PLOT 6,13: PLOT 9,10
510  COLOR= 13: PLOT 3,32: PLOT 15,33: PLOT 28,34: PLOT 18,34
520  COLOR= 6: PLOT 4,15: PLOT 36.13: PLOT 21,11: PLOT 30,12
530  COLOR= 13: PLOT 8.34: PLOT 30.30: PLOT 13,32: PLOT 36,31
540  COLOR= 6: PLOT 8,14: PLOT 28,15: PLOT 19.11: PLOT 15,13
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ATTACHMENT 10

```
     COLOR= 12: PLOT 33,33: PLOT 15,35: PLOT 28,31: PLOT 11,34
     COLOR= 12: PLOT 13,21: COLOR= 6: PLOT 21,14: PLOT 5,10: PLOT 27,12
     COLOR= 13: PLOT 3,34: PLOT 22,33: PLOT 31,33: PLOT 18,32
     COLOR= 12: PLOT 24,2 : COLOR= 6: PLOT 3,13: PLOT 14,10: PLOT 25,12
     COLOR= 13: PLOT 8,32: PLOT 21,30: PLOT 13,30: COLOR= 12: PLOT 19,22
     COLOR= 6: PLOT 9,11: PLOT 32,14: COLOR= 13: PLOT 4,30: PLOT 26,32
     PLOT 3,35
620  HOME : HTAB 10: PRINT "BY HARVEY LEISTER": PRINT ""
630  HTAB 8: PRINT "PRESS  ANY KEY TO BEGIN.": CALL  - 756:D$ = "": TEXT : HOME
640  PRINT "    THIS PROGRAM PROVIDES A METHOD TO OP-"
650  PRINT "TIMALLY POSITION AN RTT FOR VIEWING THE"
660  PRINT "STRUCTURE ON A GLIDE SLOPE FACILITY."
670  PRINT "THIS IS DONE USING AN INITIAL POSITION"
680  PRINT "(USUALLY THE RTT BACKSITED TO THE GLIDE"
690  PRINT "SLOPE ANTENNA BASE), AND RECORDING A"
700  PRINT "STRUCTURE RUN.  THEN THE PROGRAM FITS A"
710  PRINT "STRAIGHT LINE TO THE RECORDED DATA BY A"
720  PRINT "LINEAR REGRESSION USING THE METHOD OF"
730  PRINT "LEAST SQUARES.  BASED ON THE LINE IN"
740  PRINT "SPACE REPRESENTED BY THE LINEAR REGRES-"
750  PRINT "SION AND ITS ANGLE TO THE HORIZONTAL."
760  PRINT "THE PROGRAM CALCULATES WHERE TO MOVE"
770  PRINT "THE RTT TO ALIGN IT TO THE LINEAR RE-"
780  PRINT "GRESSION IN SPACE.  THIS PROVIDES THE"
790  PRINT "A CONSTANT VIEWING ANGLE TO OBSERVE THE"
800  PRINT "GLIDE PATH AND MEASURE ITS STRUCTURE"
810  PRINT "PERFORMANCE.": PRINT "": PRINT ""
820  PRINT "PRESS  ANY KEY TO CONTINUE.": CALL  - 756: HOME
830  PRINT "NOW, HOW TO USE THE PROGRAM.": PRINT ""
840  PRINT "FIRST, YOU WILL BE ASKED FOR SOME VARI-"
850  PRINT "ABLES WHICH TAILOR THE CALCULATIONS TO"
860  PRINT "THE FACILITY BEING CHECKED."
870  PRINT "THEN, YOU PUT IN X AND Y COORDINATES OF"
880  PRINT "DATA POINTS FROM THE STRUCTURE RUN. YOU"
890  PRINT "SELECT YOUR X-AXIS, SUCH AS SECONDS,"
900  PRINT "NAUTICAL MILES, ETC.  THE Y COORDINATES"
910  PRINT "ARE LIGHT LINE VALUES ON THE RECORDING."
920  PRINT "90 HZ READINGS ARE NEGATIVE; 150 HZ "
930  PRINT "READINGS ARE POSITIVE.": PRINT ""
940  PRINT "PRESS  ANY KEY TO CONTINUE. ": CALL  - 756: HOME
950  PRINT "PRESS <S> TO STOP ENTERING COORDINATES."
960  PRINT "ONCE YOU VERIFY YOUR COORDINATES ARE"
970  PRINT "CORRECT, THE PROGRAM WILL CALCULATE AN"
980  PRINT "EQUATION FOR THE LINEAR REGRESSION.  IT"
990  PRINT "WILL ALSO PROVIDE A TERM CALLED THE"
1000  PRINT "COEFFICIENT OF DETERMINATION, WHICH"
1010  PRINT "LETS YOU KNOW HOW WELL THE LINEAR RE-"
1020  PRINT "GRESSION FITS YOUR DATA.  THE CLOSER "
1030  PRINT "THE COEFFICIENT IS TO 1, THE BETTER THE"
1040  PRINT "FIT.  YOU WILL ALSO GET THE AVERAGE Y"
1050  PRINT "VALUE FOR COMPUTING THE AVERAGE GLIDE"
1060  PRINT "ANGLE.": PRINT ""
1070  PRINT "PRESS ANY KEY TO START.": CALL  - 756
1080 X0 = 0:Y0 = 0:XY0 = 0:X2 = 0:Y2 = 0:P = 0:A1 = 0:A0 = 0
1090  HOME : PRINT "DO YOU WANT:": PRINT ""
1100  HTAB 5: PRINT "1)  ENTER NEW DATA": HTAB 5: PRINT "2)  GET DATA FROM DISK": HTAB 5: PRINT "3)  CATALOG DISK": PRINT
1110  PRINT "WHICH CHOICE? ": GET A$: IF  VAL (A$) < 1 OR  VAL (A$) > 3 GOTO 1110
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1120  IF VAL (A$) = 1 GOTO 1150
1130  IF VAL (A$) = 2 GOTO 2230
1140  PRINT : HOME : GOSUB 1260: PRINT D$;"CATALOG": PRINT  CHR$ (4);"CATALOG": CALL  - 756: GOTO 1080
1150  HOME : PRINT "FACILITY VARIABLES:": PRINT ""
1160  INPUT "FACILITY LOCATION: ";F$: PRINT ""
1170  INPUT "RUNWAY NUMBER: ";RW$: PRINT ""
1180  INPUT "G/S OFFSET DISTANCE: ";DOFF: PRINT ""
1190  INPUT "G/S-THRESHOLD DISTANCE: ";DTH: PRINT ""
1200  INPUT "RTT EYEPIECE ANGLE: ";EYE: PRINT ""
1210  INPUT "TERRAIN SLOPE IN DEGREES: ";S: PRINT ""
1220  INPUT "REMARKS ( 40 CHAR.): ";RM$: PRINT ""
1230  PRINT " IS THE DATA CORRECT? ": GET Y$
1240  IF Y$ = "Y" THEN  GOTO 1260: IF Y$ <  > "N" GOTO 1230
1250  GOTO 1150
1260  HOME : PRINT "REMEMBER THESE POINTS!": PRINT ""
1270  PRINT "NOTE YOUR X COORDINATES FOR POINTS A "
1280  PRINT "AND B.  Y VALUES ARE IN LIGHTLINES."
1290  PRINT "IF YOU ARE READY, PRESS ANY KEY.": CALL  - 756
1300  HOME
1310 X0 = 0:Y0 = 0:XY0 = 0:X2 = 0:Y2 = 0:P = 0:A1 = 0:A0 = 0
1320 P = P + 1.
1330  PRINT "X ";P;" COORDINATE IS: ": INPUT Z$
1340  IF Z$ = "S" THEN  GOTO 1370
1350 DX(P) =  VAL (Z$)
1360  PRINT "Y ";P;" COORDINATE IS: ": INPUT Y:DY(P) = Y: PRINT "": GOTO 1320
1370  HOME : PRINT "YOUR DATA PAIRS ARE:": PRINT "":Q = 0
1380  PRINT "NUMBER","X","Y"
1390  FOR I = 1 TO P - 1:Q = Q + 1: PRINT I,DX(I),DY(I)
1400  IF Q = 20 THEN  GOTO 1420
1410  GOTO 1440
1420  PRINT "PRESS  ANY KEY TO CONTINUE. ": CALL  - 756
1430 Q = Q - 20: HOME : PRINT "NUMBER","X","Y": PRINT ""
1440  NEXT I: PRINT ""
1450  PRINT "ARE ALL YOUR DATA PAIRS CORRECT? ": GET Y$: PRINT ""
1460  IF Y$ = "Y" THEN  GOTO 1500: IF Y$ <  > "N" GOTO 1450
1470  INPUT "ENTER # OF INCORRECT PAIR: ";N: PRINT ""
1480  PRINT "X IS ";DX(N);"  AND Y IS ";DY(N): PRINT ""
1490  INPUT "CHANGE X COORDINATE TO: ";DX(N): INPUT "CHANGE Y COORDINATE TO: ";DY(N): GOTO 1370
1500  PRINT "": PRINT "X-COORDINATE FOR POINT A IS:";XA: PRINT "X-COORDINATE FOR POINT B IS:";XB
1510  PRINT "": PRINT "ARE THESE CORRECT?": GET Y$: IF Y$ = "Y" GOTO 1550
1520  IF Y$ <  > "N" GOTO 1510
1530  PRINT "": INPUT "CHANGE POINT A X-COORDINATE TO:";XA: INPUT "CHANGE POINT B X-COORDINATE TO:";XB: PRINT ""
1540  GOTO 1500
1550  PRINT "": PRINT "DO YOU WISH TO SAVE THE RAW DATA": PRINT "TO DISK?": GET Y$
1560  IF Y$ = "Y" GOTO 2410: IF Y$ <  > "N" GOTO 1550
1570  HOME : PRINT "HERE COMES THE LINEAR REGRESSION!": FOR II = 1 TO 500: NEXT II: PRINT ""
1580 P = P - 1
1590  FOR I = 1 TO P:X0 = X0 + DX(I):Y0 = Y0 + DY(I):XY0 = XY0 + (DX(I) * DY(I))
1600 X2 = X2 + (DX(I) ^ 2):Y2 = Y2 + (DY(I) ^ 2): NEXT I
1610 A1 = (XY0 - (X0 * Y0 / P)) / (X2 - (X0 ^ 2 / P))
1620 A0 = (Y0 / P) - (A1 * X0 / P)
1630 R = (XY0 - (X0 * Y0 / P)) ^ 2 / ((X2 - (X0 ^ 2 / P)) * (Y2 - (Y0 ^ 2 / P)))
1640 AVG = Y0 / P
1650  REM  SPEW FORTH LINEAR REG RESULTS.
1660  HOME : PRINT "THE LINEAR EQUATION IS:": PRINT ""
1670  HTAB 10: PRINT "Y  =  A1(X)  +  A0": PRINT ""
1680  PRINT "WHERE": PRINT "": HTAB 20: PRINT "A1 = ";A1: HTAB 20: PRINT "A0 = ";A0: PRINT ""
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ATTACHMENT 10

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1690  PRINT "COEF OF DETERMINATION = ";R: PRINT ""
1700  HTAB 7: PRINT "AVERAGE OF X VALUES = ";AVG: PRINT ""
1710  HTAB 7: PRINT "NUMBER OF DATA PTS. = ";P: PRINT ""
1720  PRINT "DO YOU WANT TO CALCULATE OTHER POINTS"
1730  PRINT "USING THE LINEAR REGRESSION EQUATION? ": GET Y$: PRINT : IF Y$ < > "Y" AND Y$ < > "N" GOTO 1720
1740  IF Y$ = "Y" THEN  GOTO 1760
1750  GOTO 1800
1760  INPUT "X COORDINATE IS: ";XX
1770 YY = (A1 * XX) + A0: PRINT "Y COORDINATE IS: ";YY
1780  PRINT "": PRINT "ANY MORE? ": GET Y$: PRINT ""
1790  IF Y$ = "Y" THEN  GOTO 1760: IF Y$ < > "N" GOTO 1780
1800  PRINT "DO YOU WANT LINEAR REGRESSION DATA PRS.": PRINT "USING YOUR X COORDINATES?": GET Y$: PRINT : IF Y$ < > "Y" AND
     Y$ < > "N" GOTO 1900
1810  IF Y$ = "Y" THEN  GOTO 1830
1820  GOTO 1910
1830  HOME : PRINT "LINEAR REGRESSION DATA PAIRS:": PRINT ""
1840  PRINT "X","Y": PRINT "":W = 0
1850  FOR J = 1 TO P:W = W + 1: PRINT DX(J),A0 + (A1 * DX(J))
1860  IF W = 20 THEN  GOTO 1880
1870  GOTO 1900
1880  PRINT "PRESS ANY KEY TO CONTINUE.": CALL  - 756: PRINT
1890 W = W - 20: HOME : PRINT "X","Y": PRINT ""
1900  NEXT J: PRINT ""
1910  PRINT "" : PRINT "PRESS  ANY KEY TO START CALCULATING THE": PRINT "NEW RTT POSITION. ": CALL  - 756
1920  HOME : PRINT "GIVE ME A SECOND!": FOR I = 1 TO 300: NEXT I:CN = 0.017453286
1930 DA =  SQR (DOFF ^ 2 + ((DTH + 24304) ^ 2))
1940 DB =  SQR (DOFF ^ 2 + ((DTH + 3500) ^ 2))
1950 YA = (A1 * XA) + A0:YB = (A1 * XB) + A0
1960 AA = CN * (EYE + (YA * 0.7 / 40)):AB = CN * (EYE + (YB * 0.7 / 40))
1970 LIN =  ATN (((DA *  TAN (AA)) - (DB *  TAN (AB))) / 20804)
1980 R1 = DB * (1 - ( TAN (AB) /  TAN (LIN)))
1990 SR = S * CN:RTT = R1 * ( SIN (LIN) /  SIN (LIN - SR))
2000  REM  SPEW PLACEMENT RESULTS.
2010  HOME : PRINT "****************************************"
2020  INVERSE : PRINT "RTT PLACEMENT ANALYSIS FOR": NORMAL
2030  PRINT F$;"   R/W ";RW$: PRINT RM$
2040  PRINT "****************************************": PRINT ""
2050  HTAB 5: PRINT "RTT EYEPIECE ANGLE: ";EYE
2060  HTAB 4: PRINT "G/S OFFSET DISTANCE: ";DOFF
2070  PRINT "G/S-THRESHOLD DISTANCE: ";DTH
2080  HTAB 2: PRINT "TRRN SLOPE IN DEGREES: ";S
2090  HTAB 3: PRINT "EYE ANGLE TO POINT A: ";AA / CN
2100  HTAB 3: PRINT "EYE ANGLE TO POINT B: ";AB / CN
2110  HTAB 7: PRINT "# OF DATA POINTS: ";P
2120  HTAB 3: PRINT "LIN REGRESSION ANGLE: ";LIN / CN
2130 AVA = EYE + (AVG * 0.7 / 40)
2140  HTAB 10: PRINT "AVERAGE ANGLE: ";AVA
2150  PRINT "": PRINT "****************************************"
2160  HTAB 11: PRINT "MOVE THE RTT  "; INT (RTT * 10) / 10;" FEET."
2170  PRINT "****************************************": PRINT ""
2180  PRINT "NEGATIVE VALUE MEANS MOVE TOWARD G/S:"
2190  PRINT "POSITIVE VALUE MEANS MOVE TOWARD RNWY."
2200  PRINT "ANOTHER ANALYSIS? ": GET Y$: PRINT : IF Y$ < > "Y" AND Y$ < > "N" GOTO 2200
2210  IF Y$ = "Y" GOTO 1060
2220  HOME : PRINT "INSERT PROGRAM DISK AND PRESS": PRINT "ANY KEY": CALL  - 756
2230  PRINT :D$ = "": REM  CTRL D.
2240  PRINT D$;"RUN MENU"
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ATTACHMENT 10

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2250  END
2260  PRINT "": PRINT "INSERT DATA DISK AND PRESS ANY KEY." : CALL - 756: RETURN
2270  PRINT D$;"CLOSE RTT "; LEFT$ (F$,8);" R/W ";RW$;" "; LEFT$ (RM$,9): POKE 216,0: RETURN
2280  REM  GET DATA.
2290  ONERR  GOTO 2510:ZIP = 1
2300  HOME : INPUT "FACILITY LOCATION: ";F$: PRINT ""
2310  INPUT "RUNWAY NUMBER: ";RW$: PRINT ""
2320  INPUT "REMARKS (<40 CHAR.): ";RM$: PRINT ""
2330  GOSUB 2260
2340  HOME : VTAB 10: PRINT "GETTING ";: INVERSE : PRINT "RTT "; LEFT$ (F$,8);" R/W ";RW$;" "; LEFT$ (RM$,9);: NORMAL : PRINT
     " FILE."
2350  PRINT D$;"READ RTT "; LEFT$ (F$,8);" R/W ";RW$;" "; LEFT$ (RM$,9)
2360  INPUT P: INPUT DOFF: INPUT DTH: INPUT EYE: INPUT S
2370  INPUT F$: INPUT RW$: INPUT RM$
2380  FOR I = 1 TO P - 1: INPUT DX(I): INPUT DY(I): NEXT I
2390  INPUT XA: INPUT XB
2400  GOSUB 2270: GOTO 1370
2410  PRINT "": REM  SAVE DATA.
2420  GOSUB 2260: ONERR  GOTO 2510:ZIP = 2
2430  HOME : VTAB 10: PRINT "SAVING ";: INVERSE : PRINT "RTT "; LEFT$ (F$,8);" R/W ";RW$;" "; LEFT$ (RM$,9);: NORMAL : PRINT
     " FILE."
2440  PRINT D$;"OPEN RTT "; LEFT$ (F$,8);" R/W ";RW$;" "; LEFT$ (RM$,9)
2450  PRINT D$;"WRITE RTT "; LEFT$ (F$,8);" R/W ";RW$;" "; LEFT$ (RM$,9)
2460  PRINT P: PRINT DOFF: PRINT DTH: PRINT EYE: PRINT S
2470  PRINT F$: PRINT RW$: PRINT RM$
2480  FOR I = 1 TO P - 1: PRINT DX(I): PRINT DY(I): NEXT I
2490  PRINT XA: PRINT XB
2500  GOSUB 2270: GOTO 1570
2510  PRINT "": PRINT "BAD TRANSFER OF DATA!!!": PRINT "": FOR I = 1 TO 1000: NEXT I: POKE 216,0
2520  IF ZIP = 2 GOTO 2500
2530  GOSUB 2270: GOTO 1080
```

ATTACHMENT 11

TITLE

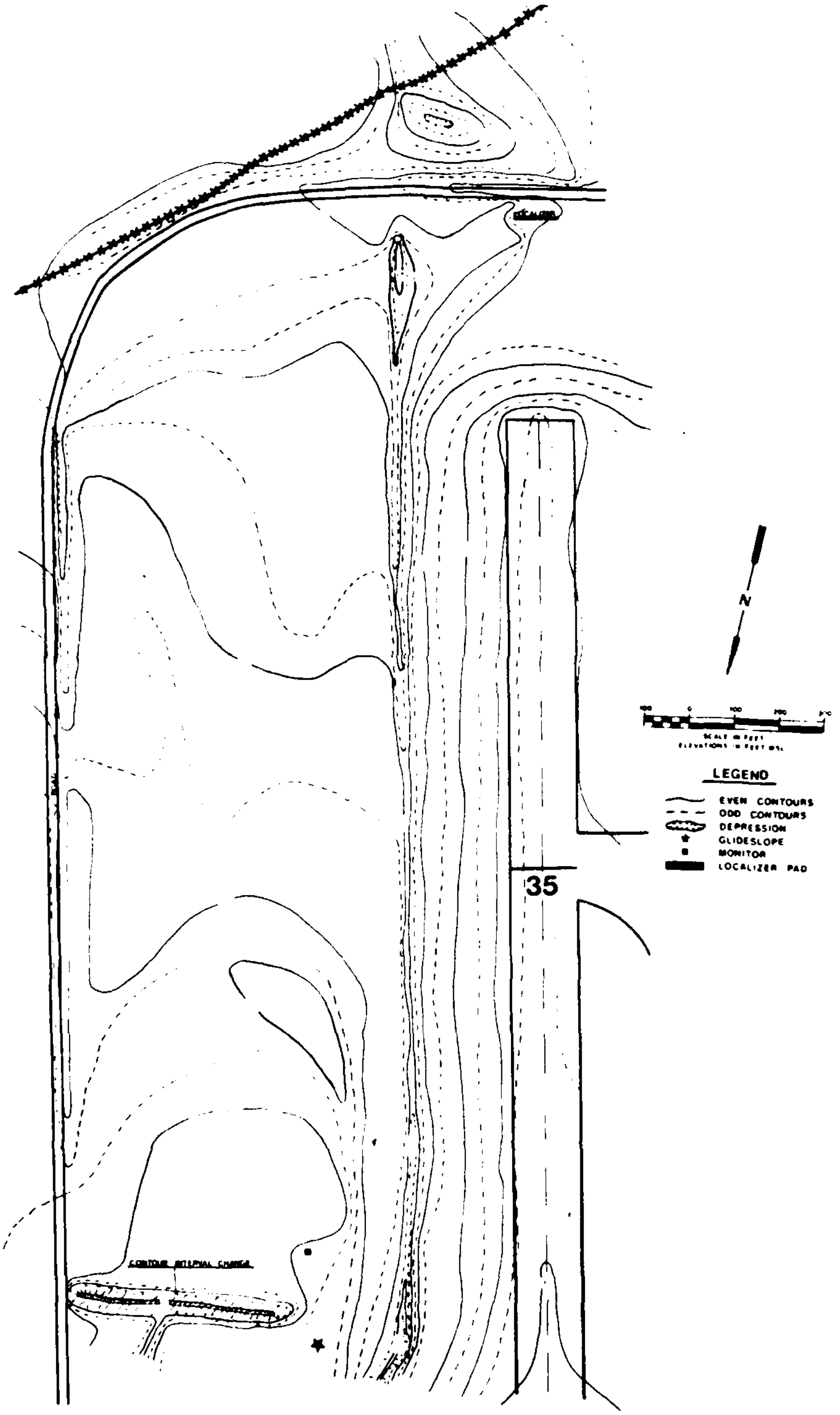
Glide Slope Contour Study

LOCATION

Myrtle Beach AFB

DATE

January 1982



REMARKS

TITLE:

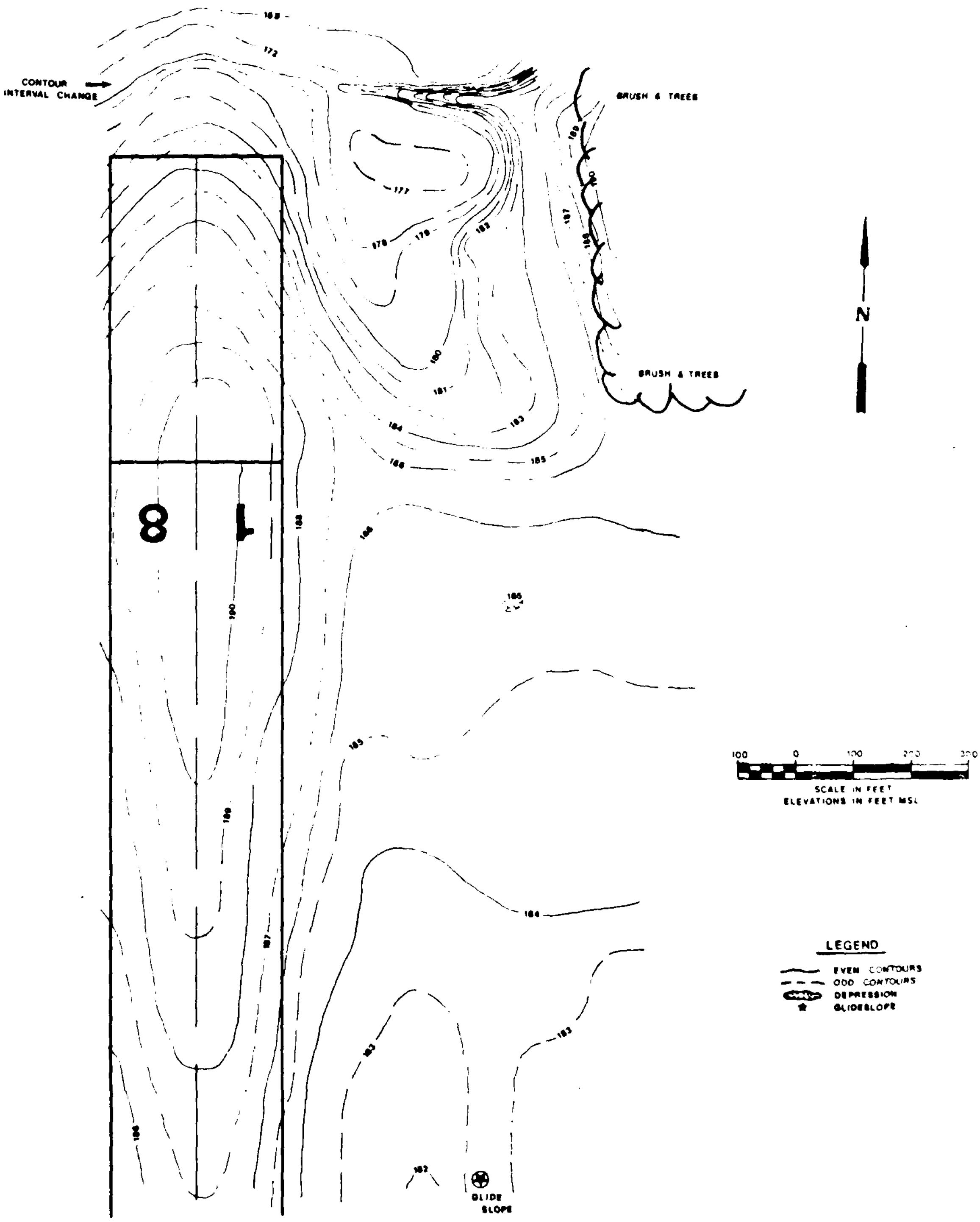
GLIDE SLOPE CONTOUR STUDY

LOCATION

Duke Field, Eglin Auxiliary 3

DATE

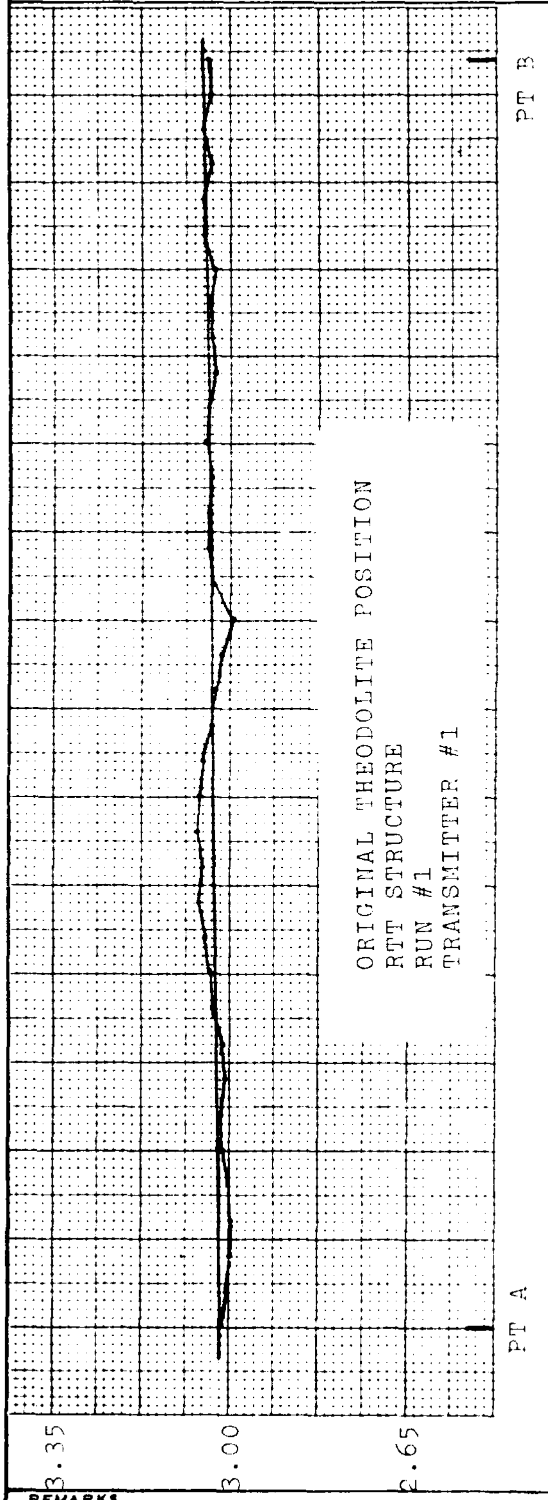
March 1982

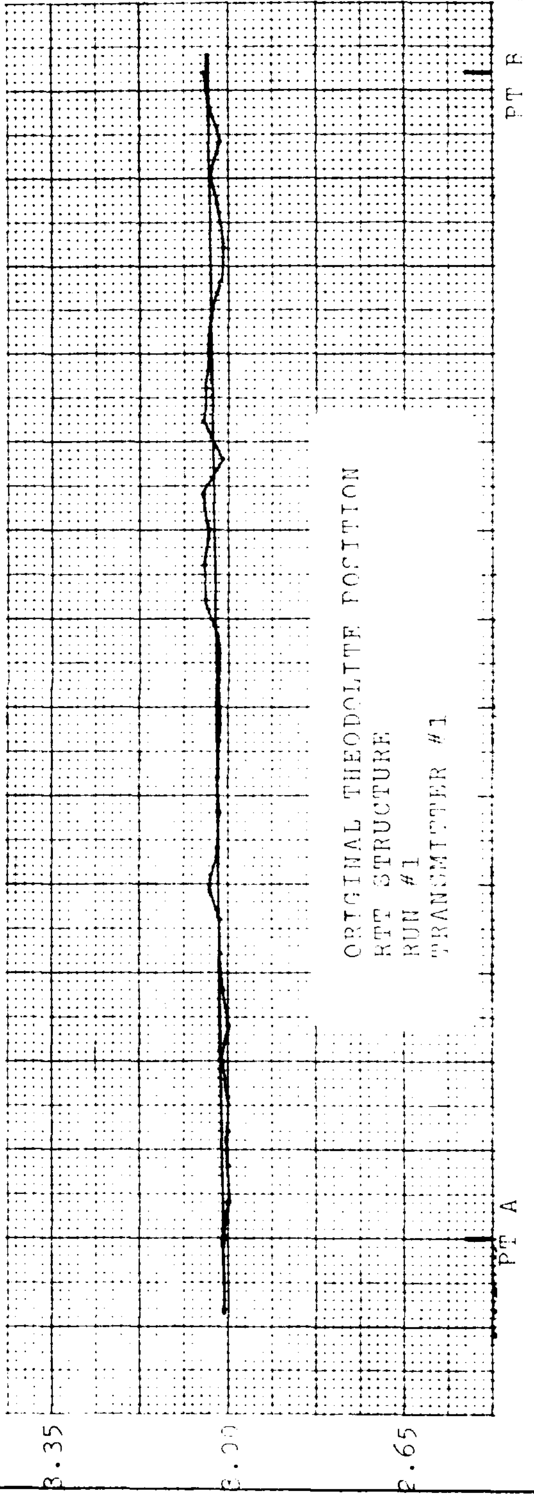


REMARKS

ATTACHMENT 12

TITLE RTT STRUCTURE RUNS	
LOCATION Myrtle Beach AFB	DATE February 1982





REMARKS

AFCS FORM MAY 73 906

ATTACHMENT 12

TITLE

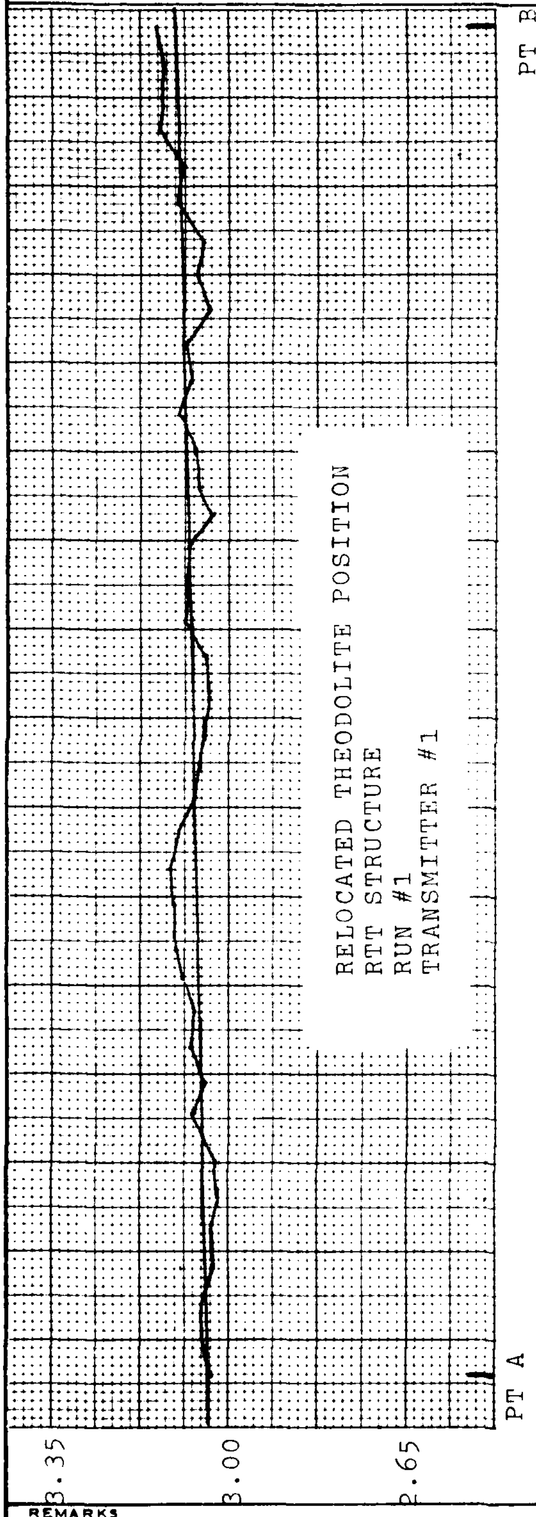
RTT STRUCTURE RUNS

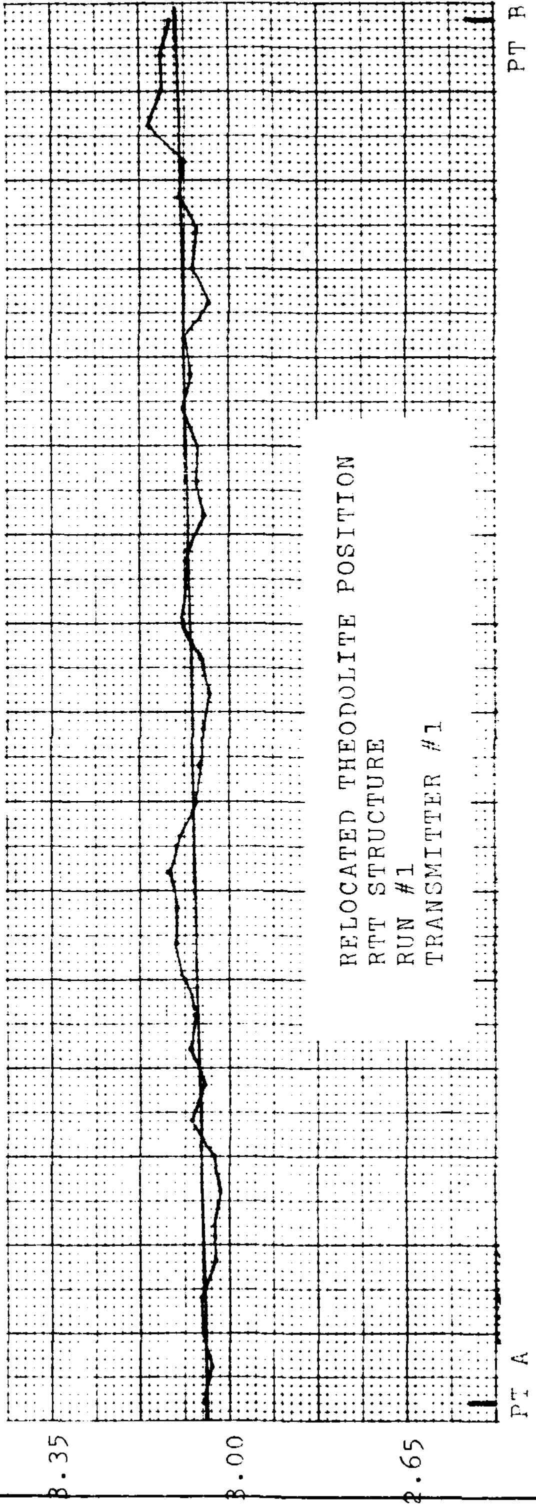
LOCATION

Myrtle Beach AFB

DATE

February 1982



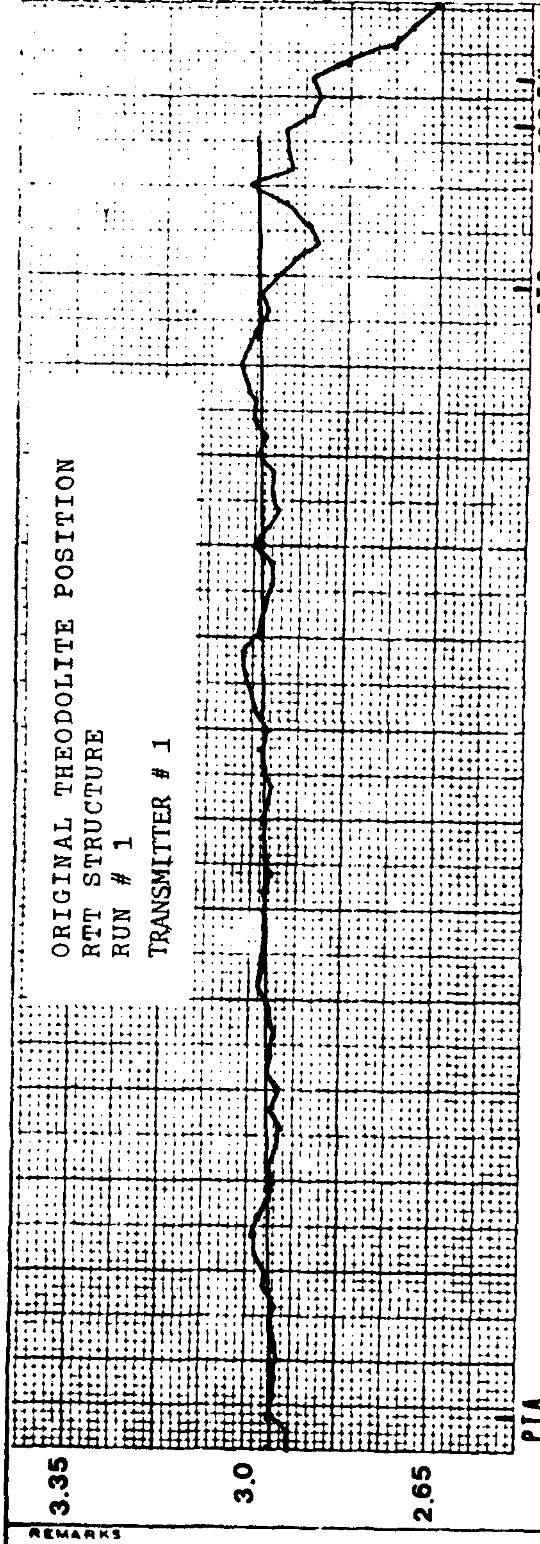


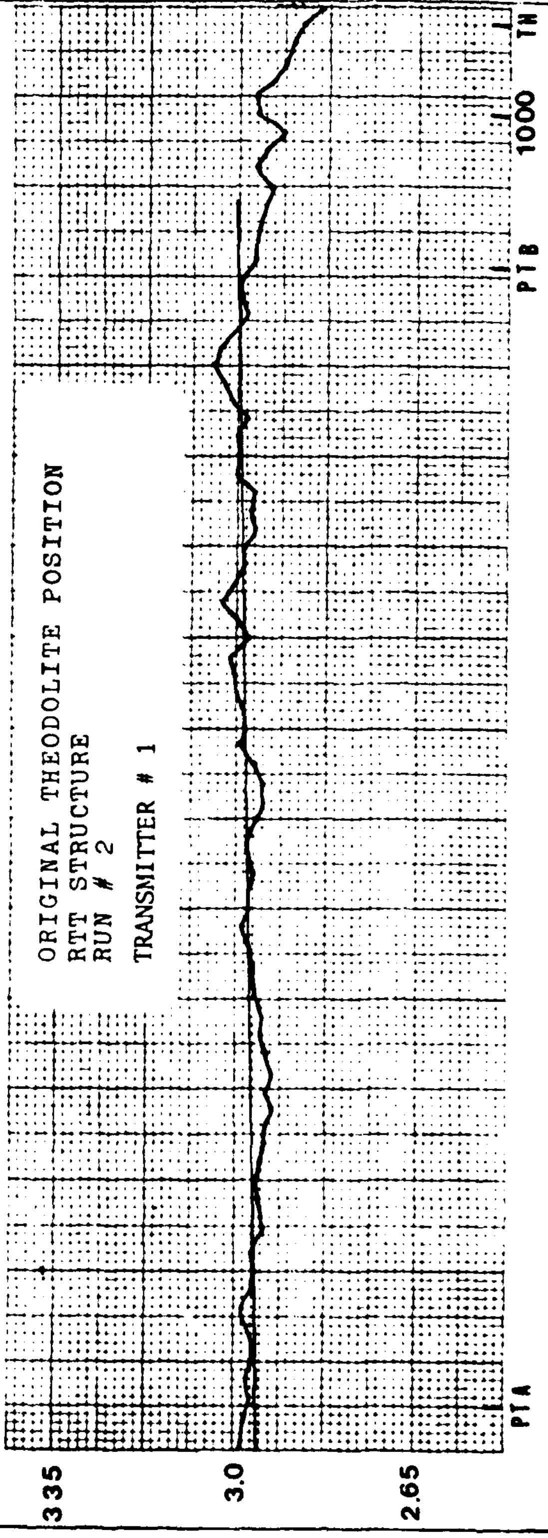
REMARKS

Distance moved is +60 feet from original position

ATTACHMENT 12

TITLE RTT STRUCTURE RUNS	
Duke Field Eglin Auxiliary 3	DATE March 1982


ORIGINAL THEODOLITE POSITION
RTT STRUCTURE
RUN # 1
TRANSMITTER # 1


ORIGINAL THEODOLITE POSITION
RTT STRUCTURE
RUN # 2
TRANSMITTER # 1

REMARKS

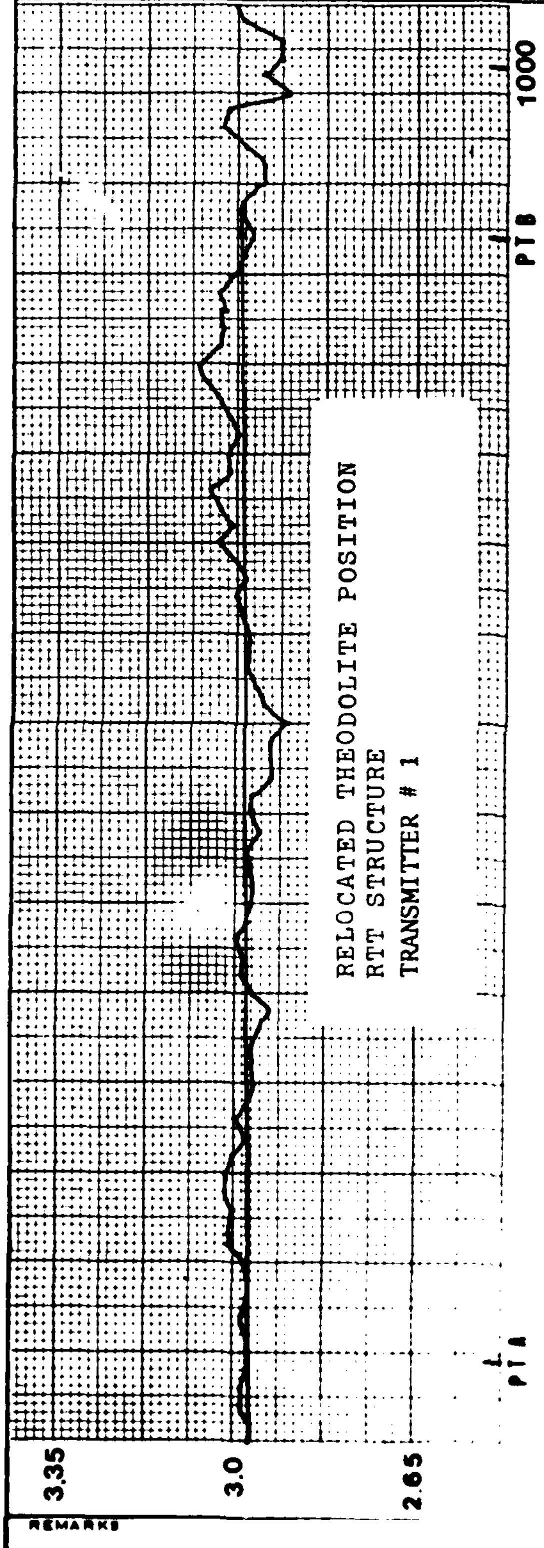
AFCC FORM MAY 73 906

ATTACHMENT 12

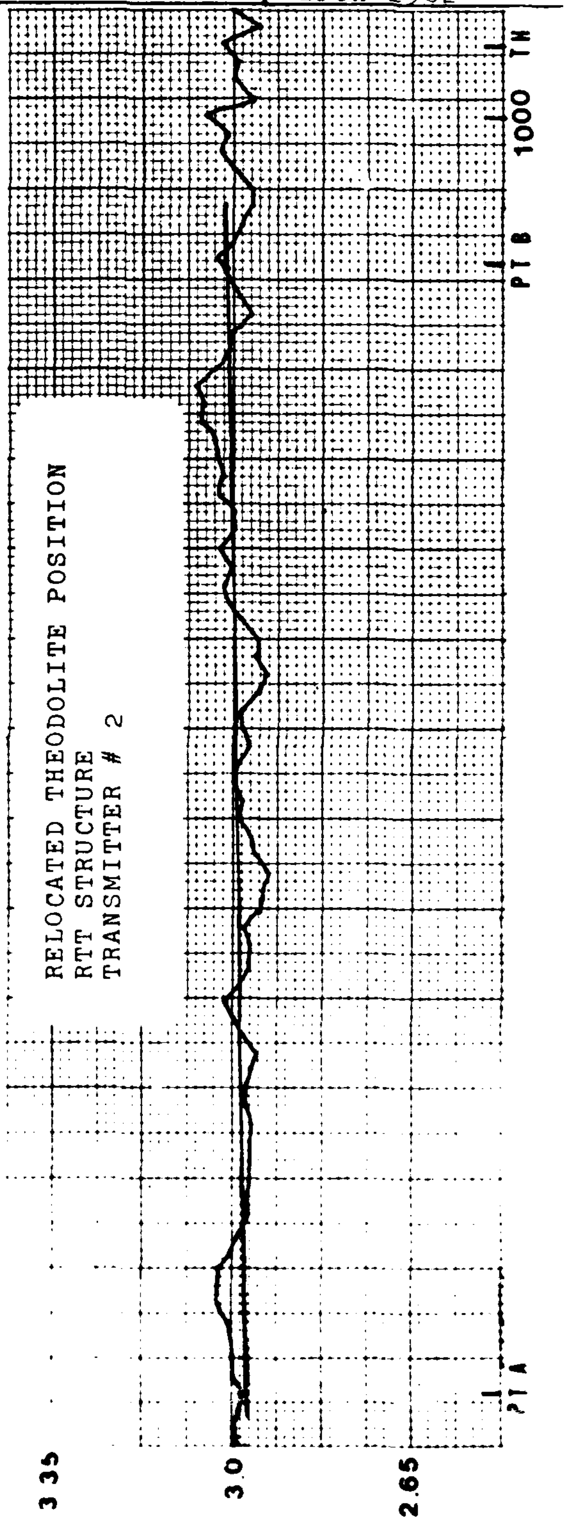
TITLE

RTT STRUCTURE RUNS

LOCATION	DATE
Duke Field Eglin Auxiliary 3	March 1982



RELOCATED THEODOLITE POSITION
RTT STRUCTURE
TRANSMITTER # 1



RELOCATED THEODOLITE POSITION
RTT STRUCTURE
TRANSMITTER # 2

REMARKS

[illegible] •40

AFCS FORM MAY 78 906