TECHNICAL MEMORANDUM
OU/AEC **07-10**TM-15689/0005-1

VALIDATION OF THE AUTOMATIC-FLIGHT-INSPECTION INSTRUMENT-LANDING-SYSTEM BEST FIT STRAIGHT LINE APPLICATION

The Federal Aviation Administration Flight Inspection Office is responsible for measuring and publishing the aircraft altitude at runway threshold known as Threshold Crossing Height (TCH). A Best Fit Straight Line (BFSL) algorithm is used to determine TCH for Category II/III facilities. The BFSL algorithm projects the aircraft glide path height at threshold. Aircraft altitude derived from the BFSL algorithm is designated as the Reference Datum Height. To validate the implementation of the BFSL algorithm used in the Automated Flight Inspection System, an independent assessment has been performed using similar data sets from two distinct flight inspection platforms. The results of this validation effort are presented in this memorandum along with recommendations.

by

David A. Quinet

Avionics Engineering Center
School of Electrical Engineering and Computer Science
Ohio University
Athens, Ohio 45701-2979

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Flt Prog Planning & Resource Team
P.O. Box 25082, HGR 8W, Room 206
Oklahoma City, OK 73125-0082

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Task 0005

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1.0 INTRODUCTION

1.1 Background

The concept of Reference Datum Height (RDH) has been defined in the United States for the last 21 of the 65-year ILS history. The motivation for the application of this term, which has found use internationally, came from both the Federal Aviation Administration (FAA) and U.S. Air Force needs. In 1982, Captain Harvey Leister of the United States Air Force Communication Command was concerned principally with the positioning of the reference system for evaluating the ILS glide slope. He observed that, in some cases, facilities were being disqualified principally because of the evaluation techniques being used. Certain glide slopes were failing commissioning tests due to out-of-tolerance path structure as specified in Reference 1. Per Reference 2, Captain Leister proposed applying a linear regression technique to determine where the reference theodolite should be placed to provide the best opportunity for obtaining in-tolerance structure measurements while still maintaining the necessary level-of-safety.

The concept of applying a linear regression analysis to landing system guidance has some attractive as well as unattractive features. For example, this type of analysis permits the aiming point (AP) for the aircraft to be at any location with respect to the transmitting antennas. On the other hand, it requires a point outside the data field to be defined by extrapolation in order to determine the RDH.

Lyle Wink of the FAA became involved in 1983 when he was tasked to incorporate some of the new concepts concerning application of the line of regression to the FAA flight inspection operation. Also, there was a need to make some glide paths, which were showing up as marginal and out of tolerance, acceptable. Because these glide paths were flown by flight inspectors, they were deemed to be safe in practice even though they did not meet published tolerances.

Wink's work is the basis for Reference 3 (included as Appendix A) which specifies the regression technique, i.e., Best Fit Straight Line (BFSL), used by FAA flight inspectors to qualify and commission glide slope facilities. Appendix A provides guidance for determining the RDH through application of the BFSL algorithm and also defines the Achieved Reference Datum Height (ARDH). ARDH yields a "close-in" measure of the glide-path-segment height over threshold. In addition, as a companion project, Wink developed the glide slope Threshold Crossing Height (TCH) requirements [4].

1.2 AFIS Validation

FAA AVN requested that the Avionics Engineering Center (AEC) at Ohio University (OU) provide an independent validation of the BFSL algorithm implementation used in the Automated Flight Inspection System (AFIS), Software Revision P2 (Release Number ENG-0306-P27-069). In particular, the following parameters were of interest on the ILS-3 NAVTEST Page 4:

- Z3 T HGT — Height of Zone 3 BFSL relative to the commissioned Glide Slope at threshold
- Z3 C HGT — Height of Zone 3 BFSL relative to the commissioned Glide Slope at Point C

- Z3 B HGT — Height of Zone 3 BFSL relative to the commissioned Glide Slope at Point B
- ARDH — Achieved Reference Datum Height
- Z3 BFPA — Zone 3 BFSL determined path angle
- Z3 BF RDH — Zone 3 BFSL Reference Datum Height
- Z3 BF GPI RNG — Zone 3 BFSL Ground Point Intercept as determined from Zone 3 RDH

Also of interest are the final reported values (average of last three results):

- Z2 BF PA — Z2 BF angle determined using the BFSL algorithm of the software. The angle is determined independent of the Glide Slope offset and glide slope elevation.
- ARDH — Achieved Reference Datum Height - NOTE: The final ARDH is computed by correcting the Z2BF angle to the commissioned angle, and then apply that difference to the Z3BF angle for a final ARDH height computation.
- Z2BF GPI — Zone 2 BFSL Ground Point Intercept using Zone 2 BFSL Reference Datum Height (average of 3 runs).

This report documents the results of this validation effort.

2.0 VALIDATION PROCESS

Using a King-Air flight inspection aircraft, FAA Flight Inspection collected eleven approaches at a single facility, Oklahoma City/Wiley Post Airport, Oklahoma City, Oklahoma (PWA). Electronic data files provided to AEC contained the following information:

Aircraft Position in NAD-83 Coordinates (Latitude, Longitude, Height)

Runway Data in NAD-83 Coordinates

Threshold (Latitude, Longitude, Height)

Bearing, Length and Magnetic Variation

Glide Slope Data in NGVD29 Coordinates

Mast Location (Setback, Offset, Height)

Commissioned Path Angle and Width

Glide Slope Deviation in microamperes

This data was processed using software developed by Ohio University to produce the Glide Slope Error vs. Distance-to-Threshold results. Figure 1 contains the flow chart for this processing.

A review of the AFIS software indicated that this initial processing took into account earth curvature. Further analysis indicated that this error is minor in computing RDH/ARDH. In fact, at four miles (the most sensitive location for the RDH calculation) the difference in altitude for earth curvature versus a flat earth is 14.10 feet. This introduces an error in the RDH calculation of 1.78 feet. In the Ohio University implementation, all values are converted to East-North-Up coordinates in a locally-level plane referenced to the runway threshold.

The output data, glide slope error/deviation, and distance to threshold were processed through the AFIS BFSL algorithm as documented in FAA Order 8200.47 (see Appendix A). Figure 2 contains the flow chart for this processing. Note that the aircraft pitch and roll attitudes are taken into account. A description of the implementation is contained in Appendix B. The output is listed below:

- BFSL Angle (degrees) Zone 2 and Zone 3
- Average Angle (degrees) Zone 2
- RDH (feet)
- ARDH (feet)
- Aiming-Point Adjustment (feet) Horizontal and Vertical

The FAA order [4] states that the commissioned glide-path angle must be used for the final calculation of the RDH once the aiming-point (AP) adjustment converges to less than 3.0 feet. Since the BFSL angle is the actual path angle and the average angle must be within ±0.05 degree of the commissioned angle (per 8200.1 Chapter 15, paragraph 15.60b), and assuming the 3-foot stipulation is met, then the BFSL and average angle will be in agreement such that any error introduced by using a value not measured (i.e., using the commissioned angle) could add up to 0.85 feet of error to the RDH. As the average/BFSL glide-path angle approaches the commissioned glide-path angle, the amount of error introduced is further reduced (see Figure 3).

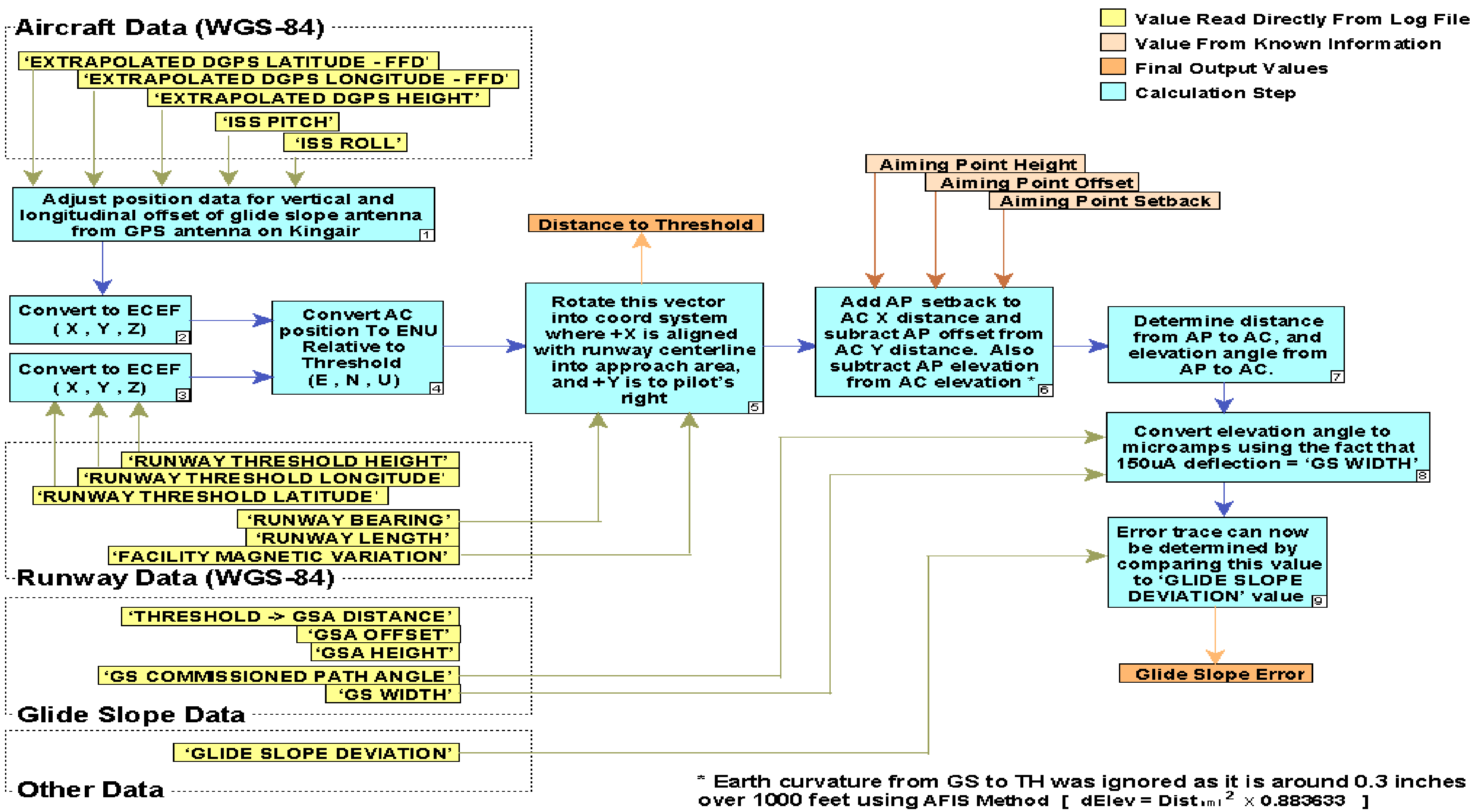

Figure 1. Flow Diagram -- Calculation of CDI Error vs. Distance-to-Threshold from Raw Data (Ohio University Software).

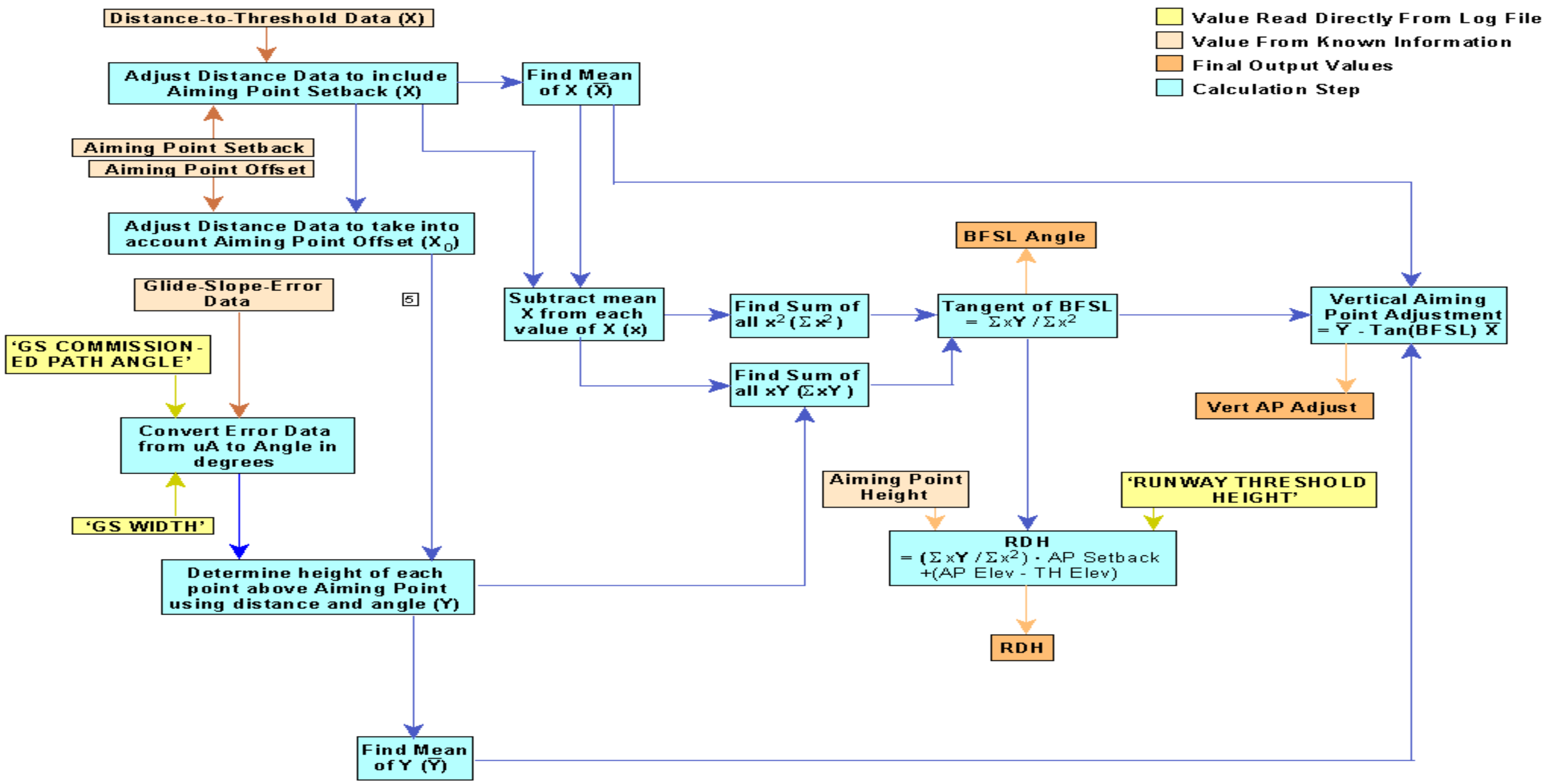

Figure 2. Flow Diagram -- AFIS Implementation of the RDH Algorithm (FAA Order 8200.47).

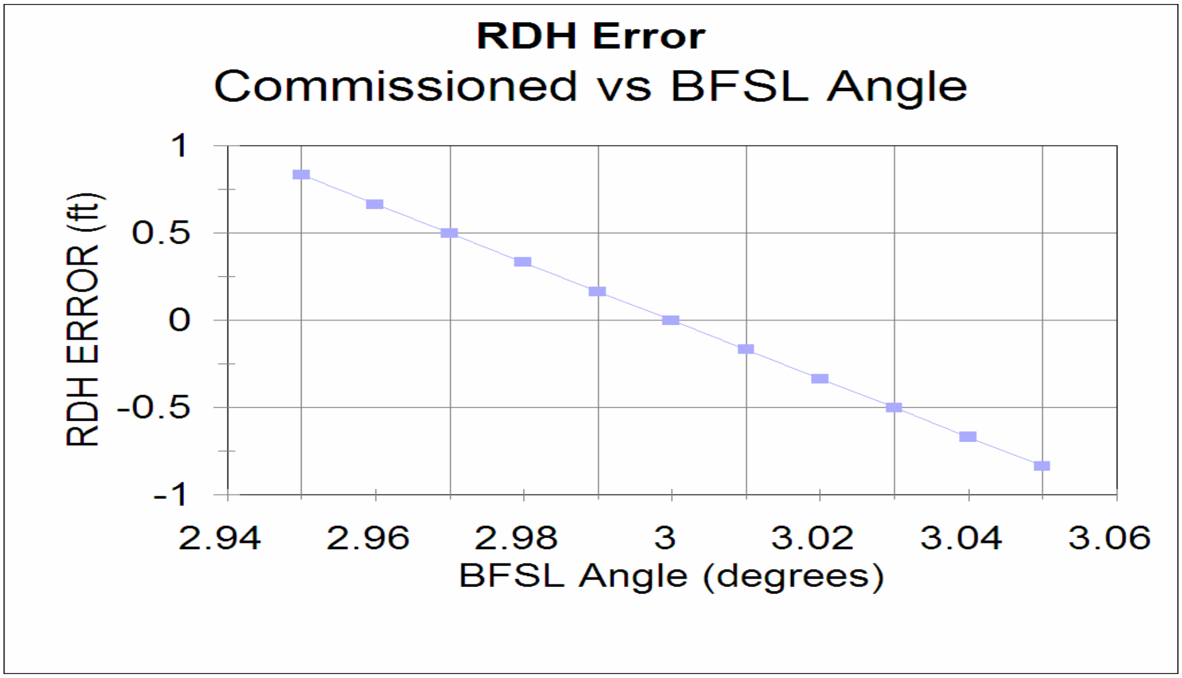

Figure 3. Potential RDH Error Introduced by Using the Commissioned Glide-Path Angle Instead of the Computed BFSL Angle (For a Commissioned Angle of 3 Degrees).

The data from each of the approaches at PWA was analyzed using the Ohio University data processing; these results were then compared with the AFIS-reported results (see Appendix C). A summary of these results is provided in Table 1 and shown in Figures 4 and 5.

Table 1. Summary Comparison Between Ohio University and AFIS Algorithm Results -- Eleven Approaches.

Parameter	Difference (OU-AFIS)	
	Mean	Standard Deviation
RDH (ft)	-0.21	0.30
ARDH (ft)	-0.71	0.84
BFSL (deg)	0.002	0.003
Average Angle (deg)	-0.007	0.023

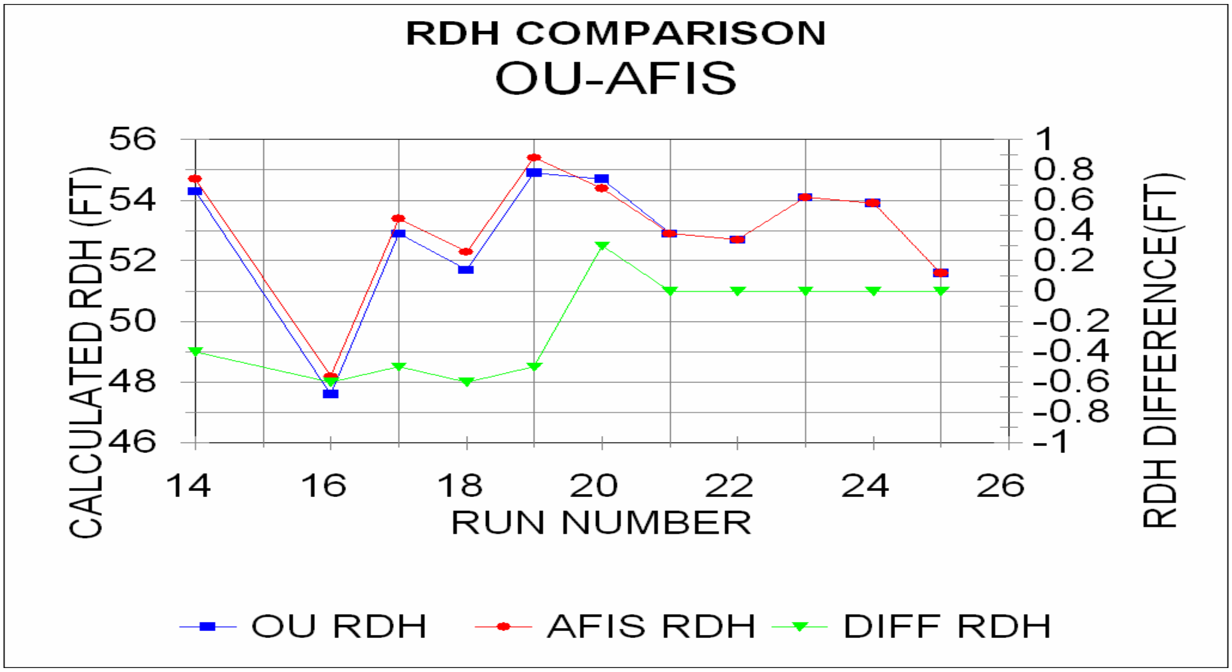

Figure 4. Comparison Between Ohio University and AFIS RDH Computed Values.

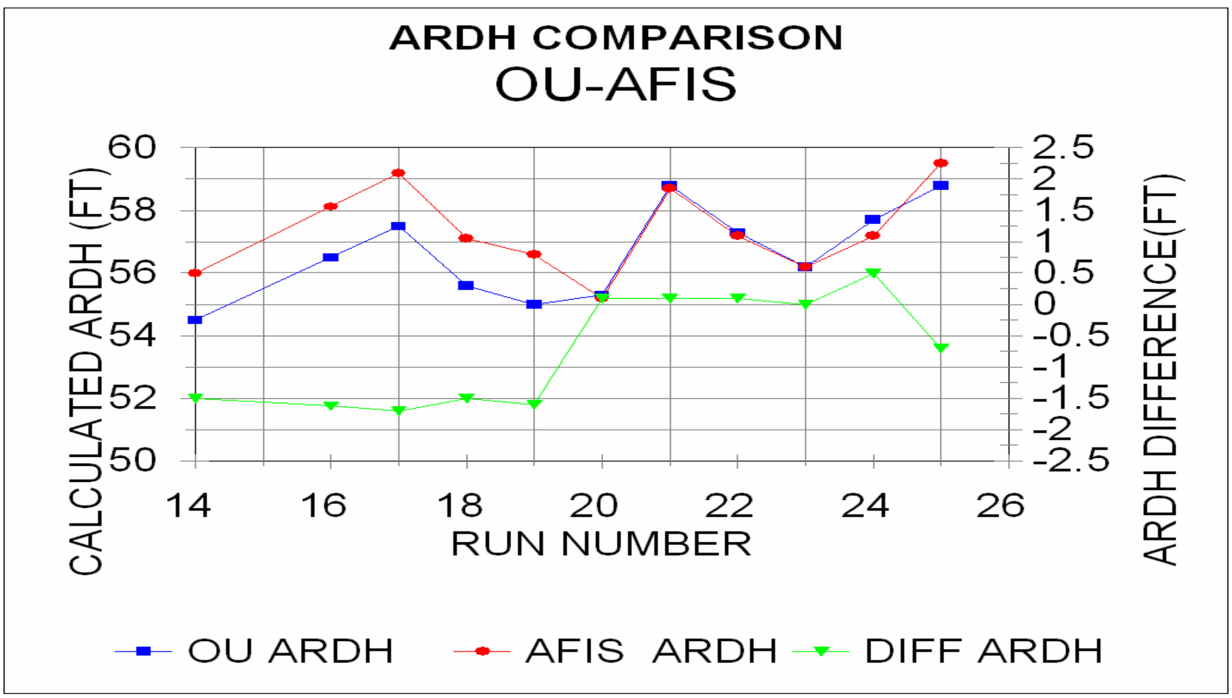

Figure 5. Comparison Between Ohio University and AFIS ARDH Computed Values.

Statistically, these results show that the differences between the two methods are insignificant. Differences in RDH/ARDH are a result of failure to obtain the same average/BFSL angle. In fact, from Runs 21-25, there are no differences in RDH, whereas prior, the differences were averaging 0.6 feet. To further investigate, the minimum and maximum CDI error values for all runs versus distance were determined; these are shown in Figure 6. The run-to-run variation in the CDI error measurement was most likely the cause for deviations in the RDH/ARDH values.

Also, considering that the greatest change in glide-slope error occurred near threshold, it is not surprising that there is more variation in the ARDH, i.e., closer-in, values.

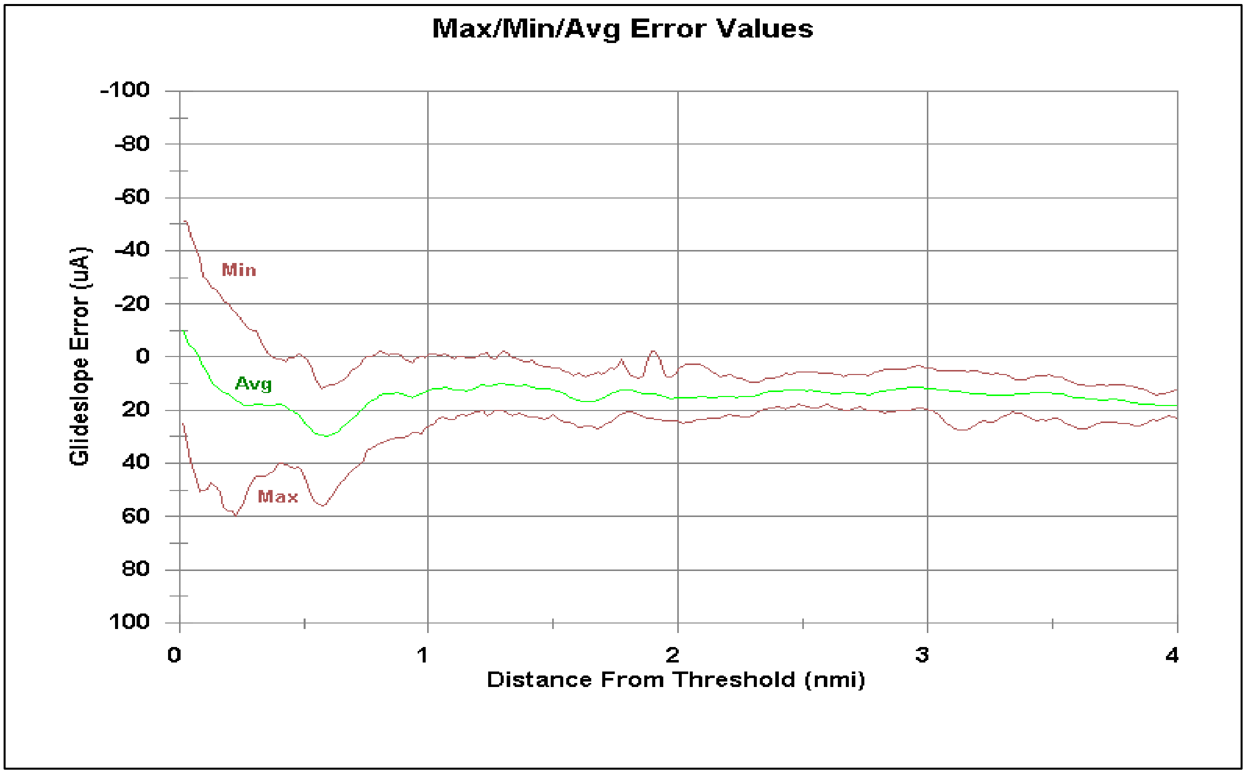

Figure 6. Minimum and Maximum CDI Error for the First Data Set Provided.

Since there were differences in the average angle, there must be differences in the CDI error being processed. To eliminate this difference, the printed CDI error trace was manually digitized and these data were processed with the Ohio University BFSL algorithm. A summary of these data is contained in Table 2 and the processed output in Appendix D. These results indicate that there is slightly more error introduced with the manual digitization process but that processing the raw AFIS CDI error data with the Ohio University BFSL algorithm remains accurate.

Table 2. Summary of Digitized CDI Error Data.

Parameter	Difference (OU-AFIS)	
	Mean	Standard Deviation
RDH (ft)	4.02	0.037
ARDH (ft)	-0.815	1.39
BFSL (deg)	-0.07	0.01
Average Angle (deg)	-0.067	0.028

Since there was a variation in the parameters and the run-to-run repeatability of the structure roughness, another set of flight inspection data was collected by FAA Flight Inspection at PWA using a Lear Jet. This data set was subsequently provided to AEC for processing. Appendix E contains the processed output and the results are summarized in Table 3. The reference system used in the King Air for flight inspection is inertially based. Data collected onboard are corrected using information obtained as the aircraft passes both the runway threshold and runway stop end. The Lear Jet, on the other hand, uses Differential GPS (DGPS) information for generating flight-inspection data corrections. Figure 7 shows the variation in CDI error.

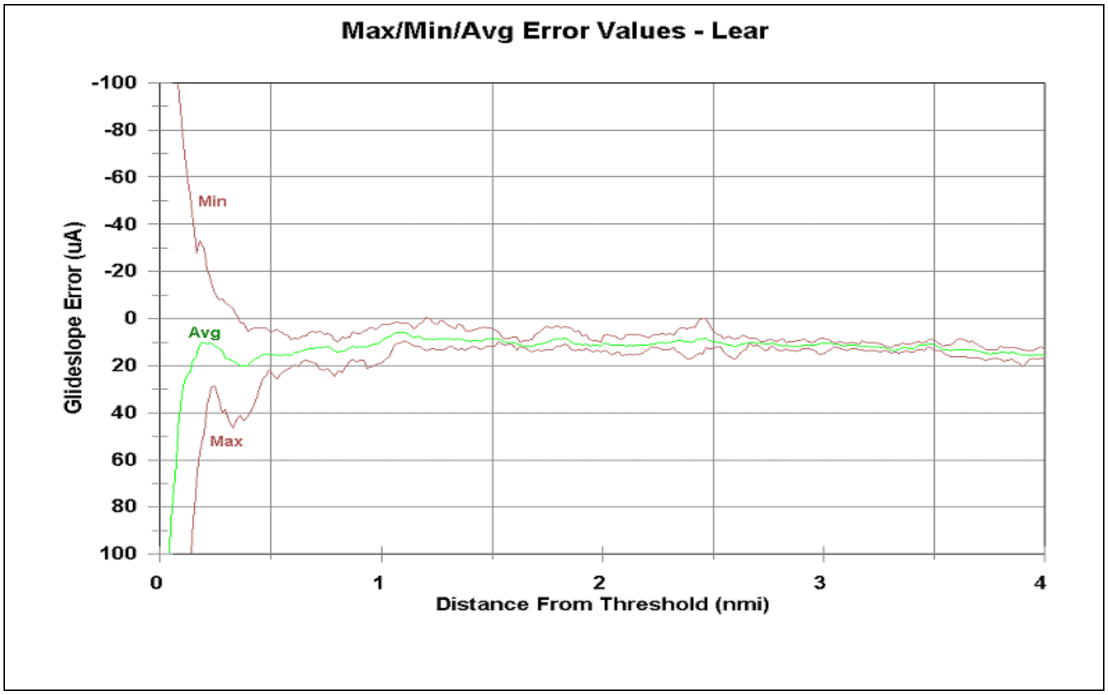

Figure 7. Minimum and Maximum CDI Error for the Second Data Set Provided.

Table 3. Summary of Lear-Jet Data Set.

Parameter	Difference (OU-AFIS)	
	Mean	Standard Deviation
RDH (ft)	Not Available	Not Available
ARDH (ft)	Not Available	Not Available
BFSL (deg)	0.005	0.001
Average Angle (deg)	0.058	0.018

FAA Order 8200.47, Appendix I, Section 4(a), suggests that 20 equal line segments be used to calculate the BFSL. This equates to 21 data points. The AFIS currently utilizes all points collected during the approach, and upwards of 2000 points are processed to determine the BFSL. The Ohio University software was modified to select 20 equal line segments (21 data points) for processing. Table 4 shows a comparison between the use of all points for a randomly-selected run versus a reduced set of 21 data points. Appendix F contains a summary of the results for each run in the first data set, i.e., the King Air.

Table 4. Comparison Between Use of All Data Points Versus Use of 21 Data Points in the BFSL Algorithm for Run #14 of the First Data Set.

Parameter	21 Data Points	All Data Points
RDH (ft)	47.8	47.7
ARDH (ft)	55.3	56.0
BFSL (deg)	3.059	3.063
Average Angle (deg)	3.100	3.103

Based on these results, it appears there is minimal difference between using all of the measured data points versus a reduced 21-point sample of the data. No further adjustment is required if the AP adjustment is less than 3.0 feet. The first data set was reprocessed and the RDH and ARDH values were computed when the required AP adjustment was varied from -3, -2, -1, 0 and 1, 2, 3 feet, respectively. The results are shown in Figure 8. Based on this figure, the RDH value varies by as much as 6 feet, whereas there is no variation in the ARDH.

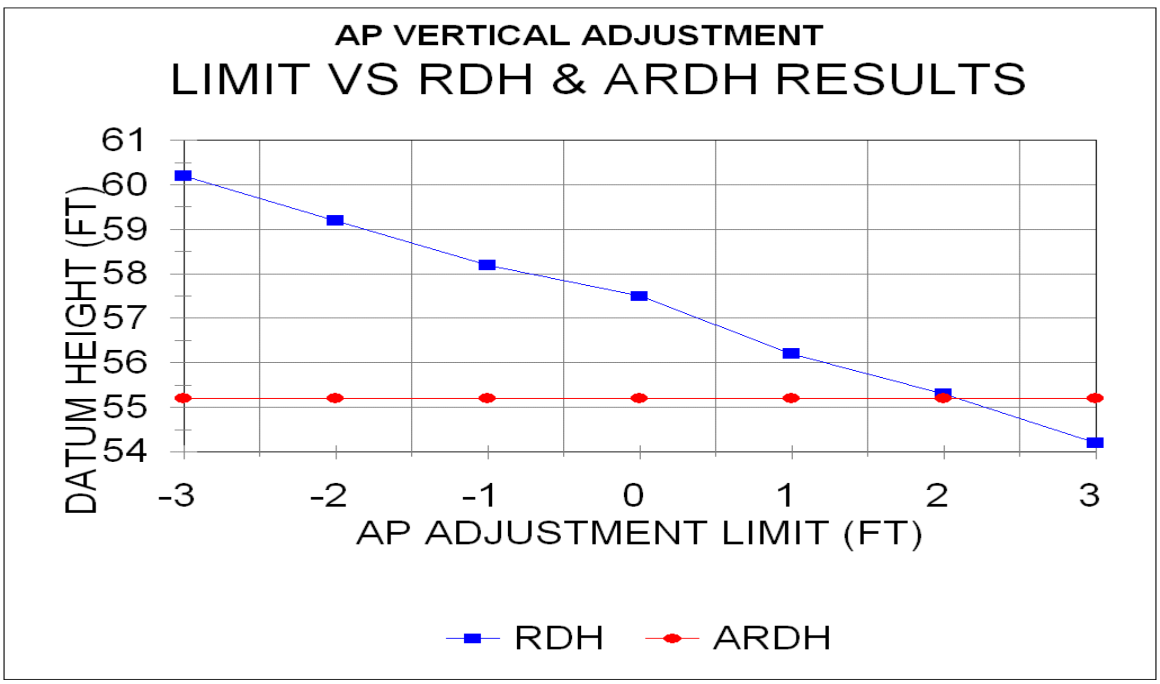

Figure 8. Range of RDH and ARDH with AP Height Adjustment When Limited to ±3 Feet.

Discussions with the FAA Navigation and Landing System National Resource Engineer (NRE) indicated that the AP reference point is now located on runway threshold. The King-Air data set was reprocessed with the AP referenced at (0, 0, 0). The results are shown in Table 5. By using the threshold reference, the AP vertical adjustment is the RDH value. Since the BFSL angle is not dependent on the AP, the values are very close to those reported by the AFIS. However, since the AP now differs significantly in height, the average angle and structure roughness no longer accurately represent the actual radiated signal. Fortunately, the BFSL, RDH, and ARDH values are not dependent on the AP and appear reasonably close to the actual radiated signal. As an initial starting point, use of the threshold for the offset (Y), setback (X), and TCH (Z) values would provide a common location for measuring all facilities. With Z equal to the TCH, the average angle and structure roughness would be close to the actual radiated signal.

Table 5. Summary of Results with AP Referenced to Runway Threshold (0,0,0) (King-Air Data Set).

Parameter	Difference (OU-AFIS)	
	Mean	Standard Deviation
RDH (ft)	-.422	.4043
ARDH (ft)	-.7414	0.7647
BFSL (deg)	0.006	0.002
Average Angle (deg)	0.2788	0.0318

The first data set was reprocessed using the threshold and the TCH. These results are summarized in Table 6 and indicate that through the use of this method, average angle and difference between RDH and ARDH are minimal.

Table 6. Summary of Results with AP Located at the TCH Height at Runway Threshold (0,0,54.0) (King-Air Data Set).

Parameter	Difference (OU-AFIS)	
	Mean	Standard Deviation
RDH (ft)	0.258	0.603
ARDH (ft)	-.680	.732
BFSL (deg)	0.0048	0.002
Average Angle (deg)	0.2556	-0.31

3.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the data processed, the following conclusions have been reached:

1. The implementation of the RDH/ARDH calculations in the proposed Automated Flight Inspection Software (AFIS) appears to provide accurate results; however, this implementation is not consistent with FAA Order 8200.47. The current AFIS flight inspection implementation does not take the glide-slope-mast setback into account.

2. The variation in measured structure roughness is the major cause of differences among the RDH/ARDH and BFSL values. Based on the flight-inspection data set from the Lear Jet, use of DGPS as a truth reference system provides more repeatable structure roughness results. Run-to-run variations in average angle and BFSL angle are the result of lack of repeatability between flight measurements. If difficulty is encountered in obtaining repeatable RDH values given a site that has significant path roughness, consideration then should be given to using the DGPS for this measurement.

3. The requirement in the current Order of .47, that the aiming-point converge to within ±3.0 feet introduces a reported RDH error of up to ±3.0 feet. Such an error in RDH can consume up to 60% of the error-budget requirement. In addition, using the commissioned angle to compute the RDH value instead of the measured value can also add an additional 0.9 feet of error. The potential of both of these errors may result in the RDH not meeting the requirements.

The following recommendations are made with regard to measuring the RDH for glide slope facilities.

1. The aiming-point (AP) vertical limit adjustment or Latitude/Longitude position should be replaced with a difference between the average path angle and BFSL angle of ±0.03 degrees. This will reduce the potential error from 3.0 feet to 0.5 feet. Additionally, the BFSL angle should also be used in the final RDH calculation and not the commissioned angle. This will also reduce the error in the RDH calculation.

2. The effect of the earth curvature is minor and consideration should be given to an AFIS implementation using East-North-Up coordinates with the locally-level plane referenced to the runway threshold. If another method is currently implemented then a change should not be made to the software.

3. To standardize the AP reference for measuring glide slope facilities, the initial reference point should be the runway centerline at threshold with a height equal to the TCH.

4. The DGPS reference system appears to provide more repeatable facility measurements and most likely will minimize run-to-run variation. Consideration should be given to using the DGPS reference system when applying FAA Order 8200.47 at new as well as existing facilities which exhibit unrepeatable RDH measurements or significant path roughness.

4.0 REFERENCE DOCUMENTS

[1] *United States Standard Flight Inspection Manual*, Federal Aviation Administration Handbook O AP 8200.1.

[2] Leister, Harvey, *A Procedure for RTT Position Improvement Using a Linear Regression Analysis of Glide Slope Structure*, SRDS Report No. RD-69-4, January 1969.

[3] *Determination of Instrument Landing System (ILS) Glidepath Angle, Reference Datum Heights, and Ground Point of Intercept*, FAA Order 8240.47.

[4] *Glide Slope Threshold Crossing Height Requirements*, FAA Order 8260.34.

[5] McFarland, Richard H., *Investigation of Reference Datum Height (RDH) Values at Jacksonville Craig Runway 32*, OU/AEC 97-25TM00019/2.3F-1, Avionics Engineering Center, Ohio University, Athens, Ohio, September 1997.

[6] *International Standards and Recommended Practices*, Aeronautical Telecommunications, Annex 10, International Civil Aviation Organization (ICAO).

APPENDIX A. DETERMINATION OF INSTRUMENT LANDING SYSTEM (ILS) GLIDEPATH ANGLE, REFERENCE DATUM HEIGHTS (RDH), AND GROUND POINT OF INTERCEPT (GPI)

ORDER

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

8240.47C

03/01/01

SUBJ: Determination of Instrument Landing System (ILS) Glidepath Angle, Reference Datum Heights (RDH), and Ground Point of Intercept (GPI)

1. PURPOSE. This order prescribes the method by which the actual flight inspection glidepath angle, instrument landing system (ILS) reference datum height (RDH), achieved ILS reference datum height (ARDH), and ground point of intercept (GPI) are determined.

2. DISTRIBUTION. This order is distributed to the branch level in the National Procedures Office and Flight Inspection Operations Division in Aviation System Standards, to the branch level in the National Airway Systems Engineering Division, Washington headquarters; to the branch level in the regional Airway Facilities and Flight Standards divisions; to the International Flight Inspection Office; all Flight Inspection Offices; and special military addressees.

3. CANCELLATION. Order 8240.47B, dated November 12, 1996, and Change 1, dated March 18, 1997, are canceled. Genot 8240.36, dated February 17, 1999, is also canceled.

4. BACKGROUND. Prior to the inception of this order, the documented threshold crossing height and (TCH) ground point of intercept (GPI) were calculated procedural values based on ground geometry. The revised inspection methods contained in this order will analyze glide slope performance based on actual achieved results, not theoretical values. The methods presented provide flexibility in siting glide slope facilities while preserving the critical aspects of assuring adequate wheel crossing heights at the threshold. This revision includes changes to some definitions, defines when this order should be applied, clarifies required procedural actions, authorizes the use of achieved ILS RDH (ARDH) for certain glide slope facilities, and authorizes the application of this order on U.S. military glide slopes.

5. EXPLANATION OF CHANGES.

a. Paragraph 6e: Redefines Aiming Point.

b. Paragraph 7f: Clarifies end fire glide slope application.

c. Paragraph 7g: Adds guidance following a Mark 20 glide slope conversion.

d. Paragraph 9a: Redefines aiming point coordinates when using AFIS.

e. Paragraph 11b: Clarifies use of ARDH.

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A-X (AF/FS)-3; A-FFS-4(All);
Special Military Addressees**

Initiated By: AVN-230

6. DEFINITIONS.

a. Best Fit Straight Line (BFSL). A straight line segment of the glidepath derived by using a least squares mathematical technique. The slope of this straight line defines the height of the glidepath angle relative to the approach surface baseline and threshold. Upon application of this order, the BFSL in ILS Zone 2, projected through the threshold to the runway surface, becomes the RDH reference.

b. ILS Reference Datum Height (RDH). The height of the commissioned glidepath located vertically above the runway threshold. The RDH is derived by computing the glidepath between points “A” and “B” and by projecting an extension of this glidepath through the threshold. The RDH value replaces the mathematical procedural TCH value when this order is applied. RDH is synonymous with the ILS reference datum as defined in the International Civil Aviation Organization (ICAO) Annex 10.

Figure 1
Calculated TCH

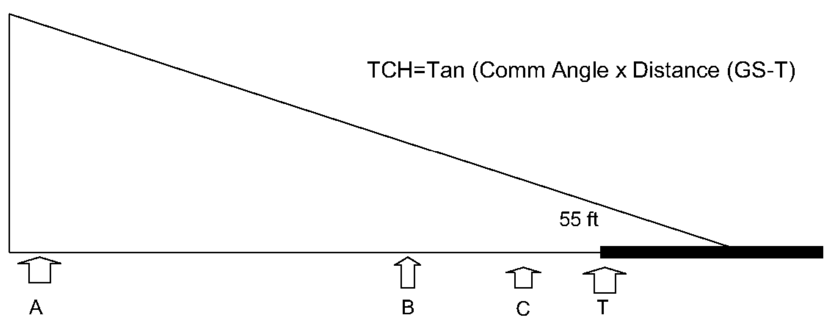
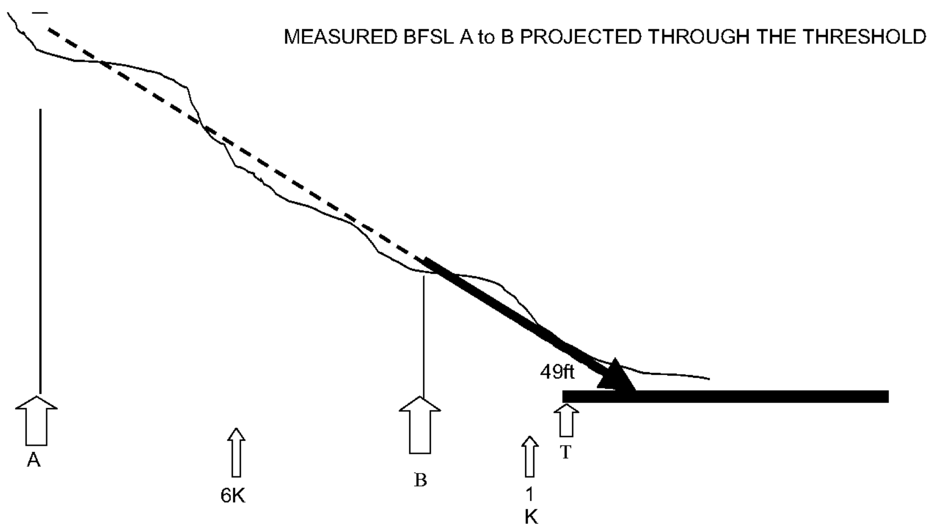
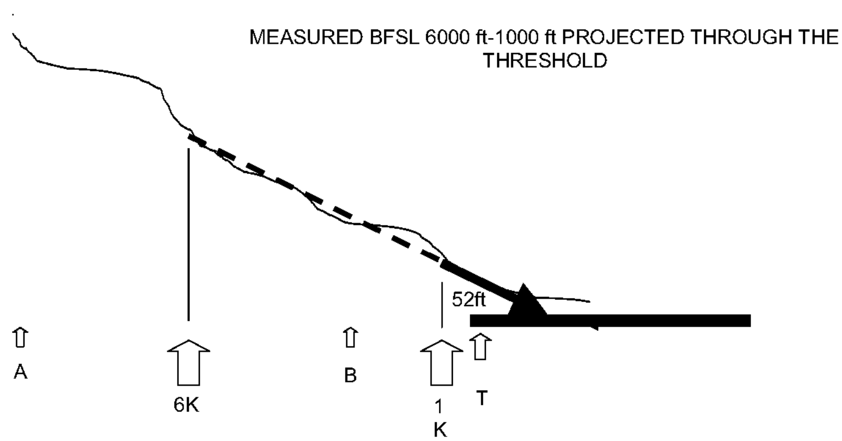


Figure 2
RDH



c. Achieved ILS Reference Datum Height (ARDH). The height that the "close in" glide path segment crosses the runway threshold. The ARDH is derived by computing the BFSL glidepath between 6,000 feet and point "C" and projecting the downward extension through the threshold.

Figure 3
ARDH



d. Glide Slope Origination Point. Prior to the application of this order, it is a calculated point, generally at the center or base of the glide slope antenna array, which has been defined by engineering to be the point of theoretical signal emanation. After the application of this order, this point is redefined to be the same as the aiming point latitude, longitude, and elevation (AFIS glide slope height).

e. Aiming Point. A location which is programmed into the automated flight inspection system (AFIS) from which glidepath measurement results are referenced. The aiming point may not be coincident with the glide slope origination point. For application of this order using AFIS, the AFIS will be programmed to use, as the measurement reference, the glide slope latitude (GLA) and longitude (GLO) coordinates which coincide with the point on the commissioned localizer course which is abeam the theoretical glide slope origination point. In the current FAA facility database, this is defined as AIM-PT LAT/LON.

7. APPLICATION. This order shall be used to establish the glidepath angle, RDH, ARDH, and GPI for all U.S. civil and military glide slope facilities regardless of "Official Category" proposed to provide published or "Special" Category II/III approach minimums. Paragraphs 7a, 7b, 7c, and 7d define those conditions that shall require application of this order for all Category II/III facilities, as well as any Category I facilities proposed to support Special Category II/III minima. Paragraph 7e may be applied for all other Category I type facilities if jointly deemed advantageous by flight inspection and facilities engineering personnel. Paragraph 7g provides additional guidance for determining if the application of this order shall be required on a Mark 20 glide slope conversion. Application to non-U.S. facilities shall be discussed with the facility managers and may be requested by the owning nation. When applying the provisions of this order, use the AFIS program for calculating glidepath angle, RDH, ARDH, and GPI.

a. Site, commissioning, and initial categorization inspections.

b. Reconfiguration or special inspections as a result of a glide slope site relocation.

c. A change to the glide slope antenna configuration (null reference to capture effect, etc.)

d. Site improvements which change the documented aiming point or threshold elevation by more than 3 feet.

e. To establish a flight inspection aiming point for CAT I glide slopes when:

(1) All the requirements for a Category I glide slope commissioning are satisfactory in accordance with FAA Order 8200.1, United States Standard Flight Inspection Manual, Section 217.

(2) The flight inspection derived RDH meets the criteria of FAA Order 8260.3, United States Standard for Terminal Instrument Procedures (TERPS).

(3) Procedural review does not identify new obstacle penetrations or require a waiver to FAA Order 8260.3, United States Standard for Terminal Instrument Procedures (TERPS).

f. End Fire Glide Slope. Initial reference aiming point elevation corrections exceeding ± 3 feet shall be reported to the installation engineer. Engineering personnel may request a normal transverse structure evaluation in lieu of an approach to establish adjustment references. Changes to site elevation for use as the AFIS aiming point elevation shall only be accomplished by coordinating with the facilities engineering personnel. Following adjustments, conduct additional AFIS approach evaluations.

g. Guidelines following a Mark 20 glide slope conversion. If the following requirements are met, the application of this order is not required.

(1) Facility is currently classed as a Category II/III glide slope.

(2) Prior to the conversion, the RDH was satisfactory by application of FAA Orders 8240.47, 8240.47A, or 8240.47B.

(3) No change in glide slope radiation characteristics, such as a null reference to a capture effect, or significant (as determined by engineering) change to siting environment, etc.

(4) All requirements of FAA Order 8200.1A, United States Standard Flight Inspection Manual, are completed satisfactory.

(5) The facility was not relocated.

8. COMMISSIONING SEQUENCE. Facilities engineering, flight standards operations, and procedures personnel shall agree on the **proposed** glidepath angle, TCH, and GPI when a location has been selected for a glide slope installation. These values will be based on operational requirements, obstruction considerations, and siting constraints.

a. Engineering. Evaluate siting conditions and install the antenna at a position which should provide a glidepath conforming to the **proposed** values. After the flight inspection, a procedural review of the achieved values will be accomplished using the flight inspection derived data. If the changes result in an obstruction penetration, RDH (TCH) problems, facility restrictions, etc., the glide slope antenna may have to be relocated to a more optimal position. Facilities not meeting RDH requirements for Category II/III glide slope commissioning and that are otherwise satisfactory in accordance with FAA Order 8200.1, Section 217, shall be commissioned as Category I until a waiver is issued or the problem corrected.

b. Procedures Development. Procedures will conduct the initial evaluations and perform calculations using the installation values referenced in paragraph 8a. If the flight inspection derived aiming point elevation exceeds ± 3 feet of the original aiming point elevation, a procedural reevaluation of the TCH, GPI, and the final approach obstacles is required. Upon application of this order, the flight inspection derived RDH values shall replace the calculated TCH value for the procedure under evaluation.

c. Flight Inspection. When engineering has installed the glide slope and it is ready for evaluation, check the glidepath and determine the actual angle, RDH, ARDH, and GPI using the BFSL procedures in this order. All elevations, including the final RDH/ARDH, shall be rounded to the nearest foot in accordance with FAA Order 8200.1, Section 302. RDH/ARDH rounding to achieve tolerance is acceptable, provided all glide slope angle and structure parameters are satisfactory in accordance with the requirements of FAA Order 8200.1, Section 217.

d. Facility Data. When the aiming point elevation used during the flight inspection evaluation changes, facility data shall be updated to reflect the flight inspection derived reference elevation. The final AFIS data shall be the reference data for all subsequent glide slope flight inspections. Notify the appropriate procedure development office of any changes to the initial reference elevation, as well as the RDH, ARDH, and GPI associated with the new elevation.

9. FLIGHT INSPECTION PROCEDURES FOR AN AUTOMATED FLIGHT INSPECTION SYSTEM (AFIS).

a. Programming the AFIS. Program the glide slope latitude (GLA) and longitude (GLO) coordinates to coincide with the point on the commissioned localizer course which is abeam the glide slope origination point. Enter the glide slope AIM-PT LAT/LON from the data sheet for AFIS GS LAT/LON. Enter the glide slope CL-ELEV-ABM elevation for AFIS GS HGT. For AFIS GS OFF, enter 1L.

(1) For glide slope facilities with unusual siting characteristics, engineering/installation personnel may request to modify the glide slope origination point as referenced in FAA Order 8200.1A, Section 217. This request shall only apply to Category I glide slopes evaluated in accordance with paragraph 7e of this order. If and only if, the Flight Inspection Operations Division, AVN-200, approves the requested deviation in writing, the glide slope may be commissioned for Category I operation. The written approval shall be incorporated into the facility reference data file (FRDF).

(2) An alternative method of computing the initial reference elevation if no other source is available may be accomplished as follows:

(a) Add the proposed TCH to the threshold MSL elevation.

(b) Multiply the tangent of the proposed commissioned angle by the aiming point distance to the threshold.

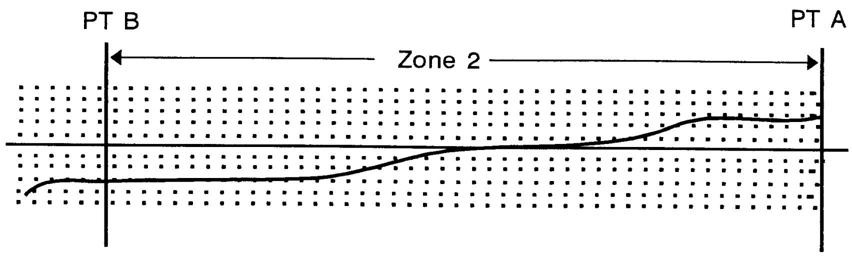
(c) Subtract result of Step b from the preceding TCH + threshold MSL elevation (Step a). Insert this elevation value into the AFIS as the glide slope height.

b. Optimizing. Complete the glide slope transmitter modulation balance, phasing (if required), and optimize the glide slope path width and angle to within commissioning tolerances.

c. Data Collection. Conduct at least three glide slope approaches that produce similar trends in the AFIS Zone 2 corrected error traces. This similarity is required to ensure accurate and repeatable results. On previously commissioned glide slopes, current AFIS ILS-3 evaluations can be used to determine whether or not application of this order is feasible. Current ILS-3 data shall only be used provided the width and angle are within commissioning tolerances. Actual implementation will require a flight inspection documented in accordance with the provisions of this order.

d. Analysis. Refer to the AFIS Zone 2 corrected error trace (Figure 4). If a skew in the trace is present, it is indicative of a change in the glide path on course locations throughout ILS Zone 2 as viewed from the aiming point. This skewing may be caused by an incorrect AFIS aiming point reference elevation or be induced by environmental conditions. Each change in the reference elevation to correct the skew will require a reevaluation. Once the skew is minimized, the average values of all runs determine the actual Zone 2 BFSL glide slope angle and the glide slope **aiming point elevation.** When initial evaluation of Zone 2 corrected error trace results in no skew and all requirements of FAA Order 8200.1, Section 217 for glide slope commissioning are satisfactory, the procedures derived TCH values may be used for the RDH.

Figure 4
Skewed trace presented on an AFIS recording
(This example indicates the programmed GS-HGT is higher than optimum)



e. Adjustments. The installation engineers shall make adjustments to the glidepath angle predicated on the average of the BFSL angle evaluations. Before making further evaluations, the AFIS glide slope height shall be reprogrammed to coincide with the new average glide slope **aiming point elevation.** Unusual glide slope siting conditions may produce bends or distortions in the glidepath. This condition can produce excessive glide slope aiming point elevation corrections and inconsistent glide slope angles. If the evaluation is to proceed under these conditions, use the BFSL angle as the reference and make both elevation and angle adjustments in half step increments.

f. Confirmation.

(1) Conduct additional AFIS glide slope evaluations until the glide slope **aiming point elevation** corrections repeat within 3 feet of zero and within 3 feet of each other on three separate flight inspection approaches. The average of these corrections, algebraically added to the initial AFIS glide slope height determined in paragraph 9a, is the final flight inspection glide slope **aiming point elevation** and the new AFIS glide slope height. If the final aiming point elevation is within ± 3 feet of the initial proposed value, the original value may be used. When the aiming point elevation is changed, notify AVN-210 of the actual aiming point elevation used. The elevation shall be documented on the facility data sheet as the aiming point reference elevation for the facility.

Note: When applying the order to a CAT II or CAT III facility, it is permissible to apply corrections within the 3 feet window due to tighter RDH tolerances.

(2) The final computed BFSL and announced angle shall be within ± .05° of the desired commissioned angle. When the announced AFIS angle is within .03° of the computed BFSL angle, the glide slope angle and origination point have been optimized. A Zone 2 AFIS corrected error trace that has no skew relative to the zero microamp reference plot indicates the reference elevation has been optimized. (See Figure 4 for an example of a Zone 2 AFIS corrected error trace that is skewed.)

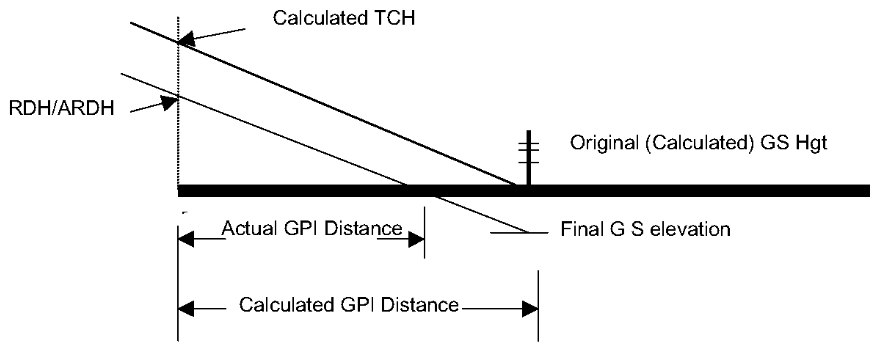
(3) The Data Analysis Section, AVN-210, shall enter the RDH, ARDH, and GPI values in the facility data.

g. Application.

(1) Flight Inspection. The AFIS announced angle and Zone 2 structure analysis are predicated on the AFIS glide slope height. These evaluations are not valid until the height is correct.

(2) Procedural Values. When a new aiming point is derived, the AFIS program will compute the RDH, ARDH, and GPI.

Figure 5
Final 8240.47 Results



10. PERIODIC INSPECTIONS. There are no requirements to apply this order during periodic flight inspections. However, when the AFIS Zone 2 corrected error trace is not centered about the zero microampere reference line, it indicates one or more of the following conditions: (1) Incorrect AFIS glide slope height (aiming point elevation), (2) Inaccurate AFIS runway position updates, (3) The glide slope angle is not linear in Zone 2, or (4) change in environmental condition affecting the glidepath. If an AFIS error trace is not centered about the zero microamp line on an established glide slope facility, it is possible that the flight inspection evaluations could be improved if a new glide slope height/aiming point elevation, RDH, GPI, etc., is established.

11. CATEGORY I, II, AND III REFERENCE DATUM HEIGHTS.

a. CAT I. The RDH shall not be commissioned at a height which results in a wheel crossing height (WCH) of less than 20 feet or greater than 50 feet for the types of aircraft with the greatest glidepath-to-wheel height, normally expected to use the runway (see FAA Order 8260.3, TERPS). Military authorities may grant additional exceptions on military use only glide slopes.

b. CAT II and III. The RDH, as determined by the application of this order, shall be commissioned at a height of 50 to 60 feet.

c. Use of ARDH. If the ARDH meets Category II/III RDH requirements and all other requirements for Category II/III glide slope commissioning are satisfactory in accordance with FAA Order 8200.1, Section 217, use of the ARDH to meet the RDH requirements may be requested as a waiver.

d. Deviations/waivers from the above shall be reviewed by the National Flight Procedures Office, AVN-100, and the Flight Inspection Operations Division, AVN-200, and approved by Flight Standards Flight Technologies and Procedures Division, AFS-400, or the equivalent applicable military headquarters.

/s/

Thomas C. Accardi
Program Director of Aviation
System Standards

APPENDIX 1. COMPUTATION OF THE BEST FIT STRAIGHT LINE

1. This appendix provides the methods for computing the BFSL. Some AFIS perform many or all of the following calculations automatically. The following mathematical procedure may be used when the complete AFIS solutions are not available. A programmable calculator or a computer is recommended when performing these calculations.

2. Symbols and Formulas.

θ_m = Measured angle as derived from the AFIS Zone 2 corrected error trace.

X = Distance from a point on the localizer course; the AFIS aiming point; or a point directly abeam, if offset; to the sample point as derived from the corrected error trace.

0 = Perpendicular distance the glide slope aiming point is offset from the localizer course if the offset is not zero.

$X_o = \sqrt{X^2 + 0^2}$ = Distance from the glide slope offset to the sample point. This value is used to determine Y and is required only if the glide slope aiming point is offset from the localizer course when analyzing old AFIS recordings where the glide slope coordinates were used for the aiming point.

Y = $[(\tan \theta_m)(X)]$ = Height of the sample point above the glide slope aiming point.

NOTE: Use X_0 if offset.

$\overline{X}$ = Average of all X distances.

$\overline{Y}$ = Average of all Y heights.

$x = X - \overline{X}$ (i.e., each individual distance value minus the average of all sample distances).

$\sum xY$ = The sum of all the products of x and Y.

$\sum x^2$ = The sum of all the squares of x.

$\frac{\sum xY}{\sum x^2}$ = The tangent of the angle of the BFSL.

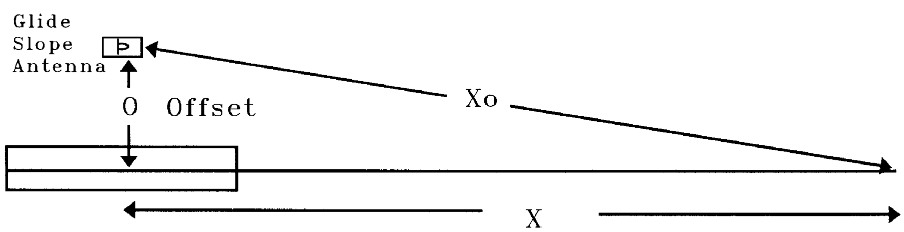
θ_b = Angle of the BFSL.

$\overline{Y} - [(\tan \theta_b)(\overline{X})]$ = Vertical height of the aiming point elevation must be adjusted to be in line with the extended BFSL. A minus value would indicate that the aiming point elevation must be lowered.

3. Symbol Illustration.

a. Plan View. Determine "X" and "X_O."

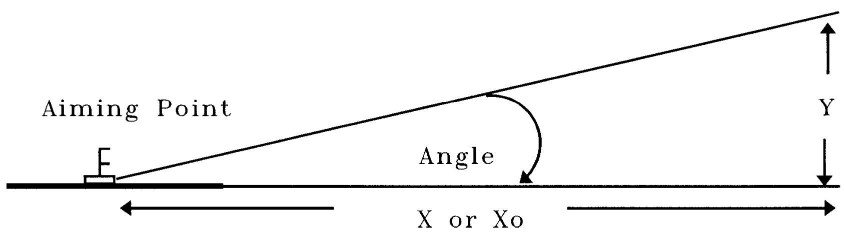
Figure 2



X_O = Distance used to calculate Y when the offset is used for the aiming point.
X = Distance used to calculate Y when the CL is used as the aiming point.

b. Profile Views.

Figure 3



Determine Y by use of X or X_O as appropriate

4. Preparing for the Calculation.

a. The calculations for BFSL angle, RDH, and GPI are made using an AFIS Zone 2 corrected error trace. Identify and mark points "A" and "B" on this trace and divide this segment into 20 equal parts. A 10-point divider may be utilized for this task. The calculations for ARDH are automatically made by AFIS, using corrected error data taken from 6,000 feet from the threshold to point "C".

b. Record the MEAN angle about each sample point (i.e., plus or minus one-half the distance to the adjacent samples). Each mean angle measurement is recorded as a "light line" value. For analysis, each "light line" will equate to 1.0 (estimate to a tenth of a line for repeatability). "Light lines" are considered "plus" values when above the announced AFIS angle reference, and "minus" values when below the reference.

c. Determine the horizontal distance "X" for each angle. Calculate the distance "X_O" if the AFIS aiming point was offset from the localizer course.

d. Compile all the preceding data and perform the following BFSL calculations.

5. BFSL Calculation. The following is an example of a Zone 2 BFSL calculation.

- Distance from the point abeam the glide slope on the localizer centerline to the runway threshold = 1,075 feet.

- Height of the AFIS aiming point relative to the runway threshold = +1 foot higher than threshold elevation.

- Offset distance = 401 feet.

Sample#	θ_m	X	X_O	Y	x
Pt. "A"	3.00	25379	25382	1330	10402
2	3.00	24339	24342	1276	9362
3	3.00	23299	23302	1221	8322
4	3.00	22258	22262	1167	7281
5	2.99	21218	21222	1108	6241
6	2.98	20178	20182	1051	5201
7	2.98	19138	19142	997	4161
8	2.97	18098	18102	939	3121
9	2.97	17057	17062	885	2080
10	2.96	16017	16022	828	1040
11	2.95	14977	14982	772	0
12	2.95	13937	13943	719	- 1040
13	2.94	12897	12903	663	-2080
14	2.93	11856	11863	607	-3121
15	2.92	10816	10823	552	-4161
16	2.91	9776	9784	497	-5201
17	2.90	8736	8745	443	-6241
18	2.89	7696	7706	389	-7281
19	2.84	6655	6667	331	-8322
20	2.80	5615	5629	275	-9362
Pt. "B"	2.74	4575	4593	220	-10402

a. Results of BFSL Calculations.

$\overline{X} = 14977$ $\overline{Y} = 774.77$ $\sum x Y = 44483336$ $\sum x^2 = 833160000$

b. Tangent of BFSL Angle.

$$\frac{\sum xY}{\sum x^2} = \frac{44483336}{833160000} = 0.0533911 = \text{Tan of } 3.056 \text{ degrees.}$$

c. Determining the difference in height between the aiming point elevation and the BFSL extension.

$\overline{Y}$ - [(Tan θ_b)($\overline{X}$)] = Adjustment to height.

774.77 - [(0.0533911)(14977)] = -24.87 feet.

d. Determining the Commissioned RDH.

(1) Step 1. Multiply the tangent of the COMMISSIONED angle by the "distance" from the threshold to the AFIS aiming point. If the localizer is offset from the runway centerline, the "distance" shall be from a point abeam the AFIS aiming point to a point abeam the threshold on the commissioned final approach course.

(2) Step 2. Subtract the threshold elevation from the final AFIS aiming point elevation. Then, algebraically add the difference to the value determined in step 1. This value is the commissioned RDH and the published TCH for CAT I glide slopes.

e. Determining the GPI. Divide the RDH by the tangent of the commissioned angle.

f. Determining the Commissioned AFIS ARDH.

(1) Step 1. Obtain the announced "deviation in feet" of the BFSL at the threshold from the AFIS ILS-3 glide slope zone 3 data (e.g., PT-T = +2 (feet)). The "+2" is the distance in feet that this one evaluation differed from the commissioned mathematical value.

(2) Step 2. Algebraically add the deviation to the RDH obtained in Appendix 1, paragraph 5d, step 2 (e.g., 55 feet (RDH) + 2 = 57 feet (ARDH)).

APPENDIX B. DESCRIPTION OF OHIO UNIVERSITY DATA PROCESSING

1. The GPS antenna is located 7.7 feet above, and 19 feet behind the ILS glide slope antenna on the Kingair. Determine the magnitude and angle from level ground made by a line between these antennas. Rotate this line as necessary based on the pitch and bank of the aircraft:

```
dblKAAntAngle = Atn(7.7 / 19#)
dblKAAntDist = Sqr(7.7 ^ 2 + 19 ^ 2)

dblAntDifCorrection = -1 * (dblPitch - dblKAAntAngle)
dblAntDifCorrection = -1 * Sin(dblAntDifCorrection * Deg2Rad) * dblKAAntDist
dblAntDifCorrection = dblAntDifCorrection * Abs(Cos(dblRoll * Deg2Rad))

Elevation of GS antenna = Elevation of GPS antenna + dblAntDifCorrection
```

2 and 3. Convert aircraft and threshold coordinates from WGS84 Lat/Lon/Elev to Earth-Centered, Earth-Fixed (ECEF) cartesian coordinates.

- Origin at the Earth's Rotational Center
- X-Axis in the Equatorial Plane at 0° longitude
- Y-Axis in the Equatorial Plane at 90° East longitude
- Z-Axis along the mean rotational axis

4. Given the aircraft location and the threshold location in ECEF, determine the location of the aircraft in East-North-Up (ENU) coordinates relative to the threshold.

- Origin is at the runway threshold
- East axis points to True East
- North Axis point to True North
- Up axis points directly opposite of a vector from the origin to the Earth's Rotational Center

5. Given runway heading, rotate the runway and aircraft positions so that the runway points down the negative-X axis. And the aircraft is seen to approach from the positive X direction.We can now get 'setback from threshold' directly from the X-Axis, and 'offset from centerline' directly from the Y-Axis. The distance from the aircraft to the threshold along the centerline can now be determined easily.

6. We can now determine the relative distances (X,Y,Z) from the aircraft to the Aiming Point (AP) given that we know the setback, offset, and elevation of the AP.

- dX = Aircraft X value + the magnitude of the AP setback from threshold
- dY = Aircraft X value - the AP offset from centerline (Where a negative offset = a negative Y value)
- dZ = Aircraft Z value - the AP Height above threshold

7. The elevation angle and distance from the AP to the aircraft can now be easily determined:

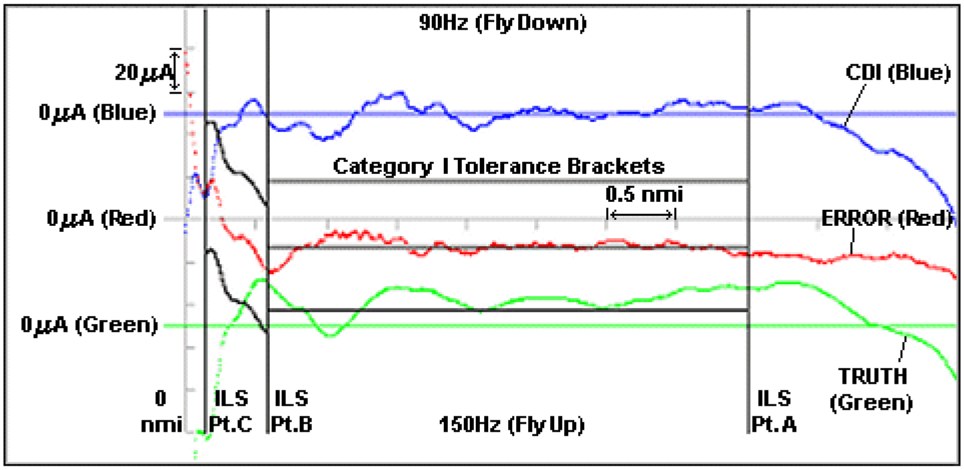
- DistanceAP = sqrt(dx^2 + dy^2)
- ElevationAngleAP = atan(dz / DistanceAP)

8. Convert Elevation Angle to Microamps (uA) given the desired path angle and the path width and knowing that the path width in degrees is equivalent to a deflection of 150uA on the Course Deviation Indicator (CDI):

Angle(uA) = (ElevationAngleAP - DesiredAngle) * 150uA / DesiredWidth

9. Add the angle in microamps to the recorded CDI value and we have a corrected error trace.

APPENDIX C. PROCESSED RESULTS FROM DATA SET ONE (KING AIR).



Legend for Figures in Appendix C.

Figures C-1 through C-11 should be interpreted using the legend above. ILS Points A, B, and C are respectively located at 4 nmi, 3500 ft, and 860 ft (nominally) from runway threshold (0 nmi). The ERROR trace is derived from the difference between the CDI and TRUTH traces. The TRUTH is determined using the algorithm in Figure 1 of the report. Category I tolerance brackets are set at ±30 µA on the ERROR trace horizontal scale between Points A and B and ±30 µA from the graphical average path between Points B and C.

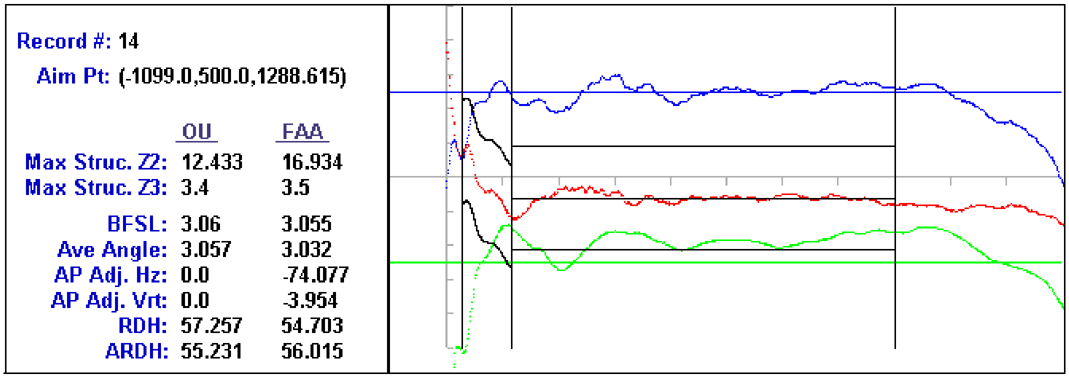


Figure C-1 . Processed Results for Run 14.

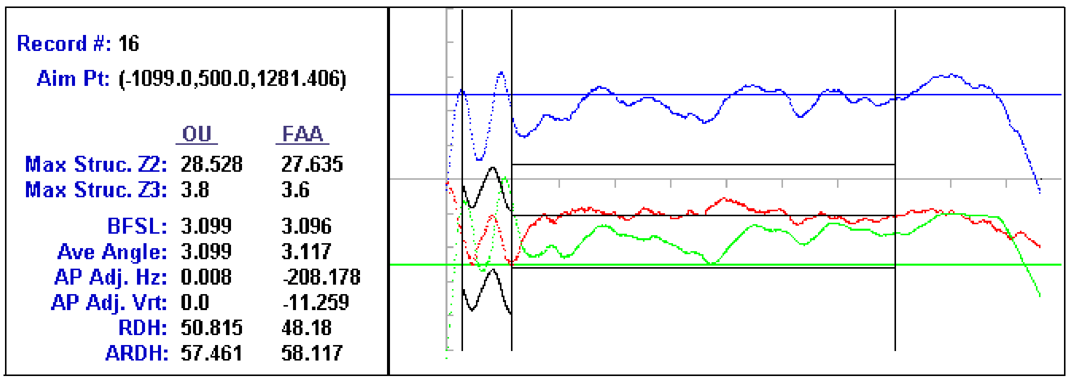


Figure C-2 . Processed Results for Run 16.

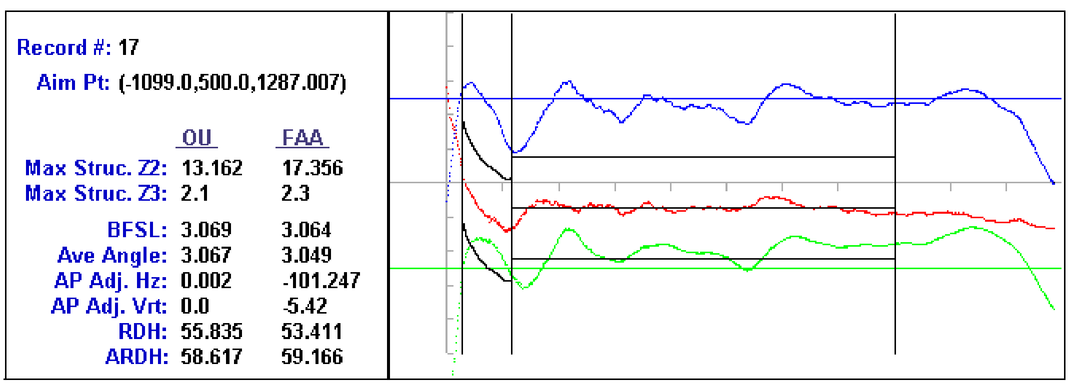


Figure C-3 . Processed Results for Run 17.

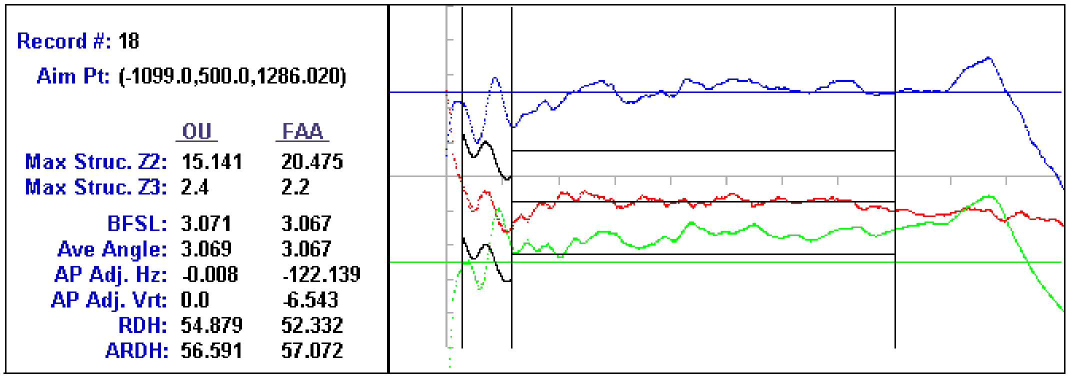


Figure C-4 . Processed Results for Run 18.

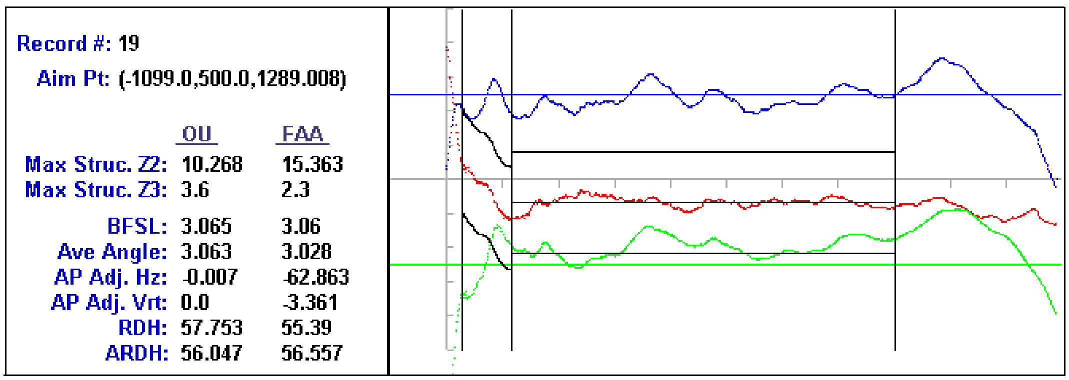


Figure C-5 . Processed Results for Run 19.

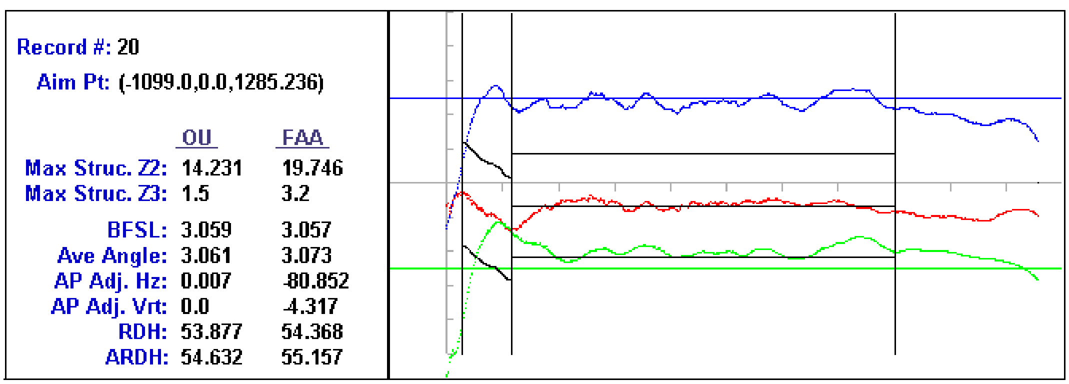


Figure C-6 . Processed Results for Run 20.

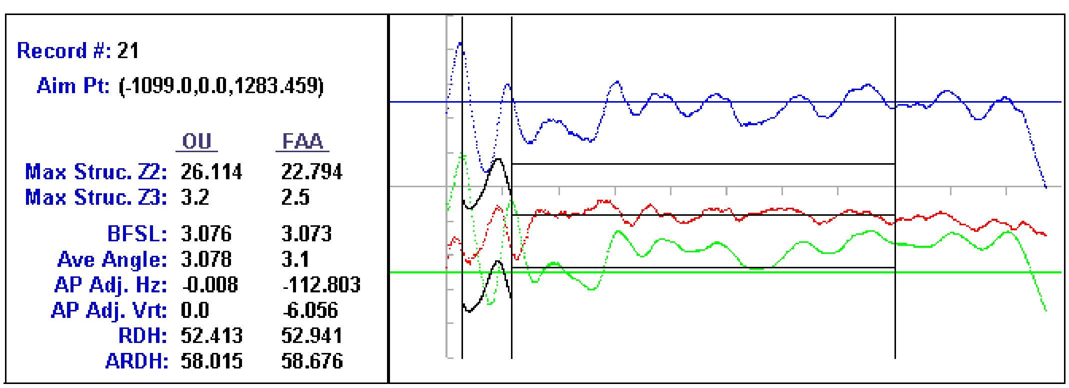


Figure C-7 . Processed Results for Run 21.

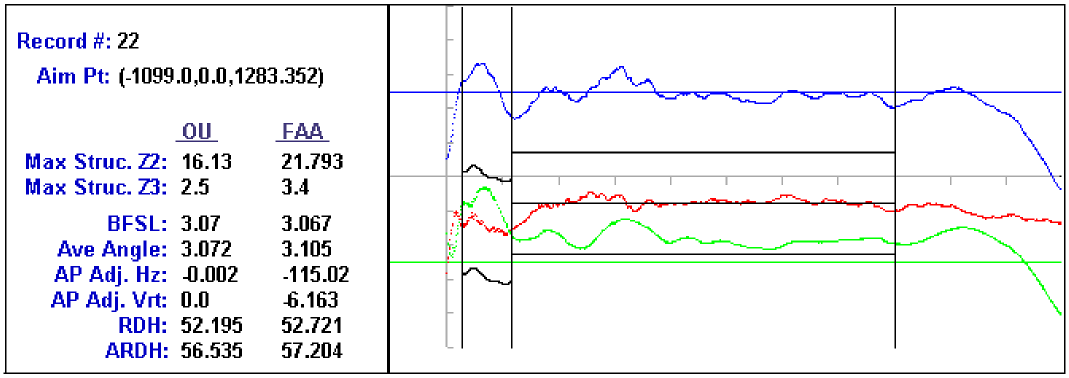


Figure C-8 . Processed Results for Run 22.

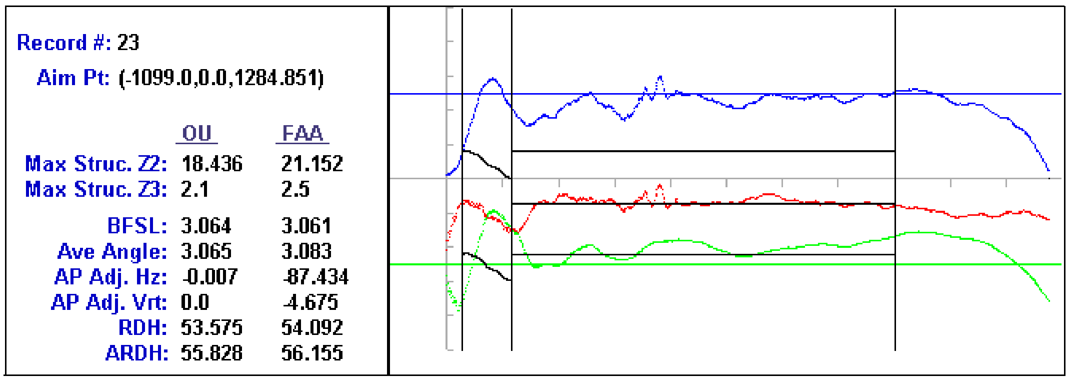


Figure C-9 . Processed Results for Run 23.

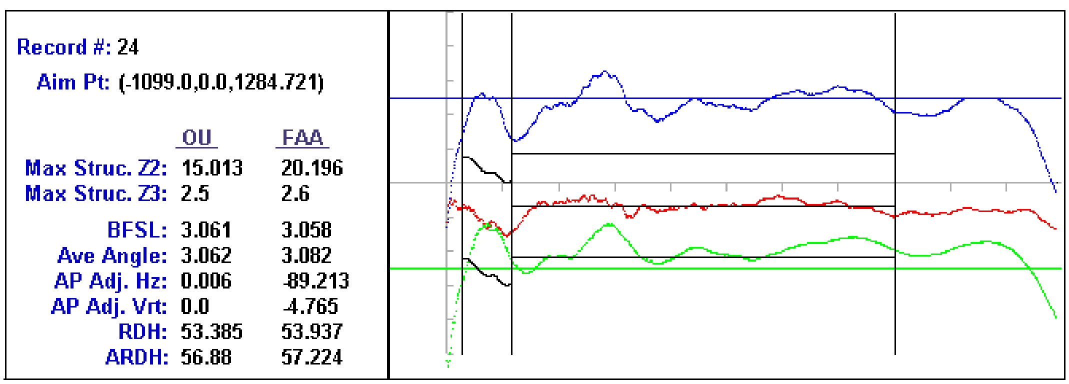


Figure C-10 . Processed Results for Run 24.

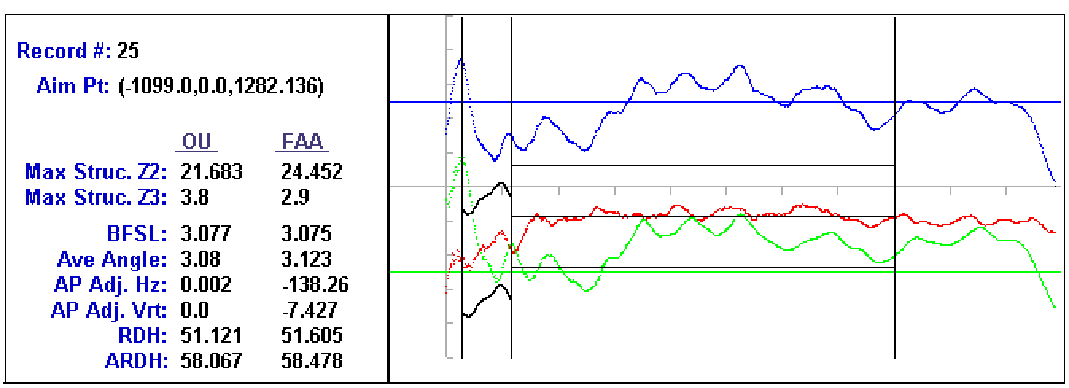
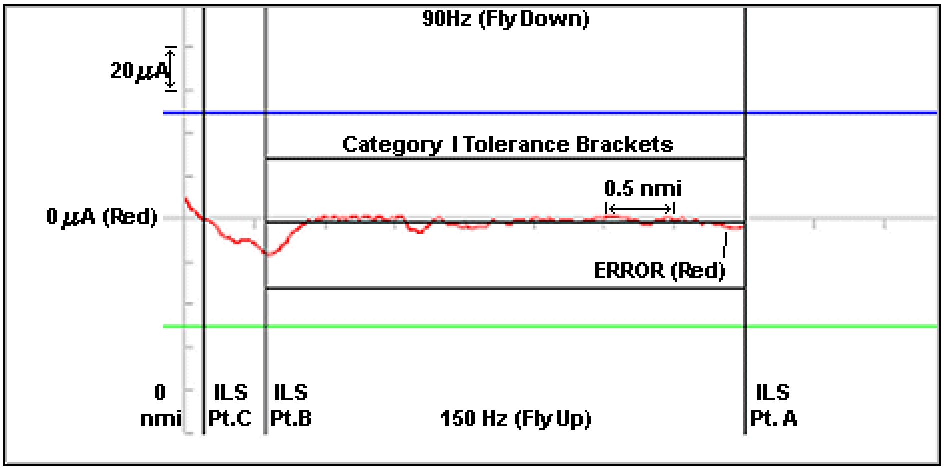


Figure C-11 . Processed Results for Run 25.

APPENDIX D. DIGITIZED RESULTS FROM DATA SET ONE (KING AIR).



Legend for Figures in Appendix D.

Figures D-1 through D-10 should be interpreted using the legend above. ILS Points A, B, and C are respectively located at 4 nmi, 3500 ft, and 860 ft (nominally) from runway threshold (0 nmi). Category I tolerance brackets are set at ±30 µA on the ERROR trace horizontal scale between Points A and B.

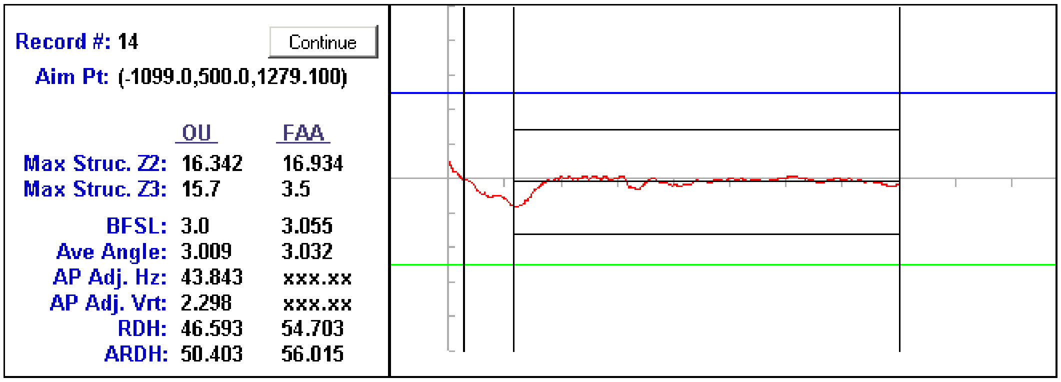


Figure D-1. Digitized Results for Run 14.

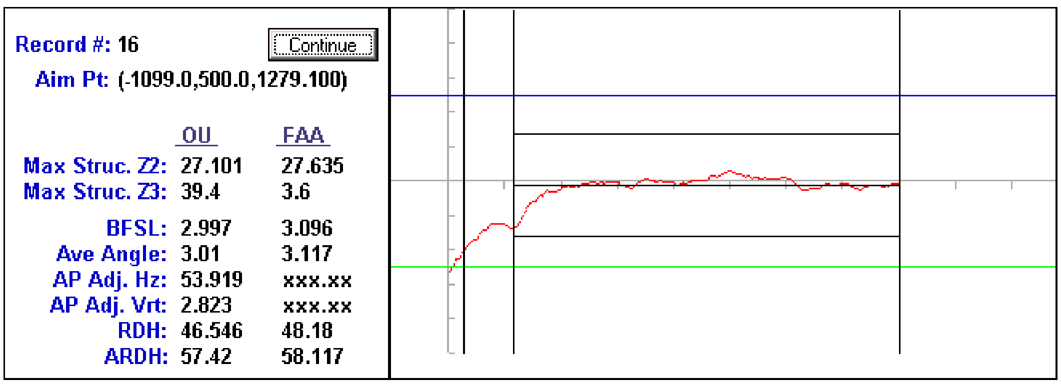


Figure D-2. Digitized Results for Run 16.

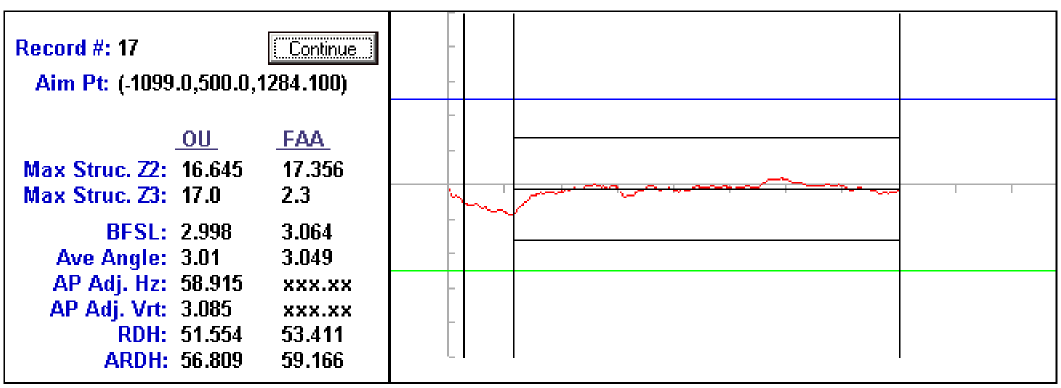


Figure D-3. Digitized Results for Run 17.

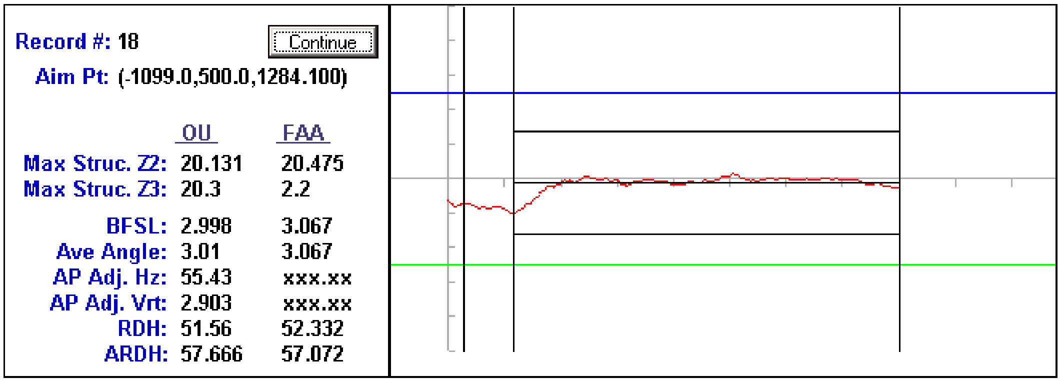


Figure D-4. Digitized Results for Run 18.

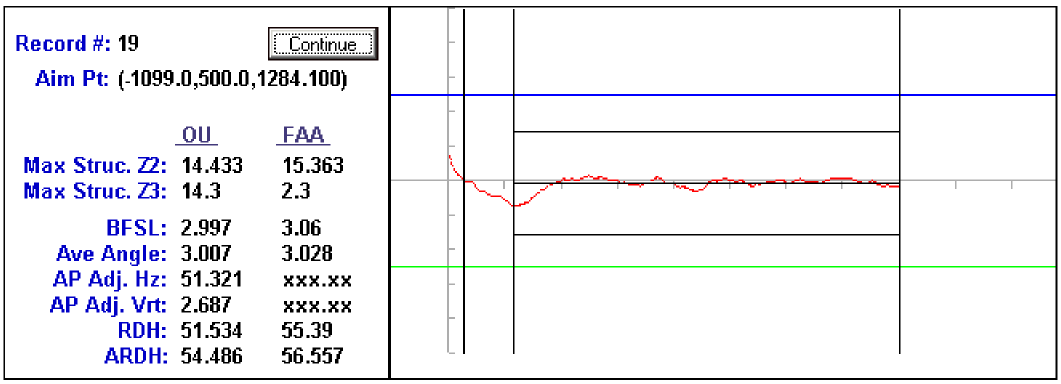


Figure D-5. Digitized Results for Run 19.

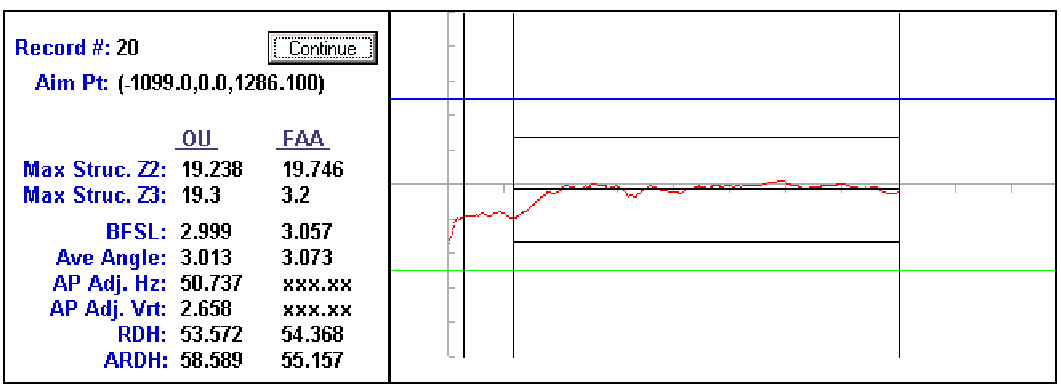


Figure D-6. Digitized Results for Run 20.

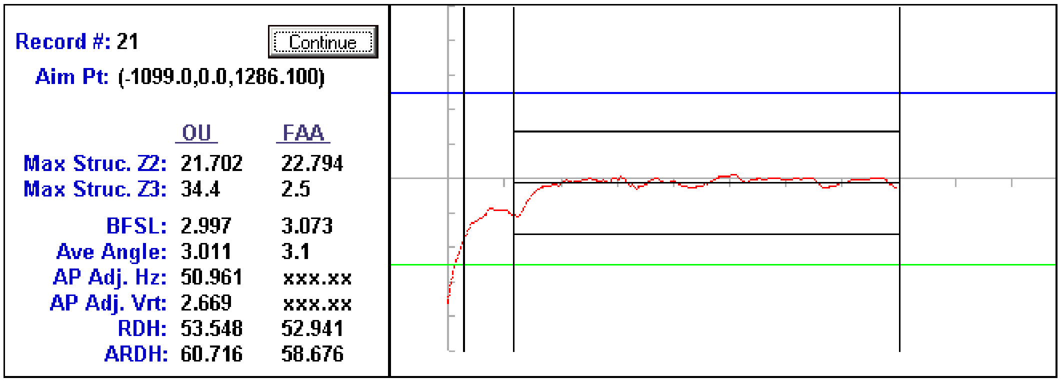


Figure D-7. Digitized Results for Run 21.

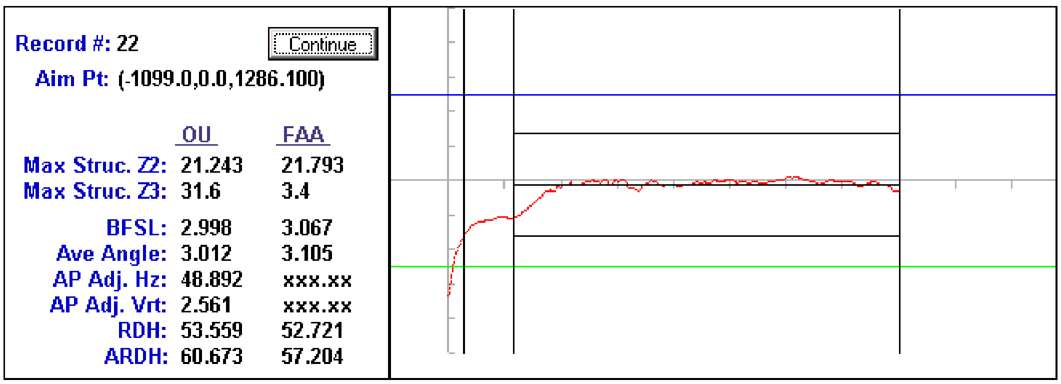


Figure D-8. Digitized Results for Run 22.

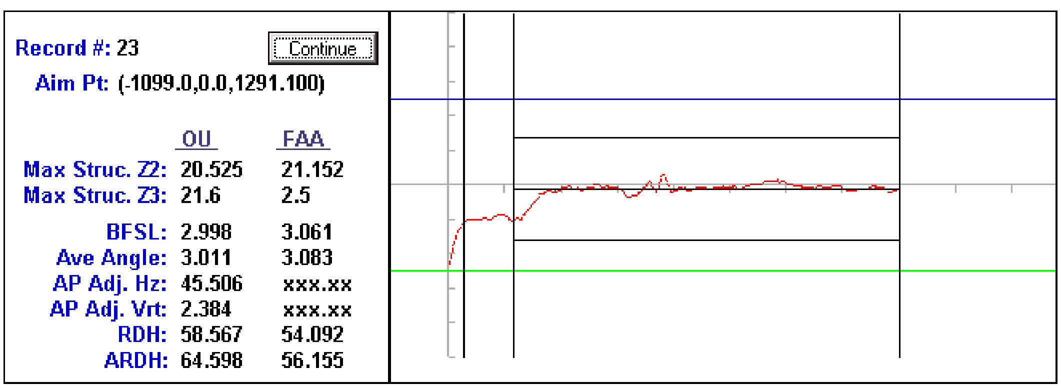


Figure D-9. Digitized Results for Run 23.

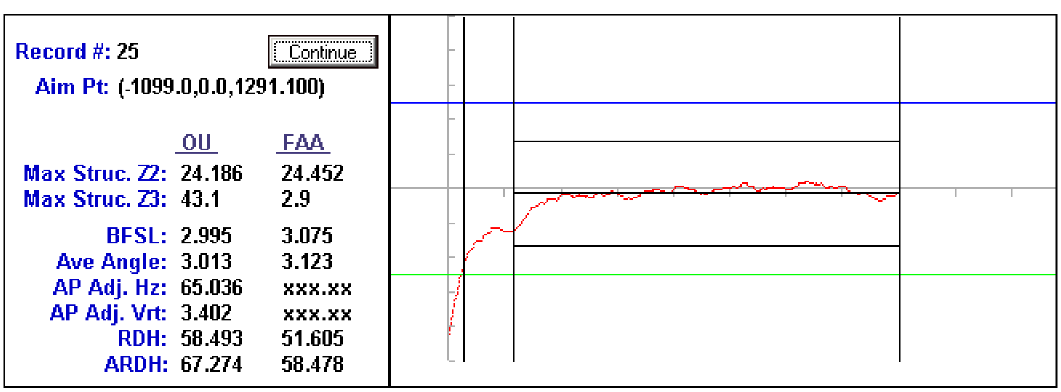


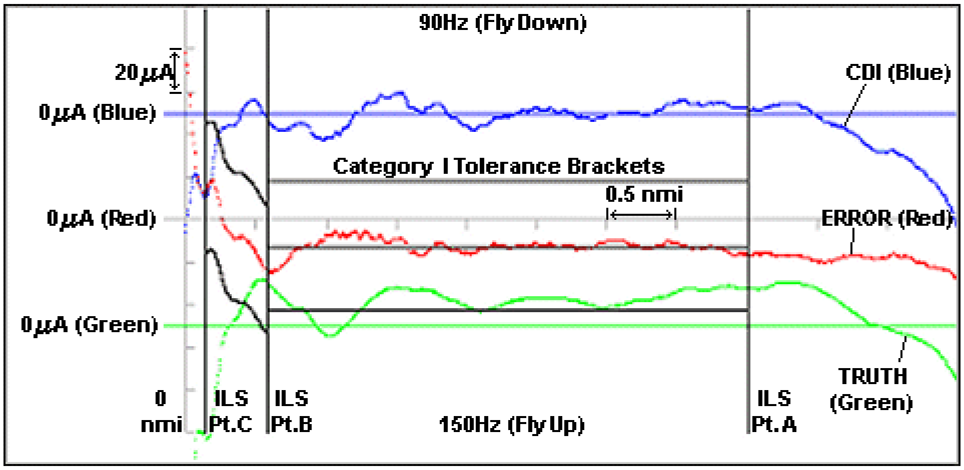
Figure D-10. Digitized Results for Run 25.

APPENDIX E. PROCESSED RESULTS FROM DATA SET TWO (LEAR JET)

```
============================================================================
File: d:\projects\RDHCompare\BFSL121206\1.txt
Data Points: 1057
 Parameter          OU             FAA            Difference
 --------------     ----------     ----------     ----------
 Ave Angle Z2            3.093          3.025          0.069  deg
 Struct Z2 (ua)         14.847         17.052         -2.205  uA
 BSFL Angle Z2           3.067          3.063          0.005  deg
 BSFL Angle Z3           3.147          3.130          0.017  deg
 RDH                    47.888          0.008         47.880  ft
 ARDH                   49.245          0.008         49.237  ft

              Aiming Point Location = (  -1099.00,    500.00,   1279.10)
     Final OU Aiming Point Location = (  -1099.00,    500.00,   1279.10)
                         Difference = (      0.00,      0.00,      0.00)

============================================================================
File: d:\projects\RDHCompare\BFSL121206\3.txt
Data Points: 948
 Parameter          OU             FAA            Difference
 --------------     ----------     ----------     ----------
 Ave Angle Z2            3.098          3.034          0.064  deg
 Struct Z2 (ua)         23.517         16.113          7.404  uA
 BSFL Angle Z2           3.067          3.061          0.006  deg
 BSFL Angle Z3           3.107          3.084          0.022  deg
 RDH                    47.885          0.008         47.876  ft
 ARDH                   52.640          0.008         52.631  ft

              Aiming Point Location = (  -1099.00,    500.00,   1279.10)
     Final OU Aiming Point Location = (  -1099.00,    500.00,   1279.10)
                         Difference = (      0.00,      0.00,      0.00)

============================================================================
File: d:\projects\RDHCompare\BFSL121206\4.txt
Data Points: 1111
 Parameter          OU             FAA            Difference
 --------------     ----------     ----------     ----------
 Ave Angle Z2            3.103          3.023          0.080  deg
 Struct Z2 (ua)         21.279         15.746          5.533  uA
 BSFL Angle Z2           3.063          3.058          0.005  deg
 BSFL Angle Z3           3.125          3.109          0.016  deg
 RDH                    47.812          0.009         47.803  ft
 ARDH                   52.796          0.008         52.788  ft

              Aiming Point Location = (  -1099.00,    500.00,   1279.10)
     Final OU Aiming Point Location = (  -1099.00,    500.00,   1279.10)
                         Difference = (      0.00,      0.00,      0.00)

============================================================================
File: d:\projects\RDHCompare\BFSL121206\5.txt
Data Points: 951
 Parameter          OU             FAA            Difference
 --------------     ----------     ----------     ----------
 Ave Angle Z2            3.103          3.050          0.053  deg
 Struct Z2 (ua)         17.678         18.006         -0.328  uA
 BSFL Angle Z2           3.080          3.075          0.005  deg
 BSFL Angle Z3           3.094          3.075          0.019  deg
 RDH                    48.129          0.008         48.120  ft
 ARDH                   53.634          0.009         53.626  ft

              Aiming Point Location = (  -1099.00,    500.00,   1279.10)
     Final OU Aiming Point Location = (  -1099.00,    500.00,   1279.10)
                         Difference = (      0.00,      0.00,      0.00)
```

```
============================================================================
File: d:\projects\RDHCompare\BFSL121206\7.txt
Data Points: 1650
 Parameter           OU             FAA            Difference
 --------------      ----------     ----------     ----------
 Ave Angle Z2             3.055          3.029          0.026  deg
 Struct Z2 (ua)          11.084         16.240         -5.156  uA
 BSFL Angle Z2            3.072          3.069          0.003  deg
 BSFL Angle Z3            3.102          3.095          0.007  deg
 RDH                     54.984          0.008         54.976  ft
 ARDH                    51.128          0.008         51.120  ft

              Aiming Point Location = (  -1099.00,      0.00,   1286.10)
     Final OU Aiming Point Location = (  -1099.00,      0.00,   1286.10)
                         Difference = (      0.00,      0.00,      0.00)
```

APPENDIX F. PROCESSED RESULTS FROM DATA SET ONE (KING AIR) WITH AP REFERENCED TO RUNWAY THRESHOLD



Legend for Figures in Appendix F.

Figures F-1 through F-10 should be interpreted using the legend above. ILS Points A, B, and C are respectively located at 4 nmi, 3500 ft, and 860 ft (nominally) from runway threshold (0 nmi). The ERROR trace is derived from the difference between the CDI and TRUTH traces. The TRUTH is determined using the algorithm in Figure 1 of the report. Category I tolerance brackets are set at ±30 µA on the ERROR trace horizontal scale between Points A and B and ±30 µA from the graphical average path between Points B and C.

COMPARING THE USE OF ALL POINTS AT THE ASSIGNED AP LOCATION, TO THE USE OF 21 PTS PER ZONE:

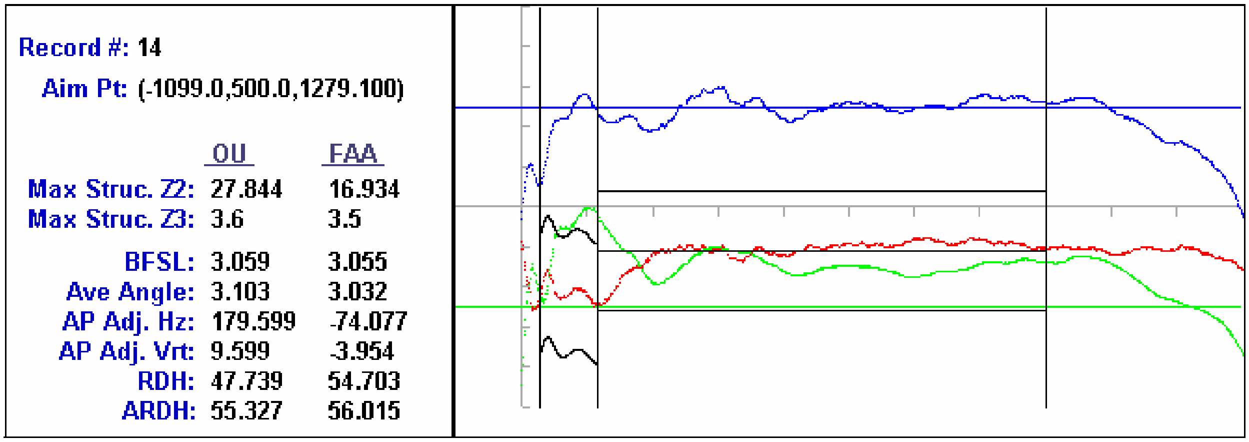


Figure F-1. Record #14, Aiming Point at GS and 1279.1 Ft Elevation, Using All Points.

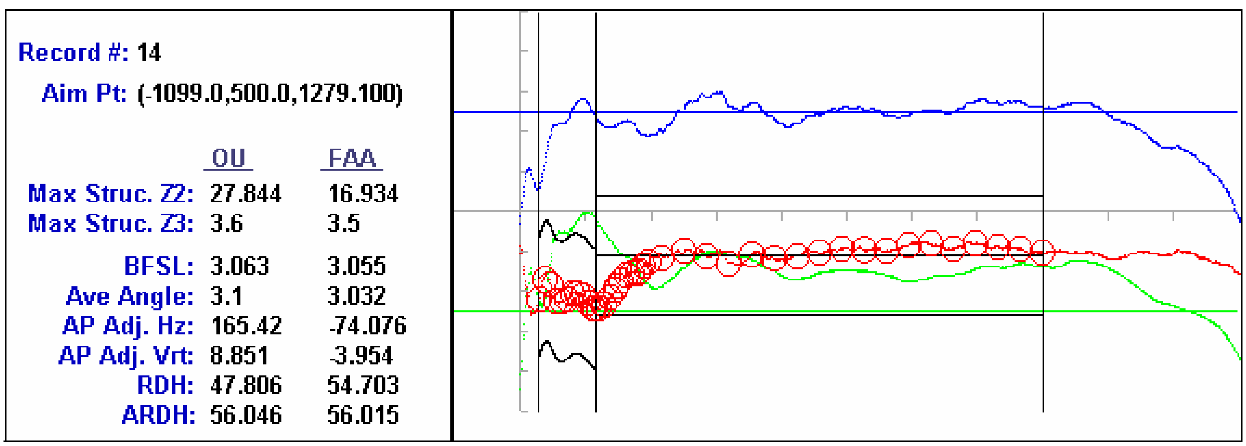


Figure F-2. Record #14, Aiming Point at GS and 1279.1 Ft Elevation, Using 21 Points (Circled in Red) for RDH and ARDH.

ADJUSTING FOR 0 FT VERTICAL AP ADJUST:

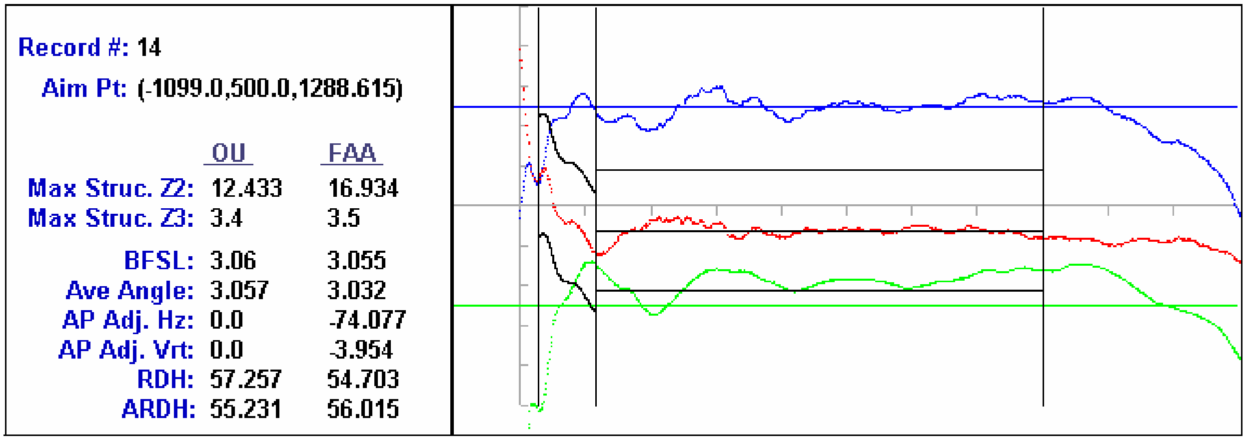


Figure F-3. Record #14, Aiming Point at GS and 1288.615 Ft Elevation, Adjusting for 0 Ft Vertical AP Adjust.

ADJUSTING FOR OU CALCULATED RDH VALUE EQUAL TO FAA CALCULATED RDH VALUE:

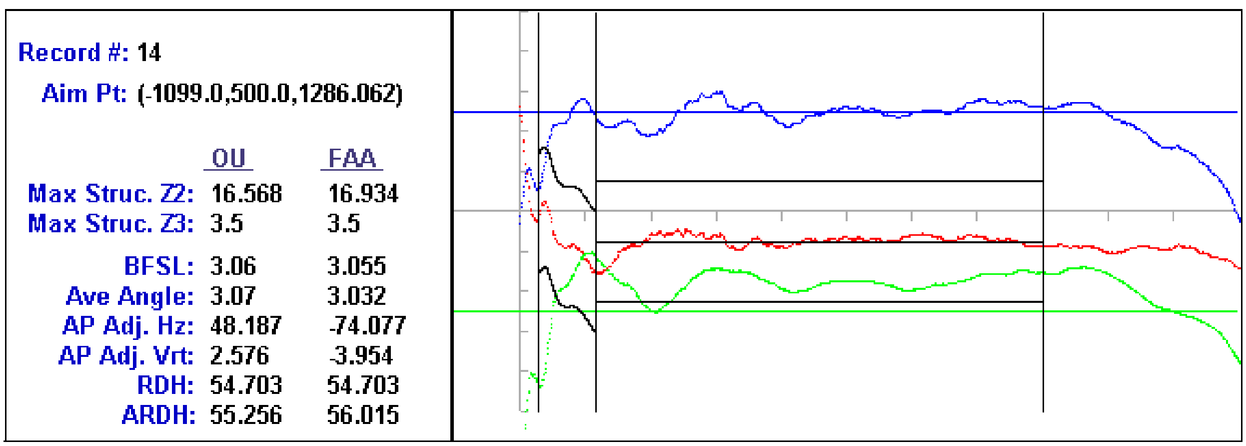


Figure F-4. Record #14, Aiming Point at GS and 1286.062 Ft Elevation, Adjusting for RDH Equal to FAA Result.

ADJUSTING FOR +3, +2, +1, -1, -2, AND -3 FT VERTICAL AP ADJUST:

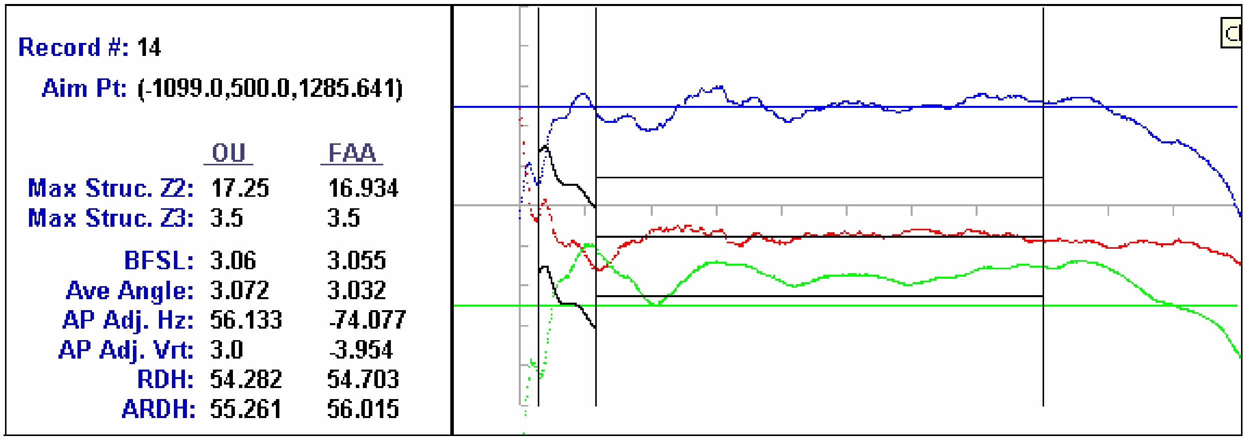


Figure F-5. Record #14, Aiming Point at GS and 1285.934 ft Elevation, Adjusting for +3 ft Vertical AP Adjust.

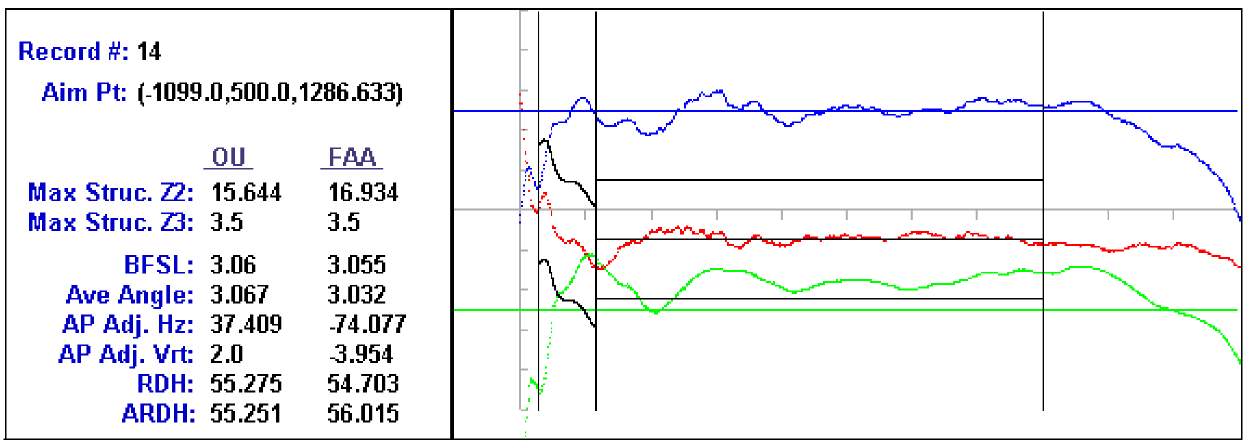


Figure F-6. Record #14, Aiming Point at GS and 1286.633 ft Elevation, Adjusting for +2 ft Vertical AP Adjust.

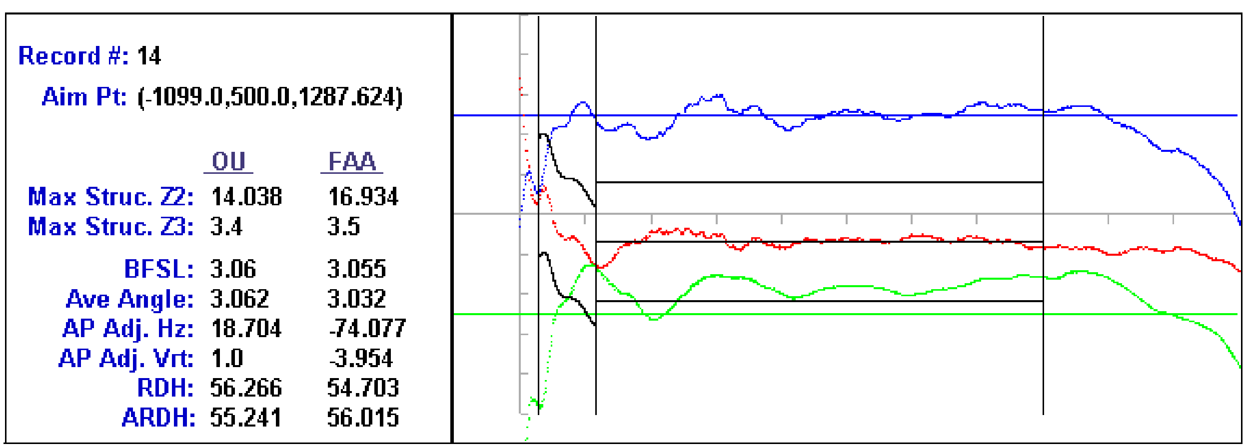


Figure F-7. Record #14, Aiming Point at GS and 1287.624 Elevation, Adjusting for +1ft Vertical AP Adjust.

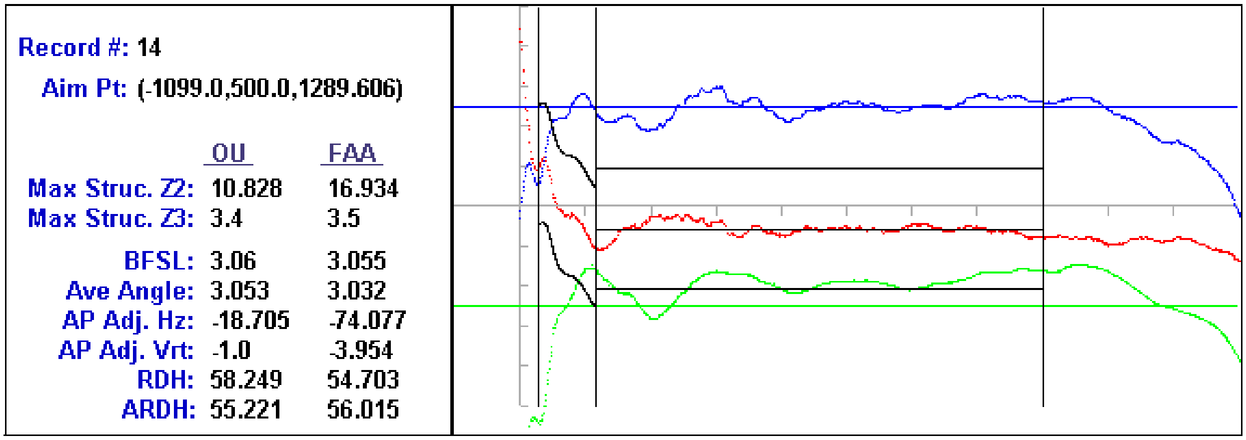


Figure F-8. Record #14, Aiming Point at GS and 1289.606 ft Elevation, Adjusting for -1ft Vertical AP Adjust.

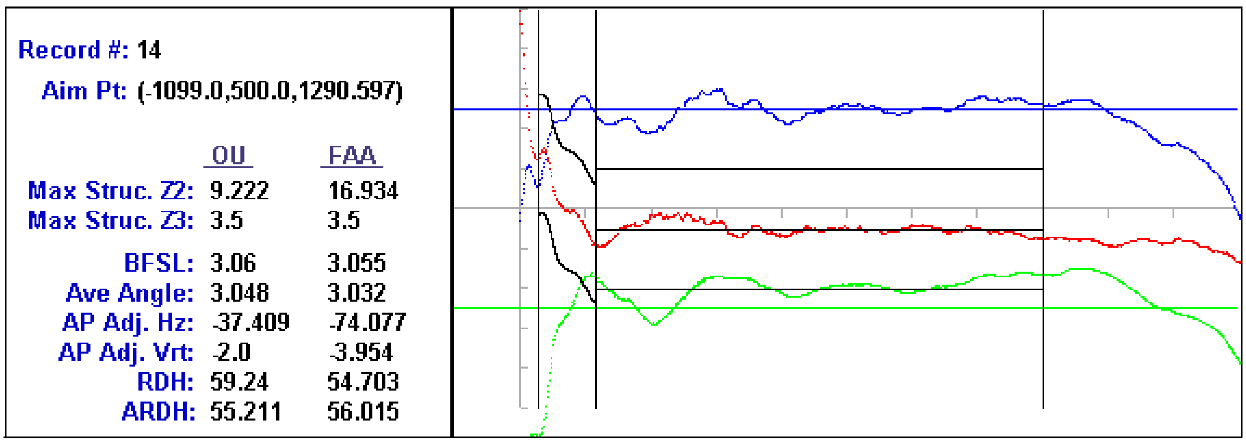


Figure F-9. Record #14, Aiming Point at GS and 1290.597 ft Elevation, Adjusting for -2ft Vertical AP Adjust.

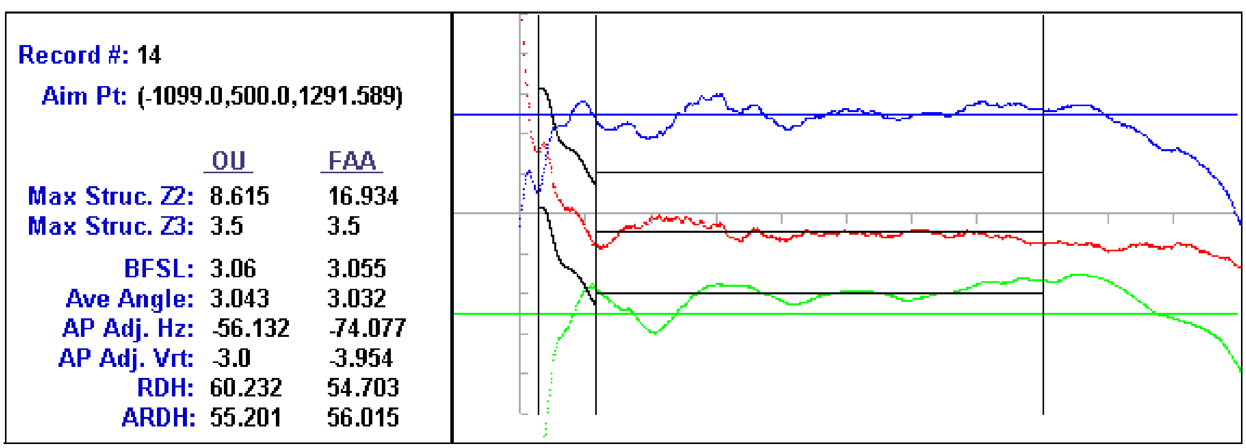


Figure F-10. Record #14, Aiming Point at GS and 1291.589 ft Elevation, Adjusting for -3ft Vertical AP Adjust.