TECHNICAL MEMORANDUM
OU/AEC 08-21TM-15689/0006-1

ASSESSMENT OF THE EFFECTIVENESS OF THE RDH/ARDH EVALUATION METHODOLOGY FOR THE ILS GLIDE SLOPE

Presented are the results of a study assessing the effectiveness of the reference datum height (RDH) and achieved reference datum height (ARDH) evaluation methodology used by the Flight Inspection branch of the Federal Aviation Administration (FAA) to determine the measured threshold crossing heights (TCH) at Instrument Landing System (ILS) glide slope facilities. A thorough review of the mathematical computations used in FAA Order 8240.47C to apply a best-fit-straight-line analysis to glide slope flight recordings shows that the application of the BFSL process to some glide slope course structures yields unrepresentative aiming point adjustment and RDH values. In the event that the RDH tolerance is not met, Flight Inspection should have the latitude to use an alternative analysis method, which is permitted by ICAO guidance material. Three example alternative methods are described.

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I. INTRODUCTION

Prior to the 1983 Federal Aviation Administration (FAA) Order 8240.47 [1], no distinction was made between the calculated and measured threshold crossing heights (TCH) of instrument landing system (ILS) glide slope facilities. In addition to requiring that a glide slope meet the standards set forth in the U.S. Flight Inspection Manual [2], this order put into effect a revised flight inspection method that analyzes glide slope performance based on actual achieved results instead of theoretical values and provides a procedure for establishing the aiming point. For the first time, the aiming point was decoupled from the glide slope mast which allowed for a more optimal placement. The new methodology applies a linear regression or best-fit-straight line (BFSL) mathematical technique to two particular segments along the measured approach path to yield a reference datum height (RDH) value and an achieved reference datum height (ARDH) value. While these measured TCH values, RDH and ARDH, are primarily applied to Category II and III glide slope facilities, this new method also affects Category I facilities because it is used to establish the aiming point.

A. OHIO UNIVERSITY – APPLICABLE HISTORICAL EFFORTS

Ohio University's first involvement with the aiming point and close-in flare issues came about in 1969. Runway 09R at Atlanta GA could not meet the Category II, 20 microampere flare tolerance. A report was written containing the results of flight measurements and mathematical computations which showed that the theodolite eyepiece should be placed at the glide path transmitting antenna mast and at the same elevation as the runway [3]. At that time, techniques for reference point placement were simplistic and did not provide for referencing the ideal glide path. Use of this recommended placement technique eliminated the perceived flare and allowed the Atlanta facility to be qualified for Category II operation.

In early 1984, Ohio University became involved in an investigation concerning the general applicability of the new FAA Order 8240.47 and more specifically with the glide slope serving Runway 18R at the Dallas-Fort Worth Airport (DFW). Although this Category II facility had met the requirements of the FAA Flight Inspection Manual for many years, the application of the recent 8240.47 order yielded an out-of-tolerance RDH value. While the DFW RDH issue was an early example of difficulty applying the order, it was not the first. Ohio University experienced problems with applying the order in the fall of 1983 at facilities in Gillette WY and Norfolk NE. The glide slope RDH problem at DFW spawned three Ohio University studies/reports.

The first report [4] contained flight recordings of the DFW glide slope performance measured by Ohio University with a theodolite truth-reference. Repeatable flight recordings were obtained which precisely characterized the course structure for an in-depth evaluation. Additionally, this report questioned the properness of extrapolating outside the data field of a linear regression process and indicated that there is no known flight director system that makes use of such a computation to provide guidance.

The second report [5] contained the results of a unique solution to restore Category II, glide slope operation at DFW. The plan was to actually measure the wheel crossing heights of a multitude of landing aircraft which were on autopilot-coupled approaches. Positioned at a known distance from the threshold, a theodolite and communication system was established to measure the elevation angle of the wheels as the aircraft crossed threshold. For each aircraft type, a correction was applied to determine the antenna crossing height or measured TCH value. For 143 approaches, decoupled at 100 feet or below, the mean TCH fell comfortably within allowable limits. Application of FAA Order 8240.47 was waived and the DFW facility restored to Category II operation.

The third and final study [6] focused on the use of mathematical modeling to determine if terrain grading modifications could allow the DFW glide slope facility to meet the requirements of the 8240.47. Computer modeling showed that three bowl-shaped depressions under the approach path contributed to the out-of-tolerance RDH. A parametric analysis was performed to determine how the depth of the depressions affected the RDH and ARDH values.

The mathematical modeling work for DFW led Ohio University to later develop a series of plots which show the effect on RDH and ARDH values for elevated and depressed terrain at various distances from the glide slope mast. Another series of curves were generated to compute RDH/ARDH values as a function of glide slope setback and offset for ideal ground planes. These plots were added to an appendix in the ILS Siting Manual [7] to provide installation personnel with the tools to site a glide slope to meet RDH/ARDH requirements.

B. MORE RECENT ISSUES

In the late 1990's, next generation ILS equipment was certified and procured. For the next several years the older Wilcox Mark 1D (Category I) and Mark III (Category II/III) equipment were systematically replaced with the new Thales Mark 20 equipment. It is estimated that most of these facilities had been in service for 15-20 years. No requirement exists to apply the BFSL process during periodic flight inspections and the only time these sites were evaluated for RDH/ARDH was during the commissioning flight check. Those sites installed before FAA Order 8240.47 was in existence had never been evaluated for RDH and ARDH. Although, in most cases, the physical location of the glide slope mast had remained unchanged during the switch-over to the new ILS equipment, a number of these Category II/III facilities did not initially pass the RDH/ARDH requirements. Some glide slope masts were relocated to attain in-tolerance RDH and/or ARDH values.

In 2007, Ohio University performed an independent study for the FAA to validate the implementation of the BFSL algorithm used in the FAA's Automated Flight Inspection System (AFIS) [8]. The FAA was in the process of adding Lear 60 jet aircraft to their fleet of King Air aircraft and the performance of two distinct flight inspection platforms were evaluated. The report concluded that a variation in measured course structure roughness is the major cause of differences in RDH/ARDH and BFSL values. The Differential-GPS (DGPS) equipment in the new Lear jet aircraft provided more accuracy and better repeatability than the inertial system used in the King Air aircraft.

C. PURPOSE OF STUDY

During a recent FAA product quality review, a Category III glide slope facility was found to have an out-of-tolerance RDH that had likely existed for several years. The facility had not had any operational issues related to this and it has motivated the FAA Office of Aviation System Standards (AVN) to review the validity of the RDH/ARDH evaluation methodology. The FAA has tasked Ohio University to perform a study and to prepare this written report addressing the following:

1. Determine the representativeness of the RDH/ARDH methodology.
2. Determine the glide slope signal to radar altimeter value weighting ratio for autoland systems in the near-touchdown region.
3. Review ICAO TCH/RDH/ARDH methods for comparison with FAA methods.
4. Review and provide recommendations regarding the current RDH/ARDH tolerance range of 50-60 feet.

II. BACKGROUND

This section provides the background knowledge to understand the terminology and methodology associated with siting and measuring an ILS glide slope system.

A. ILS GLIDE SLOPE

1. DESCRIPTION

The glide slope is the part of the ILS electronic navigation system that provides vertical guidance to landing aircraft (see Figure 1). Typically sited alongside the runway in the area adjacent to the desired touchdown point, the antenna and transmitting system aim an electronic course out into the approach region that is 3 degrees above the horizon. A fly-up signal is received at elevation angles below 3 degrees and a fly-down signal exists above 3 degrees. Proportional guidance is received at elevation angles between approximately 2.3 and 3.7 degrees. The on-course, fly-up and fly-down signals drive a vertical-deviation-indicator (VDI) in the cockpit that the pilot or autopilot uses to control the altitude of the landing aircraft during the approach.

2. TYPES AND CONFIGURATIONS

Image and non-image glide slopes are the two types in use. The image type systems use two or three antennas mounted on a vertical tower which can vary in height from 20 to 50 feet depending on the configuration (see Figure 2). Depending on the tower height, the offset from the runway centerline can vary between 250 and 600 feet. Image systems use the terrain in front

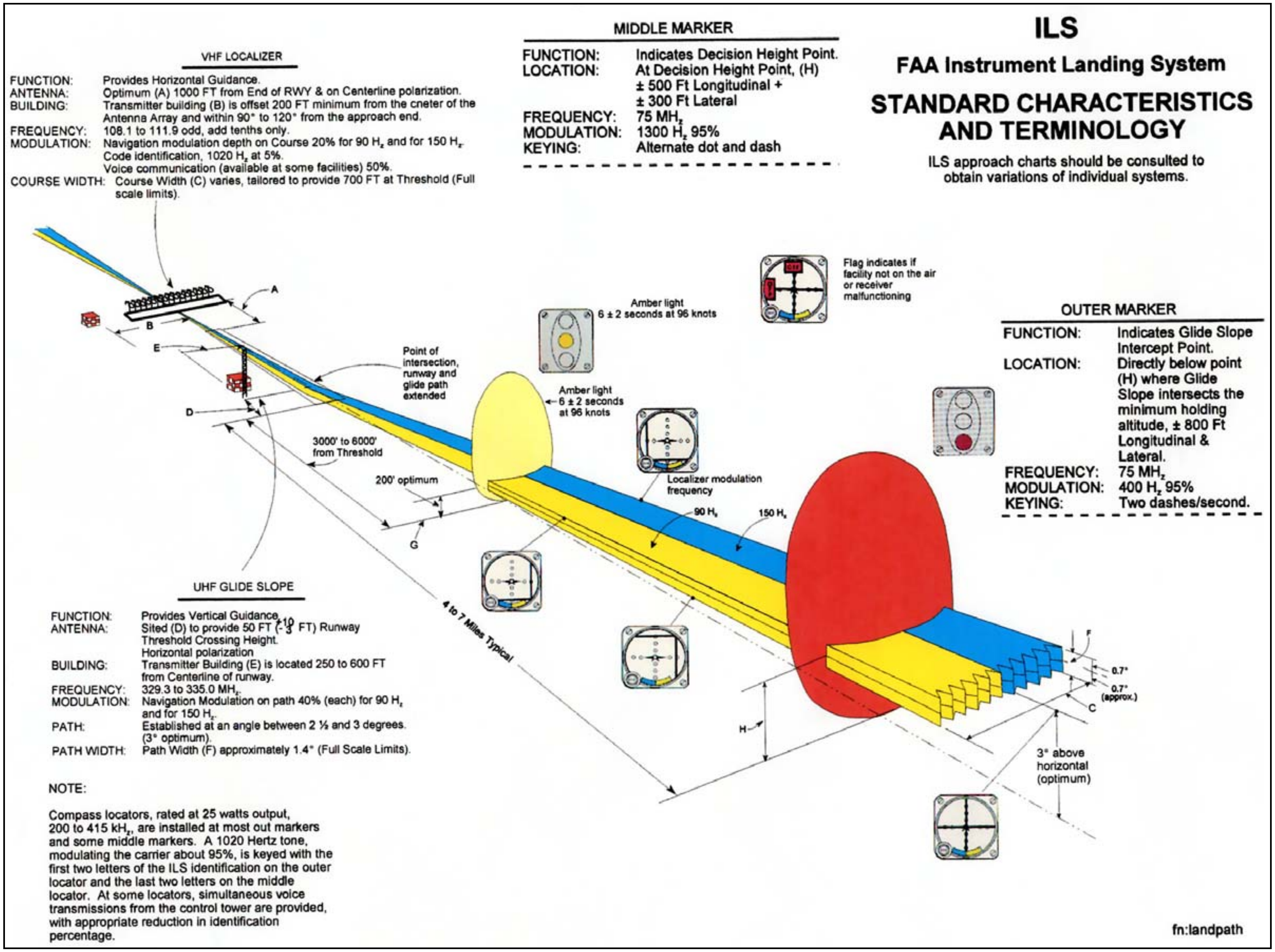


Figure 1. Description and Layout of the Typical Instrument Landing System.

Figure 2. Photograph of an Image Glide Slope System, Ohio University Airport.

of the antennas to form the glide path. Three different configurations are used depending on the amount and character of the terrain in front of the glide slope antennas. The base of the tower is the glide slope origination point.

Most non-image glide slopes in the NAS are endfire systems and do not use the terrain under the approach path to form the glide path. The endfire system employs two horizontal, slotted-cable antennas which are positioned alongside the runway and separated by 400 feet. Figure 3 shows a photograph of one of these two antennas. The glide slope origination point is halfway between the two antennas. Offset from the runway centerline is typically 175 feet. As of this writing, all endfire glide slope systems operating in the U.S. are certified only for Category I use.

3. THRESHOLD CROSSING HEIGHT AND SITING

FAA document 6750.16D [9] contains the specific procedure to site an ILS glide slope. The glide slope setback distance from threshold is computed given the runway slope, desired threshold crossing height (TCH) and glide path angle. Glide slope offset is not a factor in determining the required setback. The illustration in Figure 4 provides information about the TCH computation and influencing factors. Threshold crossing heights are typically established between 50 and 60 feet.

4. THE FLARE

Although the on-course glide slope signal is conically shaped and originates from ground level at the base of the glide slope mast, the flight path of a landing aircraft on the glide slope is hyperbolic in shape. This is because a landing aircraft is flying towards the runway instead of the glide slope mast. The path of the aircraft approaching the runway threshold is flattening out or flaring. The degree of flare is dependent on the glide slope offset distance from the runway centerline and the general elevation difference between the base of the mast and the runway centerline.

5. CATEGORIES OF OPERATION

The ILS category of operation defines the minimum descent altitude and the visibility requirements for an approach. They are defined as:

Category I - A precision instrument approach and landing with a decision height not lower than 200 feet (61 m) above touchdown zone elevation and with either a visibility not less than 2,625 feet (800 m) or a runway visual range not less than 2,400 feet (730 m), (with touchdown zone and center lightning, RVR 1,800ft). An aircraft equipped with an Enhanced Flight Vision System may, under certain circumstances, continue an approach to CAT II minimums. [14 CFR Part 91.175 amendment 281]

Category II - Category II operation: A precision instrument approach and landing with a decision height lower than 200 feet (61 m) above touchdown zone elevation but not lower than 100 feet (30 m), and a runway visual range not less than 1,200 feet (370 m).

Figure 3. Photograph of a Non-Image Glide Slope System.

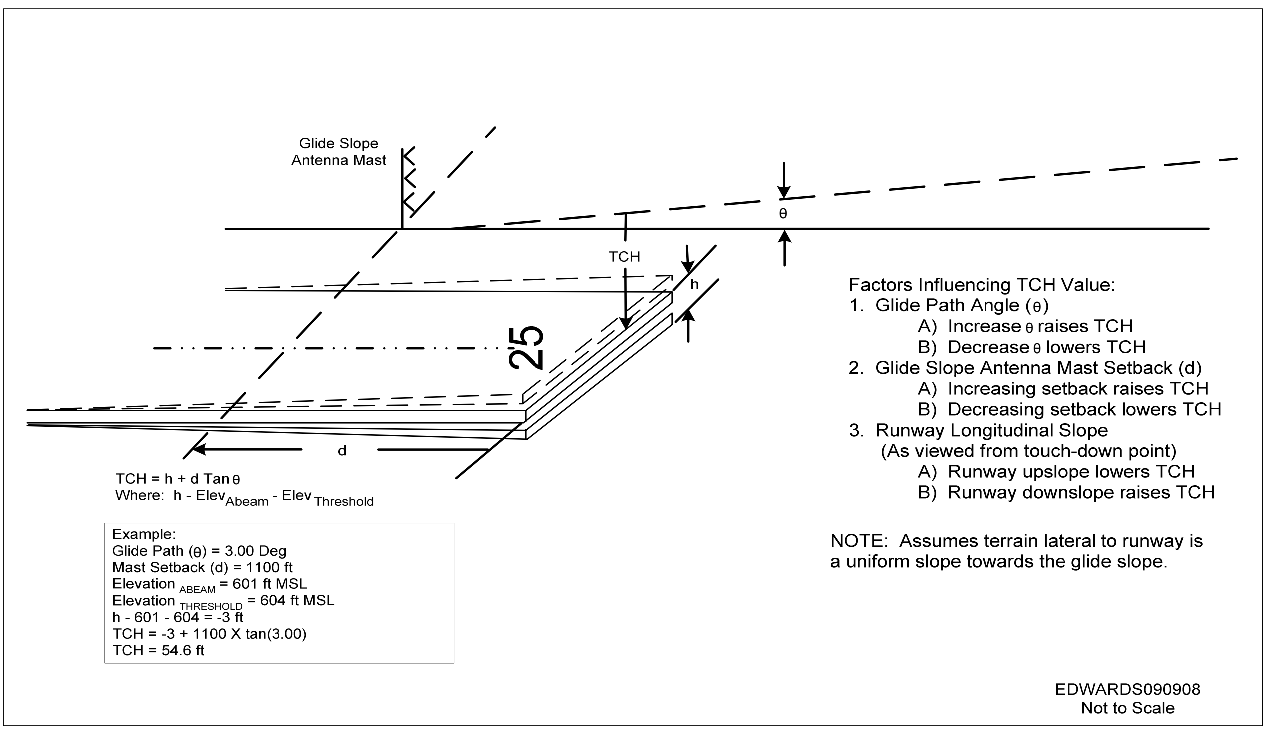


Figure 4. The TCH Calculation.

Category III A - A precision instrument approach and landing with: A decision height not lower than 100 feet (30 m) above touchdown zone elevation, or no decision height; and a runway visual range not less than 700 feet (210 m).

Category III B - A precision instrument approach and landing with: A decision height not lower than 50 feet (15 m) above touchdown zone elevation, or no decision height; and a runway visual range less than 700 feet (210 m) but not less than 150 feet (46 m).

Category III C - A precision instrument approach and landing with no decision height and no runway visual range limitations. A Category III C system is capable of using an aircraft's autopilot to land the aircraft and can also provide guidance along the runway surface.

In each case a suitably equipped aircraft and appropriately qualified pilot/crew are required. Cat I relies only on altimeter indications for decision height, whereas Cat II and Cat III approaches use radar altimeter to determine decision height.

B. FAA FLIGHT INSPECTION AND ORDER 8240.47C

1. BACKGROUND AND METHODOLOGY

Prior to the 1983 FAA Order 8240.47, no distinction was made between the calculated and measured threshold crossing heights at ILS glide slope facilities. The TCH is a purely theoretical value based on the glide slope mast setback, the glide path angle and the amount of longitudinal runway slope.

The actual height above threshold where the glide slope on-path indication is found almost never coincides with the calculated TCH value (see Figure 5). Since the path-forming terrain at most glide slope facilities is irregular, the glide path may exhibit roughness or bends which may yield actual crossing height values several feet above or below expected. As a result, the theoretical TCH and glide slope origination point (aiming point) provided by engineering personnel were not always accurate at many glide slope facilities. A method was needed which used actual flight data to measure the TCH and to determine the proper aiming point location.

FAA Order 8240.47C [10] (fourth revision since 8240.47 was introduced) defines the procedure to calculate the reference datum height (RDH) and achieved reference datum height (ARDH) from measured flight recordings. These RDH and ARDH values are analogous to measured TCH.

From an ideal signal-in-space viewpoint, a logical method to find the actual TCH might involve the use of a portable ILS receiver (PIR) and a tall tower positioned on the runway threshold to determine the height above the runway surface where the on-path indication occurs. Although technically correct, it is impractical and not entirely representative. For example, imagine a 200,000 pound, landing aircraft autopilot coupled to the glide slope approaching at 140 knots. In order to keep the VDI within one dot of centered (1/5 of full-scale deflection), the aircraft must

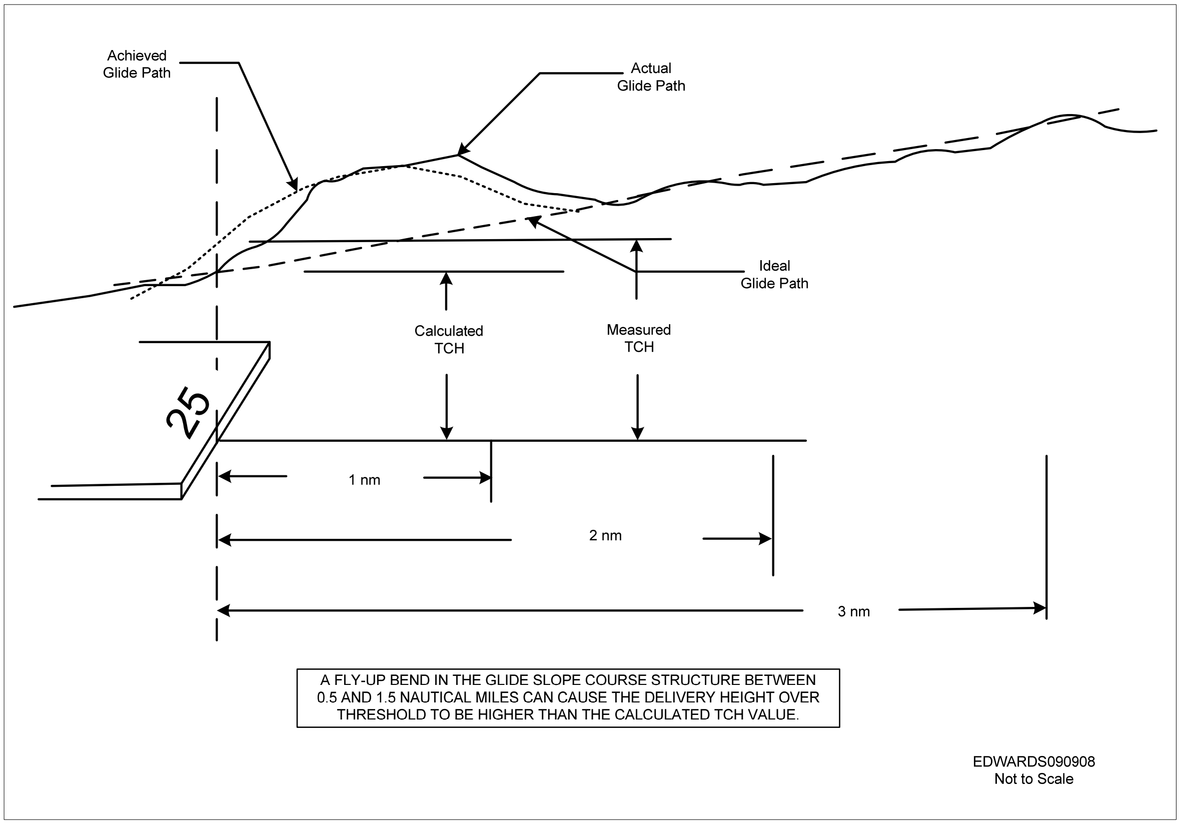


Figure 5. Effect of Course Structure Roughness on Measured TCH.

pass through a window which has a vertical height of 5 feet at the threshold (see Figure 6). The aircraft and autopilot system are simply incapable of following terrain or multipath induced VDI excursions which occur near the runway threshold. The aircraft momentum is too large to change altitude quickly enough to maintain a centered VDI. Knowing this, one can reason that the actual TCH is based on a portion of the descent path which is established prior to reaching the runway threshold (see Figure 7). Hence, the significance of the RDH and ARDH values are established. The concept involves projecting a specific, statistically averaged segment of the measured flight path down to the runway surface. This segment, calculated using the method of least-squares, is known as the best-fit-straight-line (BFSL). The height above the runway threshold over which the projected BFSL passes is the RDH or ARDH value (see Figure 8).

In order to calculate the RDH, the specified portion of the descent path, called ILS Zone 2, is used between ILS Point A (4 nmi from threshold) and ILS Point B (3500 feet from threshold). The applicable portion of the descent path used to calculate the ARDH is between 6000 feet and ILS Point C (approximately 1000 feet from threshold). The RDH and ARDH have no relevancy for Category I operation, however, for Category II/III operation, the RDH and ARDH values must be between 50 and 60 feet. The BFSL process is typically performed on all newly installed Category I sites to determine the proper aiming point height.

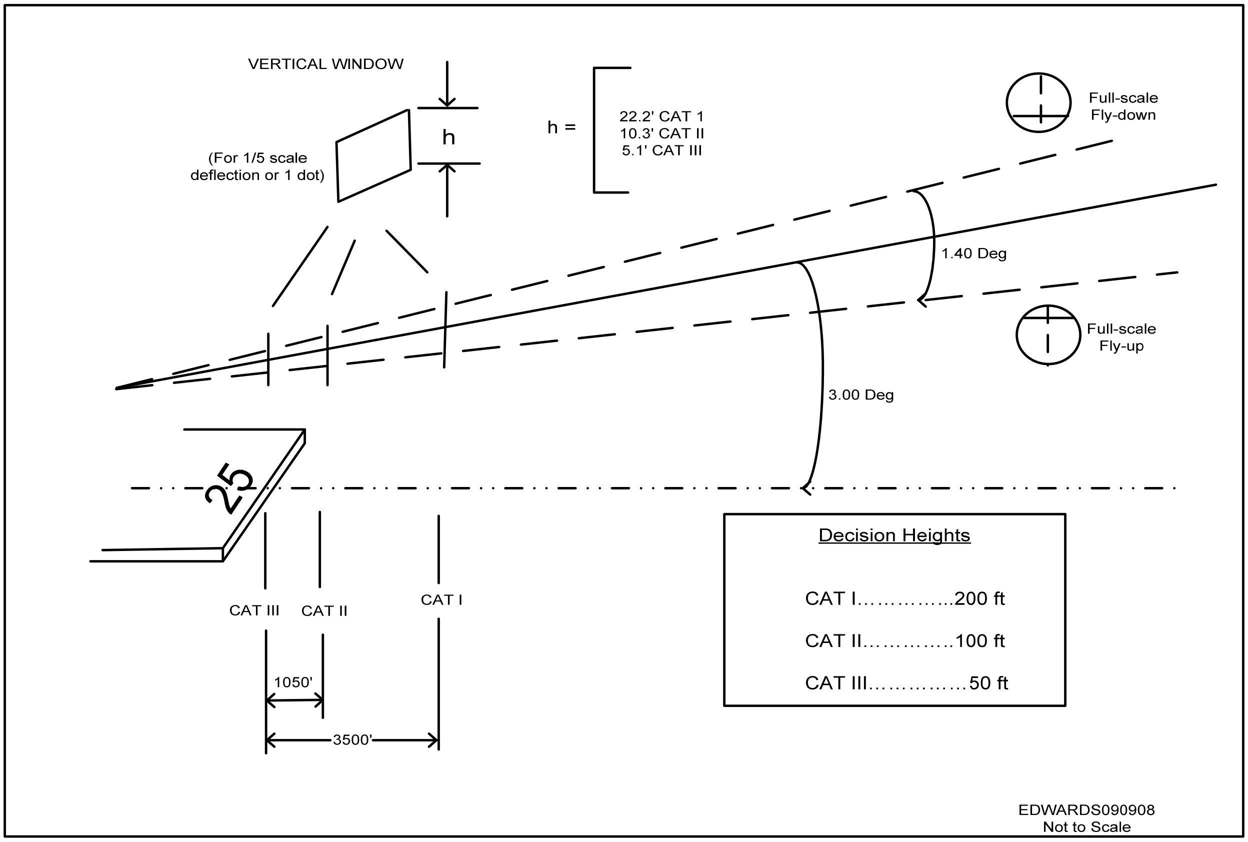


Figure 6. Glide Path Course Sensitivity versus Distance from Threshold.

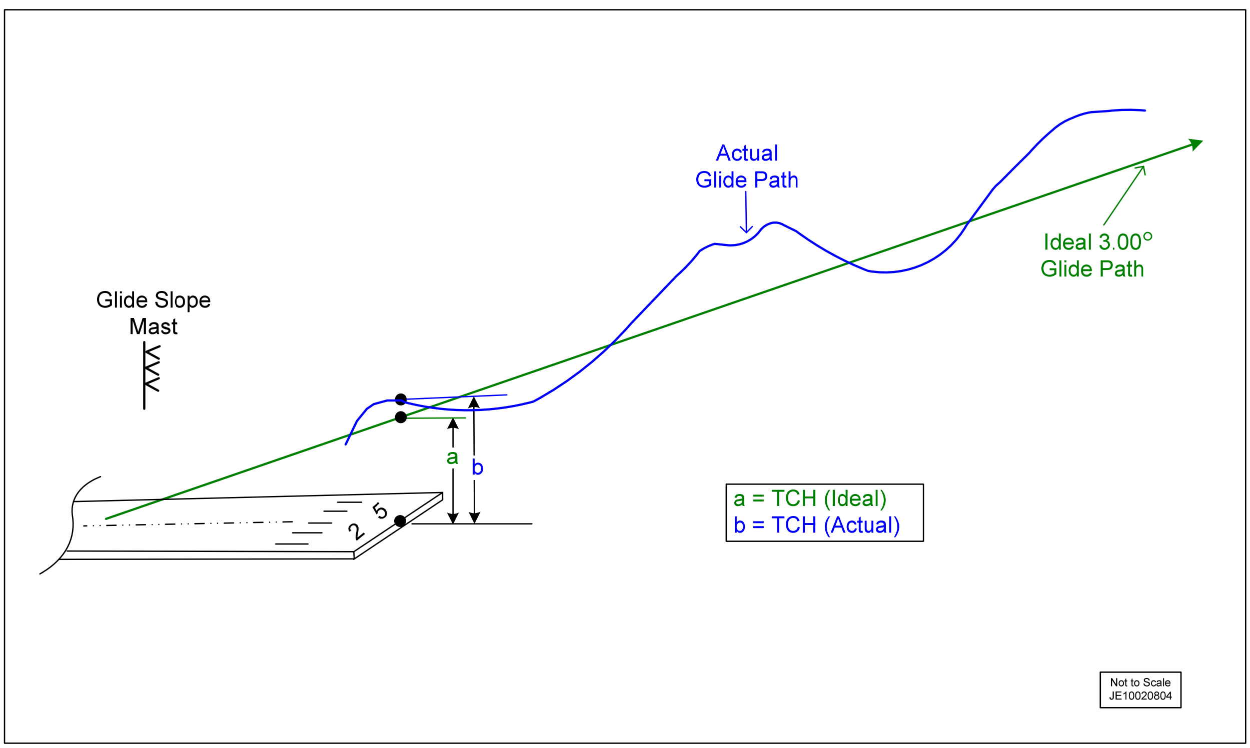


Figure 7. Measured TCH.

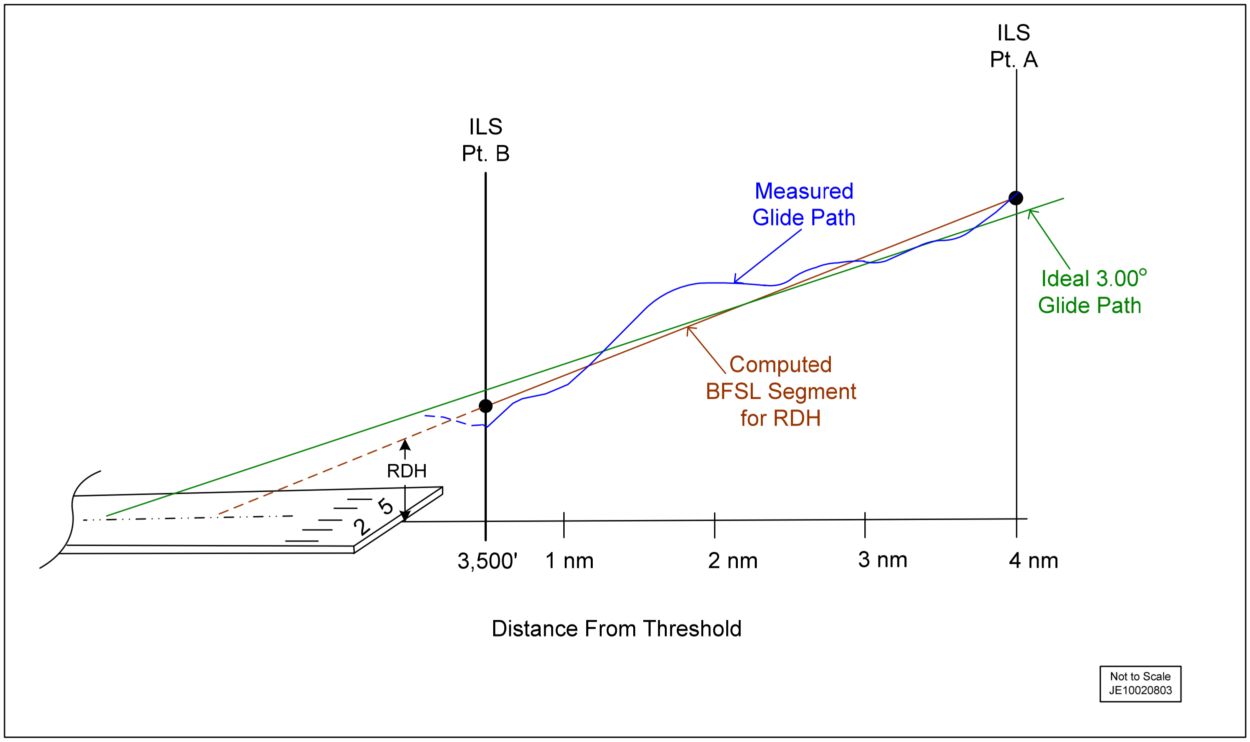


Figure 8. Best-Fit-Straight-Line and RDH.

2. BEST FIT STRAIGHT LINE AND AIMING POINT

Further discussion of the BFSL requires an understanding of aiming point theory. Measuring the path angle and course structure roughness of an ILS glide slope requires precise knowledge of aircraft position during the approach. FAA flight check aircraft use an inertial navigation system (INS) to precisely keep track of aircraft heading and velocity throughout the approach. An on-board automated camera system takes downward looking photographs as the aircraft crosses the approach and stop ends of the runway. Using the threshold markings seen in the picture and radar altimeter values, the INS data is post-processed to compute aircraft position throughout the approach with a high degree of accuracy. The computed aircraft position for each instant of time during the approach must be referenced to some known point on the airfield. This point is arbitrarily chosen to be on the runway centerline surface abeam the glide slope mast (or abeam the phase center in the case of an endfire system) and is called the aiming point.

Typically the initial aiming point location is not coincident with the glide path on-course. In other words, an approaching aircraft tracking the ILS glide path does not appear to be aimed at this reference point and will either pass overhead or under this point (see Figure 9). The BFSL process uses a method of least-squares to determine a new elevation value for the aiming point that will maximize aiming point and glide-slope coincidence. The BFSL is a line defined by a slope and an intercept point that crosses a vertical line positioned on the runway centerline abeam the ILS glide slope mast that best fits the measured data points between ILS Pt A and ILS Pt B. The height at which this line crosses the threshold is defined as the RDH.

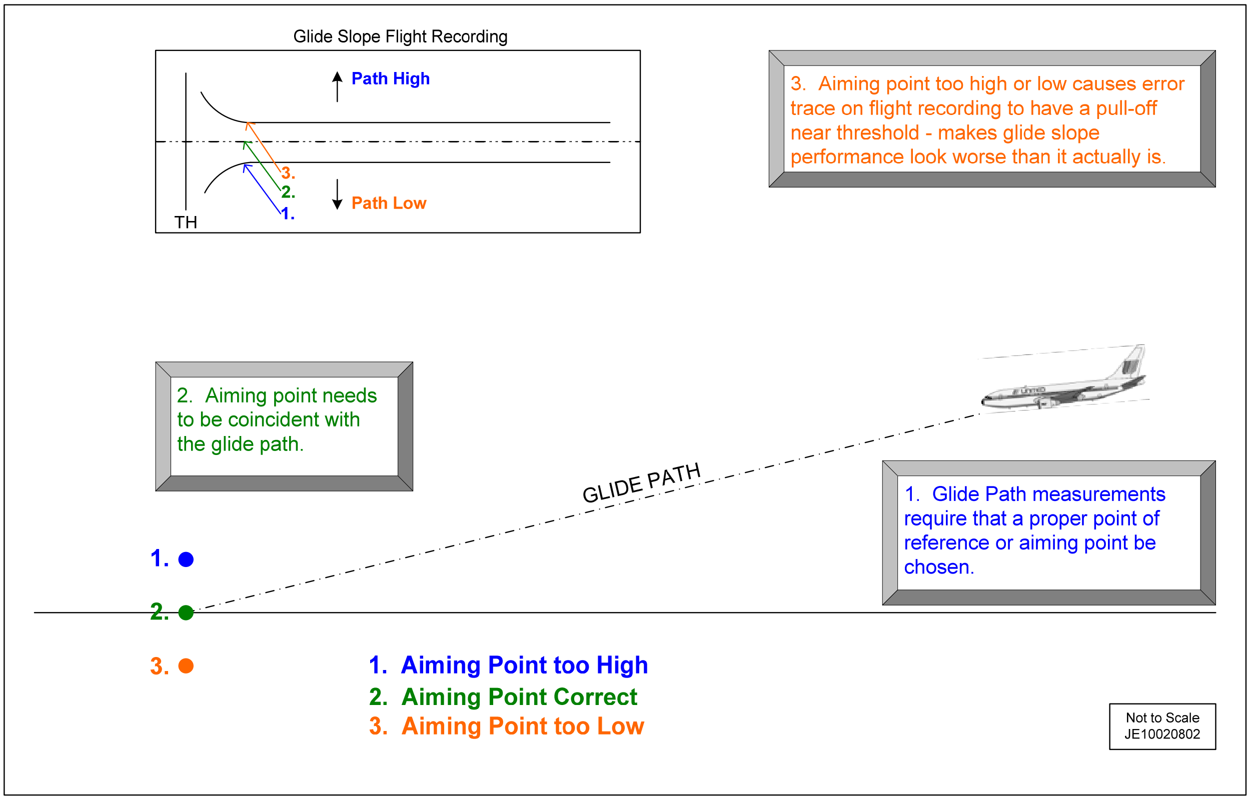


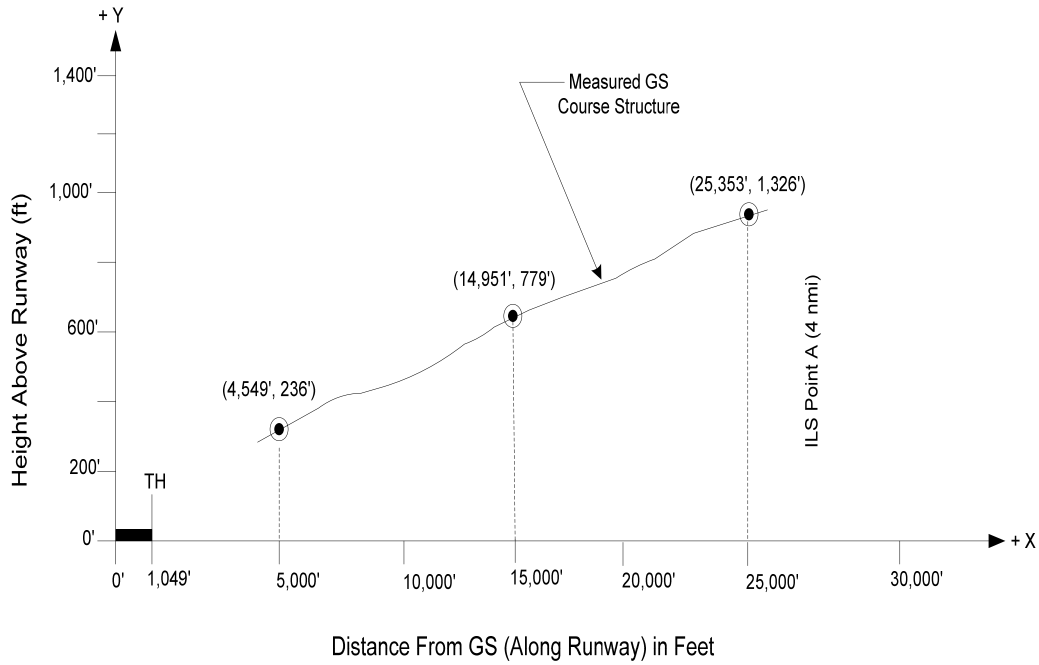
Figure 9. Effect of Aiming Point Height on Glide Slope Course Structure Measurements.

It is also important to note that the aiming point location directly effects the reported structure roughness in ILS Zone 2. The optimal aiming point location minimizes the reported structure roughness in ILS Zone 2.

3. SAMPLE BFSL AND RDH CALCULATIONS:

Figure 10 shows the complete process of computing a BFSL, aiming point adjustment and computing a RDH. The process was simplified by using only 3 points along the approach instead of the usual 21 points. The RDH value is not representative until the aiming point adjustment is applied and the flight measurement is repeated.

Table 1 is a spreadsheet showing the BFSL computation to determine a RDH value for an ideal glide path. The parameters with the bold titles are the given values. This spreadsheet performs the BFSL computation based on 21 uniformly spaced samples along the approach. The terrain and runway surface are assumed perfectly flat and in the same plane. Also, the glide path is perfectly straight and coincidental with the aiming point. Achieving this coincidence requires the initial aiming point elevation to be 20.96 feet (400 ft times the Tan 3.00 deg). This sample case produces a RDH value of 55.0 feet that is identical to the TCH value and a height adjustment to the aiming point is not required. A description of the values and columns are provided in Appendix A.



Determination of Best-Fit-Straight-Line (BSFL):

BFSL is a line having form: $Y = mX + b$

where: $$M = \frac{\sum xY}{\sum x^2} = \tan\theta_{BFSL}$$

$$b = \overline{Y} - m\overline{X} = \text{Aiming Point ADJ}$$

Point	X	Y	$x = X - \overline{X}$
Pt. A	25,353'	1,326'	10,402'
2	14,951'	779'	0'
Pt. B	4,549	236'	-10,402'

$\overline{X} = 14{,}951'$ $\Sigma xY = 11{,}338{,}180$

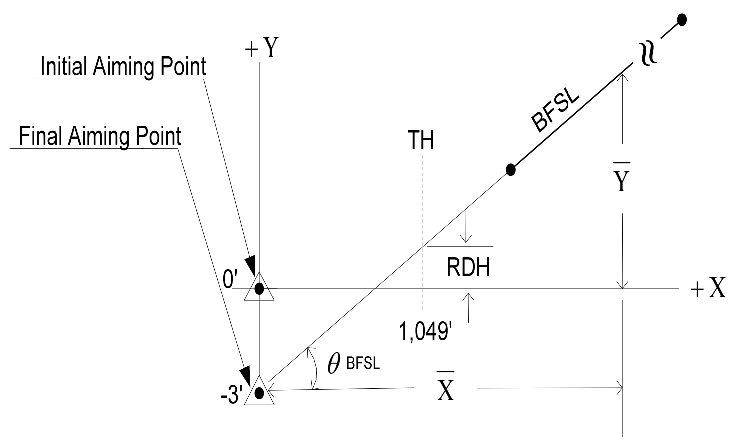
$\overline{Y} = 780.3'$ $\Sigma x = 216{,}403{,}208$

$$M = \frac{\sum xY}{\sum x^2} = \frac{11{,}338{,}180}{216{,}403{,}208} = 0.052394$$

$$\theta_{BFSL} = Tan^{-1}(0.052394) = 3.00°$$

$$b = \overline{Y} - m\overline{X} = 780.3(0.052394)(14{,}951) = {}^{-}3.0'$$

Determination of RDH:



$$\text{RDH} = (Tan\theta_{BFSL}) + \text{Aiming Point ADJ}$$
$$= (1{,}049)(Tan3.00°) + (-3)$$
$$= 52.0'$$

Not to Scale
JE10020801

Figure 10. BFSL and RDH Sample Calculation**.**

Table 1. Sample BFSL/RDH Spreadsheet with Correct Aiming Point.

RDH Spreadsheet

GS setback	1049	ft	Sum xY	43663665.16	
GS offset	400	ft	Sum xx	833152350.80	
GS elev	0	ft	meanX	14951.00	
GS angle	3.00	deg	meanY	783.55	
GS width	0.70	deg	Average Angle	3.00	deg
AP setback	1049	ft	BFSL Angle	3.00	deg
AP offset	0	ft	AP adjustment	0.00	ft
AP height	20.96	ft			
TH elev	0	ft	TCH	55.0	ft
Abeam elev	0	ft	RDH	55.0	ft

Point #	Dist to AP (X)	GS uA	Ht abv AP (Y)	X-meanX (x)	xY	xx
ILS Pt A	25353.00	0	1328.69	10402.00	13821080	108201604
2	24312.80	0	1274.18	9361.80	11928617	87643299
3	23272.60	0	1219.67	8321.60	10149567	69249027
4	22232.40	0	1165.15	7281.40	8483929	53018786
5	21192.20	0	1110.64	6241.20	6931702	38952577
6	20152.00	0	1056.12	5201.00	5492888	27050401
7	19111.80	0	1001.61	4160.80	4167486	17312257
8	18071.60	0	947.09	3120.60	2955497	9738144.4
9	17031.40	0	892.58	2080.40	1856919	4328064.2
10	15991.20	0	838.06	1040.20	871753.4	1082016
11	14951.00	0	783.55	0.00	0	0
12	13910.80	0	729.03	-1040.20	-758341	1082016
13	12870.60	0	674.52	-2080.40	-1403271	4328064.2
14	11830.40	0	620.01	-3120.60	-1934788	9738144.4
15	10790.20	0	565.49	-4160.80	-2352893	17312257
16	9750.00	0	510.98	-5201.00	-2657585	27050401
17	8709.80	0	456.46	-6241.20	-2848866	38952577
18	7669.60	0	401.95	-7281.40	-2926735	53018786
19	6629.40	0	347.43	-8321.60	-2891191	69249027
20	5589.20	0	292.92	-9361.80	-2742236	87643299
ILS Pt B	4549.00	0	238.40	-10402.00	-2479868	108201604

Table 2 is a spreadsheet showing what happens if the aiming point is moved downward three feet to 17.65 feet. Re-measuring the glide slope course structure with the new aiming point yields non-zero, VDI microampere values along the approach that become progressively larger (more positive for aiming point moved down) as the aircraft approaches threshold (see values in GS µA column). Note that the computed RDH value has changed upward by three feet. This seems to indicate that the RDH is dependent on aiming point location. Caution must be exercised here as this is counter-intuitive. Since the glide slope transmitting system or path-forming terrain has not changed, an aircraft coupled to the glide path crosses the threshold at the same height, approach-after-approach, no matter where the aiming point is located. The RDH value is only representative when the aiming point adjustment value is zero. In other words, to determine the true RDH value, it is necessary to re-position the aiming point to the computed height based on the BFSL process and repeat the low-approach flight measurement. Table 3 shows an upward aiming point movement of 3 feet to 23.65 feet. Again, the recorded VDI microampere values along the approach become progressively larger (more negative for aiming point moved up) as the aircraft approaches threshold (see values in GS µA column). The computed RDH value has changed downward by three feet.

Prior to the commissioning flight check of a new ILS glide slope, the aiming point is initially set to the elevation of the runway surface directly abeam the glide slope mast. This initial aiming point typically needs adjusted through the use of a few low-approaches and BFSL computations to achieve a near-zero adjustment recommendation. The goal is to attain three repeatable low-approach recordings that produce aiming point elevation adjustment values within 3 feet of zero and within 3 feet of each other. The origination point is considered optimized when the average glide path angle and the BFSL angle are within 0.03 degrees.

III. ANALYSIS

A. REPRESENTATIVENESS OF THE RDH AND ARDH LINEAR REGRESSION METHOD

While the RDH/ARDH theory is sound, implementation can be problematic at some glide slope sites. Each glide slope path or course structure is unique. The unique path shape comes from terrain irregularities under the approach path and multi-path reflections from physical structures on or near the airport such buildings, fences, power lines and and/or trees. It should also be stated that on image glide slope systems, improper antenna offsets can cause hyperbolic-shaped flares in the glide path that are virtually indistinguishable from aiming point errors. Fortunately, antenna offset calculations are straight-forward to compute based on the mast offset from the runway centerline and this is typically not an issue. In the case of endfire glide slopes, course path shape is defined mostly by the positioning of the glide slope antenna sections. The RDH/ARDH computation process assumes that the path is not straight because the aiming point is not optimum. Figure 11 shows an ideally straight course structure that has been corrupted by only aiming point misplacement. Note the hyperbolic shape associated with this misplacement.

Table 2. Sample BFSL/RDH Spreadsheet with Aiming Point Lowered Three Feet.

RDH Spreadsheet

GS setback	1049 ft	Sum xY	43663665.16	
GS offset	400 ft	Sum xx	833152350.80	
GS elev	0 ft	meanX	14951.00	
GS angle	3.00 deg	meanY	786.55	
GS width	0.70 deg	Average Angle	3.01	deg
AP setback	1049 ft	BFSL Angle	3.00	deg
AP offset	0 ft	AP adjustment	3.00	ft
AP height	17.96 ft			
TH elev	0 ft	TCH	55.0	ft
Abeam elev	0 ft	RDH	58.0	ft

Point #	**Dist to AP (X)**	**GS uA**	Ht abv AP (Y)	X-meanX (x)	xY	xx
ILS Pt A	25353.00	1.448818	1331.69	10402.00	13852286	108201604
2	24312.80	1.510804	1277.18	9361.80	11956703	87643299
3	23272.60	1.578331	1222.67	8321.60	10174532	69249027
4	22232.40	1.652177	1168.15	7281.40	8505773	53018786
5	21192.20	1.733272	1113.64	6241.20	6950426	38952577
6	20152.00	1.822739	1059.12	5201.00	5508491	27050401
7	19111.80	1.921944	1004.61	4160.80	4179969	17312257
8	18071.60	2.03257	950.09	3120.60	2964858	9738144.4
9	17031.40	2.156709	895.58	2080.40	1863160	4328064.2
10	15991.20	2.296998	841.06	1040.20	874874	1082016
11	14951.00	2.456807	786.55	0.00	0	0
12	13910.80	2.640517	732.03	-1040.20	-761462	1082016
13	12870.60	2.85392	677.52	-2080.40	-1409512	4328064.2
14	11830.40	3.104851	623.01	-3120.60	-1944149	9738144.4
15	10790.20	3.404161	568.49	-4160.80	-2365375	17312257
16	9750.00	3.767336	513.98	-5201.00	-2673188	27050401
17	8709.80	4.217255	459.46	-6241.20	-2867590	38952577
18	7669.60	4.789215	404.95	-7281.40	-2948579	53018786
19	6629.40	5.540659	350.43	-8321.60	-2916156	69249027
20	5589.20	6.571795	295.92	-9361.80	-2770321	87643299
ILS Pt B	4549.00	8.074487	241.40	-10402.00	-2511074	108201604

Table 3. Sample BFSL/RDH Spreadsheet with Aiming Point Raised Three Feet.

RDH Spreadsheet

GS setback	1049	ft	Sum xY	43663665.16	
GS offset	400	ft	Sum xx	833152350.80	
GS elev	0	ft	meanX	14951.00	
GS angle	3.00	deg	meanY	780.55	
GS width	0.70	deg	Average Angle	2.99	deg
AP setback	1049	ft	BFSL Angle	3.00	deg
AP offset	0	ft	AP adjustment	-3.00	ft
AP height	23.96	ft			
TH elev	0	ft	TCH	55.0	ft
Abeam elev	0	ft	RDH	52.0	ft

Point #	Dist to AP (X)	GS uA	Ht abv AP (Y)	X-meanX (x)	xY	xx
ILS Pt A	25353.00	-1.44884	1325.69	10402.00	13789874	108201604
2	24312.80	-1.51082	1271.18	9361.80	11900532	87643299
3	23272.60	-1.57835	1216.67	8321.60	10124602	69249027
4	22232.40	-1.6522	1162.15	7281.40	8462084	53018786
5	21192.20	-1.7333	1107.64	6241.20	6912979	38952577
6	20152.00	-1.82277	1053.12	5201.00	5477285	27050401
7	19111.80	-1.92198	998.61	4160.80	4155004	17312257
8	18071.60	-2.03261	944.09	3120.60	2946135	9738144.4
9	17031.40	-2.15675	889.58	2080.40	1850678	4328064.2
10	15991.20	-2.29704	835.06	1040.20	868632.8	1082016
11	14951.00	-2.45686	780.55	0.00	0	0
12	13910.80	-2.64058	726.03	-1040.20	-755221	1082016
13	12870.60	-2.85399	671.52	-2080.40	-1397029	4328064.2
14	11830.40	-3.10493	617.01	-3120.60	-1925426	9738144.4
15	10790.20	-3.40426	562.49	-4160.80	-2340410	17312257
16	9750.00	-3.76746	507.98	-5201.00	-2641982	27050401
17	8709.80	-4.21741	453.46	-6241.20	-2830143	38952577
18	7669.60	-4.78941	398.95	-7281.40	-2904891	53018786
19	6629.40	-5.54092	344.43	-8321.60	-2866226	69249027
20	5589.20	-6.57216	289.92	-9361.80	-2714150	87643299
ILS Pt B	4549.00	-8.07504	235.40	-10402.00	-2448662	108201604

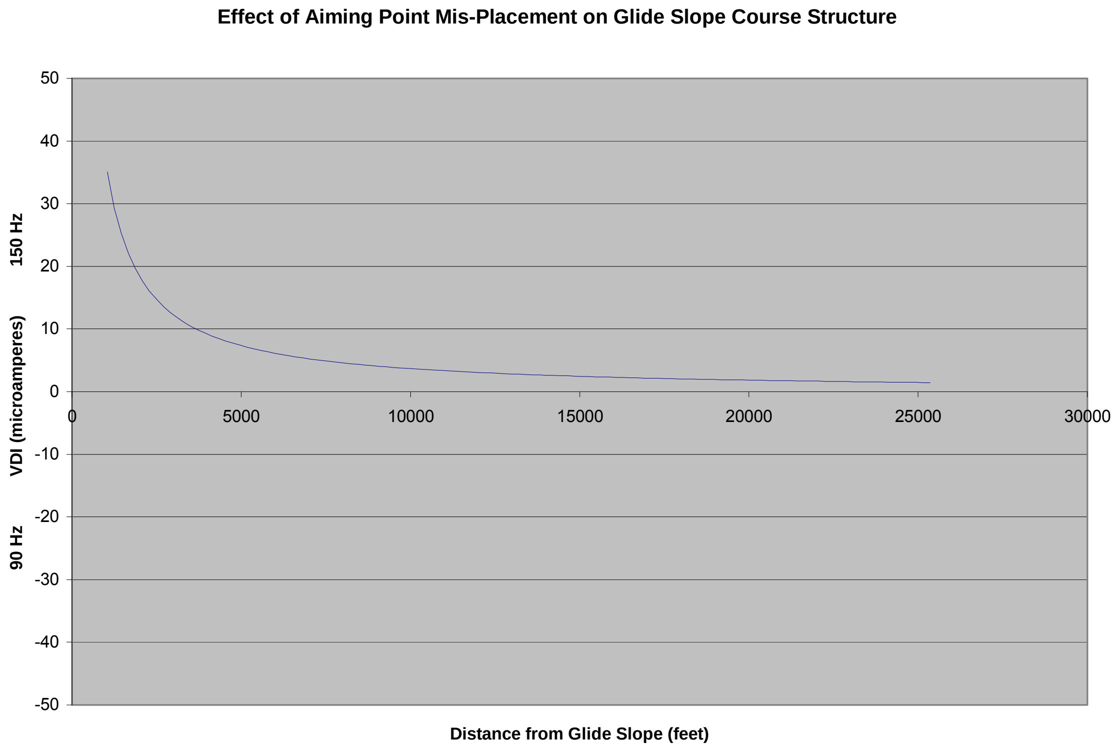


Figure 11. Effect of Misplaced Aiming Point on Glide Slope Course Structure.

VDI deflections are small at the further-out distances and become progressively larger approaching the threshold. Glide slope facilities having course structures that exhibit a similar trend can benefit greatly from optimizing the aiming point with the RDH/BFSL process. This minimizes the reported course structure values for ILS Zone.

1. SAMPLE FLIGHT RECORDINGS AND BFSL ANALYSIS

The Ohio University flight recordings in Figure 12 through Figure 15 are of actual glide slope facilities which exhibit anomalous behavior during application of the RDH/BFSL process. In the relatively small sample of twenty glide slope facilities measured by Ohio University in the last ten years, approximately 1-in-5 do not benefit from the application of the BFSL process. Each of these flight recordings has two course structure traces. One is the measured course structure roughness with the initial aiming point. The second trace is representative of re-measuring the glide slope facility using the new aiming point. In all cases, the initial aiming point is assumed to coincide with the base of the glide slope mast (image system) or at the phase-center (non-image system). Category I tolerances lines have been added to add perspective to the magnitude of the course roughness. Applying the BFSL process to this trace yields a new aiming point location. None of the examples in Figure 12 through Figure 15 exhibit the hyperbolic shape associated with a misplaced aiming point that must exist along the entire low-approach. Instead, the path angle is only skewed in a large portion of Zone 2. The skew is significant enough that the difference between the average glide path angle and the BFSL angle greater than 0.05 degrees. Adjusting the aiming point elevation based on the computation yields a flight recording with a severe close-in flare. This flare can cause the ILS Zone 3 reported structure roughness

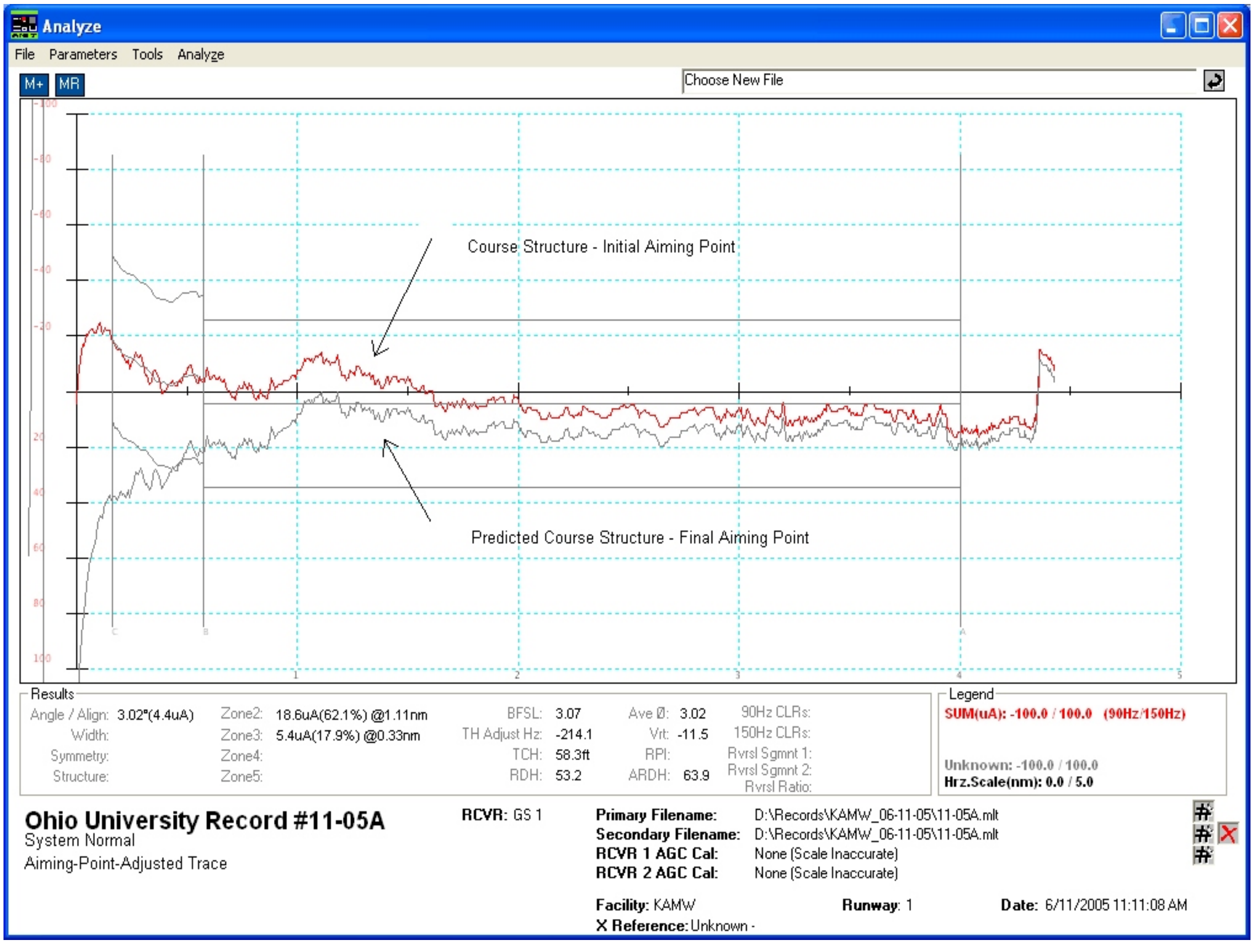


Figure 12. Problematic Example of OU Measured Glide Slope Course Structure, Ames IA.

Narrative for Figure 12.

Facility Location: Ames, IA
System type: Model 106 Endfire

Description:

Although the initial aiming point produces an acceptable course structure in both ILS Zones 2 and 3, application of the RDH/BFSL process shows that a significant adjustment to the aiming point height is required. Close examination of the course structure in Zone 2 shows that the glide path angle gradually changes from 10 microamperes into the 150 Hz (path high) at 4 nmi to 10 microamperes into the 90 Hz (path low) at approximately 1.2 nmi. A skew in the glide path angle along the approach such as this indicates that an aiming point adjustment is needed. Applying the RDH/BFSL process yields a 0.05 degree difference between the average angle (3.02 deg) and the BFSL angle (3.07 deg). The computation indicates that the aiming point should be lowered by 9.4 feet.

The second trace on the graph shows what the course structure would look like with the new, adjusted aiming point. Although the path angle skew in Zone 2 is no longer present, a significant pull-off near the threshold now exists. This pull-off occurred because the skewed trend in Zone 2 did not continue into Zone 3 and beyond.

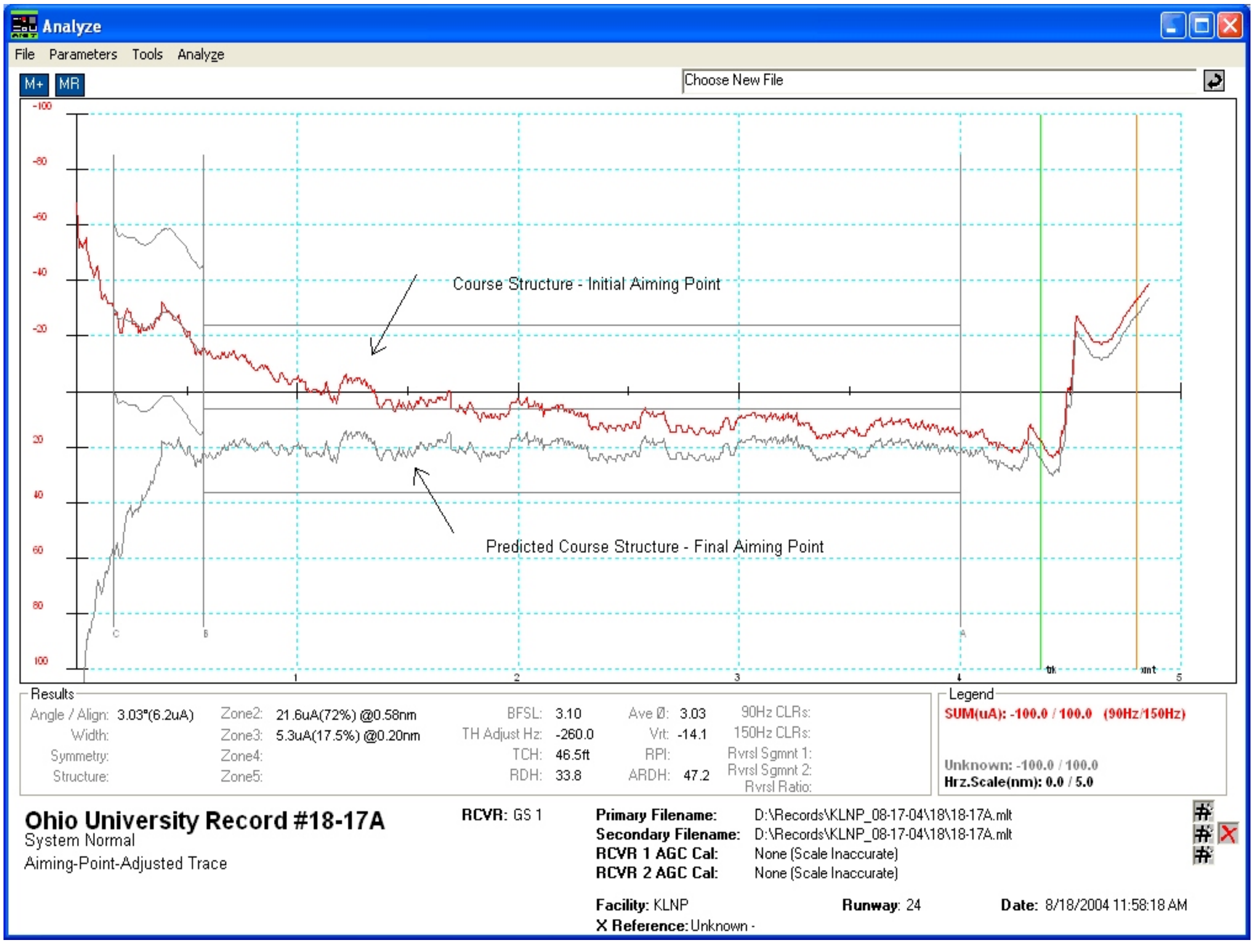


Figure 13. Problematic Example of OU Measured Glide Slope Course Structure, Wise VA.

Narrative for Figure 13.	Facility Location: Wise, VA (LNP) System type: Capture-Effect

Description:

The course structure produced by the initial aiming point shows a significant path angle skew from path-high to path-low in Zone 2. Over 70 percent of the allowable tolerances are consumed at ILS Point B (0.58 nmi). It is also noted that the sloping trend in Zone 2 continues to the threshold. Applying the RDH/BFSL process yields a 0.06 degree difference between the average angle (3.03 deg) and the BFSL angle (3.09). The computation indicates that the aiming point should be lowered by 13.8 feet.

The second trace on the graph shows what the course structure would look like with the new, adjusted aiming point. The course structure in Zone 2 is straight and the reported roughness is now less than 15 percent. The negative aspect is that the structure in Zone 3 and on to the threshold has a significant pull-off. This pull-off occurred because the magnitude of the skewed trend between 0.5 nmi and threshold did not continue to increase at the necessary rate.

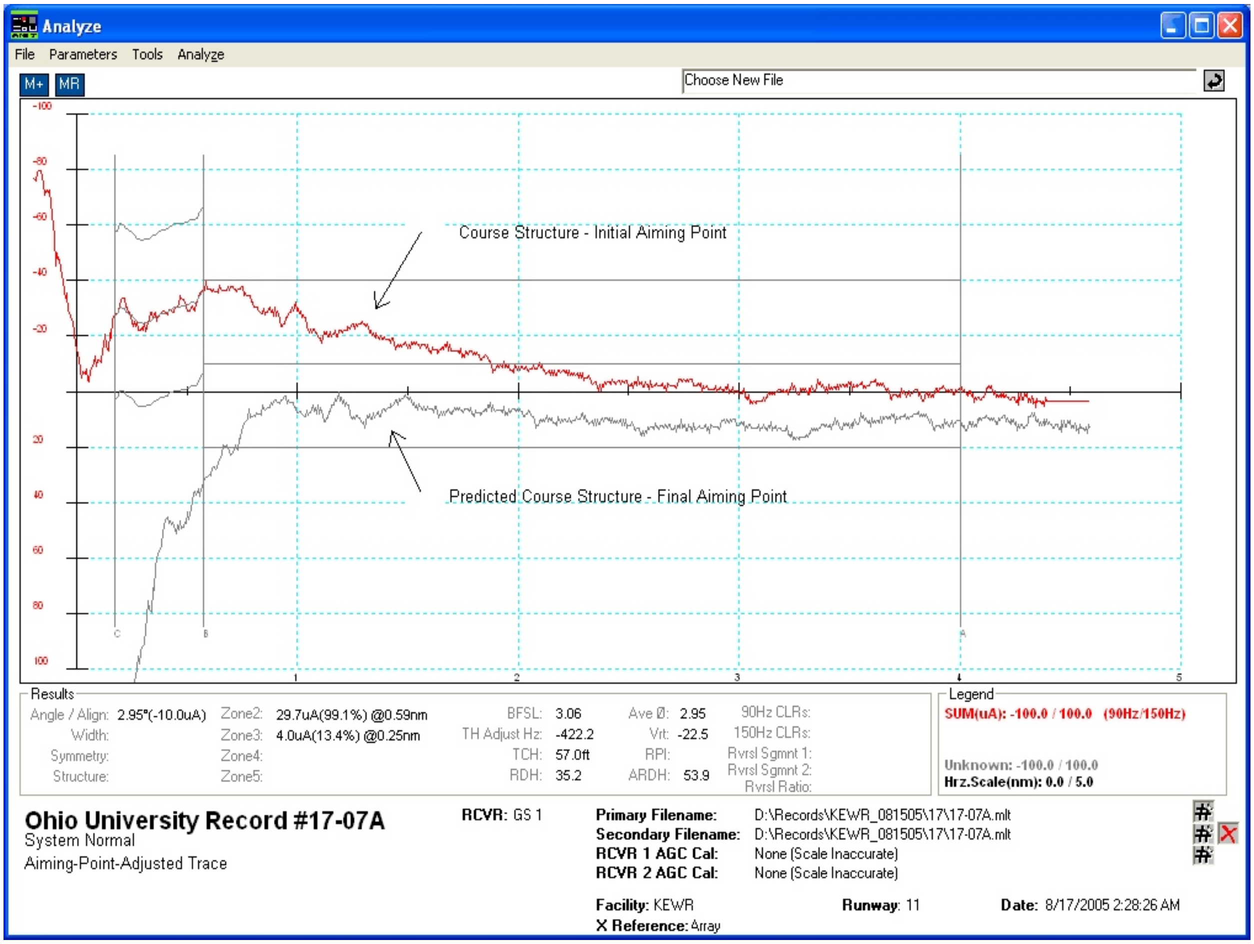


Figure 14. Problematic Example of OU Measured Glide Slope Course Structure, Newark NJ.

Narrative for Figure 14.	Facility Location: Newark, NJ (EWR) System Type: Model 105 Endfire

Description:

Use of the initial aiming point shows a significant skew in the Zone 2 path angle. Ninety three percent of the tolerances are consumed at 0.80 nmi. Applying the RDH/BFSL process yields a 0.11 degree difference between the average angle (3.06 deg) and the BFSL angle (2.95 deg). The computation indicates that the aiming point should be lowered by 25.7 feet.

The course structure using the new, adjusted aiming point is shown in the second trace. Only a slight improvement in the Zone 2 structure roughness is attained and the pull-off that begins at 0.75 nmi is unacceptable. This pull-off occurred because there is essentially no skew in the glide path in Zone 3.

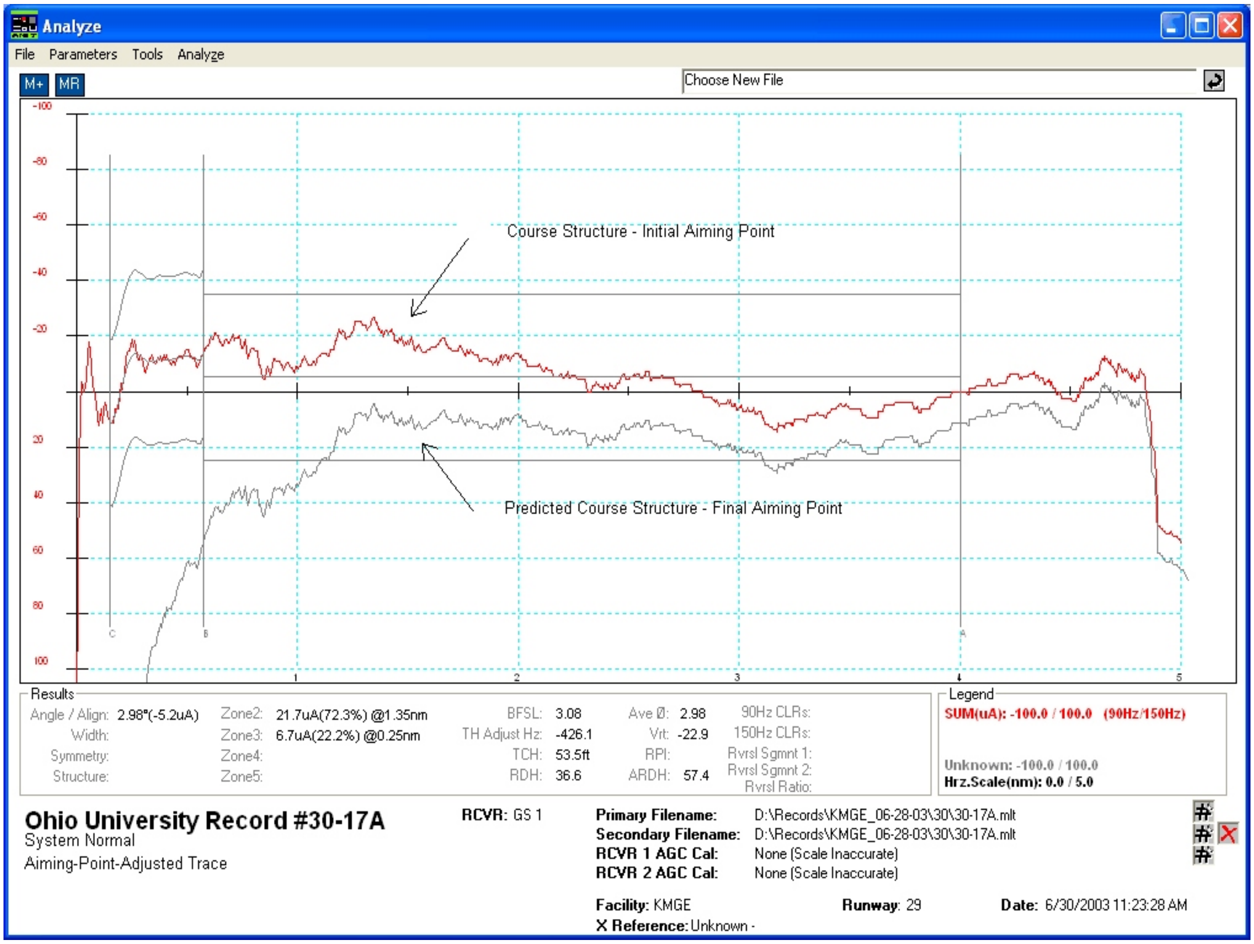


Figure 15. Problematic Example of OU Measured Glide Slope Course Structure, Marietta GA.

Narrative for Figure 15.

Facility Location: Marietta, GA (MGE)
System Type: Model 106 Endfire

Description:

The course structure produced by the initial aiming point shows a significant path angle skew from path-high to path-low in Zone 2 between 3.2 and 1.3 nmi. Applying the RDH/BFSL process yields a 0.10 degree difference between the average angle (2.98 deg) and the BFSL angle (3.08 deg). The computation indicates that the aiming point should be lowered by 22.8 feet.

The course structure using the new, adjusted aiming point is shown in the second trace. A massive pull-off begins at 1.0 nmi and continues all the way to the threshold. This pull-off occurred because there is no skew in the glide path in Zone 3 values to be inconsistent from run to run. Also, the computed RDH value significantly differs from the TCH value and isn't representative of the actual performance of the glide slope system.

values to be inconsistent from run to run. Also, the computer RDH value significantly differs from the TCH value and isn't representative of the actual performance of the glide slope system.

One of the problems with the RDH calculation is that the computation is affected by aberrations in the glide path which are far from the threshold. Figure 16 is an example of a straight glide path between 3 nmi and ILS Point B, however, between 3 and 4 nmi the path has an aberration that peaks at 20 microamperes below path (2.91 degrees into the 150 Hz). Applying the RDH/BFSL process to this data yields a recommendation to raise the aiming point by 12.38 feet (see RDH/BFSL spreadsheet in Table 4). The BFSL angle is 2.93 degrees and the average path angle is 2.98 degrees (difference is 0.05 degrees). Table 5 shows the RDH/BFSL spreadsheet for the re-flown approach with the aiming point raised by the 12.38 feet. Although the computed RDH is only 1.4 feet lower than the theoretical TCH because the BFSL and average angles are now equal at 2.92/2.93 degrees, it is not a representative value. An aircraft flying this particular approach would have adequate time to re-capture the VDI after passing the 3-mile transition point, stabilize and cross the threshold on the glide path at the designed TCH. More importantly, the large aiming point adjustment has significantly changed the appearance of the course structure roughness (see Figure 17).

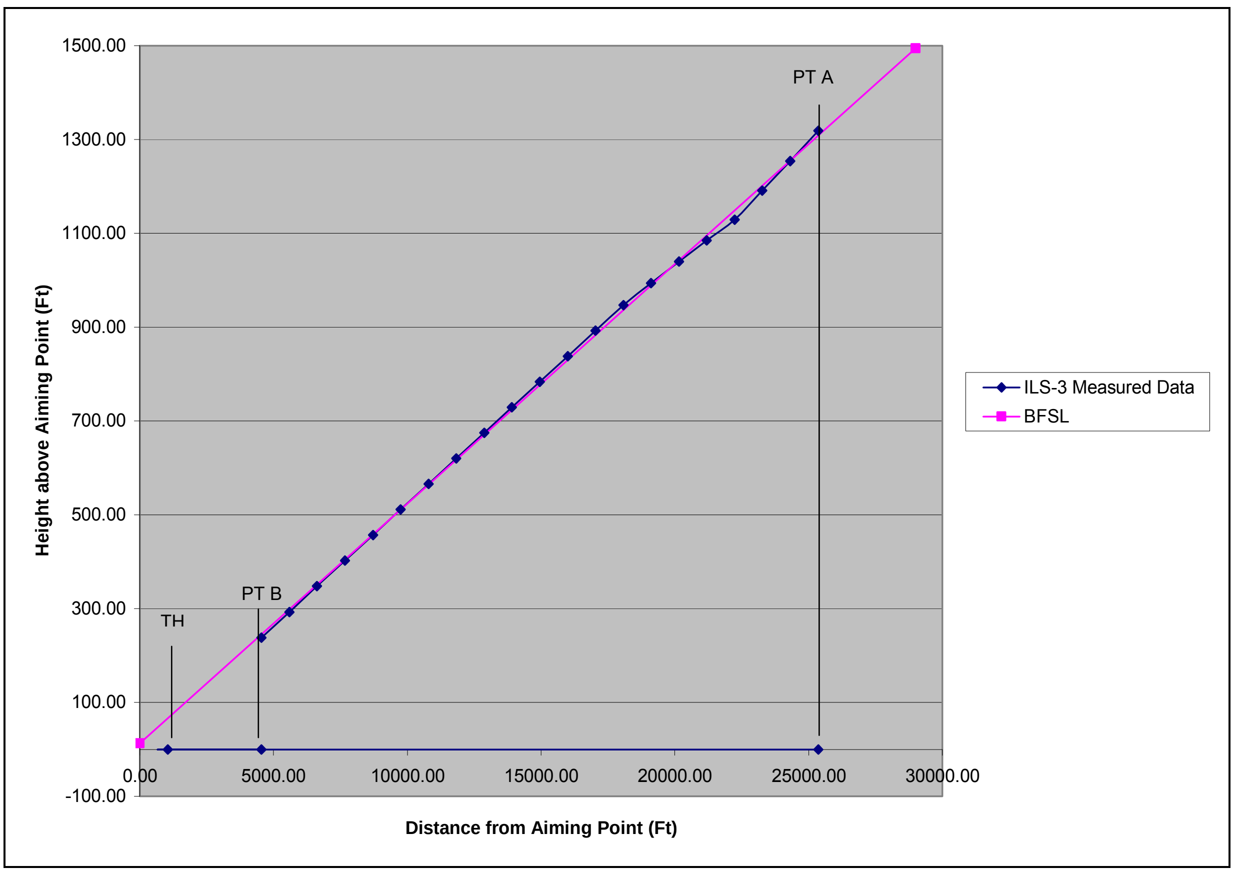


Figure 16. Glide Path Course Structure with Course Aberration Outside of 3 nmi.

Table 4. BFSL Spreadsheet for Glide Path Course Structure with Course Aberration Outside of 3 nmi.

RDH Spreadsheet

GS setback	1049	ft	Sum xY	42588343.31	
GS offset	400	ft	Sum xx	833152350.80	
GS elev	0	ft	meanX	14951.00	
GS angle	3.00	deg	meanY	776.63	
GS width	0.70	deg	Average Angle	2.98	deg
AP setback	1049	ft	BFSL Angle	2.93	deg
AP offset	0	ft	AP adjustment	12.38	ft
AP height	20.96	ft			
TH elev	0	ft	TCH	55.0	ft
Abeam elev	0	ft	RDH	66.0	ft

Point #	Dist to AP (X)	GS uA	Ht abv AP (Y)	X-meanX (x)	xY	xx
ILS Pt A	25353.00	-5	1318.34	10402.00	13713388	108201604
2	24312.80	-10	1254.32	9361.80	11742729	87643299
3	23272.60	-15	1191.16	8321.60	9912325	69249027
4	22232.40	-20	1128.84	7281.40	8219523	53018786
5	21192.20	-15	1084.68	6241.20	6769677	38952577
6	20152.00	-10	1039.66	5201.00	5407291	27050401
7	19111.80	-5	993.80	4160.80	4135014	17312257
8	18071.60	0	947.09	3120.60	2955497	9738144.4
9	17031.40	0	892.58	2080.40	1856919	4328064.2
10	15991.20	0	838.06	1040.20	871753.4	1082016
11	14951.00	0	783.55	0.00	0	0
12	13910.80	0	729.03	-1040.20	-758341	1082016
13	12870.60	0	674.52	-2080.40	-1403271	4328064.2
14	11830.40	0	620.01	-3120.60	-1934788	9738144.4
15	10790.20	0	565.49	-4160.80	-2352893	17312257
16	9750.00	0	510.98	-5201.00	-2657585	27050401
17	8709.80	0	456.46	-6241.20	-2848866	38952577
18	7669.60	0	401.95	-7281.40	-2926735	53018786
19	6629.40	0	347.43	-8321.60	-2891191	69249027
20	5589.20	0	292.92	-9361.80	-2742236	87643299
ILS Pt B	4549.00	0	238.40	-10402.00	-2479868	108201604

Table 5. BFSL Spreadsheet for Aiming Point Adjusted Glide Path Course Structure with Course Aberration Outside of 3 nmi.

RDH Spreadsheet

GS setback	1049 ft	Sum xY	42588343.31	
GS offset	400 ft	Sum xx	833152350.80	
GS elev	0 ft	meanX	14951.00	
GS angle	3.00 deg	meanY	764.25	
GS width	0.70 deg	Average Angle		2.92 deg
AP setback	1049 ft	BFSL Angle		2.93 deg
AP offset	0 ft	AP adjustment		0.00 ft
AP height	33.34 ft			
TH elev	0 ft		TCH	55.0 ft
Abeam elev	0 ft		RDH	53.6 ft

Point #	**Dist to AP (X)**	**GS uA**	Ht abv AP (Y)	X-meanX (x)	xY	xx
ILS Pt A	25353.00	-10.9792	1305.96	10402.00	13584611	108201604
2	24312.80	-16.2353	1241.94	9361.80	11626830	87643299
3	23272.60	-21.5143	1178.78	8321.60	9809304	69249027
4	22232.40	-26.8194	1116.46	7281.40	8129380	53018786
5	21192.20	-22.1538	1072.30	6241.20	6692411	38952577
6	20152.00	-17.5228	1027.28	5201.00	5342902	27050401
7	19111.80	-12.9319	981.42	4160.80	4083503	17312257
8	18071.60	-8.38811	934.71	3120.60	2916864	9738144.4
9	17031.40	-8.90044	880.20	2080.40	1831164	4328064.2
10	15991.20	-9.47942	825.68	1040.20	858875.8	1082016
11	14951.00	-10.139	771.17	0.00	0	0
12	13910.80	-10.8972	716.65	-1040.20	-745464	1082016
13	12870.60	-11.7779	662.14	-2080.40	-1377515	4328064.2
14	11830.40	-12.8136	607.63	-3120.60	-1896155	9738144.4
15	10790.20	-14.0489	553.11	-4160.80	-2301382	17312257
16	9750.00	-15.5478	498.60	-5201.00	-2593197	27050401
17	8709.80	-17.4048	444.08	-6241.20	-2771600	38952577
18	7669.60	-19.7655	389.57	-7281.40	-2836591	53018786
19	6629.40	-22.8672	335.05	-8321.60	-2788170	69249027
20	5589.20	-27.1235	280.54	-9361.80	-2626337	87643299
ILS Pt B	4549.00	-33.3265	226.02	-10402.00	-2351091	108201604

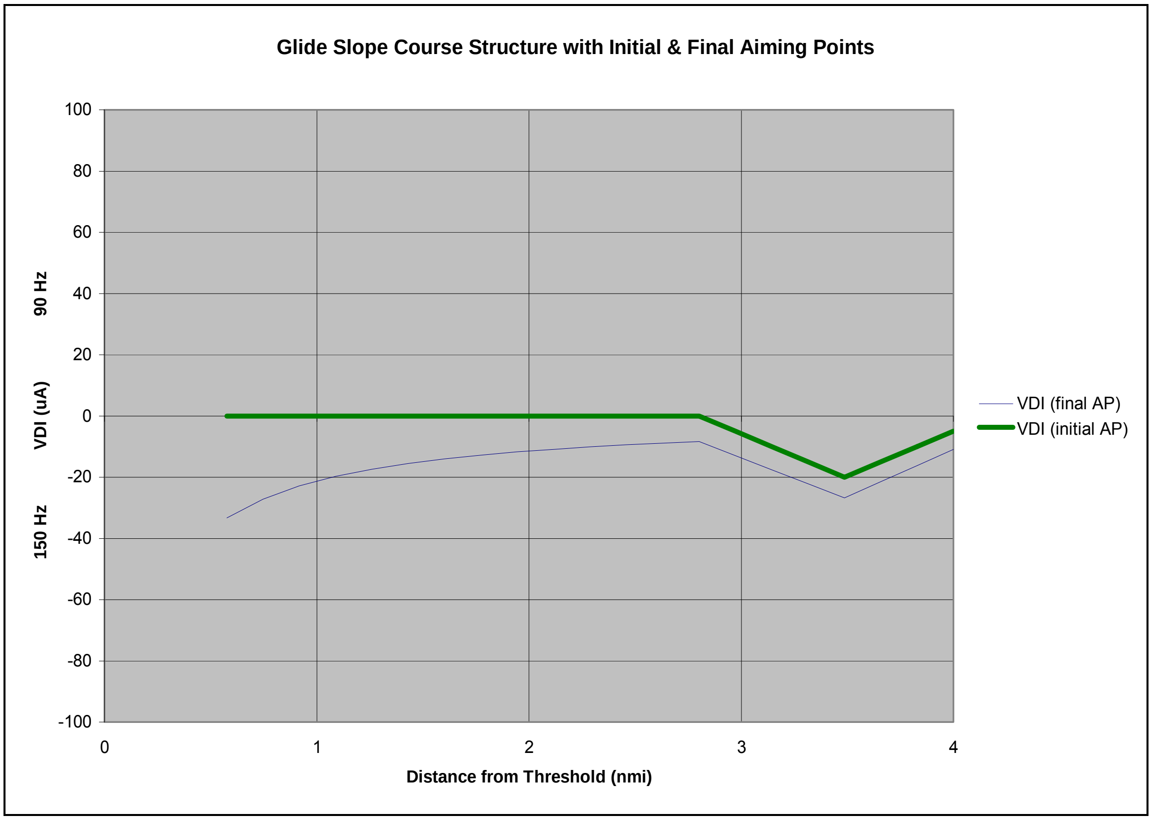


Figure 17. Glide Slope Course Structure for Initial and Final Aiming Points.

Figure 18 takes the above example a step further. This graph shows the effect on the RDH value of migrating an instantaneous "VDI blip" through the ILS Zone 2 course structure. A 100 microampere (fly-down) value was used in this scenario. ILS Zone 2 was divided into 100 equally spaced points. Point "1" is at ILS Point A (4 nmi from threshold) and Point "100" is at ILS Point B (3500 feet from threshold). The 100 microampere excursion was stepped, one point at a time, through the field of 100 points in Zone 2 while the remaining 99 points had zero microampere values. A BFSL computation was performed for each of the 100 scenarios. The nominal RDH value is 55 feet. This graph shows the non-linearity of the BFSL computation. VDI excursions at ILS Point A (furthest from threshold) produce a 6-foot RDH change whereas those at ILS Point B (closest to threshold) produce RDH changes which are less than 2 feet. This exercise shows again that the BFSL process is overly sensitive to VDI excursions which are far from threshold.

2. DISCUSSION – ALTERNATE RDH COMPUTATION METHODS

Listed below is a summary of the advantages and disadvantages associated with the current use of the BFSL computation to compute a measured TCH:

Advantages:

- Simple
- Minimizes Zone 2 structure roughness

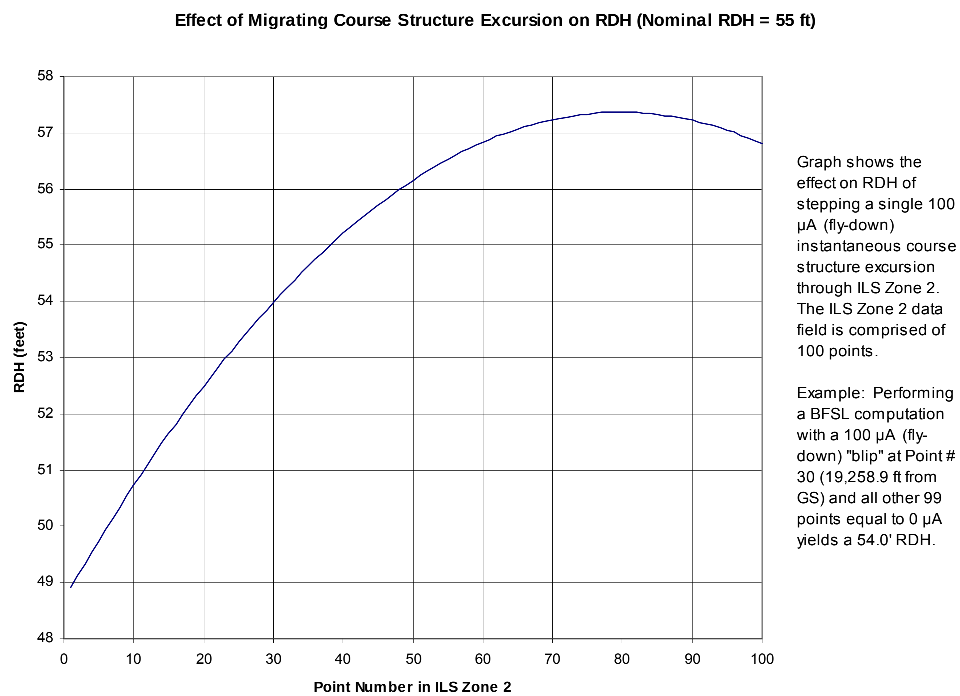


Figure 18. Effect of Migrating Course Structure Excursion on RDH.

Disadvantages:

- In many cases, BFSL process puts a significant flare in Zone 3
- Course structure deviations far from threshold are too heavily weighted
- Doesn't discern roughness caused by an aiming point height error from transmitted glide slope system error (due to antenna adjustments or terrain)

Is it possible to modify the existing BFSL process or come up with an entirely new process that eliminates the above-listed disadvantages? In order of the most simple to the most complex, are listed below are some ideas:

a. Modify the RDH segment length.

Changing the RDH segment from ILS Point A-to-ILS Point B to 2 nmi-to-ILS Point C (or Threshold) is a possibility. This segment is long enough to be used for aiming point computation and would produce a representative measured TCH. Additionally, irrelevant effects outside of 2 nmi are eliminated.

b. Correct aiming point elevation based on threshold VDI value.

In the early days of ILS flight inspection when a theodolite was used for the truth reference, a close in flare was typically assumed to be a theodolite (aiming point) issue. Common procedure was to determine the average microampere value measured at threshold on the approach and compute the required theodolite movement to make the threshold value zero microamperes. The negative aspect of this is that the Zone 2 structure roughness is not necessarily minimized to the fullest possible extent.

c. Correct aiming point elevation based on presence of hyperbolic component.

It may be possible to mathematically analyze the flight recording to determine if a hyperbolic characteristic exists. If this is possible and its magnitude can be quantified, an aiming point adjustment can be made that would be truly representative.

B. AUTOLAND SYSTEMS IN THE NEAR-TOUCHDOWN REGION

Autopilot systems authorized to support autoland operations typically use both glide slope and radar altimeter data during the approach to landing. It is assumed that the glide slope guidance signals need to be such that the aircraft is delivered to a height above threshold from which a normal and safe landing can be made. In order to determine how the glide slope and radar altimeter data are blended and processed in the autopilot system, contact was established with engineering personnel at Rockwell Collins, a well-known manufacturer of aircraft avionics systems. A summary of the information obtained is listed below:

- Once inside the final-approach-fix (FAF) and up to the runway threshold, the sole function of the vertical guidance portion of the autopilot is to keep the aircraft, at all times and as closely as possible, on the zero-microampere, glide slope course position. In other words, the autopilot does not gradually transition from glide slope guidance to radar altimeter guidance as the aircraft progresses along the approach. The autopilot is designed to immediately discontinue use of the glide slope information at a specific radar altimeter height above the ground that would generally coincide with crossing the runway threshold.

- Radar altimeter data is used from the FAF to the runway threshold to estimate range from touchdown (Distance Measuring Equipment (DME) range data is assumed unavailable). This estimated height data is used to progressively de-sensitize the glide slope guidance information as the aircraft nears the runway threshold. Linearization of the angular glide slope guidance is necessary to assure that the autopilot equations do not become divergent.

- ILS Glide slope guidance is not used inside threshold.

C. COMPARISON - ICAO VERSUS FAA TCH/RDH/ARDH METHODS

International Civil Aviation Organization (ICAO) documents have been reviewed to determine how the international ILS community views measured TCH or RDH. ICAO Annex 10, Volume I [11] contains the international standards, recommended practices and procedures for air navigation services. The only mention of RDH in this document is a reference to ICAO Doc 8071 “Manual on Testing of Radio Navigation Aids: Vol I – Testing of Ground-Based Radio

Navigation Aids" [12]. Below is the only RDH reference found in all ILS related ICAO documents surveyed:

Section 4.3.81 Reference Datum Height (RDH)

"*For commissioning and categorization flight tests, it may be necessary to determine the glide path RDH. This is done using a high-quality approach recording, from which the angle and structure measurements are made. Position-corrected DDM values for a selected portion of the approach (typically from Pt A to Pt B for Cat I and the last mile of the approach for Cat II and III facilities) are used in a linear regression to extend a best-fit line downward to a point above the threshold. The height of this line above the threshold is used as the RDH. If the tolerances are not met, an engineering analysis is necessary to determine whether the facility should be used for the regression analysis, or another type of analytical technique should be used*."

Doc 8071 text was developed with the following objectives in mind:

- Allow each member country to determine their need for performing RDH assessments.
- Provide guidance on at least one method of obtaining a RDH value for the benefit of member countries with limited expertise on subject matter.
- Allow latitude in method used so member countries with sufficient expertise can apply alternative methods for obtaining a RDH value.

D. REVIEW OF CURRENT RDH/ARDH TOLERANCE

The required tolerances for RDH/ARDH are contained in FAA Order 8240.47C. A summary of the requirements are:

"*1. Category 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 glide slopes.*

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

3. 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."

It is assumed that the Category II/III tolerance range of 50-60 feet was established to provide safe wheel crossing heights for all sizes of aircraft and assure that the touch-down point is not too far down the runway. Maintaining a minimum safe WCH essentially fixes the lower limit to 50 feet. A 60-foot crossing height with the designed touch-down point being 1050 feet from the runway threshold requires a 3.27-degree descent angle. This makes sense for an upper limit value considering that the ILS course structure tolerances require that the glide slope angle generally remain between 2.72 and 3.28 degrees. Also, aircraft manufacturers have established landing distance performance data that is based on the tolerance range as it exists now.

IV. CONCLUSIONS AND RECOMMENDATIONS

The fundamental concept of FAA Order 8240.47C is sound. The establishment of a proper aiming point is necessary and the determination of a representative RDH estimate for a glide slope facility is useful. This study has shown that the application of the BFSL process to some glide slope course structures yields unrepresentative aiming point adjustment values and RDH values. Glide paths which are skewed in Zone 2 but not Zone 3 and/or exhibit a single, rapid transition in the course structure between 2.5 and 4 nmi are problematic examples. Non-image, endfire glide slope systems are more prone to have this type of behavior than image glide slopes because the shape of the path is controlled by a multitude of individual radiating antennas. An aiming point adjusted course structure that is straight in Zone 2 but exhibits an excessive pull-off in Zone 3 is one indicator that the application of 8240.47C is not well-suited to that particular glide slope system.

Although this report has shown that in some instances, the current BFSL/RDH process does not provide the proper aiming point height and RDH value for some glide slope systems, justification does not exist to replace 8240.47C with an entirely new process. Developing and implementing a new process to determine RDH would be costly.

However, in those cases where the existing BFSL process is not representative, FAA Flight Inspection should have the latitude to apply alternative analysis methods. ICAO approves use of alternate methods and FAA Order 8240.47C already allows a waiver to be issued at facilities where the RDH is out-of-tolerance, however, ARDH is acceptable. Although a waiver is authorized, the approval for the waiver comes from FAA facilities personnel. In most cases, waivers, for any reason, are not approved. In order to solve this problem, it is recommended that the wording in the requirements section of 8240.47 be changed to remove the need for a waiver. Listed below are other alternative analysis methods which could be used:

- Compute BFSL using a different or longer segment of the approach
- Use aiming point adjustment value based on VDI value measured at threshold
- Use radar altimeter data to determine actual TCH

Although information is limited, research as to how autopilots with autoland capability use the ILS glide slope signals shows that the on-course signal is tracked as closely as possible all the way to the threshold. Only at this point does the autopilot system switch to complete reliance on radar altimeter data for the flare and landing. The expectation is that the glide slope, on-course signal exist within a certain height range above threshold. In other words, the specific computational method used to estimate RDH is not important as long as it is representative.

Although RDH is referenced in ICAO documentation, there is no requirement to determine the RDH for a glide slope facility. Furthermore, ICAO does not limit the computational method of determining RDH value to only the BFSL method. ICAO allows the use of alternative methods.

There is an operational need for the current RDH/ARDH tolerance limit of 50-60 feet and this range seems appropriate. Relaxing the tolerance is not seen as a viable method for compensating for the occasional short-comings of the BFSL method as it could lead to the inadvertent reduction of safety margins. The preferred approach is to allow alternate methods to be used to determine the representative RDH value.

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APPENDIX A

Description of BFSL/RDH Spreadsheet Columns and Values.

Givens:

GS Setback – Along the runway distance between GS mast and runway threshold
GS Offset – Distance from GS mast to runway centerline
GS elev – Elevation of base of GS mast
GS angle – Glide Path Angle (used to convert CDI microampere values to heights)
GS width – Course Width of the GS (used to convert CDI microampere values to heights)
AP setback – Along the runway distance between aiming point and runway threshold
AP offset – Distance from aiming point to runway centerline
AP height – aiming point height relative to runway centerline abeam the GS mast
TH elev – Elevation of runway threshold
Abeam elev- Elevation of runway centerline abeam GS mast

Point # - data point along approach
Dist to AP (X) – Data point distance to aiming point
GS uA – Data point value of CDI in microamperes

Computed:

meanX = Average value of X values
meanY = Average value of Y values
Average Angle = Average value GS uA values converted to degrees

Ht abv AP (Y) = X Tan (GS Angle + (GS uA * .7 /150))
X-meanX (x) = Data point X value minus meanX
xY = Data point product of x and Y
xx = Data point product of x^2

Sum xY = sum of all xY data point values
Sum xx = sum of all xx data point values

BFSL Angle = aTan(Sum xY / Sum xx)
AP Adjustment = meanY –meanX Tan (BFSL Angle)
RDH = AP setback ((meanY-APadj)/meanX) + (Abm elev – TH elev)
TCH = GS setback Tan (GS angle) + (Abm elev = TH elev)