TECHNIQUES TO CHANGE GLIDE PATH REFERENCE DATUM HEIGHT (RDH) WITHOUT RELOCATING THE GROUND FACILITY

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ABSTRACT

The US Federal Aviation Administration (FAA) Flight Inspection Office is responsible for publishing the aircraft height at runway threshold known as the Threshold Crossing Height (TCH). US policy and practice is to mathematically calculate this height for Category I ILS facilities from airport geometry, elevations, and glide path mast setback. For Category II/III ILS facilities, the US actually measures the aircraft height at threshold. The measured threshold height is determined by evaluating the signal-in-space performance of the glide path during the final phase of flight and then projecting a line through the average glide path angle in this final segment to determine the aircraft height at threshold. Measured height at threshold is referred as Reference Datum Height (RDH). The height requirement for Category II/III ILS facilities is between 50 and 60 feet. In a perfect world, TCH and RDH are one in the same, but in the real world the radiated signal is influenced by the surrounding environment resulting in the TCH and RDH not necessarily being equal. TCH and RDH rarely agree at operational facilities. When the RDH is less than 50 feet or greater than 60 feet, the glide path ground facility is typically relocated to correct the out of tolerance aircraft height above threshold. Since the RDH is based on the measured data set, including glide path roughness, adjustments to the radiated signal can change the measured values of aircraft height above threshold. If care is taken when altering the radiated signal, the RDH can be changed to be within tolerance without degrading any other requirement and negating the cost of relocating the facility. This technique has been demonstrated at three sites. RDH adjustments of 6-10 feet are achievable without moving the glide path facility. This paper presents a historical overview of the TCH/RDH concept, the process used to determine the appropriate facility adjustment in correcting a RDH, and the results as obtained at three sites.

PURPOSE

To provide a cost effective solution in optimizing threshold crossing height / reference datum height for glide path facilities focusing on engineering solutions that do not involve relocating the ground facility.

OVERVIEW OF TCH/RDH

“United States Standard for Terminal Instrument Approach Procedures”[1] (TERPS) defines the requirements for instrument approach procedures in the United States. It is similar to PanOps in the International arena. TERPS further defines the threshold crossing height requirements for glide path facilities. Threshold crossing height is the height of the extended glide path vertically above the threshold. Performance category I facilities must not exceed a threshold crossing height of 60 feet. Performance category II and III facilities must achieve a threshold crossing height between 50 and 60 feet with 55 feet considered optimum. The required threshold crossing height for glide path facilities is achieved from the longitudinal setback of the glide path ground facility from runway threshold. Factors considered in locating the facility include threshold elevation, runway elevation abeam the glide path facility, runway slope, elevation at the glide path antenna, and characteristics of the runway shoulder. Simple trigonometry is used to determine the generic glide path ground facility location. “Siting Criteria for Instrument Landing Systems”[2] provides detailed guidance for locating glide path facilities. Glide path siting parameters are illustrated in figure 1.

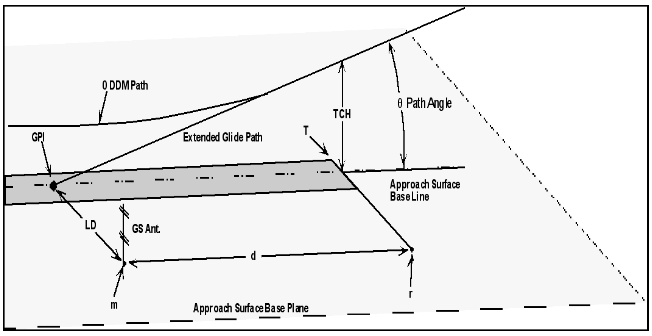
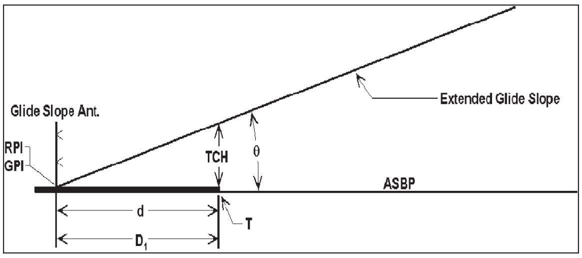


Figure 1: Glide Path Siting Parameters

Threshold crossing height is easily calculated for glide path facilities sited on a runway where the elevation at threshold and the elevation abeam the glide path the facility are the same. Figure 2 illustrates how threshold crossing height is calculated for the ideal terrain situation.



TCH = d * tan (ı)

TCH is threshold crossing height
d is the longitudinal distance from the threshold to the point on the runway abeam the glide path facility
θ is the glide path angle

Figure 2: TCH Determination

For Category II/III glide path locations, the United States measures the actual performance of the glide path signal to determine the threshold crossing height and refers to this measure as the reference datum height. Detailed information on determining reference datum height is contained in FAA Order 8240.47[3]. Reference datum height is the height of the commissioned glidepath located vertically above the runway threshold and is derived by computing the glidepath between ILS points “A” and “B” and by projecting an extension of this glidepath through the threshold. ILS point “A” is located 4 nautical miles from the runway threshold and ILS point “B” is located 0.58 nautical miles from the runway threshold. The actual glidepath is determined by a least sum of squares mathematical technique called best fit straight line. This technique averages roughness of the actual glidepath signal to determine the angle. For an ideal glide path facility, where no glidepath roughness exists, reference datum height and threshold crossing height are synonymous.

CORRECTING RDH

The traditional method to correct a reference datum height found out of tolerance is to relocate the glide path facility longitudinally from threshold. There is an expense to relocating the facility and some airport constraints may not allow the facility to be located in the optimum position.

Consideration of how reference datum height is determined leads one to consider that altering the radiated performance of the glide path facility can effect changes to reference datum height. The best fit straight line technique to determine the glidepath is reasonable, but analysis shows reference datum height can be affected by the magnitude and location of the glide path structure roughness. A summary of the weighting is provided in Figure 3.

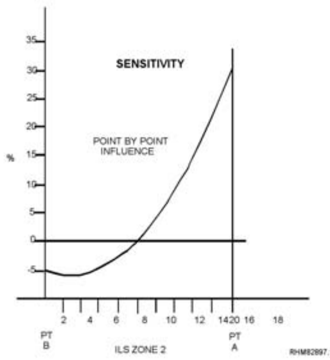


Figure 3: Sensitivity of RDH to Glidepath Changes

One can see that changes to structure roughness around ILS point “A” yield the most significant changes to reference datum height, but these changes must generally be effected by altering terrain in the glidepath forming area. Changes to structure roughness around ILS point “B” can be effected by changes to the glide path facility and are easier to calculate and realize.

Changing the glide path signal characteristics around ILS point “B” to fly-up (150 Hertz predominance) will increase the reference datum height. Similarly, changing the glide path characteristics to fly-down (90 Hertz predominance) will decrease the reference datum height.

By changing the power level of the upper antenna, the glidepath angle can be raised or lowered. Since the glide path mast is offset from the runway centerline, the aircraft transverses across the azimuth pattern of the glide path while on the approach. Figure 4 shows the azimuth angle to the glide path mast as a function of distance throughout the approach. The azimuth rate of change increases as the aircraft gets closer to the threshold.

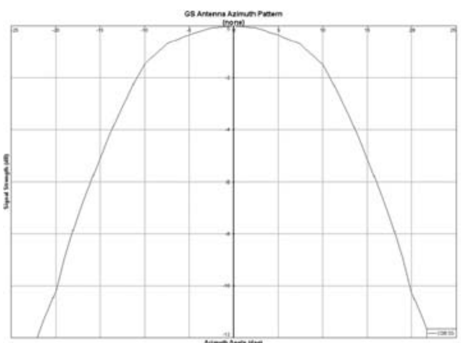


Figure 4: Azimuth Angle of Mast Throughout Approach

A rotation of the upper antenna at the capture effect glide path facility will cause variations in signal levels between the upper and lower antenna as a function of azimuth angle. Rotating the upper antenna toward the runway will cause the path angle to be slightly lowered at ILS point “A” and increase as a function of range. Since the glidepath characteristics are different, the apparent glidepath point of signal emanation (i.e. reference point or aiming point) needs to be re-established. This may further require antenna height adjustment at the glide path facility to optimize the glidepath angle. Similarly, rotating the upper antenna away from the runway will cause the path angle at ILS point “A” to increase and then decrease as a function of range.

EXAMPLE SITES

Minneapolis

Runway 12L at Minneapolis – St. Paul International Airport was scheduled for upgrade from ILS Category I to Category III performance in 2003. The glide path facility could not be located in the optimum location due to proximity of a taxiway. Flight Inspection of the facility determined the reference datum height was out of tolerance at 63 feet[4]. Optimizing flight inspection techniques and lowering the glidepath angle from the usual 3.0 degrees to 2.8 degrees realized a reference datum height of 56 feet. The 2.8 degree glidepath angle was acceptable for signal-in-space performance as well as obstruction clearance, but caused changes in noise contours that would necessitate $5 million USD of noise mitigation. Options of lowering the reference datum height by relocating the facility to the optimum location or lowering the glidepath angle were not reasonable at Minneapolis.

A site test was conducted to determine if locating the glide path facility 89 feet forward of its present location would be sufficient to bring the reference datum height in tolerance. 89 feet is the maximum distance the facility could be moved without impacting the use of taxiway Romeo. The site test resulted in reference datum height being below tolerance. Locating the test glide path facility closer to the existing glide path facility still produced low reference datum heights. Finally, during the site test the entire glide path array was rotated 11 degrees toward the runway. The result of the array rotation was a reference datum height decrease of 8 feet. The conclusion of the site test is that reference datum height does not follow longitudinal changes in the glide path location in a traditional sense at this site. It also became apparent that rotation of antenna(s) on the glide path mast may hold promise for providing an acceptable facility.

Data was extracted from the flight inspection recordings to analyze structure roughness between ILS points “A” and “B”. The 21 point method was used to calculate the reference datum height. This manual method concluded the reference datum height was 63 feet which agreed with the announced results of flight inspection’s automated flight inspection system. Further analysis of the data suggested that changing the structure roughness around ILS point “B” to additional fly-down would lower the reference datum height. Structure roughness was altered in the analysis to yield a reference datum height of 55 feet. The analysis showed 30 µAs of fly-down needed to be added at ILS point “B” to produce a reference datum height of 55 feet. This translates to reducing the upper antenna signal level by 1.5 dB when the aircraft position is considered as a function of azimuth from the glide path mast at ILS point “B”. 5.5 degrees of upper antenna cant was calculated to produce this amount of signal decrease. Figure 5 illustrates the approach performance of the uncanted glide path facility. Figure 6 illustrates the approach performance required to produce a reference datum height of 55 feet.

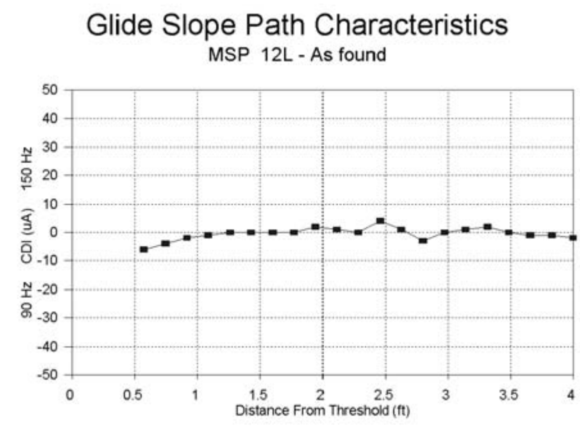


Figure 5: Glide Path Performance before Upper Antenna was Canted

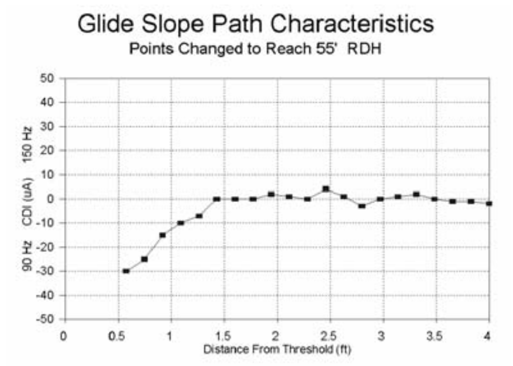


Figure 6: Glide Path Performance Required to Achieve RDH of 55 feet

5 degrees of upper antenna rotation away from the runway was added to the glide path facility. Final flight inspection results showed the facility to meet all ILS Category III requirements with a 3.02 degree glidepath angle, a reference datum height of 54 feet, ILS Zone 1 Structure of 2 µA, ILS Zone 2 Structure of 8 µA, and ILS Zone 3 Structure of 2 µA.

Singapore

The Singapore Royal Air Force purchased ILS equipment to support Category II service at Paya Lebar Air Force Base and Tengah Air Force Base. Flight Inspection measured the reference datum height on the runway 02 glide path at Paya Lebar to be 46 feet and on the runway 36 glide path at Tengah to be 40 feet. Rotating the upper antenna at these two facilities seemed a logical direction.

Paya Lebar Air Force Base.

Traditional threshold crossing height determination methods predicted a result of 47 feet. The measured reference datum height of 46 feet suggests the tune-up of the glide path facility was proper. Analysis of the flight inspection data shows a slight fly-down (90 Hertz predominance) trend starting at approximately 1.5 nautical miles is the cause of the reference datum height to be slightly lower than the calculated threshold crossing height. The flight inspection approach is shown in Figure 7. By changing the signal characteristic to fly-up (150 Hertz predominance) at ILS point "B", the reference datum height can be increased. The suggested change to achieve a reference datum height of 50 feet is shown in Figure 8.

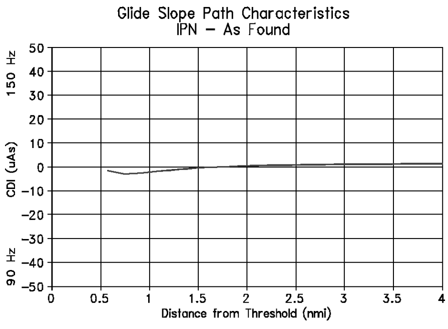


Figure 7: Paya Lebar Glide Path as Found

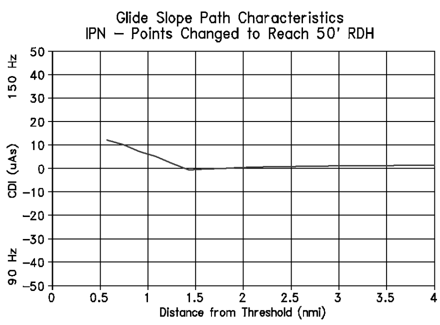


Figure 8: Approach Change to Achieve RDH of 50 Feet at Paya Lebar

An initial rotation of the upper antenna 5 degrees toward the runway caused the reference datum height to increase from 46 to 57 feet. This rotation also caused the average glidepath angle to lower by 0.06 degrees due to changing the glidepath characteristics. The glidepath point of signal emanation (i.e. reference point or aiming point) was changed, producing a glidepath that is straight while minimizing structure roughness in ILS Zone 2. The final measurements showed a reference datum height of 56 feet with structure roughness at 25%, 30%, and 75% of Category II tolerance for ILS Zones 1, 2, and 3, respectively. Figure 9 shows the flight inspection approach after the upper antenna was rotated – before and after the aiming point change.

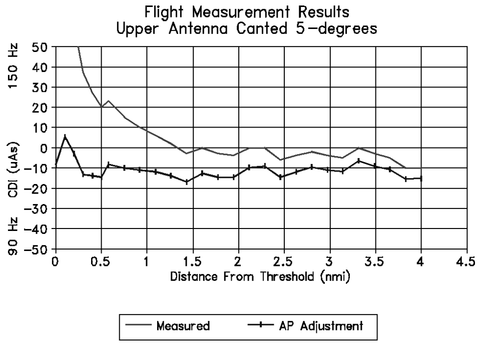


Figure 9: Paya Lebar Glidepath Approach after 5 degree Upper Antenna Rotation

Tengah Air Force Base.

Traditional threshold crossing height determination methods predicted a result of 49 feet. The measured reference datum height of 40 feet is attributed to the actual glidepath angle being lower from 2 nautical miles to inside ILS point "B". The measured approach is shown in Figure 10.

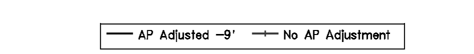


Figure 10: Tengah Glidepath Performance

Significant changes to the glide path characteristics are required to raise the reference datum height. Both individual antenna rotation as well as system phasing changes were attempted to raise the reference datum height. Throughout these adjustments, the maximum measured reference datum height was 50 feet. At the maximum value, some problems were experienced with de-phasing the system for monitor verification – to the point the system could not be maintained. A system configuration was chosen that resulted in acceptable Category II structure roughness but a reference datum height of 44 feet.

Future attempts to produce an acceptable reference datum height at Tengah will include use of achieved reference datum height and computer modeling to optimize the system. Achieved reference datum height is similar to reference datum height except the glidepath is evaluated 6,000 feet from the threshold to ILS point "C" (where the downward extended straight portion of the glidepath passes at a height of 100 feet above the horizontal plane containing the runway threshold). ICAO Annex 10, paragraph 2.4.12 states that achieved reference datum height is considered to be of important operational significance and should be recognized. On a few occasions during the adjustments at Tengah, the achieved reference datum height was greater than 50 feet. Computer modeling can be used to make further predictions on how to optimize the system based on actual glide path performance and accurate topographical data. Modeling could suggest optimized antenna positions as well as antenna drive currents, both amplitude and phase.

CONCLUSION

The following conclusions are reached:

1. Glide path facilities can generally be located to achieve the required threshold crossing height / reference datum height by using runway characteristics and simple trigonometry.

2. Site tests can be used to determine the optimum glide path ground facility location when irregular terrain is a concern.

3. Glide path facilities found to have an out of tolerance reference datum height or those ground facilities that cannot be optimally sited due to environmental constraints can adjust the reference datum height by changing the radiation characteristics of the glide path. Rotating the upper glide path facility antenna away from the runway lowers the reference datum height while rotating the upper antenna of the glide path facility toward the runway raises the reference datum heights.

4. Glide path facilities failing to meet required reference datum height by simply rotating the upper antenna of the glide path facility may benefit with consideration of use of achieved reference datum height and computer modeling to reveal other appropriate system changes.

REFERENCES

1. United States Standard for Terminal Instrument Procedures, FAA Order 8260.3
2. Siting Criteria for Instrument Landing Systems, FAA Order 6750.16
3. Determination of Instrument Landing System Glidepath Angle, Reference Datum Heights, and Ground Point of Intercept, FAA Order 8240.47
4. United States Standard Flight Inspection Manual, FAA Order 8200.1