THRESHOLD CROSSING HEIGHT – A FRESH PERSPECTIVE.

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ABSTRACT

It is evident, both from recent experiences, and from papers previously presented at IFIS and other forums, that a degree of confusion exists in both the understanding of threshold crossing height and how it is measured.

To appreciate the applicability of threshold crossing height, both from an operational perspective, and in terms of its measurement by flight inspection, it is necessary to understand both the background of the ICAO requirements, and how the ILS is used operationally.

Once these questions have been answered, it is essential that the method of flight inspection measurement is commensurate with the parameter requirements, both in terms of accuracy and method of measurement.

This paper seeks to understand the concepts surrounding the measurement of threshold crossing height, and question the applicability of some of those concepts.

BACKGROUND

ICAO specifies criteria for ILS reference datum height and threshold crossing height and attaches great importance to them. This paper investigates the background to the ICAO requirements, looks at how we measure the parameters, and questions the relevance of the application of ILS reference datum height.

ICAO REQUIREMENTS

ILS Reference Datum Height (RDH), what is it? From the definitions stated in ICAO Annex 10[1]: "A point at a specified height located above the intersection of the runway centre line and the threshold and through which the downward extended straight portion of the ILS glide path passes." This seems quite straightforward, so why do we need it? ICAO annex 10[1] goes on to state in 3.1.5.1.3 "The downward extended straight portion of the ILS glide path shall pass through the ILS reference datum at a height ensuring safe guidance over obstructions and also safe and efficient use of the runway served." This means that the aircraft should be high enough to safely clear any obstructions on the ground, but low enough to make the best use of the runway length available. These two objectives are mutually exclusive. Safe obstacle clearance would predicate a high threshold crossing height to maximise terrain clearance, but this would reduce the runway distance available for landing.

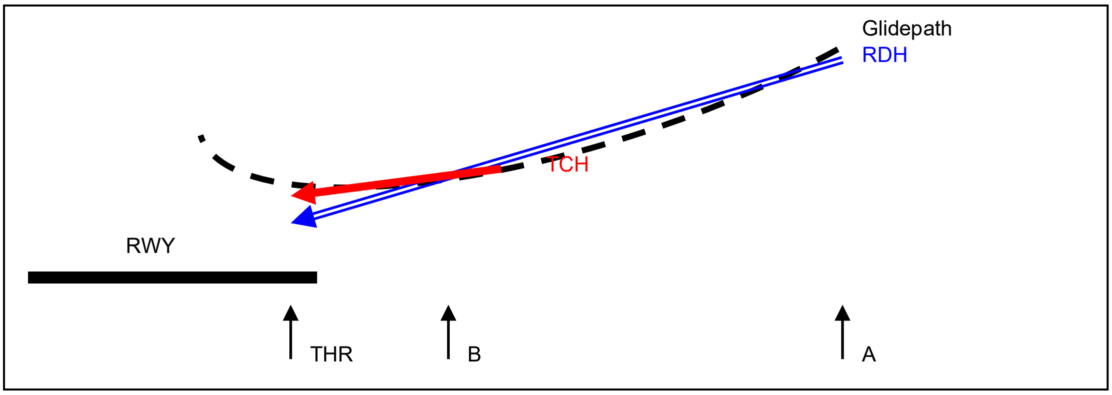
Annex 10[1] goes on to state "The height of the ILS reference datum for Facility Performance Categories II and III — ILS shall be 15 m (50 ft). A tolerance of plus 3 m (10 ft) is permitted. In arriving at the above height values for the ILS reference datum, a maximum vertical distance of 5.8 m (19ft) between the path of the aircraft glide path antenna and the path of the lowest part of the wheels at the threshold was assumed." Annex 11[2] appendix 5; table 2 further states that the data accuracy for Threshold Crossing Height for precision approaches shall be 0.5m or 1ft with an integrity classification of $1x10^{-8}$ (critical)

Instrument Approach Procedure designers use the ILS Reference Datum Height to determine the obstacle clearance surfaces of the approach in accordance with ICAO DOC8168[4](Pans-Ops). This is why the reference datum height is quoted as 15m with only a positive tolerance. If the instrument approach procedure is constructed using a reference datum height of 15m, then any increase in RDH serves to increase the safety margin of the procedure. The problem with increasing the RDH is that for a level runway with a 3° glidepath, each 1m increase in RDH pushes the touchdown point 20m further down the runway. It is therefore desirable to have the RDH as close to 15m as practicable.

RDH and TCH

ICAO Annex 10[1] talks of ILS Reference Datum Height, or RDH. Threshold Crossing Height is referred to as Achieved Reference Datum Height (ARDH). It is often assumed that the two are the same. Indeed, in an ideal world, with perfectly flat terrain, they would, to all intents and purposes be the same. To understand TCH, it is best to look at how the glidepath is used by the automatic flight control systems during autoland. The data used here is for the Smiths SEP6 autopilot, the first system certified for Cat III autoland.

During descent from glidepath intercept, the aircraft vertical guidance channel follows the glidepath beam. At 133' on the radio altimeter (1600' prior to threshold), glidepath guidance is disconnected, and the aircraft enters an 'attitude-hold' phase, having memorised and averaged the previous 10 seconds of aircraft attitude data. This continues until 70' on the radio altimeter, when the radio altimeter takes over the vertical guidance, flaring out the aircraft for landing. For a typical aircraft approach speed of 175kts, the part of the glidepath that determines the TCH is therefore the portion between 4500' and 1600' from threshold. This may be different to the extended straight-line portion between points 'A' & 'B' used to calculate RDH.
Attachment C to volume 1 of Annex 10[1]recognises this difference, and



specifies that the measurement of ARDH be calculated over the segment of 6000’ to 1000’ prior to threshold. Although recognising the operational significance, annex 10 makes no specifications for ARDH; however, Annex 11[2] specifically states the data quality requirement for TCH.

Where there is a significant cross-slope and forward-slope between the glidepath and the runway, the glidepath structure may show a pronounced early flare characteristic. In this instance, there may be marked differences between RDH and ARDH/TCH. In most cases, TCH is higher than RDH due to the curvature of the glidepath, but this is not always so. If the glidepath exhibits marked ‘negative flare’, the ARDH may be significantly lower than the RDH. The older version of DOC8071[3] specifically mentioned the undesirability of negative flare; the current edition makes no reference to it. Annex 10[1] states:— “In regions of the approach where ILS glide path curvature is significant, bend amplitudes are calculated from the mean curved path, and not the downward extended straight line.” It is assumed from the basic physics of the glidepath, that the curved portion will be upwards. Any tendency to downward curvature will have a detrimental effect on ARDH/TCH, but may have little effect on RDH.

RELEVANCE OF ILS REFERENCE DATUM HEIGHT

When the concept of autoland using ILS was introduced in the early 1960s, glidepath siting and the determination of RDH by flight inspection were both carried out by simple geometry of glidepath back set distance, threshold elevation relative to the glidepath, and mean glidepath angle as calculated using optical tracking techniques. To the best of my knowledge, there has not been any grave safety concerns raised by the use of this simple method during the past 40 years experience of autoland.

Considering the potential errors in measurement by all of the variables concerned in calculation of RDH, it may lead to questioning the accuracy requirements for RDH measurement. Indeed, do we need to know the value for RDH?

The purpose of the ILS RDH is twofold:

1 The basis for the calculation of the

obstacle assessment surfaces for the instrument approach procedure design. In this instance, the ILS RDH is assumed to be 15m. (Pans-Ops[4] 21.1.3). ICAO does allow for a higher RDH to be promulgated for reasons of obstacle clearance in attachment C to Vol 1 of Annex 10[1].

The obstacle assessment surfaces are calculated on a RDH of 15m. This allows a target level of safety of 1×10^{-7} to be achieved. If the RDH is higher than 15m, then safety is increased.

However, the glidepath might radiate a lower than promulgated angle and yet remain within the operating tolerances. In this instance, the RDH could be lower than 15m. This would invalidate the basic premise of the obstacle surface assessment and the instrument approach procedure design.

2 To provide a safe threshold crossing height for aircraft whilst making maximum use of the available runway. Annex 10[1] assumes a maximum of 5.8m between the path of the aircraft glide path antenna and the path of the lowest part of the wheels at the threshold. Additionally, a maximum vertical glidepath displacement due to perturbations of 1.2m is assumed. Thus with a 15m RDH, there should be a clearance of 8m between the aircraft wheels and the runway surface at threshold.

The important factor here is ARDH or TCH. The ARDH should be high enough to preserve obstacle clearance but the final path angle over the range 6000' – 1000' is also important in determining the touchdown point.

For cat I operations, where the decision height is not less than 200', the aircraft is 3,800' or 1,160m from touchdown at decision height. The importance of ARDH in this instance is quite low provided that the aircraft is in a stable attitude at the decision height whereby the pilot can take control and land using visual references.

For Cat II operations, the decision height may be as low as 50'. In this instance, ARDH is very important to ensure that safe obstacle clearance is maintained and the aircraft is well positioned in relation to the touchdown point as the pilot has little time for large corrections to the aircraft path after decision height.

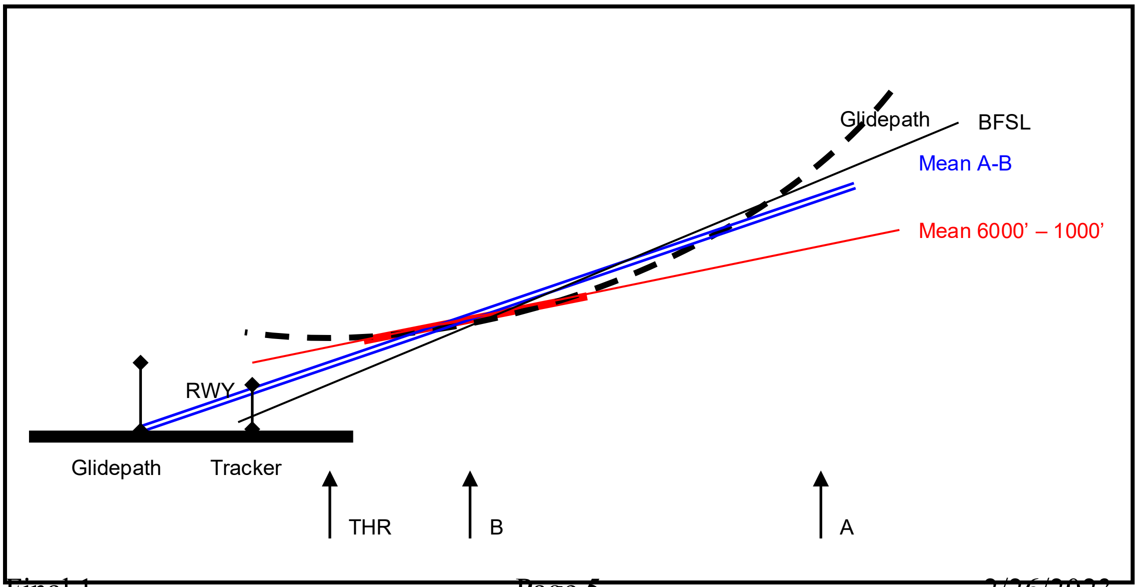
The Cat III case was examined earlier. Here, the ARDH is very important to ensure safe obstacle clearance; also, the final path angle, and the runway slope from threshold will influence location of the touchdown point.

MEASUREMENT OF REFERENCE DATUM HEIGHT

The accuracy of measurement of RDH depends on the method of measurement used, and to a certain extent, the interpretation of what RDH actually is.

Before the advent of computer analysis of flight inspection data, the calculation of RDH was simply a geometric calculation based on the mean measured glidepath angle, the back set distance of the glidepath from threshold, and the difference in elevation between glidepath and threshold. This is the same process outlined in attachment C to part 1 of annex 10[1] to determine the siting of the glidepath equipment.

When measuring glidepath angle with a theodolite or other optical tracking system, the derived angle is dependant on the position chosen for the siting of the measurement system. Most of these systems are sited based on the premise that the glidepath signal originates from the base of the glidepath mast. The physical height of the tracking system dictates that the measurement point is some distance ahead of the glidepath such that the measurement device is located in the plane of the nominal glidepath. This is further complicated by the placement of the measurement system towards the runway, but away from the runway centreline. Automatic flight inspection systems define an 'aiming point' from which all angular calculations are made. This is normally a theoretical point on the runway centreline abeam the glidepath equipment, at the same elevation as the base of the glidepath mast, from which the glidepath signal is assumed to originate.[6]



It can be seen from the (exaggerated) diagram above that several interpretations of RDH are possible. Firstly there is the line of glidepath 0ddm, the dashed line on the diagram. There is the arithmetic mean angle as measured by the theodolite system, the double line on the diagram. The Best Fit Straight Line (BFSL) between points A and B, and the TCH as measured between 6000' and 1000', either as an arithmetic mean, or by BFSL.

This gives two possible values for RDH, and two possible values for TCH, depending on the method used for calculation.

The siting of the tracking device as mentioned earlier, or definition of the 'aiming point' in automatic flight inspection systems, further complicates this situation. It is from these points that all angular calculations are made; therefore the choice of these points is fundamental to the calculation of RDH/ARDH.

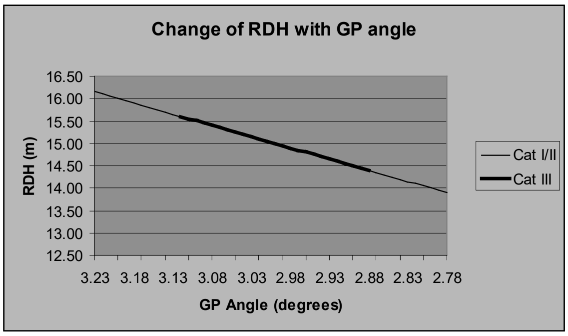
The siting of optical tracking devices is at best an engineering judgement based on assumptions of the origin of the glidepath signal and estimations of the local topography. The procedures for determining this point vary from state to state.

The calculation of an aiming point for automatic flight inspection systems still assumes the origin of the glidepath signal, but does bring some degree of uniformity in measurement. There have been attempts to refine this process further in recent years by calculating the BFSL between points A and B[6], and using this data to redefine the aiming point, allowing a recalculation of angle, structure and RDH/ARDH. Although there is some merit in this process, the experience of Flight Precision Ltd is that the results obtained do not show a great deal of repeatability for more unusual glidepath siting conditions compared to 'traditional' methods, and the spread of values is sometimes quite large. Where there are significant distortions to the overall glidepath structure, this method can produce excessive corrections to the elevation of the glidepath aiming point as calculated from the BFSL. In these situations, differences of up to 6m in calculated RDH have been noted. The question also remains as to which is the correct value of RDH?

Although this refined process allows for a redefinition of the aiming point for RDH, it does not allow a redefinition of the aiming point for calculation of ARDH/TCH. Thus the inherent errors in ARDH/TCH still remain. If the glidepath curvature is upwards, then ARDH/TCH should be higher than RDH, and safe obstacle clearance will be preserved. If the glidepath exhibits a downward curvature prior to threshold, then TCH and obstacle clearance may be compromised.

A more fundamental matter to the question of measurement of RDH is the definition of threshold itself. National Authorities, individual airports, and flight inspection organisations all have different interpretations on the definition of threshold. The DOC8168[4] definition is 'The beginning of that portion of the runway useable for landing.' The application of that definition means different things to different people. To illustrate the problem, FPL asked the UK CAA to make a statement on the definition of threshold, and three different departments had three different views, the answer is not so obvious. Changing the definition of threshold from the leading edge of the 'piano keys' to the threshold lighting bar (typically 6m) changes the RDH calculation by 0.3m for a 3° glidepath.

A further observation is the relationship between the glidepath angle, within the operating tolerances, and RDH. The graph below illustrates the effect of changing the glidepath angle on the RDH. This assumes a 3° glidepath with a RDH of 15.0m when operating at the promulgated angle.



It can be seen that the change in RDH with glidepath angle is significant, even though the glidepath remains within the operating tolerances. Calculated RDH may change by ±1.1m from the nominal with the glidepath remaining within Cat I/II angular operating tolerances, and ±0.6m for Cat III. Can one assume that if the RDH is not less than 15m at the promulgated glidepath angle, the obstacle surface assessment safeguards the operation to the limits of tolerance of the glidepath angle?

FLIGHT INSPECTION ISSUES

Problems currently arise in the measurement of RDH/ARDH because the technology is available to the flight inspection organisations to calculate these parameters by more advanced methods than were previously possible, and come up with answers that may be significantly different from traditional methods. ILS installation engineers are also able to use advanced computer modelling techniques to optimise glidepath siting by three dimensional terrain modelling rather than the more basic methods outlined in annex 10. This gives rise to incompatibilities between the flight inspection measurement methodology and the ILS siting criteria.[7]

It is not reasonable to site an ILS for a planned RDH by one method, and then validate the RDH value by flight inspection using a totally different method. The two methods are incompatible.

It is also irrational to henceforth change the flight inspection measurement methodology and find that Cat III ILS systems that have been operating satisfactorily for more than 30 years no longer meet ICAO requirements purely because the flight inspection measurement philosophy has changed.

There is a requirement for greater understanding between the ILS installation engineers and the flight inspection organisations to ensure that the methods of measurement are appropriate to validate the premise on which the planned ILS performance is based.

CONCLUSIONS

It is clear that RDH is critical to the obstacle surface assessment for ILS Instrument Approach Procedure design, but from Pans-Ops, the actual value is not critical provided it is not less than 15m. The actual value only becomes critical if a higher value of RDH has been chosen to facilitate obstacle clearance and this must be validated.

If safeguards are built in to Pans-Ops obstacle surface assessment criteria to allow for the glidepath angle tolerance, then any assessment of RDH should be corrected to the promulgated glidepath angle rather than that existing at the time of the flight inspection.

RDH is published in the facility data for an ILS in national and international publications. This is largely irrelevant if the RDH exceeds the 15m that the obstacle surface assessment has been based on. Aircraft operations are much more concerned with ARDH, which is rarely published. It may be better to publish all ILS RDH as 15m, only quoting the measured RDH if it falls outside of ICAO criteria.

The current diversity of measurement methods and the subsequent results is undesirable. There is a need to agree a common methodology of measurement that is consistent regardless of the flight inspection service provider or type of flight inspection system used. It is irrational to henceforth change the flight inspection measurement methodology and find that Cat III ILS systems that have been operating satisfactorily for more than 30 years no longer meet ICAO requirements purely because the flight inspection measurement philosophy has changed. This factor must be considered before changes are implemented.

It is the TCH parameter that so much importance is attached to in Annex 11[2], but experience would indicate that the accuracy required is not achievable with the diverse methods of measurement used for flight inspection, and the glidepath angle tolerances are much wider than the desired tolerance on TCH.

ARDH/TCH is an important parameter for the operation of the aircraft and the behaviour of the aircraft during autoland. The path angle during this final segment also has a bearing on the safe operation and the location of the touchdown point. The difficulty here is the accuracy and applicability of the measurement by flight inspection. The obvious method of validation is to equip the flight inspection aircraft with a certified category II autopilot capable of coupled approaches to an MDH of 50', and assess the threshold crossing height directly. This is probably impractical and the cost prohibitive for most flight inspection companies, therefore, thought must be given to standardisation of measurement that results in consistent and accurate determination of TCH.

The philosophy used for ILS siting criteria must be commensurate with the flight inspection methodology used for validation of parameters such as RDH and vice-versa. If the flight inspection community is to adopt advanced techniques of determining ILS parameters such as those outlined in FAA Order 8240.47C[5], then the ILS siting criteria and modelling techniques must also change to take this into account.

This paper raises several issues, and leaves many questions unanswered. The situation whereby the measurement of a parameter specified as critical by ICAO is open to so much interpretation and differences due to measurement techniques cannot continue. Rather than prescriptive regulation of flight inspection, it may be better to fundamentally review the ICAO requirements regarding the applicability of RDH and ARDH/TCH, together with the associated influencing factors, before deciding on the optimum method for validation. What is needed is a fresh perspective.

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