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Glide Slope Considerations to Provide Support for Aircraft Certification for Steep Angle Approaches.

ABSTRACT

Due to obstacle constraints under the glide path, it is sometimes necessary to use a non-standard glide path angle to maintain acceptable separation between the aircraft and the obstacle. The London City Airport (LCY) is an example of an airport that has a steep angle approach. This airport has a 5.5-degree glide path angle. Aircraft, specifically the Flight Management System (FMS), must undergo a series of flight tests on an actual glide slope signal under various aircraft conditions. The FAA National Instrument Landing System (ILS) test facility on Runway 09L at the Kendall-Tamiami Executive Airport (TMB), just south of Miami, Florida, has recently been used to collect certification data for steep angle approaches for five-different aircraft ranging in size from an E-175 to a Cessna Mustang. TMB can support Group III size aircraft. Documentation must be provided to the regulators that the glide slope signal has not changed during the test flights. Careful consideration should be given to the glide slope configuration used in this test. The stability of the glide slope signal needs to be guaranteed by using standard ground measurement tests, without the need of periodic flight inspection measurements throughout the the flight testing period. This paper contains the measured glide slope performance for three different glide slope angles (5.5, 6.65 and 8.65) and the measurements used to certify the signal stability.

PURPOSE

To provide support to aircraft and avionics manufacturers to obtain regulatory approval for coupled approaches into steeper than normal approach angles.

BACKGROUND

A few aircraft have recently started the process of certifying their aircraft to allow operations at various airports within Europe which require a steeper than normal glide-path angle (e.g., London City Airport (LCY), London, England, which has a 5.5 degree glide path angle). To gain certification, the aircraft must perform a number of approaches at this non-standard glide-path angle. Typically, aircraft manufacturers have performed these types of flight tests at Blythe Airport, CA; however, this facility has been recently removed from service. The Avionics

Engineering Center (AEC) at Ohio University was contacted by Embraer aircraft concerning the feasibility of setting up a temporary glide slope system for these tests. AEC operates the FAA National Instrument Landing System (ILS) test facility on Runway 09L at the Kendall-Tamiami Executive Airport (TMB), south of Miami, FL, and has past experience in setting up steep angle approaches at this test facility. TMB is capable of supporting Group III-C size aircraft.

For steep angle approaches, the guidance quality for both the localizer and glide slope must meet Category I signal-in-space requirements along with the following additional characteristics:

A. Localizer

- Course aligned with Runway 09L centerline.
- A course displacement sensitivity of 5.0 degrees.
- Guidance quality must meet ICAO signal-in-space requirements for Category I operation.

B. Glide Slope

- A glide path angle of 5.5 (±0.1 degree), 6.65 and 8.65.
- A glide path displacement sensitivity of 1.32 degrees.
- Guidance quality must meet ICAO signal-in-space requirements for Category I operation down to 344 ft AGL.

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Table 1 lists the aircraft types which have recently used the facility to obtain engineering data for certification purposes.

Table 1. Summary of aircraft using facility.

Aircraft Type	Avionics	Path Angles flown (Degrees)	Engineering Flight Dates
E-175	Honeywell	5.5	5/08-6/1/08
Cessna Mustang	Garmin	5.5	2/20-2/21/07
Gulfstream G-550	Honeywell	5.5	1/09/07
Gulfstream G -150	Honeywell	5.5	1/09/07
Cessna Encore+	Rockwell Collins	5.5	3/14/07
Cessna Excel	Rockwell Collins	5.5	3/31-4/01/08
Falcon 900	Honeywell	5.5, 6.65, 8.65	8/10-8/12/08;10/24-26/07

SIGNAL-IN-SPACE

A. General

The Kendall-Tamiami Executive Airport (TMB) was chosen because the signal quality for various equipment configurations, both localizer and glide slope, is well known. In addition, the proper infrastructure, e.g., shelters, power, etc., was already established. Further, a good working relationship with airport and local FAA Air Traffic Control personnel was beneficial for seamless operations.

Figure 1 shows the layout of the site used for these tests. Note that the glide slope mast is located in front of the threshold and does not align the landing aircraft with the hard surface of the runway. Since this is a test facility, the mast was located in an area which would not interfere with airport operations.

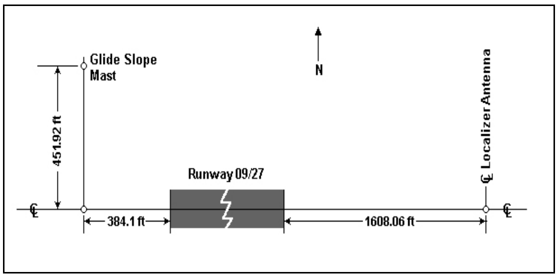

Figure 1. Test Facility Equipment Locations with Reference to Runway 09L at TMB.

For these tests, the missed approach point is 344 feet AGL or 3500 feet prior to the glide slope antenna mast; the latter distance should provide ample opportunity for the pilot to make adjustments for landing on the runway.

Table 2 lists the equipment and configuration installed at TMB to achieve the guidance signal characteristics. The antenna configuration chosen was selected not only to meet the guidance characteristics but also to minimize the chance of equipment failure, and allow for guidance signal verification during the flight tests.

Table 2. TMB Equipment Configuration Used During the Testing.

Parameter	Equipment	
	Localizer	Glide Slope
Frequency (MHz)	109.7	333.2
Antenna Type	Log Periodic Dipole	FAA 8971
Array Type	8-Element Single-Frequency	Null Reference
Transmitter	Mark 20	Mark 1F
SBO Power (mW)	140	60
CSB Power (W)	15.0	4.0
Standby Power	Batteries (6 hours minimum)	Batteries (6 hours minimum)

B. Glide Slope

Initial certification flights only required a path angle of 5.5 degrees where later flights required 6.65 and 8.65 degree angles as well. To facilitate switching between path angles during the engineering and certification flights, two transmitters were used (see Figure 2). For each glide path angle, two antennas are required. Four antennas were mounted on the mast and adjusted to provide the proper angle of 5.5 and 6.65 degrees. Since the glide slope mast was heavily populated, a separate structure was attached to the glide slope mast to accommodate the two antennas that provided the 8.65 degree angle (see Figure 3). This configuration of equipment allowed efficient switching between antenna systems, and thus path angles, which minimized the probability of radiating the wrong angle.

AEC personnel set the path angles by adjusting the height above ground of the upper antenna on the glide slope mast. Flight measurements were performed to verify that the guidance signal met Category I requirements. Table 3 provides a summary of the glide slope vertical guidance performance. The traces in Figure 4 through Figure 6. show the glide slope vertical guidance performance for the various angles.

Figure 2. Picture Showing the Glide Slope Transmitting Equipment Used to Generate RF Signals for the Steep Angles. Transmitter on the Right is for 5.5 Degrees and on the Left for 6.65 and 8.65 Degrees.

Figure 3. Picture Showing the Glide Slope Antennas Used to Generate the Proper Glide Path Angle.

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Table 3. Summary of the Glide-Slope Vertical Guidance Performance

Parameter	Flight Measurement Results	Flight Inspection Tolerance
Path Angle 5.5 Degrees 5/12/06 - 8/27/07		
Width (degrees)	1.36[1.41]	1.22 -1.42
Symmetry (%)	47[47]	33 - 67
Structure Angle (degrees)	3.50[3.41]	1.65 (minimum)
Path Angle (degrees)	5.49[5.46]	5.4 - 5.6
Path Angle 6.65 Degrees 8/27/07		
Width (degrees)	1.61	1.5-1.7
Symmetry (%)	46	33 - 67
Structure Angle (degrees)	4.3	2.0 (minimum)
Path Angle (degrees)	6.61	6.6 - 6.7
Path Angle 8.65 Degrees 8/27/07		
Width (degrees)	3.0	3.0-3.2
Symmetry (%)	47	33 - 67
Structure Angle (degrees)	4.8	2.6 (minimum)
Path Angle (degrees)	8.51	8.5- 8.8

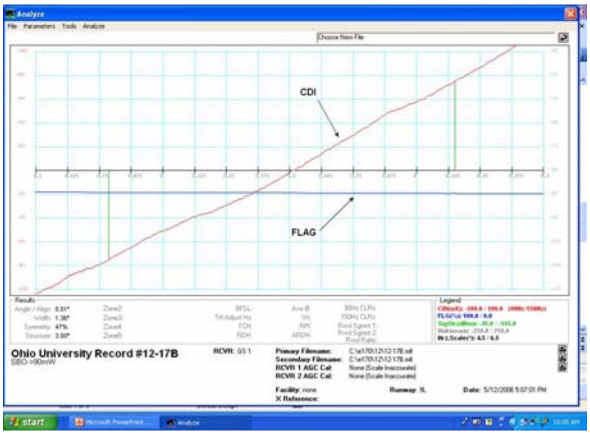

Figure 4. Measured Glide-Slope Guidance Performance (5.5-degrees). [5/12/2006]]

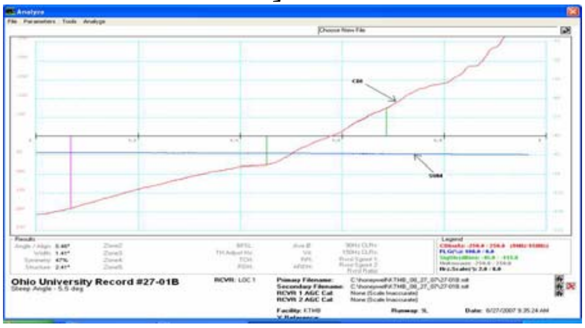

Figure 5. Measured Glide-Slope Guidance Performance (5.5 Degrees).[8/27/07]

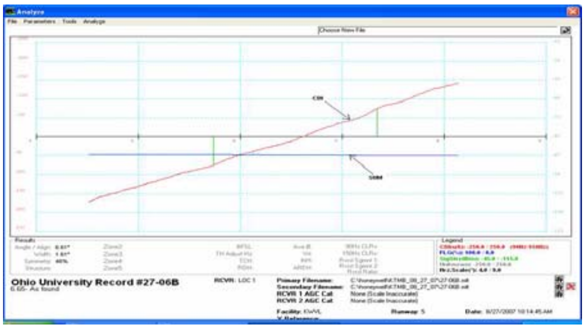

Figure 6. Measured Glide-Slope Guidance Performance (6.65 Degrees). [8/27/07]

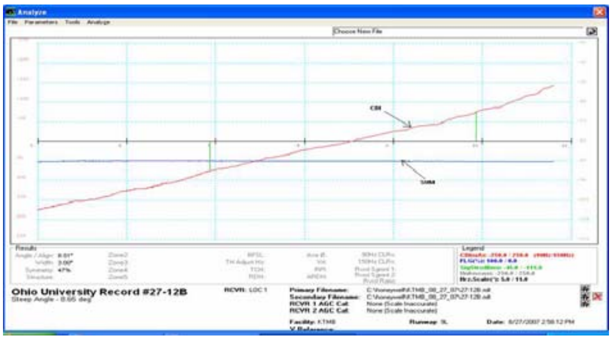

Figure 7. Measured Glide-Slope Guidance Performance (8.65 Degrees). [8/27/07]

The glide-path angle from the above measurements was obtained from a sample of one point; the average angle throughout the entire approach can then be verified based on the path roughness. An approach was then flown and the glide-slope guidance quality evaluated against Category I and Category III tolerance limits. A summary of the glide slope performance along an approach is provided in Table 4 and shown in Figures 8 through 11 and Figures 12 through 15 against Category I and Category III tolerances, respectively.

The average path angle is calculated from 4 nmi to 0.58 nmi. This measured angle can be affected by the reference point location. To minimize the error introduced by the reference point location and height, a Best-Fit-Straight-Line (BFSL) algorithm is used to determine the actual glide path angle.

Table 4. Summary of Glide Slope Performance.

Category	Structure Roughness (μA / % Tolerance / nmi)	
	ILS Zone 2	ILS Zone 3
Path Angle 5.5 Degrees 5/12/07		
	18.2/66.5/2.96	4.5/14.8/0.23
III	16.8/82.5	11.1/59.4/0.20
Path Angle 5.5 Degrees 8/27/07		
I	23.3 / 77.5 / 4.0	5.8 / 15.9 / 0.18
III	19.7 / 96.6 / 0.72	4.8 / 23.9 / 0.18

Path Angle 6.65 Degrees 8/27/07		
I	9.9 / 33 / 073	3.8 / 12.7 / 0.09
III	9.9 / 48.5 / 0.73	3.8 / 19.1 / 0.09
Path Angle 8.65 degrees 8/27/07		
I	9.0 / 30.1 / 1.78	8.4 / 27.8 / 0.13
III	8.5 / 42.4 / 0.59	8.4 / 41.7 / 0.13

Figure 11. Glide-Slope Path Quality (Category I Tolerances) (Path Angle 8.65 Degrees).[8/27/07]

Figure 8. Glide-Slope Path Quality (Category I Tolerances) (Path Angle 5.5 Degrees).[5/12/06]]

Figure 12. Glide-Slope Path Quality (Category III Tolerances) (Path Angle 5.5 Degrees)[5/12/06]

Figure 9. Glide-Slope Path Quality (Category I Tolerances) (Path Angle 5.5 Degrees).[8/27/07]

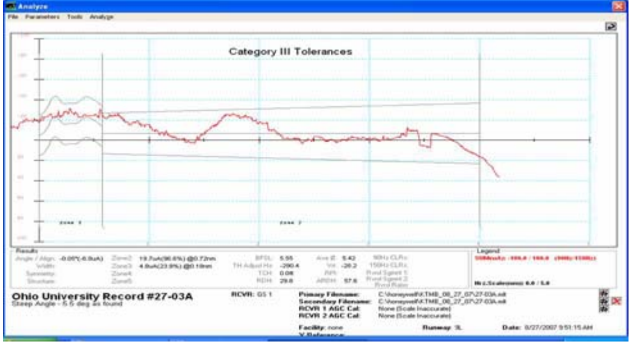

Figure 13. . Glide-Slope Path Quality (Category III Tolerances) (Path Angle 5.5 Degrees).[8/27/07]

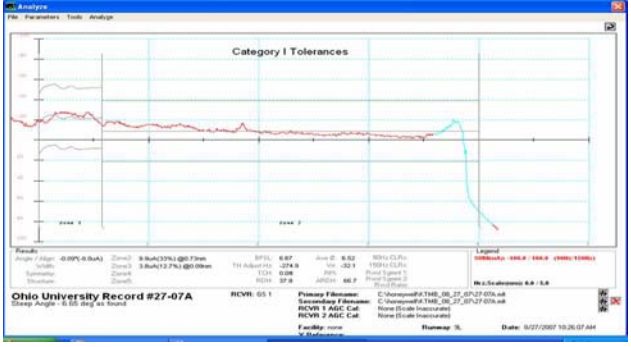

Figure 10. Glide-Slope Path Quality (Category I Tolerances) (Path Angle 6.65 Degrees).[8/27/07]

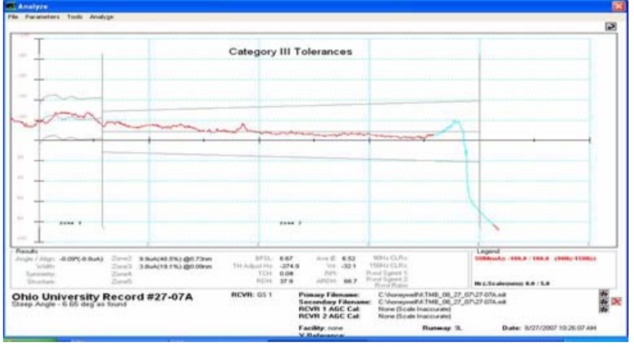

Figure 14. Glide-Slope Path Quality (Category III Tolerances) (Path Angle 6.65 Degrees).[8/27/07]

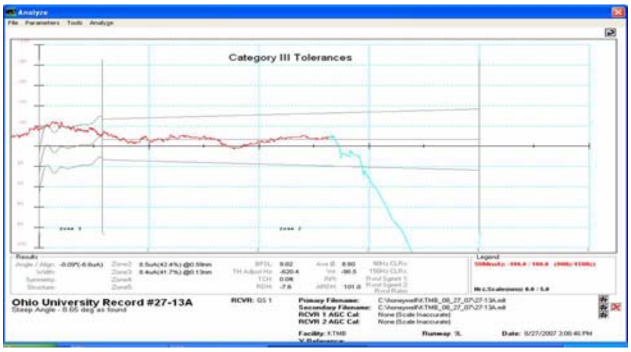

Figure 15. Glide-Slope Path Quality (Category III Tolerances) (Path Angle 8.65 Degrees).[8/2/07]

B. Localizer

The localizer antenna array was aligned to the Runway 09L centerline by trimming the antenna cables. The localizer course width was established by adjusting the transmitter SBO power. The results of the localizer horizontal guidance performance is provided in Table 5 and shown in Figure 16. These flight measurements also confirmed that the localizer was aligned with the centerline of Runway 09L.

Table 5. Summary of Localizer Horizontal Guidance Performance.

Parameter	Flight Measurement Results	Flight Inspection Tolerance
Width (degrees)	4.97	4.5 - 5.5
Symmetry (%)	48	45 - 55
Minimum Clearance 90 Hz (μA)	155	150 (minimum)
Minimum Clearance 150 Hz (μA)	165	150 (minimum)

Figure 106. Measured Localizer Horizontal Guidance Performance.

An approach was then flown and the localizer guidance quality was evaluated against Category I and Category III tolerance limits. A summary of the localizer performance along with an approach is provided in Table 6 and shown in Figures 17 and 18 against Category I and III tolerances, respectively.

Table 6. Summary of Localizer Performance.

ILS Zone	Structure Roughness (μA / % / nmi)	
	Category I	Category III
2	2.6 / 13.6 / 1.46	1.9 / 36.3 / 0.62
3	2.1 / 13.8 / 0.76	3.9 / 52.3 / 0.02
4	N/A	5.4 / 108.3 / 0.42
5	N/A	2.9 / 36.9 / 0.59

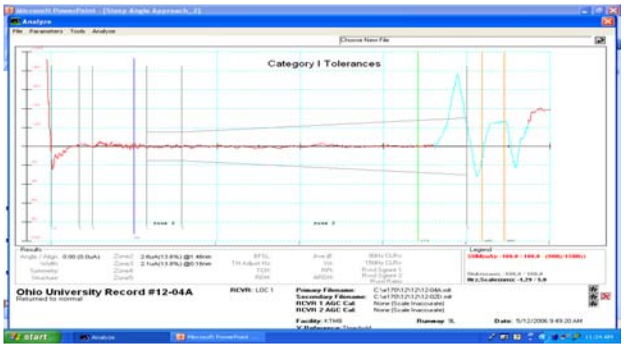

Figure 17. Localizer Guidance Quality (Category I Tolerances) [5/12/06].

Figure 18. Localizer Guidance Quality (Category III Tolerances).[5/12/06]

SIGNAL STABILITY VERIFICATION

As previously mentioned, the equipment configurations selected were based on the manner in which the system would maintain the documented performance during the flight tests. No system failures or adjustments were required during the flight tests.

A change in the upper antenna height above the ground of 1 inch equates to a 0.01-degree path angle change. The height of each antenna was measured prior to and after each flight test using a tape measure. In addition, the path angle can also be changed with a change in the transmitter modulation balance. For a 5.5 degree path angle, a 0.001 DDM change equates to a 0.0075-degree path angle change. The modulation balance was also verified prior to and after each flight test. These ground measurements confirmed (see Figure 19) that the path angle was maintained within ICAO limits during the entire testing period.

The glide slope structure roughness can be affected if the terrain in front of the mast is changed. A visual inspection confirmed no earth movement occurred in the path forming area during the testing period. In addition, the CSB-SBO power ratio change can alter the path structure roughness. Power measurements using BIRD wattmeter elements were taken prior to and after each flight test. These measurements (see Figure 20), along with the visual inspection of the terrain, confirm that the course structure roughness did not increase beyond ICAO Category I tolerances.

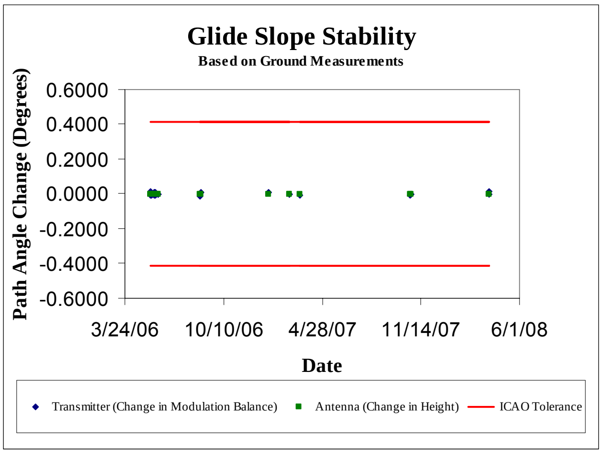

Figure 19. Confirmation That Path Angle Remained Within Tolerance During Tests - TX Modulation and Antenna Height.

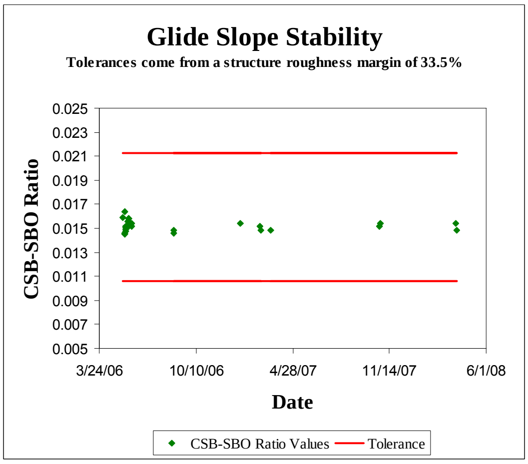

Figure 2011. Confirmation That Path Angle Remained Within Tolerance During Tests - TX Parameters.

CONCLUSIONS

Based on the data presented in this report, the following conclusions are reached regarding the performance of the ILS localizer and glide slope systems serving Runway 09L at the Kendall Tamiami Executive Airport, in Kendall, FL:

1. Both the localizer and glide-slope radiated signals met the ICAO performance requirements. In fact, the glide slope met Category III performance tolerances and the localizer met Category III performance tolerances in four out of five zones.

2. During the flight test period, the glide slope remained well within Category I tolerances. In fact, the guidance signal was stable and the glide slope path angle remained within 0.000015 degree of the desired glide path angle based on reference readings.