Recent Issues in Demanding ILS Ground and Flight Measurement Environments

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ABSTRACT
This is a continuation from previous International Flight Inspection Symposia of a series of discussions and papers by the authors on demanding flight inspection measurements. It presents investigations into current technical problems encountered during simulations and ground/airborne ILS measurements. Some of the issues presented include:
• Practical considerations when gathering raw data in ground and flight measurements
• Receiver performance under dynamic input conditions.
• Correlation between ground and flight measurements and operational use.
• Treatment of raw data by filtering processes, including intended as well as unintended filtering effects.
• Incomplete filtering definitions for ILS measurements in ICAO documents.
• Simulation parameters used to define critical and sensitive area boundaries for new aircraft.
• Missing sampling definitions and their potential consequences for ILS and navaids measurements with digital receivers.
This paper presents current low visibility ILS qualification issues, especially with regard to Localizer structure in Zones 4 and 5 (between ILS Points T and E), and in particular for CAT III applications on the runway. Practical effects on ground and flight measurements are discussed. The paper concludes with recommendations in areas such as choice of simulation parameters, use of raw and filtered data in ground and airborne measurements, and ICAO Standards and Guidance Material.

INTRODUCTION
This paper continues an ongoing discussion of challenging measurement issues for low-visibility Instrument Landing Systems (ILS). Previous papers have dealt primarily with aircraft positioning, airborne antenna patterns, threshold crossing heights, digital receiver design techniques and their effects on ILS measurements, and capture effect issues[1,2,3].
This paper focuses on additional topics that make high-accuracy predictions and measurements challenging:
• Receiver behavior with dynamic input conditions
• Navigation receiver output and Flight Inspection System (FIS) filtering
• Non-specific and missing International Civil Aviation Organization (ICAO) definitions.

BACKGROUND
Category II and Category III ILS installations often exhibit challenging measurement problems. These typically arise from demanding tolerances near and over the runway, capture effect antenna systems, variability between measurements, multipath effects, and receiver and measurement system design characteristics. Because major airport environments are constantly changing and the unplanned loss of an instrument approach is unacceptable, mathematical modeling is routinely used to predict the effects of the changes[4].
However, ground and airborne receiver characteristics are incompletely specified or tested by regulatory authorities. Little guidance exists for the many simulation variables used to predict flight inspection results and define ILS critical/ sensitive area boundaries. Receiver performance under dynamic input signal conditions is addressed poorly or not at all. These conditions exist, perhaps at least in part, due to the earlier expectation that ILS would be completely replaced by the Microwave Landing System MLS and later by the satellite-based navigation GNSS. As a result, the engineering and flight inspection communities experience occasions for which differences between high-performance modeling and ground/airborne measurements are significant.

RECEIVER RESPONSE TO DYNAMIC SIGNALS

Warning and Status Flag Behavior
All ILS receivers are required to implement the ICAO-specified warning flag to alert the pilot when the ground station has developed flaws such as low modulation or signal level. But modern digital design receivers with microprocessors have the ability to monitor additional characteristics the manufacturers deem appropriate.
An example is the Non-Computed Data or NCD output of a popular cabin-class receiver. This discrete output changes state when any internally monitored parameter exceeds tolerances set by the manufacturer or in some cases by the user. The NCD output is used to functionally disable the use of the output by an autopilot, Flight Management System (FMS), or any other avionics fed by the receiver. For example, when used in a flight inspection system, the NCD output can be used to inhibit plotting of the flight inspection recording during the periods of "out-of-tolerance" operation.
Depending on the parameters monitored in the receiver, these additional monitoring circuits can inhibit the receiver's output usage even when the ILS signals are well within tolerances. One popular parameter for this monitoring is the rate of change of parameters such as Difference in Depth of Modulation (DDM), which is also referred to as Crosspointer or Deviation. The basic concept is to inhibit any use of the DDM output if it is changing faster than appropriate with achievable aircraft dynamics. But in-tolerance multipath signals can also cause high rates of change of DDM, falsely triggering the NCD signal or otherwise changing the receiver's output, if improperly filtered, in a way not presented by the ILS signal in space. (This is in contrast to the effects such as sampling circuit design as discussed in a previous paper)[3].
Table 1 summarizes orbital measurements of Localizer clearance signals during a commissioning flight inspection. The inspector noted highly unrepeatable course width and low clearances results, and tried various altitudes and ranges seeking repeatability. Note that the clearances are consistently lower on the 150 Hz side, and that there are four mentions of receiver "unlocks."
Other flight and ground measurements confirmed the array was radiating symmetrically, with high clearances of 350 uA, and that the low clearances are caused by multipath conditions. Figure 1 compares the low clearances area of ~ 23 degrees (150 Hz side) from Runs 1 and 2 of Table 1. The vertical scale runs from zero uA at the bottom to would exceed tolerances without the vertical 400 uA at the top.
Because the runs in Figure 1 were made in opposite directions, the lower graphic has been flipped horizontally and scaled for similar angular speeds. Two vertical segments or "repositioning" (see arrows) of the crosspointer trace are immediately notable on each recording, occurring at almost twice the azimuthal extent in the lower (CCW) recording. The left-most shifts in the two recordings are in opposite directions (high to low, and low to high DDM values), making it difficult to imagine how the recording would look without these offsets. The instantaneous offsets in recorded DDM position cannot be produced by the localizer, and therefore it is likely they are a result of the receiver's (or FIS system's) response to rapidly changing input signals.
Figure 2 presents a segment of Run 17 (CW) including the STATUS traces, labeled L1ST and L2ST, for the two FIS receivers. The inspector has circled the three STATUS events - Receiver #1 did not alert when receiver #2 alerted the second time. The status trace indicates when internal

Table 1. Summary of Clearances Data from a Localizer Commissioning Effort

Run #	Altitude Ft, AGL	Direction	Range NM	Remarks	LOW CLEARANCES, UA/DEG 150 HZ	90 HZ
1	1200	CW	4	Establish Width	139/23	231/20
2	1200	CCW	4	Compare	180/20	227/20
3	1200	CW	4	Repeatability	188/20	230/20
4	1200	CCW	4	Repeatability	181/20	227/20
5	1400	CW	6	Repeat, “unlocks”	0*/19	200/20
6	1400	CCW	6	Repeat	136/20	231/18
7	1400	CW	6	Repeat, “unlocks”	0*/19	204/20
8	1400	CCW	6	Repeat	115/20	234/18
14	2000	CCW	8	300 mw	151/22	222/18
15	2000	CW	8	300 mw	167/20	199/18
16	2000	CCW	8	Wide 235 mw	128/20	194/20
17	2000	CW	8	Sharp 355 mw, “unlock”	0*/18	214/18
18	2000	CCW	8	Repeat, #1 Rx no “unlocks”	179/20	240/20

* 0 uA entered due to appearance of Receiver Status Flag; actual clearances higher

receiver alarms or abnormal conditions are present. The deflection amount of the status trace indicates the particular condition: 0.1" = Signal Strength, 0.2" = Modulation, 0.4" = Deviation. In Figure 2, the lengths are 0.7", indicating simultaneous alarm conditions for all three parameters. However, the traces for signal strength and modulation both exceed tolerances by a comfortable margin; likewise, the DDM trace crosspointer trace accompanies each STATUS event.)

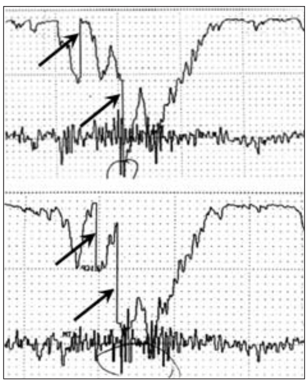

Figure 1. Low Clearances Compared, Runs 1 and 2, ~23 Degrees/150 Hz, Opposite Directions

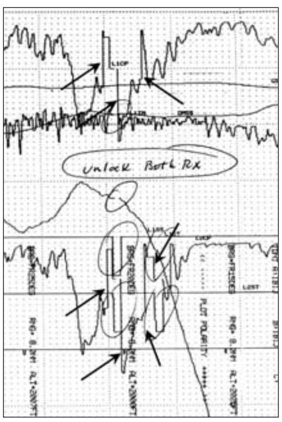

Figure 2. Low-Clearance Area, CW Flight, ~1228 Degrees (150 Hz), Run 17, 8 NM, Narrow Alarm

Some of the runs in Table 1 include remarks from the flight inspector about "unlocks". Technically, localizer receivers do not "unlock" in the same sense that search-type receivers, such as DME or TACAN, unlock. Rather, the remark "unlocks" is used to describe the STATUS trace events, and the corresponding brief cessation of plotting of the traces, such as circled in the middle of Figure 2 on the L1SS (signal strength) trace. In this example case, the NCD output of the receiver is used to stop plotting of the traces.

To better illustrate the correspondence between receiver status alarms and the vertical segments, Figure 3 shows an expanded recording segment without the modulation traces. It shows more clearly the relation between status alerts, vertical crosspointer segments, and reported low clearances. In the Figure, there are at least 11 vertical segments on the crosspointer trace. Six of them coincide exactly in time with the leading and trailing edges of the three Status alerts for Receiver 1, as shown by the hand-drawn dashed and solid vertical lines between the status and crosspointer traces. A hand-drawn smooth heavy line through the average of the crosspointer trace indicates the level of clearances that would be provided by this localizer in the absence of any multipath or receiver effects. The high-frequency, oscillatory nature of the actual trace results from the multipath --several discrete frequencies are visible, indicating two or more reflectors are producing the multipath.

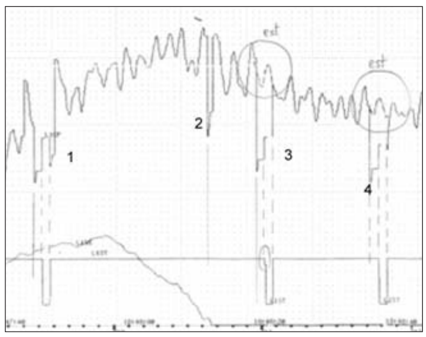

Figure 3. Run 11, CCW Orbital Measurement

Four "vertical segment" events on the crosspointer trace have been numbered. Events 1, 3, and 4 correspond to conditions severe enough to cause the status alert on the L1ST trace, while event 2 does not occur with a status alert. For all four events, the initial portion of the crosspointer trace has been shifted vertically from its correct position (downward in all these examples, but sometimes upward in other recordings). For a brief time, the crosspointer data are plotted in the new vertical location.

During the status indicator state changes for events 1, 3, and 4, DDM data plotting stops. Also during the status event, a horizontal line replaces the DDM data for half the status event, followed by a gap in the DDM trace for the second half of the status event. For event 2, the actual DDM data continues to be plotted, but is displaced downward by approximately 1 inch on the recording. For events 3 and 4, a hand-plotted dashed line shows the likely raw DDM data that WOULD have been plotted from an analog-only receiver. These handgenerated estimates of actual localizer performance are circled and labeled "est" (estimated).
The vertical offsets in the crosspointer trace must be receiver or FIS-caused, since they cannot be caused by the localizer. They are likely related to one or more of the internal thresholds that comprise the NCD function being exceeded. In the case of strong multipath conditions, it is likely that the DDM rate of change threshold is involved, but these recordings do not provide sufficient data to prove this conclusively.
From Figure 3, the apparent low clearances are approximately 115, 182, 130, and 115 uA for events 1-4 respectively. However, due to the vertical offsetting of the trace by receiver or FIS, these values are highly suspect. The FIS announcement for low clearances on this run was 125 uA, which does not correspond well with any of the four plotted events. All of the reported abnormally low or out-of-tolerance clearance values during the commissioning effort correspond to recordings that show vertical offsets in the DDM trace.
It is important to note that different receivers using varying software philosophies can exhibit different behaviors at sites with high multipath. While a purely analog (typically older) receiver might not see any parameters out of tolerance on an orbital measurement, receivers with different software algorithms can show different results, all without any ground adjustments or other changes in measurement conditions. These differences arise from design considerations such as digital sampling rates, filtering time constants, internallybased alert criteria, etc.

NAV RECEIVER AND FIS FILTERING

The recent introduction of the A380 aircraft has again raised the issue of ILS receiver filtering, and how best to simulate the effects of multipath for the purposes of defining critical/sensitive area boundaries, and hold line positions. This topic is routinely addressed at various forums, and an active international debate is ongoing. As a result, numerous requests for ICAO clarification have been made.

ICAO ILS Receiver Filtering Definition

Paragraph 2.1.7 of ICAO's ILS Guidance Material5 defines a [low-pass] filter for the measurement environment of the ILS signal in space. The implied concept is that DDM variations fast enough to be rejected by this filter used for flight testing purposes are not of concern to the user. In 1968, the Annex text read:

"Owing to the complex frequency components present in the ILS beam bend structures, measured values of beam bends are dependent on the frequency response of the airborne receiving and recording equipment. It is intended that beam bend measurements be obtained by having a total time constant for the receiver DDM output circuits and associated recording equipment of 0.5 second."

During the 1960s, prior to any significant Category II and III flight operations, flight measurements were generally concerned with ILS signal performance prior to threshold. As lower visibility operations were introduced, it became necessary to measure performance near and inside the runway threshold. Ground measurements at reasonable driving speeds were one way to do this, and it was desirable to compare ground measurements at differing driving speeds. It also became necessary to translate the slower but convenient ground measurements to flight speed conditions, for operational purposes such as defining critical and sensitive areas. As a result, a speed-dependent formula was introduced in place of the fixed time constant:

"It is intended that beam bend measurements be obtained by using a total time constant (in seconds) for the receiver DDM output circuits and associated recording equipment of 92.6/V, where V is the velocity in km/h of the aircraft or ground vehicle as appropriate."

Although both versions make clear the total time constant of the measurement system is in seconds, the conversion from time constant to lowpass filter corner frequency is unspecified. Today, some measurement organizations and simulation activities use a simple inversion of time constant to frequency, $F_{(Hz)} = 1/t$. Others consider the inverse of the time constant to be a radian frequency, $2\pi F_{(Hz)} = 1/t$, or $F_{(Hz)} = 1/(2\pi t)$. This difference in interpretation results in a 2π or approximately 6:1 difference in corner frequency, which propagates to significant differences in hold line positions, protected area sizes, and accommodation of proposals for construction of reflectors. Which method should be used?
One way to answer this question is to consider technological conditions at the time the Guidance Material was prepared. In the late 1960's, tube-type and early generation solid-state receivers were common, but high-performance operational amplifiers were not readily available to implement filters. "Communications theory" was taught in electronic curricula, with frequency being simply the reciprocal of time. (Many text books continue this description.) Simple filters were commonly specified by a single R-C (resistor-capacitor) time constant. This correlates closely to the 1968 Guidance Material phrasing, "a total time constant for the receiver DDM output circuits and associated recording equipment of 0.5 second." Later, as modern filter theory and synthesis techniques, and more complex filters using integrated circuit operational amplifiers became common in circuit design, radian frequencies were used for filter mathematics. Therefore it is unlikely that the original authors' intent of paragraph 2.1.7 of the Guidance Material was to use radian frequencies, which were uncommon until some years later,
While it is perhaps feasible to implement speeddependent filters in flight inspection systems, none is known to do so, and it is quite unlikely that any user receivers do so. Therefore, although a service provider might simulate the effects of a reflector, and be able to confirm the validity of the simulation via flight testing if the time constants used in the two activities match, it is a separate issue whether the user community will be affected less or more by the multipath effects of the reflector. Thus user receiver time constants need to be considered.

User Receiver Filtering Considerations

Table 2 illustrates low pass filter corner frequencies for three common measurement speeds, as derived using the two mathematical seconds-to-frequency conversion methods. The MLS SARPS measurement frequency is also included for comparison.

60 ~ driving 185 ~ 100 Kt (flying slow) 260 ~ 140 Kt (typical approach)	60 Km per hour	185 Km per hour	260 Km per hour
Guidance Material formula, 92.6/V	1.54 sec	0.5 sec	0.36 sec
Corresponding Frequency, Hz 1/t (inversion method) 1/2πt (radian method)	 0.65 0.10	 2.00 0.32	 2,78 0.44
MOPS, Hz (minimum) 1/t (inversion method) 1/2πt (radian method)	DNA	(min) 1.67 0.27	(min) 1.67 0.27
MLS SARPS, Hz (para 3.11.4.9.3, 10 rad/s)	DNA	1.60	1.60

Table 2. Common Measurement and User Speeds vs. Filter Characteristics

Airborne receiver time constants are addressed in the Minimum Operational Performance Specification (MOPS) for the LOC receiver, RTCA DO-131A (1978)[6] and EUROCAE ED46B (1998). The Electrical Course Deviation Output chapter specifies the Deviation current response as the response to a step function that reaches 67% within 0.6 sec. For this first-order low pass filter, the corresponding corner frequencies are Fc = 1.67 Hz (inversion method) or 0.27 Hz (radian

method).
The Guidance Material's formula matches the earlier 0.5 second specification at a speed of 186 Km/hr, or 100 Kt. This speed may indeed have been typical of slower propeller-driven aircraft during the 1960s. Today, however, user approach speeds are more typically 140 Kt, or about 260 Km/hr. To achieve the same user Deviation response to multipath conditions at a given runway at today's approach speed as would be obtained at 100 Kt requires a filter corner frequency of about 2. 2.8 Hz or 0.4 Hz, depending on the calculation method chosen.
The MOPS and MLS corner frequencies (both for airborne use) are nearly identical at 1.67 (minimum) and 1.60 Hz, and larger by a factor of approximately four (or more) than the highest of the corner frequencies obtained by the radian conversion method. This is a significant argument for using the inversion calculation method, because Multi-Mode Receivers are now common. Typical implementations have a single output circuit for the internal ILS, MLS, and Satellite receivers to feed the aircraft systems. Figure 4 shows a typical block diagram of this arrangement. Regardless of the Navigation system used for a given instrument approach, the user expects that the aircraft will behave similarly. This requires that the response characteristics of the three receivers are similar. Thus we might conclude MMRequipped air carrier aircraft likely will have an overall filter response in the 1.6 Hz or higher frequency range, at least due to the MOPS and MLS SARPS specifications.

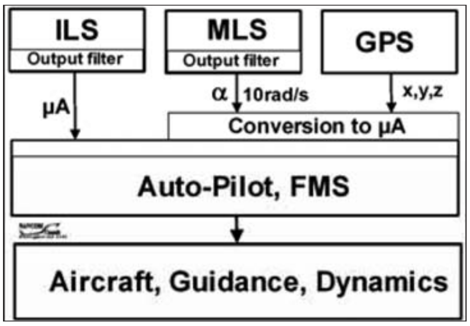

Figure 4. Multi-Mode Receiver feeding Avionics and Aircraft Systems

If ILS simulations and flight inspection measurements are performed with filter frequencies in the 0.1 to 0.4 Hz (radian method) range, substantially lower structure results will be seen in the results, thus qualifying more facilities in demanding multipath conditions. Obviously, this is popular for service providers. However, the user meanwhile will experience much larger magnitude (beyond tolerance) roughness, scalloping, and bends due to the 1.6 Hz (or higher) airborne corner frequency. This will result in user complaints at best, and perhaps autopilot or Flight Management System disconnects or aircraft displacements at worst during approaches.
Although actual user ILS receiver corner frequencies are not readily obtained, they do appear from extensive field multipath experience to vary substantially. A popular (>15,000 in service) "cabin-class" receiver even has selectable time constants. Therefore, corner frequencies higher than the RTCA specified minimum values of 0.27 Hz (radian method) are likely to be encountered in service.

FIS Filtering

Current filter implementations are extremely simple to realize at ILS crosspointer frequencies, and multiple pole filters are very common - 4-pole filters can be implemented with a single operational amplifier chip. In a flight inspection system it is common to separate error components into high-frequencies (roughness and scalloping), mid-frequencies (bends), and low frequencies (alignment), since the tolerances differ. Several filters will be used in such an implementation, and if filter roll-off or attenuation above the corner frequency is slow, some error components will appear simultaneously in the roughness and bends categories, or in the bends and alignment categories. This is clearly undesirable, and as a result, multiple pole filters are usually used.
As an example, the U.S. Automatic Flight Inspection System (AFIS) user four-pole filters to separate Alignment, Bends, and Roughness/Scalloping error components for VHF OmniDirectional Range (VOR) signals. Since VOR signals are not used for low approaches over the runway, the filtering demands are different than for low-visibility ILS signals. (Similar techniques are used for Microwave Landing System flight inspections, to separate Path-Following Error, Path-Following Noise, and Control Motion Noise.) Figure 5 shows a conceptual diagram of this filtering system.

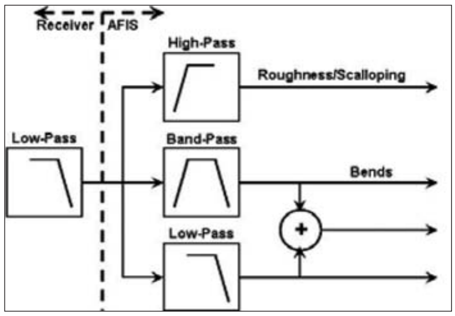

Figure 5. U.S. AFIS VOR Crosspointer Filtering

In this implementation, the VOR receiver's output filter removes high-frequency (e.g., >2 Hz or "don't care") components which are too fast to be visible to the pilot or used by the flight controls. An AFIS filter defines roughness/scalloping as error components shorter than 10 seconds in length (>0.1 Hz by inversion method), on the basis that a pilot is not likely to alter the ground path of the aircraft until an off-course presentation persists at modern flight speeds for about 10 seconds. A second filter defines bends, which are flown by the pilot or autopilot to alter the ground track, as error components lasting between 10 and 34 seconds. Error components lasting longer than 34 seconds are considered alignment errors. Finally, for convenience in application of VOR tolerances, the sum of the alignment and bends errors are also presented to the inspector.

Practical Application of Receiver Design, Simulations, and Flight Measurements

The A380 aircraft requires a fresh determination of ILS critical/sensitive area boundaries and hold line positions. With modern techniques, this is frequently accomplished with simulations, which of course must be capable of validation by both flight inspection organizations and by users' experiences.
In the figures which follow, the effects of sampling techniques (as discussed in previous paper[3]), filtering choices as discussed above, and measurement speeds are combined. A highfidelity model of the A380 is positioned at an angle of 30 degrees to a parallel taxiway. DDM results are predicted against Category III tolerances for varying low-pass filter frequencies, digital sampling rates, and measurement speeds.
Figure 6 contrasts unfiltered DDM and the DDM obtained using filters with frequencies of 0.1 and 0.6 Hz (see column 2 of Table 2). The measurement conditions are driving speeds (60 km/h) on the runway, using a receiver with properly selected sampling rates (in this case 4 samples per meter of travel), and an antenna height of 4m over the runway. The maximum scalloping amplitudes are approximately 1.5 uA (30% of tolerance) and 11 uA (220% of tolerance) for filter frequencies of 0.1 and 0.6 Hz respectively. These filter frequencies would yield widely differing sizes for predicted critical and sensitive areas, and widely different hold line positions.
Figure 7 shows the same runway multipath environment, but the measurement is conducted at a flight speed of 250 km/h, 15 meters above the runway. Filter frequencies of 0.415 and 2.7 Hz (nearly identical to column 3 of Table 2) are contrasted. Again, properly selected sampling rates (in this case 4 samples per meter of travel, a higher sampling rate than for Figure 5) are used. The maximum scalloping amplitudes are approximately 0.5 uA (10% of tolerance) and 4.5 uA (90% of tolerance) for filter frequencies of 0.415 and 2.7 Hz respectively. These results are approximately one third of the magnitudes achieved with the ground measurements, regardless of the method of obtaining the filter frequency. This in turn implies that signal structure conclusions at 15m above the

runway will have poor correlation with the signal structure experienced by the user during a landing rollout.

Finally, Figure 8 again shows the same runway multipath environment, with the measurement conducted at a flight speed of 250 km/h, 15 meters above the runway. The filter frequencies of 0.415 and 2.7 Hz (nearly identical to column 3 of Table 2) are the same as in Figure 6. However, an inappropriately low sampling rate of 10 samples per second is used - one sample for every 7m of forward travel. Unlike the results of Figures 5 and 6, the nature of the DDM oscillations is rough and irregular - i.e., they lack the proper sinusoidal character of a sufficiently sampled result. The maximum scalloping amplitudes are approximately 7 uA (140% of tolerance) and 15.5 uA (310% of tolerance) for filter frequencies of 0.415 and 2.7 Hz respectively. It is inappropriate to compare these magnitudes to those of Figures 5 and 6, due to the undersampling conditions.

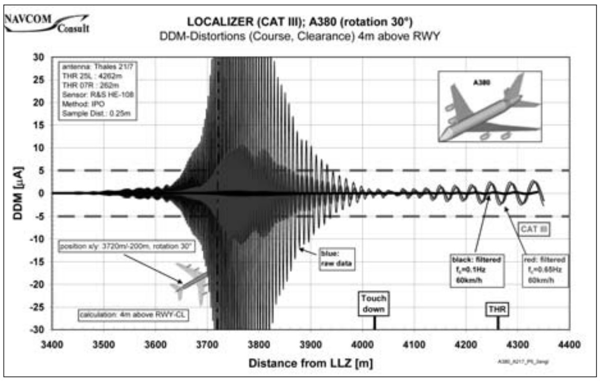

Figure 6. Ground Measurements at 4 Meters, Varying Filter Characteristics, Proper Sampling

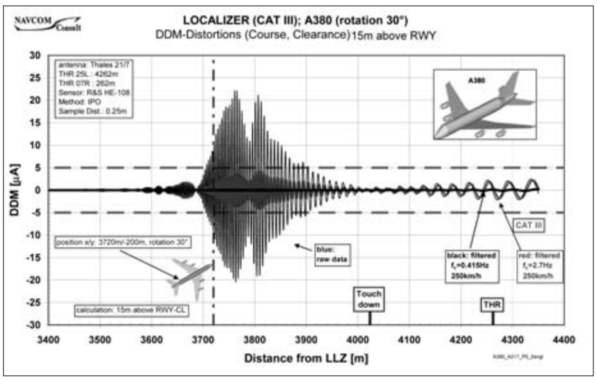

Figure 7. Flight Measurements at 15 Meters, Varying Filter Characteristics, Proper Sampling

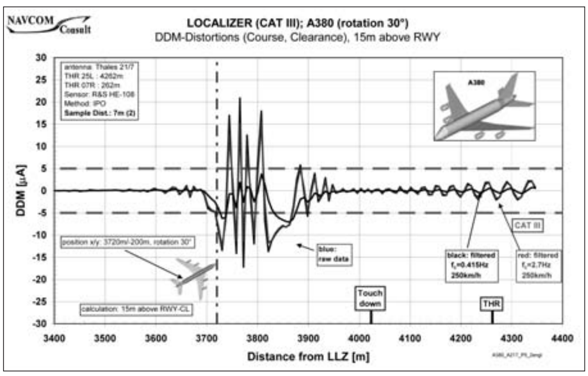

Figure 8. Flight Measurements at 15 Meters, Varying Filter Characteristics, Insufficient Sampling Rate

CONCLUSIONS

a. Standards-setting bodies such as ICAO and RTCA generally deal with signals in a static environment.

b. ICAO Standards and Guidance Material do not define ILS receiver response characteristics to dynamic input signal conditions.

c. Receiver design characteristics can substantially alter the normally specified and expected outputs when the input signal exhibits dynamic conditions such as rapidly changing signal strength or multipath effects.

d. Different receivers can show substantially different results under dynamic signal conditions, due to design choices for control loops, filtering, and sampling techniques.

e. Flight inspection organizations routinely see and record the detailed symptoms of ILS receivers in a dynamic signal environment.

f. Due to software implementation differences, announced FIS results may be suspect when dynamic conditions exist.

g. Receiver outputs such as Non-Computed Data, while perhaps useful for the originally intended purposes, can inhibit signals normally recorded for flight inspection purposes, at the time when Navaids engineers most wish to see the results.

h. ICAO's speed-dependent ILS Filtering formula was intended to facilitate low-speed groundbased measurements on the runway, and the translation of those results to expected user results in flight.

i. At the time of the introduction of the speed-dependent filtering formula, filters were implemented with simple R-C time constants, and Communications Theory (inversion of time to frequency) was common.

j. ICAO Standards for MLS measurements define user receiver filtering with a corner frequency of 1.6 Hz, while RTCA and EUROCAE standards for ILS receivers specify a minimum corner frequency of 1.67 Hz, if inversion of the time constant is used to calculate frequency.

k. Considering the history and conditions under which Annex 10 has evolved, it is likely that the authors of the speed-dependent ILS measurement filter intended that its time constant be converted to frequency by simple mathematical inversion, rather than using radian frequencies.

l. Despite the existing differences between ILS and MLS filtering definitions in Annex 10, crosspointer filtering for ILS, MLS, and GNSS applications should have a common engineering approach based on the aircraft's navigation requirements.

m. To provide more clarity in the Guidance Material, and to promote comparability between simulations, ground/flight testing results, and user experiences, it is essential to specify a common method by which the filter time constant in seconds is converted to a filter corner frequency. Alternatively, a filter corner frequency can be defined.

n. Use of multiple pole filters for both simulations and ground/flight testing should be encouraged, to consistently and readily separate roughness and scalloping, bends, and alignment errors.

RECOMMENDATIONS

a. ICAO should formally define ILS receiver response characteristics to dynamic input signal conditions.

b. ILS receiver response characteristics to dynamic signal conditions should be tested and fully understood before being used for flight inspection purposes.

c. Flight inspection organizations should document all unusual receiver behavior characteristics, and forward examples to standards-setting bodies for consideration and investigation.

d. Flight inspection organizations should ensure that all raw data is recovered and recorded or displayed, independent of protective outputs provided by the manufacturer for other purposes.

e. Multipath simulation and flight measurement activities should adopt common definitions for relevant parameters that match user receiver characteristics as closely as possible.

f. ICAO should embellish the ILS Guidance Material (paragraph 2.1.7) and other relevant documents to explicitly define ILS filtering characteristics for simulation and flight inspection purposes, consistent with MLS and GNSS filtering characteristics as much as possible.

ACKNOWLEDGEMENTS

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