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The correlation between methods of the Localiser displacement sensitivity measurement

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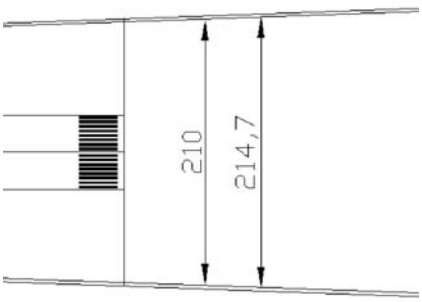
ABSTRACT

ICAO Doc 8071 refers to two basic methods of localiser displacement sensitivity measurement: approaches on the edges of the course sector, and crossovers or orbits through the course sector. While the approaches are considered as more precise method recommended to commissioning flight inspections, the crossover is in some circumstances solution saving flight time and money. It is recognised, that displacement sensitivity values obtained from approach flights differ from the cross flight values. To overcome this difference, it is practice in some countries to establish relationship between these two methods during commissioning flight inspection and later apply cross flights only.

This articles analyses magnitude and possible causes of differences between results of two basic methods of displacement sensitivity measurement considering factors as field strength, sum of modulations and speed of the aircraft. A method of calculation of the correction coefficient is proposed.

INTRODUCTION

The Displacement Sensitivity of the localiser is defined in ICAO ANNEX 10 Volume I [1] as „the ratio of measured DDM to the corresponding lateral displacement from the appropriate reference line". It is specified, that the nominal displacement sensitivity within the half course sector at the ILS reference datum shall be 0.00145 DDM/m (0.00044 DDM/ft). Hereafter, the "Note 1" explains, "These are based upon a nominal sector width of 210 m (700 ft) at the appropriate point, i.e., ILS Point "B" on runway codes 1 and 2, and the ILS reference datum on other runways".



Picture 1 Nominal tailored sector width (in scale)

So, the nominal tailored sector width at the reference point is,

$$SW = 2 * \frac{0.155}{0.00145} = 213.8\,m$$

when based on DDM per meter of ICAO ANNEX 10/I
or

$$SW = 2 * \frac{0.155}{0.00044} * 0.3048 = 214.7\,m$$

when based on DDM per foot of ICAO ANNEX 10/I
or

$$SW = 210.0\,m$$

when taken directly from the "Note 1" of ICAO ANNEX 10/I
or

$$SW = 700 * 0.3048 = 213.8\,m$$

When based on value of 700ft from the "Note 1".
or

$$SW = 2 * \frac{150}{1.45} = 206.9\,m$$

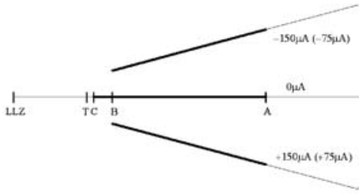
when based on microamperes per meter figure of former version of ICAO Doc 8071 Volume II (1972) [3] .
The uncertainty of the nominal tailored sector width as resulted solely from ambiguity of ICAO specification exceeds 2%!
On the other hand, an acceptable uncertainty of in-flight displacement sensitivity measurement, as specified in ICAO Doc 8071 Volume I [2] is 3% or even 2% for localiser of CAT III.

METHODS OF DISPLACEMENT SENSITIVITY MEASUREMENT

There are three ways, how to express the Displacement Sensitivity: as DDM per meter (foot), in term of tailored sector width in meters (feet) or as a course width in degrees. The later one is the most common in the Flight Inspection.
Basically, two methods of localiser displacement sensitivity measurement are available – approaches and cross flight.

1. Approaches

To measure a width of a localiser is necessary to perform 3 approaches: one centreline approach to establish mean azimuth of DDM=0µA and two approaches with appropriate offset of the centreline.
A Method of Approaches is recommended [2] for commissioning flight inspection. Therefore, in this article is considered as a reference method of width measurement.



Picture 2 Approach method of the course width measurement

Offset approaches can be performed on ±75µA or ±150µA. Because of shape of the course sector, these different offsets may lead to two different results of course width. Only for perfectly linear course sector, the results have a chance to be equal.

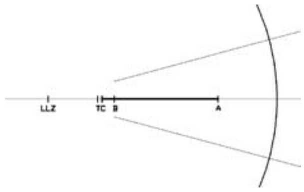
Antenna Type	±75µA offsets	±150µA offsets	Width Difference
NM06S	4.00	3.99	0.3%
NM12S	4.00	3.98	0.5%
CM11S	4.00	3.96	1.0%
NM24D	4.00	3.81	4.8%
SL12S	4.00	4.04	1.0%
SL12D	4.00	4.09	2.3%
SL21D	4.00	3.82	4.5%
WX14D	4.00	4.05	1.3%
WX20D	4.00	4.10	2.5%

Table 1 The difference of the course width measured at different offsets

The offset effect is shown in the Table 1 for some of LLZ antenna types. It is resumed, that the nominal course width was set to 4.00° at ±75µA offsets and the width measurement (for example during following inspection) will be performed at ±150µA offsets. The difference in results may reach up to 5%.

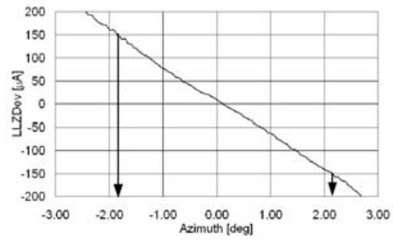
2. A Cross Flight

A Flight cross LLZ sector at appropriate distance is considered as an acceptable method of width measurement. As it is stated in ICAO Doc 8071 Volume I [2] , a cross flight method is suitable for periodic flight checks, while FAA OAP 8200.1C [4] refers to cross flight method as to the only one.



Picture 3 Crossover method of the course width measurement

Calibration flight may be conducted as perpendicular to the centreline or along partial orbit.



Picture 4 Cross flight Localiser Deviation record

Course width can be calculated:

1. measuring the angle between passing -150μA and +150μA, or
2. measuring the angle between passing -75μA and +75μA multiplied by 2, or
3. measuring the aircraft speed and time between passing -150μA and +150μA, or
4. measuring the aircraft speed and time between passing -75μA and +75μA, or
5. from DDM and position data collected during cross flight.

As it is visible from the overview of applicable methods of the course width calculation, the diversity of methods itself or in combination with ambiguous nominal course width definition may outcome to different LLZ nominal or monitor alarm setting. Such divergences evidently exceed allowed uncertainty of the measurement as specified in ICAO Doc 8071[2].

BEHAVIOUR OF NAVIGATION RECEIVER DURING CROSS FLIGHT

To investigate the cause of different width results, it is necessary to consider static as well as dynamic features of navigation receivers, which may affect accuracy of the measurement. Widely used flight inspection receiver, the Bendix-King RNA-34AF, was used to testing, but some consideration might be generalised.

The Localiser Deviation should be obtained as

$$LLZDev = K * (DM_{90Hz} - DM_{150Hz})$$

Where

- LLZDEV means the Difference in depth of Modulations in microamperes,
- K means a transformation coefficient of percents DDM to microamperes and
- DM_{90Hz}, DM_{150Hz} mean Depth of modulations of 90Hz and 150Hz in percents

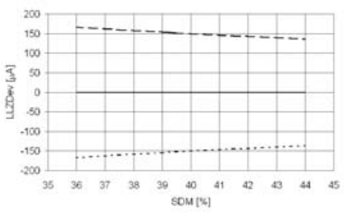
Some of navigation receivers, including the Bendix King RNA-34AF [5], obtain the DDM as

$$LLZDevR = K * \frac{DM_{90Hz} - DM_{150Hz}}{DM_{90Hz} + DM_{150Hz}} * 40$$

Where

- LLZDevR means Localiser Deviation Reading of the receiver

It does mean, that the course width measured using receiver of one type will be the same as measured with the other only for localiser having sum of depth of modulations (SDM) equal to 40%. For SDM equal to 36%, the LLZDevR would be 167μA instead of expected 150μA and for SDM equal to 44%, the LLZDevR would be 136μA. This effect has a potential to generate error in width measurement over 10%. Graphical presentation of this algorithm is shown at Picture 5 .



Picture 5 Receiver readings of -15.5%, 0% and +15.5% DDM versus Sum of

Modulations

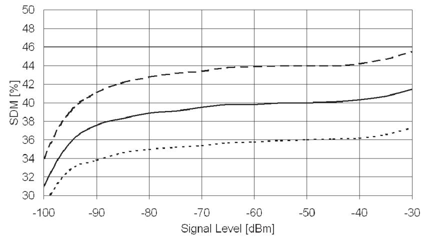
When such algorithm is built into flight inspection receiver, a measurement of truth-full localiser deviation values call for compensation of this effect. Such compensation can be done using the SDM reading of the receiver. Than corrected value is

$$LLZDevC = LLZDevR * \frac{SDM}{40}$$

Where

- LLZDevC means corrected value of the Localiser Deviation reading and
- SDM means the Sum of Modulations in percent

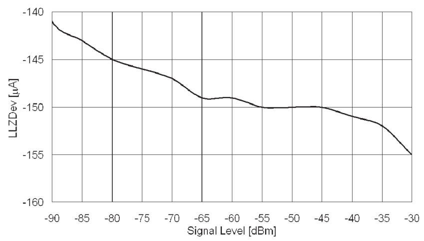
This corrected deviation value is independent on the SDM of the Localiser. Unfortunately, proper compensation of receiver's algorithm is complicated with the quality of the SDM output. The SDM reading is more distorted comparing to the DDM and - what is more important - there is observed significant SDM dependency on the input signal level. This is illustrated at Picture 6 .



Picture 6 Sum of Modulations reading versus input signal level

As a consequence of this receiver feature, actual signal level at the input of the navigation receiver affects corrected value of localiser deviation, as it is shown at Picture 7 .

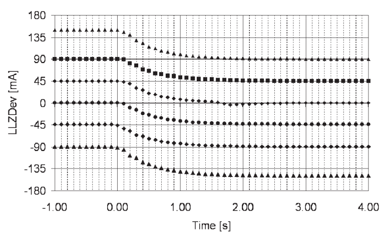
SDM value as a required parameter is measured in a centreline flight; SDM output is calibrated to signal level corresponding to position somewhere between ILS point A and the runway threshold. Crossover or partial orbit is usually flown at distances between 6NM to 25NM from the localiser. At these positions, SDM reading is already out of its calibration range and negatively affects calculation of corrected DDM values. Consequently, the localiser course sector appears wider when measured at longer distance from the facility.



Picture 7 Localiser Deviation after correction using of SDM reading for -15.5%DDM

Besides demonstrated static features of navigation receivers, the course width measurement might be affected with the receiver's dynamic.

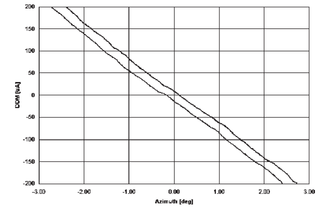
It is known, that any navigation receiver has certain delay, i.e., time between change of the input signal and adequate response at the receiver output. Receiver response to step changes of the DDM at the receiver input is shown at Picture 8. It is visible, that shapes of responses are almost independent on initial and final DDM values.



Picture 8 Receiver reaction on step changes of the DDM

Because the cross flight is performed at relatively stabilised speed, the DDM change can be described as "nearly linear". Thus, it is not so important to know absolute value of the receiver delay, but such delay has to be stable passing the localiser course sector. Mathematically expressed, the first derivation of LLZDev by time should be constant.

Due to the receiver's delay, the actual localiser deviation reading appears as "hung" behind the tail of the aircraft. It is obvious from the comparison of clockwise and counter clockwise direction of flight. Passing the centreline, the LLZDevR value has still a sign of preceding segment.



Picture 9 The difference between clockwise and counter clockwise flight - effect of receiver's delay

It is important, that slopes of characteristics of the clockwise and counter clockwise flights are parallel.

CORRECTION COEFFICIENT COMPUTATION

Because the cross flight technique is generally considered as a more cost effective, the question is, weather it is a sufficient alternative to approach flights. As it was shown above, differences between methods of measurement really exist and they have their technical explanation.

Considering the course width value obtained from offset approach flights as a reference one, the task was concentrated to find a relationship between this reference width and the course width obtained from the crossover flight.

Detailed view at crossover record shows presence of short–term divergences of the LLZDev (or LLZDevR) from general trend of the deviation change - the structure. These may have an adverse influence on identification of exact points of passing predefined values of LLZDev or LLZDevR (-150µA, -75µA, 0µA, 75µA and 150µA).

To eliminate the structure effect, it is recommended to collect as much as possible cross flight data. Than a regression line can be computed from relevant part of the record, for example between -150µA and +150µA. A slope of the trend line has its physical interpretation - as microamperes per degree and the course width than can be easy computed.

As was mentioned above, LLZDevR reading has to be corrected using the SDM to compensate receiver's algorithm, but SDM reading from the cross flight cannot be considered as valid data because of lower signal level.

Therefore, known SDM value measured during an alignment/course structure flight can be used instead of improper SDM readings at the cross flight. In reality, SDM measured during offset approaches are usually slightly lower than SDM at the centreline. Thus, total conformity is not expected (at least for this reason) and relationship between these two values can be described using correction coefficient.

A procedure of correction coefficient computation can be described as follow.

Commissioning/Annual Flight Inspection:

a) run one centreline approach and calculate SDM average between ILS points A-B
b) run two offset (±75µA or ±150µA) approaches
c) calculate reference course width (REFCW)
d) run one partial orbit or crossover and record LLZDevR and A/C position
e) create a graph LLZDevR versus Azimuth
f) calculate Slope of the regression line between points -150µA and +150µA
g) calculate crossover course width

$$COCW = \frac{300}{SLOPE_{CROSSOVER}} * \frac{40}{SDM_{APPROACH}}$$

Where
COCW means Course width resulted from crossover flight in degrees,
SLOPE means the slope of the regression line in µA per degree and
SDM means average SDM from the approach flight in percent

h) Calculate Correction Coefficient

$$CC = \frac{REFCW}{COCW}$$

Periodic/Routine Inspection:

a) run one centreline approach and calculate SDM average between ILS points A-B
b) run one partial orbit or crossover and record LLZDevR and A/C position
c) create a graph LLZDevR versus Azimuth
d) calculate Slope of the regression line between points -150µA and +150µA
e) calculate Crossover course width
f) calculate course width as

$$CW = CC * COCW$$

VALIDITY AND RELIABILITY OF RESULTS

To verify described method, flight inspection records taken in 3 years from 2 localisers were analysed. As crossover data were used data from clearance (6NM -10NM) or coverage (10NM, 17NM or 18NM) partial orbits.

Course width values were obtained using 3 different methods:
1. As an angle between passing -150µA and +150µA
2. From a slope of regression line of LLZDev versus Azimuth
3. As described above

For each of these methods were computed appropriate correction coefficients and results were statistically analysed.

	Localiser 1		Localiser 2	
	Corr. Coeff.	2σ (95%)	Corr. Coeff.	2σ (95%)
Method 1	1.031	**0.058**	1.001	**0.060**
Method 2	1.032	0.050	0.987	0.042
Method 3	1.001	**0.020**	1.012	**0.029**

Table 2 Correction coefficient and its confidence interval

As it is demonstrated in Table 2 , the method described in this article significantly improve the uncertainty of the crossover course width measurements.

It is evident, that the Correction Coefficient has to be computed from series of comparisons of crossover width results against approach width results. It is feasible, when historical data in suitable electronic form are available. However, for newly installed facilities appears to be necessary to continue with approach method for a period of time due to building up sufficient database of comparable data.

CONCLUSION

The localiser course width is not clearly defined in applicable standards. In addition, there exist more measurement techniques providing different results. For this reason, required [2] course width measurement uncertainty 3% or 2% is applicable only to one measurement method and not as an absolute figure.

As a consequence, step change of measured course width can be observed, after a Localiser is flight-checked by another flight inspection organisation or after flight inspection system upgrade. Maintenance personnel should have sufficient knowledge about flight inspection techniques to avoid possible misinterpretation of dissimilar results.

Proposed method of course width measurement eliminates problematic reliability of localiser deviation reading of some navigation receivers during cross flight. An advantage is, that a cross flight can be performed at any distance from localiser without relevant impact on results.

REFERENCES

[1] ICAO ANNEX 10 - Aeronautical Telecommunications, Volume I - Radio Navigation Aids, Fifth edition, 1996

[2] ICAO Doc 8071 - Manual on testing of Radio Navigation Aids, Volume I – Testing of Ground Based Radio Navigation Systems, Fourth edition, 2000

[3] ICAO Doc 8071 - Manual on testing of Radio Navigation Aids, Volume II - ILS, Third edition, 1972

[4] FAA Order 8200.1C – United Stated Standard Flight Inspection Manual, 2005

[5] Dennis BEAUDOIN - Localiser False Capture- The Root Cause and Implications on Flight Inspection, 8th IFIS, Denver, Colorado, USA, 1994