Study on Glide Slope's Clearance Flight Check Criteria

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BIOGRAPHY (IES)

Shuming Liu is a flight Inspector of Flight Inspection Center of CAAC (CFIC). He joined CFIC and became a flight inspector in the year 2011 after he graduated from Beihang University where he got a master of Electronic and Communication Engineering.

Tong Liu is a flight Inspector of Flight Inspection Center of CAAC (CFIC) and he is also the director of the Inspection Department of CFIC.

Huawei Ma is one of China's first female flight inspectors, calibration engineer. She graduated from Beihang University in 2006 and began to work on flight inspection. Her main research directions are flight inspection of traditional navigation facility, ADS-B and GBAS flight inspection.

ABSTRACT

Flight check of Glide Slope (GP) clearance is a very important profile of ILS flight inspection. Compared with the GP angle/TCH or structure, sometimes the clearance check maybe not so noticeable, but at least 3 GPs did not pass the commissioning/periodic check in China during the past 2 years and it has aroused widespread concern in CAAC.

This paper introduces how Flight Inspection Center of CAAC (CFIC) conducts GP clearance check. As for the definition "*The DDM below the ILS glide path shall* ***increase smoothly*** *for decreasing angle until a value of 0.22 DDM is reached*" in ICAO Annex 10, the writers try to offer a suggestion on the tolerance for the roughness/scalloping of the clearance DDM curve considering the navigation receiver's accuracy and linearity. Besides, the writers introduce some methods to improve the performance of GP clearance.

INTRODUCTION

According to the definition in Annex 10, Volume 1 "*Radio Navigation Aids* and Doc 8071, a satisfactory GP clearance should meet the following 4 requirements:

1. *The DDM below the ILS glide path shall increase* **smoothly** *for decreasing angle until a value of -190μA (0.22 DDM) is reached.*
2. *-190μA shall be achieved at an angle not less than 0.3θ above the horizontal.*
3. *If -190μA is achieved at an angle above 0.45θ, the DDM value shall not be less than -190μA at least down to 0.45θ or to such lower angle, down to 0.3θ as required to safeguard the promulgated glide path intercept procedure.*
4. *Above Path—must attain at least 150μA and not fall below 150μA until 1.75θ is reached.*

An ideal GP clearance curve as required in Annex 10 is very smooth, but during a real check, many GP clearance curves may have roughness/scalloping. Whether a few microamperes' roughness/scalloping on the clearance curve is acceptable? Since 2016, the writers have been studying on this topic and it can be clear that:

1. At present, the requirement of GP clearance in ICAO annex 10 is very stringent, the DDM below the ILS glide path shall increase **smoothly** for decreasing angle until a value of -190*μA* (0.22 DDM) is reached.
2. A few microamperes' roughness/scalloping is acceptable. However, if we don't pay any attention to the roughness/scalloping of the curve, only check if there is a false glide path, and the writers think it may be too loose.

To study on the tolerance of the roughness/scalloping, the authors thinks that it is necessary to start from the actual application perspective, including the deviation linearity and the center accuracy of the navigation receiver.

THE FLIGHT METHOD AND CHECK CONCLUSION OF GP CLEARANCE CHECK

Flight Method

During a GP clearance check, the flight inspection aircraft flies towards the facility at a constant height (typically 450*m*), following the localizer center line, commencing at a distance corresponding to 0.45θ and should continue until a point equivalent to twice the glide path angle has been passed, as shown in Figure 1. If terrain prevents a safe flight, then a different height is used, but the height should not be higher than the intercept height.

If the ILS approach procedure uses the GP signal between 0.3θ and 0.45θ, then the check must commence from 0.3θ.

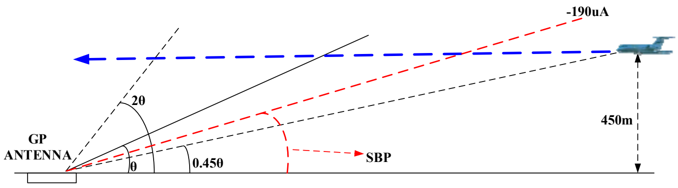

Figure 1 Flight Method of the Flight Check of GP Clearance

The Check Conclusion

If the GP clearance check cannot start from 0.45θ due to terrain, then signal below GP path angle should be restricted, and the restriction conclusion should meet the following requirements:

1. The deviation of the restricted angle must be more than -190μA.
2. Taking account of the 150m minimum obstacle clearance (MOC) of the intermediate segment, if there is no step descend procedure between IF and FAF, the restricted angle should not be higher than the angle of the point which is 150m below IF, as shown in Figure 2.
3. If there is step descend procedure between IF and FAF, the restricted angle should not be higher than the angle of the point which is 150m below the start point of the level-flight segment before intercepting the GP, as shown in Figure 3.
4. If such restrictions are applied for the first time, it shall be approved by the administrative agency.

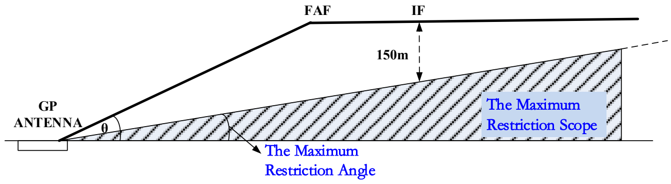

Figure 2 The Restriction Scope of The GP Angle

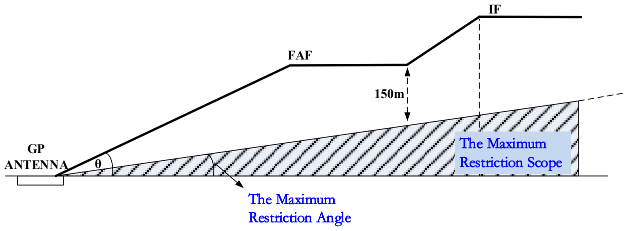

Figure 3 The Restriction Scope of The GP Angle
when there is step descend procedure between IF and FAF

Analysis on the GP Clearance Check

1. The check must start from where the GP deviation is more than -190μA. All the international criteria take the -190μA deviation very seriously. The -190μA deviation is not only treated as an effective "fly-up" indication, but also as an important factor to evaluate the GP clearance. Even if there is restriction due to terrain, the GP clearance check must start from where the GP deviation is more than -190μA.
2. -190μA should not appear more than once, otherwise the GP would be treated as unacceptable. This is derived from the definition in Annex 10 "*If -190µA is achieved at an angle above 0.45θ, the DDM value shall not less be than -190µA at least down to 0.45θ*".
3. The flight height of GP clearance shall not be higher than the intercept height. As for the ILS approach procedure, the GP signal is only used by the intermediate and the final segment, if the GP clearance is checked higher than the intercept height, we cannot acquire the GP signal's quality of the level-run segment before the intercept point. For some GPs which are installed in mountainous areas, if -190μA cannot be acquired at the intercept height, the aircraft can descend until -190μA is acquired, and then pull up to the intercept height.

Unacceptable GP Clearance

As shown in Figure 4, the GP DDM does not increase **smoothly** from -190μA to 0μA, there is obvious roughness/scalloping and the GP clearance result is unacceptable according to the flight inspection principles followed by CFIC.

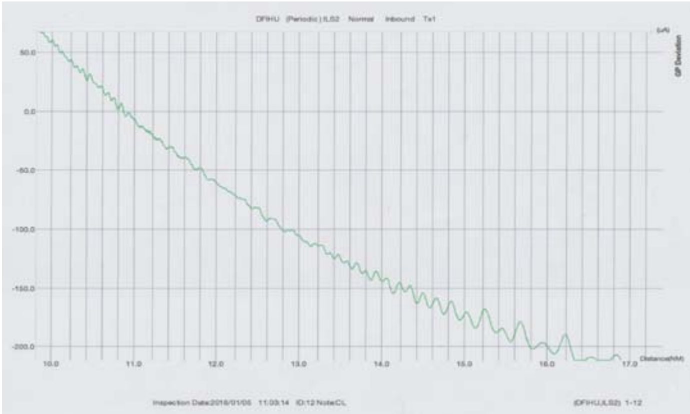

Figure 4 An unacceptable GP clearance curve

DISCUSSION ON THE GP CLEARANCE CRITERION

The Purpose the GP Clearance Check

The GP clearance check focuses on the GP deviation, which is the extent of the GP pointer deviates from the GP path on the HSI indicator. The purposes of the GP clearance check are as following:

1. To make sure there is no false glide path between $0.3\theta \sim 1.75\theta$.
2. To make sure the GP deviation increase smoothly between $0.3\theta \sim 1.75\theta$, so as to provide the pilots with correct indications.
3. To make sure that the airborne autopilots can arm and intercept the GP path accurately and effectively.

Acceptable GP Clearance Curve

The aircraft's real-time elevation angle relative to the GP antenna can be calculated according to the flight method in shown in Figure 1.

$$\theta = arc\tan(\frac{H}{L+300}) \times \frac{180}{\pi}$$

H is the flight height, L is the distance from the threshold.

For a GP with 3° path angle, 0.72° width, the relationship between the deviation I_{dev} and the elevation angle θ:

$$I_{dev} = (\theta - 3) \times 75 / 0.36 = \left[arc\tan(\frac{H}{L+300}) \times \frac{180}{\pi} - 3 \right] \times 75 / 0.36$$

Suppose the flight height H is $450m$ high, we can draw a curve of the relationship between I_{dev} and L using Mathematic, as shown in Figure 5.

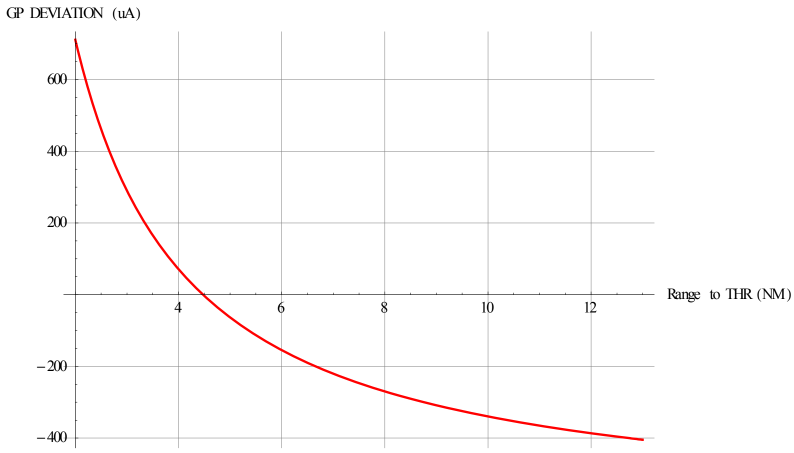

Figure 5 A GP clearance curve derived from theoretical calculation

Figure 6 shows a representative acceptable GP clearance curve from a real check.

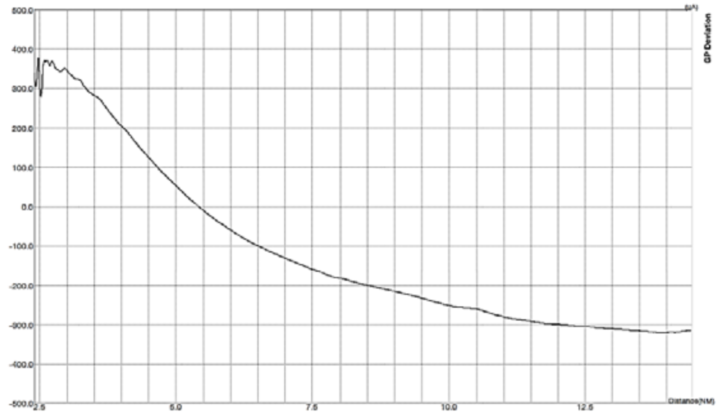

Figure 6 A Representative Acceptable Curve

Figure 7 shows a GP who has an obvious false glide path at 6*NM* from the threshold. During the approach, if the aircraft intercepts and captures the false path, especially under the low visibility weather, it would be very dangerous.

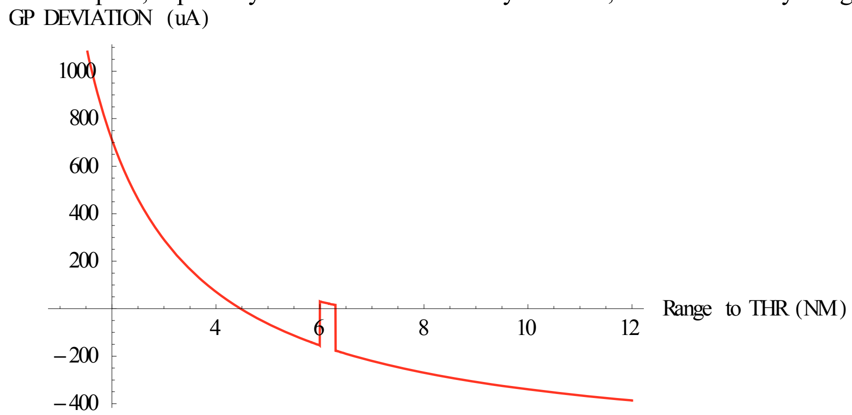

Figure 7 An Obvious False Glide Path

Discussion on the Tolerance of the Roughness/scalloping of the GP Clearance Curve

The writers had considered many factors, and finally we chose the deviation linearity and the center accuracy of the navigation receiver to set the tolerance of GP clearance check.

<u>The Deviation Linearity of the Navigation Receiver</u>

In Doc RTCA-DO-192 (Minimum Operational Performance Standards for Airborne ILS Glide Slope Receiving Equipment Operating within the Radio Frequency Range of 328.6-335.4 MHz 2.2.4.1 a), there is a definition as following:

"*Over the course deviation range from zero to ±0.175 ddm, the deviation current shall be within 10% of being proportional to the difference in depth of modulation of the 90 and 150 Hz signals, or the deviation current shall be within 5% of standard deviation current of being proportional to the difference in depth of modulation, whichever is greater. Additionally, as the difference in depth of modulation is increased from 0.175 to 0.8 ddm, the deviation current shall not decrease. These standards shall be met over the range of signal input from -76 dBm to -33 dBm.*"

<u>The Center Accuracy of the Navigation Receiver</u>

The center accuracy of a navigation receiver CFIC using now is ±0.002DDM (corresponding to±1.71μA) as specified in its handbook. It can be interpreted as the minimum scale value the receiver can distinguish is 1.71μA, therefore, for this navigation receiver, the 1.71μA roughness/scalloping on the clearance curve is acceptable. And The Deviation Accuracy of a certain type of civil navigation receiver is 0.01183 DDM, corresponding to 10.14μA.

If we choose 10% deviation from linearity to determine the tolerance of the GP clearance curve, we have to draw a curve as shown in Figure 5 through theoretical calculation for each GP, and then compare the results with the check results, which is very difficult to implement. Therefore, it is appropriate to use the 5% deviation current error as the calculation factor, which means that the receiver allows a maximum 5% deviation error between the standard input and the output DDM.

The deviation linearity and center accuracy of the navigation receiver are selected as two factors to determine the tolerance of the GP clearance, each accounted for 50% of the calculation weight. It can be obtained that a preliminary tolerance:

$$\Delta = \pm(0.05X \times 50\% + 1.71\mu A \times 50\%) = \pm(0.025X + 0.85\mu A)$$

X is the value of GP deviation where the roughness/scalloping happened. The tolerance is **NOT** a fixed value and it becomes stricter as the deviation be closer to 0μA. In this way, a maximum 4.6µA's roughness/scalloping is acceptable near 150μA on the GP clearance curve.

The Uncertainty of the GP Clearance Check

For a calibration test parameter, the uncertainty is usually considered in addition to the tolerance. The writers calculate the uncertainty from two aspects including the turbulence of inspection flight and equipment calibration.

The Effect of Instantaneous Turbulence on the GP Clearance Curve

When the inspection aircraft conducts a level-run flight to check the GP clearance, the flight altitude would be decreased or increased due to an instantaneous turbulence, thus, the elevation angle of the antenna is reduced or increased accordingly, and it could also cause a roughness /scalloping in the GP DDM curve.

Suppose the GP path angle is 3°, the inspection aircraft checks the GP clearance at 450m height with a ground speed of 180NM/hour, and at the point of -150μA deviation, the aircraft descends 2m in 0.2 second.

In theory, the elevation angle between -150μA and GP antenna is: $3^o - \frac{150}{75} \times 0.36^o = 2.28^o$

The distance between -150μA and GP antenna is: $\frac{450m}{tan(3-0.72)^o} = 11302.41m$

After the turbulence, the aircraft flies over $180 \times 1.852 \times 1000 \div 3600 \times 0.2 = 18.52m$.

And the height of the aircraft is $450-2=448m$, the elevation angle between -150μA and GP antenna is:

$$arctan\frac{450-2}{11302.41-18.52} = 2.2736^o$$

And now the deviation of GP is -151.33μA, which means that the turbulence brings a -1.33µA's roughness/scalloping to the curve.

In the same way, a same turbulence happens at -75μA would cause a -1.40μA's roughness/scalloping, and -1.4μA at +75μA, -1.33μA at +150μA.

The Uncertainty Brought by the Calibration Instrument

The uncertainty brought by navigation receiver calibration:

$$u_{B1} = \frac{\text{Calibration Equipment's } U}{\sqrt{3}} = \frac{0.0034}{1.732} = 0.00196 \text{ ddm}$$

Converted to microampere is $0.00196 \times 75 \div 0.0875 = 1.68\mu A$

At present, the GP DDM is calibrated at discrete points, continuous compensation is made according to the linearity of DDM, and therefore the calibration uncertainty of the 1.68μA can also be regarded as one of the elements to calculate the value of roughness/scalloping.

Synthetical calculation

It can be taken into consideration of several factors that influence the GP clearance curve's smoothness. The uncertainty at -75μA is $\sqrt{1.40^2+1.68^2} = 2.21\mu A$ and the uncertainty at -150μA is $\sqrt{1.33^2+1.68^2} = 2.14\mu A$.

According to the above analysis, we suggest that the tolerance of the roughness/scalloping is set according to the DDM where the roughness/scalloping happens. However, the curve shown in Figure 4 has several roughness/scalloping and it is not the optimal working condition of the equipment, so it should be optimized and adjusted.

SPECIFIC CASE

Case 1

The GP DDM curve shown in Figure 8 was given an unqualified conclusion by inspector recently in a commissioning airport, there are 4 reasons:

1. There is roughness/scalloping between -190μA and -50μA, the maximum value is almost 20μA, far from the definition in Annex 10.
2. -190μA appeared more than once.
3. The airport's altitude is more than 3,800m. The weather is complex and changeable, so the GP should operate at a high level to support the flight procedures, so as to ensure the security of the airport operation in the future.
4. It is a commissioning flight inspection for the GP, and the specification shall be strictly implemented.

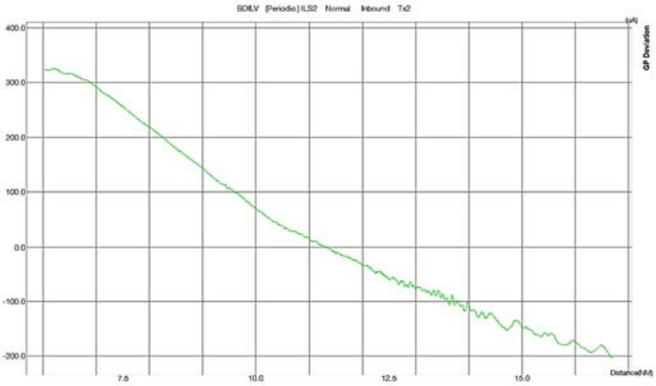

Figure 8 A Commissioning GP Clearance Curve

Case 2 The Adjustment Methods to Improve GP Clearance Performance

There are several reasons for the unsatisfactory GP clearance curve:

1. Terrain: although the GP protected areas meet the specification requirements inside the airport, the rugged terrain along the localizer center line below the flight check path reflects the glide signal. The direct wave and the obstacle reflected wave are synthesized in the air, causing roughness/scalloping in the GP DDM curve.

2. Equipment: If there is a problem with the equipment itself, there may also be roughness/scalloping in the GP DDM curve.

The roughness/scalloping caused by the equipment is relatively rare, and it is easier to find out the reason through ground equipment test. However, the roughness/scalloping caused by terrain is more common and it is not so easy to identify the cause of the problem. The cost of site formation is usually huge.

The maintenance engineers and navigation experts usually adopt the following methods to improve the GP clearance:

1. Lower the DDM of the clearance transmitter, so as to lower the roughness/scalloping happens at low angle near -190μA, after that the DDM increases smoothly from 0μA to -190μA, but the path angle remains unchanged. This method can be adopted when there is roughness/scalloping near -190μA but the curve is smooth above the angle where -190μA appears. As shown in Figure 9 and Figure 10, after the GP DDM is lowered, -190μA appeared only once and from -190μA to 0μA, the DDM curve is smooth.

2. Reducing the power of the clearance transmitter to reduce the reflection of terrain, and this can also improve the GP clearance.

3. Raising the path angle to reduce the reflection of terrain.

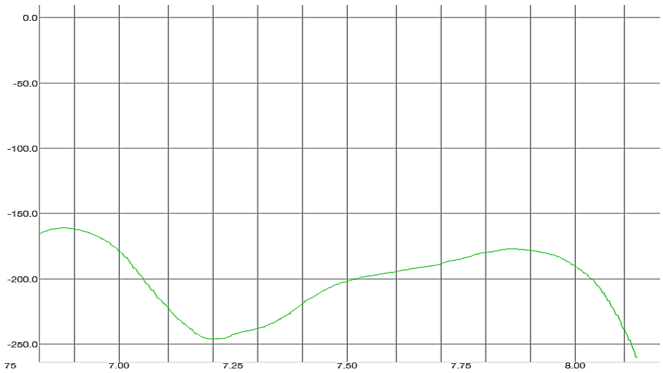

Figure 9 GP Clearance Curve before the DDM is lowered

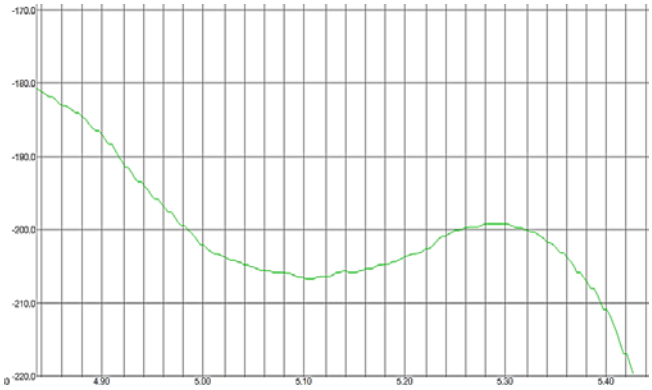

Figure 10 GP Clearance Curve after the DDM is lowered

Other Clearance Need to Be Noticed

For some GP, even if the GP clearance curve meets the specification requirements, the equipment may also have other problems. As shown in Figure 11, the inspector found that the clearance curve is smooth in terms of the results, but the DDM of low angle is too close to -190μA, which is only -240μA, and it is different from common facilities. Then experts checked the ground site, it was found that the antenna base loosened due to perennial rain and the antenna tower leaned forward.

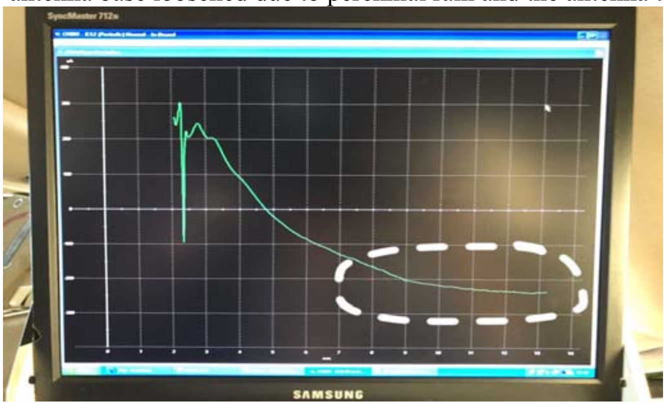

Figure 11 A GP Clearance Curve whose DDM is only -240μA at low angle

CONCLUSION

Every parameter is important during a GP flight inspection, the parameters such as glide path angle and TCH are quantified, but the clearance is also very important. The writers proposed a suggestion to the tolerance of the roughness/scalloping in the GP clearance curve, and they also suggest that ICAO make the GP clearance criterion to be quantified.

FURTHER WORK

The writers also believe it is essential to know how the autopilot arms and intercepts the GP path, how many microamperes' roughness/scalloping will affect the autopilot. But the writers did not get the answer from Doc RTCA-DO325 (Minimum Operation Performance Standards (MOPS for Automatic Flight Guidance and Control Systems and Equipment). So this paper does not take the autopilot into account and treats it as a future research work.

ACKNOWLEDGMENTS

I would like to thank my colleagues who participated in the study with me and I also want to thank all the international flight inspection experts and navigation specialists who answered my emails and gave me advice on this topic.

REFERENCE

[1] Flight Inspection Rule MH 2003-2000 of CAAC（MH2003-2000）
[2] ICAO Doc 8071（Fourth Edition-2000）
[3] ICAO Annex 10（Sixth Edition-1996）
[4] ICAO Doc 8168 OPS/611（Fifth Edition-2006）
[5] RTCA-DO-192-1986
[6] RTCA-DO-325-2010