The Comparison Of In-Flight Pitot Static Calibration Method By Using Radio Altimeter As Reference with GPS and Tower Fly By Methods On CN235-100 MPA

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Abstract. The new proposed In-Flight Pitot Static Calibration Method has been carried out during Development and Qualification of CN235-100 MPA (Military Patrol Aircraft). This method is expected to reduce flight hours, less human resources required, no additional special equipment, simple analysis calculation and finally by using this method it is expected to automatically minimized operational cost. At The Indonesian Aerospace (IAe) Flight Test Center Division, the development and updating of new flight test technique and data analysis method as specially for flight physics test subject are still continued to be developed as long as it safety for flight and give additional value for the industrial side. More than 30 years, Flight Test Data Engineers at The Flight Test center Division work together with the Air Crew (Test Pilots, Co-Pilots, and Flight Test Engineers) to execute the flight test activity with standard procedure for both the existance or development test techniques and test data analysis. In this paper the approximation of mathematical model, data reduction and flight test technique of The In-Flight Pitot Static Calibration by using Radio Altimeter as reference will be described and the test results had been compared with another methods ie. By using Global Position System (GPS) and the traditional method (Tower Fly By Method) which were used previously during this Flight Test Program (Ref. [10]). The flight test data case are using CN235-100 MPA flight test data during development and Qualification Flight Test Program at Cazaux Airport, France, in June-November 2009 (Ref. [2]).

1. Introduction

This paper is proposed to introduce a new in-flight pitot static calibration method by using Radio Altimeter as a reference. Many pitot static in-flight calibration methods are available to determine position error correction, such as GPS (Global Position System) Method, Tower Fly By Method, Pacer Aircraft Method, Trailing Cone Method, Trailing Boom Method etc (Ref. [5]). This new method is still under development and in case it is applicable, it is going to be applied in Indonesian Aerospace for the
development and certification flight of the new N219 aircraft, the CN235-220 Modified Version aircraft, the NC212i aircraft etc.

When we measure some physical quantity with an instrument and obtain a numerical value, usually we are concerned with how close this value may be to the “true” value (Ref. [1]). Therefore precise flight test data in altitude and airspeed position error calibration is needed in determining aircraft flight performance and flight dynamics especially in type certification process. The altitude and airspeed indicator are actuated by pressure and sensed by pitot static systems (Ref. [4]). The position of installed pitot static tube to free airstream resulted an error that effects the value indicated by altitude and airspeed instrument. These error are called position error. Therefore beside corrected from instrument error, the indicated altitude and airspeed should be corrected from position error (Ref. [3]). Therefore by using this new method, it is expected to get the position error accurately.

The In-flight Pitot Static Calibration Using Radio Altimeter as Reference test technique is performed by flying the aircraft at height of out of ground effect (recommended at about 100 - 150 feet above ground level for CN235 airplane) with the acceleration speed at specified test configuration and condition. Then repeat for other flaps and landing gear configurations setting. By recording height of Radio Altimeter during acceleration flight together with indicated altitude, indicated airspeed and outside air temperature via OBDAS (On Bord Data Aquition System), the position error correction of altitude and airspeed can be calculated.

As previously mentioned, this method is still under development, the test data are using CN235-100 MPA flight test data during Tower Fly By Method with several constant speeds for each flaps configuration.

2. Aircraft Description

![Figure 1. CN235-100 MPA Military Version](image_url)

The test aircraft was using CN-235-100M MPA version as depicted in Figure 1. The aircraft external shape has been changed due to installation of several additional equipment, which did not exist on the original CN-235-100M, in order to meet a certain mission requirements. Modifications of CN-235-100M MPA from CN-235-100M (Ref. [2]) are:

- OM Radar Radome (belly),
- FLIR/TV (belly),
- Bubble Windows (rear fuselage),
- Different Nav/Com Antennas,
- ADFU Antennas (front upper fuselage and rear fuselage),
- UV Sensors (front upper and lower fuselage, landing gear fairing and tail cone),
- MAD Boom (tail cone),
- Chaff & Flare dispensers (front and rear fuselage)

The pitot static system location are shown in Figure 2 and Figure 3 for Pilot and Co-Pilot side systems respectively. Figure 4 shows the installation location of radio altimeter antenna on the test aircraft CN235-100 MPA.
Figure 2. Pilot Pitot Static Probe location (Ref. [2])

Figure 3. Co-Pilot and Standby Pitot Static Probe location (Ref. [2])

Figure 4. Radio Altimeter location (Ref. [11])
3. Mathematical Model Approximation

3.1 General Calibration Equation

By using radio altimeter calibration method, when the aircraft is passing the runway as shown in figure 5, it can be shown that:

\[ H_{ref} = H_{radio} + dH_{pitchrad} + dH_{CR} + Hairport \]  

Where:
- \( H_{ref} \): Reference Height
- \( H_{radio} \): Radio Altimeter height
- \( dH_{pitchrad} \): The different height of pitot static to the Radio Altimeter corrected by pitch and bank angle
- \( dH_{CR} \): Vertical height due to Runway contour
- \( Hairport \): Elevation of Airport Runway

The correction are then divided into:
- Pilot system position error correction and
- Co-Pilot system position error correction

These correction are described below on the next paragraph

4. Pilot System Position Error Correction

![Figure 5. Aircraft illustration flies passed on the runway](image)

![Figure 6. Pilot Pitot System Position Error Correction due to bank angle correction](image)
\[ H\Phi L = dh \cos\Phi + dw \sin\Phi \]

(2)

**Figure 7.** Pilot System Position Error Correction due to bank and pitch angle correction

From the above figure 7 it can be seen that

\[ \Delta H\Phi L = \Delta H\Phi L \cos\theta + dl \sin\theta \]

and by using equation (2)

\[ = (dh \cos\Phi + dw \sin\Phi)\cos \theta + dl \sin\theta \]

\[ = dh \cos\Phi \cos\theta + dw \sin\Phi \cos\theta + dl \sin\theta \]

(3)

5. Co-Pilot System Position Error Correction

**Figure 8.** Co Pilot System Position Error Correction due to bank angle correction

From the above figure 8 it can be seen that

\[ \Delta H\Phi R = dh \cos\Phi - dw \sin\Phi \]

(4)
Figure 9. Co Pilot System Position Error Correction due to bank and pitch angle correction

From the above figure 9 it can be seen that

\[ \Delta H \theta \Phi R = \Delta H \Phi R \cos \theta + dl \sin \theta \]
\[ = (dh \cos \Phi - dw \sin \Phi) \cos \theta + dl \sin \theta \]
and by using equation (4)
\[ = dh \cos \Phi \cos \theta - dw \sin \Phi \cos \theta + dl \sin \theta \]

(5)

Finally for pilot and co-pilot system it can be determined that

\[ H_{\text{pref}} = H_{\text{radio}} + dH_{\text{pitchrad}} + dH_{CR} + H_{\text{airport}} \]
\[ = H_{\text{radio}} + dh \cos \Phi \cos \theta - dw \sin \Phi \cos \theta + dl \sin \theta + dH_{CR} + H_{\text{airport}} \text{ (pilot system)} \]  
\[ (6) \]

And

\[ H_{\text{pref}} = H_{\text{radio}} + dH_{\text{pitchrad}} + dH_{CR} + H_{\text{airport}} \]
\[ = H_{\text{radio}} + dh \cos \Phi \cos \theta - dw \sin \Phi \cos \theta + dl \sin \theta + dH_{CR} + H_{\text{airport}} \text{ (co-pilot system)} \]  
\[ (7) \]

6. Calculation of dHpc and dVpc

Altitude position error correction is now:

\[ dHpc = H_{\text{pref}} - H_{\text{A/C}} \]  
\[ (8) \]

The pressure change surrounding basic pitot static probe is:

\[ dP = -\rho_A \cdot g \cdot dHpc \]  
\[ (9) \]

Where \( \rho_A \)-density at test altitude
\( g \)-constant of gravity = 9.80665 m/s\(^2\)
Calibrated airspeed now can be calculated by:

\[
V_c = \sqrt{\frac{-2dP}{\rho_0} + V_{ka/c}^2}
\]  

(10)

With \( \rho_0 \) - standard sea level density = 1.225 kg/m\(^3\)

Position error correction for airspeed is:

\[
dV_{pc} = V_c - V_{ka/c}
\]  

(11)

For standardization and correction, which is dedicated for supporting Aircraft Flight Manual (AFM) chart, the formulation is start by calculation lift coefficient at test actual weight. Then plotting pressure coefficient is function of lift coefficient by using a polynomial regression of second order. By using this equation, the altitude and airspeed position error correction can be determined for the other weight and altitude (Ref. [5]).

7. Method Verification

CN235-100 MPA had finished the qualification test program (Ref. [2]). The method used during in-flight pitot static calibration test were Tower Fly By Method and GPS Method (Ref.[8], [9]). These flight test data from Tower Fly By Method are used to verify this method. In the following table there are flight test data which is used for verification this method.

**Table 1. Flight Test Data F00, LGUP, 100%RPM, PLF (Ref. [2])**

| Hi  | Vi   | Hrad | OAT  | THETA | PHI  |
|-----|------|------|------|-------|------|
| [feet]| [knots]| [feet] | [deg.C]| [deg.] | [deg.] |
| 279.59 | 197.41 | 148.25 | 22.16 | 1.53 | -0.5 |
| 255.15 | 171.94 | 137.1 | 21.64 | 2.99 | 6.17 |
| 246.99 | 148.51 | 115.03 | 20.27 | 4.53 | -0.9 |
| 263.29 | 128.32 | 143.7 | 19.75 | -6.06 | 1.75 |
| 255.14 | 118.15 | 139.15 | 19.49 | -6.95 | 2.04 |

**Table 2. Flight Test Data F10, LGUP, 100%RPM, PLF (Ref. [2])**

| Hi  | Vi   | Hrad | OAT  | THETA | PHI  |
|-----|------|------|------|-------|------|
| [feet]| [knots]| [feet] | [deg.C]| [deg.] | [deg.] |
| 255.14 | 160 | 148.03 | 20.44 | 0.3 | -1.36 |
| 255.14 | 131.21 | 137.56 | 19.49 | 3.65 | -0.63 |
| 246.99 | 120.18 | 144.6 | 19.84 | 3.39 | 1.63 |
| 246.99 | 103.64 | 132.78 | 19.32 | 8.78 | 0.23 |
Table 3. Flight Test Data F15, LGUP, 100%RPM, PLF (Ref. [2])

| Hi [feet] | Vi [knots] | Hrad [feet] | OAT [deg.C] | THETA [deg.] | PHI [deg.] |
|-----------|------------|-------------|-------------|--------------|------------|
| 444.31    | 158.51     | 340.54      | 21.13       | -3.49        | 4.32       |
| 246.99    | 141.43     | 138.01      | 20.27       | 0.74         | 0.92       |
| 255.14    | 121.06     | 147.34      | 19.75       | 2.53         | 0.74       |
| 246.99    | 106.77     | 141.2       | 19.67       | 4.84         | 5.26       |

Table 4. Flight Test Data F23, LGUP, 100%RPM, PLF (Ref. [2])

| Hi [feet] | Vi [knots] | Hrad [feet] | OAT [deg.C] | THETA [deg.] | PHI [deg.] |
|-----------|------------|-------------|-------------|--------------|------------|
| 322.53    | 153.81     | 229.04      | 20.61       | -3.7         | 6.43       |
| 287.74    | 132.7      | 191.72      | 20.18       | -1.79        | -0.59      |
| 238.84    | 117.86     | 131.19      | 19.41       | -1.15        | 1.15       |
| 230.69    | 98.07      | 123.45      | 19.24       | 4.65         | 2.41       |

By using all equations in mathematical model approximation, and with $dl$ (distance between Pitot Static and Radio Altimeter, longitudinal direction) 6.693 feet, $dh$ (distance between Pitot Static and Radio Altimeter, vertical direction) 3.642 feet, and $dw$ (distance between Pitot Static and Radio Altimeter, lateral direction) 3.297 feet, the altitude and airspeed position error correction for flaps 0, 10, 15, and 23 can be determined then it can be shown as the following figures respectively.

**Figure 10.** Altitude Position Error Correction F00, LGUP, 100%RPM, PLF
Figure 11. Airspeed Position Error Correction F00, LGUP, 100%RPM, PLF

Figure 12. Altitude Position Error Correction F10, LGUP, 100%RPM, PLF

Figure 13. Airspeed Position Error Correction F10, LGUP, 100%RPM, PLF
Figure 14. Altitude Position Error Correction F15, LGUP, 100%RPM, PLF

Figure 15. Airspeed Position Error Correction F15, LGUP, 100%RPM, PLF

Figure 16. Altitude Position Error Correction F23, LGDW, 100%RPM, PLF
Figure 17. Airspeed Position Error Correction F23, LGDW, 100%RPM, PLF

From all that figures above, it can be seen that all altitude and airspeed position error correction by using Radio Altimeter for flaps 0, 10, 15 and 23 are well within the boundaries as stated by FAR 25.1325 and FAR 25.1323 (Ref. [6] and Ref. [7]). Comparing to Tower Fly By Method and GPS Method the test results are closed.

For the future, by using acceleration flight during the test for each flap configuration, it is expected to reduce flight hours due to all speed range can be taken in the same time. This method is also less human resources required compare to the Tower Fly By Method and take more efficient time comparing to GPS method.

8. Conclusions

From the description above it can be concluded that the altitude and airspeed position error correction by using Radio Altimeter as reference are well within the the boundaries of FAR 25.1325 and FAR 25.1323 regulation. By using acceleration airspeed flight test technique during the test, this Radio Altimeter Method is more efficient in term of reducting flight hours, less human resources required, and not require any additional special equipment compare to the Tower Fly By and GPS Method.

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References

[1] “Measurement System Application & Design”, Ernest O. Doeblin 3rd, Mc Grow Hill Book Company, 1983.

[2] “CN235-100M MPA1 Position Error Calibration (PEC) Flight Test Results”, Qualification Document, Indonesian-Aerospace (Iae), July 21th 2009.

[3] “Light Aircraft Performance For Test Pilots And Flight Test Engineers”, Sean C. Roberts, Flight Research. INC., Mojave, California 93501.
“Measurement of Aircraft Speed and Altitude”, William Gracey, Aeronautical Research Scientist, NACA/NASA (Ret.)

“Flight Test Analysis Description Manual”, Flight Test Engineering Analysis Department, Flight Test Center, Indonesian-Aerospace, Doc. No. D000NA12113, June 1996.

“Federal Aviation Regulation (FAR), Part 25”.

“Advisory Circular 25-7A, Flight Test Guide for Certification of Transport Category Airplane”.

“Flight Test Log, Airspeed Calibration Using GPS”, Doc. No. TASFR00636990-F011.

“Flight Test Log, Airspeed Calibration Using TFB”, Doc. No. TASFR00636990-F011.

“CN235-100 MPAP Development Flight Test Program – Flight Physic With Clean Wing”, Flight Test Plan for first phase of CN235-100 MPA Program, Doc. No. 3M0006021, January 2009.

“CN235-100M MPA1 Drag Polar Flight Test Results”, Qualification Document, Indonesian-Aerospace (IAe), July 23rd 2009.