Application and Analysis of the Wheel Method in the Measurement of the Center of Gravity of a General-Purpose Aircraft

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Abstract. This paper starts with the commonly used wheel method of aircraft center of gravity measurement, and analyzes the more convenient horizontal attitude measurement method derived from the wheel method in the practice of gravity measurement of a certain type of general aircraft. Then through practical application and data analysis, it is determined that the factor that has the greatest influence on the measurement accuracy in this method is the measurement error of the front and the main wheel track. Finally, a special tooling measurement method for accurate measurement of the wheelbase is proposed for this factor, which makes the measurement accuracy of the center of gravity of the aircraft effectively guaranteed.

1. Introduction
The center of gravity is an extremely important flight parameter for the aircraft. It has a great impact on the flight safety, handling performance and operational economy of the aircraft. After the assembly work is completed, the center of gravity of the aircraft should be measured in accordance with the corresponding manual to ensure that it is within the scope of the aircraft model design requirements. Regarding the measurement of the center of gravity of the aircraft, the Aircraft Design Manual gives two test methods: the jack method and the wheel method. A common feature of the jack method and the wheel method is that the aircraft is adjusted to three different postures, so that the center of gravity of the aircraft is measured three times and averaged. This is very suitable for transport aircraft with complex construction, slow production cycle and extremely high airworthiness requirements, but for general-purpose aircraft with simple construction, fast production cycle and relatively low airworthiness requirements, these two methods are too cumbersome. Complex and long cycle. Therefore, it is extremely important to find a method for measuring the center of gravity of a general-purpose aircraft production line that satisfies both airworthiness management requirements and fast-paced general-purpose aircraft production lines.

In the two test methods of the jack method and the wheel method, the measurement error of the center of gravity of the jack method increases with the increase of the tonnage and attitude angle of the aircraft, and there is a large safety risk, and the measurement accuracy of the wheel method is high, and the measurement error is high. It does not change with the attitude, and the safety is higher. Therefore, this paper only studies the wheel method [1].

2. Theoretical Introduction and Analysis of the Wheel Method in the Measurement of the Center of Gravity of the Aircraft
The wheel method is to place the aircraft wheel on three electronic scale platforms, and generally place the aircraft in three different postures - one horizontal attitude and two upward postures. The
weight is measured by the sensor, and the center of gravity is obtained by an analytical method according to the principle of torque balance.

Figure 1 Schematic Diagram Of the Center of Gravity of the Aircraft

The schematic diagram of the center of gravity of the aircraft is shown in Figure 1. In the X'O'Z' coordinate system, according to the principle of torque balance, the force of the aircraft is balanced against the o' point, so the following torque balance equation can be obtained:

\[ G \times \frac{\Delta H}{D} \cdot \zeta - G \times \frac{\Delta L}{D} \cdot \xi + G_N \cdot \Delta L = 0 \]  

(1)

In the formula,

- \( G \) - the total weight of the aircraft, the sum of the three electronic readings, taking the average of three measurements;
- \( G_N \) - the front wheel electronic scale reading of the aircraft.

Analysis of formula (1) shows that it contains \( \xi \)' and \( \zeta \)' two unknown quantities. Therefore, the coordinates \( (\xi, \zeta) \) of the plane's center of gravity in the plane's body coordinate system-XOZ coordinate system can be obtained by taking the two head-up postures of the plane for joint solution after measurement and coordinate conversion, wherein the formulas of \( \xi \) and \( \zeta \) are as follows

\[ \xi = \frac{-D \times \left( G_{N1} \times \frac{\Delta H}{\Delta L_2} + G_{N2} \times \frac{\Delta H}{\Delta L_7} \right) \times \cos \psi - D \times \left( G_{N1} - G_{N2} \right) \times \sin \psi}{G \times \left( \frac{\Delta H_2}{\Delta L_2} - \frac{\Delta H_1}{\Delta L_7} \right) + \Gamma} \]  

(2)

\[ \zeta = \frac{D \times \left( G_{N1} - G_{N2} \right) \times \cos \psi - D \times \left( G_{N1} \times \frac{\Delta H}{\Delta L_2} - G_{N2} \times \frac{\Delta H}{\Delta L_7} \right) \times \sin \psi}{G \times \left( \frac{\Delta H_2}{\Delta L_2} - \frac{\Delta H_1}{\Delta L_7} \right) + \psi} \]  

(3)

In the formula,

- \( \Delta H_1 \) - When the aircraft lifts the front wheel for the first time, the vertical height difference between the front and the main wheels;
- \( \Delta H_2 \) - When the aircraft lifts the front wheel for the second time, the vertical height difference between the front and the main wheels;
Δ **L**₁-When the aircraft lifts the front wheel for the first time, the front and main wheels are horizontally spaced;
Δ **L**₂-When the aircraft lifts the front wheel for the second time, the front and main wheels are horizontally spaced;
Δ **G**₁-the reading of the front wheel scale when the aircraft lifts the front wheel for the first time;
Δ **G**₂-the reading of the front wheel scale when the aircraft lifts the front wheel for the second time;
Other variables are shown in Figure 1.

3. Application and Analysis of the Horizontal Altitude Measurement Method on a General-Purpose Aircraft

It can be seen from the above that when measuring the center of gravity of the aircraft by the wheel method, it is necessary to adjust the aircraft to three different postures, and then obtain the data of the three postures and then take the average value as the final result. Finally, it is necessary to measure the center of gravity of the aircraft on the aircraft axis. In the current general-purpose aircraft manufacturing field, the horizontal center of the three attitudes mentioned in the wheel method is basically used to measure the center of gravity of the aircraft, that is, the horizontal attitude measurement method. This method only needs to measure. The coordinate value of the center of gravity of the aircraft along the axial direction of the aircraft. Although this measurement method is not rigorous and the error is relatively large, due to its simple and convenient operation, its practical application in the field of navigation manufacturing is very extensive. The following Fig. shows the AMM manual of a certain type of general aircraft. A double statement of the imprecision and effectiveness of the method.

![Figure 2](image)

Figure 2 Dual Statement Of the Imprecision and Effectiveness of a Model of General-Purpose Aircraft

Technical Data on Horizontal Attitude Measurement

In order to find out the factors that have the greatest influence on the measurement accuracy in this method, and to improve the measurement accuracy on the basis of not increasing the convenience of operation, it can compensate for the loss in accuracy compared with the traditional wheel method. Here, this method is used to measure the center of gravity of a general-purpose aircraft of 8 sorties, and the necessary data analysis is performed to find out the factors affecting the measurement accuracy. The relevant data is shown in the table below.

| Table 1 Horizontal Attitude Method to Measure the Center of Gravity of the Aircraft |
|-----------------|-----------------|-----------------|-----------------|---------------|-----------------|
| Front wheel weight / kg | Left main wheel weight / kg | Right main wheel weight / kg | Front, main wheel track/mm | Center of gravity coordinates / mm |
| 268.5 | 600 | 596 | 1871 | 2446 |
| 264 | 605 | 592 | 1869 | 2450 |
Through regression analysis, the regression statistics, variance analysis and regression parameters of the data in Table 1 can be obtained as shown in the following table.

Table 2 Regression Statistics

|            |       |
|------------|-------|
| Multiple R | 0.998455 |
| R^2        | 0.996912 |
| Adjusted R^2 | 0.992794 |
| Standard error | 1.335114 |
| Observations | 8      |

Table 3 Analysis of Variance Table

|                | df  | SS      | MS        | F        | Significance F |
|----------------|-----|---------|-----------|----------|----------------|
| regression analysis | 4   | 1726.152 | 431.5381032 | 242.0932 | 0.000428       |
| Residual        | 3   | 5.347587 | 1.782529016 |          |                |
| total           | 7   | 1731.5  |           |          |                |

Table 4 Regression Parameter Table

|                | Coefficients | Standard error | t Stat   | P-value |
|----------------|--------------|----------------|----------|---------|
| Intercept      | 1726.213     | 361.468        | 4.775563184 | 0.017449 |
| Front wheel weight / x1 | -0.94676 | 0.096753     | -9.785315703 | 0.002268 |
| Left main wheel weight / x2 | 0.256411 | 0.148842     | 1.722707473 | 0.043416 |
| Right main wheel weight / x3 | 0.281801 | 0.228686     | 1.232265647 | 0.045621 |
| Front, main wheel track / x4 | 0.348611 | 0.172421     | 2.021863376 | 0.016411 |

As can be seen from Table 2, the regression correlation coefficient Multiple R is 0.998445, indicating that the sub-variable is highly correlated with the dependent variable. The complex determination coefficient R^2 was 0.999192, indicating that the independent variable explained 99.69% of the variation of the dependent variable. The adjusted complex determination coefficient Adjusted R^2 was 0.992794, indicating that the independent variable can account for 99.28% of the dependent variable. It can be seen from Table 3 that the F-significance statistic of the F is 0.000428, which is much smaller than the significance coefficient of 0.05, indicating that the regression equation has a significant regression effect. As can be seen from Table 4, the regression equation is:

\[ Y = 1726.213 - 0.94676X_1 + 0.256411X_2 + 0.281801X_3 + 0.348611X_4 \]  \(\text{(4)}\)

It can be known from formula (4) that in the horizontal attitude measurement method, the variable that has the greatest influence on the measured value of the center of gravity of the aircraft is the front wheel weight of the aircraft, followed by the front of the aircraft, the main wheel track, and the weight of the left and right main wheels of the aircraft again. Since the influence of these four variables on the measured value of the center of gravity of the aircraft is linear, the degree of influence is also linearly related to the coefficient size. According to the analysis, the weights of the front wheel and left and right main wheels of the aircraft are all calculated by the verified electronic scale. The accuracy of the selected electronic scale is 0.01kg. Since the readings of the three wheel weights of the aircraft are directly read by the electronic scale, the maximum theoretical deviation that can be produced from the measurement results is only affected by the accuracy of the electronic scale, so they are 0.00947 mm, 0.00256 mm and 0.00282 mm, respectively. The accuracy of the gauge used to measure the aircraft
track is 1 mm, and the maximum theoretical deviation per 1 mm of measurement error is 0.35 mm. In the actual measurement process, the front and the main wheels are in a plane relationship. Before the measurement and the main wheel track, the contacts of the three wheels and the ground are extracted, and then the indirect measurement is performed through the extracted contacts. In the actual operation process, the flatness of the ground and the accuracy of extracting the theoretical contact from the contact surface between the tire and the ground will have a large deviation from the measurement result of the track, and thus have a very significant influence on the measurement of the center of gravity. Make the measurement results inaccurate and uncontrollable.

Therefore, in the process of measuring the center of gravity of the aircraft, the accuracy of the measurement of the aircraft's track is the most influential factor on the accuracy of the measurement of the center of gravity of the aircraft. Improving the accuracy of the measurement of the altitude of the aircraft is an important task to improve the accuracy of the measurement of the center of gravity of the aircraft.

4. Method for Improving Measurement Accuracy of Horizontal Attitude Measurement Method

In order to minimize the factors affecting the accuracy of the aircraft track measurement, the measurement accuracy of the horizontal attitude measurement method is improved. This paper proposes a special tooling measurement method for aircraft front and main wheel track measurement. When measuring the aircraft track, all the measuring points are taken from the aircraft wheel axle. By designing the special measuring tooling method, the tooling is only installed and fixed by the axle holes of the three wheels of the aircraft, and the track value of the aircraft is directly read through the scale on the tooling. The measurement tool reading only relies on the axles of the three wheels of the aircraft, completely avoiding the influence of other factors such as the ground flatness, tire condition, etc., so the measurement accuracy is only affected by the manufacturing error of the tool itself and the error of the scale reading.

![Figure 3 Special Tooling Measurement Method to Measure the Front and Main Wheel Track Construction Drawings](image)

The tooling is processed according to the GB/T1804-2000 standard m class. The theoretical wheelbase of this model is 1.735m (taken from the AMM manual). According to the table, the size can produce a maximum manufacturing deviation of 1.2 mm at the m-level tolerance level, and the maximum deviation of the scale can be 1 mm for the scale measurement reading. According to the comprehensive analysis, the maximum theoretical measurement deviation that can be produced by the special tooling measurement method during the wheel gauge measurement is 2.2 mm. Therefore, it can be known from formula (4) that the maximum theoretical deviation that can be produced by the special tooling measurement method for the measurement of the center of gravity of the aircraft is 0.77
mm, which satisfies the tolerances required by the product design data to meet the m-level tolerance class of ±1.2 mm in the ISO2768 standard. Claim.

5. Conclusion
For general-purpose aircraft, the horizontal center of view measurement can be used to measure the center of gravity coordinates of the aircraft. In practical applications, this method is simpler and more convenient than the wheel method. The most influential factor in the horizontal attitude measurement method is the measurement error of the front wheel and the main wheel track. The special tooling measurement method can effectively ensure that the error is within the range required by the aircraft model design data. In addition, the method also makes the measurement of the front and main wheel tracks easier and more convenient, which makes the measurement accuracy and efficiency double guarantee, which will greatly promote the general aircraft manufacturing field.

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