Research on the Evaluation Method of the Deviation of the Horizontal Tail Cathedral Angles and the Engine Installation Angles in the Leveling and Measurement of Civil Aircraft

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Abstract. The leveling and measurement of the aircraft is performed after the final assembly is completed. Measurements are used to check the accuracy of the geometric relationships within and between the various components of the aircraft and checks whether the aircraft assembly meets the overall design requirements. It is performed on the datum marks of the level measurement. During the leveling and measurement of a certain type of aircraft, the horizontal tail cathedral angles, and the engine installation angles of many aircraft have been found to have different degrees of deviation. These deviations have impact on aerodynamic characteristics, stability performance, and on-site production schedule of the aircraft. This paper has carried out special research on this deviation of the horizontal tail cathedral angles and the engine installation angles, by using empirical formulas and other methods to evaluate the deviation of the leveling and measurement, to provide a basis for the deviation evaluation of the leveling and measurement, improve the evaluation efficiency, and ensure the aircraft mass production. In addition, this paper also summarizes the root causes of the deviation, and provides an improvement direction for the aircraft's configuration control, fuel consumption reduction and carbon dioxide emission reduction.

1. Introduction

For newly-developed aircraft, after the final assembly, the leveling and measurement is used to check whether the aircraft assembly meets the general design requirements. The measurement is used to check the deviation between the actual configuration of the aircraft and the theoretical configuration[1-2]. If there is a large deviation during the measurement, it indicates that the structure may be damaged. It is of great significance to the shape control of the aircraft.

The leveling and measurement is to check the quality of aircraft assembly through datum marks. The datum marks are made in accordance with the aircraft design and manufacturing requirements at the specified positions on the surface of the components during the assembly of the aircraft. The traditional method of level measurement usually uses level gauge or engineer’s transit level to measure. At present, the more commonly used method is to measure with laser tracker[3-4].
The laser tracker is a portable three-dimensional large-size measuring device that reflects the laser beam emitted by the tracker through the SMR to measure the three-dimensional coordinates of any point in space. It has the advantages of high accuracy, fast sampling speed and wide measurement coverage, which can better meet the requirements of the leveling and measurement of aircraft.

By analyzing the level measurement data, evaluating the impact of the horizontal tail cathedral angles on the aerodynamic characteristics and the stability performance of the aircraft, it can provide a theoretical basis for eliminating such adverse effects, reducing fuel consumption, and improving the economy and competitiveness of civil aircraft.

2. Methods and Materials

2.1 The measuring requirements and coordinate system of the leveling and measurement

2.1.1 The coordinate system

This paper uses the fuselage coordinate system to analyze the data of leveling and measurement. The YOZ plane is defined as the plane of symmetry of the aircraft. The Y-axis points from the nose to the tail, the Z-axis is vertically upward, and the X-axis is determined by the right-hand rule. The Z=0 plane is defined as the fuselage reference plane, as shown in figure 1.

![Fig. 1. Schematic diagram of the fuselage coordinate system.](image)

2.1.2 The environmental requirements for measurement

The measurement environment should meet the following requirements:

- The measurement should be carried out indoors, without any interference that affects the measurement,
- The measurement site should be hard and flat, and no subsidence that affects the measurement is allowed,
- 1 hour before the measurement until the end of the measurement, the aircraft should be protected from direct sunlight,
- If it is not possible to measure indoors, the wind must be below level 3,
- The measurement site should be hard and flat, and no subsidence that affects the leveling and measurement is allowed.

2.1.3 The aircraft status requirements for measurement

The state of the aircraft should meet the following requirements:

- The aircraft shall be lifted steadily in accordance with the relevant design requirements for lifting and hoisting, and the aircraft jacks shall be adjusted to make the aircraft in a longitudinal horizontal state and a lateral horizontal state,
- If there is oil in the oil tank, it needs to be drained,
- The front landing gear and main landing gear should be lowered and locked, and the wheels should be off the ground,
- All doors and panels should be closed,
- No other work on the plane is allowed during the measurement.
2.2 The deviation of the horizontal tail cathedral angles

2.2.1 Data processing for the deviation of the horizontal tail cathedral angles

Figure 2 shows the level measurement of the horizontal tail cathedral angles of a certain type of aircraft. Among the measurement item $Z_{21} - Z_{22}$, the coordinates of points 21 and 22 are shown in Table 1.

![Measurement diagram of the horizontal tail cathedral angles.](image)

Table 1. Datum marks of the horizontal tail cathedral angle measurement.

| Element | X     | Y     | Z     |
|---------|-------|-------|-------|
| 21#     | 319.71| 30702.62| 5495.21|
| 22#     | 4547.98| 32796.49| 5333.58|

2.2.2 Evaluation method for the deviation of the horizontal tail cathedral angles

Some measurement data are shown in Table 2. Based on the conversion relationship between the measured value and the angle deviation, convert measurement values to angle data. The results are shown in Table 2.

![Diagram](image)

Table 2. Some measurement data of the horizontal tail cathedral angles.

| Measurement item | $Z_{21L} - Z_{22L}$ | $Z_{21R} - Z_{22R}$ |
|------------------|----------------------|----------------------|
| Tolerance (mm)   | 167.0±5              | 167.0±5              |
| Measured value (mm) | 177.49              | 162.90              |
| Deviation (mm)   | 5.49                 | 0                   |
| Angle deviation ($^\circ$) | 0.074               | 0.000               |

It can be seen from the result that the left side is out of tolerance by 5.49mm. When converted into an angle value, the left horizontal tail cathedral angle has an out-of-tolerance of 0.074°, which is manifested as an increase angle[5-6].

According to formula (1), it can be estimated that the projected area change of the left horizontal tail on the horizontal plane is less than 0.2%. The left side horizontal tail efficiency $C_{L\phi}$ has a loss of not more than 0.00008 and $C_{M\phi}$ has a loss of not more than 0.00002.

$$\Delta C_L \delta_m = S_H / S_H$$

$\Delta C_L \delta m$ in the formula represents horizontal tail efficiency, $S_H$ in the formula represents projected area.
In addition, according to formula (2) and formula (3), it can be estimated that the distance from the left side horizontal tail pressure center to the symmetry plane is reduced by about 0.355mm. Therefore, a rolling moment is generated, the magnitude of which is not greater than 0.00008, which is converted into a balance deflection angle of the aileron that does not exceed 0.01° in high-speed conditions and 0.01° in low-speed conditions.

\[
\Delta C_l = \Delta C_{1H} \times \frac{L}{b} \quad (2)
\]

\[
\delta a = \frac{\Delta C_l \times 2}{C \delta a} \quad (3)
\]

In the formula \( \Delta C_l \) represents additional rolling moment. \( \Delta C_{1H} \) represents additional rolling moment coefficient, \( b \) represents wingspan. \( \delta a \) represents balanced deflection angle of aileron. \( C \delta a \) represents aileron efficiency.

2.3 The deviation of the engine installation angles

2.3.1 Data processing for the engine installation angles

Figure 3 shows the measurement of the engine installation angles of a certain type of aircraft. Among the measurement item Z25-Z27, the coordinates of points 25 and 27 are shown in Table 3.

![Fig. 3. Measurement diagram of the engine installation angles.](image)

Table 3. Datum marks of the engine installation angle measurement.

| Element | X   | Y     | Z    |
|---------|-----|-------|------|
| 25#     | 3802.19 | 21315.51 | 571.79 |
| 27#     | 2874.19 | 24753.70 | 513.74 |

2.3.2 Evaluation method for the deviation of the engine installation angles

Some measurement data are shown in Table 4. Based on the conversion relationship between the measured value and the angle deviation, convert measurement values to angle data. The results are shown in Table 4.
Table 4. Some measurement data of the engine installation angles.

| Measurement item | $Z_{21L} - Z_{22L}$ | $Z_{21R} - Z_{22R}$ |
|------------------|----------------------|----------------------|
| Tolerance (mm)   | $58 \pm 4$           | $58 \pm 4$           |
| Measured value (mm) | 43.62               | 46.04               |
| Deviation (mm)   | 10.38                | 7.96                 |
| Angle deviation (°) | 0.173               | 0.133               |

The result shows that the left side is out of tolerance by 10.38mm and the right side is out of tolerance by 7.96mm. When converted into an angle value, the left engine installation angle has an out-of-tolerance of 0.173° and the right has an out-of-tolerance of 0.133°, both of which are manifested as angle reductions.

According to formula (4) and formula (5), the lift coefficient can be estimated. When the engine is in the state of maximum thrust, the change in lift coefficient is 0.0029, which has very little effect on the maximum lift coefficient. The influence of engine installation angle deviation on drag due to lift and intake drag can be ignored, and the amount of drifting moment change is less than 0.0006.

$$\Delta C_{IL} = \Delta C_L \times \Delta \Psi_E / 2$$  \hspace{1cm} (4)

$$\Delta C_n = \Delta C_{nE} \times 1 / h$$  \hspace{1cm} (5)

In the formula $\Delta \Psi_E$ represents deviation of the engine installation angles.

$\Delta C_L$ represents lift coefficient.

$\Delta C_{nE}$ represents drifting moment coefficient.

According to the estimation of formula (6), it can be seen that the influence of the over-tolerance of the engine installation angle on the aircraft take-off distance is less than 1 meter.

$$\Delta S = \Delta S_g + S_{\text{flare}}$$  \hspace{1cm} (6)

Among them,

$$\Delta S_g = \Delta V \times \frac{0.07716(\bar{V}_r - \bar{V}_w)}{g(T - W - \mu_B - \mu_B \bar{C}_L \frac{qS}{W} \alpha \tau_r)}$$

$$S_{\text{flare}} = 0.2778 \times (\frac{V_r + V_2}{2} - \bar{V}_w) \Delta t$$

By analyzing the deviation from the usual phenomenon, the author found that there are three main reasons as follows:

- The weight factor is not considered or the weight correction is inaccurate,
- Insufficient positioning accuracy of aircraft assembly tooling.
- Manufacturing deviation of the datum marks of the level measurement.

3. Conclusions

This paper is aimed at the analysis of level measurement data, evaluation of the common deviation of the horizontal tail cathedral angles and the engine installation angles in the leveling and measurement. From the impact on the aerodynamic characteristics, operation stability, etc., the analysis is carried out, and the evaluation basis and method of such deviation are proposed.

This paper proposes that the deviation of the horizontal tail cathedral angles and the engine installation angles in the level measurement will have a slight adverse effect on the aerodynamic
characteristics and the stability performance such as maximum lift coefficient, horizontal tail efficiency, rolling moment, take-off distance and other indicators. The magnitude of the influence can be evaluated by the method proposed in this paper according to the amount of deviation.

In addition, this article also considers the reasons for the deviation. When it occurs, improvements can be made by correcting the weight factor, improving the positioning accuracy of the assembly tooling or improving the manufacturing accuracy of the level measurement datum marks.

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