Research on Trim Simulation and Flight Test of a General Electric Aircraft

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Abstract. In order to study the stable flight of an electric aircraft in the whole flight speed range, taking the manned electric aircraft as an example, the method and principle of Longitudinal Trim for high aspect ratio aircraft are presented. Based on the wind tunnel test data, the torque produced by different gravity centers and tension lines as input parameters, and ignoring the influence of lateral and heading parameters, the three-degree-of-freedom motion equation of the aircraft is established, the difference of the performance parameters before and after the trim state is analyzed, which reflects the flight characteristics of the aircraft in a comprehensive way, and is compared with the flight test data. The simulative simulation data and the flight test data are in good agreement and have certain feasibility, it provides a reference for analyzing the performance parameter modification of other high aspect ratio electric aircraft in the future.

1. Introduction
In general, the flight of general electric aircraft has to go through five stages: take-off, climb, cruise, glide and landing. In these five stages, endurance flight is the stage with the longest time and the longest distance, and endurance performance is also one of the key technical indicators to measure the performance of the aircraft. Therefore, it is an important part of aircraft design to study the performance at this stage in order to ensure a stable and safe flight. [1-3].

In the stage of aircraft model design and development, a suitable aerodynamic layout scheme is usually proposed. In order to judge the advantages and disadvantages of this aerodynamic layout scheme, one method is to use simple and effective engineering estimation of aerodynamic characteristics [4] and the other method is to use CFD to carry out numerical simulation calculation. However, the above two methods are finally verified by wind tunnel test data to verify the feasibility of the aerodynamic layout scheme. In the early and middle stage of aircraft design, aircraft is generally regarded as the mass point in aircraft performance simulation calculation method [5-10], and the balance of its external torque is not considered. However, with more and more detailed design, when analyzing aircraft flight performance parameters, it is necessary to treat the aircraft as a rigid body or an elastic body. In order to achieve stable flight and performance requirements, it is necessary to determine the external force acting on the aircraft and derive the motion equation of the aircraft center of mass in order to study the longitudinal flight performance. The main external forces acting on the aircraft are gravity of aircraft,
aerodynamics (including lift, drag) and engine thrust which become the original data needed to calculate the flight performance. Generally, the lift, drag, side force and engine thrust of the aircraft do not pass through the center of mass of the aircraft, so the moment around the center of mass will be generated [11]. Therefore, when calculating the flight performance, the lift and drag used in the calculation are all parameters in the flight balance state. Generally, there are six degrees of freedom in the space motion of an aircraft. It is difficult to build a complete six degree of freedom aircraft model because of its huge system, complex structure and many aerodynamic data. In the past, the main method to study the performance parameters of longitudinal aircraft is to model the aircraft separately according to the longitudinal and transverse directions, and adopt the small disturbance increment aircraft equation. In the longitudinal direction, there are two external force balances and one moment balance which is commonly known as the three degree of freedom equation [12]. The deflection of the elevator surface at the tail of the aircraft makes the moment of the whole aircraft reach zero to achieve moment balance, but the trim of the elevator surface will cause the change of the lift-drag ratio of the whole aircraft [13].

Guided by airworthiness terms, a dual seat electric aircraft is taken as an example to study the state of aircraft trim, and analyze the performance loss caused by trim in this paper. The accuracy and loss of aerodynamic balancing calculation are directly related to the guidance of aerodynamic layout scheme, and provide reference for model development and model change.

2. Mathematical theory and calculation method
The equation of motion of the center of mass can be established by Newton’s second law, but the form of the equation is related to the coordinate system used. For the study of flight performance, it is more convenient to use the track coordinate system. The origin o of the coordinate system coincides with the center of mass of the aircraft and moves with the aircraft. The external forces acting on the aircraft mainly include the available thrust of the engine, aerodynamic force and aircraft gravity. If all these forces are projected into the path coordinate frame, the dynamic equation of the aircraft center of mass relative to the coordinate system can be obtained, which is formed as follows:

2.1. Three degree of freedom equation
When the aircraft is flying without sideslip, the balance equation of external force is as follows:

\[
m \frac{dV}{dt} = P_{s_y} \cos(\alpha + \varphi_p) - Q - G \sin \theta \]
\[
mV \frac{d\theta}{dt} = [P_{s_y} \sin(\alpha + \varphi_p) + Y] \cos \gamma_s - G \cos \theta \]
\[
-mV \cos \theta \frac{d\gamma_s}{dt} = [P_{s_y} \sin(\alpha + \varphi_p) + Y] \sin \gamma_s
\]

As a longitudinal flight characteristic of cruise, \( \gamma_s = 0 \), \( \theta = 0 \) then (1) is simplified as:

\[
m \frac{dV}{dt} = P_{s_y} \cos(\alpha + \varphi_p) - Q - G \sin \theta \]
\[
mV \frac{d\theta}{dt} = [P_{s_y} \sin(\alpha + \varphi_p) + Y] - G \cos \theta
\]

Where \( V \) is the aircraft speed, in \( \text{m/s} \); \( \alpha \) is the angle of attack, in \( \text{deg} \); \( \varphi_p \) is the angle between the pull action line and the horizontal line, in \( \text{deg} \); \( P_{s_y} \) is the propeller pull, in N; \( Q \) is the obstruction, in N; \( G \) is the aircraft weight, in N; \( Y \) is the lift, in N; \( \theta \) is the track inclination, in \( \text{deg} \);
Moment balance equation:

\[ m_c = m_c^\varepsilon \Delta c_\varepsilon + m_c^\delta \Delta \delta + m_c^{\sigma_\varepsilon} \omega_c \frac{b_h}{V} + p_{by} \ast y_p \ast l \ast (qSb_A) \]  \tag{3}

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2.2. Balancing calculation method
In the process of calculation, it is necessary to carry out iterative computations to find the appropriate trim angle of attack and rudder deflection.

For the first iteration, let \( Y = G \), and calculate \( C_y \) at different flight speeds according to this formula. According to the values of \( C_y \), the angles of attack \( \alpha \) and \( m_c \) corresponding to five different rudder deflections are interpolated. \( \alpha \) and \( \delta \) are determined by \( m_c = 0 \), and the values of \( C_c \) can be obtained by interpolation. Then, according to the first formula in the above formula, the corresponding \( p = qsc_y \ast \cos(\alpha + \varphi_p) \) can be obtained.

In the second calculation, the required tension \( P \) in the above calculation results is brought into equation \( c_y = \frac{G - P \sin(\alpha + \varphi_p)}{qs} \), and the iterative calculation is carried out again by the above steps. After two iterations, the result is the required trim angle of attack and rudder deflection angle.

3. Example analysis
Taking an electric two seater aircraft as an example, the calculation and analysis of the performance parameters in the two states of unbalancing and balancing are carried out.

3.1. Flight without trim
Taking the overall parameters, wind tunnel test aerodynamic data, dynamic parameters and atmospheric parameters as input parameters, the dynamic equation as the mathematical model, then the cruise performance parameters are calculated by the equation that the elevator deflection is zero.

When the aircraft is not trimmed, the angle of attack and lift drag of the aircraft are shown in Fig. 1 and Fig. 2, and the lift coefficient and drag coefficient corresponding to the cruise of the aircraft are shown in Fig. 3 and Fig. 4.
Figure 1. Cruising angle of attack.

Figure 2. Cruising lift-drag ratio.

Figure 3. Cruising lift coefficient.
Figure 4. Cruising drag coefficient.

3.2. Flight in trim

Figure 5. Trim cruising angle of attack.

Figure 6. Trim cruising angle of elevator.
Figure 7. Trim cruising lift coefficient.

Figure 8. Trim cruising drag coefficient.

Figure 9. Trimed cruising lift-drag coefficient.
3.3. Parameter comparison

Figure 10. Trimed cruising lift-drag coefficient.

Figure 11. Contrast of lift coefficient.

Figure 12. Contrast of drag coefficient.
Through the comparison of the above four trim and non trim performance parameters comparison curves, we can understand the difference of aircraft performance in different states. Figure 10 shows that the angle of attack required to be trimmed is greater than the angle of attack not trimmed at low speed through the comparison between before and after angle of attack trim. The reason is that at a small speed, the balanced elevator deflects upward. When the elevator deflection angle of attack exceeds the stall angle of attack, the airflow separates and the lift produced by the elevator decreases. In order to balance with the gravity, it is necessary to increase the angle of attack to increase the lift; On the other hand, at high speed, the required angle of attack is smaller than the angle of attack, which is because the greater the speed, the smaller the elevator deflection required for trim. At this time, the elevator deflects downward, resulting in a larger lift than the one without trim, so the required angle of attack is smaller than that without trim. At the speed of 100km/h, the elevator deflection in the trim state is zero, which is consistent with the non trim state. Figure 11, Figure 12 and figure 13 show the comparison of lift coefficient, drag coefficient and lift drag ratio, whose analysis results are consistent with the angle of attack. The lift drag ratio in Figure 13 is an important parameter of the aircraft. In the whole speed range, the lift drag ratio without trim is about 5% larger than that in trim. Only when the speed is 100km/h, do the lift drag ratio of two statues become the same.

4. Comparison between test results and theoretical calculation

![Figure 14: Performance parameters of flying tests(V=100km/h).](image-url)
Figures 14 and 15 show the corresponding angles of attack and elevator deflection at speeds of 100km/h and 120km/h respectively. From the analysis of test results, under the same speed of flight test, the corresponding angle of attack is basically consistent with the elevator deflection angle, but there is a gap in size, the main reason is that the model of wind tunnel test is basically regarded as rigid body, while the real aircraft material is composite material. In flight, the wing, fuselage and tail will have elastic deformation, which will produce the results of forward focus and reduced rudder efficiency.

5. Conclusions
This paper introduces the engineering calculation of performance parameters before and after aircraft trim, the treatment of wind tunnel test, the comparison of performance parameters before and after trim, the comparison of theoretical calculation and test results. The results show that the performance parameters before and after the trim have a certain rule to follow, the aerodynamic force after the trim has a certain loss, and the lift drag ratio loss is close to 5%. In addition, the performance parameters after trimmed are in good agreement with the flight test results, but there are also errors, the main reason is that the elastic deformation of composite aircraft with large aspect ratio in flight is large, which results in the change of focal point and steering effect, thus leading to the change of performance parameters.

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