Research into Nose Wheel Steering Deviation Angle Calculation of a Civil Aircraft

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Abstract. This document, based on a civil aircraft, describes the basic principle of nose wheel steering deviation angle calculation. The taxiing deviation angle of aircraft in ground test can be balanced by adjusting the nose wheel angle, but the deviation angle cannot be read directly, it needs to be calculated according to the field data. In this paper, we research a method to calculate the deviation angle by try three different modelling: simplified point modelling, calculus modelling and trigonometric modelling. Finally, we find the third modelling is more practical, we can rectified the deviation angle by adjusting the nose wheel turning control system pre-set parameters according with the result. We also transform the mathematic modelling into a computer program, to improve the efficiency in practical use.

1. Introduction
The aircraft nose wheel turning performance is an important indicators in its ground control, to maintain in the course and provide hydraulic to prevent the landing gear shimmy [1], the modern aircraft should have the ability to do large angle turn in low-speed taxiing, and rectify the small deviation in high-speed taxiing. Research in this paper, is on basis of a civil aircraft, to study a method for calculating the balancing angle in straight taxiing. By modelling analysis, we find the optimal modelling to calculate the deviation angle. Also it has great guiding significance for aircraft test fly and airline operation.

2. Introduction of the nose wheel steering system of the aircraft
The aircraft nose wheel turning system adopts digital teletype turning technology. It is a closed-loop system with teletype control, electro-hydraulic servo actuation, rack and pinion drive and position feedback. The turning system is powered by 2# hydraulic system. Hydraulic oil goes through the landing down pipe and valve to support the nose landing gear put down and turning. The oil only goes into the turning pipe when landing gear is put down to prevent the nose wheel landing with a deviation by hand wheel or foot pedal wrong operation[2].
3. Background of aircraft taxiing deviation angle calculation
During the aircraft ground test, it is necessary to check the ability of the aircraft to maintain a straight line when taxiing at a certain speed that is the ability of the nose wheels to remain centre while activating the turning function. When nose wheel deviates greatly, it can be rectified by adjust the balancing angle. The problem is we do not know the exact angle before deviation tendency appeared, the actual number should be calculated according to the actual taxiing situation.

4. Mathematical modelling method of the nose wheel deviation

4.1. Simplified to a point model
The idea of the simplification model is to simplify the aircraft as a whole to one point (as shown in Figure 2), Determine the starting and ending points of the aircraft and the initial taxiing direction of the aircraft to simplify the entire taxiing process (see Figure 3).
Figure 3. Simplified model of aircraft taxiing

Connection starting point and end point to simplify actual operation for aircraft track record for L, where L and the plane glide direction will form an angle for $\alpha$, means the deviation angle, the end point and initial taxiing aircraft in the direction of vertical distance for H, at this time, the L & H form a triangle model (see figure 3), from figure 3 we can derive the following formula:

$$H = L \cdot \sin \alpha$$  \hspace{1cm} (1)

H represents the vertical distance between the terminal point of the aircraft and the initial taxiing direction of the aircraft, and L represents the actual taxiing track of the simplified aircraft. According to formula (1), the angle calculation formula is as follows:

$$\alpha = \arcsin\left(\frac{H}{L}\right)$$ \hspace{1cm} (2)

Both L & H can obtain specific data through field measurement. We verified the formula (2) by test, when taxiing speed is at 15 knots and the distance of the aircraft from the axis of the runway was 5.6 meters after 15 seconds taxiing. Combined with the above data, a simple calculation can be made: L=115.7, H=5.6. Put it into the formula to calculate the deviation angle $=2.8^\circ$, that is, based on the triangle model, it is calculated that the amount of adjustment needed for the nose wheel turning balance of the aircraft is $2.8^\circ$. But in fact, it can be rectified by $0.5^\circ$ to maintain in the course, there is a large gap between the theoretical and practical situation.

4.2. Calculus model

Improvements were made in the calculus model, the actual taxiing track of the aircraft was added (see Figure 4). It was found through experiments that the actual taxiing track of the aircraft was close to the arc. Therefore, the arc calculus model is formed by combining the arc trajectory of the actual airplane taxi with the deflection angle of the airplane.
Similarly, the whole aircraft is simplified to a single point (see Figure 2), the starting position, ending position, and the initial taxiing direction of the aircraft are determined. The actual arc trajectory of the aircraft taxi is denoted as $L$, and the vertical distance from the end point to the initial direction of the aircraft is denoted as $H$. Considering the deflection angle exist at all times during the aircraft taxi process, the entire aircraft taxi trajectory $L$ is divided into $N$ stages, calculus model: In the first stage, when the deflection angle of the aircraft is $L_1$, the corresponding taxiway is $L_1$. The vertical distance from the end point of the first stage to the initial taxiway of the aircraft is $H_1$. In the second stage, the deflection angle of each stage is maintained on the basis of the deflection angle of the first stage, that is, the corresponding deflection angle of the second stage is $2\alpha$, and the taxiway trajectory is $L_2$. The vertical distance from the end point of the second stage to the end point of the first stage is denoted as $H_2$. By the same analogy, $L$ consists of $L_1, L_2, L_3...L_n$ is composed of $H_1, H_2, H_3...H_n$, the Angle between the taxiing direction and the initial direction of the terminal position of the aircraft is $n\alpha$. The relationships can be obtained from Figure 4:

\[
\begin{align*}
H_1 &= L_1 \times \sin \alpha \\
H_2 &= L_2 \times \sin 2\alpha \\
H_3 &= L_3 \times \sin 3\alpha \\
H_1 &= H_1 + H_2 + H_3 + \cdots + H_n \\
L &= L_1 + L_2 + L_3 + \cdots + L_n \\
L_1 &= L_2 = L_3 = \cdots = L_n
\end{align*}
\]

When each segment is sufficiently small, we can assume that the actual taxiing trajectory of the aircraft at each stage is equal, so the formula is finally obtained as follows:

\[
H = \frac{L}{n} \times (\sin \alpha + \sin 2\alpha + \sin 3\alpha + \cdots + \sin n\alpha) \quad (3)
\]

After mathematical model, we analysed the formula. Since formula (3) is a sine function, which belongs to an infinite loop function, the function does not converge when $n$ approaches infinity, that is, there is no solution. So, we found that the calculus model is not valid.

4.3. Triangular model

Through further research, we simplified the three-point layout of the aircraft landing gear into a triangular model [3] (see Figure 5).
Although simplified to triangle model, when analyse the deviation, we only consider the nose wheel track, the beginning and the end of the nose wheel (as shown in figure 6). When the aircraft deviate its taxiing course, the track of nose wheel slide from beginning to the end, is equivalent to orbiting at a distance of a unknown centre, the nose wheel sliding track arc for L, circle radius R. The included angle between the front wheel taxi tangent and the initial direction of the plane's initial position is denoted as $\alpha$, also we can know the angle of two lines which are line between centre and original nose landing gear and the line between the centre and original main landing gear is $\alpha$ too, the angle of two lines which are line between centre and original nose landing gear, and the line between the centre and final nose landing gear is $\beta$. The distance between the nose landing gear and main landing gear is denoted as H. The deviation angle of the aircraft is calculated through mathematical model, as shown in Figure 6. According to Figure 8, the following relationship can be obtained:

- $L = v \times t$
- $\beta = \frac{L}{R} \times \frac{180^o}{\pi}$
- $R = \frac{h}{\sin \alpha}$
- $A = B + H$
- $A = R \cos \alpha$
- $B = R \cos(\alpha + \beta)$

By combining the calculation, the formula is obtained as follows:

$$
\frac{h}{\sin \alpha} \cos \alpha = H + \frac{h}{\sin \alpha} \cos(\alpha + \frac{180^\circ L \sin \alpha}{\pi h})
$$

(4)

The model was used to calculate the angle in an example: the plane’s taxiing speed was 15 knots and the runway was 45 meters wide. The flight crew recorded aircraft deviation from the axis of the runway approximately 1/8 of the distance after 15 seconds taxiing, use formula (4) to calculate the deviation angle $=0.6^\circ$; The actual balancing angle was $0.5^\circ$. The gap is small. Considering the human error in the actual measurement, the triangle model is very practical.

In conclusion, the third "triangle model" is the closest to the actual taxiing deviation of aircraft, and the calculation is the most consistent.

5. Conclusion
Due to the complexity of aircraft taxiing deviation model and mathematical formula calculation, it is not convenient to use in the actual production process. In actual production, the most direct parameters are recording the taxiing time and the percentage of aircraft departure distance from the runway (aircraft deviation). Therefore, complex model and mathematical calculation formulas are programmed for practical use (see Figure 7), the calculation results can be obtained only by inputting common parameters.

Through the analysis of three different models, it is concluded that the "triangle model" is the closest to the actual aircraft turning situation, and the accuracy of model directly affects the accuracy of the final calculation results, which is of great significance to the study of aircraft nose wheel deviation. And it is more convenient for practical use to transform the complex model into computer program.

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