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Research on clearance provisions of airport terminal clearance zone under the takeoff climbing model

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Abstract. In order to make the clearance provisions of the Airport Terminal Clearance Zone (ATCZ) more scientific, safe, and reasonable, we need to analyze the takeoff climbing trajectory of the aircraft using fight dynamics theory. We design the calculation program to make the model calculation process simpler. Through the examples, the calculation results of the takeoff climbing model and the measured results are comparatively analyzed to verify the validity and rationality of the takeoff climbing model. We provide the calculation method and theoretical basis to ensure the flight safety of the aircraft in the ATCZ and to make the ATCZ provisions more scientific.

Key words. ATCZ, takeoff climbing, flight dynamics, numerical analysis.

1. Introduction

As an important part of airport clearance zone, the ATCZ' obstacle limitation provisions is the most important safety measure to ensure the aircraft takeoff, leave, approach, land, fly and other flight activities [1].During the aircraft takeoff climbing, the magnitude of the climbing angle has a decisive impact on the height limit of the ATCZ [2].

Some scholars have conducted some research on takeoff climbing performance of aircrafts. Robinson and Loomis adopt the indirect method and gradient method to find the optimal flight control, and discuss the advantages and disadvantages of the two methods [3]. Slater adjust the engine thrust by energy rate based on observation and calculation in aircraft rise stages to improve the prediction of the aircraft climb performance [4]. Cavcar adopt four equations to calculate the piston propeller plane's optimal angular velocity and maximum climb rate [5]. Huang, Miller and Koch simplify the takeoff climbing gradient calculation by the acceleration factor [6]. Torenbeek and Wittenberg use simple thrust method which assumes the plane as a steady movement in a vertical plane to calculate the maximum climb angle

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[7]. Based on the above-mentioned research, we select the takeoff climbing trajectory as the research object, and establish the takeoff climbing angle calculation model under the influence of atmospheric conditions, which is used to analyze the climbing's influence on the ATCZ provisions, so as to provide scientific calculation method and theoretical basis to determine the ATCZ obstacle limitation surface.

2. Aircraft takeoff climbing process division

The aircraft takeoff climbing starts from the departure point, and ends up with the state of the aircraft's clean configuration. In the process, the pilot will operate the aircraft according to the prescribed driving technique, constantly adjust the thrust of the engine, and change the aircraft's configuration and cruise in the fixed flight route. The takeoff climbing process of aircraft can be divided into 4 segments: Airborne phase, Wheel up, Flap up and Clean configuration, which are denoted as the jth climb mission segment ($j = 1, 2, 3, 4$) in turn, as shown in Fig. 1.

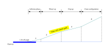

Fig. 1. Typical schematic diagram of aircraft takeoff climbing process

3. Equations of motion for takeoff climbing

In the ATCZ, the takeoff climbing trajectory of the aircraft can be determined by using the equations of the aircraft climbing motion in the vertical plane in the track coordinate system, as shown in (1)–(4)

$$P\cos(\alpha + \varphi_{\mathrm{p}}) - \frac{1}{2}C_{\mathrm{D}}\rho S V^2 - G\sin\gamma = \frac{G}{g}\frac{\mathrm{d}V}{\mathrm{d}t}\,, \tag{1}$$

$$P\sin(\alpha + \varphi_{\mathrm{p}}) + \frac{1}{2}C_{\mathrm{L}}\rho S V^2 - G\cos\gamma = \frac{G}{g}V\frac{\mathrm{d}\gamma}{\mathrm{d}t}\,, \tag{2}$$

$$\frac{\mathrm{d}h}{\mathrm{d}t} = (V \pm V_{\mathrm{w}})\sin\theta\,, \tag{3}$$

$$\frac{\mathrm{d}L}{\mathrm{d}t} = (V \pm V_{\mathrm{w}})\cos\theta\,. \tag{4}$$

Here, G is the weight of the aircraft (N), g is the acceleration of gravity (m/s^2), V is the aircraft vacuum speed (m/s), t is the time (s), γ is the aircraft climbing angle (rad), P is the engine thrust (N), α is the angle of attack (rad), φ_{p} is the engine mounting angle (rad), C_{D} is the resistance coefficient, ρ is the actual air density (kg/m^3), S is the wing area(m^2), C_{L} is the lift coefficient, l is the aircraft climbing horizontal distance (m), h is the aircraft climbing vertical geometric height, relative to the airport elevation (m), and V_{w} is the wind speed (m/s): with the flowing wind the coefficient is positive, and with the head wind, the coefficient is negative.

4. Example analyses

4.1. Takeoff climbing model program

The basic idea of programming is as follows:

(1) Discretize the chart data of different types of aircraft for storage and establish a database.

(2) Set input parameters of the program interface according to the calculation principle of takeoff climbing angle model, including airports, aircrafts and other relevant parameters.

(3) The input parameters are linked to the database, and the takeoff climbing angle of each equal pressure height segment is calculated.

(4) The calculation results are stored, analyzed, and exported, with the output parameters including an aircraft's total time of flight, flight distance, the minimum angle of climb, the airport terminal clearance each takeoff climbing mission segment ' slope and terminal height.

4.2. Validation of takeoff climbing model

For example, the elevation of an airport is 19 m, and the actual environmental temperature is 15 °C. The airport has A-type aircraft with 2 engines, the engine reduction factor is 0.9, and the engine installation angle is ignored. When the aircraft takes off, the aircraft takeoff mass is 24100 kg, with the onboard fuel 1900 kg.

The above known conditions are used as the input parameters of the program to calculate and analyze the takeoff climb process, and the output calculation results are shown in Figs. 2 and 3.

Fig. 2. Program interface of takeoff climbing model

In order to verify the accuracy and rationality of the model results, the take-

Pressure altitude(m)	True airspeed (km/h)	Angle of attack (°)	Climb angle (°)
18.99	315.35	6.548	0.000
23.99	335.34	7.888	3.164
28.99	350.26	8.262	3.009
33.99	365.67	7.668	2.874
58.97	380.41	7.185	13.924
83.96	387.19	6.394	13.546
108.95	398.50	5.273	13.234
133.94	406.09	5.427	12.917
158.93	417.50	5.977	12.614
183.92	425.27	2.747	12.333
208.91	435.00	3.186	12.078
233.90	443.14	3.120	11.823
258.89	455.74	3.120	11.570

Fig. 3. Results calculated by the program

off climbing track data [4] is obtained by field test which are compared with the calculated results, as shown in Fig. 4.

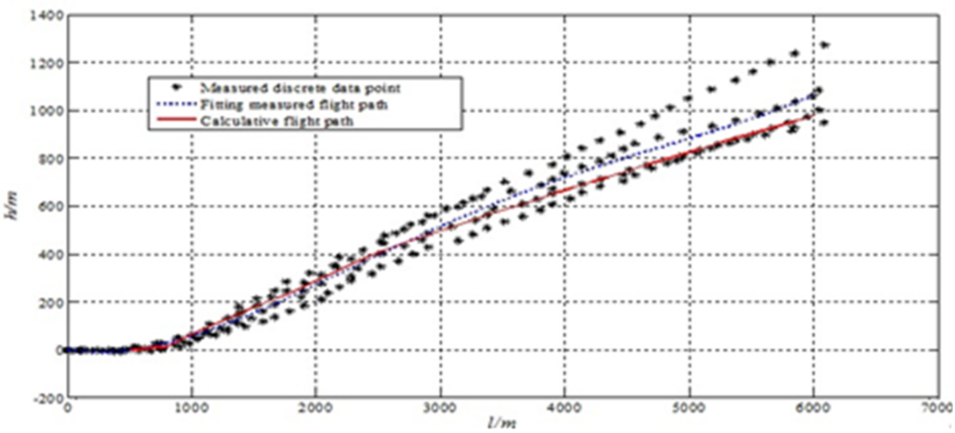

Fig. 4. Results calculated by the program

It can be seen from Fig. 4 that the model calculation results coincide well with the measured results. At the beginning of takeoff climbing, the calculated track is in good agreement with the measured track. However, there is a big error at the end of takeoff climbing process. At the horizontal distance, the maximum error between the measured track and the calculated track does not exceed 200 m. In the height direction of climb, the maximum error between the measured actual track and the calculated track does not exceed 100 m. It is mainly due to the fact that the actual track is less affected by external factors at the beginning of climb. As the takeoff climbing process continues, due to the accumulation of navigation errors or uncertain wind shear and other effects, the actual track and the calculated track deviations have occurred. However, for the determination of the takeoff climbing clearance provisions, the results of this model are biased towards safety. Therefore, this model can basically reflect the actual climbing situation of A-type aircraft and can be used in the analysis of the takeoff climbing clearance provisions.

The takeoff climbing model is used to obtain the takeoff climbing tracks under Case 1 and Case 2 respectively, as shown in Fig. 5. Considering the takeoff climbing clearance provisions of each takeoff climbing mission segment in the two cases, select the lower takeoff climbing track combination, in order to more safely meet the A-type aircraft takeoff climbing clearance requirements. Finally, the ACTZ clearance provisions are shown in Table 1.

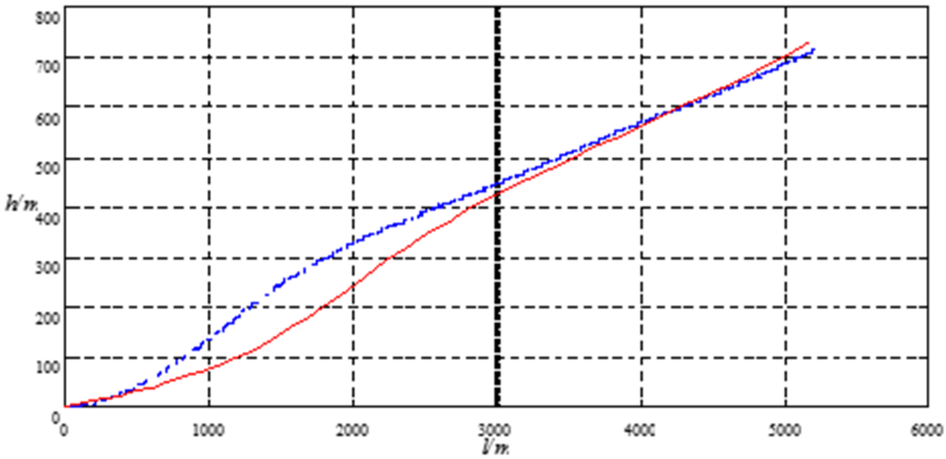

Fig. 5. The takeoff climbing track of Case 1 and Case 2

Table 1. A-type aircraft takeoff climbing clearance provisions

Takeoff climb section	Terminal clearance slope	Terminal clearance tip height (m)
Airborne phase	0.0263	7.5
Wheel up	0.112	120
Flap up	0.118	210
Clean configuration	0.081	490

5. Conclusion

The takeoff climbing angle of the aircraft plays a decisive role in limiting the height of obstacles in the ARCZ and becomes the basis for formulating the ATCZ clearance provisions. Therefore, we firstly define the speed correction coefficient and height correction coefficient. Secondly, the calculation formula of the takeoff climbing performance applicable to the actual atmospheric conditions is converted into the standard atmospheric conditions, and then applies to the ATCZ takeoff climbing model. Based on the established takeoff climbing model, the simulation of aircraft takeoff climbing track is realized. Compared with the measured data, the track calculated by the model basically reflects the takeoff climbing track of the aircraft, which can provide computational analysis and theoretical basis to determine the takeoff climbing obstacle limitation surfaces. Although the calculation results of the takeoff climbing model are similar to the measured results, a large number of measured data of the takeoff climbing trajectory are needed in the follow-up work, so as to further correct the ATCZ takeoff climbing model which becomes more scientific and reasonable to determine the airport clearance provisions.

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