Simulation study on anti-sliding performance of runway surface gathered water

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Abstract. In order to study the anti-sliding performance of the aircraft on the runway especially for the surface gathered water condition, a finite element method is used to establish a finite element model considered the contact between aircraft tire and road surface. The vertical deformation of tire is analyzed and compared with empirical formula to verify the feasibility of the model. The adhesion coefficient is used as the anti-sliding evaluation index, and the influence of aircraft speed, tire load, tire pressure and water film thickness on the adhesion coefficient is analyzed by model. The specific conclusions are as follows: The adhesion coefficient between the tire and surface decreases with speed increases, increases with the tire load increases, and decreases with the tire pressure increases. The adhesion coefficient decreases with the increase of water film thickness, and when the water film thickness is thin, the adhesion coefficient decreases more obviously with the increase of velocity.

1. Introduction
Taking off and landing process is very important for the safe flight of aircraft. When an aircraft is taxiing on the runway gathered water, the water in the track area is squeezed by the tires, which generates dynamic water pressure on the tires. The combined force can cause the aircraft malfunction and reduce the handling performance, threaten the takeoff and landing safety of the aircraft[1]. Therefore, it is extremely necessary to study the anti-sliding performance of the airport surface in rainy days.

Ji explored the relationship between pavement water thickness, rainfall intensity, slope length and rough surface by simulating[2]. Yang used finite element method to analyze the influence of load, road surface structure, tire pressure and driving speed on the adhesion coefficient between tire and pavement[3]. Novikov researched a method that can test the road adhesion coefficient when automobile slips during an accident[4]. Cong combined fluid dynamics theory and finite element method to propose a method to determine the braking distance when considering road friction characteristics[5]. It can be seen that existing researches mostly focus on the anti-sliding performance of automobile tires on the hydrops surface, and less research on aircraft tires. Based on the analysis of the tire-pavement contact mechanism, this paper uses the ABAQUS to establish the model of the aircraft tire running on the runway gathered water, and the adhesion coefficient is used as the
anti-sliding performance evaluation index to evaluate the anti-sliding performance under different conditions.

2. Establish tire-runway pavement model

2.1. Tire model
In the simulation, select the main landing gear tire H46×17-R20 of Airbus A320 as the research object. Tires consist of rubber, cord-rubber composite materials, rims, etc. The rubber material is represented by the super elasticity Neo-Hookean model. The cord-rubber composite material is an orthotropic material, which is simulated by using the Rebar element in ABAQUS, and rim is a rigid material. First, a two-dimensional cross-section model of a 1/2 tire was built using ABAQUS as figure.1. Then use the SYMMETRIC MODEL GENERATION function to rotate the two-dimensional model 360° around the circumference to obtain a three-dimensional model of the 1/2 tire. Finally, the axisymmetric transformation of the 1/2 tire 3D model is completed to establish a complete 3D tire model as figure.2.

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\delta = C_1 \frac{W^{0.85}}{S_0^{0.7} D^{0.43} P^{0.6}} K_0
\]

In which, \(\delta\) is the amount of compression deformation of the tire (cm). \(C_1\) is the parameter related to tire design, radial tire \(C_1=1.5\). \(W\) is the load on the tire (daN). \(D\) is the outer diameter of the tire (cm). \(S_0\) is the width of the tire (cm). \(P\) is the internal pressure of the tire (100 KPa). \(K_0=15\times10^{-3}\times S_0+0.42\).

As in equation (1), the deformation of the tire is calculated to be 3.08 cm, the finite element simulation value is 2.71 cm, and the error is 12.01%. Although not the same object, it verifies the rationality of the finite element model of tire inflation from the side.

2.2. Tire-ponding runway contact model
The tire-ponding runway contact model consists of four parts: tire, air layer, water film layer and rigid pavement, while the pavement and water film model remain stationary and the tire rolls forward. It can be known from the regulations that the aircraft is forbidden to take off and land when the water film thickness exceeds 13 mm [7]. Therefore, the thickness of the pavement water film in the simulation is 1–12 mm.
3. Anti-sliding performance evaluation standard

The contact area between the tire and the runway surface can be divided into two parts: the adhesion area $I_a$ and the sliding area $I_b$. The force acting on the adhesive region has a normal reaction force $P_a$ and a static friction force $F_{xa}$, and the force acting on the sliding region has a normal reaction force $P_b$ and a sliding friction force $F_{xb}$. The adhesion coefficient is the ratio of the horizontal reaction force to the normal load acting on the entire contact surface.

$$\phi_x = \frac{F_x}{P}$$

$F_x$ is the horizontal reaction force of the entire contact surface. $P$ is the normal load. $\phi_x$ is the adhesion coefficient.

4. Analysis and discussion of calculation results

4.1. Effect of tire load on adhesion coefficient

Assuming a tire pressure of 1.14 MPa, the tire rolls on a pavement with a 4 mm water film thickness at different velocity, and calculates the adhesion coefficient under different loads (64 kN, 70 kN, 76.6 kN).
Figure 5. Adhesion coefficient varies with tire load

It can be seen from figure 5 that the adhesion coefficient becomes larger as the tire load increases. Moreover, the change of the adhesion coefficient is relatively smooth when the speed is low, and the downward trend is faster when the speed is higher than 120 km/h. At 40 km/h, the adhesion coefficients of the tire load of 64 kN, 70 kN, and 76 kN are 0.44, 0.51, and 0.55 respectively. At 240 km/h, the adhesion coefficients of 64 kN, 70 kN and 76 kN are 0.16, 0.20 and 0.23 respectively. The adhesion coefficients were 0.28, 0.31 and 0.32 lower than those at 40 km/h. This shows that the runway surface adhesion coefficient is significantly affected by the tire load and the driving speed, especially at high speeds and heavy loads. When the tire pressure is constant, an increase in the tire load results in an increase in the contact area between the tire runways, thereby increasing the adhesion coefficient.

4.2. Effect of tire pressure on adhesion coefficient

Changes in tire pressure affect the elastic modulus of the tire. When the tire pressure is low, the tire deforms greatly and the rolling resistance will also increase. Assuming a tire load of 76.6 kN, rolling on a pavement with a 4 mm water film thickness at different velocity, and changing the tire pressure (1.0 MPa, 1.2 MPa, 1.4 MPa) to calculate the adhesion coefficient between the tire and the runway. The calculation results are shown in Figure 6.

Figure 6. Adhesion coefficient varies with tire pressure

It can be seen from figure 6 that as the tire pressure increases, the road surface adhesion coefficient decreases. At 40 km/h, the adhesion coefficients of tire tire pressures of 1.0 MPa, 1.2 MPa, and 1.4 MPa are 0.59, 0.54, and 0.48 respectively. At 240 km/h, the adhesion coefficients of tire loads of 1.0 MPa, 1.2MPa, and 1.4MPa are 0.26, 0.23, and 0.18 respectively. The adhesion coefficients were 0.33, 0.31 and 0.30 lower than those at 40 km/h. The change in tire pressure affects the rigidity of the tire. When the tire pressure increases, the tire elastic modulus increases and the tire deformation decreases. The contact area between the tire and the runway is reduced, resulting in a decrease in the adhesion coefficient. On the contrary, when the tire pressure decreases, the tire deformation and the contact area
between the tire and the runway become larger, resulting in an increase in the adhesion coefficient.

4.3. Effect of water film thickness on adhesion coefficient

Assume that the tire pressure is 1.14 MPa, the load is 76 kN, rolling on the runway with different water film thickness, and the adhesion coefficient between the tire and the runway when calculating at different water film thickness (2 mm, 4 mm, 6 mm, 8 mm, 10 mm, 12 mm).

![Figure 7: Effect of water film thickness on adhesion coefficient](image)

It can be seen from figure 7 that the thickness of the water film increases and the adhesion coefficient between the tire and the runway surface decreases. At 40 km/h, the adhesion coefficients of water film thicknesses of 2 mm and 12 mm were 0.62 and 0.33 respectively. At a speed of 240 km/h, the adhesion coefficients of water film thicknesses of 2 mm and 12 mm were 0.26 and 0.11 respectively. The adhesion coefficients were 0.36 and 0.22 lower than those at 40 km/h. When the water film is thin, the adhesion coefficient varies obviously with the velocity. When the water film is thick, the adhesion coefficient changes relatively slowly with speed. At lower velocity, the effect of water film thickness on the adhesion coefficient is greater. As the velocity increases, the effect of the thickness of the water film on the adhesion coefficient gradually decreases. The water film generates a high dynamic water pressure, which causes the tire to completely disengage from the runway. On the other hand, the water film acts as a lubricant film between the tire and the runway, reducing the frictional resistance between the tire and the runway. The combined effect of the two aspects reduces the runway adhesion coefficient and reduces its anti-sliding performance.

5. Conclusions

A tire-ponding runway anti-sliding model was established based on ABAQUS finite element software, and the sensitive factors affecting the anti-sliding performance are analysed by simulating. The main conclusions are as follows:

1) The tire load has a significant influence on the adhesion coefficient. When the tire pressure is 1.14 MPa, the water film thickness is 4 mm, and the speed is 40 km/h. When the tire load is increased from 64 kN to 76 kN, the adhesion coefficient is increased from 0.44 to 0.55. Accelerated to 240 km/h, when the tire load increased from 64 kN to 76 kN, the adhesion coefficient increased from 0.16 to 0.23. It indicates that the greater the tire load is, the greater the adhesion coefficient is.

2) When the tire load is 76 kN, the water film thickness is 4 mm, and the velocity is 40 km/h. When the tire pressure is increased from 1.0 MPa to 1.4 Mpa, the adhesion coefficient is reduced from 0.59 to 0.48. After the speed increased to 240 km/h, when the tire pressure increased from 1.0 MPa to 1.4 MPa, the adhesion coefficient decreased from 0.26 to 0.18. As the tire pressure increases, the tire elastic modulus increases, and the tire deformation decreases. The contact area between the tire and the runway decreases, resulting in a decrease in the adhesion coefficient.

3) The thickness of the water film increases and the adhesion coefficient between the tire and the runway surface decreases. When the speed increased from 40 km/h to 240 km/h, the adhesion coefficient of the 2 mm thick water film decreased from 0.62 to 0.26. The 12 mm thickness water film adhesion coefficient decreased from 0.33 to 0.11, and the adhesion coefficient decreased by 0.36 and
0.22. It shows that the adhesion coefficient between the tire and the runway surface decreases with the increase of the speed, and decreases with the increase of the water film thickness. Moreover, when the water film is thin, the adhesion coefficient varies obviously with the velocity. When the water film is thick, the adhesion coefficient changes relatively slowly with speed.

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