INFLUENCE OF TRANSVERSE GROOVE SPACING ON HYDROPLANING RISK AT AIRPORT

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Abstract

Hydroplaning is a dangerous phenomenon during operations at airports that causes loss of control of aircraft during takeoff and landing. In tropical climates with high average annual rainfall like Vietnam, the risk of hydroplaning is very high. Currently, the commonly used solution is to cut transverse grooves on the runway surface. To evaluate the influence of groove spacing on hydroplaning, the article uses CFD simulation with Ansys Fluent software to determine the impact of groove spacing for 2 cases of A350-900 and A321-200 aircraft. From the research results, it can be affirmed that the smaller the groove spacing is more risk of hydroplaning is reduced. To ensure the stability of the structure, the groove spacing should not be less than 38 mm (center-to-center) according to the recommendations of FAA and many aviation organizations under ICAO.

Keywords: *Hydroplaning; runway; airport; Ansys Fluent; CFD; transverse groove.*

1. Introduction

Hydroplaning, also known as aquaplaning, causes the moving wheel of an aircraft to lose contact with the runway surface on which it is rolling with the result that braking action on the wheel is not effective in reducing the ground speed of the aircraft.

- Dynamic hydroplaning [1]: arises when the aircraft travels over a puddle or a flooded section of pavement, causing completely separate the aircraft tires from the runway pavement surface. Most researchers refer to dynamic hydroplaning as hydroplaning, as it is the most commonly encountered form on runways.

- Visco hydroplaning [1]: occurs specifically on surfaces with minimal microtexture. In such cases, a thin fluid layer persists between the tire and the pavement due to the lack of microtexture to disrupt it. Unlike dynamic hydroplaning, which is speed-dependent, viscous hydroplaning can happen at any speed and with any fluid film depth.

- Reverted rubber hydroplaning [1]: occurs exclusively when large vehicles, such as trucks or aircraft, lock their wheels while traveling at high speeds on wet pavements with high macrotexture but minimal microtexture. The friction generated by the sliding

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motion on the pavement heats up the tread rubber, causing it to revert and liquefy. Consequently, the tire glides on a cushion composed of molten rubber, water, and steam. This type of hydroplaning not only implicates wet traction mechanisms but also involves the wear mechanism of rubber under elevated temperatures.

Fig. 1. Aircraft skid accident due to hydroplaning at Tan Son Nhat airport in 2020.

The solution to roughen the runway surface (including microtexture and macrotexture) is the most basic solution to create friction between aircraft tires when moving on the runway. To improve braking performance on the runway, in addition to the surface roughening solution, creating a surface with good drainage capacity, converting from wet friction coefficient to dry friction coefficient [1] with a higher value is a popular solution, which is the solution to construct a runway pavement surface transverse groove.

Transverse grooves are cut horizontally on the runway surface, with specified dimensions and distances [2], constructed on the surface of the runway after completion, with the aim of quickly draining surface water, improving surface friction conditions, and reducing the risk of dynamic hydroplaning.

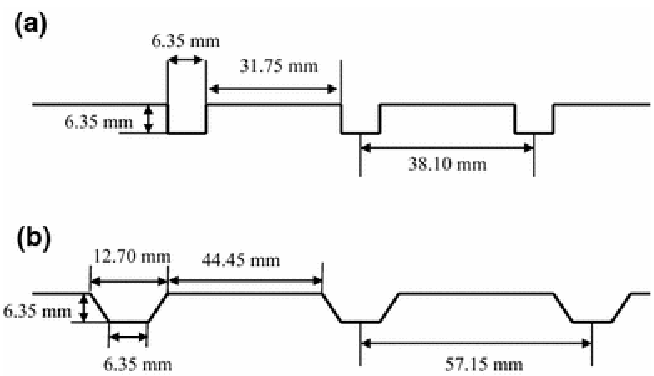

Fig. 2. Dimensions of transverse groove according to FAA's recommendation [2]
a) Square grooves; b) Trapezoidal grooves.

2. Hydroplaning simulation analysis

In a stationary observer frame of reference, the hydroplaning phenomenon can be simulated by a locked wheel moving at a speed of U (m/s) sliding on a smooth pavement flooded with water. In a moving wheel frame of reference, the problem can be modeled as a jet comprising of a layer of air and a layer of water, and a smooth plane pavement surface all moving at a speed of –U (m/s) towards the wheel using a steady-state analysis. Hydroplaning is assumed to occur when the average ground hydrodynamic pressure is equivalent to the tire pressure of the wheel, i.e. when the aircraft load is equal to the hydrodynamic lift force [1].

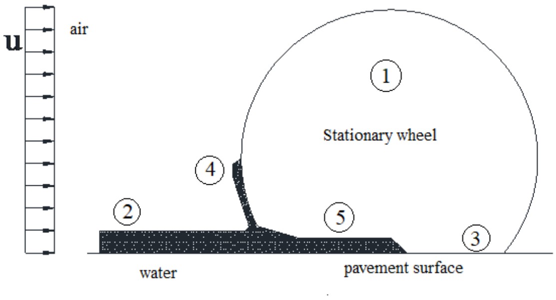

Fig. 3. Concept of hydroplaning modeling
1 - stationary wheel; 2 - inlet water; 3 - tire-pavement contact area; 4 - splash water; 5 - water move between tire and pavement.

Based on the above concept, the research of Ong and Fwa [1] built a simulation model of hydroplaning and analyzed it using Ansys Fluent software.

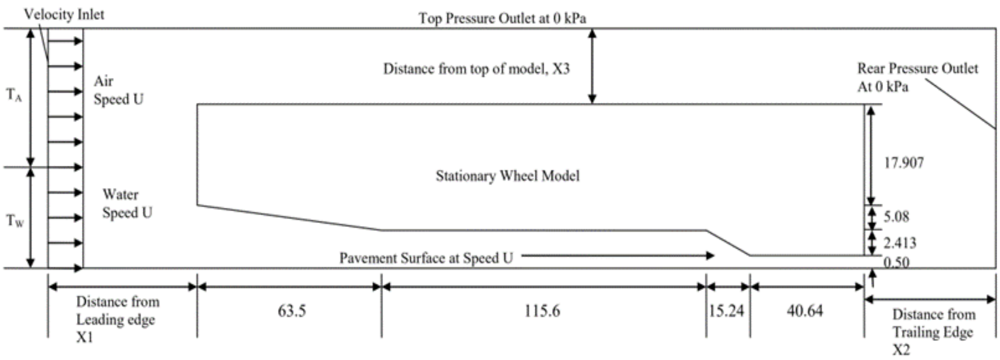

Fig. 4. Geometry of the model (Dimensions are in mm).

The simulation based on the fundamental laws of turbulent flow [1]:

a) Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla(\rho u) = 0 \tag{1}$$

where ρ is density of fluid, u is velocity of fluid, t is time.

b) The momentum Navier-Stokes equations

$$\begin{aligned}
&\frac{\partial(\rho u)}{\partial t}+\nabla(\rho uU)=-\frac{\partial p}{\partial x}+\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}+\rho f_x \\
&\frac{\partial(\rho v)}{\partial t}+\nabla(\rho vU)=-\frac{\partial p}{\partial y}+\frac{\partial \tau_{xy}}{\partial x}+\frac{\partial \tau_{yy}}{\partial y}+\frac{\partial \tau_{zy}}{\partial z}+\rho f_y \\
&\frac{\partial(\rho w)}{\partial t}+\nabla(\rho wU)=-\frac{\partial p}{\partial z}+\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}+\rho f_z
\end{aligned} \tag{2}$$

where $f_{x,y,z}$ are body forces, p is pressure on the surface by surrounding elements, τ is the shear and normal stresses on surface by friction, u, v, w represent x-velocity, y-velocity, z-velocity, respectively.

c) Equations k-ε

$$\begin{aligned}
&\frac{\partial(\rho k)}{\partial t}+\nabla(\rho k u)=\nabla\left(\frac{\mu_t}{\sigma_k}\nabla k\right)+2\mu_t E_{ij}\cdot E_{ij}-\rho\varepsilon \\
&\frac{\partial(\rho \varepsilon)}{\partial t}+\nabla(\rho \varepsilon u)=\nabla\left(\frac{\mu_t}{\sigma_\varepsilon}\nabla \varepsilon\right)+C_{1\varepsilon}\frac{\varepsilon}{k}2\mu_t E_{ij}\cdot E_{ij}-C_{2\varepsilon}\rho\frac{\varepsilon^2}{k}
\end{aligned} \tag{3}$$

where k is the turbulent kinetic energy, ε is the viscous dissipation.

The standard k-ε model employs values for the constants that arrive at by comprehensive data fitting for a wide range of turbulent flows: C_μ = 0.09; σ_k = 1.00; σ_ε = 1.30; $\sigma_{1\varepsilon}$ = 1.44, and $\sigma_{2\varepsilon}$ = 1.92.

3. Analysis of the influence of transverse groove spacing on hydroplaning

To analyze the influence of transverse groove spacing (center-to-center) on the hydroplaning phenomenon, the article chooses to analyze for 2 representative aircraft types, A321-200 and A350-900, with the condition that the runway surface has transverse grooves of size 6.35 mm × 6.35 mm (according to FAA's recommendation); the groove spacing takes the values of 10, 20, 32, 38, 52 mm (center-to-center, according to FAA's recommendation, China, Australia, Canada). The velocity of the water and air phases is taken according to the operating velocity of each type of aircraft. The thickness of the water layer is taken as 5 mm [1]. For each simulation analysis, the results determine the pressure formed under the aircraft tire, the hydroplaning occurs when this pressure is greater than the tire pressure of the aircraft.

Aircraft parameters are taken from Table 1.

For each set of transverse groove length, width and spacing values, the simulation is performed by adjusting the surface condition and keeping the velocity value constant.

Table 1. Aircraft parameters

Type	Maximum load (kg)	Landing velocity (km/h)	Landing velocity (m/s)	Tire pressure (kPa)
A321-200	93500	220	61.1	1282.4
A350-900	275000	260	72.2	1660

Table 2. Dimension of transverse groove used in simulation

Length (mm)	Width (mm)	Spacing (mm)
6.35	6.35	10; 20; 32; 38; 52

The water phase in the model separates into two parts: one part collides with the tire and splashes upwards, the other part moves between the tire and the runway surface, causing the water layer pressure to increase to a certain value.

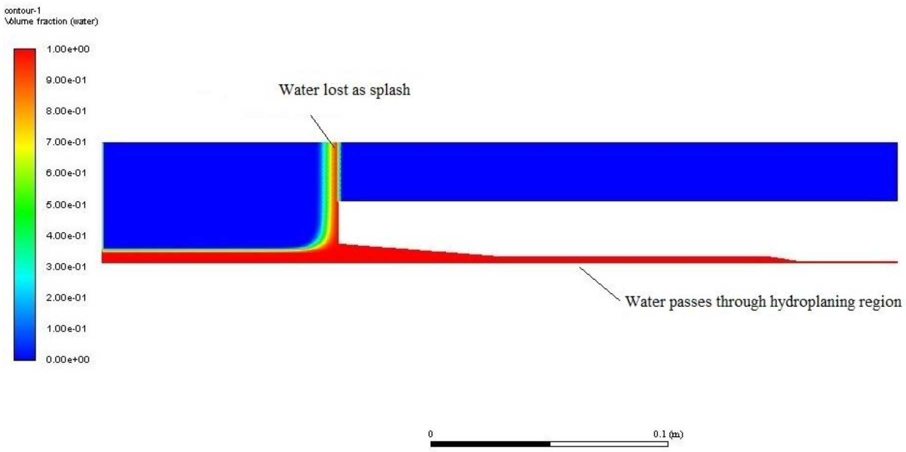

Fig. 1. Water volume fraction in result.

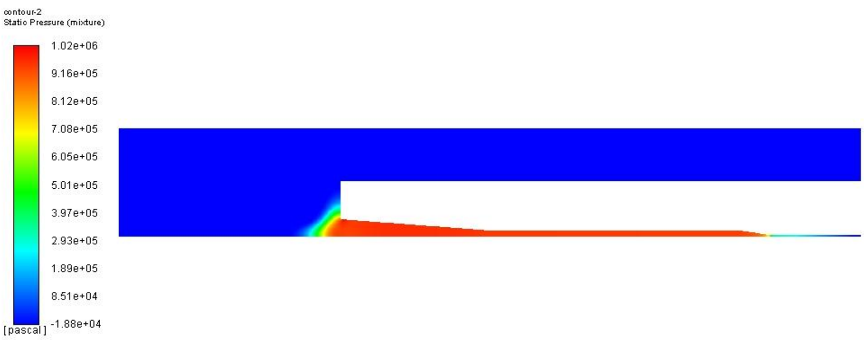

Fig. 2. Pressure under the aircraft tire.

Table 3. Pressure value result (Pa)

Aircraft type	Non-groove pavement	Groove spacing (mm)				
		10	20	32	38	52
A321-200	1454749.90	853042.69	1009397.90	1099419.30	1130144.40	1180709.00
A350-900	2043602.30	1192703.50	1410332.90	1537180.10	1579197.90	1650005.10

From the analysis results, it can be seen that when the water film thickness is 5 mm, the runway surface without transverse grooves will form a pressure under the tire that is larger than the tire pressure of the aircraft, thus causing hydroplaning. Meanwhile, the surface with transverse grooves gives the pressure results that are all smaller than the tire pressure. It shows that the use of transverse grooves has a significant effect in preventing hydroplaning.

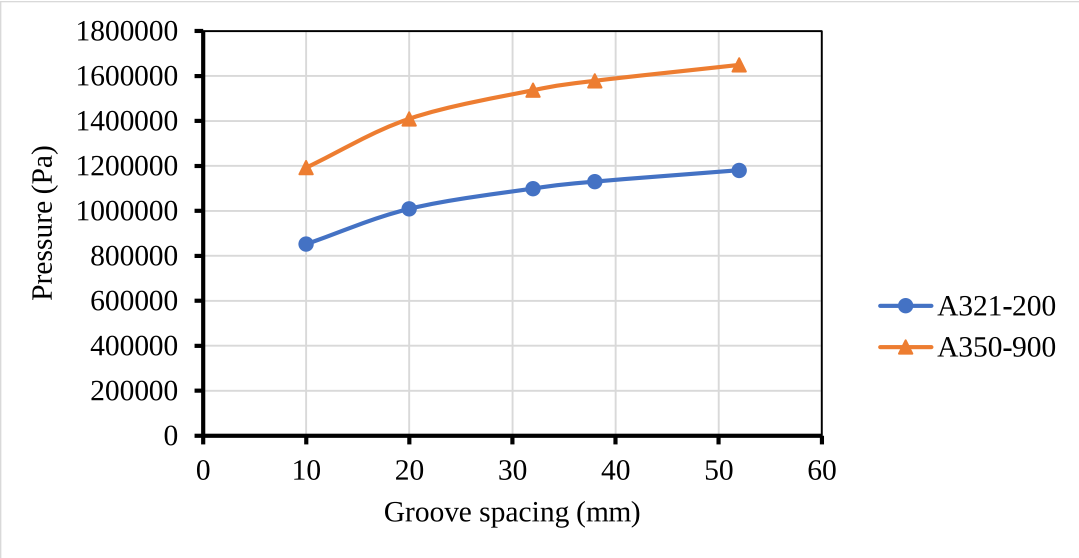

Fig. 4. Effect of transverse groove spacing on pressure under aircraft tires.

From the graph in Fig. 4, it can be seen that when groove spacing value increases, the pressure formed under the aircraft tire increases, leading to a decrease in the efficiency of using the transverse grooves. When the groove spacing value increases from 10 to 30 mm, the pressure under the tire increases rapidly, when groove spacing value is 30 mm or more, the pressure value increases gradually. According to FAA recommendations, the optimal groove spacing is 38 mm.

This transverse groove configuration has also been successfully applied at Noi Bai, Tan Son Nhat, Dien Bien Airport, bringing about clear effects on roughness and friction coefficient and is being deployed at Tan Son Nhat International Airport.

Fig. 5. Transverse groove construction in Noi Bai International Airport.

4. Conclusion

The article uses a 2D simulation analysis model using Ansys Fluent software to determine the influence of groove spacing on the pressure formed under the aircraft tire, a parameter that determines the risk of hydroplaning. From the simulation analysis results, the article constructs graphs of the relationship between groove spacing and pressure formed under the tire with a groove size of 6.35 mm × 6.35 mm in width and length to clarify the influence of transverse groove spacing on the effectiveness of preventing hydroplaning.

When the groove spacing value reduces (the number of grooves increases), the phenomenon of hydroplaning reduces. The distance between the grooves cannot reduce beyond certain values, however, because when groove spacing value reduces to a value less than 1.5Dmax of the crushed stone concrete mix, it is easy to cause chipping of the groove ribs, causing FOD objects that affect flight safety. Therefore, currently, in the FAA's recommendations, the groove spacing is chosen to be 38 mm (from center to center).

Acknowledgement

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ĐÁNH GIÁ ẢNH HƯỞNG CỦA KHOẢNG CÁCH RÃNH KHÁNG TRƯỢT ĐẾN HIỆN TƯỢNG TRƯỢT THỦY LỰC TRÊN BỀ MẶT ĐƯỜNG CẤT HẠ CÁNH SÂN BAY

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Tóm tắt: Trượt thủy lực là hiện tượng nguy hiểm trong quá trình khai thác tại các cảng hàng không sân bay gây mất khả năng điều khiển máy bay trong quá trình cất hạ cánh. Đối với điều kiện khí hậu nhiệt đới có lượng mưa trung bình hàng năm lớn như Việt Nam, nguy cơ xảy ra trượt thủy lực là rất lớn. Hiện nay, giải pháp phổ biến thường được sử dụng là xẻ rãnh kháng trượt trên bề mặt đường cất hạ cánh. Để đánh giá mức độ ảnh hưởng của khoảng cách rãnh kháng trượt đến hiện tượng trượt thủy lực, bài báo sử dụng phương pháp phân tích mô phỏng CFD bằng phần mềm Ansys Fluent nhằm đánh giá tác động của từng thông số cho 2 trường hợp máy bay A350-900 và A321-200. Từ kết quả nghiên cứu có thể khẳng định rằng, khoảng cách rãnh kháng trượt nhỏ, hiện tượng trượt thuỷ lực càng giảm đi, để đảm bảo độ ổn định cho kết cấu, khoảng cách rãnh kháng trượt không nên nhỏ hơn 38 mm theo đúng khuyến nghị của FAA và nhiều tổ chức hàng không thuộc ICAO.

Từ khóa: *Trượt thủy lực; đường cất hạ cánh; cảng hàng không-sân bay; Ansys Fluent; CFD; rãnh kháng trượt.*

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