International Association of Chinese Infrastructure Professionals

THE 13th IACIP Annual Workshop: Adaptive Infrastructure under Climate Change

Analysis of skid resistance and braking distance of aircraft tire landing on grooved runway pavement

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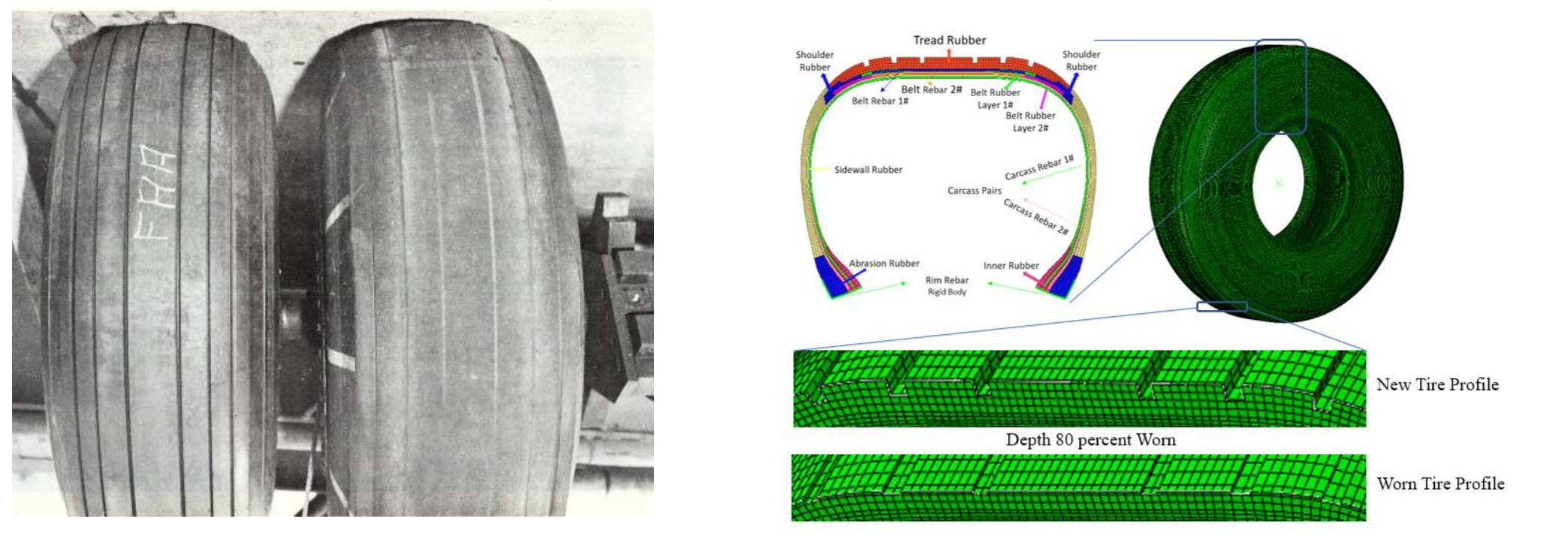
INTRODUCTION

- Many situations occurred during the aircraft landing process will affect safety risk, such as high approach speed and height, delayed touchdown location from the threshold, and wet or flooded covered runway (Van Es, G. W. H 2005).
- Although the field experiments provided direct measurement of skid resistance and braking performance of aircraft tire on runway, the testing procedure is time consuming and labor intensive to match practical landing operational conditions.
- The current numerical simulation approaches to calculate braking distance cannot take all the factors into considerations, such as locked wheel tire sliding without rolling and neglecting deterioration of tire wear.
- Moreover, Few studies on numerical simulation of aircraft tire have validated tire model and considered the effect of worn tire on the braking performance on wet grooved runway.
- Few studies considered the effect of wet friction between runway surface and aircraft tire model to compute the braking distance of landing aircraft during ground rolling under various conditions.
  The objective of this paper is to evaluate skid resistance and braking distance of aircraft tire during aircraft landing process using tire-water-pavement interaction modeling.

AIRCRAFT TIRE MODEL CONSTRUCTION

- The cross-section model of the simulated 49 × 17 aircraft tire was built using the general dimension and the measured tire profile reported in the literature (Tielking 1989).
- The outer radius of tire is 622 mm. The tire height is 351 mm. The wall-to-wall tire width is 427 mm with six grooves.
- For the worn tire profile, the depth for all the grooves was considered 80 percent worn and the depth was 20 percent of that in the new tire profile



Demonstration of Aircraft Tire Structural Profile

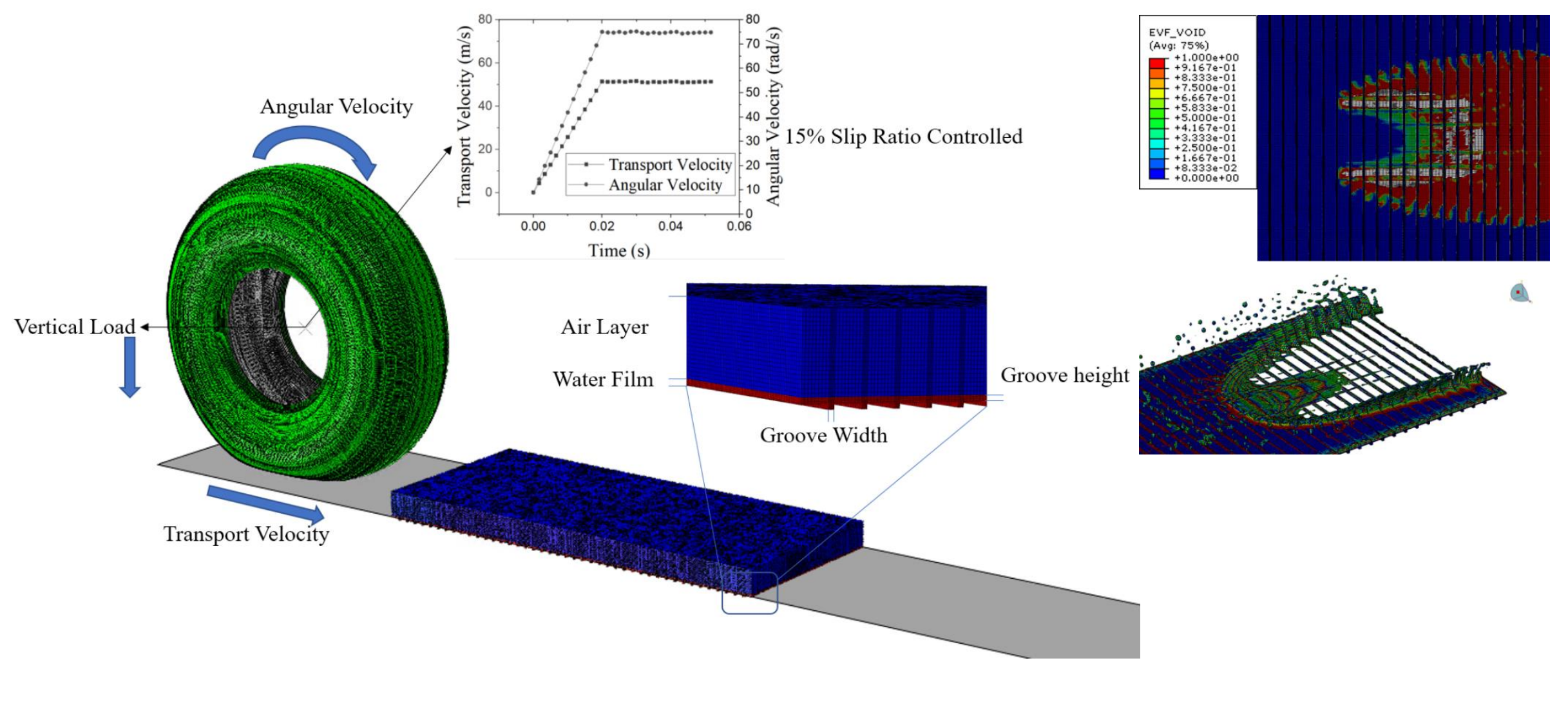
- The rubber components and reinforcements were simplified as linear elastic material
- The material parameters were calibrated based on experimental measurements of tire footprints and load-deflection curves that indicates tire contact behavior and stiffness.

Tire Model Material Parameters

Component / Property	Modulus (MPa)	Density (Kg/m^3)	Poisson's Ratio
Tread Rubber	25	1.17E+03	0.45
Inner Rubber	25	1.17E+03	0.45
Sidewall Rubber	6	1.17E+03	0.45
Belt Rubber #1 & #2	15 & 8	1.17E+03	0.45
Shoulder Rubber	30	1.17E+03	0.45
Abrasion Rubber	40	1.17E+03	0.45
Belt Rebar #1 & #2	1.20E+04	1.17E+03	0.28
Carcass Rebar	2.00E+04	1.17E+03	0.23
Rim	Rigid body	1.17E+03	-

FLUID-STRUCTURE INTERACTION MODEL

- The Coupled Eulerian–Lagrangian (CEL) method has been utilized to study the hydroplaning characteristics of the simplified FE modeling tire.
- The aircraft tire was loaded first than then accelerated to the specific transport velocity and angular velocity to reach the desired slip ratio while rolling towards the fluid domain at certain distance away on the grooved pavement.



Tire-Water-Pavement Interaction Model on Grooved Pavement

- A thin layer of Eulerian water elements was placed in the grooves and above the pavement surface, above which is the air elements.
- The squared grooves with 6.35 mm (0.25 inch) in depth, 6.35 mm (0.25 inch) in width, and 38.1 mm (1.5 inch) in center-to-center spacing was used for validation in this study.

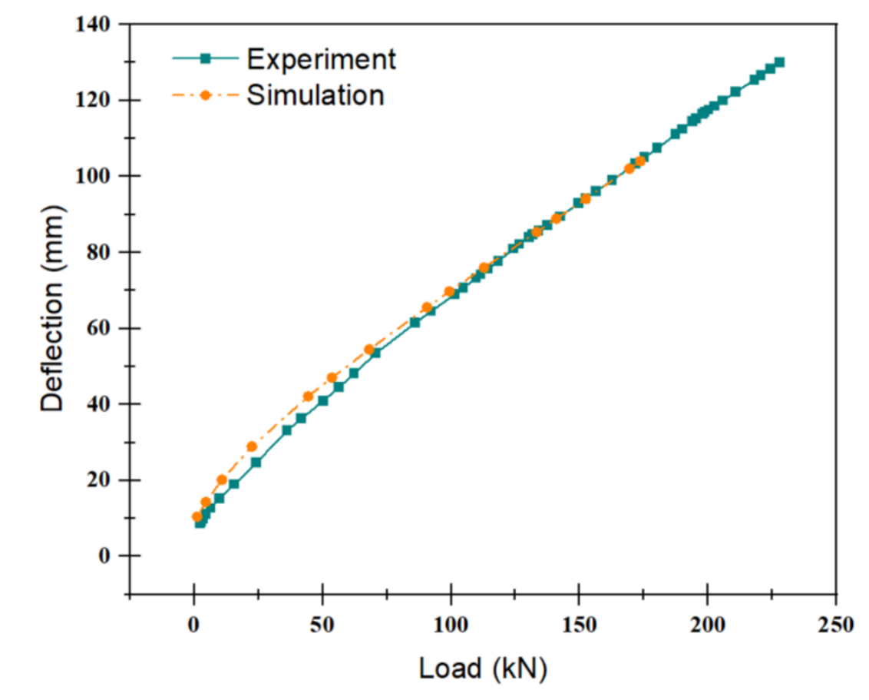
TIRE VALIDATION & FRICTION COMPARISON

- The good match between the tire contact footprint obtained from simulation results and measurements under different test loads was obtained.
- The tire load-deflection curve compares well with the measured data published in the previous report.

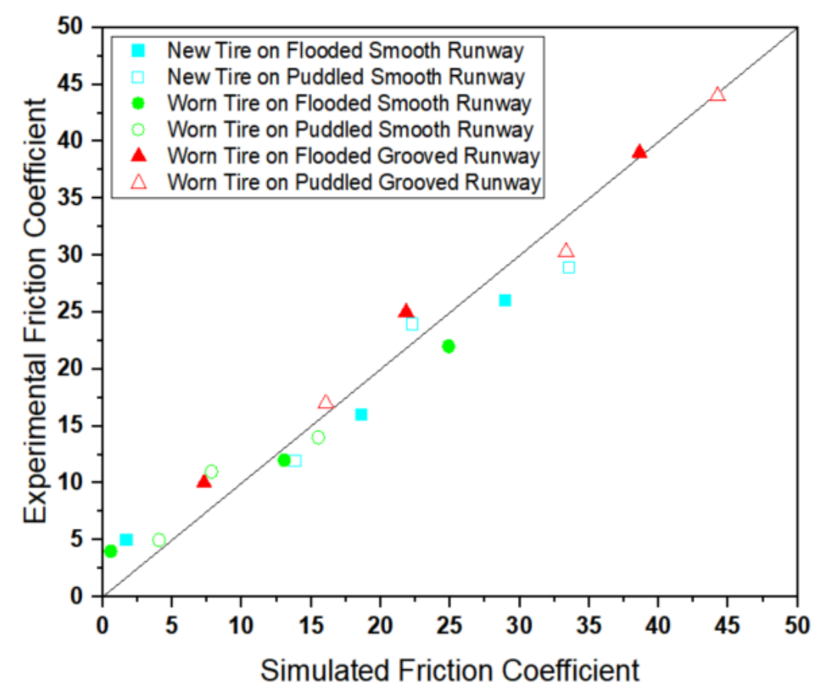
Applied load (kN) (1.31-MPa pressure)	Simulated Tire Footprint			Measured Tire Footprint		
	Length (mm)	Width (mm)	Aspect ratio (width to length)	Length (mm)	Width (mm)	Aspect ratio (width to length)
106.8	406.5	238.2	0.59	393.7	247.7	0.63
160.1	469.9	279.4	0.59	467.8	279.3	0.60
200.1	520.7	298.5	0.57	528.6	307.0	0.58

Comparison of Contact Footprint

- The simulated skid resistance of both new and worn tires rolling under different velocities (three speeds for each scenario), and two water film thickness (flooded and puddled) were plotted against experimental data



Validation of LD Curve

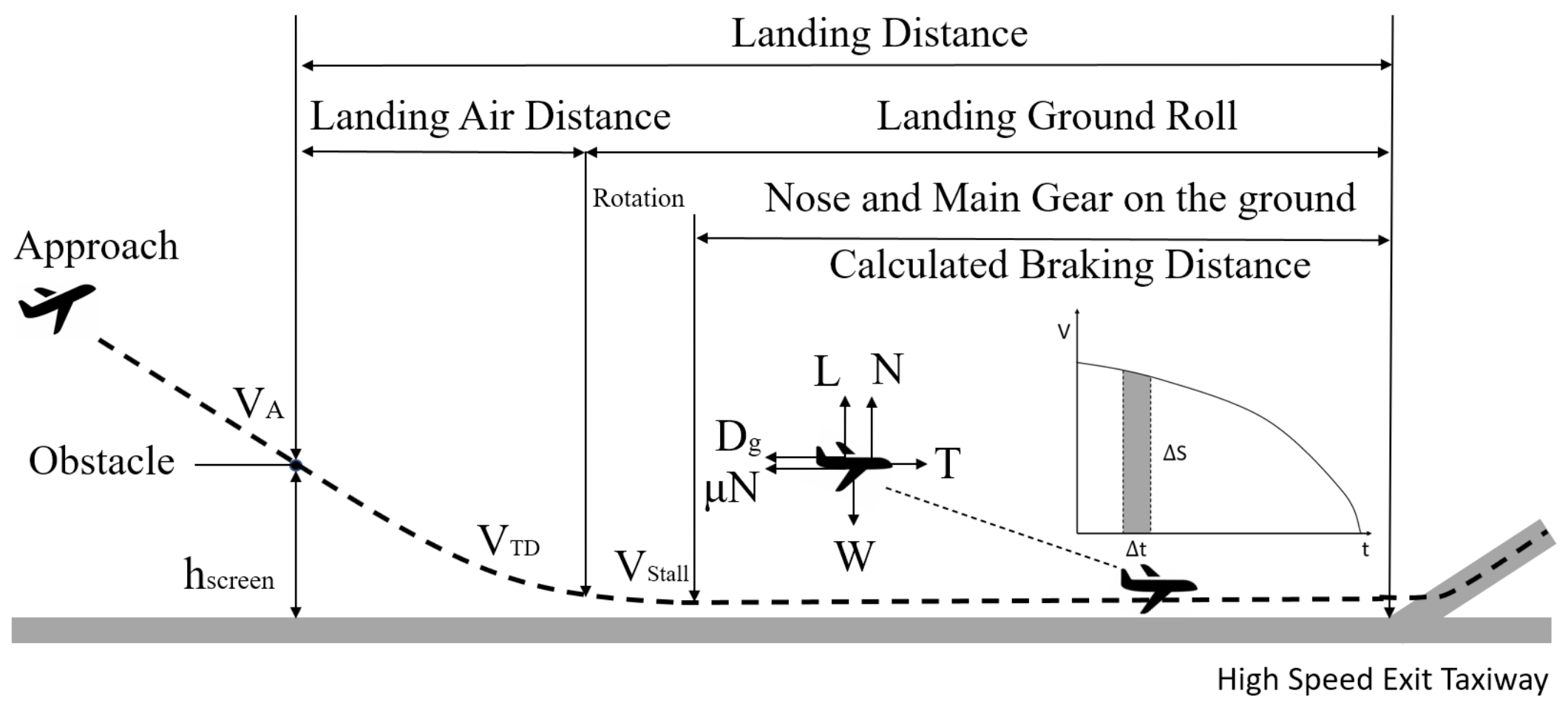


Comparison of Friction

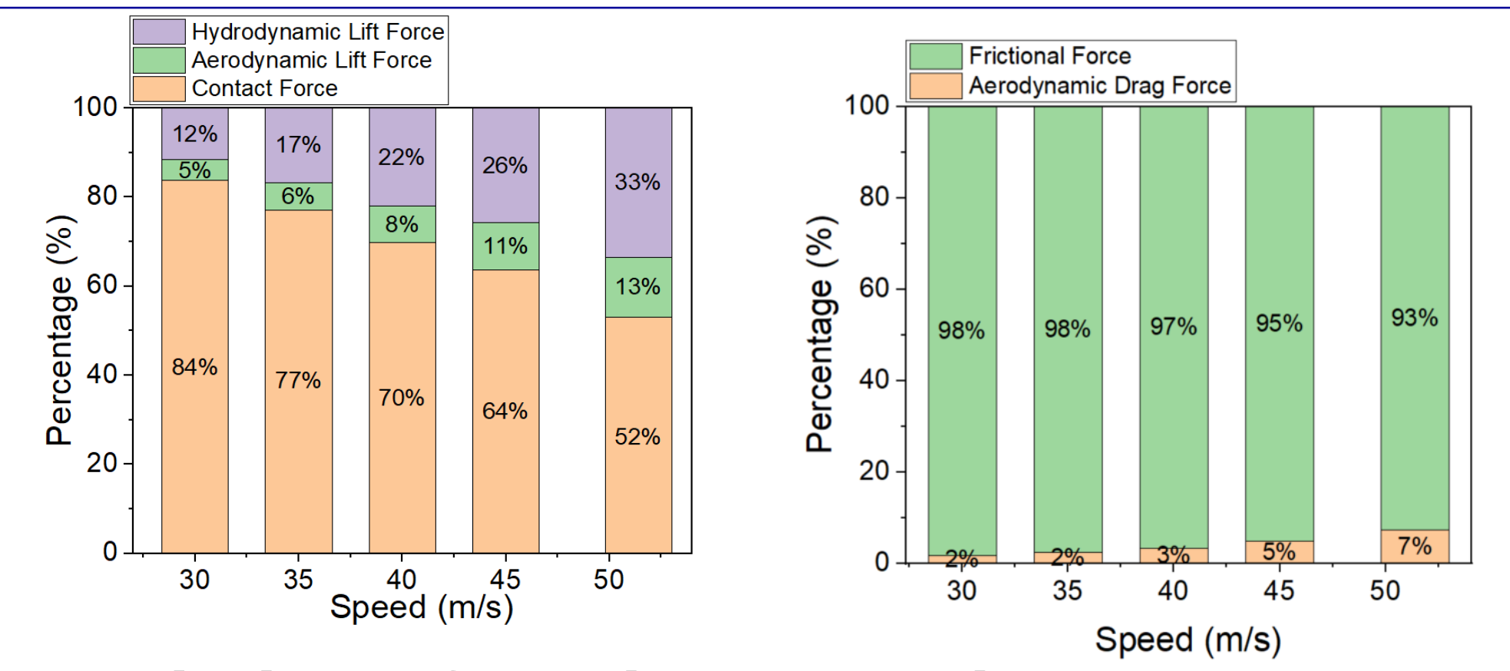
CALCULATION OF BRAKING DISTANCE

- The landing approach speed is about 1.3 times the stall speed at landing; the stall speed at landing is assumed as the initial braking speed; the approach speed of A320 was selected as 66.88 m/s (130 knots) and the initial braking speed was determined as 51.4 m/s empirically.

$$S=\int_{V_{stall}}^{V_{end}}\frac{V}{a}dV=\int_{V_{stall}}^{V_{end}}\frac{V}{-\left[\mu g+\frac{g\rho V^2A(C_D-\mu C_L)}{2W}\right]}dV$$



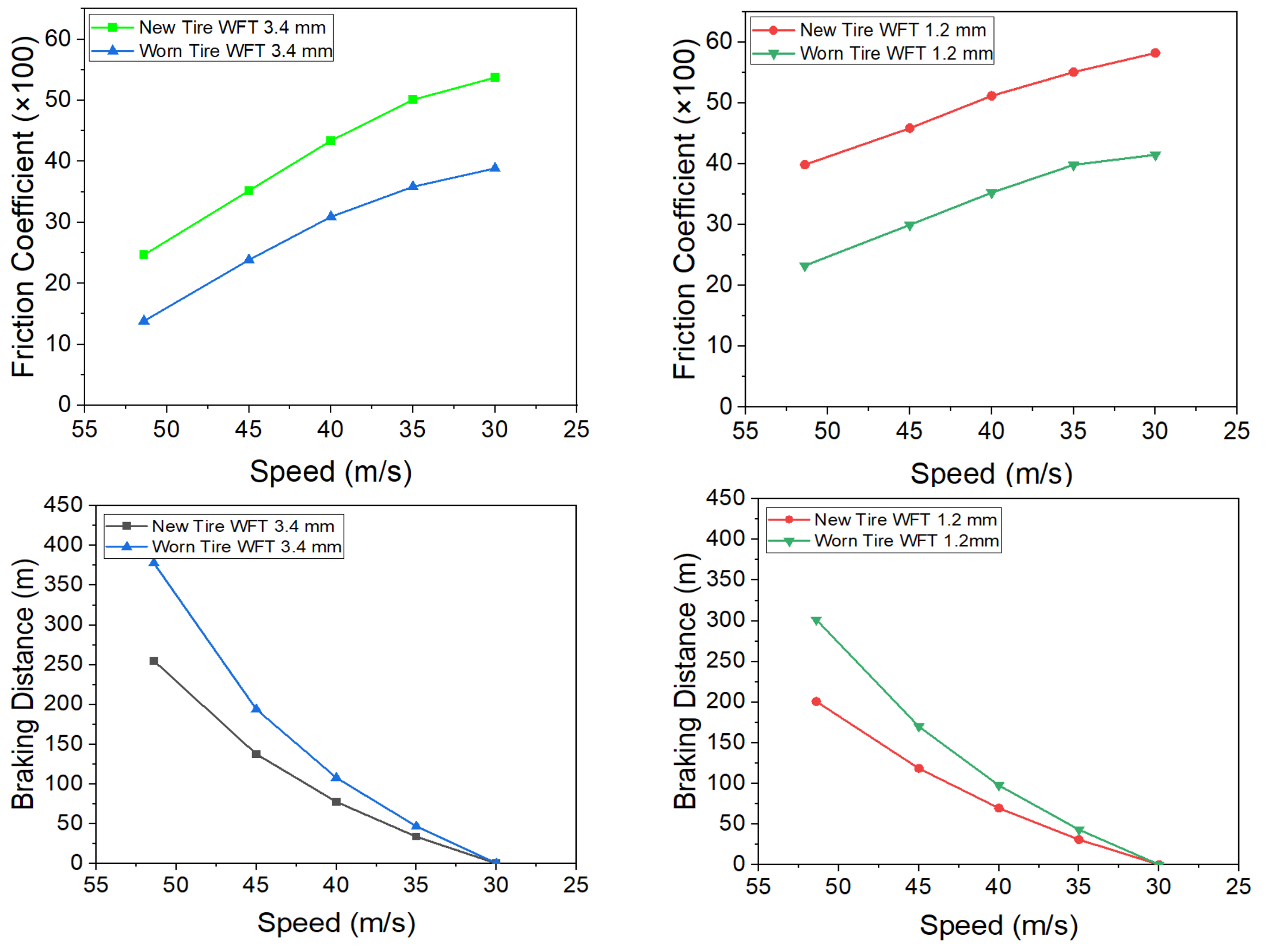
Methodology for the Calculation of Braking Distance (Kermode 1997)



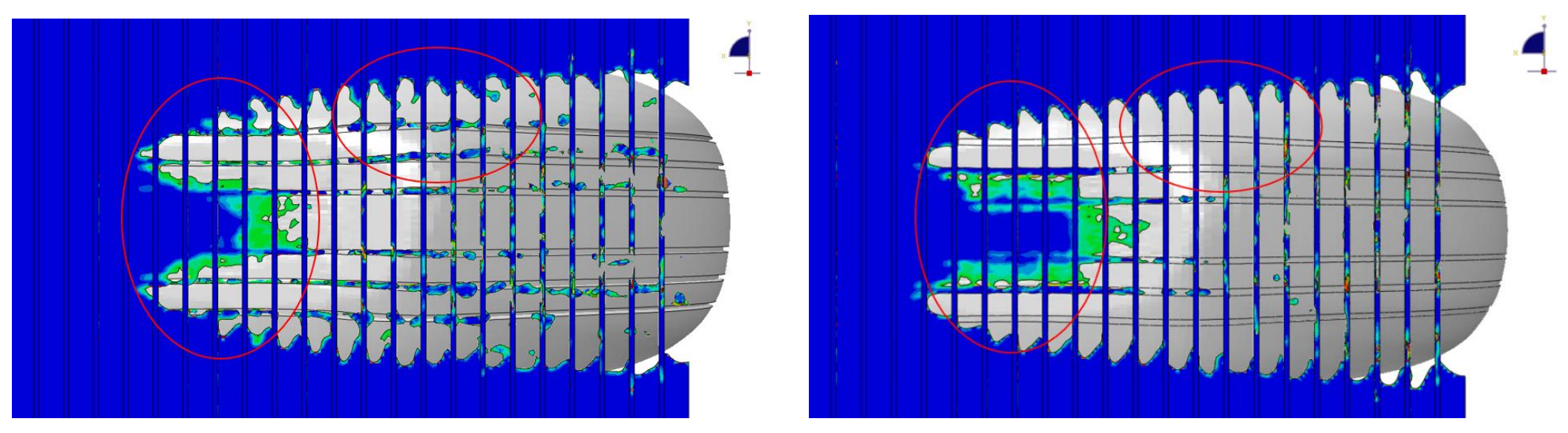
Variation of Vertical & Horizontal Forces

RESULTS & DISCUSSION

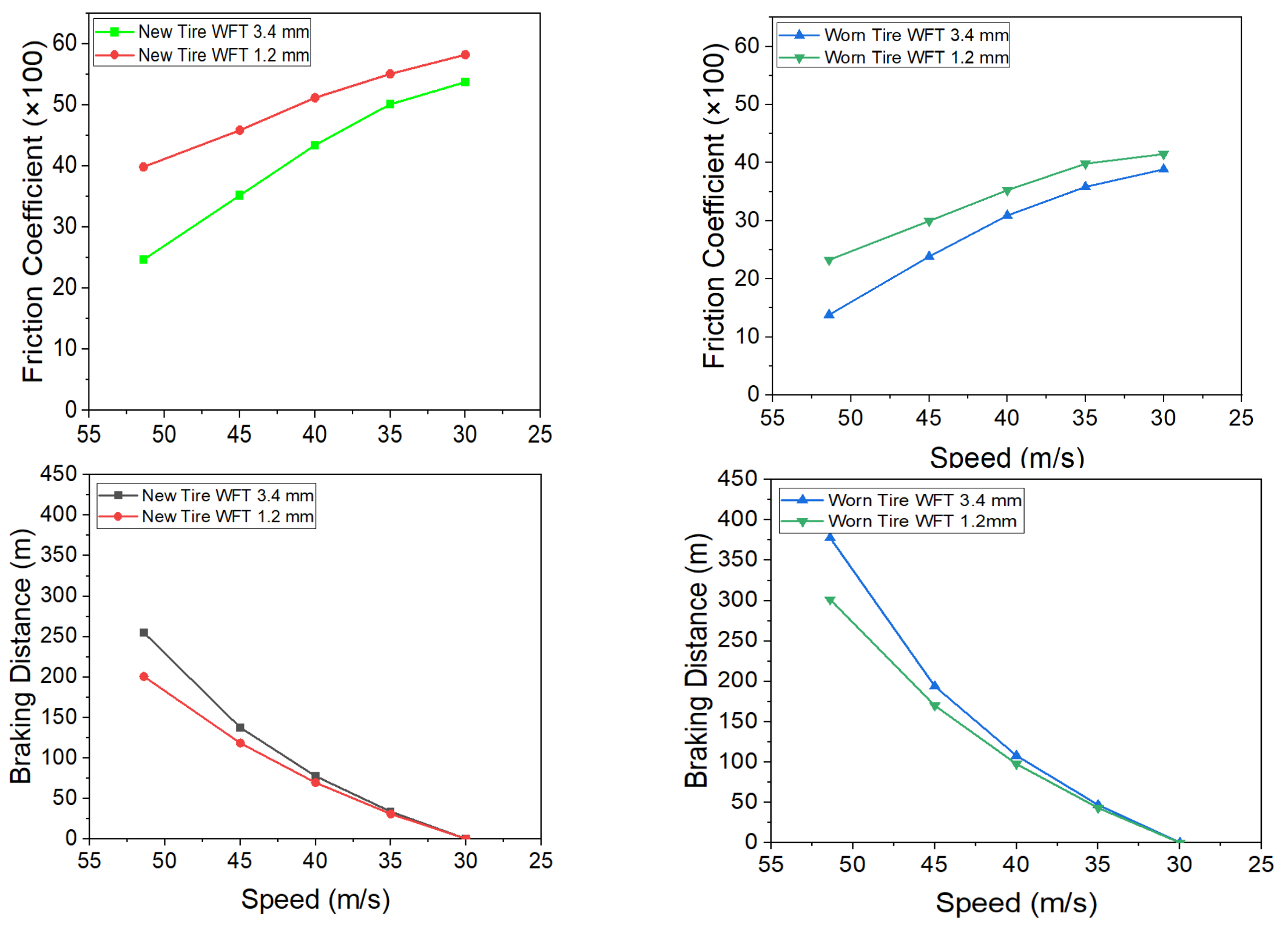
- The results indicate that the skid resistance and the calculated braking distance suggest significant reduction due to the loss of tire tread depth.



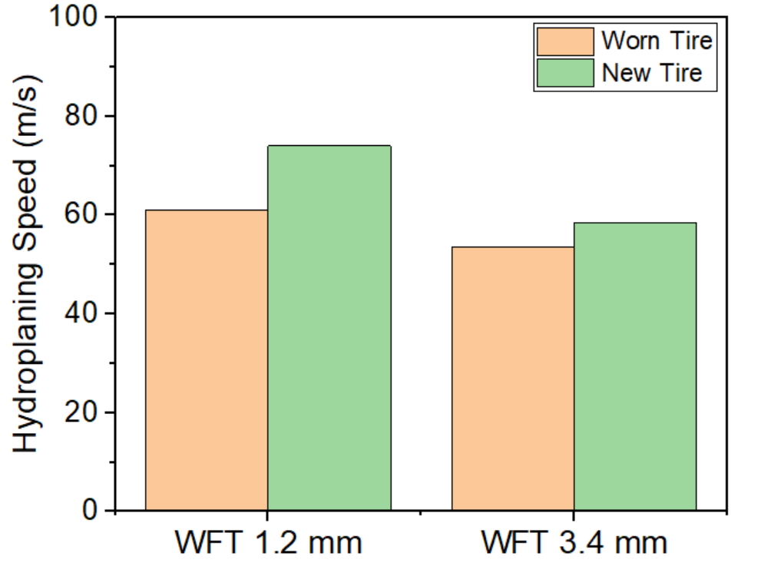
Effect of Tire Wear on FC and BD



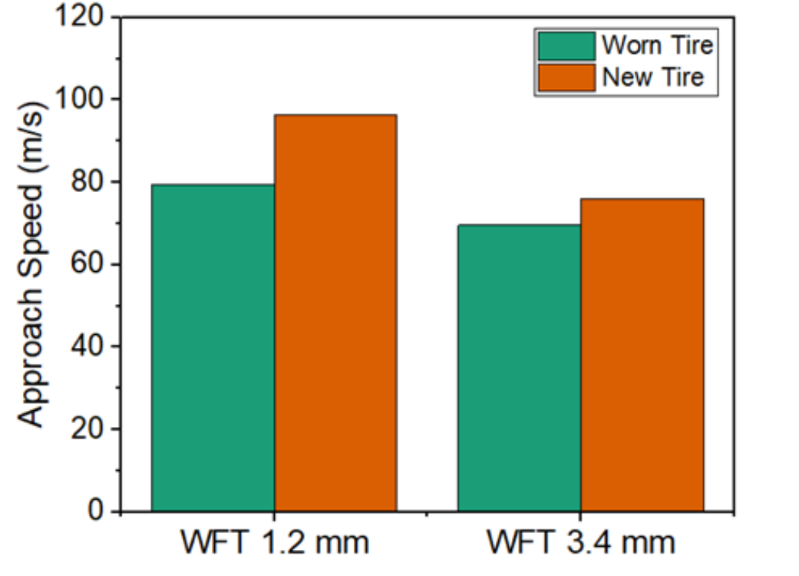
Contact Area & Drainage Path of New Tire & Worn Tire



Effect of Water Film Thickness on FC and BD



Predicted Hydroplaning Speed after TD



Required Maximum TD Speed

CONCLUSIONS

- The developed tire-water-pavement interaction model using CEL method and the introduced methodology considering the aircraft landing configurations have potential to predict the skid resistance and braking distance during aircraft ground landing on the wet grooved runway.
- During aircraft ground rolling, the skid resistance decreases with the increase of ground speed, water film thickness, and tire wear. In particular, the loss of tire wear significantly decreases skid resistance and increases braking distance.

Low Carbon Technologies and Resilience for Long-Lasting Infrastructure

The 12th Annual Workshop of the International Association of Chinese Infrastructure Professionals (IACIP)

January 2022