An advanced method to relate ground friction measurements to aircraft braking

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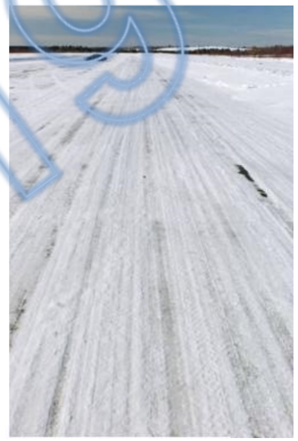
Introduction

Ice and 5 mm of dry snow

Ice

Standing water

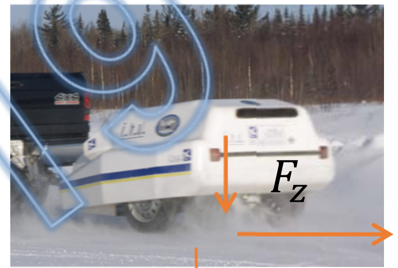


Dry snow over compacted snow

What will aircraft braking performances be on such runways?

Introduction

1 – Reverse thrust 2 – Aerodynamic drag



$$M\,a = F_R - F_A - F_D - F_B \longrightarrow F_B = \mu_B (Mg - F_L)$$

$$LFC = \frac{F_x}{F_z}$$

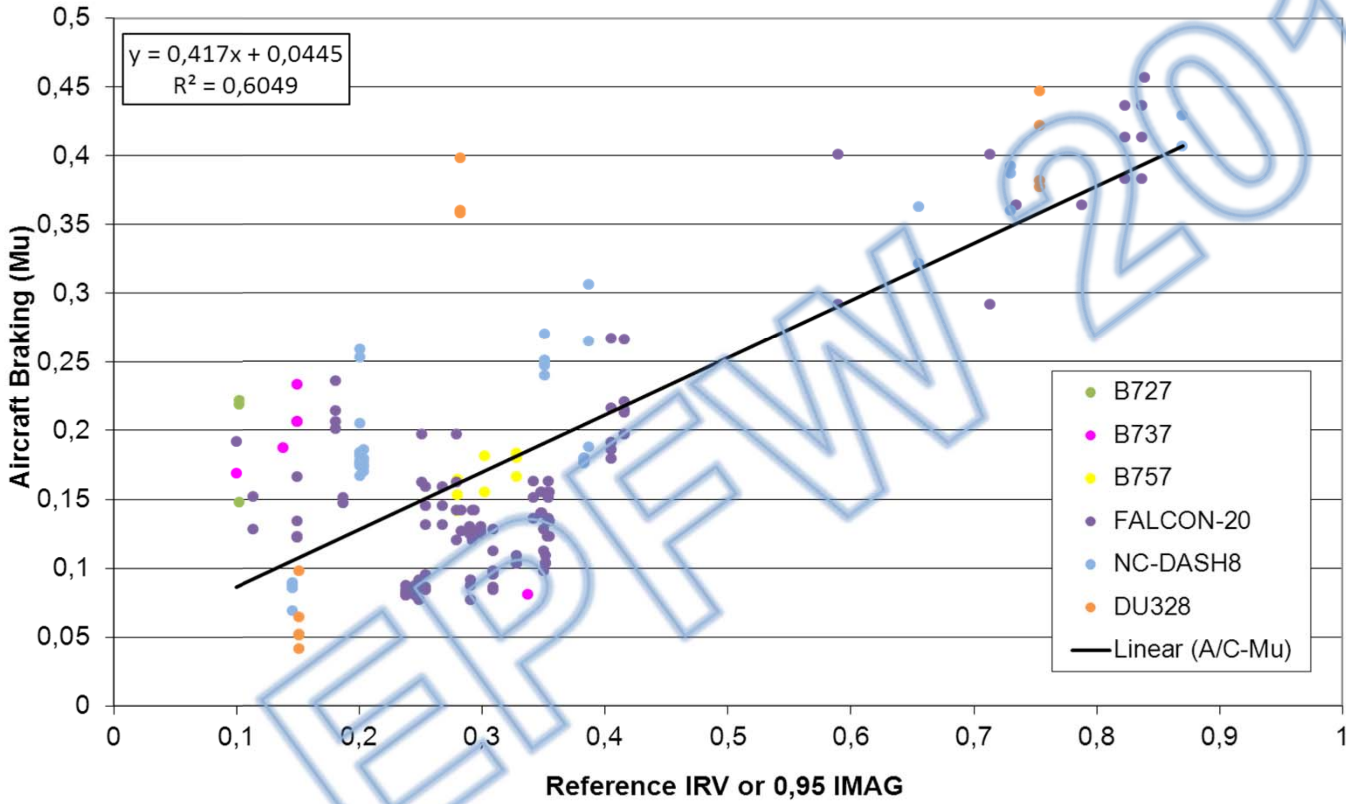
3 – Projection and compression drag

4 – Mecanical braking

Can aircraft braking coefficient be predicted from the Longitudinal Friction Coefficient?

State of the art

Previous approach



[Yager et al., 1988]
[Yager, 1996]
[Croll et al., 2002]
[Wambold et al., 2003]

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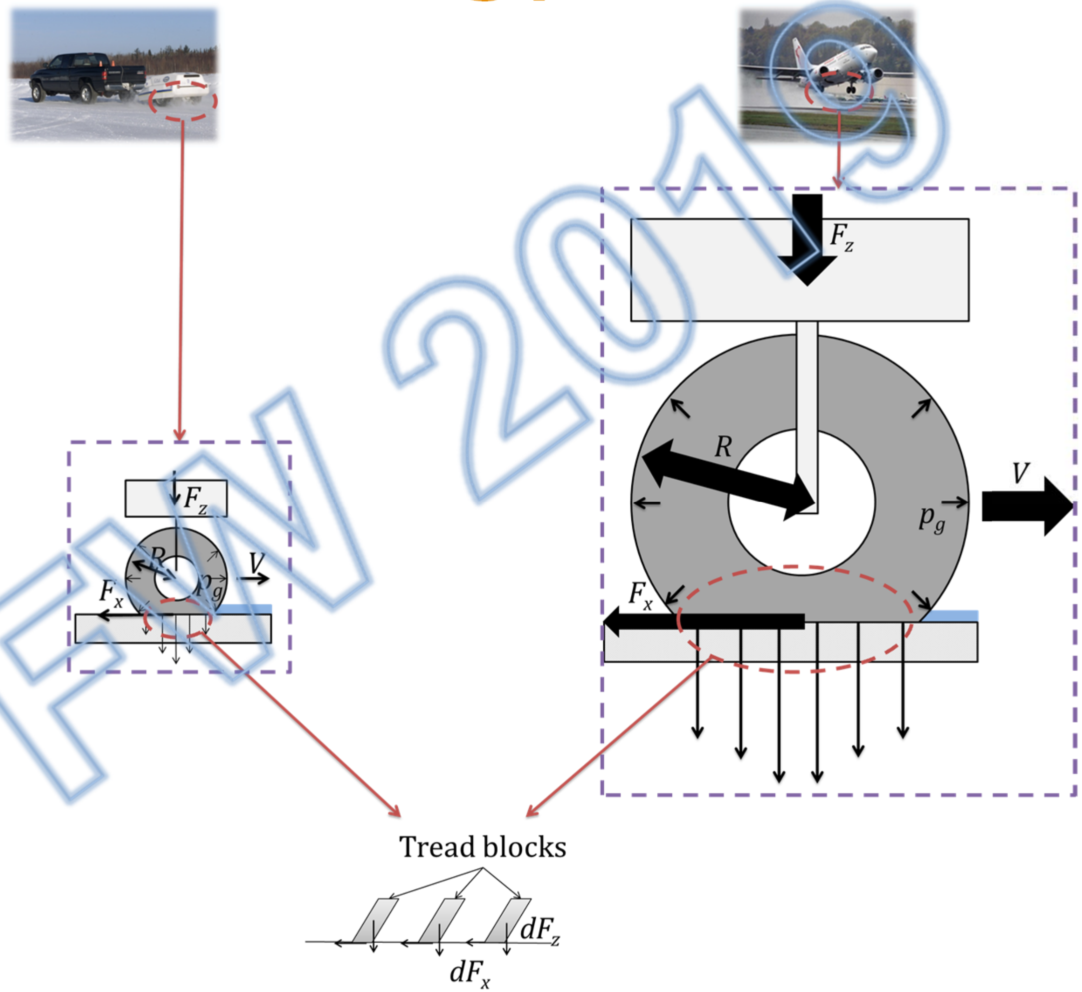
Research methodology

Vehicle

Tire/runway contact

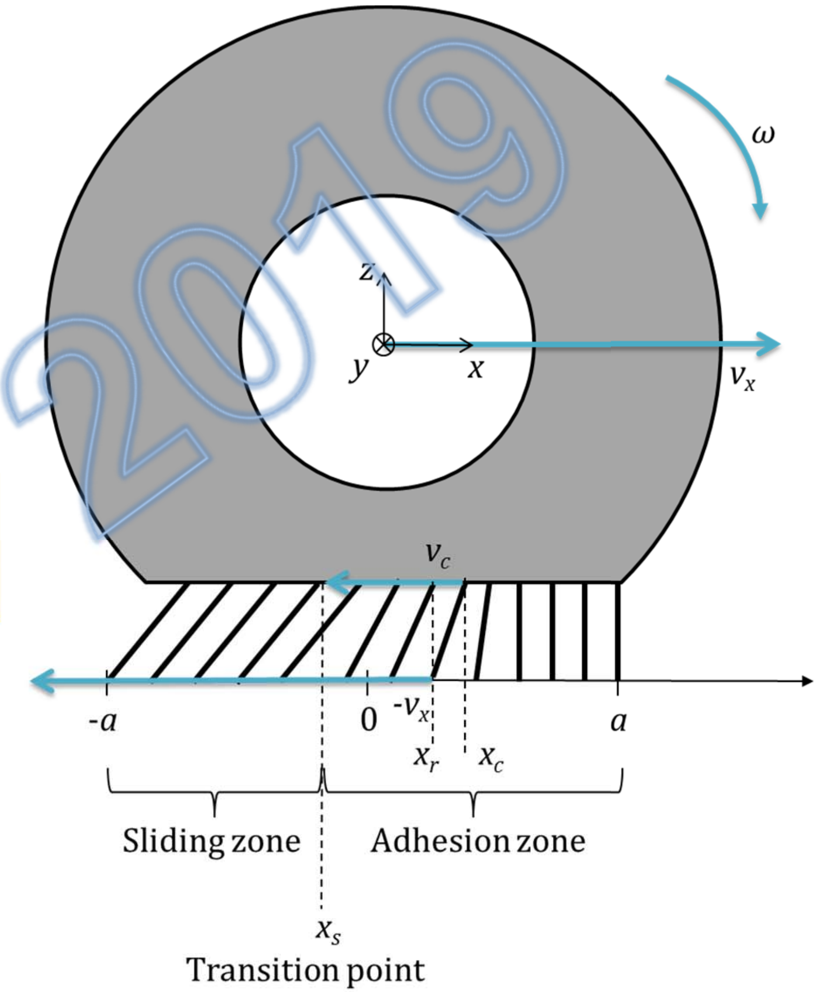
Tread block/runway contact



Tire Brush model

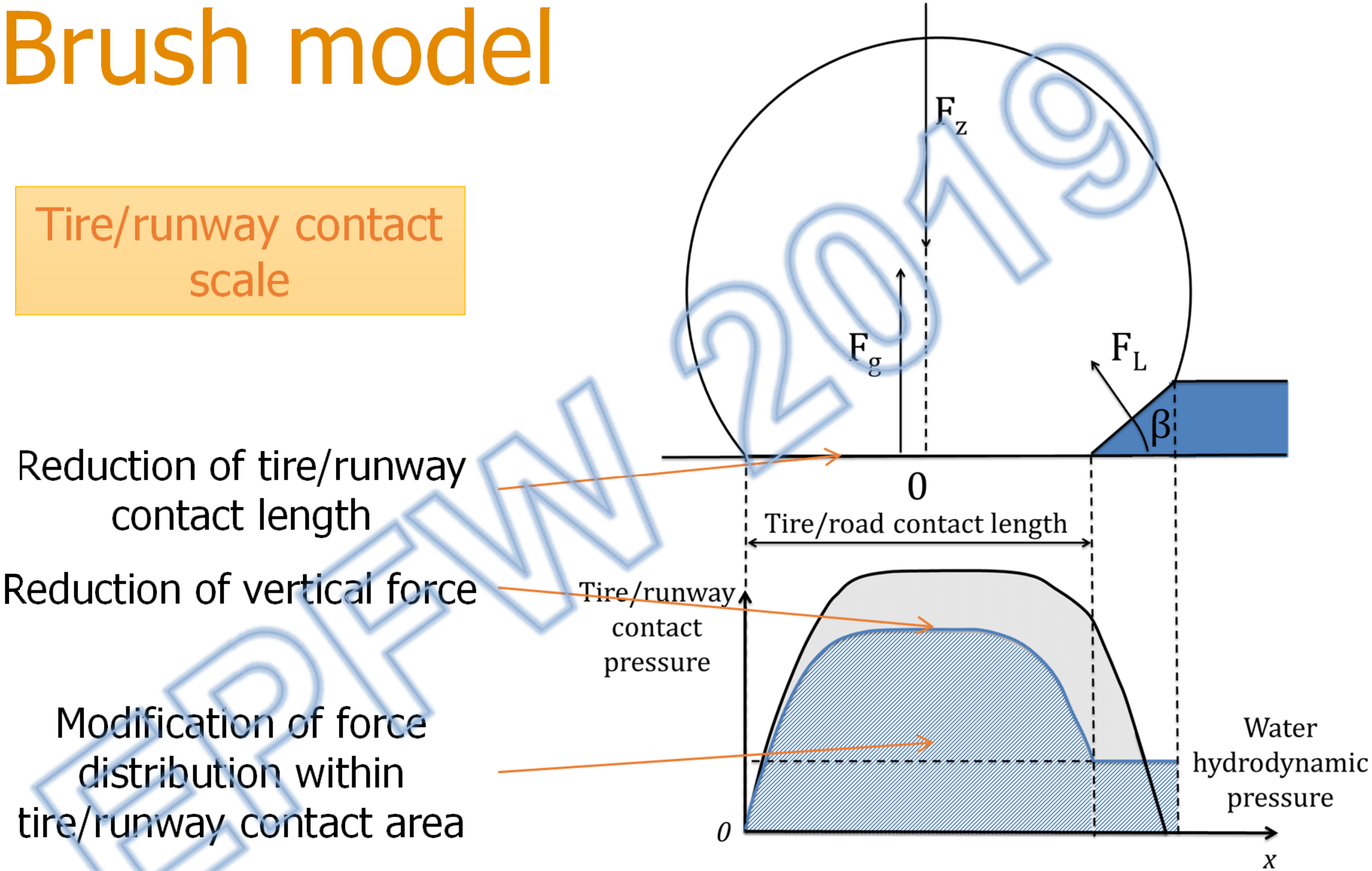
Brush model
- Automobile [Svendenius, 2007]
- Aircraft, dry contact [Jones, 2012]

Adapt the model to contaminated runways

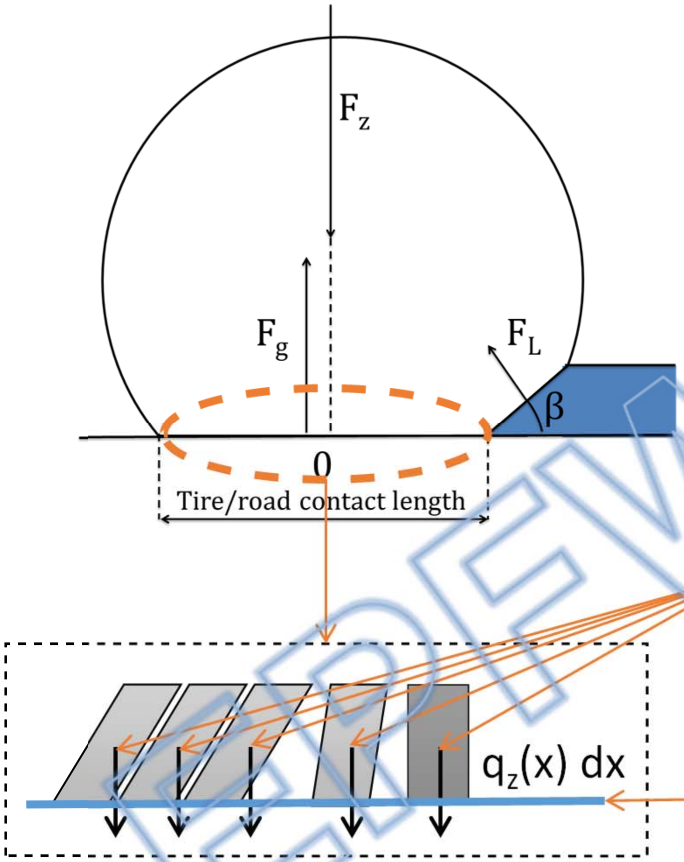


Inclusion of water effect into the Brush model

Tire/runway contact scale



Inclusion of water effect into the Brush model



Tread block/runway contact scale

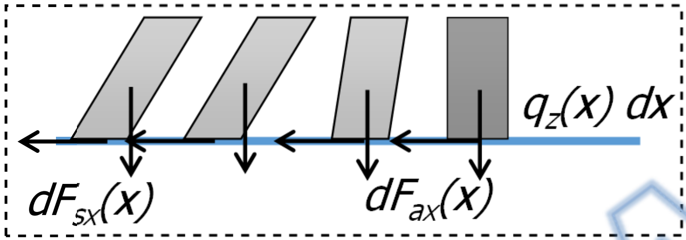
A reduced vertical load on the tread blocks

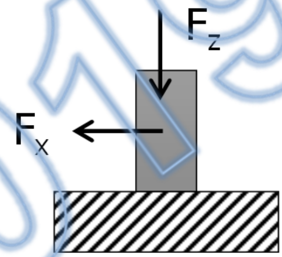
A remaining microfilm of water => not a pure dry contact

Static and dynamic friction coefficients

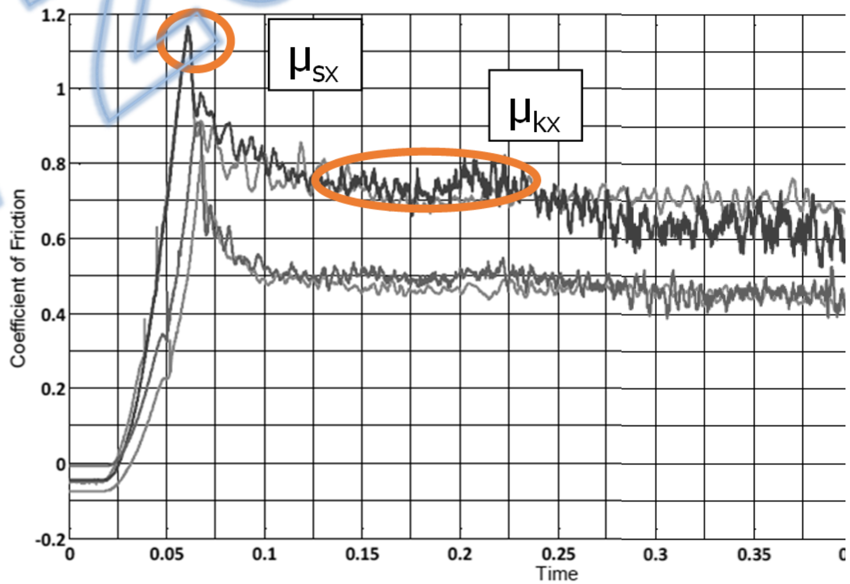
$$\mu_{kx} = \frac{1}{q_z(x)} \frac{dF_{sx}(x)}{dx}$$

$$dF_{ax}(x) \leq \mu_{sx}\, q_z(x) dx$$





[Jones, 2012]

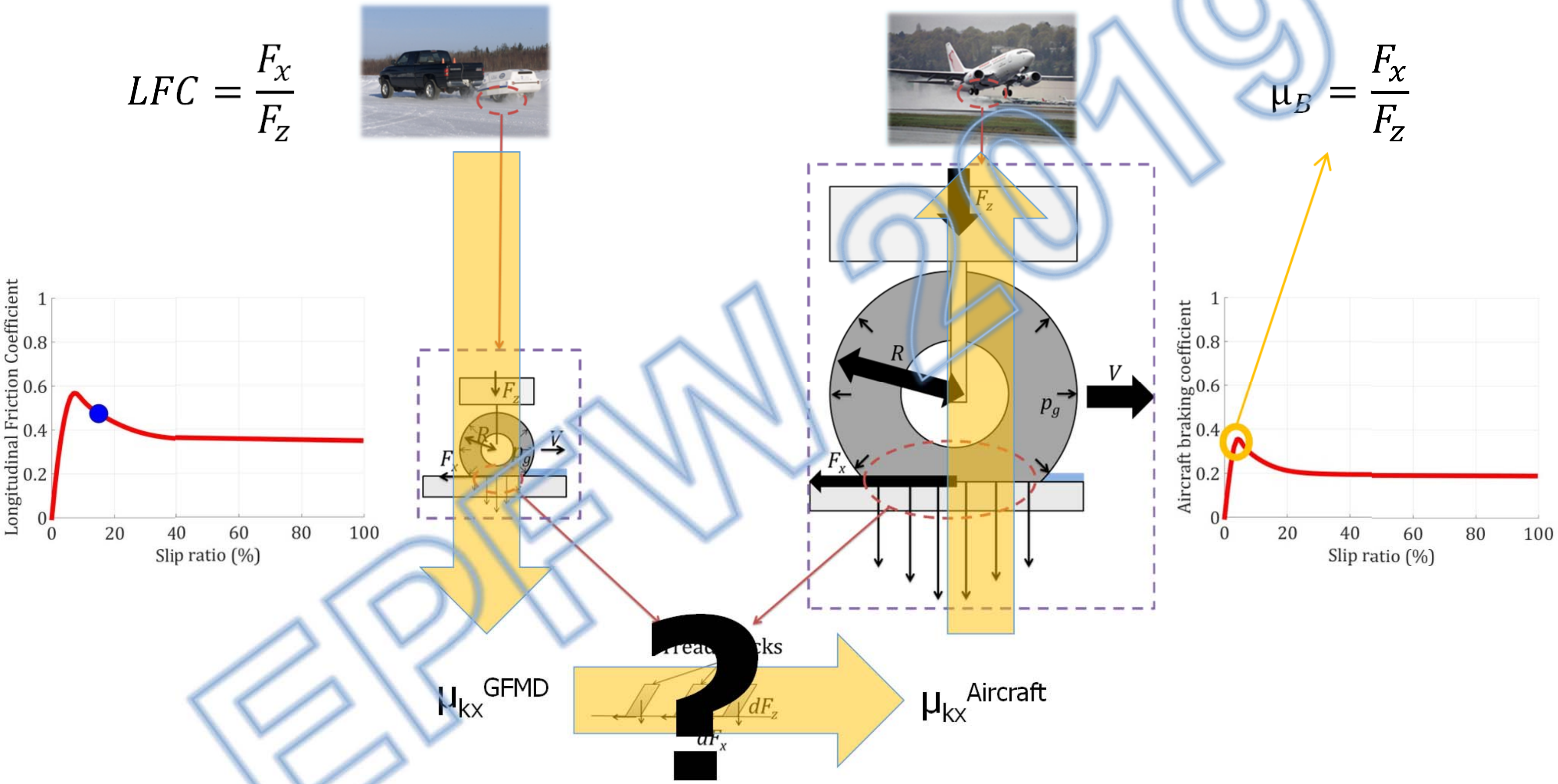


$$\mu_{sx} = \frac{\mu_{kx}}{Av_x + B}$$ [Dugoff, 1970]

Callibration

[J. Gerthoffert, V. Cerezo, M. Thiery, M. Bouteldja, M-T. Do (2019), A Brush-based approach for modelling runway friction assessment device, International Journal of Pavement Engineering]

Prediction of aircraft braking coefficient



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Friction model

μ_{kx} related to the real contact area

↓

Tire/runway direct contact described by a Hertzian contact

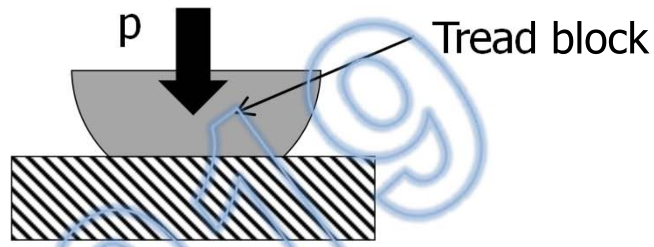
↓

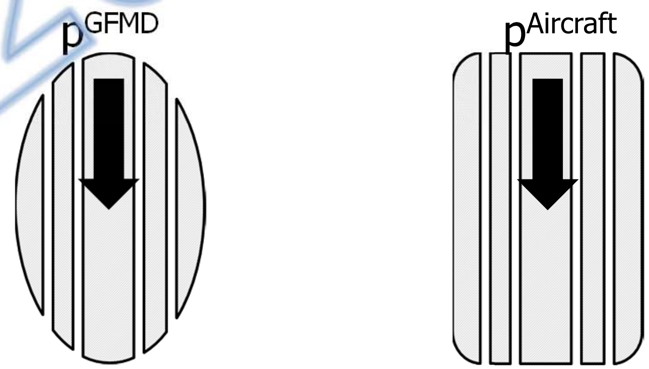
$$\mu_{kx} = C\left(\frac{p}{E}\right)^{-k}$$

↓ $E^{GFMD} \approx E^{aircraft}$

$$\frac{\mu_{kx}^{Aircraft}}{\mu_{kx}^{GFMD}} = \left(\frac{p^{Aircraft}}{p^{GFMD}}\right)^{-k}$$

[Schallamach, 1952]
[Schallamach, 1958]
[Archard, 1957]
[Thirion, 1966]
[Berger, 2000]
[Trinko, 2007]
[Koutny, 2007]
[Van der Steen, 2010]





250 - 500 kPa

1000 - 2000 kPa

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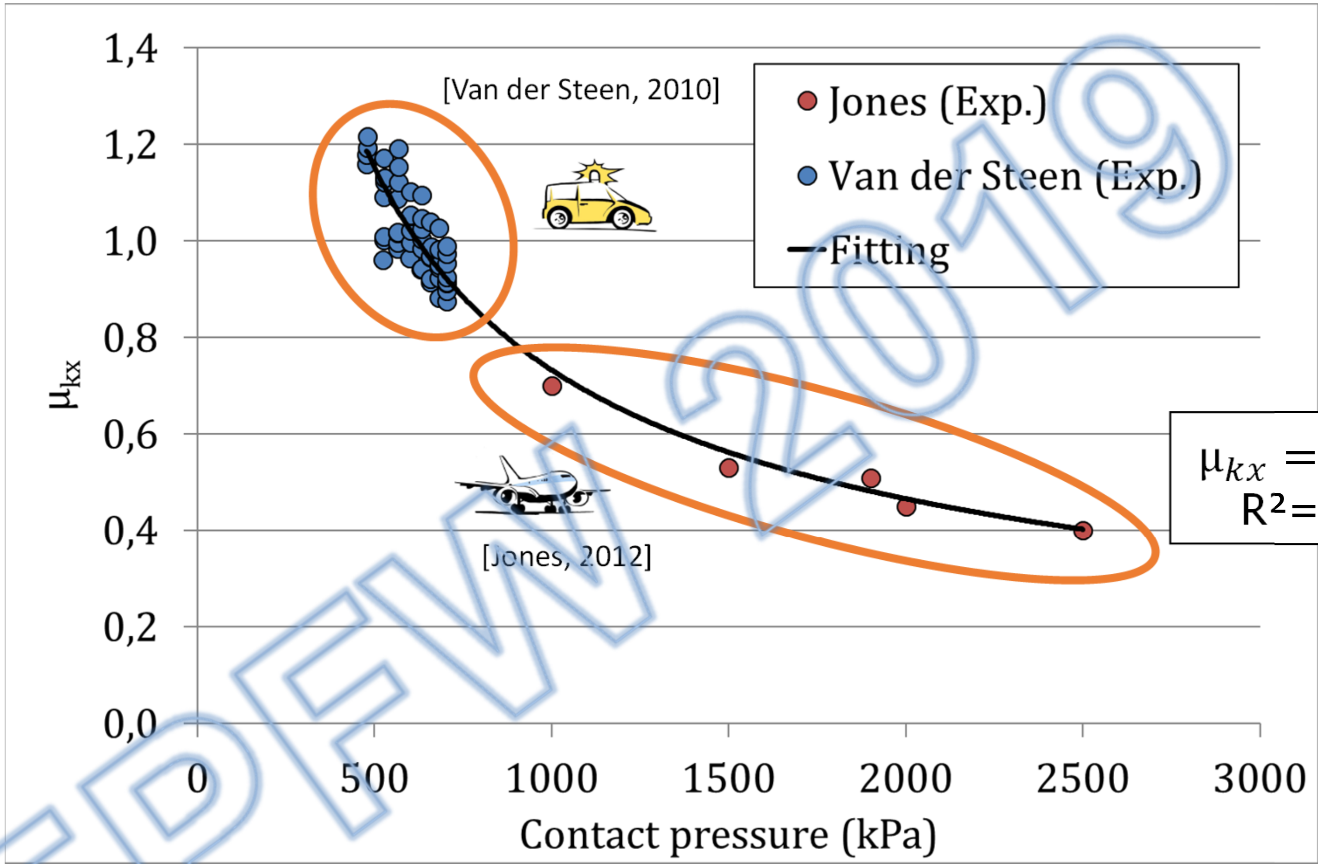
Friction model



$\mu_{kx} = C\,p^{-k}$

$R^2 = 0{,}94$

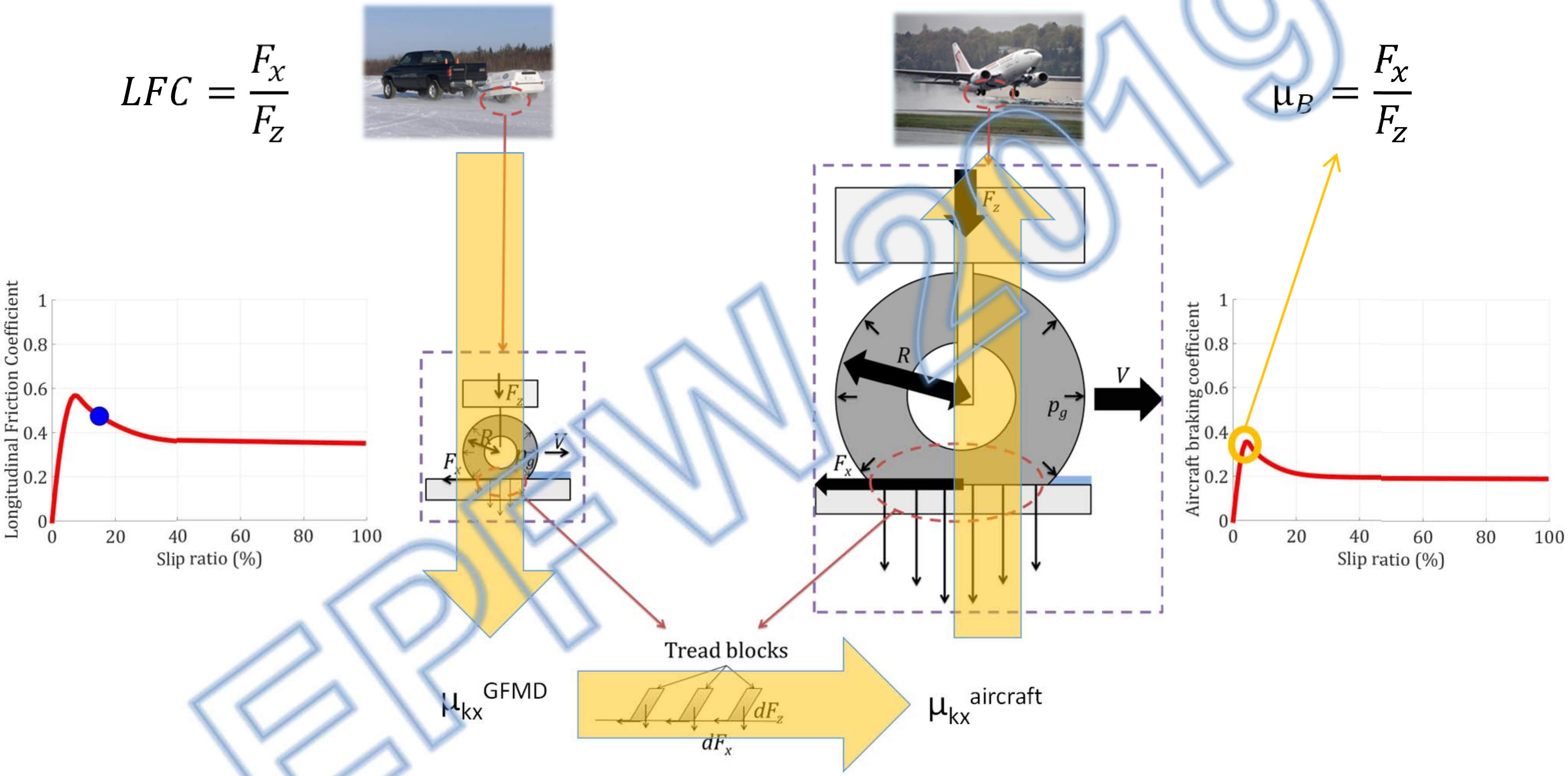
GFMD/Aircraft connexion

$$\frac{\mu_{kx}^{Aircraft}}{\mu_{kx}^{GFMD}} = \left(\frac{p^{Aircraft}}{p^{GFMD}}\right)^{-k}$$

Prediction of aircraft braking coefficient

$$LFC = \frac{F_x}{F_z}$$

$$\mu_B = \frac{F_x}{F_z}$$



$$\frac{\mu_{kx}^{aircraft}}{\mu_{kx}^{GFMD}} = \left(\frac{p^{aircraft}}{p^{GFMD}}\right)^{-k}$$

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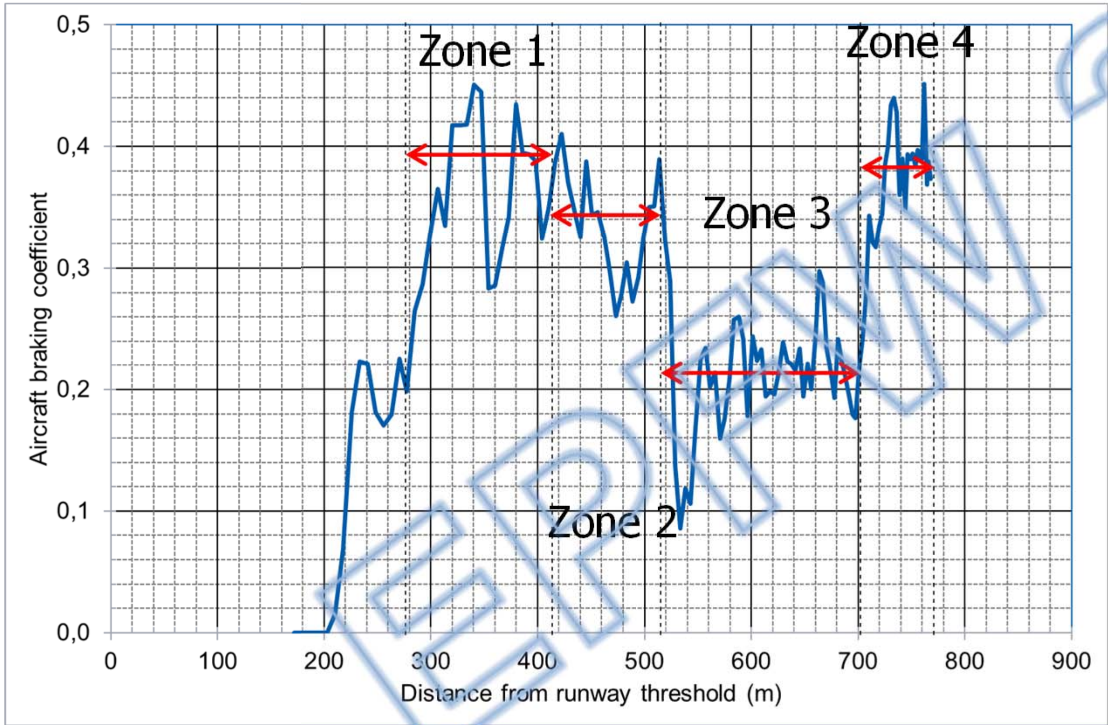
Experimental data

IMAG/Aircraft intercomparison

Runway length : 1900 m
Braked length : 558 m



IMAG device

Runway central axis

Bleeding

Landing threshold

4 IMAG/aircraft couples

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Experimental data

Extraction of JWRFMP data base

[illegible]

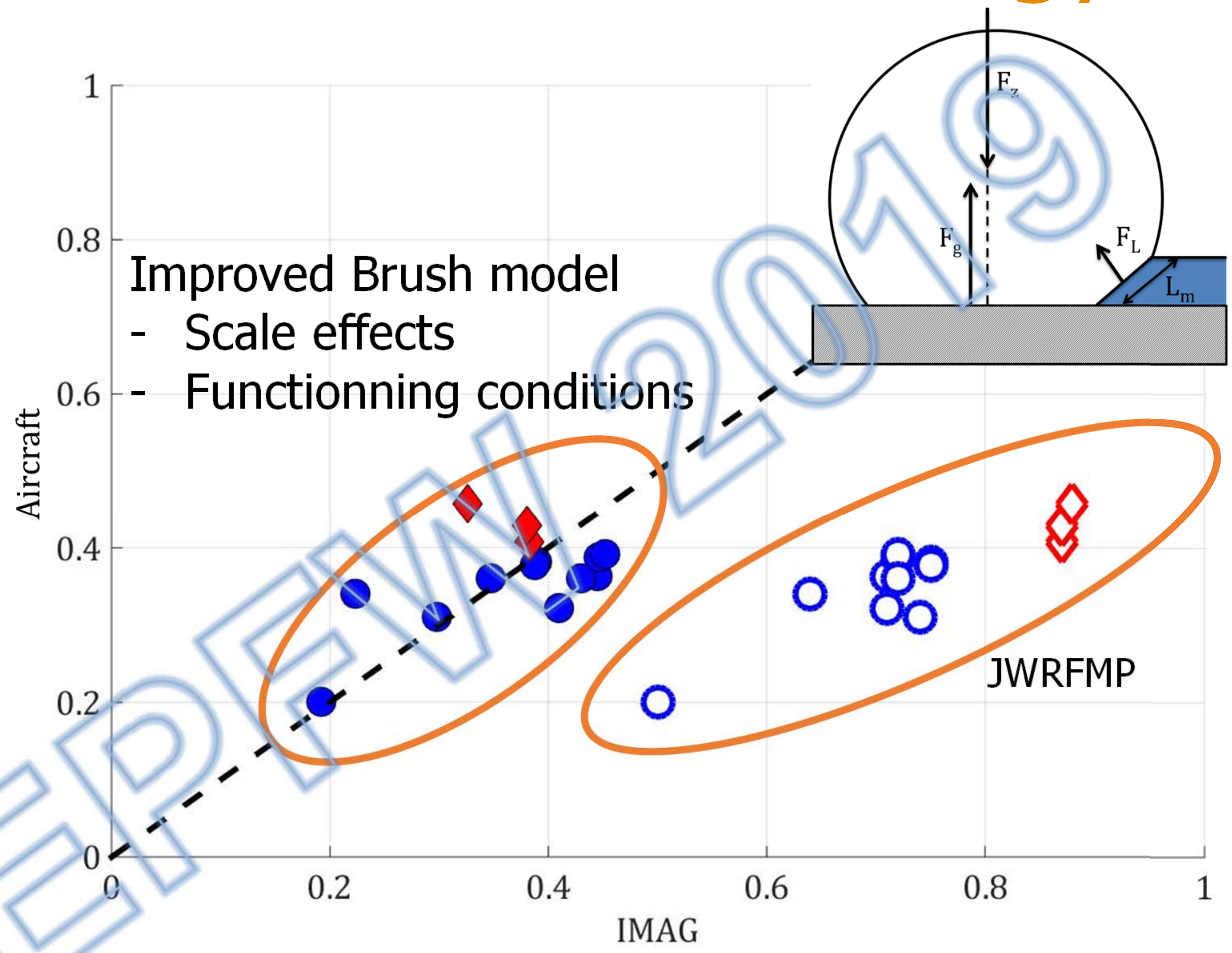
Aircraft	Dry	Wet	Dry snow (<3 mm)	Dry snow (>3 mm) or dry snow (any depth) over compacted snow	Slush	Ice	Dry snow over ice
Falcon 20	1	0	0	18	0	5	6
Dornier 328	0	2	0	0	0	0	0
Dash 8	2	5	3	11	3	8	14
B727	0	0	0	6	0	0	0
B737	0	0	0	4	0	1	0
B757	0	0	0	5	0	0	0


Dash 8

Dornier 328


Falcon 20

Validation of methodology



Conclusion

Multi-scale model of wheel/water/runway system applied to IMAG and aircraft

Brush model adapted to include the effect of water

Relation between ground friction coefficient and aircraft braking performances improved compared to the state of the art

Physical model

Thank you for your attention !

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