AUN2014 : Airports in Urban Networks
15-16 Apr 2014 CNIT - Paris la Défense (France)

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Modelling of aircraft braking coefficient from IMAG friction measurements

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Introduction

Ice and 5 mm of dry snow

Ice

Standing water

Dry snow over compacted snow

- What will the aircraft braking performances be on such runways?

Current practices

- How to measure runway friction?

Decelerometer
μ=a/g
CRFI

Continuous Friction Measuring Equipment
$\mu=F_h/F_v$
Eg: IMAG

Current practices

- What is the relation between friction coefficient and aircraft braking performances?

Current practices

- ICAO table

Measured Coefficient μ	Estimated surface friction	Code
0,40 and above	Good	5
0,39 to 0,36	Medium to good	4
0,35 to 0,30	Medium	3
0,29 to 0,26	Medium to poor	2
0,25 and below	Poor	1

Current practices

- TALPA matrix

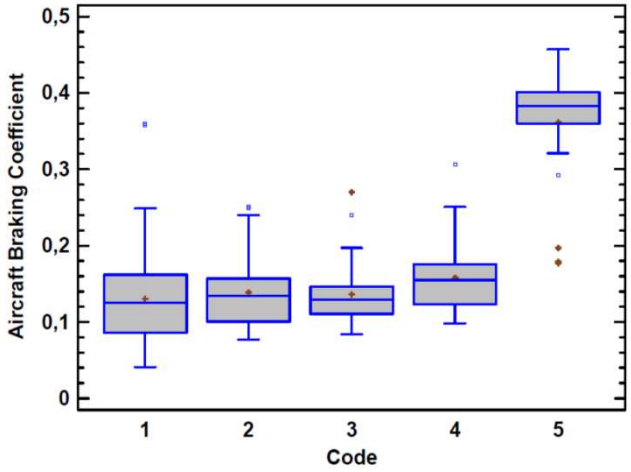
Runway Condition Assessment Matrix (RCAM)				
Assessment Criteria		**Downgrade Assessment Criteria**		
Code	Runway Condition Description	**Mu (μ) [1]**	**Vehicle Deceleration Or Directional Control Observation**	**PIREP**
6	• Dry	40 or Higher	---	---
5	• Frost • Wet (Includes Damp and1/8" or less depth of Water) ***1/8" or less depth of:*** • Slush • Dry Snow • Wet Snow		Braking deceleration is normal for the wheel braking effort applied AND directional control is normal.	Good
4	***-15°C and Colder outside air temperature:*** • Compacted Snow	39	Braking deceleration OR directional control is between Good and Medium.	Good to Medium

Joint Winter Program

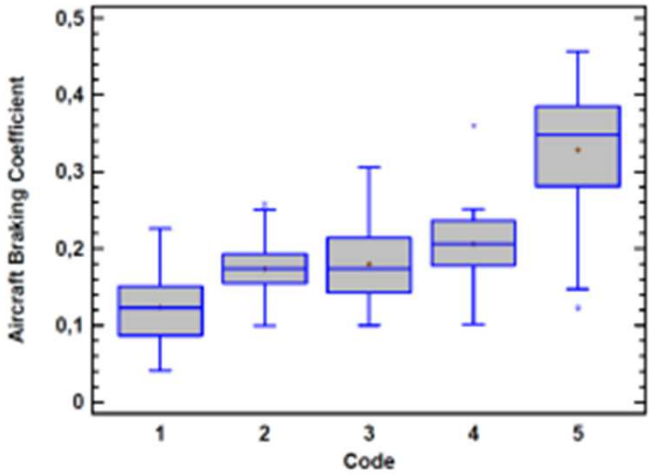
- From 1996 to 2003
  - 10 aircrafts and 14 friction measuring devices
- Extensive database
  - Runway conditions
  - Ground friction values
  - Aircraft braking coefficients

Evaluation of current practices

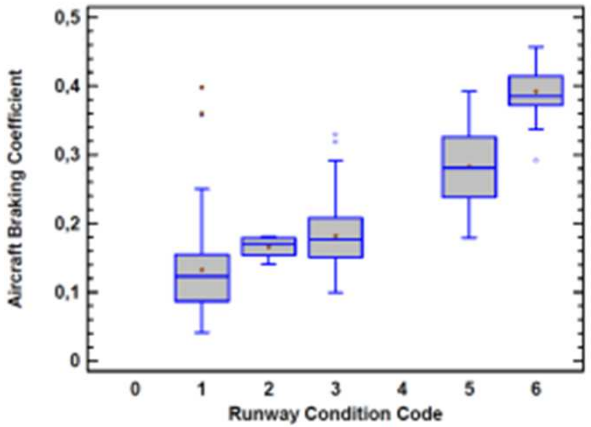
ICAO table (from IMAG data)



ICAO table (from CRFI data)



TALPA matrix



Research methodology

- **Goal:** develop a new method to relate friction measurements to aircraft braking coefficients
  - Use of the so-called ESDU model to relate ground friction measurement to aircraft braking coefficient
  - Adjust measured friction coefficient – using the model – to aircraft characteristics such as speed, mass and tire pressure
  - Use of IMAG device

Use of ESDU model

- Empirical model
- Analytical equations for slip friction

$$\mu_{Slip}^{AC} = \frac{\left(1 - e^{\eta_2 s}\right)}{\left(1 + \left(\eta_0 + \eta_1 \frac{v^2}{2g}\right) \frac{p / p_a}{Z^{1/3}}\right)} \mu_{\mathrm{Re}\,f}^{AC} = K^{AC} \mu_{\mathrm{Re}\,f}^{AC}$$

Aircraft braking coefficient

Fonction of tire pressure, mass, slip speed, slip ratio

Reference friction coefficient

Hypothesis

- Hypothesis 1
  - Same model applies for IMAG friction measurements

$$\mu_{Slip}^{IMAG} = \frac{\left(1 - e^{\eta_2 s}\right)}{\left(1 + \left(\eta_0 + \eta_1 \frac{v^2}{2g}\right) \frac{p/p_a}{Z^{1/3}}\right)} \mu_{\mathrm{Re}\,f}^{IMAG} = K^{IMAG}\ \mu_{\mathrm{Re}\,f}^{IMAG}$$

- Hypothesis 2
  - IMAG reference friction coefficient = Aircraft reference coefficient

$$\mu_{\mathrm{Re}\,f}^{IMAG} = \mu_{\mathrm{Re}\,f}^{AC} \quad \Rightarrow \quad \mu_{Slip}^{AC} = \frac{K^{AC}}{K^{IMAG}} \mu_{Slip}^{IMAG}$$

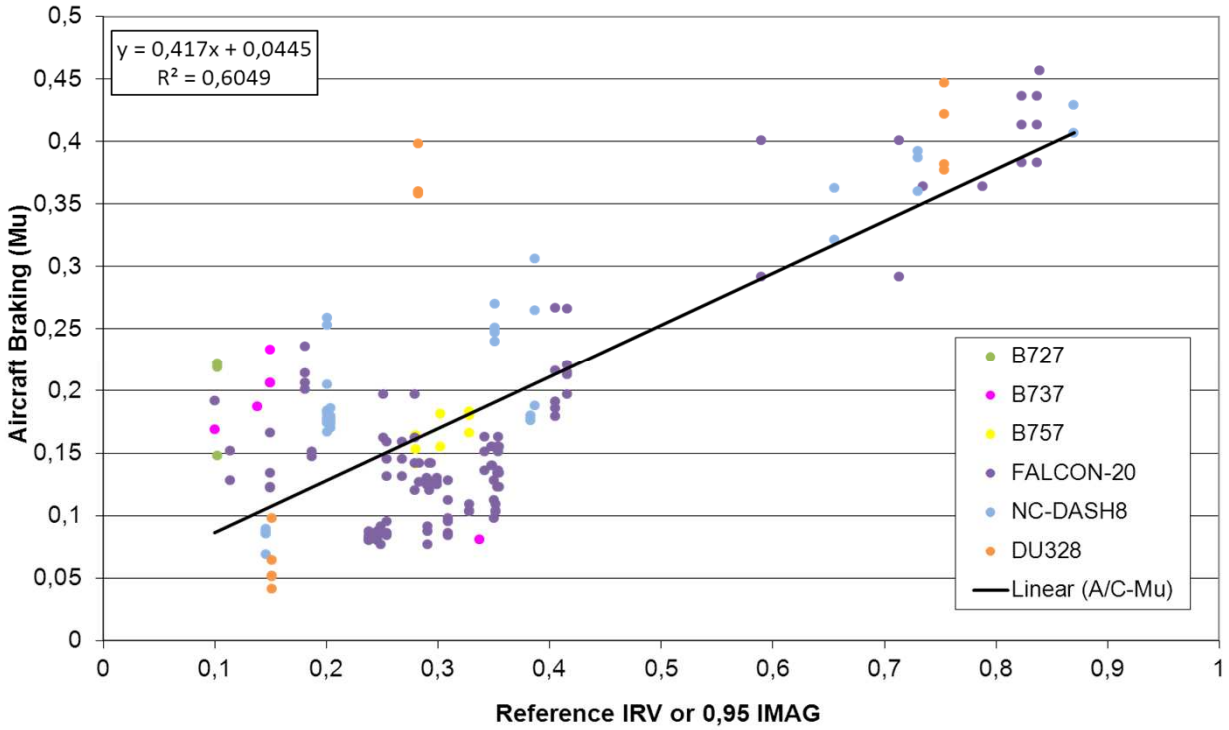
Hypothesis

- Hypothesis 3
  - Aircraft slip ratio is surface condition dependant
  - Slip measurements during JWP

Smooth ice	0,05
Sanded ice	0,05
Ice longitudinally scarified	0,08
Compacted snow	0,05
60% ice, 40% compact snow over ice, scarified longitudinally	0,04
Smooth Ice with Chemicals	0,09
Loose snow	0,09
Sanded loose snow	0,07
Slush	0,09

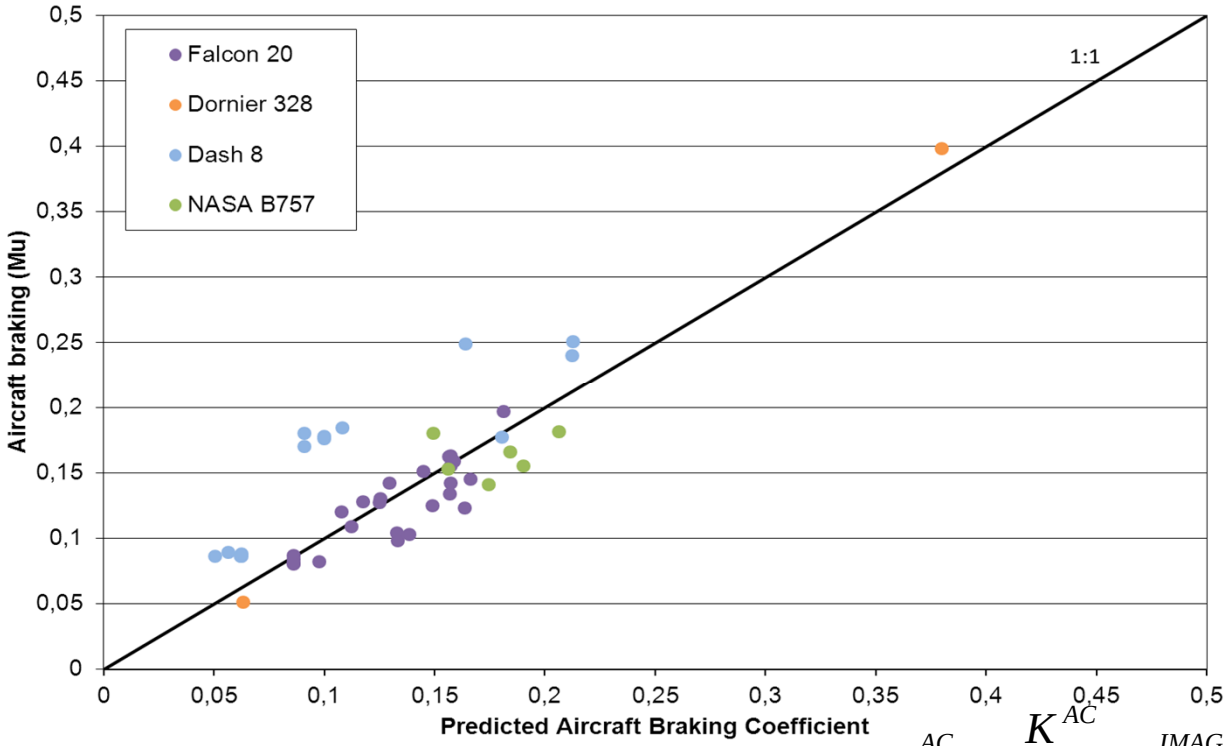
Joint Winter Program

- Results of the JWP [International Runway Friction Index (IRFI) versus Aircraft Braking Coefficient (Mu), Wambold, 2003]



Application of proposed method

- Results with the proposed method



$$\mu_{Slip}^{AC} = \frac{K^{AC}}{K^{IMAG}} \mu_{Slip}^{IMAG}$$

Conclusion and perspectives

- New method to relate aircraft braking performance to friction index using a model

- Further developments required
  - Use of physical models
  - Consider tire characteristics
  - Contaminant drag efforts have to be determined

Thank you for attention…

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