Modelling of aircraft braking coefficient from IMAG friction measurements

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Introduction

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

- How to measure runway friction?

Decelerometer
\[ \mu = \frac{a}{g} \]
CRFI

Continuous Friction Measuring Equipment
\[ \mu = \frac{F_h}{F_v} \]
Eg: IMAG
Current practices

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

### ICAO table

<table>
<thead>
<tr>
<th>Measured Coefficient $\mu$</th>
<th>Estimated surface friction</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.40 and above</td>
<td>Good</td>
<td>5</td>
</tr>
<tr>
<td>0.39 to 0.36</td>
<td>Medium to good</td>
<td>4</td>
</tr>
<tr>
<td>0.35 to 0.30</td>
<td>Medium</td>
<td>3</td>
</tr>
<tr>
<td>0.29 to 0.26</td>
<td>Medium to poor</td>
<td>2</td>
</tr>
<tr>
<td>0.25 and below</td>
<td>Poor</td>
<td>1</td>
</tr>
</tbody>
</table>
Current practices

- TALPA matrix

<table>
<thead>
<tr>
<th>Code</th>
<th>Runway Condition Description</th>
<th>Assessment Criteria</th>
<th>Downgrade Assessment Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>• Dry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>• Frost</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Wet (Includes Damp and 1/8” or less depth of Water)</td>
<td>Mu (μ)</td>
<td>Vehicle Deceleration Or Directional Control Observation</td>
</tr>
<tr>
<td></td>
<td>• 1/8” or less depth of:</td>
<td>40 or Higher</td>
<td>Good</td>
</tr>
<tr>
<td></td>
<td>• Slush</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Dry Snow</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Wet Snow</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-15°C and Colder outside air temperature:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Compacted Snow</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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
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

\[ \mu_{\text{Slip}}^{AC} = \frac{1 - e^{\eta_2 s}}{1 + \left( \eta_0 + \eta_1 \frac{v^2}{2g} \right) \frac{p}{p_a} Z^{1/3}} \mu_{\text{Ref}}^{AC} = K^{AC} \mu_{\text{Ref}}^{AC} \]

- Aircraft braking coefficient
- Function of tire pressure, mass, slip speed, slip ratio
- Reference friction coefficient

Gerthoffert et al.
Hypothesis

- Hypothesis 1
  - Same model applies for IMAG friction measurements
    \[ \mu_{\text{Slip}}^{\text{IMAG}} = \frac{(1 - e^{\eta_2 s})}{1 + \left( \eta_0 + \eta_1 \frac{v^2}{2g} \right) \frac{p}{p_a} \frac{Z^{1/3}}{Z_0^{1/3}}} \mu_{\text{Ref}}^{\text{IMAG}} = K^{\text{IMAG}} \mu_{\text{Ref}}^{\text{IMAG}} \]

- Hypothesis 2
  - IMAG reference friction coefficient = Aircraft reference coefficient
    \[ \mu_{\text{Ref}}^{\text{IMAG}} = \mu_{\text{Ref}}^{\text{AC}} \]
    \[ \mu_{\text{Slip}}^{\text{AC}} = \frac{K^{\text{AC}}}{K^{\text{IMAG}}} \mu_{\text{Slip}}^{\text{IMAG}} \]
Hypothesis

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

<table>
<thead>
<tr>
<th>Surface Condition</th>
<th>Slip Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth ice</td>
<td>0.05</td>
</tr>
<tr>
<td>Sanded ice</td>
<td>0.05</td>
</tr>
<tr>
<td>Ice longitudinally scarified</td>
<td>0.08</td>
</tr>
<tr>
<td>Compacted snow</td>
<td>0.05</td>
</tr>
<tr>
<td>60% ice, 40% compact snow over ice, scarified longitudinally</td>
<td>0.04</td>
</tr>
<tr>
<td>Smooth Ice with Chemicals</td>
<td>0.09</td>
</tr>
<tr>
<td>Loose snow</td>
<td>0.09</td>
</tr>
<tr>
<td>Sanded loose snow</td>
<td>0.07</td>
</tr>
<tr>
<td>Slush</td>
<td>0.09</td>
</tr>
</tbody>
</table>
Results of the JWP [International Runway Friction Index (IRFI) versus Aircraft Braking Coefficient (Mu), Wambold, 2003]

\[ y = 0.417x + 0.0445 \]
\[ R^2 = 0.6049 \]
Results with the proposed method
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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