A scenario based model for assessing runway conditions using weather data

Arne Bang Huseby\textsuperscript{1} Marit Rabbe\textsuperscript{2}

\textsuperscript{1}University of Oslo, Norway

\textsuperscript{2}Avinor, Norway

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Background

Slippery runways represent a significant risk to aircrafts especially during the winter season.

Figure: Southwest Airlines jet skidding off a runway at Chicago Midway Airport in December 2005
The IRIS System

IRIS (Integrated Runway Information System) - Developed by Avinor

Figure: Web/SQL-based information and support system currently in use on 14 Norwegian Airports.
The Weather Model

**Model input:** Observations from the four most recent hours of *precipitation type, air temperature, relative humidity, horizontal visibility* and *runway temperature* – sampled every minute.

*Figure:* Vaisala FD12P, All in one Weather Sensor.
The Weather Scenarios

Scenarios with precipitation
- Dry Snow
- Snow
- Freezing rain/drizzle
- Freezing fog
- Rain or drizzle on ice-coated or supercooled runway

Scenarios without precipitation
- Wet runway, clearing sky
- Stratus/fog, air temperature below 0°C
- Rime, sublimation, ice crystals
Model validation

To validate the weather model, flight data was obtained from the Quick Access Recorder of Boeing 737-600/700/800 NG airplanes, operated by Scandinavian Airlines Services and Norwegian Air Shuttle AS.

Figure: Boeing 737-600 NG airplane.
Starting at the time of touchdown, a 60 seconds record was taken including among others the following main parameters:

- Airplane weight
- Longitudinal acceleration
- Airspeed
- Ground speed
- Flaps settings
- Spoiler settings
- Engine rotational speed
- Brake pressures
- Auto brake settings
- Longitude and latitude positions
Let $\epsilon$ denote the slope of the runway, and $W$ the weight of the aircraft.  According to the general equations of aircraft motion along the direction of the runway we have:

$$\frac{W}{g} \cdot \frac{dv}{dt} = -D_{aero} - D_{rev.\,thrust} - W \sin(\epsilon) - D_{brakes}. \quad (1)$$

From this equation we determine $D_{brakes}$, the drag contribution from wheel braking. Given the aerodynamic lift $L$, this force can also be expressed as:

$$D_{brakes} = \mu (W \cos(\epsilon) - L), \quad (2)$$

which allows us to determine the quantity of interest, $\mu$, the effective braking friction coefficient at each point of time.
Friction limited landings

- When the brakes are not fully applied, the maximum friction available from the runway may not have been utilized. In this case $\mu_B$ reflects the amount of tire-pavement friction that was used.

- When wheel brakes are fully applied, the maximum friction available from the runway is used during the stop. In this case $\mu_B$ reflects the amount of tire-pavement friction that was available.

- It is therefore crucial to determine whether or not the stop was limited by the friction available from the runway. A landing where this is the case, is said to be friction limited.
Runway assessments and $\mu_b$

When a landing (or part of a landing) is classified as friction limited, $\mu_B$ is interpreted according to the following runway condition categories:

<table>
<thead>
<tr>
<th>$\mu_B$</th>
<th>Runway assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$&gt; 0.20$</td>
<td>Good (5)</td>
</tr>
<tr>
<td>$(0.15, 0.20]$</td>
<td>Medium-good (4)</td>
</tr>
<tr>
<td>$(0.10, 0.15]$</td>
<td>Medium (3)</td>
</tr>
<tr>
<td>$(0.075, 0.10]$</td>
<td>Medium-poor (2)</td>
</tr>
<tr>
<td>$(0.05, 0.075]$</td>
<td>Poor (1)</td>
</tr>
<tr>
<td>$\leq 0.05$</td>
<td>NIL (0)</td>
</tr>
</tbody>
</table>

**Table:** Interpretation of $\mu_B$
Available friction limited landings

In the validation of the weather model only the friction limited landings were used.

In this study we included data from the winter seasons 2008/2009 and 2009/2010 from two Norwegian airports, Oslo and Tromsø.

<table>
<thead>
<tr>
<th>Airport</th>
<th>Friction limited landings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oslo</td>
<td>564</td>
</tr>
<tr>
<td>Tromsø</td>
<td>321</td>
</tr>
<tr>
<td>Total</td>
<td>885</td>
</tr>
</tbody>
</table>

Table: Number of friction limited landings
### Observed weather scenarios

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Oslo All</th>
<th>$\mu_B \leq 0.15$</th>
<th>Tromsø All</th>
<th>$\mu_B \leq 0.15$</th>
</tr>
</thead>
<tbody>
<tr>
<td>No scenarios</td>
<td>85</td>
<td>59</td>
<td>193</td>
<td>158</td>
</tr>
<tr>
<td>1</td>
<td>7</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>322</td>
<td>295</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 + 3</td>
<td>38</td>
<td>34</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 + 5</td>
<td>4</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2 + 3 + 5</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>3</td>
<td>3</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>8</td>
<td>37</td>
<td>31</td>
<td>57</td>
<td>52</td>
</tr>
<tr>
<td>7 + 8</td>
<td>9</td>
<td>7</td>
<td>21</td>
<td>19</td>
</tr>
<tr>
<td>Not enough data</td>
<td>55</td>
<td>48</td>
<td>37</td>
<td>29</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>564</td>
<td>485</td>
<td>321</td>
<td>271</td>
</tr>
</tbody>
</table>

**Table:** Number of occurrences of the various weather scenarios
Summary of results

Oslo:
- No scenarios are identified in 85 landings, (i.e., 15 %) in the full set, and 59 landings (i.e., 12 %) in the filtered set.
- The snow scenario is identified in 365 landings (i.e., 65 %) in the full set, and 333 landings (i.e., 69 %) in the filtered set.
- The rime scenario is identified in 46 landings (i.e., 8 %) in the full set, and 38 landings (i.e., 8 %) in the filtered set.

Tromsø:
- No scenarios are identified in 193 landings, (i.e., 60 %) in the full set, and 158 landings (i.e., 58 %) in the filtered set.
- Scenarios with no precipitation are identified in 91 landings (i.e., 28 %) in the full set, and 84 landings (i.e., 31 %) in the filtered set.
Pre-existing conditions

Oslo:
- 485 landings with $\mu_b \leq 0.15$
- The weather model did not identify any scenario in 59 of these landings
- No pre-existing runway conditions were reported in 14 of these landings

Tromsø:
- 271 landings with $\mu_b \leq 0.15$
- The weather model did not identify any scenario in 158 of these landings
- No pre-existing runway conditions were reported in 4 of these landings

Thus, when the weather model is used in combination with runway reports, almost all landings with $\mu_B \leq 0.15$ are identified.
Conclusions

- By monitoring meteorological parameters like air and ground temperature, humidity, visibility and precipitation, the proposed weather model enables us to detect scenarios and issue warnings to the ground personnel.

- The weather model is able to identify potentially slippery conditions for a large number of friction limited landings. In cases where the model does not identify any of the scenarios, this can often be traced back to pre-existing conditions already captured in the runway reports.

- In an upcoming paper the weather model will be analyzed in more details, handling issues like false alarms, responsiveness etc.