A scenario based model for assessing runway conditions using weather data

Arne Bang Huseby[1] Marit Rabbe[2]

[1]University of Oslo, Norway

[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

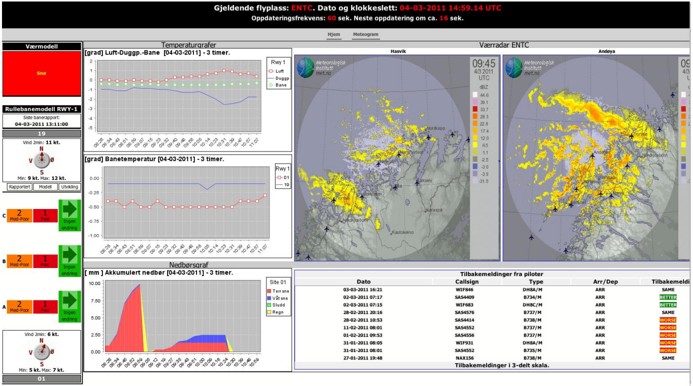

Figure: Web/SQL-based information and support system currently in use on 14 Norwegian Airports.

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
- Frezzing fog
- Rain or drizzle on ice-coated or supercooled runway

Scenarios without precipitation

- Wet runway, clearing sky
- Stratus/fog, air temperature below $0^\circ\mathrm{C}$
- 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.

Model validation (cont.)

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

Boeing Aircraft Braking Performance model

Let ϵ 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:

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

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:

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

which allows us to determine the quantity of interest, μ, 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 μ_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 μ_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 μ_b

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

μ_B	Runway assessment
> 0.20	Good (5)
$(0.15, 0.20]$	Medium-good (4)
$(0.10, 0.15]$	Medium (3)
$(0.075, 0.10]$	Medium-poor (2)
$(0.05, 0.075]$	Poor (1)
≤ 0.05	NIL (0)

Table: Interpretation of μ_B

Available friction limited landings

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

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

Airport	Friction limited landings
Oslo	564
Tromsø	321
Total	885

Table: Number of friction limited landings

Observed weather scenarios

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

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. set.

Pre-existing conditions

Oslo:

- 485 landings with $\mu_b \leq 0.15$
- The weather model did not identify any scenarion 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 scenarion 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.