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Airplane braking friction on dry snow, wet snow or slush contaminated runways

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ABSTRACT

Airplanes need tire-pavement friction during taxiing, take-off and landing. The presence of snow reduces the friction and therefore there is need to understand how much friction can be expected on the different types of snow. This study analyses the braking performance of Boeing 737 airplanes on snow or slush contaminated runways. Airplane braking performance on runways contaminated with dry snow, wet snow and slush as analysed. The main finding is that airplanes experienced wet snow covered runways more often as very slippery, compared to slush covered runways. The fraction of the landings experiencing the conditions as "poor" or "less than poor" was significantly higher on wet snow (21%), compared to landings on slush (11%). This can be caused due to higher precipitation intensity during wet snow precipitation, or possibly because wet snow, in contrast to slush, is a compressible material that gets compacted and fills the underlying pavement texture.

1. Introduction

Airplanes need a certain amount of tire-pavement friction for retardation and directional control during taxiing, take-off and landing. The magnitude of the required friction depend mainly on the aircraft type, gross weight, runway length, cross wind, reversed engine thrust usage and pilot skills. The presence of snow or ice on runways reduces the available friction and therefore it is important that pilots get correct information on the prevailing runway conditions.

In aviation, snow and ice is considered as a type of runway contamination (such as oil, sand and rubber deposits) and are therefore referred to as "winter-contaminants". The available braking friction for airplanes is called the "braking action". Historically, the term originated from the subjective feeling of the pilots how well the aircraft responds (decelerates) when pressing the brake pedals. The braking action was expressed in a scale from 1 to 5, ranging from "poor" to "good" (ICAO, 2003). More recently the scale has been extended from 0 to 6 to indicate "less than poor" and "dry runway" respectively (Subbotin and Gardner, 2013). Nowadays it is possible to measure the braking action during the parts of the landings where the frictional conditions limit the total stopping distance (Klein-Paste et al., 2012).

Before operating on winter-contaminated runways, pilots calculate the required stopping distance based on the landing weight, wind and runway conditions. These calculations are known as performance calculations. To make the performance calculations pilots need accurate information on how much braking action can be expected. Historically, airports have estimated the braking action by conducting measurements with ground friction measurement devices (GFMD's) (Andresen and Wambold, 1999). Unfortunately, it has proven difficult to establish a reliable correlation between actual aircraft braking performance and the readings of GFMD's on winter contaminated runways (Boccanfuso, 2004). An alternative approach is to estimate the braking action based on descriptive data, such as the type, depth and spatial coverage of the contamination. This data is collected by means of a visual inspection, conducted by the ground personnel of the airport. The Talpa-Arc matrix (Subbotin and Gardner, 2013) uses type, depth and temperature to estimate the braking action. Another model, known as the IRIS runway model also includes other parameters such as coverage, use of sand and chemicals, runway temperature and dew point (Klein-Paste et al., 2015). To support further development of these models and provide a correct situation awareness, there is still a need for better understanding how aircraft perform under real-life operational winter conditions.

The Norwegian aerodrome operator Avinor performed a five-year R&D project, called IRIS (Intelligent Runway Information System) where it collected landing data and coupled this with reported runway condition information and weather data. The present paper presents a study using this dataset to investigate the differences in braking performance on dry snow, wet snow or slush.

2. Method

Data was collected during the winters 2008/2009 to 2012/2013 at different airports in Norway. The number of airports increased from two in 2008/2009 to 15 in 2012/2013. Data from the Quick Access

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Recorder (QAR) was obtained from all landings of Boeing 737-600, 700, 800, 900 models that were operated by Scandinavian Air Services (SAS) and Norwegian Air Shuttle AS.

The airplane braking coefficient μ_B was determined by a methodology described earlier (Klein-Paste et al., 2012). In short, the total retardation force during landing is measured and the contribution of wheel braking is determined. This provides an estimate of the used friction during the landing. Only when the airplane's anti-skid system becomes activated it is certain that the airplane utilized all of the available friction and μ_B can be determined. In these cases the landing distance is limited by the frictional conditions of the runway, hence denoted a friction limited landing (FL-landing). The obtained μ_B of the FL landings were interpreted into the common scale braking action scale, according to Table 1.

During operation under winter conditions, runway inspectors regularly enter the runway and report the surface conditions for each third of the runway length (called a RWY section). The frequency of these inspections varies with the conditions, but typically ranges in Norway between 30 min and 8 h. The type of the contamination (dry, wet, rime, dry snow, wet snow, slush, compacted snow, or ice), the depth (in mm), the spatial coverage (in %) and other relevant information such as the use of sand or anti-/de-icing chemicals is registered. Weather stations placed near the runway (within 500 m) measured air temperature, runway temperature, dew point temperature and wind at one-minute intervals.

The GPS data from the QAR was used to identify on which runway section the FL state occurred and the braking friction coefficient μ_B was coupled with the observed runway condition of that section. The current size of the database is shown in Table 2. Only data from runways contaminated with dry snow, wet snow or slush with 100% spatial coverage were used for the present analysis.

Table 2
Size of the landing database.

Number of winter seasons	5
Airports	15
Landings	117,849
FL-landings	5097
RWY sections	353,547
RWY sections with FL-landing	6418
Number of FL-landings on	
Dry snow, 100% coverage	135
Wet snow, 100% coverage	382
Slush, 100% coverage	221

3. Results

The measured aircraft braking coefficient on dry snow, wet snow and slush contaminated runways is plotted against runway temperature in Fig. 1.

Fig. 1 shows that there is a large scatter present for each type of runway contamination. The aircraft braking friction can range from below 0.05 (less than poor) to above 0.2 (good) in all three types of runway contamination. The average braking friction coefficient is very similar (ranging only between 0.1 and 0.12), but due to the large scatter, an average number has little value/meaning.

There is no clear temperature dependency visible for any of the contamination types. Again, the scatter in the data dominates the picture. Naturally, wet snow and slush mostly occur around 0 °C. However, also at lower temperatures wet snow and slush can be present due to the usage of anti-/de-icing chemicals on runways.

Fig. 2 presents the distribution of the μ_B, converted into the braking action scale (0–5) and the percentage of landings experiencing the runway as 0 (less than poor) or 1 (poor) is highlighted by the dashed rectangles.

Snow, (b) wet snow, (c) slush. The red rectangles highlight the percentage of landings experiencing the runway as “less than poor” or “poor”.

Table 1
Conversion of measured airplane braking coefficient into the common braking action scale (Klein-Paste et al., 2012).

Airplane braking coefficient	Braking action
$\mu_B > 0.2$	5 – good
$0.15 < \mu_B \leq 0.2$	4 – medium/good
$0.10 < \mu_B \leq 0.15$	3 – medium
$0.075 < \mu_B \leq 0.10$	2 – medium/poor
$0.05 < \mu_B \leq 0.075$	1 – poor
$\mu_B \leq 0.05$	0 – less than poor

On wet snow, 21% of the landings experienced the runway as 0 or 1 (less than poor or poor). This percentage is significantly higher than on dry snow (7%) or slush (11%). Hence, the runways contaminated with

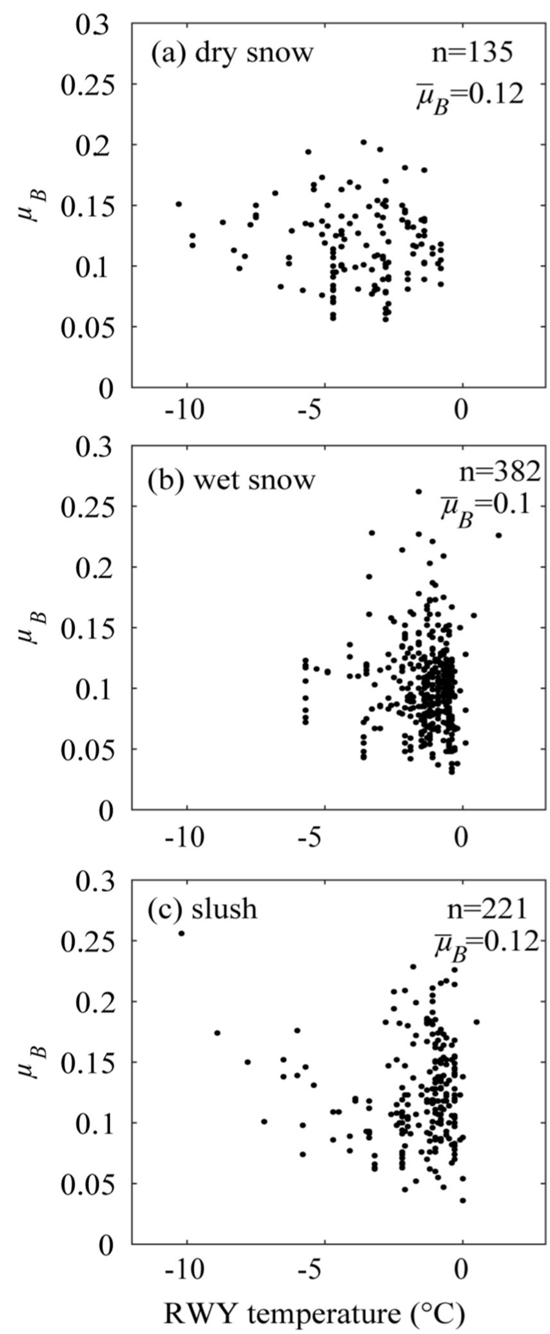

Fig. 1. Airplane braking friction coefficient of FL landings on (a) dry snow, (b) wet snow, and (c) slush contaminated runways.

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