



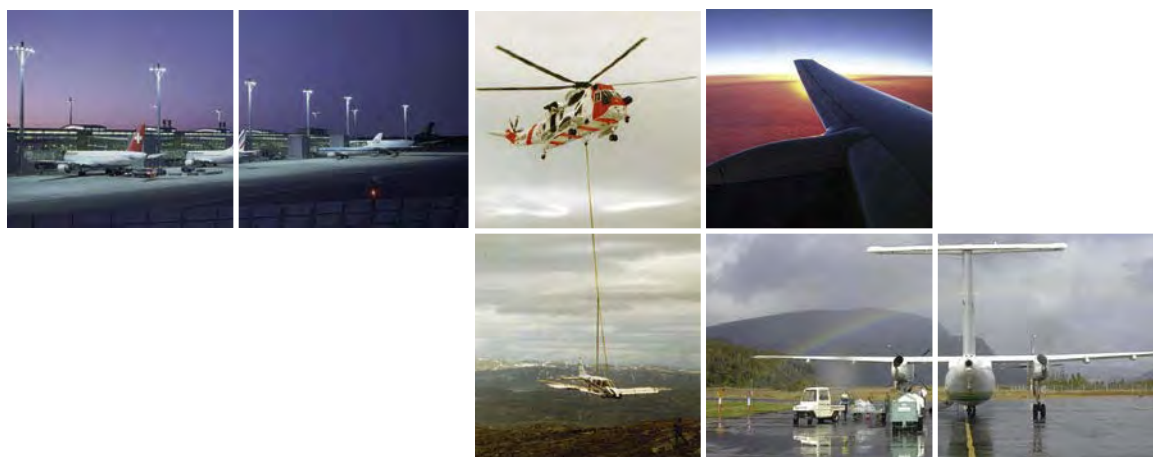
aibn

Accident
Investigation Board
Norway

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REPORT

SL 2011/10



WINTER OPERATIONS, FRICTION MEASUREMENTS AND CONDITIONS FOR FRICTION PREDICTIONS

VOLUME II - MAIN REPORT

This report has been translated into English and published by the AIBN to facilitate access by international readers. As accurate as the translation might be, the original Norwegian text takes precedence as the report of reference.

The Accident Investigation Board has compiled this report for the sole purpose of improving flight safety. The object of any investigation is to identify faults or discrepancies which may endanger flight safety, whether or not these are causal factors in the accident, and to make safety recommendations. It is not the Board's task to apportion blame or liability. Use of this report for any other purpose than for flight safety should be avoided.

*The report is divided into three volumes. Volume I Executive Summary,
Volume II Main Report and Volume III Appendices A-Z.*

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SUMMARY

There is much uncertainty associated with measured/estimated runway friction coefficients (FC) and aircraft braking coefficients (ABC). Hence landing distances or maximum landing weights calculated on the basis of measured/estimated friction coefficients are also uncertain. This has contributed to accidents and incidents where aircraft departed the runways because the surface was more slippery than expected. This theme investigation focuses on the general framework for winter operations and the factors related to meteorology, runway, regulations and operations that reduce the safety margins and increase the uncertainty on contaminated and slippery runways.

Over a 10-year period, the Accident Investigation Board Norway (AIBN) has received 30 reports of accidents and incidents related to operations on contaminated and slippery runways. In the same period AIBN has published 12 investigation reports and issued 36 safety recommendations.

This theme investigation focuses on the general framework for operations on contaminated and slippery runways and the potential for safety improvements in general. The AIBN has accumulated and analysed a large volume of documentation, reports, test and research data from various national and international sources in addition to consulting expertise in the field of micrometeorology.

In the 30 investigated occurrences, the AIBN found that the aircraft braking coefficient (ABC) was not in accordance with the measured/estimated runway friction coefficients (FC). The AIBN has identified numerous common factors that have reduced the safety margins and factors that explain the differences between ABC and FC. These factors are related to meteorological conditions and friction measurements uncertainty, runway treatment, operational aspects and regulatory conditions.

The AIBN believes that incidents relating to slippery runways occur because the involved parties do not realise that existing rules and regulations are based on a simplification of the actual physical conditions. The measured/estimated friction values are used as scientific truths and not compared to other meteorological conditions („safety indicators“). The safety margins are reduced by operational procedures which to a limited degree take into account the uncertainties connected to input parameters used for landing distance calculations. The AIBN's findings are supported by research programmes and studies.

The AIBN findings show that the national regulations governing operations on contaminated and slippery runways are less strict than those that govern operations in summer conditions. This is in spite of the ICAO and EASA guidelines and regulations which prescribe that if winter operations are to be performed on a regular basis, the authorities require the operators to take special measures in order to attain an „equivalent level of safety“ to summer conditions.

The many incidents and accidents relating to contaminated and slippery winter runways, reveal that an “equivalent level of safety” is not achieved in connection with Norwegian winter operations. The CAA Norway seems to lack an overall risk assessment quantifying the level of safety of winter operations as part of the State Safety Program (SSP) and establishment of an Acceptable Level of Safety (ALoS).

Based on the above, the AIBN issues seven (7) safety recommendations.

0. INTRODUCTION

This theme report is based on the facts behind accidents and incidents that the Accident Investigation Board Norway (AIBN) has investigated in the past decade relating to operations on slippery runways during winter.

0.1 Background to this theme investigation

Since 1945, Norwegian aviation has experienced strong growth, and today our society is absolutely dependent on safe and predictable air traffic. The Norwegian climate and geography create challenges with respect to maintaining a reasonable degree of regularity in the air traffic throughout the year. The climate with varying temperatures, frost and frequent snowfalls, combined with difficulties in keeping the runways free from snow and ice, have forced the authorities and operators to allow routine operations on winter-contaminated¹ runways. Most Norwegian airports are situated along a hilly coast line where winter conditions involve frequent frost-thaw fluctuations, often combined with turbulent wind conditions and strong gusty crosswinds. The past decade's climate changes, with rising average temperatures during the winter months, seem to have increased these temperature fluctuations.

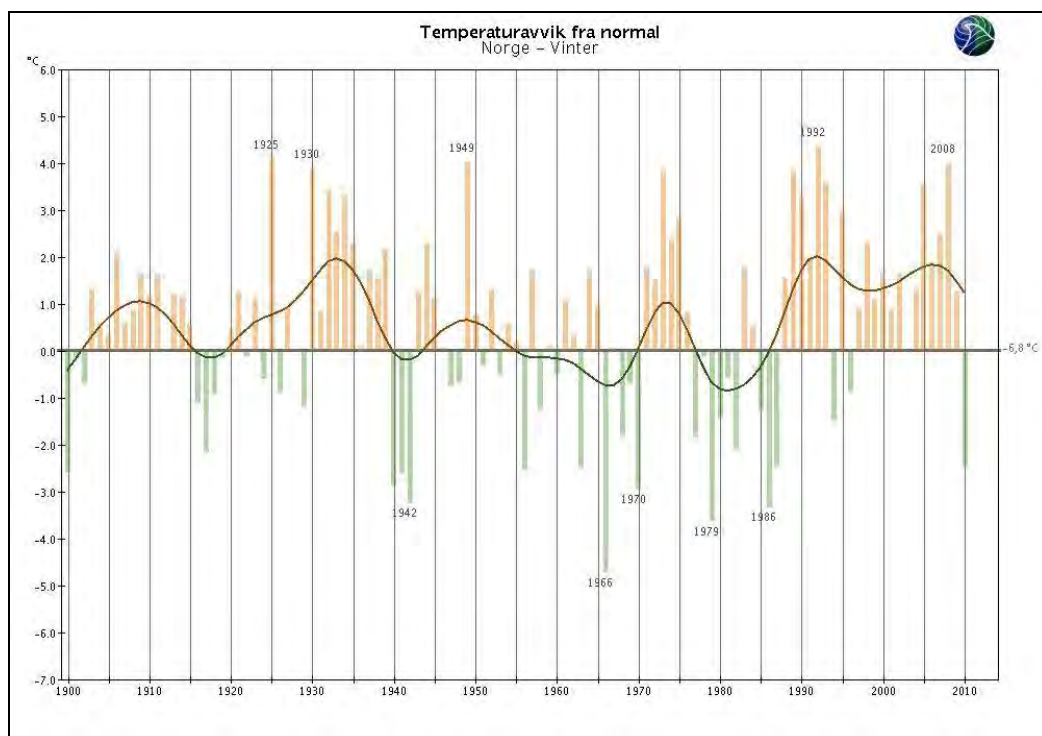


Figure 1: Annual deviation from mean winter (November-April) temperature in Norway. Normal period 1961-1990 (met.no). [Met.no/Winter temperature last 150 years/Norway](http://Met.no/Winter%20temperature%20last%20150%20years/Norway)

In recent times airports in the North of Norway with sub-arctic climate, and particularly on Svalbard which used to have an arctic climate, have experienced the same type of temperature fluctuations that used to be most common on the west coast of Norway. The

¹ Within the meaning of this report, a winter-contaminated runway is a runway covered by hoar frost, slush, wet snow, dry snow, compact snow or ice.

winters on Svalbard are becoming notably milder with more frequent frost-thaw fluctuations.

The Norwegian practice of operating on special winter-prepared runways worked reasonably well for many years, with relatively few runway excursions and few incidents reported to the AIBN. Since 1999, there has been an increase in the number of reports received by the AIBN.

In Norway, it has been a practice since 1950 to measure runway friction on winter-contaminated runways. This is normally carried out in accordance with ICAO Annex 14/15 and ICAO Airport Services Manual Doc. 9137.²

Friction coefficients were previously used by the flight commanders in a conservative manner as advisory information. As a consequence of technological developments and the desire for less subjective and more efficient aircraft operations, it has become common practice for the airlines to use a cockpit performance computer (CPC) in which the friction coefficient (FC)³ is used as input data to calculate the landing distance or maximum landing weight on a contaminated runway. In addition the flight crews do no longer receive a personal weather and runway status briefing from a weather office, but are left to do their own evaluation of weather and runway reports received via Avinor's Internet Pilot Planning Centre (IPPC). Hence, the previous personal subjective overall assessment based on experience and airmanship has been exchanged by a more numerical approach and „non-critical“ use of computers.

There is much uncertainty associated with measured FC and the correlation between the measured FC and „aircraft μ (μ_{ac})“⁴, „effective μ “⁵ or ABC⁶. Hence landing distances or maximum landing weights calculated on the basis of measured and estimated friction coefficients are also uncertain. This has been the cause factors of accidents and serious aviation incidents where aircraft departed the runways because the surface was more slippery than expected.

Since 1999, the AIBN has received 30 reports of aviation accidents, serious aviation incidents and aviation incidents relating to slippery runways during winter operations. This corresponds to an average of three per year. Of the total number of incidents listed in section 1.1, nine were accidents or serious aviation incidents. This corresponds to an average of one accident or serious incident per year relating to slippery runways over the past decade. The AIBN has conducted 12 safety investigations, based on which it has published reports and submitted 36 safety recommendations (see 1.1).

Most of the incidents were of a less serious nature in that the pilots were able to recover control of the aircraft before the incident escalated, or the aircraft ran off the runway or

² Presently pilots in Norway are not receiving double digit measured friction numbers, only estimated single digit numbers. Cf. Norwegian [AIC 1 08/09](#)

³ The friction coefficient is measured using a friction measuring device and is abbreviated as FC = μ = μ_u . or default FC based on estimated input value to ICAO SNOWTAM table.

⁴ „Aircraft μ “ (μ_{ac}) is a generic term for the aircraft friction

⁵ „Effective μ “ is defined by Airbus as „the available friction between a braked wheel and the runway surface taking into account the aircraft weight distribution among braked and free-rolling wheels“. Airbus is reducing the „eff μ “ by a factor ($\eta * \mu$) taking into account the efficiency of the anti-skid system (max 0.92)

⁶ The airplane braking coefficient is abbreviated as ABC and is defined by Boeing as the relationship between the braking force and the weight of the aircraft. By definition the „effective μ “ is larger than the ABC, but in practical terms the end result is not much different due to the reduction factor, and is approximately 50 % of measured FC.

taxiway at low speed resulting in little or no damage to personnel or aircraft. Based on all the minor incidents, actual accidents and serious aviation incidents, the AIBN found that the risk situation seems to have been saved by the crew as the final safety barrier. This is not in compliance with the general aviation safety philosophy which dictates that the development of an accident must be stopped at safety barriers well in advance of the final barrier („*dfence in depth*”).

According to Civil Aviation Authority Norway (CAA-N)’s statistics the combined frequency of accidents and incidents related to runway excursions for air carriers in Norway during the last 10-year period is $4 \cdot 10^{-6}$. The frequency of runway excursion accidents alone is $2 \cdot 10^{-6}$, where the fatal accident frequency is $0.9 \cdot 10^{-6}$. Norwegian Aviation Administration (NAA), Aviation Inspection Department (AID) specified in 1996-97 a maximum probability of a „*low speed overrun*” of $1 \cdot 10^{-6}$. Hence, the CAA-N’s actual statistics for the last 10-year period is exceeding the NAA/AID’s accepted occurrence rate of 1996-97. In order to achieve the 1996-97 goal, 95 % of all operations per year and a minimum of 80 % of all operations per month was said to be performed on a „black” runway.

The accident at Stord Airport in 2006⁷ shows the accident potential following a runway excursion from a Norwegian runway. International accident statistics show that runway excursions are on the increase and are the cause of many fatalities. Reference 23 show a study of runway excursions in Europe by NLR⁸. Main points are that 58.8 % of runway excursions occur on wet or contaminated runways. Further, studies show that the risk of having a runway excursion is 13 times higher when landing on a wet or contaminated runway. Reference 24 show a study by Australian Transport Safety Board on Runway Excursions worldwide. The report show that the accident trend from runway excursions worldwide is on the increase, and that wet or contaminated runways are common cause factors.

It is not for AIBN to decide what frequency of accidents or incidents is acceptable in a „State Safety Program” (SSP) or a national „Acceptable Level of Safety” (ALoS)⁹. AIBN’s mandate is to investigate reported accidents and serious incidents. Based on the investigation results it is expected of AIBN to issue appropriate Safety Recommendations which it believes may contribute to increased safety.

It is on the above grounds that the AIBN has initiated this theme investigation relating to Norwegian winter operations and friction measurements.

⁷ See the published intermediate factual report on www.aibn.no/luftfart/rapporter/06-470

⁸ Nationaal Lucht- en Ruimtevaartlaboratorium - NLR

⁹ State Safety Program (SSP) and Acceptable Level of Safety (ALoS) are defined in ICAO Safety Management Manual, Doc 9859 AN7474, Second edition 2009.
http://www2.icao.int/en/ism/Guidance%20Materials/DOC_9859_FULL_EN.pdf

0.2 AIBN's approach to the investigation

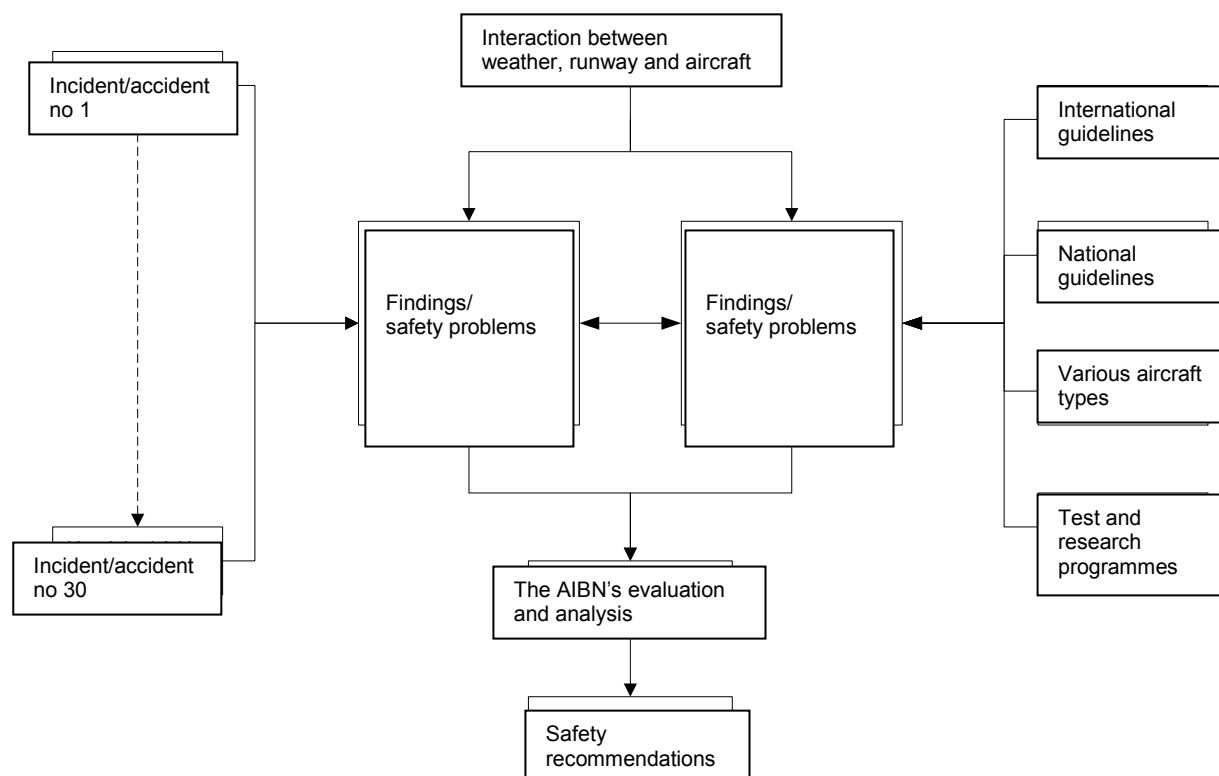


Figure 2: The AIBN's investigation process.

Figure 2 shows the AIBN's investigation process. In this theme investigation the AIBN has focused on the joint findings/safety problems from the 30 incidents/accidents relating to slippery runways that have been reported since 1999. One of the most significant findings from those investigations was that, under certain weather and runway conditions, there are substantial differences between measured/reported friction coefficients (FC) and airplane braking coefficients (ABC) or „aircraft μ “ (μ_{ac}).

Furthermore, the AIBN has reviewed both international and national framework conditions regulating winter operations on contaminated runways and the use of friction coefficients. The AIBN has also looked at the different policies of various aircraft manufacturers. AIBN has studied some important test, development and research projects relating to operations on slippery runways in order to get an overview of the work that has been put into finding better methods of measuring friction and the development of new friction measuring devices.

The national and international framework conditions/provisions regulating winter operations have then been evaluated in relation to the findings from specific accidents/incidents. On the basis of that evaluation the AIBN has identified a safety potential relating to how to achieve a reduction in the number of incidents/accidents.

In its work on winter operations and friction measurements, the AIBN has obtained meteorological assessments, including assessments by an expert¹⁰ in micro-meteorology (Appendix J). His expertise provided an important basis for this theme report and

¹⁰ Mook, Reinhard. PhD geophysics, Professor Emeritus, University of Tromsø (UiT), Norway.

contributed to AIBN's questioning of the scientific basis for applicable international and national guidelines and regulations relating to winter operations.

The AIBN has tried to look at the complete system relating to winter operations in an overall perspective, relying on among other things James Reason's theories as presented in the book *"Managing the Risks of Organizational Accidents"*¹¹:

„Organizational accidents have multiple causes involving many people operating at different levels of their respective companies. By contrast, individual accidents are ones in which a specific person or group is often both the agent and the victim of the accident. The consequences to the people concerned may be great, but their spread is limited. Organizational accidents, on the other hand, can have devastating effects on uninvolved populations, assets and the environment." (James Reason, 1997).

The AIBN's investigation of several accidents and incidents relating to slippery runways indicate that the personnel involved were loyal in their attempts to comply with regulations and procedures based on their training and their understanding of these ("Compliance versus Safety").

Details emerge in the investigations of all the accidents and incidents relating to how the personnel could have thought and acted differently to prevent the accident or incident. The AIBN believes it is important to understand why the aircrews and ground staff thought and acted as they did.

The investigation shows that minor deviations from operating procedures, which are only natural and occur on a regular basis, may not be equally important in relation to built-in and certified safety margins in connection with summer operations. On the other hand, the effect of the same non-conformities can be dramatic in connection with winter operations. This may be because the safety margins approved by the authorities for winter operations are lower than those that apply for summer operations. In that context, the AIBN has related to studies carried out by Sidney Dekker at Lund University¹²:

„The challenge is to understand why it made sense to people to continue with their original plan. Which cues did they rely on, and why? When cues suggesting that the plan should be changed are weak or ambiguous, it is not difficult to predict where people's trade-off will go if abandoning the plan is somehow costly... People need a lot of convincing evidence to justify changing their plan in these cases. This evidence may typically not be compelling until you have hindsight..." (Sidney Dekker, 2006).

0.3 The AIBN's published investigation reports relating to slippery runways

0.3.1 Submitted reports and the status of safety recommendations

Since 1999, the AIBN has received reports of 30 accidents and incidents related to the topic of slippery runways. A total of 12 investigation reports have been published and 36 safety recommendations have been submitted. Of these, 9 were Immediate Safety Recommendations (ISR) and 27 were regular Safety Recommendations (SR). By the time

¹¹ Reason, James. *Managing the Risks of Organizational Accidents*. Ashgate 1997.

¹² Dekker, Sidney. *The Field Guide to Understanding Human Error*. Ashgate 2006.

of closure for print of this report 4 ISR and 4 SR (total of 8) remain open. By "open" means that AIBN has not been notified of how the recommendation will be acted upon.

0.3.2 Immediate safety recommendations relating to this report

This theme investigation into the general topic of winter operations and friction measurements was initiated by the AIBN in 2006 on the basis of the many incidents relating to slippery runways. The AIBN identified several weaknesses in the current practice relating to winter operations and friction measurements, and submitted four immediate safety recommendations to the Civil Aviation Authority Norway in a letter dated 7 September 2006 (AIBN's letter with reference 06/362-1):

- **Immediate Safety Recommendation SL 06/1350-1.** The Norwegian Aeronautical Information Publication (AIP Norway) and the Norwegian Civil Aviation Regulations (CAR Norway) E contain Norwegian rules relating to friction measuring devices and measurement ranges. The AIBN has demonstrated that actual friction figures are often quite different from the measured/reported figures. Experience has shown that none of the approved friction measuring devices are reliable under moist/wet conditions; including temperature conditions involving an air temperature-dewpoint spread of 3 Kelvin (K) or less. The AIBN therefore believes that when friction is reported during moist/wet conditions, it should be reported as POOR. The AIBN recommends that the Civil Aviation Authority considers changing the measurement ranges for approved friction measuring devices in AIP Norway and CAR Norway E. Open.
- **Immediate Safety Recommendation SL 06/1350-2.** The AIBN's investigations show that the various airlines use different correlation curves/tables. The investigations show that, in several instances, these correlation curves have an uncertain basis and result in highly uncertain braking coefficients for the relevant type of aircraft. The figures in the ICAO SNOWTAM table showing measured friction values are in parts per hundred and are independent of the type of friction measuring device that is used. The AIBN's investigations have shown that the various types of friction measuring devices return different friction values when used on the same surface. AIP Norway describes the use of friction measuring devices in general and warns that the measurements are associated with such a high degree of uncertainty that the figures should not be reported to more than one decimal. On the basis of the above findings, the AIBN recommends that the Civil Aviation Authority Norway should consider simplifying the SNOWTAM table by eliminating the intermediate levels so that we are left with the ranges GOOD, MEDIUM and POOR, and to discontinue the use of two decimals and ban the use of interpolation between these ranges. Open.
- **Intermediate Safety Recommendation SL 06/1350-3.** The AIBN's investigations have shown that performance data for landing on slippery runways by using reverse thrust is published in the case of newer types of aircraft (e.g. Airbus and newer Boeing aircraft). Such data were not published for older types of aircraft. The investigations also show that the effect of using reverse thrust is limited to approximately 20% of all available braking power, and that this braking power should constitute a back-up when landing on slippery runways. The AIBN recommends that the Civil Aviation Authority Norway consider prohibiting the

inclusion of reverse thrust in the calculation of actual landing distances on slippery runways (maximum 30 minutes before landing). Open.

- **Immediate Safety Recommendation SL 06/1350-4).** The AIBN's investigations show that the airlines' crosswind calculations in combination with slippery runways are much too optimistic. The investigations also confirmed that, for some types of aircraft, these tables were not produced by the aircraft manufacturers, but by individual airlines on the basis of experience. None of the crosswind tables have been approved by the authorities (AIBN's comment – *in the form of certification*). Transport Canada has published such a table of crosswinds versus friction values. It is much more conservative than the tables used by Norwegian airlines. The AIBN recommends that the Civil Aviation Authority Norway evaluate the airlines' crosswind limits in relation to friction figures/braking coefficients, and considers whether they should be subject to approval by the authorities. Open.

0.4 The structure of this report

The AIBN has worked on incidents and accidents related to winter operations and contaminated runways for a long period and have collected a large volume of material. The AIBN has chosen to include many of the supporting documents in the form of appendices and to concentrate on the main points of those documents in the actual report. The AIBN has structured the rest of the theme report on this topic as follows:

Chapter 1: Factual information (1.1 – 1.7)

This chapter contains the factual information that has been collected by the AIBN concerning winter operations and contaminated runways.

- Section 1.1: ***The results of AIBN's investigations*** into Norwegian aviation accidents/incidents relating to winter operations since 1999. The AIBN's findings and submitted safety recommendations relating to the 12 accidents and incidents that were investigated are summed up.
- Section 1.2: ***Summary of findings from 30 incidents/accidents***. Common features of the AIBN's findings are listed here, together with relevant airports and safety indicators.
- Section 1.3: ***The AIBN's significant findings*** relating to winter operations and friction.
- Section 1.4: ***Weather and runway conditions*** on a randomly selected winter's day in Norway. The AIBN has chosen to present data from a randomly selected day of snowfall (2 February 2010) in order to illustrate what information is available to aircraft crews and air traffic controllers during winter operations in Norway: TAF, METAR and SNOWTAM as reported via Avinor's Internet Pilot Planning Centre (IPPC).
- Section 1.5: ***International guidelines*** for winter operations. The guidelines of the following international organisations have been included: International Civil Aviation Organisation (ICAO), European Aviation Safety Agency (EASA),

Federal Aviation Agency (FAA), Transport Canada (TC) and the UK Civil Aviation Authority (UK CAA).

- Section 1.6: ***Guidelines for winter operations for various types of aircraft*** (operating manuals / flight manuals), including Boeing, Bombardier and Airbus.
- Section 1.7: ***Norwegian guidelines*** (Norwegian Civil Aviation Administration, the Civil Aviation Authority Norway, Avinor)¹³ relating to winter operations and winter maintenance, including the history of such guidelines and work in progress.
- Section 1.8: ***International and national test programmes*** relating to winter operations and friction measurements. Documentation and information about test programmes spanning 60 years.

Chapter 2: Analysis (2.1 – 2.8)

The factual information described in Chapter 1 serve as the basis for the AIBN's analysis of winter operations and contaminated runways. The analysis will mainly discuss the facts section by section, but the analysis will be based on a total review of the factual information seen together.

Chapter 3: Conclusions

A summary of the AIBN's findings and conclusions of the investigation.

Chapter 4: Safety recommendations

The analysis and results of the AIBN's investigations provide the basis for its recommendations. The immediate safety recommendations submitted in 2006 are maintained, though in a revised form. A total of seven (7) safety recommendations are issued.

¹³ Civil Aviation Authority of Norway (CAA Norway/Luftfartstilsynet) was split from Norwegian Civil Aviation Administration (Norwegian CAA/Luftfartsverket) in 2000. Norwegian CAA became Avinor in 2003.

1. FACTUAL INFORMATION

1.1 Investigations by AIBN with results, findings and safety recommendations.

1.1.1 Introduction

This part provides an overview of aviation accidents, serious aviation incidents and aviation incidents relating to slippery runways reported to the AIBN since 1999. For each incident/accident that is discussed the associated weather data and runway status is included. In the 12 occurrences where the AIBN has published investigation reports concerning the incident/accident under discussion, the report includes the AIBN's assessment of the incident/accident, any safety recommendations submitted in connection with the specific investigation report and the status of the safety recommendations (open/closed).

Reference is made to the following METAR and TAF codes:

METAR:	Meteorological Aerodrome Report
ENGM:	Oslo Airport Gardermoen
282020Z:	28 FEB 2020 hrs UTC
13007KT:	Wind from 130°, 7 knots
01013G24KT:	Wind from 010° 13 kt with gusts up to 24 kt
090V170:	Variable wind direction of between 90° and 170°
1700 SN:	Visibility 1,700 m in snow
FEW001:	Few clouds at 100 ft
SCT002:	Scattered clouds at 200 ft
BKN 003:	Broken clouds at 300 ft
00/M00:	Air temperature of 0 °C and dew point temperature of minus 0 °C, both measured at a height of 2 m above the runway level
Q0991:	QNH (barometric altimeter setting) of 991 hPa
TEMPO 1000:	Temporary visibility of 1,000 m
RVR:	Runway visual range
01R:	Runway 01 right
DZFG:	Drizzle and Fog
VV001:	Vertical visibility 100 ft

VCSH:	Showers in vicinity
SHSNGS:	Snow and hail showers
BCFG:	Shallow fog
IC:	Ice crystals
ARCTIC SEA FOG:	Arctic sea fog

1.1.2 Serious aviation incident, 28 February 1999. Gardermoen, ENGM ([RAP 2003-02](#))

Scandinavian Airlines System (SAS) DC-9-41 skidded off the side of runway 19R during a crosswind landing.

1.1.2.1 *Weather:*

METAR ENGM 282020Z 13007KT 090V170 1700 SN FEW001 SCT002 BKN 003 00/M00 Q0991 TEMPO 1000

1.1.2.2 *Runway status:*

Just after the incident the runway was covered with 50 mm of wet snow, which was outside the measurement range of the friction measuring device. Friction measurements were carried out one hour earlier when the runway was covered with 3-4 mm of wet snow with measured friction values of 23-22-23¹⁴ (SFH)¹⁵. Actual Aircraft Braking Coefficient (ABC) was perceived by the crew as POOR.

1.1.2.3 *The AIBN's evaluation/safety recommendations:*

The AIBN did not issue any safety recommendations, but referred to previous reports:

...

„The Board has produced a series of safety recommendations relating to issues surrounding slippery runways during the last 2-3 years“

...

„Since this incident occurred, there has been strong focus on winter operations generally and at Gardermoen in particular, and the AIBN does not therefore make any new recommendation beyond those already submitted with previous reports.“

1.1.3 Aviation accident. 6 December 1999. Gardermoen, ENGM. ([RAP 2001-05](#))

Premiair DC-10-10 skidded off the end of runway 19L during landing.

1.1.3.1 *Weather:*

ENGM METAR 061950Z 02003 700 RVR 01R 900-1100 DZFG VV001 00/M00 Q0979 TEMPO 0500 FG

¹⁴ The Friction Coefficient (FC) is measured as, for example, 0.23, but is reported as 23.

¹⁵ Friction measuring device (surface friction tester) with high pressure tyres (SFH).

1.1.3.2 *Runway status:*

The runway was reported as wet after having been treated with chemicals. The measured friction coefficient (FC) was 53-51-54 (SFH). Actual ABC as deducted from FDR data was in the order of 0.05 (POOR).

1.1.3.3 *The AIBN's evaluation/safety recommendations/status:*

(Safety recommendations relating to slippery runways)

The AIBN made five Immediate Safety Recommendations (ISR) to the Norwegian Civil Aviation Administration on 17 December 1999. The recommendations were reiterated in the report and the Civil Aviation Authority Norway (the CAA Norway)¹⁶ was recommended to consider whether it could issue instructions that could lead to improvements:

Immediate safety recommendations:

- ***Immediate safety recommendation 2001/05.*** *That the Norwegian Civil Aviation Administration evaluate the information given to operators and crews concerning actual braking action, especially in connection with sudden weather changes after cold periods when there is little spread between temperature and dew point, because, in practice, runways, taxiways and aprons have proved to be significantly more slippery than indicated by the reported values for braking action.* ISR 2001/05 was closed by CAA-N in letter to DoT 18 May 2001. The reason for closing was that CAA-N together with Norwegian Aviation Administration (NAA, later Avinor) and the airlines were working on improvements to the information system and that CAA-N would work internationally to revise the SNOWTAM format. So far no revision has materialized.
- ***Immediate safety recommendation 2001/06.*** *That the Norwegian Civil Aviation Administration consider whether the current presentation of reported values for braking action can be improved so that the actual conditions are reflected in the information given to operators and crews.* ISR 2001/06 was closed 18 May 2001 on the same basis as ISR 2001/05.
- ***Immediate safety recommendation 2001/07.*** *That the Norwegian Civil Aviation Administration considers whether Oslo Airport Gardermoen has the necessary resources and permits to create satisfactory friction on runways, taxiways and aprons.* ISR 2001/07 was closed 18 May 2001 on the basis of a study by NAA with recommendations to improve the regulations for use of chemicals on Oslo Airport Gardermoen.

In a letter dated 4 April 2000 the Norwegian Civil Aviation Administration¹⁷ stated:

¹⁶ The predecessor body to the CAA Norway (CAA-N, Luftfartstilsynet) was separated from the Norwegian Civil Aviation Administration (NAA, Luftfartsverket) on 1 January 2000.

¹⁷ The Norwegian Civil Aviation Administration (NAA, Luftfartsverket) became a state-owned company limited by shares with the name Avinor on 1 January 2003.

„The Norwegian Civil Aviation Administration has carried out such an evaluation. The work has been coordinated by the Norwegian Civil Aviation Administration's central management and has been carried out in close collaboration with Oslo Airport Gardermoen. The consultancy firm TerraMar has assisted with the work. Comprehensive work has been carried out, including an assessment of incidents beyond the scope of what is required by the Norwegian Civil Aviation Regulations (CAR Norway) D 3-1.“

Related to ISR 2001/07 the following text is quoted from a CAA-N letter to the DoT dated 18 May 2001:

„The NAA has carried out an assessment as recommended by the AIBN, and has informed the CAA Norway of the result. (Copies of the letters of 4 April 2000 and 9 April 2001 are enclosed.) The resources were found to be satisfactory as far as crew and technical equipment for snow and ice removal was concerned, but the NAA pointed out that the following were most important in order to increase the safety margins:

- 1. Preparations must be made for the use of chemicals on taxiways and aprons.*
- 2. The regulatory framework for pollution must be amended so that accidents can be accepted provided that they do not involve permanent pollution.*
- 3. Preparations must be made to allow for flexible use of chemicals to reflect climate variations.*

*As is known, Oslo Airport Gardermoen (OSL) has appealed against the Norwegian State Pollution Control Authority's emission permit of October 2000, and the case will be finally decided by the Norwegian Ministry of the Environment. The CAA Norway agrees with the NAA's views.
Recommendation No 7/2001 is closed.“*

- **Immediate safety recommendation 2001/08.** *That the Norwegian Civil Aviation Administration consider whether the current methods of measuring braking action could be improved or replaced to advantage, based on the knowledge that exists in this specialist area. ISR 2001/08 was closed 18 May 2001 on the same basis as ISR 2001/05.*

ISR 2001/05/06/08 is related to the AIBN ISR issued as SL 06/1350-1 in 2006. Since then the Norwegian Aeronautical Information Publication (AIP Norway) 1.2-6 has been revised regarding measurement on wet contamination. The methods and the regulations relating to friction measurements however, are basically the same even though the measured friction numbers are no longer reported to aircrews.

Related to ISR 2001/05/06/08 the following text is quoted from a CAA-N letter to the DoT dated 18 May 2001:

*„Recommendations 5, 6 and 8/2001 all concern problems related to the measurement and reporting of braking action to operators and pilots, and are therefore dealt with together:
The CAA Norway recognises, as does the Norwegian Aviation Administration (NAA) and the wider international environment, that the information about braking action that is given to operators and crew concerning effective braking*

action is highly uncertain, particularly in wet conditions. Warnings to prevent uncritical use of the reported values for braking action have therefore been included in AIP Norway. The problem is related to present-day technology and measuring methods and, for many years now, the NAA has participated in the international effort to develop a friction measuring method that will provide reliable information about runway friction to crews on the various aircraft types. However, this is complex work that requires a long time to complete, and the discussion about these factors divert people's attention from the real problem, namely snow and ice in the movement areas.

Despite considerable investments, it is not realistic to maintain „blackrunways“ at all times in this country. The situation can be improved by improving the actual reporting of information, and in this area the CAA Norway, the NAA and the airlines have joined forces. The CAA Norway has appointed a separate committee on „slipperyrunways“, which is considering the problems, involved and has organised two broad user meetings. A new meeting is scheduled in September. The results of friction measurements are presented to the users in the so-called „SNOWTAM“ format. A revised SNOWTAM format, which gives more weight to describing the conditions with respect to snow, ice, temperature and humidity/moisture, will provide more direct and operational information. There is wide agreement that the reporting of braking figures in parts per hundred is misleading on the basis of the available knowledge, and that it is unfortunate when presentations in the SNOWTAM format give the impression of an accuracy that does not actually exist.

The CAA Norway will participate in the international effort to revise the SNOWTAM format, so as to improve the possibility of describing weather and runway conditions. The CAA Norway has also appointed an ad hoc working group, with participants from the airport operators and airlines, which, by summer, will advise on the possibility of providing better information within the framework of the existing SNOWTAM format. In addition, we will ensure, through our supervisory activities, that information on braking action is not transmitted to the operator/pilot when the friction measurements are outside the valid range of the friction measuring device, and that the Air Traffic Service informs the pilots directly that the latest braking figures are misleading if the weather conditions have changed since the conditions were last measured.

Recommendation Nos 5/2001, 6/2001 and 8/2001 are closed.

- ***Immediate safety recommendation 2001/09.*** *That the airline review the applicable procedures and guidelines for braking to a standstill on slippery runways bearing in mind particularly that the situation under certain weather conditions/sudden changes in the weather may be significantly worse than the reported braking action would indicate. Closed 18 May 2001 on the basis of information from the airline in question that they had recommended to their pilots to use „short field landing procedure“ when in doubt of the actual runway friction.*

From the letter from CAA-N to the DoT dated 18 may 2001 is quoted:

„We are informed by the airlines that they have recommended to their pilots that they use the short field landing procedure in cases of doubts. They have also distributed written information about the special conditions at Gardermoen. (A copy of the correspondence is enclosed.)

Recommendation No 9/2001 is closed.

The AIBN also recommended:

- **Safety recommendation 2001/10.** *That the Norwegian Civil Aviation Administration/Oslo Airport Gardermoen (OSL) considers measures to improve the friction conditions on those parts of the ends of the runways at Oslo Airport Gardermoen that consist of concrete.* Closed 18 May 2001 on the basis of information from NAA that Oslo Airport would have more focus on inspections and friction measurements on the concrete areas, especially with air temperatures close to 0 °C.

From the letter from CAA-N to the DoT dated 18 May 2001 is quoted:

*„Gardermoen, Flesland and Evenes have runway end safety areas of concrete. The NAA has explained that, based on the AIBN's recommendations, it will implement measures to measure and, if applicable, improve the surfaces of the runway end safety areas at Flesland and Evenes. So far, no measures to improve friction have been implemented at Gardermoen, but there is greater focus on inspection and measurement of these areas, particularly in connection with sudden changes in the weather and zero-degrees conditions. The CAA Norway deems that the above is sufficient for the time being and the recommendation is closed.
Recommendation No 10/2001 is closed."*

- **Safety recommendation 2001/11.** *That the Norwegian Civil Aviation Administration/OSL consider whether improvements can be made to procedures/equipment with a view to assisting aircraft that run off the runway.* Closed 18 May 2001 on the basis of information from Oslo Airport that they had reviewed and improved their emergency response procedures.

From the letter from CAA-N to the DoT dated 18 May 2001 is quoted:

*„OSL has reviewed its procedures for providing assistance to aircraft that run off the runway and have, among other things, improved the emergency response plan. Recent incidents show that the procedures work much better now. The procedures are currently being reviewed again with a view to making further improvements. The CAA Norway deems the above to be satisfactory.
Recommendation No 11/2001 is closed."*

- **Safety recommendation 2001/12.** *That the Norwegian Civil Aviation Administration investigates whether there are measures that can be implemented that, under our climatic conditions, would bring aircraft to a stop before they leave runways/runway extensions at airports where runway excursions may have especially serious consequences.* Finally closed in a letter to DoT dated 2 June 2010 where CAA-N wrote:

„In a letter of 18 May 2001 to the Ministry of Transport and Communications, the CAA Norway responded to this recommendation as follows: „Requirements for runway safety areas are being evaluated in an ongoing analysis under the auspices of the CAA Norway. Any special measures will be evaluated at a later stage in this process."

In an internal memo of 2 August 2001, the case officer wrote the following: In response to repeated requests, the Norwegian Aviation Administration (NAA) has submitted an assessment of the matters referred to by the AIBN. The NAA has chosen to view the recommendation based on those aerodromes that have limited runway safety areas in combination with other marginal factors, but it also mentions that there may be transitions from runway safety areas to slopes and inaccessible terrain, crossing roads, railways, ditches, trees and the sea. It is clear that the aerodromes meet the requirements for runway end safety areas to varying degrees. The Civil Aviation Authority Norway (CAA Norway) has engaged a British consultancy firm to analyse, among other things, the need for runway safety areas and the NAA will await the results of these analyses. Whatever the result, according to the NAA, the costs of establishing complete runway safety areas on all Norwegian aerodromes will be insurmountable. Alternative measures may therefore be relevant, three well-known examples of which are briefly described by the NAA: the „Water-Twister“, the „Arrester Bed“ and the „Gravel Exit“. The NAA states that it would be interested in finding out whether such solutions can be established in Norway. The NAA will actively endeavour to find optimum safety measures, and it will initiate studies to follow up the results of the safety analysis ordered by the CAA Norway when the results become available (expected some time this autumn). The NAA aims to carry out additional analyses in the course of 2002. The CCA Norway takes a positive view of the NAA's reply. We recognise the problematic conditions, to which the CAA Norway has also repeatedly referred, and we aim to carry out further work with a view to identifying improvements that are possible to implement. The CAA Norway will follow up this work through issuing norms and through its supervisory activities; it wishes to be an initiator in getting this work underway. On the basis of the ongoing analyses, the regulations in CAR Norway E 3-2 will be revised, both as regards the width of runway safety areas and the transition to the surrounding terrain. Compliance with the regulations will be followed up in connection with the renewal of the individual aerodrome approvals, but also during the approval period in certain specific cases. "

The Risk Analysis in Support of Aerodrome Design Rules can be obtained if this is desirable.

In a letter of 23 June 2003 to Avinor, the CAA Norway writes:

„Reducing the consequences of runway excursions.

The CAA Norway would like to thank Avinor for having followed up this case, cf. AIBN Recommendation No 12/2001 following the aviation accident of 6

December 1999 involving a Premiair DC-10 at Gardermoen.

Avinor's views are generally in accordance with the CAA Norway's views, with the exception that trees with a diameter of up to 10 cm can be fatal to small aircraft. We also support the idea of an analysis in which the benefit of areas with reduced load-bearing capacity is considered in relation to accessibility for fire engines and rescue vehicles. Avinor's thoughts on alternative materials and load-bearing capacity as consequence-reduction measures are completely in line with the CAA Norway's views. The CAA Norway expects Avinor to use these views as the basis for any necessary proposals for compensatory action in connection with

the renewal of aerodrome approvals. You are also informed that AIBN Recommendation No 12/2001 has already been closed."

The CAA Norway concludes that, on the basis of the abovementioned analyses, the regulations in CAR Norway E 3-2 have been revised, both as regards the width of runway safety areas and the transition to the surrounding terrain. Compliance with the regulations is followed up in connection with the renewal of the individual aerodrome approvals, but also during the approval period in certain specific cases. The results of this include Avinor's S&L project. Safety recommendation SL no 2008/12T is hereby closed." (AIBN correction: Correct SR No should be 2001/12)

- **Safety recommendation 2001/13.** *That the competent authority considers supplementing the „National policy guidelines for planning in connection with the main aerodrome at Gardermoen" (still in force) by an addendum, which establishes the order of priority of the stated overriding objectives. Finally closed in a letter to DoT dated 2 June 2010 where CAA-N wrote:*

„In a letter of 18 May 2001 to the Ministry of Transport and Communications, the CAA Norway responded to this recommendation as follows: „The CAA Norway supports the AIBN's recommendation to establish the order of priority. Our input in this connection will be in the form of a separate letter to the Ministry which will be sent in the near future. Recommendation 13/2001 is closed."

Reference is made to the letter of 4 June 2008 from the Ministry of Transport and Communications, which states the following, among other things: „We are informed by the Ministry of the Environment that the Norwegian State Pollution Control Authority granted a new emission permit to Oslo Airport Gardermoen on 15 October 2001. The permit was appealed, but the Ministry of the Environment upheld the permit by a decision of 11 July 2002. In its letter of 24 September 2002, the Ministry of the Environment pointed out that, in its opinion, it is the emission permit that determines the actual conditions for the polluting activities at the airport. The Ministry of the Environment believes that the amended emission decision addresses the problems that were raised in the letter from the Ministry of Transport and Communications and that there is therefore no need to change the national policy guidelines. In a letter of 1 October 2002 the Ministry of Transport and Communications requested that the CAA Norway consider whether the new emission permit for Oslo Airport Gardermoen would make it unnecessary to amend the national policy guidelines and whether this would satisfy AIBN Recommendation No 13/2001."

The CAA Norway agrees with the Ministry of the Environment's view that the amended emission decision addresses the problems that were raised in the letter from the Ministry of Transport and Communications and that there is therefore no need to change the national policy guidelines.

Safety Recommendation SLNo 13/2001 is hereby closed."

1.1.4 Serious aviation incident. 11 February 2000. Hammerfest, ENHF ([RAP 2002-23](#))

Wideroe DHC-8-103 skidded off the side of runway 23 while landing on a slippery runway in crosswind conditions.

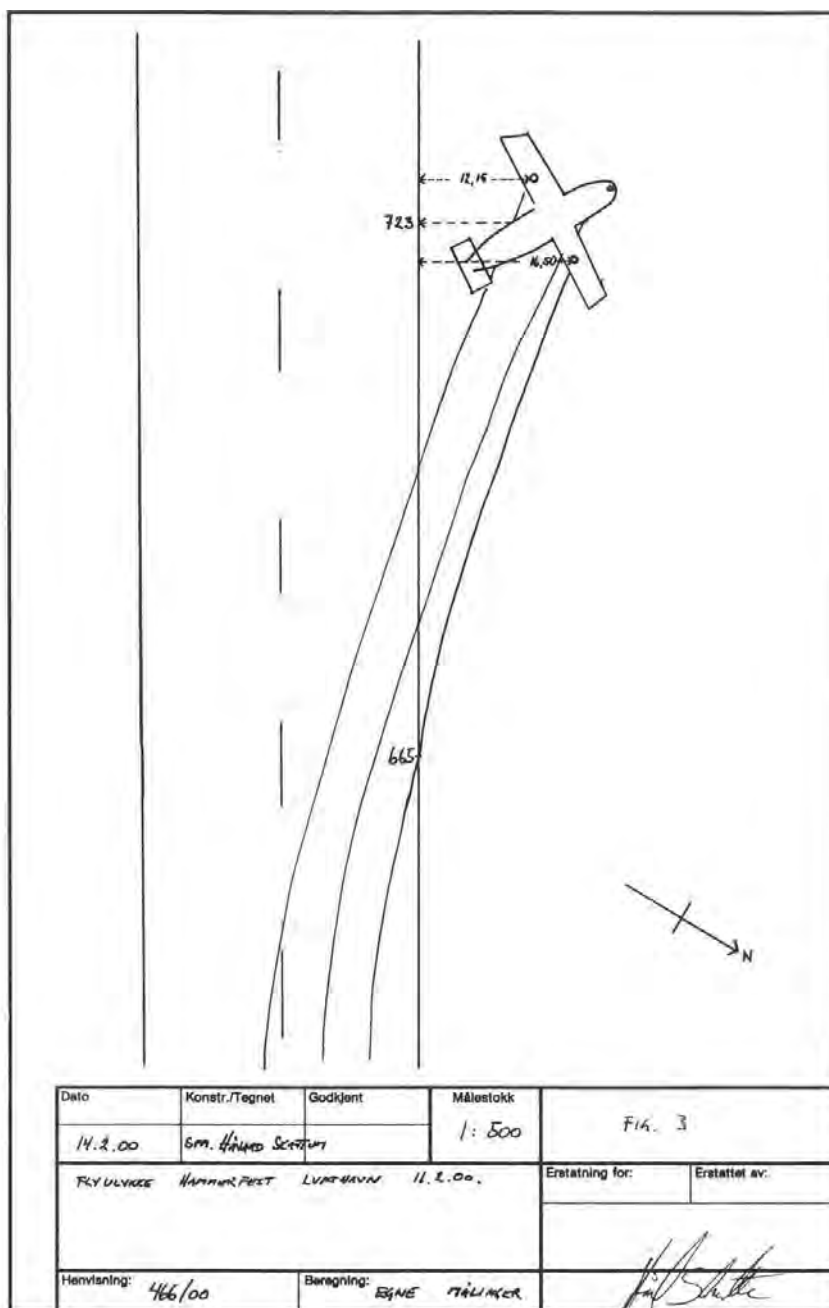


Figure 3: Serious aviation incident with LN-WIL at ENHF on 11 February 2000.

1.1.4.1 Weather:

METAR ENHF 112050Z 01013G24 260V080 9999 SCT010 01/M02 Q0967=

1.1.4.2 Runway status:

The runway was covered with compact snow and ice with 3-4 mm of slush on top. The runway had been sanded. Measured FC was 32-34-33 (Griptester/GRT)¹⁸. Actual ABC as deducted from FDR data was in the order of 0.05 (POOR).

¹⁸ Continuous Friction Measuring Device (CFMD) of the type Griptester (GRT).



Figure 4: Aviation incident with LN-WIL at ENHF on 11 February 2000.

1.1.4.3 The AIBN's evaluation/safety recommendations/status:

(Safety recommendations relating to slippery runways)

The AIBN referred to safety recommendations made in reports 2001/05 and 2001/17. In addition, the AIBN submitted the following safety recommendations:

- Safety recommendation 2002/06.** *That the Norwegian Civil Aviation Administration consider whether the regulations for the preparation of „contaminated runways“ (ref. CAR Norway E 4-2, winter maintenance and the SNOWTAM format) is in line with JAR 25 AMJ 25X 1591, section 5.1, and JAR-OPS IEM OPS 1.490(c)(3) concerning operations on „contaminated runways“.* Closed in 2003. CAA Norway wrote in a letter dated 10 December 2003 to the Norwegian Ministry of Transport and Communications (DoT):

„The CAA Norway has carried out the recommended considerations, and we believe that the provisions of CAR Norway E 4-2 relating to winter maintenance are in line with the JAR provisions referred to. Recommendation No 6/2002 is closed.“
- Safety recommendation 2002/07.** *That the Norwegian Civil Aviation Administration consider following ICAO's recommendation in Annex 14, Vol. I, section 3.1.2 about a 10 kt upper limit for the permitted crosswind component for runways shorter than 1,200 metres in length, especially for Norwegian short runway operations in winter conditions with a friction coefficient of less than 0.40.* Closed in 2003. In a letter dated 3 November 2003 to the DoT, the CAA Norway wrote:

„Therecommendation referred to in the recommendation was meant as advice in connection with the planning of a new aerodrome and any traffic it will serve. The CAA Norway does not regard the recommendation as an upper limit for normal operations.“

The crosswind limits for the various aircraft types are stated in the manuals for the aircraft type, and the operator has adapted them further to suit the operations for which the aircraft type is used. Runway length, topography in the area around the aerodrome, weather conditions, weather phenomena, friction and the operator's experience are among the conditions the operator evaluates when crosswind limits are defined in the Operations Manual. The Operations Manual must be accepted by the CAA Norway and is one of the documents that form the basis for the granting of an Air Operator Certificate (AOC).

The CAA Norway supports the AIBN's view that crosswind limits are an important safety factor. However, it is not realistic to restrict the operators on the network of short runways in Norway to a crosswind component of 10 knots for runway lengths of less than 1,200 metres. The CAA Norway finds that the monitoring of the various operators' operational limits is satisfactory, including as regards the crosswind component. We shall therefore not change our practice in response to the AIBN's recommendation and thus reject the recommendation. Recommendation No. 7/2002 is closed.

At the time in question, De Havilland/Bombardier had not published recommended crosswind limits for the DHC-8-100/300 in Flight Manual SUP 37. Widerøe's crosswind limits were much less strict than those recommended by Transport Canada (TC). Figure 5 shows the Canadian crosswind limits recommended by TC. The graph shows that at CRFI (corresponds to FC) 0.30 (MEDIUM) the recommended crosswind limit on a runway of standard length is 10 kt.

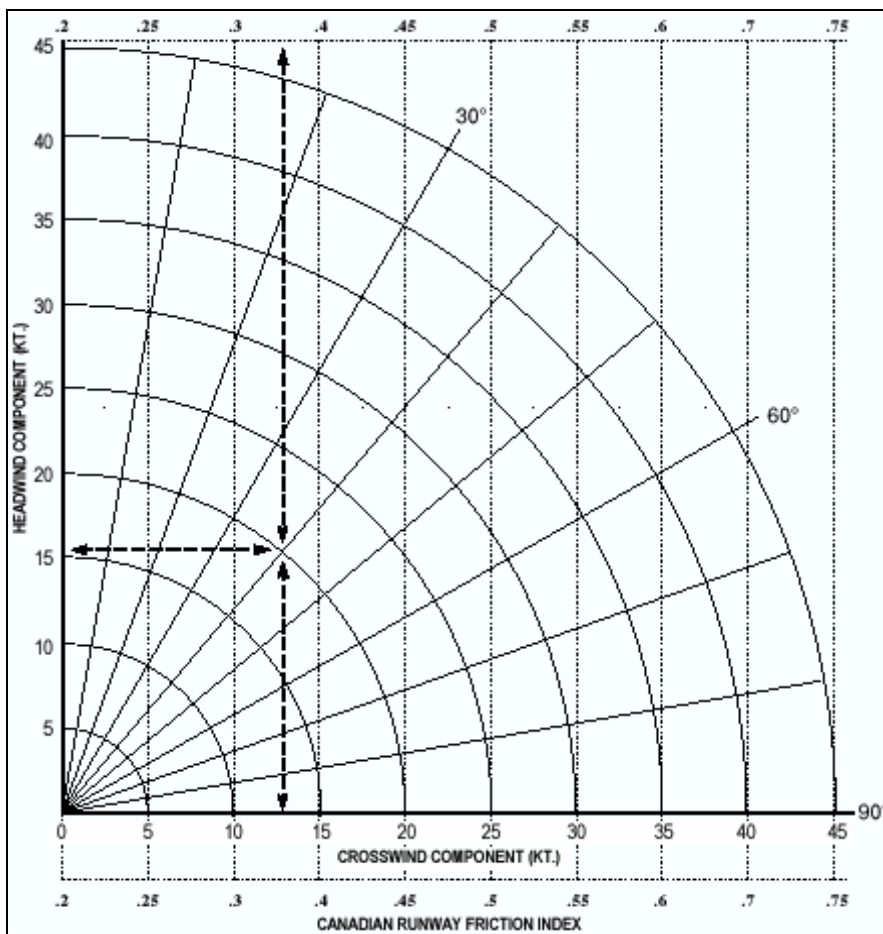


Figure 5: Crosswind Limits for Canadian Runway Friction Index (CRFI).

The intention behind this recommendation was that Widerøe's crosswind limits on slippery runways with measured FCs of less than 0.40 (GOOD), ought to be reduced to increase the safety margins on short runways. The AIBN judged that, since ICAO had already recommended a crosswind limit of max 10 kt on dry runways less than 1,200 m in length, an assessment should be carried out as to whether Widerøe should set the same crosswind limit on a shorter (800 m) runway with reduced friction of less than 0.40 (GOOD).

The AIBN has investigated subsequent incidents relating to landing on slippery runways in crosswinds, which indicate that the risk level has not changed. See 1.1.13 and 1.2.3.

- **Safety recommendation 2002/08.** *That the CAA Norway considers whether the SNOWTAM format can be improved based on present knowledge about the measuring equipment's inaccuracies and limitations, and differences that depend on the type of equipment.* Closed in 2003. The CAA Norway wrote in a letter dated 10 December 2003 to DoT:

„The CAA Norway has prepared a new reporting system with a view to providing the pilots with better and more comprehensive information about runway conditions within the framework of the existing SNOWTAM format. The system was in use last winter and was evaluated at a meeting with representatives of the market on 29 August this year. The feedback from the market has been favorable. Recommendation No 8/2002 is closed.“

The CAA Norway based the closure on the CAA not finding it expedient to change the present SNOWTAM format, which is a standard ICAO format. Hence, the combined uncertainty of the measuring equipment and a table stated in hundredths was continued. The CAA Norway found no basis for changing the SNOWTAM format since it was based on international rules. The AIBN had demonstrated that the international rules did not provide adequate safety margins and that they should be improved.

- **Safety recommendation 2002/09.** *That the CAA Norway considers whether the Norwegian practice for measuring and reporting friction coefficients on wet runways can be justified based on today's knowledge of the limitations of measuring methods and friction tables. This also includes an assessment of the use of alternative fixed friction coefficients for the various runway conditions.* Closed in 2003. The CAA Norway wrote in a letter dated 10 December 2003 to DoT:

The CAA Norway has considered the Norwegian practice of measuring and reporting friction coefficients. Based on the knowledge and experience that Norwegian operators have of today's measuring methods and based on the limitations of friction tables, which are also well-known to all the operators, the CAA Norway deems the current practice to be satisfactory. Together with representatives of the market, the CAA Norway evaluates measuring and reporting practice every winter. In addition, this area is given high priority when the CAA Norway conducts inspections of ground services at the various airports. The new version of CAR Norway E 2-4 will also impose greater restrictions on the reporting of friction figures than currently applicable rules and regulations, and the CAA Norway expects that the reliability of such figures will be improved.

We hereby find that the recommendation has been satisfactorily addressed. Recommendation No 9/2002 is closed."

The CAA Norway closed the recommendation finding that the current practice satisfactory. Hence, the practice of the time of the incident was continued.

- **Safety recommendation 2002/13.** *That the Norwegian Civil Aviation Administration considers whether the training of airport personnel in the various friction measuring devices" operating ranges and limitations and the reporting of friction coefficients, can be improved.* Closed in 2002. In a letter to DoT dated 9 October 2002 CAA Norway wrote:

„Competence among all parties is vital to a safe air transport, including airport staff. Today"s regulations for airport ground services demand that the staffs are given adequate theoretical and practical training, and the regulations allocate the responsibility for such training. The regulations do not specify the content of the training, but this will be evaluated during the ongoing revision of the CAR (BSL) E 4-3. If CAA Norway reaches the conclusion that such detailed content is necessary, details will be included as guidelines on yellow pages. The airport owners, particularly the Norwegian Aviation Administration, is performing considerable training of the airport staffs, and the training in winter maintenance has been intensified during the last two years, not least due to the incidents leading to this recommendation from the AIBN. Norwegian Aviation Administration has informed that they will coordinate the activities at the two training organisations, LVTS for airport services and LVSS for air traffic control, in order to get a common training. Based on this CAA consider that the recommendation can be closed. The Recommendation No. 13/2002 is closed"

Avinor has subsequently followed up the recommendation and carried out a comprehensive training programme for airport ground staff.

- **Safety recommendation 2002/14.** *That Widerøe considers whether training, including in friction measurement and the limitations of the various measuring methods, and training of pilots on short and slippery runways in Norway, can be improved in relation to SUP 48 NCAA, SUP 37 NCAA, AIP Norway AD 1.2, the SNOWTAM format with limits, and the CAA Norway"s approvals for short runway operations.* Closed in 2003. In a letter to DoT dated 17 December 2002 CAA Norway wrote:

The CAA Norway sent a letter to Widerøe"s Flyveselskap on 4 September 2002, requesting the company"s considerations and any measures it would take in connection with the recommendation in question. In the enclosed fax dated 31 October 2002, the company has presented its considerations and follow-up of the recommendation. Among other things, Widerøe states that it is well aware of the limitations of today"s friction measuring equipment and the related elements of uncertainty, particularly on wet runways and during zero temperature conditions. The fax describes the company"s involvement in meetings and working groups together with the CAA Norway and the Norwegian Aviation Administration (NAA). The company"s pilots are requested to report all cases of disparity between the braking action experienced by the pilots and the reported friction coefficient. Widerøe goes on to say that, for several years now, it has distributed „Winter

Topics"for the winter season to all pilots, containing important reminders relating to winter operations. In that connection, it seeks to improve the pilots" knowledge in important areas. For a complete version of Widerøe"s response, see the enclosed fax of 31 October 2002.

The CAA Norway has considered Widerøe"s response and, like the company, it deems Recommendation No 14/2002 to have been satisfactorily dealt with. Recommendation No 14/2002 is closed."

The referred fax from Widerøe dated 31 October 2002 stated:

„Recommendation No 14.

The company is well aware of the limitations of today"s friction measurement equipment and the related elements of uncertainty, particularly on wet runways and during zero temperature conditions. In recent years, we have participated in many meetings and several working groups together with representatives of both the CAA Norway and the NAA, for the very reason that we want to minimise the problems associated with winter operations in general and hence reduce the risk of misjudging prevalent runway conditions and the consequences in the form of runway excursions. The authorities as well as the operators have therefore placed great emphasis on the problem.

During the last winter seasons, the company"s pilots have been asked to report all cases of disparity between the braking action experienced by the pilot and the reported friction coefficient. The reports have confirmed that the problems relate in particular to wet conditions on top of ice or compact snow and zero temperature conditions.

Prior to every winter season, the company has distributed „Winter Topics"to all pilots, containing important reminders and useful information relating to winter operation. Last year, the trial scheme of Pilot Reporting was among the main topics. This in turn was a result of a recommendation by a working group established by representatives of the CAA Norway, the NAA and the operators. As a result of the experience gathered last year, we have decided that this year"s „Winter Topics"shall focus exclusively on the above-mentioned problem and hence improve the pilots" knowledge of the following:

- 1. The weaknesses of today"s friction measuring equipment*
- 2. The uncertainty attached to measurements carried out on various types of runway surfaces, with particular focus on wet conditions on top of ice or compact snow and zero temperature conditions.*
- 3. The unfortunate aspect of reporting average depth in Field G of today"s Snowtam Format,*
- 4. Probable restrictions with respect to the use of friction coefficients under the above-mentioned conditions.*

This year"s „Winter Topics"will most probably be in the form of a directive. The reason why the topics have not yet been distributed is that the operators (SASIBU/WF) are awaiting a clarification from the CAA Norway concerning some key issues that the operators feel are important to clarify. We plan to have

completed the distribution by 10 November. The director of flight operations believes that this year's „Winter Topics“ cover the recommendation in the Report and will send a copy to the CAA Norway.

Later incidents indicated that the measures taken in 2002 were not sufficient.

1.1.5 Aviation incident. 14 March 2000. Molde, ENML ([RAP 2001-17](#))

Norwegian Air Shuttle (NAS) F-27-50 skidded off runway 07 while landing in crosswind conditions.

1.1.5.1 *Weather:*

METAR ENML 142020Z 32016KT 9999 VCSH FEW010 SCT020 BKN035 01/M01 Q1002

1.1.5.2 *Runway status:*

The runway was covered with compact snow with 1-3 mm of wet snow on top. The runway had been sanded. Measured FC was 47-47-44 (Skiddometer/SKH)¹⁹. Actual ABC was perceived by the crew as POOR.

1.1.5.3 *The AIBN's evaluation/safety recommendations/status:*

(Safety recommendations relating to slippery runways)

- **Safety recommendation 2001/23.** *The AIBN recommends that the Norwegian Civil Aviation Administration and the CAA Norway work together to revise Norwegian regulations and associated instructions based on the 15 points listed in Annex 2, section 4 „Summary“ (RAP 2001/17). The revisions ought to have international backing. Closed in 2002. In a letter to DoT dated 20 November 2002 CAA Norway wrote:*

„Representatives of the CAA Norway and the Norwegian Aviation Administration have cooperated for a long time with a view to improving and revising procedures relating to, among other things, friction measurements, runway reports, winter maintenance of aerodromes etc. The representatives were charged with the task of evaluating and recommending changes to the relevant instructions in the Norwegian Civil Aviation Regulations (CAR Norway) E 4-2 „Instructions for aerodrome maintenance“ (Annex to CAR Norway E 4-1 „Regulations on ground services“). Section 9.6.6 of these instructions and the entire Annex 3 „Content of runway report“ were issued on 10 September 2002 and include amended procedures for communicating runway reports. It should also be noted that CAR Norway E 4-2 will be available in a fully revised edition in the near future. Furthermore, through the work of the above-mentioned working group, the CAA Norway has developed improved procedures for winter maintenance on Norwegian aerodromes, published in AIC-I 18/02 (dated 11 October 2002). AIP Norway AD 1.2 will also be revised correspondingly. Hence, the CAA Norway deems that Recommendation No 23/2001 has been satisfactorily dealt with. Recommendation No 23/2001 is closed.“

¹⁹ Continuous Friction Measuring Device (CFMD) of the type BV-11/Skiddometer with high pressure tyres (SKH).

1.1.6 Aviation incident. 20 March 2000. Bardufoss, ENDU ([RAP 2000-30](#))

SAS MD-80 skidded off the runway while turning prior to departure in crosswind conditions.

1.1.6.1 *Weather:*

METAR ENDU 201850Z 25016G27KT 220V290 9999 FEW020 SCT 040
M01/M07 Q0986=

1.1.6.2 *Runway status:*

The crew had been told that braking action was 30/30/31 (29/30/31, in the flight commander's report) on sanded ice. These measurements were taken at 1830, which was approximately 90 minutes before taxiing out. After the aircraft's departure on runway 29 a new measurement was taken at 2020, with the following results: 25/26/27. Approximately 80% of overrun 11 were covered in 1 cm of dry snow. The braking tests were carried out on the runway. No measurements were made on the overrun. It was assumed by Bardufoss Main Air Base, which carried out the braking measurements, that the braking test values measured on the runway were valid for the overrun as well. Actual ABC perceived by the crew as POOR.

1.1.6.3 *The AIBN's evaluation/safety recommendations:*

No safety recommendations were issued. Quote from the AIBN's report:

„As Norway experiences a long period each year in which it is usual for the remains of precipitation to continue to lie in the manoeuvring area, it is of the utmost importance that correct and accurate information about braking action is made available to the aircraft crew. The information provided must be updated and must describe the prevailing conditions at the time when the aircraft is scheduled to use the runway. It is also important for flight crews to use their own good judgement and request fresh measurements.“

1.1.7 Serious aviation incident. 11 May 2000. Tromsø, ENTC ([RAP 2000-77](#))

SAS DC-9-87 skidded off the end of runway 19 while landing in crosswind conditions.

1.1.7.1 *Weather:*

METAR ENTC 111920Z 28009KT 2000 SHSNGS VV012 M02/M03 Q1020 TEMPO
0500 + SHSNGR VV005=

1.1.7.2 *Runway status:*

The runway was covered in wet snow and slush from recent showers. No measured FC. Actual ABC as deduced from FDR data was in the order of 0.05 (POOR).

1.1.7.3 *The AIBN's evaluation/safety recommendations/status:*

(Safety recommendations relating to slippery runways)

- **Safety recommendation 2000/70.** *The AIBN recommends that the Norwegian Civil Aviation Administration consider whether the procedures for checking runway conditions when the weather conditions change, can be improved. This should be examined in the context of the procedures/priority for handling traffic. Closed in 2001. In a letter to DoT dated 14 March 2001 the CAA-N wrote:*

„The CAA Norway forwarded the recommendation to the Norwegian Aviation Administration (NAA) and requested that it report back on what evaluations and measures/procedural changes (if any), that it planned to implement in this connection. In a letter of 19 February 2000 (see Enclosure 1.) (Enclosure 1 not included in this AIBN report) the NAA replied that it has held a gathering of aerodrome supervisors from all regions/airports, at which one of the topics related to the recommendation. We are also informed by the NAA that a project has been set up to consider „winter condition in the movement areas, which interfaces with the recommendation. Moreover, in its reply, the NAA states that it awaits the AIBN’s investigation and report after the aviation incident of 14 March 2000 involving LN-KKD at Molde Airport in which a Fokker 50 aircraft ran off the runway as a result of slippery conditions and side winds. The NAA has decided to appoint an inter-disciplinary working group to evaluate the various aspects of this matter.

The CCA Norway has considered the NAA’s reply and finds that the measures implemented by the NAA are satisfactory. The CCA Norway would like to use this opportunity to mention that the problems relating to slippery runways are the subject of extensive work being carried out by a separate working group internally in the CCA Norway in which the NAA participates.

The CAA Norway hereby deems that this recommendation can be closed (see Enclosure 2 to the CAA Norway’s memo of 22 February 2001) (Enclosure 2 not included in this AIBN report). Recommendation No 70/2000 is closed.”

- **Safety recommendation 2000/73.** *The AIBN recommends that the authorities and companies make it known that the warming up of the wheels during rollout may reduce the accuracy of the reported braking action/measurements. Closed in 2001. In a letter to DoT dated 14 March 2001 the CAA-N wrote:*

„The CAA Norway refers to the letter from SAS dated 5 February 2001 (see Enclosure 4) and to the memo of 12 March 2001 (see Enclosure 5) (Enclosures 4 and 5 are not included in this AIBN report) from the CAA Norway’s flight operation section, which explain their views relating to the recommendation. The letter from SAS makes it clear that the company finds that it cannot support the recommendation as it claims that neither the aircraft manufacturers nor the aviation institutes have provided any documentation in support the recommendation. In its memo, the CAA Norway describes the work carried out by the interdisciplinary group that was appointed to consider the problems relating to slippery runways. Among other things, a letter has been sent to the airlines, requesting them to evaluate their documentation of these problems. Recent research has shown that there are deficiencies in the measuring methods used today. In the CAA’s opinion, the pilot in command should be informed, not only about the braking coefficient, but about a number of other factors such as pilot reports from previous landings, the ground temperature of the landing strip and whether the braking action measurements are within the valid range. On this

basis, the CAA Norway finds that the recommendation can be closed. Recommendation No 73/2000 is closed."

AIBN's comments to the above statement from SAS airline: It is recognised by tire manufacturers that braking friction and flexing in the tire structure caused by hysteresis is warming up the aircraft tires. These increased temperatures in the tires may melt snow or ice underneath the wheels and hence reduce the aircraft braking coefficient. This is substantiated by measurements at Svalbard Airport Longyear by Dr. R. Mook referred to in Appendix J, chapter 03, as shown by this quote:

„At Svalbard Airport Longyear, an infrared sensor was used to take temperature readings in the tread of the inner main wheel just after parking aircraft in the Boeing 737-400 to 737-800 series over a period of several winter seasons. As a mean, the highest temperature, which exceeded the outside air temperature (OAT) by approximately 25 K, was found near the tyre"s edges, while it was 15 K above OAT closer to the centre (of the tread). The amount by which the temperature exceeded the ambient temperature increased with the landing weight. If we look at the B 737-800 alone, the results were 35 K and 20 K above OAT, respectively. The temperature can increase during the first 10 minutes after parking. Cooling takes place very slowly. Though the progression is exponential, it can be approximated in linear terms. At an air temperature of minus 15 °C, cooling in calm air may be 0.2 K/minute, or in the order of 0.1 K/minute at an air temperature 0 °C.

1.1.8 Aviation incident. 22 December 2000. Tromsø, ENTC ([RAP 2002-22](#))

SAS MD-80 skidded off the left-hand side of runway 19 while landing in a crosswind from the right. The aircraft smashed some runway lights and damaged the undercarriage. The crew managed to steer back onto the runway.

1.1.8.1 *Weather and runway status:*

Tromsø information „V“received before commencing descent: „Runway 19. Transition level 75. Wind 260/17-27. Vis 3,000 m. Vertical visibility 1,000 ft. Temp/dewpoint 1/0. QNH 997. Visibility 1,200m. SHSN. Vertical vis 800 ft. Wind at 2,600ft 300/43-53. Runway closed for sweeping“.

During the approach, the braking action (BA)²⁰ was reported to be 43-35-37. The crew perceived the friction to be POOR. The previous landing aircraft had reported BA MEDIUM TO POOR.

1.1.8.2 *The AIBN's evaluation/safety recommendations/status:*

No safety recommendations were issued. Extract from the AIBN's report:

„The aerodrome in Tromsø is a hub for air traffic in North Norway. It is therefore important to maintain regularity. It is understandable that this puts pressure on the personnel responsible who have to make up their minds as to whether conditions have deteriorated to the extent that the runway has to be closed. The

²⁰ Braking action (BA) is an expression describing measured or estimated runway friction, which is measured as, for example, 0.43, but reported as 43. Estimated BA is reported in numbers from 1 to 5.

AIBN believes that the control tower should have closed the runway for preparation after the Braathens 737 that landed before LN-ROM had reported the runway conditions as „medium to poor“. The AIBN has subsequently received information about new improved procedures at Tromsø Airport Langnes. The AIBN takes a positive view of these measures and has expectations about the results. The AIBN also refers to the work taking place in the Norwegian Civil Aviation Administration and the CAA Norway in the so-called „Slippery runways working group“.

1.1.9 Aviation accident. 6 January 2003. Vadsø, ENVD ([RAP 2004-33](#))

Wideroe DHC-8-103 skidded off runway 08 after landing on a slippery runway in crosswind conditions.



Figure 6: Aviation accident with LN-WIN at ENVD on 6 January 2003.

1.1.9.1 *Weather:*

METAR ENVD 061250Z 17009KT 0700 BCFG IC VV004 M14/M16 Q1014 ARCTIC SEAFOG=

1.1.9.2 *Runway status:*

The runway was covered with hoar frost and ice and was partially covered with recent snow. The runway had been sanded. Measured FC was 48-52-48 (Griptester/GRT). The runway status was checked after the accident and was estimated to be POOR.

1.1.9.3 *AIBN accident report:*

AIBN concluded that the main cause factor for the lost directional control was cross connected brake lines. Hence, there was a latent fault in the brake system which only manifested itself when the ant-skid system operated in POOR braking conditions or with friction limited braking conditions. However, the aircraft had performed several previous landings without crews noticing any defects.

1.1.9.4 *The AIBN's evaluation/safety recommendations/status:*

(Safety recommendations relating to slippery runways)

- ***SL Safety recommendation 38/2004.*** *The uncertainty attached to friction measurements has been a recurring issue in landing accidents under winter conditions in recent years. The AIBN believes that uncertainty in connection with braking of aircraft landing on contaminated runways is a complex and multi-faceted issue and that there is still a need for more research and development, in respect of both friction measurements and discipline areas such as, for example, micro-meteorology, runway structure and braking systems. The AIBN recommends that the CAA Norway and Avinor intensify their efforts to increase and disseminate knowledge in all relevant discipline areas.* Closed in 2005.

The safety recommendation was closed by CAA Norway by acknowledging the challenge of estimating the correct runway friction on contaminated runways and that the CAA kept the operators updated on new developments and urged them to review their operating procedures.

- ***SL Safety recommendation 39/2004.*** *The AIBN believes that it may be possible to increase the safety margins somewhat by reinforcing the training of the pilot corps as regards to the uncertainty of friction measurements and use of the pilot's best judgement in this connection. Among other things, new factors have emerged during this investigation, as have new results from ongoing projects in the industry that must be disseminated. The AIBN therefore recommends that the Wideroe Airline should evaluate whether training in this subject should be reinforced, both for new employees and experienced pilots.* Closed in 2005.

The safety recommendation was closed by the CAA Norway based on a letter from Wideroe stating that the subject had been reviewed at Operational Proficiency Check (OPC) 2 in 2005.

1.1.10 Serious aviation incident. 25 November 2004. Evenes, ENEV ([RAP 2007-25](#))

MyTravel Airways UK Airbus A320 skidded off runway 35 during departure.

1.1.10.1 *Weather:*

METAR ENEV 252050Z 34006KT 9999 –SHSN SCT015 BKN030 M04/M06 Q1018

1.1.10.2 *Runway status:*

The runway was covered in sanded ice with 8 mm dry snow on top. Measured FC was 34-32-32 (Skiddometer/SKH). Actual „effective μ “ was perceived by the crew as POOR.



Figure 7: Serious aviation incident with G-CRPH at ENEV on 25 November 2004.

1.1.10.3 The AIBN's evaluation/safety recommendations/status:

(Safety recommendations relating to slippery runways)

- **Safety recommendation SL 2007/25T.** *The AIBN's investigations show deficiencies in the MyTravel Airways UK SOP regarding operations on contaminated runways. The AIBN recommends that MyTravel Airways UK review their OM Part A relating to these types of operations. Closed in 2010.*

The recommendation was closed by the CAA Norway, based on a letter from Thomas Cook Airlines UK (TCA UK) about altered procedures for winter operations.

- **Safety recommendation SL 2007/26T.** *The AIBN's investigation shows that the pilots' understanding of different aspects of Norwegian winter operations is limited. The AIBN recommends that MyTravel Airways UK review their training requirements for operations on contaminated runways in Norway. Closed in 2010.*

The recommendation was closed by the CAA Norway, based on a letter from TCA UK about revised training arrangements for „arctic operations“.

- **Safety recommendation SL 2007/27T.** *The AIBN's investigations show that Avinor's practice of measuring friction on compact snow or ice covered by loose dry snow, wet snow or slush may be outside the approved acceptable conditions for the measuring devices. The AIBN recommends that Avinor review the acceptable conditions for the measuring devices. Closed in 2009.*

The recommendation was closed by the CAA Norway without reviewing the acceptable measuring criteria or instructing Avinor to change its practice.

- **Safety recommendation SL 2007/28T.** *The AIBN's investigations show that Airbus Industrie's concept of basing aircraft takeoff and landing performance on „Fluid Contamination" and „Equivalent to Wet Runway" is misleading and not substantiated by scientific research. The AIBN's investigations and Norwegian experience show that „fluid contaminations" very often result in POOR braking action, contrary to the present belief of some organisations. The AIBN recommends that Airbus Industrie review the concept of „Fluid contamination being Equivalent to Wet Runway" for landing on contaminated runways. Open.*

1.1.11 Aviation incident. 16 January 2005 (1945Z). Evenes, ENEV.

NAS B737-300 skidded while landing on runway 17 in crosswind conditions and turning off onto TWY D. The investigations were concluded without a separate report.

1.1.11.1 *Weather:*

TAF ENEV 161400Z 161524 12015G30KT 8000 -SN FEW010 BKN020 TEMPO 1524 1200 SN BLSN VV010 TEMPO 1821 18010KT=

METAR ENEV 161850Z 09013G23KT 9999 VCSH FEW020 BKN040 M2/M7 Q0992

1.1.11.2 *Runway status:*

A runway report at 1845Z shows that the runway was covered with sanded ice. Friction was measured as being 32-34-35 (Skiddometer/SKH). The taxiway was reported as being covered with dry snow on ice with medium to poor friction. The crew perceived the friction to be POOR.

1.1.12 Aviation incident. 18 January 2005 (1435Z). Evenes, ENEV.

Spanair A320 skidded on the apron by the gate. The investigations were concluded without a separate report.

1.1.12.1 *Weather:*

TAF ENEV 181100Z 181221 12008KT 9999 FEW030 BKN050=

METAR ENEV 181350Z 20011KT 9999 -SHRA SCT30 BKN050 3/0 Q0981

1.1.12.2 *Runway status:*

A runway report at 1345Z shows that the runway was covered in sanded ice. Friction was measured as being 38-42-57 (Skiddometer/SKH). The taxiways had medium reported friction. The crew perceived the friction to be POOR.

1.1.13 Aviation incident. 30 January 2005. Kirkenes, ENKR ([RAP 2009-06](#))

Wideroe DHC-8-103 skidded sideways while landing in crosswind conditions on runway 24. The flight commander regained control and taxied in.

1.1.13.1 *Weather:*

METAR ENKR 301350Z 16025G33 KT 9000 SHSN BLSN SCT015 BKN035 M9/M11 Q0980

1.1.13.2 *Runway status:*

Runway report 1348: Runway 06 was 100% covered with ice with sand from previous applications frozen into it. Highest measured FC was 0.50, the lowest was 0.25. Some small snow drifts of approximately 1-2 cm on the northern half of the runway. Reported friction values of 43-42-41 measured with SKH. The crew perceived the friction to be POOR.

1.1.13.3 *The AIBN's evaluation/safety recommendations/status:*

(Safety recommendation relating to slippery runways)

- ***Safety recommendation SL 2009/13T.*** *The AIBN has found that Wideroe's crosswind limits on contaminated runways are less conservative than Bombardier's recommended crosswind limits versus friction coefficients. The AIBN recommends that Wideroe evaluates its crosswind limits on slippery runways in relation to Bombardier's recommendations. Closed in 2009.*

AIBN had investigated an earlier incident where the crosswind limits were an issue (see 1.1.4 and Safety Recommendation 2002/07). The safety recommendation was rejected by the CAA-N. During the AIBN investigation process of the new incident of 30 January 2005 at Kirkenes, Bombardier had issued recommended crosswind limits. AIBN evaluated these and found that these limits were based on „*aircraft μ* “ while the new Wideroe limits were based on measured and reported friction coefficient (FC). AIBN found during the investigation that Wideroe's table were more conservative below 0.25 (5 kt vs 8 kt) but less conservative at higher FC. Further, in the low area (POOR) the difference between „*aircraft μ* “ and measured FC is less significant based on the correlation formula. Based on this AIBN issued a new Safety Recommendation SL 2009/13T.

1.1.14 Serious aviation incident. 30 January 2005, ENEV ([RAP 2009-07](#))

SAS Braathens²¹ Boeing B737-400. Loss of directional control while landing on slippery runway 17 in crosswind conditions spun around and came to a halt across the runway. The flight commander succeeded in keeping the aircraft on the runway. The aircraft was towed in.

1.1.14.1 *Weather:*

METAR ENEV 301350Z 21026G42KT 9999 VCSH SCT 015 BKN025 02/M01 QNH 965 hPa WIND 1400 FT 23050G64KT=

²¹ Scandinavian Airlines System bought and integrated Braathens airline in 2004 into SAS Braathens. In 2007 the name was changed to SAS Norway. In 2009 SAS Norway was integrated into SAS main airline.



Figure 8: Serious aviation incident with LN-BRV at ENEV on 30 January 2005. Animation available at www.aibn.no/aviation/reports/2011-10

1.1.14.2 Runway status:

The runway was covered in 3 mm of slush on wet ice and had been sanded to a width of 30 m along the centreline. Measured FC was 24-25-26 (Skiddometer/SKH). Actual ABC was perceived by the crew as POOR.

1.1.14.3 The AIBN's evaluation/safety recommendations/status:

(Safety recommendations relating to slippery runways)

- **Safety recommendation SL 2009/14T.** The AIBN's investigations of several incidents show that there was/is a practice in Braathens/SAS Braathens/SAS Norway of accepting friction values/reported braking action for runways covered with wet or moist snow or ice. The AIBN recommends that SAS Norway (formerly SAS Braathens) re-assess this practice and instead treat runways as slippery regardless of higher indicated or reported friction on runways covered in wet or moist snow or ice. Closed in 2009.

The recommendation was closed by the CAA Norway based on a letter from SAS stating that they had partially complied with the recommendation. The CAA Norway has not produced its own closure assessment.

- **Safety recommendation SL 2009/15T.** Braathens OM Part B/SAS Norway OM-B accepted/accepts operation on winter prepared runways with a reduced width of 30 metres. This condition was not an immediate cause contributing to this incident, but the AIBN considers it to be a risk factor. The AIBN recommends that

SAS Norway (formerly SAS Braathens) re-assess its practice of accepting a greater reduction in runway width than recommended by Boeing. Closed in 2009.

The recommendation was closed by the CAA Norway on the basis of a letter from SAS Norway stating that they wished to continue operating at widths of 30 m. The CAA Norway had entrusted the assessment to SAS Airline and had not produced its own closure assessment. According to the information received by AIBN in a copy of the SAS letter to CAA-N, SAS' practice continued as before, in conflict with Boeing's recommended guidelines for crosswind limits with loss of engine power in mind, and against the regulations (see 1.3.8).

1.1.15 Aviation incident. 21 November 2005 (1250-1430Z). Svalbard, ENSB.

SAS Braathens B737-400 skidded sideways while taxiing on the apron and on the runway for departure on runway 28. The departure was cancelled. The investigations were concluded without a separate report.

1.1.15.1 *Weather:*

TAF ENSB 211100Z 211218 12012KT 9999 -SN FEW012 BKN030 PROB30 TEMPO 1218 4000 -SNRA VV012 BECMG 1517 24010KT=

METAR ENSB 211250Z 34004KT 9999 -RASN FEW015 SCT030 BKN040 03/00 Q0992 NOSIG=

1.1.15.2 *Runway status:*

The runway was covered with patches of ice and hoar frost. It had been sanded with warm sand frozen to the ice („fixed sand“) and later with cold sand („loose sand“). The friction was measured several times as being higher than FC 0.30 (30), while several pilots reported the estimated friction as being less than 30. The friction was measured to be 39-40-39 at 1215 and 45-45-43 at 1343 (SKH). The crew perceived the friction to be POOR.

1.1.16 Aviation incident. 9 December 2005 (1300Z). Svalbard, ENSB.

SAS Braathens B737-400 skidded approximately 50 m sideways while attempting to turn off the runway onto TWY A after landing on runway 28 with crosswind from the south. The investigations were concluded without a separate report.

1.1.16.1 *Weather:*

TAF ENSB 091100Z 091218 23010KT 9999 FEW015 BKN030=

METAR ENSB 091250Z 19019KT 9999 FEW020 BKN050 03/M04 Q102 NOSIG=

1.1.16.2 *Runway status:*

Sanded ice with wet patches. Measured friction before the landing was 46-42-38 (SKH). Friction measurements immediately after the landing showed 39-36-38 in the wheel tracks left by the aircraft and 49-41-39 outside the wheel tracks. The air temperature just

after landing was 1-2 °C. The runway was re-sanded to a width of 30 m before departure, with measured friction of 47-51-51. The crew perceived the friction to be POOR.

1.1.17 Aviation incident. 27 December 2005. Tromsø, ENTC.

NAS B737-300 skidded off TWY C. Towed to gate. The investigations were concluded without a separate report.

1.1.17.1 *Weather:*

TAF ENTC 270800Z 270918 18020KT 9999 -SHSNRA SCT020 BKN040=

METAR ENTC 271050Z 18015KT 9999 FEW020 SCT025 BKN033 02/M02 Q1028 NOSIG=

From the flight commander's report: Wind 170 17 kt, more than 10 km in light rain, cloud base 4,000 ft, air temperature 2 °C.

1.1.17.2 *Runway status:*

The runway was wet, while the taxiways were covered in compact snow which became very slippery by thawing conditions and precipitation. TWY C had been sanded, but the grains of sand lay deep in the snow. During the first turn the nose wheel skidded and the aircraft continued straight forward. When attempting to brake the crew found the braking action to be NIL. After sanding the friction on the taxiway was „acceptable“ (not defined).

1.1.18 Aviation incident. 16 January 2006. Svalbard, ENSB.

In crosswind from the south-southeast SAS Braathens B737-400 started a sideways skid while backtracking on runway 28 for take off on runway 10. The flight commander regained control by applying reverse thrust and stopped the aircraft in a position on the south side of the runway centre line, with approximately one quarter of the way remaining. After shut down the passengers were transported to the terminal by bus and the aircraft was towed back to the apron. The investigations were concluded without a separate report.

1.1.18.1 *Weather:*

TAF ENSB 160309 12015KT 9999 –RA FEW010 BKN0230 PROB40 TEMPO 0309 16025G40 3000 RASN VV014

METAR ENSB 160250Z VRB03KT 9999 –RA FEW015 SCT030 BKN070 07/01 Q0999 RMK WIND 1200FT 18031G45KT

METAR ENSB 160350Z 19009KT 150V230 9999 FEW012 SCT030 BKN050 06/00 Q0999 TEMPO 12015KT RMK WIND RWY28 11013KT RMK WIND 1200 FT 19030G43KT

The general weather conditions included rain showers and wind gusting from the south. TWR reported wind at threshold 10 as 100° 12 kt, maximum 21 kt.

1.1.18.2 *Runway status:*

The runway was 100 % covered with wet ice. The runway had periodically been swept and sanded between 0100 and 0400, with cold sand („loose sand“) on top. Friction measurements were carried out on runway 10 at 0435 using a Skiddometer/SKH that measured friction values of 32-33-39. The friction values indicated MEDIUM braking action while the crew perceived it as POOR.

1.1.19 Aviation incident. 22 January 2006 (1502Z). Kirkenes, ENKR.

Wideroe DHC-8-103 skidded sideways during landing roll-out on a slippery runway in crosswind conditions. The aircraft stopped at 90° to RWY 24. The flight commander regained control and taxied to the terminal. Another DHC-8 aircraft landed at 1929Z and notified that conditions were more slippery than the reported 35-50-56 (SKH measured at 1825Z). The investigations were concluded without a separate report.

1.1.19.1 *Weather:*

METAR ENKR 221450Z 17029G39KT 9999 FEW020 BKN045 M17/M21 Q1027

1.1.19.2 *Runway status:*

SNOWTAM 0281 ENKR 01221510Z showed that the runway was 100 % covered with ice. It is not apparent from the SNOWTAM but the runway had sand applied to it on 19 January that froze into the ice („fixed ice“). SNOWTAM friction was measured as being 54-50-55 using a Skiddometer/SKH. After landing, new measurements were carried out on runway 06 at 1518Z, measuring values of 54-50-56. The crew perceived the friction to be POOR.

1.1.20 Aviation incident. 17 February 2006, (1516Z). Torp, ENTO.

Eirjet (for Ryanair) A320 skidded off the runway after landing when a turn towards the taxiway was initiated. The aircraft was towed to the terminal. The investigations were concluded without a separate report.

1.1.20.1 *Weather:*

METAR ENTO 171450Z 05007KT 4000 –SN FEW008 BKN1600 M03/M04 Q0997

1.1.20.2 *Runway status:*

A runway report at 1350Z showed that the runway was covered with up to 8 mm of dry snow on top of compact snow and frozen wheel tracks. The air temperature was minus 3 °C and the runway had been sanded. Friction was measured to 33-32-33 using a Skiddometer (SKH). The flight commander perceived the friction to be POOR.

1.1.21 Aviation incident. 4 March 2006 (1459Z). Torp, ENTO.

Spanair A321 skidded off the runway in a turn prior to takeoff from runway 36. It came to a stop with its nose approximately 90° offset to the runway direction. The nose wheel was about one metre outside the western edge of the pavement. The aircraft was towed to the terminal.

1.1.21.1 *Weather:*

METAR ENTO 041450Z 01008KT 9999 FEW018 M10/M14 Q0993=

1.1.21.2 *Runway status:*

The relevant runway report was from 0508Z, approximately 10 hours prior to the incident. The explanation given why a new runway report had not been prepared was that there had been no precipitation since the previous runway report. The applicable runway report showed that the runway was covered in compact snow on frozen tracks. The runway had been sanded. The friction on runway 18 was measured to 52-39-41 using a Skiddometer (SKH). The crew perceived the friction to be POOR.

1.1.22 Serious aviation incident. 26 March 2006. Torp, ENTO ([RAP 2010-05](#))

MyTravel Airways Scandinavia A321 landed on runway 18 and skidded with locked wheels onto the clearway. The aircraft was sliding and skidding while turning to the left through 65° and came to a halt with the nose wheel against a concrete antenna basement at the very end of the pavement. The aircraft was evacuated on the runway and was later towed to the terminal.

1.1.22.1 *Weather:*

METAR ENTO 261850Z 03009KT 9999 –SN FEW003 SCT005 BKN007 M02/M03 Q1007=

1.1.22.2 *Runway status:*

The runway was reported to be covered with 8 mm of wet snow. Measured FC was 32-33-31 (Skiddometer/SKH). Actual „effective μ ” as deducted from FDR data was in the order of 0.05 (POOR).



Figure 9: Serious aviation incident with OY-VKA at ENTO on 26 March 2006 (AIBN). Animation available at www.aibn.no/aviation/reports/2011-10

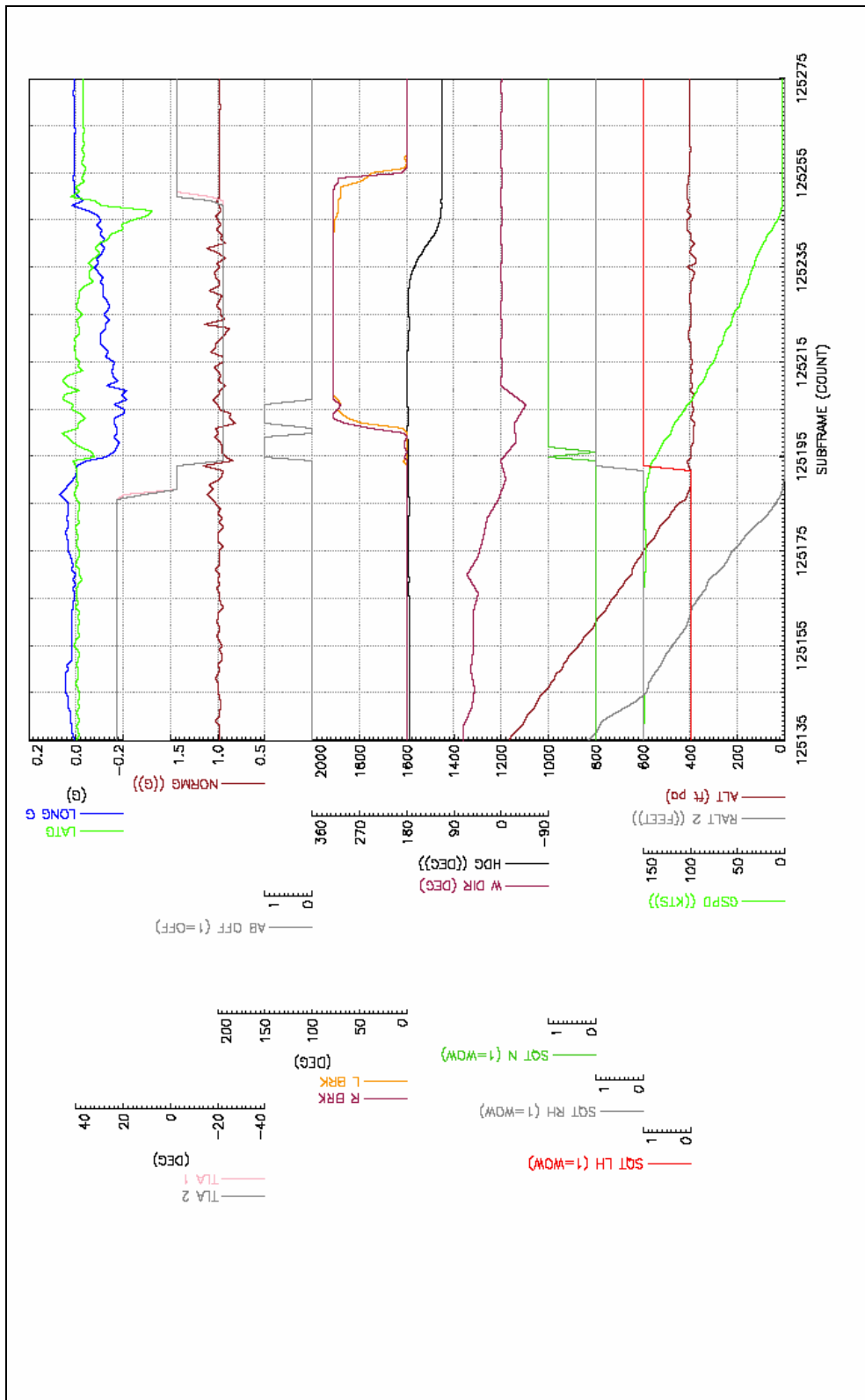


Figure 10: FDR data from OY-VKA (AIBN).

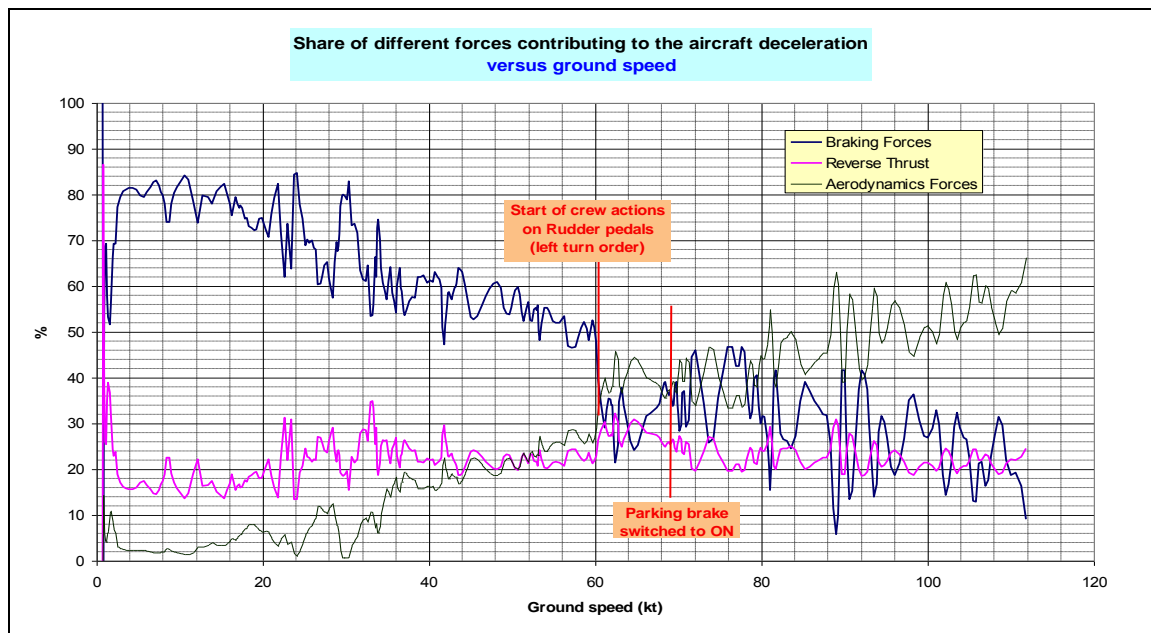


Figure 11: Graph showing the percentage distribution of braking forces from flaps/spoilers, from reversing and from wheel brakes for OY-VKA (AIBN).

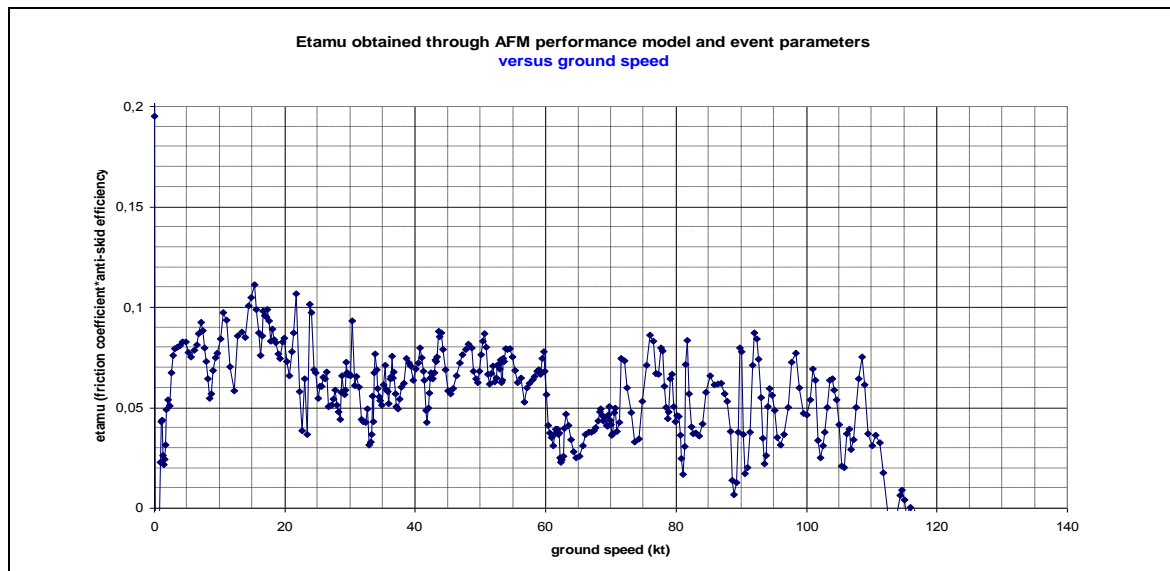


Figure 12: Graph showing the aircraft's effective braking coefficient for OY-VKA (AIBN).

1.1.22.3 The AIBN's evaluation/safety recommendations/status:

(Safety recommendations relating to slippery runways)

- Safety recommendation SL 2010/04T.** Upon touchdown on a runway contaminated by 8 mm recent snow, with an air temperature of -2°C and dew point temperature of -3°C , the crew experienced very POOR braking action, whereas it had been reported as being MEDIUM. The AIBN recommends that MyTravel Airways Scandinavia/Thomas Cook Airlines Scandinavia evaluates whether the procedures for using Airbus's concept of „fluid contaminant“ allow for the required safety margins when calculating landing distances on contaminated runways. Open.

- **Safety recommendation SL 2010/05T.** *The AIBN's investigations show there is poor (POOR) braking action on runways covered in moist contamination (loose dry snow, recent snow, slush) and at a temperature-dew point spread of less than 3 K. The AIBN recommends that MyTravel Airways Scandinavia/Thomas Cook Airlines Scandinavia evaluates whether the procedures for use of FC values for moist contaminations allow for the required safety margins. Open.*
- **Safety recommendation SL 2010/06T.** *During landing on a contaminated/slippery runway, OY-VKA was landed further along the runway due to deviation from optimum procedures for such conditions. There were also indications of uncertainties among the crew regarding the correct functioning of the autobrake system. The AIBN recommends that MyTravel Airways Scandinavia/Thomas Cook Airlines Scandinavia uses this incident as an example in training their pilots for winter operations. Open.*
- **Safety recommendation SL 2010/07T.** *The AIBN found that Sandefjord airport Torp had well prepared winter maintenance procedures but that there were uncertainties regarding the correct application of the procedures. The AIBN recommends that Sandefjord Airport Torp uses this incident as an example when training their personnel for winter operations. Closed in 2010.*
- **Safety recommendation SL 2010/08T.** *During landing on a slippery runway OY-VKA collided with a Localizer Monitoring Antennae basement which protruded above the runway surface. The AIBN recommends that Sandefjord Airport Torp performs a risk analysis/assessment regarding the safety zones adjacent to the runway. Closed in 2010.*

1.1.23 Aviation incident. 21 January 2007 (2045Z). Sola, ENZV.

KLM B737 PH-BPC experienced problems stopping on the remaining amount of runway. The aircraft was stopped using full reverse thrust and it came to a halt on the stopway at the very end of runway 36. The investigations were concluded without a separate report.

1.1.23.1 *Weather:*

TAF ENZV 211400Z 211524 10008KT 9999 FEW015 SCT050 PROB30 TEMPO 1521 33010KT 1000 SHSN VV006=

METAR ENZV 212020Z 08005KT 9999 FEW015 BKN030 M01/M03 Q1002=

From the flight commander's report: Calm, CAVOK, air temperature minus 1 °C.

1.1.23.2 *Runway status:*

The runway was bare and clear but with some ice patches. Friction was measured to be 49-41-48 (Skiddometer/SKH) at 2010Z (approximately half an hour before landing). New friction measurements were taken just after the landing and these showed an average of 30, with some measurements below 20. The crew perceived the friction to be POOR. The TWR reported that they had not previously experienced that the friction could be reduced in such a short time (implicit during CAVOK conditions).

1.1.24 Aviation incident. 2 February 2007. Bardufoss, ENDU.

During the approach to Tromsø airport (ENTC), the crew was informed that the runway at ENTC would be closed for 1.5 hours due to snow clearance and runway preparation. The crew decided to divert to Bardufoss airport (ENDU). The aircraft landed on runway 28 in crosswind conditions. The touchdown point was between TWY D and TWY C. With the use of spoilers, max autobrake and max reverse thrust the crew managed to stop the aircraft at the very end of the overrun (STOPWAY). The investigations were concluded without a separate report.

1.1.24.1 *Weather:*

TAF ENDU 021221 22008KT 9999 –SHSNRA FEW020 BKN035 TEMPO 1221 24015G25KT 1500 RASN VV008=

METAR ENDU 021250Z 20008 130V250 7000 –SHRASN FEW015 BKN030 02/00 Q0981 TEMPO 3000 –SHSNRA VV014=

The general weather conditions included sleet showers and wind gusting from the south. The wind reported by the TWR just before landing was 190° 12 kt.

1.1.24.2 *Runway status:*

Runway 28 was 100 % covered with wet ice. The runway had been sanded. Friction measurements were carried out just prior to landing using a Surface Friction Tester/SFH which measured friction values of 28-28-25. The friction measurements indicated MEDIUM to POOR braking action while the crew perceived it as being POOR. In its preliminary investigation, the AIBN concluded that the runway was more slippery than indicated by the friction measurements, and that the reported conditions indicated poor braking conditions. The AIBN's written feedback to SAS Braathens included:

„In the incident in question ENDU METAR 1150Z showed sleet showers with a temperature and dew point of 2 °C and 0 °C, respectively. Runway 28 had been sanded on wet ice and the friction conditions should therefore have been reported and interpreted as POOR. The preliminary investigation shows that the AIBN cannot add anything new to flight safety beyond what has already been submitted in the safety recommendations referred to above.“

1.1.25 Aviation incident. 19 December 2007. Tromsø, ENTC.

The flight commander of a SAS Norway B737 had problems keeping the aircraft on the runway after landing on a slippery runway in crosswind conditions in a strong and gusty south-westerly wind. Just after landing, the aircraft started to weathervane into wind. The aircraft skidded partially sideways along the whole length of the runway. The flight commander feared that the aircraft would leave the runway and ordered the cabin crew to prepare for a crash. Max manual braking was initiated (autobrake 3 selected prior to landing) without noticeable effect (friction-limited). The aircraft stopped at the very end of the paved surface of the over-run. The crew needed assistance from a tow tractor in order to maneuver the aircraft before taxiing to the terminal in a normal manner. The investigations were concluded without a separate report.

1.1.25.1 *Weather:*

METAR ENTC 191520Z 28032G49KT 8000 –SHSNRAGR FEW013CB BKN025
02/M01 Q1003 TEMPO 27040G55KT 2500 SHSNRAGR BKN012CB=

METAR ENTC 191550Z 28028G38KT 8000 –SHSNGR FEW008 FEW013CB BKN023
02/M02 Q1004 TEMPO 27040G55KT 2500 SHSNRAGR BKN012CB=

The general weather conditions included strong gusty wind from the west, with sleet and hail showers. The reported wind just prior to landing was 280° 10 kt gusting 28 kt.

1.1.25.2 *Runway status:*

The runway was 100 % covered with 3 mm of slush. Braking Action was estimated at 5 (GOOD) but the crew perceived it to be 1 (POOR).

The AIBN's written feedback to SAS Norway included:

„In the incident in question ENTC METAR at 1520Z and 1550Z showed a temporary strong crosswind from 280°, strength 28-32 kt gusting 38-49 kt, snow, rain (sleet) and hail showers, with a temperature of 2 °C and dew point -1 to -2 °C. SNOWTAM 1434Z showed that the runway was covered with 3 mm of slush. BA (Braking Action) reported for RWY 01 GOOD-GOOD-MEDIUM. ATIS 1520Z (Information Victor) indicated 6 mm of wet snow, BA RWY 19 GOOD. ATIS 1550Z (Information Whisky) indicated 6 mm of wet snow, BA RWY 19 GOOD. AIBN believes that the conditions indicated in METAR, SNOWTAM and ATIS indicated wet contamination. The friction conditions should therefore have been reported and interpreted/applied operationally as POOR. The preliminary investigation shows that the AIBN cannot add anything new to flight safety beyond what has already been presented in the safety recommendations cited, and in individual reports.“

1.1.26 Aviation incident. 5 January 2008 (1923Z). Gardermoen, ENGM.

After landing, MyTravel Scandinavia A321 entered a skid and departed the runway/taxiway structure when exiting the active runway 19R. The aircraft continued straight across the field and onto TWY M (parallel to the runway). After the incident, the aircraft was taxied to the terminal via standard taxiways. The aircraft was not damaged in this excursion. The investigations were terminated without a separate report.

1.1.26.1 *Weather:*

METAR ENGM 051850Z 10004KT 040V130 2100 SN VV005 M03/M03 Q1007

1.1.26.2 *Runway status:*

A runway report at 1836Z showed that runway 19R was covered with 8 mm of dry snow on frozen wheel tracks. Measured friction on runway 01L was 39-35-34 (surface friction tester/SFH). The runway and open exits had been sanded. The taxiways were reported as „slippery“ (not defined, but assumed to mean POOR). Friction measurements on runway 01L immediately after the incident showed 24-27-27. On taxiway A4 (exit point where the incident occurred) the friction was measured to be 20. METAR showed snowfall and

0 K dew point spread (moist contamination), which, based on experience, gave POOR friction. The aircraft „effective μ “ was perceived by the crew as POOR.

1.1.27 Aviation incident. 1 February 2008 (1711Z). Gardermoen, ENGM.

KLM B737 was unable to slow down sufficiently during braking in order to make the turn onto the last exit. The aircraft stopped 2 m outside the threshold lights at the end of the runway. The aircraft was towed to the terminal. The investigations were concluded without a separate report.

1.1.27.1 *Weather:*

METAR ENGM 011720Z 03006KT 1500 SN VV003 01/01 Q0967

1.1.27.2 *Runway status:*

The last runway report was issued at 1515Z (with the associated SNOWTAM 0354). It reported that the southernmost third part of runway 01R was covered with compact snow, while the middle and northern thirds were covered with 3 mm slush. This was immediately after sweeping. Friction was reported as MEDIUM while the crew of PH-BXU perceived the friction to be POOR. The runway had not been sanded. METAR showed that there was snowfall at the time in question and that the temperature-dew point spread was nil (wet contamination), which, based on experience, gave POOR friction. The crew who landed 2 minutes prior to PH-BXU reported friction as being MEDIUM TO POOR. METAR indicated precipitation and humid air (temperature-dew point spread of 0 K), which was yet another indication of moist runway contamination.

1.1.28 Aviation incident. 13 January 2010. Bardufoss, ENDU.

NAS B737-300 was cleared to taxi via taxiway Y to holding position runway 28. After crossing taxiway C, the crew was advised to taxi with caution since taxiway Y was „slippery“. The crew tried light braking, which caused the tyres to lock and skid sideways and as a result, the aircraft skidded off the taxiway. Taxiway Y had been closed 10 minutes earlier because it was very slippery, but the crew had not been informed. The taxiway was covered with wet ice and the crew perceived the braking action as NIL. The investigations were concluded without a separate report

1.1.28.1 *Weather:*

METAR ENDU 131150Z VRB04 9999 VCSH FEW018 SCT030 BKN050 01/M00 Q1018

METAR indicated that contamination on the runways and taxiways were wet because of (sleet) showers and a temperature-dew point spread of 1 K.

1.1.28.2 *Runway status:*

The reported, estimated braking action for the runway was 5-5-5 (GOOD). Taxiway Y was covered with wet ice and had not been sanded. The friction conditions were deemed to be „slippery“, without any degree of slipperiness being stated. It was decided to close taxiway Y 10 minutes before LN-KKS started taxiing, but it had not yet been closed. The crew had not been informed that taxiway Y was closed, but was notified that the taxiway

was „slippery“ without any indication of the degree of slipperiness (GOOD, MEDIUM, POOR or NIL). The crew perceived the friction as NIL. Friction measurement was carried out on the taxiway after the incident and this indicated a measured FC of 0.10 (10). METAR indicated precipitation that produced wet ice, at the same time as the temperature-dew point spread was 1 K, which indicated humid air and moist runway contamination.

1.1.29 Aviation incident. 23 January 2010 (1341Z). Svalbard, ENSB.

SAS B737-400 skidded sideways along the centreline while landing on runway 28 in a 10-12 kt crosswind from the southwest. The crew managed to keep the aircraft on the centre line of the runway and was able to stop on the runway. The aircraft stopped at the western end of the runway with a heading of approximately 100° off the runway direction, facing south. The crew perceived the friction to be POOR. The investigations were concluded without a separate report.

1.1.29.1 *Weather:*

METAR ENSB 1250Z 23007KT 190V270 9999 FEW015 BKN060 01/M04 Q1023
NOSIG RMK WIND 1400FT 21006KT

METAR ENSB 1350Z 22009KT 9999 FEW015 SCT060 01/M05 Q1023 RMK WIND
1400FT 20005KT

The registered meteorological data for ENSB on 23 January at 1330Z were:

Wind: 212° 12 kt, air temp: 1 °C, dew point: -4 °C, runway temp: -1 °C. Humidity: 68%.
It was reported precipitation from the west.

1.1.29.2 *Runway status:*

SNOWTAM 0396 1240Z (before landing) showed that runway 10 was 100 % covered with dry ice on frozen wheel tracks. The reported, estimated friction was 3 (MEDIUM) for the whole runway. The runway had recently been sanded. SLIPPERY conditions were reported on parts of the runway, runway thresholds, taxiways and apron.

SNOWTAM 0397 1628Z (before departure) showed that runway 10 was still 100 % covered with dry ice on frozen wheel tracks. The friction had now improved to 3 (MEDIUM) – 4 (MEDIUM TO GOOD) – 4 (MEDIUM TO GOOD) from west to east. The runway had recently been sanded. SLIPPERY parts on runways, thresholds, taxiways and the apron were still being reported. Since the conditions were similar during time of departure, it is highly probable that POOR braking action existed when the aircraft took off. If, for some reason or another, the crew had to abort the takeoff at high speed, it is unlikely that they would have been able to stop on the remaining runway.

1.1.30 Serious aviation incident. 25 January 2010 (1131Z). Svalbard, ENSB.

West Air Sweden RJC 200 skidded off the south (left hand) side of the runway after landing on runway 28. The excursion happened on the final quarter of the runway. Information was provided to the crew prior to landing that the 2-minute wind at the threshold of runway 28 was 10 kt, with a maximum 18 kt, from 190°, varying between 150° and 260°. The estimated friction was reported as 4 (MEDIUM TO GOOD) – 3

(MEDIUM) -2 (MEDIUM TO POOR) on each third in the landing direction. The crew had planned on the basis of a maximum crosswind of 10 kt with a braking action of 2. The crew perceived the braking action as varying from „medium to good“ to NIL during the course of braking. The crew used differential reverse thrust to improve directional control. The aircraft skidded sideways and finally backwards. By using forward thrust the flight commander managed to stop the aircraft between the Precision Approach Path Indicator (PAPI) and the threshold lights at the end of the runway with the aircraft's nose at 90° angle to the runway direction. Preliminary data shows that the crew based their decision to land on wind information for the eastern threshold of runway 28, while there was stronger wind and poorer friction at the western end. Investigations are ongoing and will be concluded with a separate report. Animation of the landing is available at www.aibn.no/aviation/reports/2011-10

1.1.30.1 *Weather:*

TAF ENSB 251100Z 2512/2612 23015KT 9999 FEW015 BKN030 TEMPO 2512/2518 23025G35KT TEMPO 2512/2521 -RA BKN012 BECMG 2600/2603 VRB05KT TEMPO 2603/2609 2000 SN VV012 BECMG 2606/2609 12020KT=

METAR ENSB 251050Z 22006KT 170V260 9999 FEW015 BKN030 03/M01 Q1007 TEMPO 23020KT RMK WIND 1400FT 22029KT=

METAR ENSB 251150Z 22020G33KT 9999 -RADZ FEW015 SCT025 BKN040 04/M00 Q1006 TEMPO 21010KT RMK WIND 1400FT 24028G40KT RMK WIND RWY28 21005KT=

Registered weather at 1133Z (2 min after landing): 10-minute wind at the threshold of runway 28 210° 8 kt. 10-minute wind at the threshold of runway 10 220° 14 kt (2-minute wind at the threshold of runway 10 210° 17 kt gusting 27 kt), visibility more than 10 km in light rain and drizzle, few clouds at 1,500 ft, broken cloud cover at 3,000 ft, air temperature 3.6 °C, dew point temperature minus 0.3 °C, QNH 1006 hPa, wind at 1,400 ft 240° 26 kt gusting to 33 kt.

1.1.30.2 *Runway status:*

SNOWTAM 0402. ENSB 01251121 reported that runway 01 was covered with ice and had recently been sanded. The friction was reported as 2 (MEDIUM TO POOR) – 3 (MEDIUM) – 4 (MEDIUM TO GOOD). The air temperature was 3 °C and the runway temperature was 0 °C. The temperature-dew point spread was 4 K, which in itself did not indicate humid air, and it was not forecasted or reported precipitation before the landing. On the 1200Z TAF (29 min after the landing) it was forecasted temporarily light rain, and on the 1150Z METAR (19 min after the landing) it was reported light rain and drizzle. The friction was reported as being 4-3-2 in the direction of landing about 5 minutes before landing. There was also a relatively strong crosswind from the south on the western part of the runway. The friction values were partially based on friction measurements using a Tapley meter. The ABC as deducted from the FDR data was in the order of 0.10 for the initial landing roll, quickly reducing to 0.05 (POOR) to NIL during the remaining parts of the runway.

1.1.31 Aviation incident. 27 April 2010 (kl. 2326Z). Evenes, (ENEV).

West Air Sweden CRJ 200 landed on runway 17 in crosswind conditions, with braking action reported as GOOD. The crew perceived the friction to be POOR to NIL. The aircraft skidded sideways to approximately 2 m from the edge of the runway, but the crew managed to regain directional control and steer the aircraft back towards the centreline. The aircraft stopped by taxiway D, which are approximately two thirds of the way along runway 17. ATIS at 2250Z (Victor) reported a wind of 13 kt from 250°. The investigations were completed without a separate report.

1.1.31.1 *Weather:*

TAF ENEV 272123Z 26010G20 9999 FEW015CB BKN030 TEMPO 2123 1500 SHSN VV0800=

METAR ENEV 272250Z 24013KT 9999 –SHSN FEW025 BKN045 M02/M03 Q1009 RMK WIND 1400FT 24011KT=

METAR ENEV 272350Z 25007KT 3500 –SHSN BKN025 M02/M03 Q1009 RMK WIND 1400FT 25010KT=

1.1.31.2 *Runway status:*

SNOWTAM 1053. ENEV 04272304 reported that runway 17 was 100 % covered with ice. The runway had not been sanded. The friction was reported as 4 (MEDIUM TO GOOD) – 4 (MEDIUM TO GOOD) – 3 (MEDIUM). METAR showed an air temperature of minus 2 °C and a dew point of minus 3 °C, which gave a 1 K spread indicating humid air. Both TAF and METAR forecasted / reported snow showers, indicating a layer of snow on top of the ice leading to slippery conditions. The runway had been swept 11 minutes prior to landing, but during the approach it was reported that it was snowing. After sweeping, the friction was estimated at 4 – 4 – 3 despite recent snow on ice. A Tapley meter was used to support the friction estimate.

1.2 **Summary of findings from 30 incidents and accidents**

1.2.1 Common features of reported incidents/accidents

The following conditions are the common features of the 30 reported accidents/incidents on slippery runways:

- The runway was prepared in accordance with Norwegian winter maintenance procedures.
- The runway was contaminated with compact dry or wet snow, or ice.
- The runway friction coefficient (FC) was measured with approved measuring equipment.
- The measured FC was assessed as satisfactory (MEDIUM or GOOD according to the ICAO SNOWTAM table).

- The ICAO SNOWTAM table was used in accordance with ICAO, EASA and Norwegian regulations.
- Friction coefficients were reported as being accurate to the nearest part per hundred, in conflict with AIP Norway AD 1.2, which states that only friction values stated in parts per ten are of operational value.

In 2 of the 30 reported incidents the friction/FC was measured as being in the area 0.50-0.60 or estimated as GOOD (5), while the actual ABC or „aircraft μ “ was in the order of 0.05 (POOR).

In 10 of the 30 reported incidents the friction/FC was measured as being in the area 0.40-0.50 or estimated as GOOD (5), while the actual ABC or „aircraft μ “ was in the order of 0.05 (POOR).

In 13 of the 30 reported incidents the friction/FC was measured as being in the area 0.30-0.40 or estimated as between MEDIUM and GOOD (3-4), while the actual ABC or „aircraft μ “ was in the order of 0.05 (POOR).

In 3 of the 30 reported incidents the friction/FC was measured as being in the area 0.22-0.29 or estimated as POOR to MEDIUM (1-3), while the actual ABC or „aircraft μ “ was in the order of 0.05 (POOR).

In 2 of the 30 reported incidents the friction was not measured or estimated, while the actual ABC or „aircraft μ “ was in the order of 0.05 (POOR).

1.2.2 Airports represented

The following airports were represented in the reported incidents:

- Five of the 30 incidents occurred at Svalbard, ENSB
- Five of the 30 incidents occurred at Evenes, ENEV
- Four of the 30 incidents occurred at Tromsø, ENTC
- Four of the 30 incidents occurred at Gardermoen, ENGM
- Three of the 30 incidents occurred at Bardufoss, ENDU
- Three of the 30 incidents occurred at Torp, ENTO
- Two of the 30 incidents occurred at Kirkenes, ENKR
- One of the 30 incidents occurred at Sola, ENZV
- One of the 30 incidents occurred at Molde, ENML
- One of the 30 incidents occurred at Hammerfest, ENHF
- One of the 30 incidents occurred at Vadsø, ENVD

The above shows that the airports at Svalbard, Evenes, Tromsø, Gardermoen, Bardufoss, and Torp, had the most incidents (three or more) relating to slippery runways. The frequency of incidents is related to both the climate and the air traffic volume. Of these incidents two occurred on short runways (ENHF and ENVD), two on medium-long runways (ENKR and ENML) and the rest on long runways.

1.2.3 Safety indicators

Appendix J contains Dr. Mook's evaluation of meteorological conditions that are significant for friction on runways covered with snow and ice. Chapter 13 of the appendix contains an analysis of the selection of accidents and incidents investigated by the AIBN. The appendix also contains some results from meteorological measurements at Svalbard airport. The conclusion is that friction on contaminated runways is determined by the complex interaction of dominant variables under various boundary conditions. Many of these variables may be used as practical safety indicators for assessing runway friction.

In all 30 reported accidents and incidents on slippery runways, the AIBN has found several coinciding indicators that could have a bearing on the assessment of the safety of winter operations and runway friction. These indicators are shown together in Table 1 and described as „safety indicators“. Some of them repeat themselves in almost all of the accidents / incidents, while others appear only in a few instances. It appears from the table that the following safety indicators recur frequently:

- In 21 of the 30 occurrences the spread between the air and dew point temperatures (temperature-dew point spread) was ≤ 3 K.
- In 19 of the 30 occurrences wet/moist contamination was present.
- In 19 of the 30 reported incidents/accidents there were crosswind conditions of ≥ 10 kt in combination with a slippery runway.
- In 18 of the 30 occurrences the temperature-dew point spread was ≤ 3 K in combination with an air temperature ≥ -3 °C.
- In 12 of the 30 occurrences loose slush/wet/dry snow on top of compact snow/ice was present.
- In 12 of the 30 occurrences the temperature-dew point spread was ≤ 3 K in combination with crosswind conditions of ≥ 10 kt.
- In 10 of the 30 occurrences the temperature-dew point spread was ≤ 3 K in combination with crosswind conditions of ≥ 10 kt and an air temperature ≥ -3 °C.
- In 3 of the 30 occurrences measured FC was > 0.40 while the actual ABC was POOR, the air temperature was < -9 °C, the temperature-dew point spread was 2-4 K and the crosswind was > 10 kt.

Table 1: Factors relating to accidents and incidents on slippery runways.

[illegible]

[illegible]

[illegible]

Accident/ incident	Loose slush/ wet/dry snow on compact ice/snow	Wet/ moist contami- nation	Use of CPC	Air temp °C	Difference between air temperature and dew point temperature ≤3K	Tailwind/ crosswind component	Reduced runway width (30m)	Reverse thrust included in the landing calculations	Sand on RWY	Sanded wet, compact ice/snow	Sanded loose contamination (slush or dry/wet snow)	Friction measured on wet contaminant of snow / ice	Friction measured on layered contaminant
1.1.29 ENSB				1	(5)	Approx. 12 kt crosswind		X	X				
1.1.30 ENSB		X		4	(4)	Approx. 20 kt crosswind		X		X			
1.1.31 ENEV	X	X		- 2	1	Approx. 13 kt crosswind		X					

1.3 Significant findings relating to winter operations and friction.

1.3.1 Introduction

This section contains a summary description of some features relating to winter operations and contaminated runways, including: definition of snow types, valid ranges of friction measuring devices, friction measurement error margins, correlation between friction measurement devices and between friction measurements and aircraft braking coefficients, cornering friction, crosswind conditions in combination with slippery runways, friction-improving measures (use of sand and chemicals), winter-prepared runways of reduced width.

1.3.2 The importance of humidity in definition of snow types – The 3 Kelvin Spread Rule

“Dry snow”, “wet snow” and “slush” are defined in ICAO Annex 14, and the corresponding definitions in Norwegian publications refer to those definitions (Appendix F). The findings of the AIBN’s investigations show that, in practice, it is often difficult to determine whether the snow on the runway is dry or wet. In day-to-day operations snow is defined as dry or wet by reference to the air temperature. The AIBN’s meteorological expert tells us that the content of liquid water in snow is very temperature-dependent. Hence, snow, and particularly newly fallen (recent) snow, has a relatively high content of liquid water which can contribute to the contamination of the runway being very slippery, even if the temperature is below zero. (See Appendix G and Appendix J, chapter 04):

„At air and runway surface temperatures close to or below freezing, precipitation is accumulated, most often as „snow“. The shape of the crystals is related to air temperature in the vicinity of the clouds. The overhead temperature regime may be derived roughly from the crystal structures.

Snow always contains some liquid water, which generally increases with temperature, except for very low temperatures in the cloud region and below. As a rule, super-cooled droplets are the major constituent in clouds warmer than minus 12 °C, and through to minus 20 °C droplets and ice are equally common. Droplets formed in clouds do not freeze at temperatures warmer than minus 12 °C to minus 15 °C. Frozen precipitation falling from higher regions of a cloud will catch liquid water in the zone of droplets. Due to lower saturation vapour pressure above ice than above liquid water, air just saturated in respect to liquid water will be super-saturated in respect to frozen precipitation passing through a zone of droplets. Not necessarily frost but dew may be the result, thus contributing to the content of liquid water in snow.

At surface air temperatures colder than minus 10 °C, newly fallen snow (at Svalbard Airport Longyear) contained liquid water with a mean value of less than 8 % of mass. In the temperature interval between minus 2 °C and 0 °C the mean proportion of liquid water was 17 %. Wet snow may be observed up to surface air temperatures of 3 °C. The proportion of liquid water increased with temperature above 0 °C, as a mean, from 22 to 28 %. In the latter case, the accumulated outcome must be characterised as „slush“.

Surface air temperature is not a trustworthy indicator for deciding whether snow is „dry“ or „wet“, as there may be „warm“ precipitating clouds aloft. The somewhat

subjective and uncertain way of differentiating „dry“ snow from „wet“ (based on whether it is possible to form a ball or not) might be replaced by a scale 1) snow too dry to form a ball, 2) a ball can be formed, but no liquid water can be squeezed from it, 3) possible to squeeze liquid water from the ball, 4) too much water to form a ball.

The electromagnetic properties of snow, defined by the dielectric constants of ice and water, depend on the relative permittivity and absorption of electromagnetic microwaves. These depend on frequency, density and the volumetric amount of liquid water. The Denoth device allows the proportion of liquid water to be determined, when the density of the snow is known.

The point is that new fallen snow may contain an amount of liquid water sufficient to cause significant deterioration of braking conditions, and this may happen even at sub-zero surface temperatures. In addition to the case where there is warm air aloft, precipitating clouds that are forced to rise rapidly due to mountainous terrain may yield a rather large amount of liquid water locally (at certain airports). Proximity to a windblown (churned up) sea may contribute salt dissolved in water (brine) enclosed in snow aggregates and thus make for exceptionally slippery conditions.

Sweeping devices and other sharp-edged metal devices used on new fallen snow may squeeze out a film of liquid water that immediately freezes into a slippery covering of ice. This is the case with freezing to a lamella of ice referred in chapter 03.” (Dr. R. Mook, Appendix J, chapter 04).

AIBN has found that moisture in combination with contaminated runways play a more significant role in relation to „slipperiness“ than previously understood. A common factor in the investigated accidents and incidents related to runway excursions it was found that the measured temperature and dew point at 2 m height above the runway surface (METAR values) was an indicator of slipperiness. In most occurrences the difference between the air temperature and dew point („dew point spread“) was ≤ 3 Kelvin. This is referred to as „3-Kelvin-spread-rule“ (see Appendix J, chapter 09). This is an indication that the air humidity is 80 % or more. An important issue in this regard is that the temperatures at the contaminated surface may be lower than the METAR values measured at 2 m height. Hence, the dew point spread may be lower than 3 K at the runway surface. Further, the saturation pressure over ice is lower than over water. Hence the frost point increases approximately 1 °C per minus 10 °C. This means that the 3 K margin at 0 °C air temperature is reduced to 2 K at minus 10 °C and to 1 K at minus 20 °C. AIBN has found this to be of significance with (measured) METAR air temperatures between 3 °C and minus 15 °C.

1.3.3 Valid ranges of friction measuring devices (tribometers)²²

The following validity ranges for approved friction measuring devices are listed in Appendix F:

- Dry snow up to 25 mm.
- Dry compact snow irrespective of depth

²² The adopted measuring ranges included in Norwegian AIP were based on FAA Advisory Circular 150/5200-30C.

- *Dry ice irrespective of thickness*
- *Slush up to 3 mm.*
- *Wet snow up to 3 mm.*
- *Wet ice.*

There is no mention of whether the validity range applies to dry snow, wet snow or slush on asphalted surfaces or whether it also applies to dry snow, wet snow or slush on top of compact snow or ice (layered contamination). The AIBN has not found any scientific documentation of defined limitations relating to contamination (validity ranges) as mentioned in Appendix F.

During the investigation process on this theme report CAA-N has revised the valid ranges of friction measuring devices referred to in AIP Norway. Hence, it is no longer permitted to measure friction on wet contaminations with any type of measuring device.

Appendix F also shows the definitions of „dry“ and „wet“ snow:

1. *Dry snow: Snow that can be blown away when it is loose or that dissolves when compacted in the hand; specific gravity of less than 0.35.*
2. *Wet snow: Snow that binds together when compacted in the hand and takes the form or verges on taking the form of a snowball; specific gravity of 0.35 or more, but less than 0.5.*
3. *Compacted snow: Snow that has been compacted to a solid mass and resists further compaction and remains together or divides into lumps when lifted up; specific gravity of 0.5 or more”.*

AIBN findings show that these definitions are not conclusive, but that the difference between the air temperature and dew point (frost point below 0 °C) may make the contamination moist and slippery.

The findings also indicate that varying density of „dry“, „wet“ snow and „slush“ results in different measured FC and ABC.

The findings of the AIBN’s investigations as described in Appendices G and J show that while friction measurements on layered contamination can indicate from POOR to GOOD, the airplane braking coefficient (ABC or „aircraft μ “) can be of varying degrees from POOR to NIL.

1.3.4 Friction Measurement Uncertainties

The ICAO SNOTAM table does not define any tolerances or permitted variability. The measured FC values are used as if they had an accuracy of one per hundred. Over the years, several trial results have indicated that there is uncertainty associated with measured friction values. Table 1 in Appendix G shows some documented measured FC uncertainties. Here we can see that the measured tolerances from different research programs are in the order of ± 0.10 for dry contamination and up to ± 0.20 for wet contamination. These measuring tolerances compare well to the measurement results from Norwegian wet runway testing by Avinor from testing BV-11 (SKH) and Griptester

(GRT) on various runway surface textures identified by individual Surface Numbers²³ shown in Figures 1 and 2 in Appendix G. As can be seen from the figures, the uncertainty is generally in the order of ± 0.10 . AIBN has found that similar uncertainty applies for dry conditions and up to ± 0.20 under wet or moist contaminated conditions. Based on these test results, Avinor discontinued the practice of measuring runway friction values by use of wet runway friction measurements pursuant to ICAO Doc 9137, Airport Services Manual, Part 2, Chapter 3. Norway has filed a deviation to ICAO with regard to the recommended procedure of maintaining the design objective level (DOL) and the minimum friction level (MFL) for runways by wet runway friction measurements. These tolerances also compare with data in AIP Canada, AIR 1.6, Table 4a and 4b which is based on the JWRFP in Canada:

<http://www.tc.gc.ca/publications/EN/TP14371/PDF/HR/TP14371E.pdf>

In its own investigations (see Table 1), the AIBN has found that when the friction coefficient (FC) is measured on compact snow or ice and the contaminant is wet or moist, or the temperature-dewpoint-spread is approx. 3 K or less, the aircraft braking action (or „aircraft μ “) is in the order of 0.05 (POOR) while the measured FC can be as high as 0.40 (GOOD) or higher. Furthermore, the AIBN has found that the FC on snow and ice is very dependent on the surface temperature of the contaminant. Experience indicates that the FC on compact snow or ice at a temperature of less than minus 10-15 °C is higher than at temperatures in the region of plus 3 to minus 5 °C. In practical terms this measuring uncertainty implies that if the measured FC is 0.40 (GOOD) it could be 0.30 (MEDIUM) if the contaminations was „dry“, or as low as 0.20 (POOR) if the contamination was wet. AIBN has found that this measuring uncertainty applies to all types of friction measuring devices, whether they are of the decelerometer or continuous friction measuring device (CFMD) type. For a better understanding of the physical explanations why it is difficult to measure friction on frozen water in the form of „dry“ or wet snow, „dry“ or wet compacted snow and ice, reference is made to Appendix J, chapters 02, 04, 09 and 12.

1.3.5 Correlation between friction measurement devices and between friction measurements and aircraft braking coefficients

1.3.5.1 *International work*

In 1974, ICAO published²⁴ its final report from the first international programme for defining the degree of correlation between different types of friction measuring devices. The objective of the programme was „to define the degree of correlation that exists between various types of equipment used in the measuring of runway braking action.“

From the conclusions:

„In the evaluation of the reduced test data the following was noted:

Some degree of correlation exists among the devices tested.

Correlation varies widely between equipment pairs and with changes in surface textures ...

²³ Avinor Notice 5:2003, Geir Lange, 2004.

²⁴ ICAO programme for correlating equipment used in measuring runway braking action, Final report, 22/2/74 Joint evaluation programme of equipment used to measure runway braking action undertaken by: Canada, France, Sweden, Union of Soviet Socialist Republics, United Kingdom and United States.

A lack of precision is evident among measuring devices tested. Even greater lack of precision is evident at the lower test speeds (under 40 mph) and on the lower friction surfaces."

The aircraft was brought into the loop and research activities continued in Sweden and Scandinavia. In 1980, the Aeronautical Research Institute of Sweden concluded²⁵ that:

„If reporting of brake numbers to pilots is of importance, it is necessary to continue the development of both measuring vehicles and applying processes."

In the USA there were several test and research activities. New correlation charts were developed. In March 1988, NASA published²⁶ correlation charts based on findings from a joint FAA/NASA research programme.

Figures 7 and 8 in Appendix G are copied from a paper prepared for the Air Line Pilot's Association International, by Walter B. Horne in 1990²⁷.

Walter Horne developed a theory with certain basic assumptions:

1. *When tire dissimilar surfaces rub or slide against each other, a friction pair is formed. The surface having the weakest shear strength becomes the sacrificial surface, and the friction characteristics depend upon the physical properties of this sacrificial surface.*²⁸
2. *Friction changes from tire size, vertical load, and inflation pressure are minimal for snow/ice-covered runway conditions (pressure-melting effects are minimal).*
3. *The aircraft tire and the runway friction tire have identical friction values on a snow/ice-covered runway.*

Walter Horne used an equation for braking system efficiency (published by ICAO) and with the above basic assumptions made a direct relationship between an aircraft tire and mechanical or electronic decelerometers on snow/ice/sanded ice-covered runway surfaces. Based upon findings from several test programs by NASA and other tests worldwide he extrapolate the relationship to other friction measuring devices principles and created a generic relationship in a table form based upon the braking system efficiency curve.²⁹

For validation of the results W. Horne wrote in the report:

"More experimental data are needed to validate the higher friction levels of the scale. Data from aircraft/runway friction tester correlation tests conducted at

²⁵ FFA Memo 121, Studies of contaminated runways, K. Fristedt and B. Norrbom, Stockholm 1980.

²⁶ NASA Technical Memorandum 100506, Summary report on aircraft and ground vehicle friction correlation test results obtained under winter runway conditions during joint FAA/NASA runway friction program, Thomas J. Yager, William A. Vogler and Paul Baldasare, Langley Research Center, March 1988.

²⁷ Correlation Between Aircraft/Ground Vehicle Runway Friction Measurements, Walter B. Horne, prepared for the Air Line Pilot's Association International, 1990.

²⁸ Braking Action Scales for Dry, Wet, and Snow/Ice-Covered Runways. Working Paper prepared for NASA Runway Friction Workshop by W. B. Horne. Langley Research Center, Hampton, Va, Oct. 26-27, 1985.

²⁹ ICAO did not adopt this table for compacted snow and ice. The table used by ICAO for snow and ice is the one developed in 1959 and which is part of the SNOWTAM format (Appendix O).

cold snow/ice temperatures, as well as tests conducted on sanded ice are needed in this regard.”

In 1990, NASA published a report referring to the same research programme and the major test findings included the following:³⁰

„For wet-runway conditions, the estimated aircraft braking performance from the ground-vehicle friction measurements was within ± 0.1 friction coefficient value of the measured value, except for some rain-wet data.”

„For snow- and ice-covered runway conditions, the estimated aircraft braking performance from the ground-vehicle measurements was within ± 0.1 friction coefficient value of the measured values.”

1.3.5.2 Correlation algorithms for determination of „aircraft μ “:

The various aircraft manufacturers and aviation authorities incorporate different safety factors when calculating aircraft braking coefficients. There is a major difference between propeller aircraft and jet aircraft, at the same time as there are variations within each of these two main categories.

Kollerud

The first documented correlation curve based on comparative testing of friction measuring devices (decelerometer) and aircraft (DC-4, DC-6, DC-6B) were carried out by Kollerud (1949-54, see Figure 13).

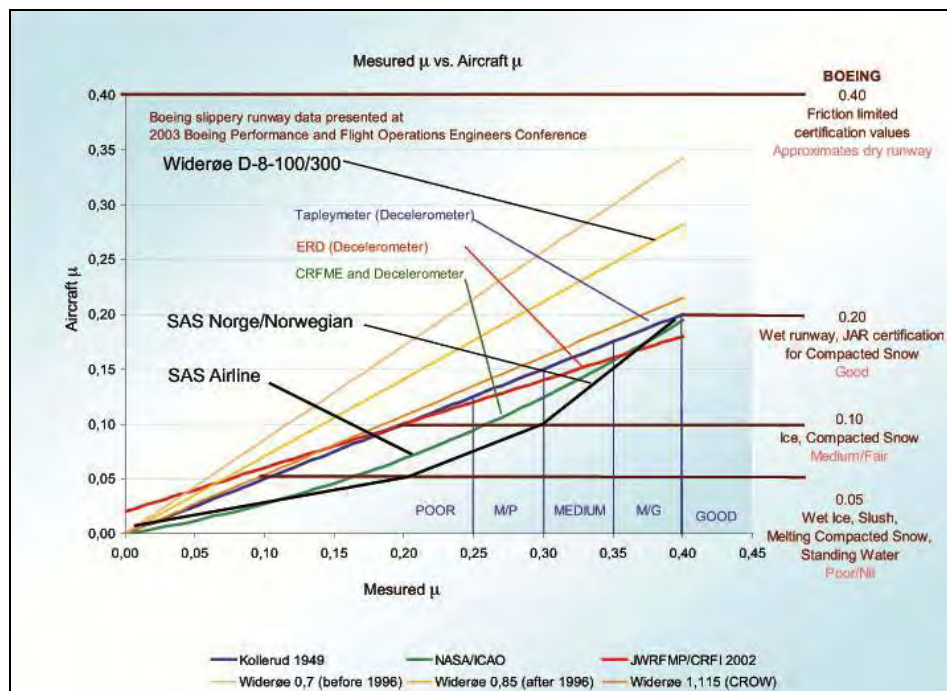


Figure 13: Measured μ (FC) vs. Aircraft μ .

³⁰ NASA Technical Paper 2917. Evaluation of two transport aircraft and several ground test vehicle friction measurements obtained for various runway surface types and conditions – A summary of test results from joint FAA/NASA runway friction program, Thomas J. Yager, William A. Vogler and Paul Baldasare, Langley Research Center, February 1990.

Kollerud

All airplane types Aircraft $\mu = 0.5 \mu_{\text{measured}}$

DeHavilland (Bombardier)

DHC-8-100/300 Aircraft $\mu = 0.6 \mu_{\text{measured cont}} / \mu_{\text{measured dry}}$

DHC-8-400 Aircraft $\mu = 0.5 \mu_{\text{measured cont}} / \mu_{\text{measured dry}}$

NASA/ICAO

The next correlation curve was extrapolated by NASA (see Figures 7 and 8 in Appendix G). This correlation curve was based on NASA's own test data from the 1970s and 1980s. An empirical mathematical function was extrapolated based on comparative testing:

All airplane types Aircraft $\mu = \{0.2 \mu_{\text{measured}} + 5/7 (\mu_{\text{measured}})^2\}$

ICAO adopted this curve based on NASA's testing and established correlation function. Figure 7 in Appendix G describes the assumptions on which NASA based its use of the correlation formula:

- A minimum change of friction with tyre dimension, vertical load and tyre pressure is assumed on snow and ice-covered runways (the pressure melting effect is minimal).
- It is assumed that the aircraft tyres and the continuous friction measuring device (CFMD) have identical friction values on snow and ice-covered runways.

JWRFMP³¹/Transport Canada

All airplane types (CRFI)³² Aircraft $\mu = 0.02 + 0.4 \mu_{\text{measured}}$

Figure 13 shows a comparison between the different correlation curves. The figure shows that for the same friction index ($\mu_{\text{measured}} = 0.30$) the „aircraft μ “ ranges from 0.10 for a B737 to 0.20 for a DHC-8-100/300, which is a doubling of the „aircraft μ “ for DHC-8 compared with B737 for the same measured runway friction coefficient. The TC curve is close to the Kollerud curve and it is significant that the data behind the curve include DHC-8. These tests were performed after the tests which the Bombardier „Aircraft $\mu = 0.6 \mu_{\text{measured cont}} / \mu_{\text{measured dry}}$ “ curve was based on. The TC curve does not separate propeller and jet aircraft (see Figure 18).

Civil Aviation Authority of Norway (CAA Norway)

Figure 13 (and Appendix G, Figure 9) includes a correlation curve approved by the CAA Norway for the B737 (SAS Norway and Norwegian) based on the Boeing data in Table 2 in Appendix G.

³¹ Joint Winter Runway Friction Measurement Program (JWRFMP).

³² Canadian Runway Friction Index (CRFI).

JAR/EU OPS 1

See Appendix C.

IEM OPS 1.485(b)

General – Wet and Contaminated Runway data

(See JAR-OPS 1.485(b))

If the performance data has been determined on the basis of measured runway friction coefficient, the operator should use a procedure correlating the measured runway friction coefficient and the effective braking coefficient of friction of the aeroplane type over the required speed range for the existing runway conditions.

1.3.5.3 *Comparison between various correlation curves.*

Figure 8 in Appendix G shows the test results of NASA's correlation tests plotted as FC (Surface Friction Tester, SFT) versus "aircraft μ ". NASA's correlation function has been plotted onto the same figure. By drawing a straight line from the origin through the plots, we get a linear function curve which corresponds to an "aircraft μ " of 0.5 FC. This means that the NASA curve coincides with the Kollerud curve which is very similar to the JWRFMP/TC curve as described under 1.3.5.2, Figure 18 and in Appendix G Figure 3. All these correlation curves are shown in Figure 13.

Bombardier/De Havilland has developed two correlation curves for DHC-8 as shown in 1.3.5.2. There is an important assumption behind these two correlation curves, which has not been taken into account in Norway.

The denominator in the correlation formula includes the term " $\mu_{\text{measured dry}}$ "³³. For the formula to be valid, FC must be measured using the same friction measuring device on the bare and dry runway as on the contaminated runway. This is not done in Norway; instead, a fixed constant = 0.85 is used for " $\mu_{\text{measured dry}}$ ". When Wideroe started using a cockpit performance computer (CPC), it used a fixed value = 0.7. However, the Norwegian Civil Aviation Administration's Aeronautical Inspection Department instructed Wideroe to use 0.85. The higher the " $\mu_{\text{measured dry}}$ " correction factor is, the lower the "aircraft μ " becomes.

The AIBN has not found any supporting documents to show why the Aeronautical Inspection Department's constant of 0.85 should apply to all types of friction measuring devices. However, values pertaining to some friction measuring devices can be found in the ICAO Airport Services Manual, Part 2, Pavement Surface Conditions, Appendix 1, Table A1-1, „Friction tester/aeroplane braked tire conditions" (Reference 4). The table shows that for the Saab Surface Friction Tester and the Saab Skiddometer the „characteristic friction coefficients" are 1.1 and 1.15, respectively. This means that in the correlation formulas used by Wideroe, the figure 1.15 might be entered (when using BV-

³³ AIBN has not found any reference to measuring speed which has a significant influence on the friction number measured. The speed dependency is not as dominant on dry surfaces as on wet and contaminated surfaces, but the measured dry friction coefficient do vary significantly between various dry runway surfaces and between the different friction devices used, even within the population of same type and model of friction measuring devices.

11/SKH) instead of 0.85. The corresponding constant for Griptester would be 1.115 as shown in the CROW report³⁴. The value of 1.115 was measured at a speed of 40.8 km/h.

If the constant 1.115 is used as the denominator, Bombardier's correlation curves become almost identical to „ $\text{aircraft } \mu = 0.6 \mu_{\text{measured contaminated}}$ ” for DHC-8-100/300 and „ $\text{aircraft } \mu = 0.5 \mu_{\text{measured contaminated}}$ ” for DHC-8-Q400, respectively. Figure 13 (and Figure 9 in Appendix G) shows that use of the corrected value for „ $\mu_{\text{measured dry}}$ ” in Wideroe's correlation formulas, results in „ $\text{aircraft } \mu$ ” values that correspond to Kollerud's and JWRFP's values. However, the AIBN's findings suggest that „ $\text{aircraft } \mu$ ” for propeller aircraft may be somewhat higher than for turbojet aircraft. This is also indicated by test data from JWRFP (see Figure 3 and Table 4 in Appendix G). This may be supported by earlier tests that indicated that lower landing weights resulted in a higher friction coefficient, but not to such an extent as indicated by the Wideroe correlation curve as shown in Figure 13. See Figure 14 and Appendix V.

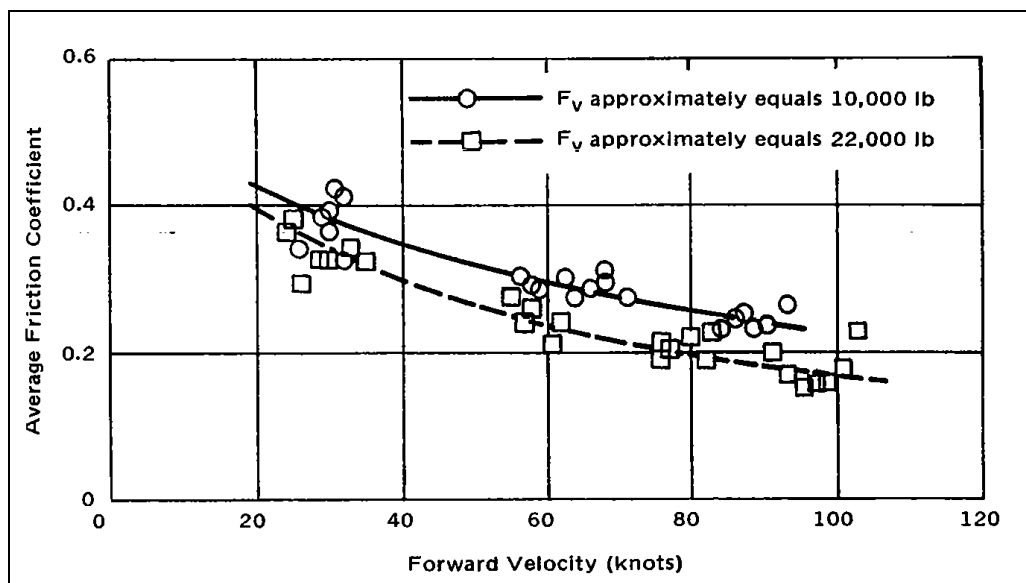


Figure 14: Average Friction Coefficient vs Velocity and Wheel Vertical Load (Horne and Leland, 1962. Appendix V).

1.3.6 Crosswind conditions in combination with slippery runways

Crosswind limits on slippery runways are not subject to international certification rules. Aircraft manufacturers are required to document the maximum demonstrated crosswind component on dry runway in the Airplane Flight Manual (AFM). This is not a certification limitation but operational information which is normally included in the AFM Performance Section. Crosswind limits on slippery runways are not subject to certification, but based on theoretical calculations and simulations. Hence, such data is usually included in the aircraft manufacturers' training manuals in the form of "Advisory material" rather than in the AFM. As a rule, the tables are roughly broken down into brackets, and it is standard practice for the airlines to prepare their own detailed crosswind tables which are then approved by the local aviation authority. The manufacturer publishes „Advisory data” that is not legally binding for the manufacturers, and the operators have to process this data to include operational limitations in their manuals. These manuals are approved by the local national aviation authority (i.e. the

³⁴ CROW report 04-05 Correlation Trial of Self-Wetting Friction-Measuring Devices for Dutch Airfield Pavements. April 2004.

Civil Aviation Authority of Norway - CAA Norway). The aircraft operators use these limitations at their own risk.

Appendix H shows an example of one airline's crosswind limits. Table 1.9.2 „*Recommended Maximum Crosswind (including gusts)*“ provides a realistic picture and is in line with Boeing's recommendations. These values reflect the basis for the landing calculations in the AFM. A Boeing-defined friction level in the form of an associated ABC is specified for each condition where a distinction is made between five conditions: Dry runway, Wet runway, BA GOOD ($ABC \geq 0.20$), BA MEDIUM ($ABC = 0.10$), BA POOR ($ABC = 0.05$). Graph 1.9.3 in Appendix H is more finely meshed in its categorisation of runway conditions. Here the pilot can consult the graph and determine the maximum crosswind component based on the stated FC, or the minimum FC based on the stated crosswind component. The FC in the graph can be estimated to an accuracy of ± 0.01 which is outside the capability of the measuring devices.

Reference is also made to AIP Canada, AIR 1.6, Table 3, Crosswind Limits for Canadian Runway Friction Index (CRFI):

<http://www.tc.gc.ca/publications/EN/TP14371/PDF/HR/TP14371E.pdf>

If the crosswind limits recommended by Transport Canada (TC) are compared with the limitations used by Norwegian aircraft operators, it is evident that Transport Canada's recommended crosswind limits are more stringent. In several of its investigations in connection with slippery runways, the AIBN has found that the airlines' use of crosswind tables were too optimistic (see 1.1.4 ([RAP 2002-23](#)), 1.1.13 ([RAP 2009-06](#)), 1.1.14 ([RAP 2009-07](#)), 1.1.19, 1.1.25, 1.1.29 and 1.1.30).

In its investigations, the AIBN has identified a special set of conditions relating to crosswind and slippery runways. What would normally be regarded as good winter conditions have proved to produce an extra slippery runway if the temperature-dew point spread is approx. $\leq 3K$ in strong crosswind conditions. This was the case when 19 of the 30 reported incidents/accidents occurred. Such conditions can cause blizzards / ice particles to polish the ice and sand grains, and cover them in a film of ice. In 3 of the 30 cases, there were below-zero temperatures of down to minus $17^{\circ}C$ and sanded runways, but with little temperature-dew point spread and strong crosswind conditions. FC was measured as more than 0.40 while „aircraft μ “/ABC was POOR. Such conditions are normally understood to constitute „*good winter runway conditions*“. It was found that blizzards / ice particles can cause the formation of a film on the surface below the aircraft's wheels which can result in planing (see 1.1.9, 1.1.13 and 1.1.19). Such conditions result in measured friction values of more than 40 ($FC > 0.40$) and can therefore result in serious mis-indication of available runway friction. In this connection reference is made to Appendix J, Chapter 11, and to the AIBN's own findings in its investigations of accidents and incidents relating to slippery runways (summarised in 1.2.3).

1.3.7 Cornering Friction

When braking and steering (cornering) at the same time, aircraft braking friction will be at the expense of aircraft cornering friction. The cornering friction is reduced by an increasing slip ratio. This is shown in Figure 15. It occurs when turning the aircraft and in connection with crosswind landings, when cornering friction is required in order to keep

the aircraft on a straight path along the runway centre line at the same time as the crew is applying the brakes.

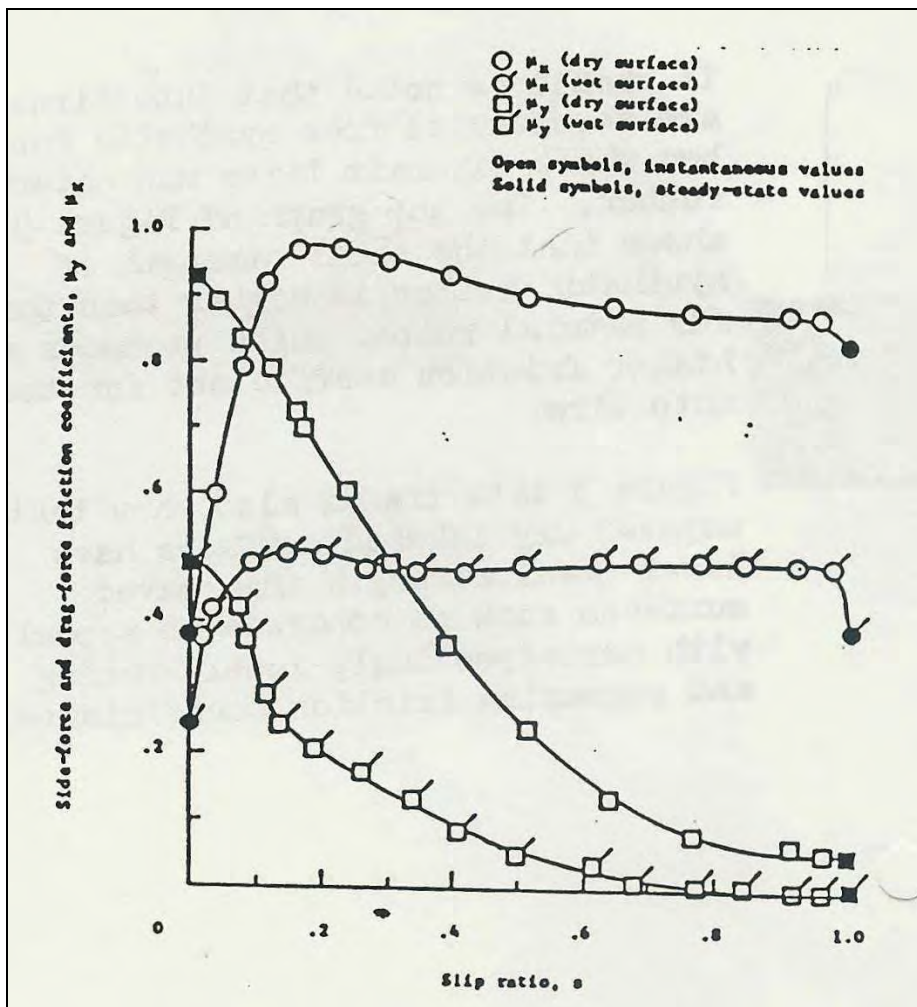


Figure 15: Cornering friction (W. B. Horne, NASA 1990).

1.3.8 Prepared runways with reduced widths

In two of its investigations the AIBN found that Avinor and the airlines have permitted operations on prepared runways with a width of only 30 metres (see 1.1.14 ([RAP 2009-07](#)) and 1.1.16).

1.3.8.1 CAR (BSL) E 4-2, Part 2, chapter 3.4.1.2

„Clearing of runways is normally performed continuously along the full length and width of the runway. Lights must not be covered by snow.

The runway length is as published. The runway starts where the take off distance (TORA/ASDA) is measured from and ends at the runway lights located furthest from the runway threshold.

The runway width is defined by the distance between the runway edge lights or edge markings. If the runway is used only by aircraft with a reference code which does not require full width, snow clearing may be reduced to the runway width as required. The aircraft operators are required to inform about their required runway width. Regardless, the minimum required runway widths are as specified

in BSL E 3-2. The reduced runway width must be symmetrical about the runway centre line."

BSL E 3-2 specify runways of lengths 1 800 m and more as Code number 4 with a runway width specified as Code letter C, D, E and F with a minimum width of 45 m.

CAA Norway has informed AIBN that the practice of clearing runway widths to 30 m width in Norway is only permitted on longer runways, with operational limitations, in situations of critical ambulance missions where the time aspect is critical.

Boeing Flight Technical Services" Guidelines for Narrow Runway Operations state that Boeing"s Recommended Crosswind Guidelines are based on the requirement that it must be possible to control the aircraft in the event of engine failure during take-off and landing under crosswind conditions on a 45 m wide runway (see 1.6.2).

1.3.9 Friction-improving measures

1.3.9.1 *Sanding*

Sanding of contaminated runways is briefly described in the ICAO *Airport Services Manual, Part 2 Pavement Surface Conditions, Chapter 7*. A grain size of between 0.297 mm and 4.75 mm is recommended. The lower limit is based on reduced friction and braking action while the upper limit is based on the risk of damage to the aircraft engines.

The AIBN has found that, international and national aviation authorities have not issued any special requirements relating to the use of sand over and above ICAO"s recommendations. In Norway, experiments with various sanding methods have been conducted since the 1940s, including the use of warm sand and sand mixed with water (warm, pre-wetted sand that bonds with the contaminant when it freezes; „*fixed sand*"). See Appendix J, chapter 07, and Reference 17.

The data in Appendix J, chapter 12, show that measured FC on various types of sanded contaminations was from MEDIUM to GOOD, while the „*aircraft μ* ” was from POOR to MEDIUM. Good friction was registered on sanded cold ice and snow-covered runway at an air temperature of minus 14.2 °C and a dew point of minus 18.8 °C, suggesting relatively dry air. This is in accordance with the AIBN"s findings that indicate good friction conditions when the air temperature is low and there is a temperature-dew point spread of >3 K. In the case in question, it resulted in a measured FC of 0.45 and an estimated „*aircraft μ* ” or ABC of 0.14 (corresponding to MEDIUM). Other conditions caused the sand and loose contamination to blow away from the wheels so that the braking action did not improve beyond POOR.

The AIBN has found that Avinor has practised runway preparation and sanding of wet ice and loose contamination in the form of snow or slush with minimum effect. Under such conditions the sand is pushed or blown away from the wheels together with loose contamination without increasing the braking action to any significant degree (see 1.1.14 [RAP 2009-07](#)). Furthermore, in several of its investigations, the AIBN has found that sanding of a wet surface or loose contamination (slush, wet or dry snow) results in incorrect friction measurements (see 1.1.4 [RAP 2002-23](#) and 1.1.10 [RAP 2007-25](#)).

1.3.9.2 Chemicals

The use of chemicals is also briefly described in the ICAO Airport Services Manual, Chapter 7.

The following extract from Appendix J, chapter 08, describes the reasons for using chemicals for runway preparation.

“According to Raoult’s Law, the freezing temperature of certain salt solutions is depressed proportional to the concentration of the salt dissolved. The coefficient of proportionality depends on the property of the solvent. The vapour pressure at the surface of the solution is lower than within the pure solvent because of forces of attraction on the dissolved molecules. Therefore, surfaces covered by a film of such chemicals may look „wet” as they attract atmospheric water. Relationships become complex when water is dominated by salt in high concentrations.

These properties can be applied either to prevent ice formation on a runway or to melt ice that has been formed earlier. In the first case, the chemical may be called „anti-icer” (preventing ice formation), in the second case, „de-icer” (removing ice). Consequently, there are two strategies: one is to prevent the accumulation of frozen water, and the other is to get rid of already accumulated ice or compacted snow. The optimum strategy is a question of climate and specifically, weather forecasts and real time changes in the weather hour by hour, together with financial considerations.

The first strategy is aimed at covering up, and, as time goes by, maintaining the cover on „black” runways by applying fluid anti-icing chemicals. The applied concentration, therefore, must be sufficient to melt several successive occurrences of solid precipitation, or the diluted chemical must be supplemented by new applications of a more concentrated solution in due course.

The second strategy is based on (wetted) granulates. Through a combination of melting and gravity, the particles penetrate an accumulated layer of ice or compacted snow. The solution then is intended to be applied at the level of the „black” runway, to melt and to release ice from the pavement and to allow removal of flakes of ice or slush mechanically.”

One problem relating to the use of chemicals is that chemicals dissolved in water can freeze at low temperatures and at low temperature-dew point spreads. The thinning of de-icing liquid as a result of melting or precipitation may contribute to this process. The capacity of de-icing liquids to lower the freezing temperature depends on precise control of the saline solution. Another situation can arise as a result of evaporation of the de-icing fluid’s water phase so that the de-icing liquid becomes more concentrated and forms a slippery film.

In Norway, the chemical Urea has been used since the 1950s and the results have been good, particularly in temperatures between zero and minus 3 °C. In practice, Urea can be used down to a temperature of minus 7 °C, but the effect drops steeply when the temperature falls below minus 5 °C. Urea (granulated „sodium chloride”) contains approximately 45 % nitrogen and it is the main ingredient in artificial fertilizer. The runoff is regarded as detrimental to the environment and, in recent years, attempts have been made to limit the use of Urea.

In Norway, a chemical called Aviform L 50 (liquid „*potassium formate*“) is used as an alternative to Urea. In addition to water, the main ingredient in Aviform is „*potassium formate*“. Aviform is said to be more environmentally friendly than Urea and can be used at lower temperatures. In practice, Urea and Aviform are used under the same temperature conditions, normally between zero and minus 5 °C. Warm, pre-wetted sand that bonds with the contaminant when it freezes („*fixed sand*“) is used at lower temperatures.

Much attention is given to the biological environmental effects of chemicals, expressed in units of oxygen required per unit of de-icer as an indirect measure of the degradation of organic compounds in water. The most favourable figure is the one for „*potassium formate*“ (0.1). The figure for „*potassium acetate*“ is 0.3 compared with 2.2 for „*technical urea*“. This is the main reason not to use Urea³⁵ though it is less expensive than any of the alternatives, and even if temperatures would allow it. Its main use is as a nitrogen releasing fertilizer.

On the other hand, in contrast to Urea, acetate disintegrates pavement, bitumen and asphalt concrete, and even results in loose stones. Corrosion of exposed aircraft components is a reported drawback compared with urea. In a recent update by Ed. Duncan³⁶, the Society of Automotive Engineers Aerospace, together with Star Alliance and Continental Airlines, identified the corrosive effect of „*potassium acetate*“, „*potassium formate*“ and „*sodium acetate*“ as causing damage to aircrafts“ landing gear systems, switches, relays and electronic components. The scope of damage includes short-circuiting of electrical systems as well as degradation of composite materials and the anti-slip properties of runway coatings. Use of chemicals can also damage airport infrastructure.

1.3.10 Operational use of wind data in landing calculations

In five (5) accident/incident investigations the AIBN has found that the landing calculations were based on TWR (tower) readings of instantaneous wind speeds (2-minute readings or 3 sec gust reading) instead of the most recent relevant METAR or ATIS data (10-minute readings). Some examples of this are included in 1.1.4 [RAP 2002-23](#), 1.1.13 [RAP 2009-06](#), 1.1.14 [RAP 2009-07](#) and LN-WIK [RAP 2009-22](#).

See also JAR OPS 1.400, IEM OPS 1.400, JAR-OPS 1.515 and 1.520, which refer to „*the weather at the aerodrome and the condition of the runway...*“, „*the latest available report*“, and „*the appropriate weather reports or forecasts, or a combination thereof*“, among other things.

The effects of wind on landing aircraft are described in Appendix J, chapter 10.

AIBN has also found during the investigations that pilots are more concerned about the combination of friction and crosswind at the touchdown point than they are about the condition further down the runway where the braking and steering (cornering) friction are more important. At the landing point the aircraft is controlled by the aerodynamic control forces, while from 100 kt and lower the aircraft becomes a „ground vehicle“ and its

³⁵ There is an EU ban on use of Urea.

³⁶ <http://www.aci-na.org/static/entransit/20100721-Duncan-SAEG12DeicingActivities.pdf>

directional control and braking is totally dependent on frictional forces. AIBN has found that runway excursion does not occur on the first third of the runway, but normally on the last third. An example of this is the serious incident at Svalbard referred to in 1.1.30. In that incident the crew based their landing calculations on the lesser wind at the landing threshold and the reported friction 4-3-2 on the basis that they did not need the last third of the runway.

1.3.11 Use of reverse thrust in landing calculations

The aircraft certification requirements are based on testing on a dry runway without the use of reverse thrust, and the prompt application of maximum manual braking (see Figure 16). Certified landing data is published in the AFM Performance Section for the type of aircraft. The data is used by the airlines as "*dispatch data*"; i.e. to calculate landing distances/maximum landing weight on the basis of information about weather and runway conditions obtained prior to departure.

No requirements for certified data for landing calculations exist for aircraft en route. Operational rules (conf. EU-OPS 1.400, Appendix C) permit the use of aircraft manufacturers' "*advisory data*", which are based on theoretical friction values for various types and depths of contamination (ice, snow, slush) and / or measured friction coefficients provided an approved correlation curve is used, use of reverse thrust, autobrakes and calculated landing distance required (LDR), plus 15 % (optional in USA and Europe).

Appendix C shows some related EU OPS regulations. AIBN is drawing attention to JAR/EU OPS 1.485:

(a) An operator shall ensure that, for determining compliance with the requirements of this Subpart, the approved performance data in the Aeroplane Flight manual is supplemented as necessary with other data acceptable to the Authority if the approved performance data in the Aeroplane Flight manual is insufficient in respect of items such as:

- 1. Accounting for reasonably expected adverse operating conditions such as take-off and landing on contaminated runways; and*
- 2. Consideration of engine failure in all flight phases.*

The regulations states that due consideration must be given to engine failure during all phases of flight (with no exception for landing). This may be interpreted as all landing calculations should be based on performance data with one thrust reverser inoperative. This interpretation is supported by EASA's own interpretation as stated to OPS-utvalget, Skandinaviska Tilsynskontor (STK)³⁷, Stockholm, in an e-mail of 11 January 2008:

³⁷ „OPS-utvalget“ is the Scandinavian Civil Aviation Authorities' board for coordination of safety regulations and supervision of jointly certified airlines and other aviation enterprises. STK-Det Skandinaviska Tilsynskontor- is an office under OPS-utvalget for supervision of these entities.

The JAA Liaison Office interpretation of the regulations, which you have already correctly identified, is that, to be absolutely correct, the worst case of the landing distance required with both thrust reversers operative and with only one thrust reverser operative, should be used. In practical terms it seems unlikely that the landing distance required could be greater with both reversers operative than with only one thrust reverser working, but perhaps there is some obscure set of circumstances where this might occur.

Returning to your specific question about the MD 80; the landing distance required with one thrust reverser inoperative needs to be calculated, as well as with both thrust reversers operative and the worst case used. By the same token, if one thrust reverser was locked out, the landing distance required to be used should be the worst case of the distance required with one thrust reverser operative and without thrust reversers at all. So, it seems that the Operations Manual of the company concerned is in error.

Based on this interpretation from EASA itself, „OPS-utvalget“ decided to enforce this regulation in Scandinavia (Sweden, Denmark and Norway). So far this has not been implemented. If implemented, this would increase the safety margins by the effect of one additional thrust reverser when landing on contaminated runways with uncertain friction coefficients.

AIBN’s investigations show that in actual operations it is left to the airlines or the aircraft commanders to decide whether use of reverse thrust should be included in the landing calculations. This is based on then JAR/EU OPS 1.400 (Appendix C):

OPS 1.400 Approach and Landing Conditions

Before commencing an approach to land, the commander must satisfy himself / herself that, according to the information available to him / her, the weather at the aerodrome and the condition of the runway intended to be used should not prevent a safe approach, landing or missed approach, having regard to the performance information contained in the Operations Manual.

IEM OPS 1.400 Approach and Landing Conditions

The in-flight determination of the landing distance should be based on the latest available report, preferably not more than 30 minutes before the expected landing time.

In practice landing calculations for turbo jet aircraft are normally based on the use of reverse thrust. For turbo propeller aircraft, on the other hand, reverse thrust is not included in the landing calculations. For propeller aircraft, it is permitted to rotate the blades to a flat pitch after landing. This results in efficient air braking, so that reverse thrust constitutes a back-up.

In practice, this means that in Norway landings with jet aircraft are calculated based on the use of reverse thrust, while landings with propeller aircraft are calculated without the use of reverse thrust. This practice is laid down by the airlines and approved by Civil Aviation Authority Norway, and all landings with jet aircraft on slippery runways are calculated using reverse thrust to allow for regular operation on contaminated and slippery runways.

1.4 Weather and runway conditions on a typical winter’s day in Norway

1.4.1 Introduction

The AIBN has chosen to present data from a typical winter’s day of snowfall (e.g. 2 February 2010, which was one such day) in order to illustrate what information is available to aircraft crews and air traffic controllers during winter operations in Norway.

On that day, snow fell over large parts of Norway. TAF, METAR and SNOWTAM, as reported via Avinor's Internet Pilot Planning Centre (IPPC), are shown in the table below. TAF and METAR are forecasted and reported weather conditions. They show what information is available to aircraft crews and air traffic controllers about forecasted and relevant weather and runway conditions. SNOWTAM provides information about runway and friction conditions based on the airport personnel's own assessment of the conditions. The information is used for planning of the flight. On the date in question, aircraft landed at all the airports mentioned without encountering any reported friction problems. The available information includes safety indicators that are currently not fully utilised. Nor are these indicators described in any detail in applicable regulations. These safety indicators are listed under 1.2.3.

1.4.2 TAF, METAR and SNOWTAM information 2 February 2010

AIRPORT	TAF	METAR	SNOWTAM
<i>Oslo Airport Gardermoen (ENG M)</i>	TAF 021400Z 0215/0315 03008KT 8000 SCT008 BKN015 TEMPO 0215/0224 2500 –SN BKN008 PROB40 TEMPO 0300/0315 1000 SN VV005	METAR 021610Z 05008KT 8000 –SN BKN009 M11/M12 Q0996 TEMPO BKN012	SNOWTAM 0755 A) ENGM B) 02021537 C) 01L F) 47/47/47 G) 8/8/8 H) 4/4/4 ... T) RWY 01L F/100/100/100/PCT. SANDED NEW APPLICATION. FRICTIN 2 ON TAXIWAYS. OPEN EXITS ARE SANDED. SLIPPERY PORTIONS ON CENTRAL APRON. SLIPPERY PORTIONS ON GA APRONS. FRICTION 3 ON OPEN EXITS.
<i>Sandefjord Airport Torp (ENTO)</i>	TAF 021400Z 0216/0222 36015KT 9000 –SN BKN012 TEMPO 0216/0222 01015G25KT 20000 SN VV005	METAR 021620Z 01012KT 5000 –SN OVC009 M09/M10 Q0994	SNOWTAM 0605 A) ENTO B) 02021613 C) 18 F) 89/89/89 H) 5/4/4... T) F/100/100/100/PCT. NO REMAINING SAND. NO DEICING. NO ANTIICING. NO MARKING ON SNOW. DRIFTING SNOW. PATCHY CONTAMINANT ON RUNWAY. SLIPPERY PORTIONS ON RUNWAY. SLIPPERY PORTIONS TAXIWAYS. SLIPPERY PORTIONS ON APRONS. TAXIWAYS SANDED.

AIRPORT	TAF	METAR	SNOWTAM
<i>Kristiansand Airport Kjevik (ENCN)</i>	TAF 021400Z 0216/0223 05020G30KT 1200 – SN DRSN VV008 TEMPO 0216/0223 03015KT 5000 –SN SCT010 BKN020	METAR 021550Z 02020G30KT 1200 SN VV014 M07/M08 Q0990	SNOWTAM 0504 A) ENCN B) 02021613 C) 04 F) 47/47/47 G) 8/8/8 H) 3/3/3... T) F/50/50/50/PCT. SANDED NEW APPLICATION. NO MARKING ON SNOW. DRIFTING SNOW. TAXIWAYS SLIPPERY. APRON SLIPPERY. ALL APRONS SANDED.
<i>Stavanger Airport Sola (ENZV)</i>	TAF 021400Z 0215/0315 04005KT 9999 FEW025 SCT060	METAR 021620Z 36005KT 9999 FEW025 BKN130 M03/M07 Q0992 NOSIG	SNOWTAM 0249 A) ENZV B) 02021533 C) 18 F) 79/79//79 H) 4/4/4 ... B) 02021533 C)11 F) 79/79/79 H) 3/3/3 ... T) RWY 18 F/25/25/25/PCT. ANTIICING. TAXIWAYS SLIPPERY. APRONS SLIPPERY.... TAXIWAYS SANDED. RWY 11 F/50/50/50/PCT. SLIPPERY PORTIONS ON RUNWAY. TAXIWAYS SLIPPERY. APRONS SLIPPERY. ALL APRONS SANDED. TAXIWAYS SANDED.
<i>Bergen Airport Flesland (ENBR)</i>	TAF 021400Z 0215/0315 04005KT 9999 FEW020	METAR 021620Z 00000KT 9999 FEW020 M04/M08 Q0993 NOSIG RMK WIND 1200FT 08003KT	SNOWTAM 0328 A) ENBR B) 02021606 C) 17 F) 27/27/27 H) 4/4/4 ... T) F/25/25/25/PCT SLIPPERY PORTIONS ON RUNWAY. TAXIWAYS SLIPPERY. APRONS SLIPPERY. RUNWAY SHOULDERS NOT CLARED...

AIRPORT	TAF	METAR	SNOWTAM
<i>Trondheim Airport Værnes (ENVA)</i>	TAF 021400Z 0215/0315 12007KT CAVOK	METAR 021620Z 13006KT CAVOK M10/M14 Q0998 NOSIG RMK WIND 670FT 09008KT	SNOWTAM 0350 C) 09 F) 379/379/379 H 5/5/5 ... T) F/10/10/10/PCT. SLIPPERY PORTIONS ON RUNWAY. SLIPPERY PORTIONS ON TAXIWAYS. APRONS SLIPPERY. ALL APRONS SANDED.
<i>Bodø Airport (ENBO)</i>	TAF 021400Z 0215/0315 09010KT 9999 FEW040 BKN100 BECMG 0215/0218 10020KT TEMPO 0221/0315 10025G35KT TEMPO 0215/0218 4000 -SN VV012	METAR 021550Z 09010KT 9999 FEW035 BKN080 M05/M11 Q1000 NOSIG	SNOWTAM 0169 A) ENBO B) 02020330 C) 07 F) NIL/NIL/NIL T) PCT/100 PCT/100 PCT/100
<i>Bardufoss Airport (ENDU)</i>	TAF 021400Z 0215/0315 VRB05KT 9999 FEW040 SCT100 TEMPO 0215/0218 4000 -SN VV012 TEMPO 0306/0315 12010KT	METAR 021550Z VRB01KT 9999 -SN FEW040 SCT050 BKN120 M13/M16 Q1004	SNOWTAM 0504 A)ENDU B) 02021520 C) 10 F) 47/47/47 G) 8/8/8 H) 4/4/4... T) F/100 RMK/RWY SANDED OLD APPLICATION RMK/TWYS SLIPPERY
<i>Alta Airport (ENAT)</i>	TAF 021400Z 0215/0223 15008KT 9999 FEW030 BKN030 BKN070 TEMPO 0215/0218 20000 SN VV009	METAR 021550Z VRB02KT 9999 VCSH FEW011 BKN025 M12/M14 Q1010 RMK WIND 700FT VRB02KT	SNOWTAM 0472 A) ENAT B) 02021531 C) 11 F) 47/47/47 G) 8/8/8 H) 3/3/3 ... T) F/100/100/100/PCT. SANDED OLD APPLICATION. NO DEICING. NO ANTIICING. NO MARKING ON SNOW. ALL APRONS SANDED. TAXIWAYS SANDED. WARM SAND APPLIED ON RUNWAY.

AIRPORT	TAF	METAR	SNOWTAM
<i>Kirkenes Airport Høybuktmoen (ENKR)</i>	TAF 021400Z 0215/0223 15010KT 9999 FEW015 BKN030 TEMPO 0215/0218 2000 SN VV00	METAR 021550Z 16005KT 9999 FEW020 M10/M11 Q1011 RMK WIND 775FT 16007K	SNOWTAM 0624 A) ENKR B) 02021520 C) 06 F) 37/37/37 H) 5/5/5 ... T) F/100/100/100/PCT. SANDED OLD APPLICATION

1.5 International guidelines for winter operations

1.5.1 Introduction

Section 1.5 provides an overview of international guidelines and frameworks for winter operations. The guidelines of the International Civil Aviation Organization (ICAO) and the European Aviation Safety Agency (EASA) are included, in addition to applicable guidelines from the USA, Canada and the UK.

1.5.2 ICAO safety recommendations and procedures

1.5.2.1 ICAO Annex 14

An extract from ICAO Annex 14, Attachment 1, Guidance material Chapter 6 is shown in Appendix B.

The following extract from the above-mentioned document deals with friction and friction measurements:

„Determining and expressing the friction characteristics of snow- and ice-covered paved surfaces

6.1 There is an operational need for reliable and uniform information concerning the friction characteristics of ice- and snow-covered runways. Accurate and reliable indications of surface friction characteristics can be obtained by friction measuring devices; however, further experience is required to correlate the results obtained by such equipment with aircraft performance, owing to the many variables involved, such as: aircraft mass, speed, braking mechanism, tire and undercarriage characteristics.

Appendix O shows the SNOWTAM table, which, as it stands, is dated from 1959 (see Appendices L, M, and Q). The following extract from Annex 14 (Appendix B) deals with the uncertainty related to the reporting of the braking effect:

„The table below with associated descriptive terms was developed from friction data collected only on compacted snow and ice and should not therefore be taken to be absolute values applicable in all conditions. If the surface is affected by snow or ice and the braking action is reported as „good“, pilots should not expect to find conditions as good as on a clean dry runway (where the available friction may well be greater than that needed in any case). The value „good“ is a comparative value and is intended to mean that aeroplanes should not experience directional control or braking difficulties, especially when landing. “

The wording of Annex 14 unambiguously states that the scientific data basis for the SNOWTAM table was based on testing on compact snow and ice and should therefore not be used indiscriminately for all conditions.

It is on the basis of these ICAO guidelines, among other things, that the rules in Civil Air Regulation (CAR) Norway, Part E and AIP Norway and the SNOWTAM table were drawn up.

1.5.2.2 ICAO Annex 15

Extract from ICAO Annex 15, Chapter 5:

„5.2.3 Information concerning snow, slush, ice and standing water on aerodrome / heliport pavements shall, when reported by means of a SNOWTAM, contain the information in the order shown in the SNOWTAM Format”

1.5.2.3 ICAO Airport Services Manual

The ICAO *Airport Services Manual*, Part 2. DOC. 9137 AN/898 (Reference 4) describes among other things, the different types of friction measuring devices, and how these devices should be used in practice. This ICAO manual and FAA Advisory Circular 150-5200-30C forms the basis for the Norwegian rules relating to friction measuring devices, reporting and the use of friction values. The manual also contains a number of general considerations relating to, among other things, sanding and the use of chemicals.

1.5.2.4 ICAO Safety Management Manual

ICAO has issued a *Safety Management Manual*, DOC. 9859³⁸ which gives advice regarding developing national safety standards. In this respect ICAO recommends that each State define an acceptable safety level.

„6.4 ACCEPTABLE LEVEL OF SAFETY (ALoS)

6.4.1 Annexes 1, 6, 8, 11, 13 and 14 require that the acceptable level of safety (ALoS) to be achieved (by an SSP)³⁹ shall be established by the State.

6.4.2 The notion of ALoS is an essential ingredient for the effective operation of an SSP. Unless the notion of ALoS is understood and properly developed and implemented, it will be difficult to progress to a performance-based regulatory environment, and to monitor the actual performance of an SSP. The operation of an SSP may then be reduced to simply “ticking the appropriate boxes” under the false pretence of managing safety.”

1.5.2.5 ICAO Friction Task Force

In 2008, ICAO established the Friction Task Force (FTF) and appointed Norwegian Armann Norheim as its chairman. Other members included representatives of the authorities, manufacturers and pilot organisations. The ICAO FTF monitors the work of the FAA Takeoff And Landing Performance Assessment - Aviation Rulemaking Committee (TALPA ARC) appointed by the FAA (see Appendices X and Y) and the work of EASA.

1.5.2.6 NASA-TM-82318. Joint Technical Conference on Slush Drag and Braking Problems. National Aeronautics and Space Administration. N81-74341. Uncals. 00/05 21663. December 19-20. 1961.

http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19810069918_1981069918.pdf

³⁸ ICAO Doc 9859 Safety Management Manual

http://www2.icao.int/en/ism/Guidance%20Materials/DOC_9859_FULL_EN.pdf

³⁹ State Safety Program

The referenced NASA web link (Reference 22) contain some important historic information on state-of-the-art regarding operations on contaminated and slippery runways in 1961.

1.5.3 USA/NTSB/Federal Aviation Administration (FAA)

1.5.3.1 *Safety Alert for Operators SAFO 06012 31 August 2006*

Following a Southwest Airlines runway excursion by a B737-700 at Chicago Midway Airport on 8 December 2005, the FAA issued a Safety Alert For Operators (SAFO), the purpose of which was to improve the understanding of operations on slippery runways among operators of Boeing aircraft. SAFO 06012 is included as Appendix I to Boeing's information memo regarding landing on slippery runways⁴⁰. This SAFO contains so much useful information about winter operations that the AIBN has chosen to include it as an appendix together with information from Boeing (see Appendix I). The following is a quote from SAFO 06012:

„Runway surface conditions may be reported using several types of descriptive terms including: type and depth of contamination, a reading from a runway friction measuring device, an airplane braking action report, or an airport vehicle braking condition report. Unfortunately, joint industry and multi-national government tests have not established a reliable correlation between runway friction under varying conditions, type of runway contaminants, braking action reports, and airplane braking capability. Extensive testing has been conducted in an effort to find a direct correlation between runway friction measurement device readings and airplane braking friction capability. However, these tests have not produced conclusive results that indicate a repeatable correlation exists through the full spectrum of runway contaminant conditions.

Therefore, operators and flight crews cannot base the calculation of landing distance solely on runway friction meter readings. Likewise, because pilot braking action reports are subjective, flight crews must use sound judgment in using them to predict the stopping capability of their airplane. For example, the pilots of two identical aircraft landing in the same conditions, on the same runway could give different braking action reports. These differing reports could be the result of differences between the specific aircraft, aircraft weight, pilot technique, pilot experience in similar conditions, pilot total experience, and pilot expectations. Also, runway surface conditions can degrade or improve significantly in very short periods of time dependent on precipitation, temperature, usage, and runway treatment and could be significantly different than indicated by the last report. Flight crews must consider all available information, including runway surface condition reports, braking action reports, and friction measurements.”

1.5.3.2 *FAA policy relating to slippery runways and the use of measured FC.*

It is the FAA's current policy not to permit the calculation of landing distance based on measured FC.

Part of the FAA's Airman's Information Manual (AIM) reads:

⁴⁰ Giesman P. Landing on Slippery Runways. Article presented at the 2007 Boeing Performance and Flight Operation Engineering Conference. Attached as Appendix I with permission from Boeing.

„No correlation has been established between Mu values and the descriptive terms „good“, „fair“, „poor“, and „nil“ used in braking action reports.“

The following can be found in FAA Advisory Circular (AC) 150/5200-31A, *Airport Winter Safety and Operations*:

„While it is not yet possible to calculate aircraft stopping distances from friction measurements, data have been shown to relate to aircraft stopping performance under certain conditions of pavement contamination, and are considered helpful by pilots“ organizations.“

An extract from the FAA’s Cert Alert 05-01, 1/14/2005, *Airport Winter Operations (Friction Measurement Issues)* reads:

„Although the International Civil Aviation Organization (ICAO) has published a comparison table for „MU“ readings and braking action, the FAA is not in harmony with ICAO on this determination and publication. The FAA has no approved publication that provides a comparable assessment rating between „MU“ readings and braking action. Further, the FAA feels that there is currently no conclusive correlation between braking action and MU value. Braking action is subjective and dependent on many factors, whereas MU value is an objective measurement. Either MU values or braking action reports are acceptable for reporting pavement conditions to the Notice to Airman (NOTAM) system. However there is no correlation between the two.

THEY ARE NOT INTERCHANGEABLE!“

The FAA’s view was reiterated in Cert Alert 95-06, October 1, 1995, *Reporting Braking Action and Friction Measurements*:

„The FAA does not support this table because there is no correlation between braking action and Mu Value. Braking action is subjective whereas Mu Value is quantitative. A pilot should know how the aircraft will react to a given Mu Value. Whereas what is considered „Good“ braking action for one person may be „Poor“ or „Nil“ to another.“⁴¹

The FAA considers the actual *Airplane Braking Coefficient* (ABC) to be an objective quantitative value, while the braking effect experienced by the pilot is a subjective value. Measured FC depends on the measuring device, and there is no scientific-based correlation between the various measuring devices and ABC.

Following the Midway accident, the FAA appointed a committee – the FAA Takeoff And Landing Performance Assessment - Aviation Rulemaking Committee (TALPA ARC). The committee’s terms of reference were to prepare proposals for revised rules for operations on slippery runways in the USA (see Appendix X). Appendix Y includes a recommended matrix for Takeoff and Landing Performance Assessment. A revised Airport Runway Condition Assessment Matrix – a proposed revision 2010-11, is included at the end of Appendix Y.

1.5.3.3 *NTSB Special Investigation Report. Large Airplane Operations on Contaminated Runways, 1983.*

⁴¹ These comments related to Ground Friction Reading Correlation Table (ICAO’s SNOWTAM table), presented by Thomas J. Yager at the International Aviation Snow Symposium i Buffalo, NY, 1988.

Quoted from the NTSB report dated April 22, 1983 (see AIR/10/5 GPN/BAC at the end of Appendix L):

„Themajor problem is that all of the airplane performance data used to establish operational limitations are obtained under ideally controlled conditions and are not representative of the performance actually attained during normal line operations. The test airplane used during certification is new, its brake and antiskid systems produce peak design performance, the tires are in good condition and at optimum operating pressures, and the test pilot's reaction times to activate deceleration devices, such as ground spoilers and wheel brakes, during a rejected takeoff or after landing may not accurately reflect line pilot performance. Most significant, however, is that all of the airplane acceleration and stopping performance data are for dry, smooth, hard runway surfaces; yet takeoff and landing operations are frequently conducted on runways covered with water, ice, slush or snow, or contaminated by rubber deposits.“

1.5.3.4 *FAA Notice of Proposed Rule Making (NPRM 63-28), July 15, 1963.*

Appendix R contains a FAA NPRM from 1963 which argues for a safety margin beyond the requirement for landing on 60 % of the landing Distance Available (a safety factor of 1.67). The NPRM states that:

„the 0.6 factor accounts for operational variations; i.e., excess threshold height and touchdown speed, variations in piloting techniques, adverse runway conditions, etc“. Further; „it is concluded that in actual operations large turbojet airplanes require 1 300 more feet under wet runway conditions. Since the presently required 0.6 factor is considered a necessary margin for landing operations under adverse runway conditions when operating the airplane in accordance with type certification procedures, we believe that the 1 300 additional distance actually being achieved in turbojets operational landings is consuming most of this margin. To restore this margin for turbojet airplanes, an equivalent of 1 200 feet should be added to the required landing runway lengths. Since for the airplanes involved in the analysis, the required runway length at higher weights was in the neighbourhood of 6 500 feet, the addition of 1 200 feet is equivalent to changing the factor from 0.6 to 0.5. In considerations of these facts, it is proposed to require that landing distances for turbojets be scheduled with a factor of 0.5 when the runways at the airport of destination are apt to be wet (visible moisture) or icy. Compliance would be determined on the basis of weather reports and forecasts at the time of dispatch. The landing runway lengths for dry runways would continue to be based on the 0.6 factor.

The NPRM concludes with a proposed requirement for a safety factor of 2 when planning on landing on a wet or icy runway.

1.5.3.5 *Part 121 Certification and Operations: Air Carriers and Commercial Operators of Large Aircraft. Landing Performance Operating Limitations for Turbojet Powered Transport Category Airplanes. July 7, 1965.*

Appendix S contains an important historic FAA comment and response document in the FAR rulemaking process based on Notice of Proposed Rule Making (NPRM) regarding Part 121 certification and operation of large turbojet transport aircraft landing on contaminated and slippery runways. The paper discusses the requirement for adding 15 %

to the required landing distance of 60 % of the available runway. Hence the safety factor for landing on wet or icy runways becomes $1.67 \times 1.15 = 1.92$. This is slightly less than the factor of 2 which was proposed in NPRM 63-28. These two documents (Appendices R and S) are the two references AIBN has found which argues for increased runway length when landing on slippery runways, and seems to be the basis for today's regulations.

1.5.3.6 *FAA AC 91-6. Water, Slush and Snow on the Runway. Effective 1/21/65.*

Appendix T contains a FAA Advisory Circular, effective 21 January 1961 containing guidelines for operations on runways covered with standing water, slush or wet snow up to 0.5 inch in depth.

Quote: „*Since SR-422 series regulations are predicted on clean, dry runways, certain correction factors should be applied to the takeoff data when operating on wet snow, slush, or standing water in depths up to 0.5 inch.*”

The AC goes on to recommend that the required runway length (for operations on 60 % of the available dry runway) be increased by 15 % in order to maintain the specified aircraft performance requirements as for dry runways. This tie in with the FAA document referred to in 1.5.3.5.

1.5.3.7 *FAA AC 121-12. Wet or Slippery Runways. Effective 8/17/67.*

Appendix U contains a FAA Advisory Circular, effective 17 August 1967 containing guidelines for operations on wet or slippery runways. From the AC is quoted:

„*In lieu of adding 15 percent to the required runway length for landing when it is anticipated the landing runway will be wet or slippery on arrival, FAR 121.195(d) permits use of a lesser additional distance based on a showing using actual operating landing techniques on wet runways.*”

1.5.3.8 *Technical report R762 Tire-Pavement Friction Coefficients. Naval Civil Engineering Laboratory. April 1970.*

Appendix V contains a report from US Naval Civil Engineering Laboratory tests investigating friction coefficients with different tire-pavement conditions, correlation tests between different measuring devices, and correlation between measuring devices and aircraft. The report results and conclusions show the challenges of correctly predict runway friction and is just as relevant today. The test results also show that the vertical load on a braked wheel affects the aircraft friction coefficient – increasing vertical load decreases the friction coefficient (see Figure 14 in this report and Appendix V, Figure 49).

1.5.3.9 *DOT FAA AR-07/7. A Study of Normal Operating Landing Performance on Subsonic, Civil, Narrow-Body Jet Aircraft During Instrument Landing System Approaches, Final Report. March 2007.*

Appendix W contains the observed aircraft threshold crossing heights and touch down distances from normal approach and landings. Figure 9 in the report shows data for A320 Landing Flare and Touchdown Recordings, and Figure 10 shows the B737 Landing Flare and Touchdown Recordings. The data show that it is normal to have threshold crossing heights of at least 50 ± 10 ft and touch down between 8 and 14 seconds from threshold. Figure 17 in the

report show that typical crossing heights were between 10 and 20 feet above threshold with touch down points between 200 and 800 m from threshold for B737-400 and A319/320/321.

1.5.3.10 *FAA Order 1110.149 Takeoff/Landing Performance Assessment Aviation Rulemaking Committee. Effective date 10/12/2007.*

Appendix X contains the *FAA Order 1110.149 Takeoff/Landing Performance Assessment Aviation Rulemaking Committee* (TALPA ARC), dated 12 October 2007. This FAA order initiated a process of a combined industry and government working group to formulate recommendations to FAA for further safety improvements to operations on contaminated and slippery runways.

An important quote from the documents is:

*„Aircraft Flight Manual (AFM) landing performance data is determined during flight testing using flight test and analysis criteria that are not representative of everyday operational practices. Landing distances determined in compliance with 14 CFR part 25, § 25.125 and published in the FAA-approved AFM do not reflect operational landing distances. Landing distances determined during certification tests are aimed at demonstrating the shortest landing distances for a given airplane weight with a test pilot at the controls, and are established with full awareness that operating rules for fractional ownership, domestic, flag, supplemental, commuter/on-demand operations with large transport category turbine-engine powered airplanes require the inclusion of additional factors when determining minimum operational field lengths. (These factors are required for dispatch, but are used by some operators at the time of arrival as well.) Flight test and data analysis techniques for determining landing distances can result in the use of high touchdown sink rates (as high as 8 feet per second) and approach angles of -3.5 degrees to minimize the airborne portion of the landing distance. Maximum manual braking, initiated as soon as possible after landing, is used in order to minimize the braking portion of the landing distance. **Therefore, the landing distances determined under § 25.125 are shorter than the landing distances achieved in normal operations.**” (Highlighted by AIBN).*

The text in the FAA order is a confirmation of the accepted view that operational landing distances are generally longer than the minimum landing distances established during certification flight tests. Appendix Y shows the TALPA ARC recommendations.

The information in the documents referred to in 1.5.3.3-1.5.3.10 explains the reasons for additional safety factors when landing on contaminated and slippery runways. Specifically, the requirement of adding a safety factor of at least 15 % to the dispatch planning landing distance factor of 1.67, making the safety factor $1.67 \times 1.15 = 1.92$ compared to the minimum certified landing distance in the AFM, is explained.

1.5.4 Canada

1.5.4.1 *General*

Based on the Joint Winter Runway Friction Measurement Program (JWRFMP, 1995-2004), Transport Canada has developed its own methods of setting friction coefficients based on friction measurements (see 1.8.3 and Appendix G).

In general, Canada follows the ICAO rules, but it has also developed a separate measuring technique using a standardised friction / retardation measuring device – an electronic recording decelerometer (ERD), which is similar in principle to the Taplayment (TAP). A decelerometer is a spot measurement device and not continuous friction measuring equipment (CFME)⁴². The decelerometer is permanently installed in a vehicle and the unit of measurement is called the Canadian Runway Friction Index (CRFI) to distinguish it from values obtained when using CFME. The reported CRFI may be used in combinations with required landing distance tables published by Transport Canada (TC) in AIP Canada.

In principle, an ERDs measured FCs (CRFI) are comparable to FC measured with a mechanical decelerometer. The CRFI must not be confused with the International Runway Friction Index (IRFI) which was meant to be an international friction index measured with a calibrated device which all types of friction measuring devices could be calibrated with. This has so far not materialized.

1.5.4.2 *Canadian Runway Friction Index (CRFI)*

The CRFI values are included in runway reports and NOTAM information. AIP Canada also contains typical friction values for different types of contamination (see Figure 10 in Appendix G). Transport Canada (TC) has drawn up tables of required landing distance versus measured CRFI, both with and without the use of reverse thrust. Conf. AIP Canada, AIR 1.6, Table 1, Canadian Runway Friction Index (CRFI) Recommended Landing Distances (No Discing / Reverse Thrust), and Table 2, Canadian Runway Friction Index (CRFI) Recommended landing Distances (Discing / Reverse Thrust): <http://www.tc.gc.ca/publications/EN/TP14371/PDF/HR/TP14371E.pdf>

1.5.4.3 *Similar incidents in Canada*

The winter weather along Canada's western and south-eastern coasts is similar to that in Norway. It is apparent that even if TC has standardised friction measurements and reporting based on Canadian tests and experience, excursions from slippery runways still occur. Many of the causal factors behind these incidents are the same as for similar incidents in Norway.

See the following web links:

<http://tsb.gc.ca/eng/rapports-reports/aviation/2002/a02a0038/a02a0038.asp>

<http://tsb.gc.ca/eng/rapports-reports/aviation/2008/a08o0035/a08o0035.asp>

<http://tsb.gc.ca/eng/rapports-reports/aviation/2007/a07a0029/a07a0029.asp>

<http://tsb.gc.ca/eng/rapports-reports/aviation/2004/a04q0199/a04q0199.asp>

<http://tsb.gc.ca/eng/rapports-reports/aviation/2002/a02a0038/a02a0038.asp>

⁴²Continuous friction measuring equipment (CFME) is a term used to describe friction measuring devices with a slip ratio between the speed of the vehicle and the speed of the measuring wheel. Decelerometers are accelerometers which measure the vehicle's retardation by use of spot measurements, which then serve as basis for calculating FC (μ).

<http://tsb.gc.ca/eng/rapports-reports/aviation/2000/a00a0185/a00a0185.asp>

<http://tsb.gc.ca/eng/rapports-reports/aviation/2000/a00o0279/a00o0279.asp>

1.5.5 European regulations

1.5.5.1 *JAR OPS I/EU OPS*

Relevant JAR OPS/EU OPS rules for operations on contaminated / slippery runways are shown in Appendix C. European rules indicate that the planning criteria for operations on slippery runways are different from the FAA's certification rules for dry and wet / contaminated runways as shown in Figure 16.

„OPS 1.520 Landing – Wet and contaminated runways

- (a) An operator shall ensure that when the appropriate weather reports or forecasts, or a combination thereof, indicate that the runway at the estimated time of arrival may be wet, the landing distance available is at least 115 % of the required landing distance, determined in accordance with OPS 1.515.*
- (b) An operator shall ensure that when the appropriate weather reports or forecasts, or a combination thereof, indicate that the runway at the estimated time of arrival may be contaminated, the landing distance available must be at least the landing distance determined in accordance with subparagraph (a) above, or at least 115 % of the landing distance determined in accordance with approved contaminated landing distance data or equivalent, accepted by the Authority, whichever is greater. (Highlighted by AIBN).*
- (c) A landing distance on a wet runway shorter than that required by subparagraph (a) above, but not less than that required by OPS 1.515 (a), may be used if the Aeroplane Flight Manual includes specific additional information about landing distances on wet runways.*
- (d) A landing distance on a specially prepared contaminated runway shorter than that required by subparagraph (b) above, but not less than that required by OPS 1.515 (a), may be used if the Aeroplane Flight Manual includes specific additional information about landing distances on contaminated runways.*
- (e) When showing compliance with subparagraph (b), (c) and (d) above, the criteria of OPS 1.515 shall be applied accordingly **except that OPS 1.515 (a) 1 and 2 shall not be applied to subparagraph (b) above.** (Highlighted by AIBN).*

IEM OPS 1.485(b) shows that JAR/EU OPS accepts the use of measured friction coefficients that are correlated with the braking coefficients for the type of aircraft in question. It is also apparent from IEM OPS 1.490(c)(3) that, according to the rules, a satisfactory level of safety can only be maintained if operations on contaminated runways are an infrequent occurrence. If such operations cannot be limited to rare occasions, the operators must implement compensatory measures to maintain an „*equivalent level of safety*“. Examples of such measures would be special training of the crew, the use of factored landing distances, more restrictive wind restrictions and a ban on operating on contaminated runways if the friction conditions are unknown.

AIBN interprets the FAA regulations for dispatch shown in Figure 16, that airlines may not deviate from the 60 % requirement as OPS 1.520(e) indicates above, or base their dispatch data on „*at least 115 % of the landing distance determined in accordance with approved contaminated landing distance data or equivalent, accepted by the Authority, whichever is greater.*” as referred to in OPS 1.520(b).

JAR/EU OPS 1.400 (Appendix C) regulates the calculations for actual landings as referred to in 1.3.11:

OPS 1.400 Approach and Landing Conditions

Before commencing an approach to land, the commander must satisfy himself / herself that, according to the information available to him / her, the weather at the aerodrome and the condition of the runway intended to be used should not prevent a safe approach, landing or missed approach, having regard to the performance information contained in the Operations Manual.

IEM OPS 1.400 Approach and Landing Conditions

The in-flight determination of the landing distance should be based on the latest available report, preferably not more than 30 minutes before the expected landing time.

As may be interpreted by the text it is left to the individual airline and commander to decide on the landing conditions, use of reversers and any additional safety margins.

Both FAA and EASA recommend adding 15 % to the required landing distance based on the manufacturers’ advisory landing data for contaminated or slippery runways.

Reference is made to EU OPS 1.485 (a)2 (see Appendix C) which require consideration of engine failure during all phases of flight (not excluding landing). AIBN interprets this regulation as a requirement to plan all landings with one reverser inoperative. This is in line with EASA’s own interpretation.

1.5.5.2 JAR 25/EASA Certification Specification/CS 25

Certification of new types of aircraft is carried out in accordance with JAR 25/EASA Certification Specifications CS 25 (see CS 25.1591 and AMC 25.1591). Appendix D shows an extract from the EASA CS 25 certification specification.

The AIBN makes special reference to section 7.3 in Appendix D, which deals with the determination and use of friction coefficients. In this connection, EASA operates with so-called „*default values*”. These values represent the effective braking coefficient for an anti-skid controlled aircraft tyre when braking. Standard values are used for „*effective μ* ”.

The AIBN makes special reference to the following text:

„Due to the nature of naturally occurring runway contaminants and difficulties associated with measuring aeroplane performance on such surfaces, any data that is either calculated or measured is subject to limitations with regard to validity. Consequently the extent of applicability should be clearly stated. The properties specified in this AMC for various contaminants are derived from a review of the

*available test and research data and are considered to be acceptable for use by applicants. This is not an implied prohibition of data for other conditions or that other conditions do not exist. It has been recently **determined that the assumption** (highlighted by AIBN) to use wet runway surface field length performance data for operations on runway surfaces contaminated with dry snow (depths below 10 mm) and wet snow (depths below 5 mm) may be inappropriate. Flight test evidence together with estimations have indicated some measure of relatively low gear displacement drag and a measurable reduction in surface friction in comparison to the assumptions associated with wet runway field performance data. As a consequence it has been agreed that additional work is required to further develop the associated methodology. As an interim measure it has been concluded that it is reasonable to consider these surfaces by recommending that they be addressed by using the data for the lowest depth of the contaminant provided.”⁴³*

„7.3 Braking Friction (All Contaminants)

On most contaminant surfaces the braking action of the aeroplane will be impaired. Performance data showing these effects can be based on either the minimum conservative „default“ values, given in Table 2 or test evidence and assumed values (see paragraph 7.3.2⁴⁴). In addition the applicant may optionally provide performance data as a function of aeroplane braking coefficient or wheel braking coefficient.

7.3.1 Default Values

To enable aeroplane performance to be calculated conservatively in the absence of any direct test evidence, default friction values as defined in Table 2 may be used. These friction values represent the effective braking coefficient of an anti-skid controlled braked wheel/tyre.

⁴³ The AIBN’s interpretation is that this means that all contamination in the form of snow may give less friction than on a bare and wet runway.

⁴⁴ See Appendix D.

Table 2: EASA Contaminant Default Friction Values.

Contaminant	Default Friction Value μ
Standing Water and Slush	$= -0.0632\left(\frac{V}{100}\right)^3 + 0.2683\left(\frac{V}{100}\right)^2 - 0.4321\left(\frac{V}{100}\right) + 0.3485$ where V is groundspeed in knots Note: For V greater than the aquaplaning speed, use $\mu = 0.05$ constant
Wet Snow below 5mm depth	0.17
Wet Snow	0.17
Dry Snow below 10mm depth	0.17
Dry Snow	0.17
Compacted Snow	0.20
Ice	0.05

Note: Braking Force = load on braked wheel x Default Friction Value μ

Table 2

Note: For a specially prepared winter runway surface no default friction value can be given due to the diversity of conditions that will apply.

7.3.3 Use of Ground Friction Measurement Devices

Ideally it would be preferable to relate aeroplane braking performance to a friction index measured by a ground friction device that would be reported as part of a Surface Condition Report. However, there is not, at present, a common friction index for all ground friction measuring devices. Hence it is not practicable at the present time to determine aeroplane performance on the basis of an internationally accepted friction index measured by ground friction devices. Notwithstanding this lack of a common index, the applicant may optionally choose to present take-off and landing performance data as a function of an aeroplane braking coefficient or wheel braking coefficient constant with ground speed for runways contaminated with wet snow, dry snow, compacted snow or ice. The responsibility for relating this data to a friction index measured by a ground friction device will fall on the operator and the operating authority."

1.5.6 UK

The UK CAA follows ICAO's guidelines for operations on contaminated runways. British airports endeavour to avoid operations on runways that are contaminated with loose snow or slush. The UK Airport Authorities' policy is to close runways and remove the contaminants before resuming aircraft operations.

British aircraft crews flying in Europe must comply with the applicable practice in each individual country. The following extract from UK AIC 61/1999 shows the UK CAA's recommended precautions relating to landing on contaminated runways:

„Landing

Attempts to land on heavily contaminated runways involve considerable risk and should be avoided whenever possible. If the destination aerodrome is subject to such conditions, departure should be delayed until conditions improve or an alternate used. It follows that advice in the Flight Manual or Operations Manual concerning landing weights and techniques on very slippery or heavily contaminated runways is there to enable the Commander to make a decision at despatch and, when airborne, as to his best course of action.

Depths of water or slush, exceeding approximately 3 mm, over a considerable proportion of the length of the runway, can have an adverse effect on landing performance. Under such conditions aquaplaning is likely to occur with its attendant problems of negligible wheel braking and loss of directional control. Moreover, once aquaplaning is established it may, in certain circumstances, be maintained in much lower depths of water or slush. A landing should only be attempted in these conditions if there is an adequate distance margin over and above the normal Landing Distance Required and when the crosswind component is small. The effect of aquaplaning on the landing roll is comparable with that of landing on an icy surface and guidance is contained in some Flight Manuals on the effect on the basic landing distance of such very slippery conditions”.

AIC 61/1999 was later superseded by AIC 86/2007 Pink 126 http://www.nats-uk.ead-it.com/aip/current/aic/EG_Circ_2007_P_086_en.pdf

From this AIC is quoted:

„3 Runways that may be slippery when wet

3.1 ICAO Annex 14 (Aerodromes) requires airports to conduct periodic surveys of runway surface friction. If a survey indicates that the runway surface friction characteristics have deteriorated below a specified Minimum Friction Level, that runway will be notified via NOTAM as „may be slippery when wet”. The term slippery should not be confused with the term icy.

3.2 The Minimum Friction Level only needs to be recorded over a continuous strip of 100 m for a runway to be notified as 'may be slippery when wet'. When a runway is notified as such, aircraft operators may request additional information relating to that notification from the aerodrome operator. However, any performance calculations or adjustment made as a result of this information is the responsibility of the aircraft operator.”

„8 Landing

8.1 JAR-OPS 1 requires that at the flight planning stage the landing distance requirements at the destination and alternate aerodromes are satisfied taking into account the runway surface condition. It follows therefore that if the runways at the destination or alternate aerodromes are forecast to be contaminated then approved landing distance data, appropriate to the anticipated conditions must be available in order to satisfy this requirement at dispatch.

8.2 In all cases however, attempts to land on heavily contaminated runways involve considerable risk and should be avoided whenever possible. If the

destination aerodrome is subject to such conditions departure should be delayed until conditions improve or an alternate used. It follows that advice in the Flight Manual or Operations Manual concerning landing weights and techniques on very slippery or heavy contaminated runways is there to enable the Commander to make a decision at dispatch and, when airborne, as to his best course of action.

8.3 Depths of water or slush, exceeding approximately 3 mm, over a considerable proportion of the length of the runway, can have an adverse effect on landing performance. Under such conditions aquaplaning is likely to occur with its attendant problems of negligible wheel-braking and loss of directional control. Moreover, once aquaplaning is established it may, in certain circumstances, be maintained in much lower depths of water or slush. Crews should be familiar with the characteristics of aquaplaning, as its symptoms can be confused with a brake failure. A landing should only be attempted in these conditions if there is an adequate distance margin over and above the normal Landing Distance Required and when the crosswind component is small. The effect of aquaplaning on the landing roll is comparable with that of landing on an icy surface and guidance is contained in some Flight Manuals on the effect on the basic landing distance of such very slippery conditions.

8.4 If a runway is found to be slippery during the landing roll the handling pilot should reduce speed to taxi speed before attempting to turn off the runway.

The British Airport Authorities (BAA)'s policy is to keep runways „black“. This is consistent with ICAO's and EASA's recommendations. Furthermore, it is not permitted in the UK to measure friction on moist contamination (see quote from CAP683 below). The CAA position is that only compacted snow and ice can be assessed by CFME for a value to be inserted in the SNOWTAM Field (H). In spite of CAA's advice not to, AIBN has been informed by a UK operator that some UK aerodromes persisting in coding (H) as 9 and the Runway State Group at the end of METAR. However, reporting code 9 for such conditions (unreliable or unknown, see Appendix O), is consistent with ICAO's guidelines stating that friction must not be reported when the runway is bare, whether dry or wet. In this case, the applicable friction values are those that were accepted as the basis for the certification of the aircrafts (on dry or wet runway).

The AIBN has been informed that the British Airlines Pilots Association (BALPA) has contacted the UK CAA about the practice of reporting 9 under such conditions, in particular just before a runway is closed for preparation and immediately after a runway is re-opened after being treated with chemicals. In principle, the runway will then be „black“ and wet, and it will be reported as wet without a friction value, assuming that the friction is of the order of GOOD. What BALPA fears is that low temperatures and small temperature-dewpoint spreads can result in the formation of black ice on the runway. BALPA claims that its members are "forced" to land on runways with unknown friction. AIBN has been informed by UK CAA that they are aware that some aerodromes report 9 for such conditions, but that the correct reporting in Field (H) shall only be used when friction is measured by CFME on compacted snow or ice. For pilots this makes no difference, as no reported friction is not more helpful than (9) „unreliable“.

In this connection, the AIBN refers to a runway excursion at ENGM, where the runway was reported as being wet, but friction was also measured with an SFH⁴⁵ that showed FC values of 53-51-54 (see 1.1.3).

UK CAA's winter regulations are generally based on the ICAO recommended standards and recommended practices. Hence, the UK CAA specified method of assessing runway surface friction is contained in the CAP683: <http://www.caa.co.uk/docs/33/CAP683.PDF>

From the CAP683 is quoted:

3.3 With the exception of Paragraph 4 below, the procedures in this document should only to be used for the acquisition of friction levels of a runway surface for maintenance purposes. Data gathered concerning friction characteristics should be made available to aerodrome users on application, but should not be communicated to the crews of aircraft intending to use the runway during periods of surface contamination.

4 Limitations to Operational Use of CFME

4.1 Deployment of CFME on contaminated runways for the purpose of obtaining friction value readings is not permitted because contaminant drag on the equipment's measuring wheel, amongst other factors, will cause readings obtained in these conditions to be unreliable. A runway is termed contaminated when water deep than 3 mm, or wet snow or slush is present over 25% or more of the assessed area.

4.2 Contaminated runways should be assessed and the surface conditions reported in accordance with CAP 168 Chapter 3, Appendix 3D.

4.3 Additionally, it should be borne in mind that, in the time taken to pass assessments to pilots, conditions may have changed. With the exception of compacted snow advice tables, (paragraph 4.4) friction value readings must not be passed to aircrew as pilots do not have the means to interpret the readings for the purpose of calculating take-off or landing performance.

4.4 Should the runway surface be affected by an even layer of compacted snow or ice, as described in CAP 168 Chapter 3, Appendix 3D, then braking action assessment may be made in accordance with the stated procedure. However, in the UK conditions conducive to the formation of compacted snow or ice are rare."

It is clear from CAP683 that CAA does not permit use of CFME on contaminated runways other than on compacted snow or ice. These are the only conditions which allow insertion in SNOWTAM format Field (H).

In UK CFME is mainly used for measuring the friction level of a runway surface for maintenance purposes. This is in line with ICAO Doc.9137 AN/898 Airport Services Manual (Reference 4). This is the same procedure that Norway has filed a deviation to ICAO on, based on Avinor's test results at Oslo Airport Gardermoen. See 1.3.4 and Appendix G, Figures 1 and 2. The UK methodology is more detailed than the prescribed ICAO procedure in order to facilitate a better way to determine that a runway „may be slippery when wet“.

⁴⁵ Continuous Friction Measuring Device (CFMD) of the type SAAB Surface Friction Tester with high-pressure tires (SFH).

The last two winter seasons with unusual heavy snowfall in UK has caused many interruptions to British air traffic, including some runway excursions. This has resulted in a trial effort led by UK CAA in order to try to improve the prediction of friction on contaminated and slippery runways as informed by the link:

<http://www.caa.co.uk/default.aspx?catid=375&pagetype=90&pageid=1364>

1.5.7 Summary

1.5.7.1 *ICAO*

ICAO has issued recommended guidelines for operations on contaminated and slippery runways through its publications Annex 14, Annex 15 and Airport Services Manual, Part 2, DOC 9137/AN898. Further, ICAO has recommended individual States to define an Acceptable Level of Safety (ALoS) within a State Safety Program (SSP).

1.5.7.2 *USA*

The USA/ FAA departs from ICAO's guidelines in that it does not accept ICAO's SNOWTAM table or the correlation of friction values obtained by the use of friction measuring devices and aircraft braking coefficient (ABC). The FAA historically requires a dispatch planned landing distance of 1.92 of the landing distance established on dry runway without use of thrust reverser during certification flight tests. Historically, FAA has permitted using lesser additional distances for actual operational landings. After the Midway accident FAA recommends adding a 15 % additional factor to the operational landing distances.

FAA regulates the certified landing criteria for wet / contaminated runways by safety factors for „dry x 1.67 x 1.15 = 1.92“ which is used for dispatch calculations. No certified regulations exist for actual airborne landing calculations. Actual landing calculations are based on manufacturers' advisory data with addition of a voluntary safety factor of 1.15. It is not regulated to consider engine (reverser) failure during landing.

1.5.7.3 *Canada*

Canada/TC mainly follows ICAO, but it has developed and standardised its own measuring technique and uses its own friction index (CRFI) in combination with published required landing distance tables published in the AIP Canada.

1.5.7.4 *EASA*

EU OPS is based on ICAO's guidelines, but goes further in that it specifies requirements for approved correlation curves if measured friction values are used in landing calculations.

EASA's certification requirements permit the conversion of friction values on the basis of "water equivalent depth" and „default values“ for the various types and depths of contamination.

EU OPS differs from FAA in that they do not require $1.67 \times 1.15 = 1.92$ factoring of dispatch planned landing distances on contaminated runways, but allow use of approved contaminated landing distance data or equivalent, factored by 1.15 (excluding the 1.67 factor).

EASA has regulated consideration of engine (reverser) failure during landing. AIBN's investigations show that this regulation is not adhered to.

1.5.7.5 *UK*

The UK CAA follows ICAO's guidelines. The policy of the British Airport Authorities is to seek to remove as much of the contamination as possible in order to avoid regular and routinely operation on contaminated runways. Common practice is to close the runways until the contamination has been removed and a bare („black“) runway established. This is basically in accordance with the ICAO and JAR/EU OPS/EASA rules which prescribe that operations on contaminated runways should only take place as exceptions.

The BAA use chemicals both as an anti-icing agent and as a de-ice agent to melt residues after available mechanical means like brushes, ploughs and snow blowers. This may result in transitional periods with loose contamination prior to preparation and wet runways after preparation, during which the friction value has been seen reported as being 9 (unreliable or unknown). UK CAA's position is that Field (H) in the SNOWTAM format shall only be used when reporting measured friction with CFME on compacted snow and ice. For pilots it is very important to know the runway surface friction and no reported friction is not more useful than (9) „unreliable“.

1.6 **Guidelines for winter operations for various aircraft types**

1.6.1 Introduction

The various aircraft manufacturers' guidelines (flight manuals / operating manuals) for winter operations are largely based on the rules and regulations of the individual countries of production (Boeing – FAA/USA, Bombardier – TC/Canada, Airbus – EASA).

Of the 30 reported incidents addressed in this report, 5 incidents concerned Boeing/Douglas, 12 Boeing, 6 Airbus, 6 Bombardier and 1 Fokker. These numbers are also representative of the most frequently used aircraft types and aircraft movements on Norwegian winter runways during the last decade.

1.6.2 Boeing

Boeing's view of operations on slippery runways is based on the FAA's policy (see Appendix I, Giesman, Boeing) which contains updated information from Boeing relating to winter operations. The document contains a great deal of information of a general nature that should also be of interest to operators of other aircraft types.

Boeing underlines that there is a great difference between certified landing data and the manufacturers' "advisory data". This is illustrated in Figure 16, which shows that certified landing data are based on test data from dry runways and maximum manual braking without the use of reverse thrust. The braking distance is required to be maximum 60 % of the landing distance available (70 % for propeller aircraft).

Certified landing distances on wet / slippery runways are not based on test data but on certified landing distances on dry runways multiplied by a factor of 1.15. This is what Boeing calls "dispatch data" and which in Norway are called "planning data" (before the

flight starts from the aerodrome of departure). Certified landing data are presented in the Aircraft Flight Manual (AFM)'s chapter on performance.

In contrast, applicable landing distances are based on data from tests on dry runways with the use of reverse thrust and on Boeing's fixed "airplane braking coefficients" for dry and wet runways, and GOOD, MEDIUM and POOR braking action. The related Airplane Braking Coefficients are shown in Figure 6 in Appendix G.

These are the friction values on which Boeing's advisory data are based, i.e. the data used by the airlines to calculate relevant landing distances based on updated information about weather and runway conditions before landing.

It is important to emphasise that, unlike the certified data, the advisory data are based on the use of thrust reversers and do not incorporate safety margins. Traditionally the advisory data have not been published in the AFM, but in the Flight Crew Operating Manual (FCOM) as advisory landing data. This means that the data are not certified and the manufacturer is not legally liable for the use of the data. The airlines and local aviation authorities (in Norway, the CAA Norway) use the data at their own risk.

The B737NG (series 600-900) is certified on WET runways and Boeing provide WET data for takeoff and landing in the AFM. For landing distances the operators can choose to display the DRY*1.15 or the *advisory wet* as the certified max manual brakes landing distance. The *advisory wet* landing distance is calculated with max manual brakes on a surface with the same braking action that the aircraft experienced during certification trials on a wet runway during rejected takeoffs.

For the B737NG (series 600-900) Boeing has provided the advisory data for contaminated runways in the AFM, and for JAA operators landing distances are factored by 1.15 on GOOD, MEDIUM and POOR. This is not the case for the B737 series 300-500).

The JAA requirements at the time of certification of the B737NG called for a 7 seconds „flare“ distance and a 7 % speed bleed off from Vref@50 feet Threshold Height (THT) to touchdown on a contaminated runway. This is a much longer „flare“ distance than on a dry runway (4.5 sec / 1 % speed bleed off). Since the flight crews try to aim for the same touchdown point, there are some hidden theoretical margins in the landing calculations for a contaminated runway. These data are published in the AFM and all electronic performance databases, but in the printed Flight Crew Operator Manual (FCOM) Boeing calculates with a fixed flare distance of 1000 feet (300 m).

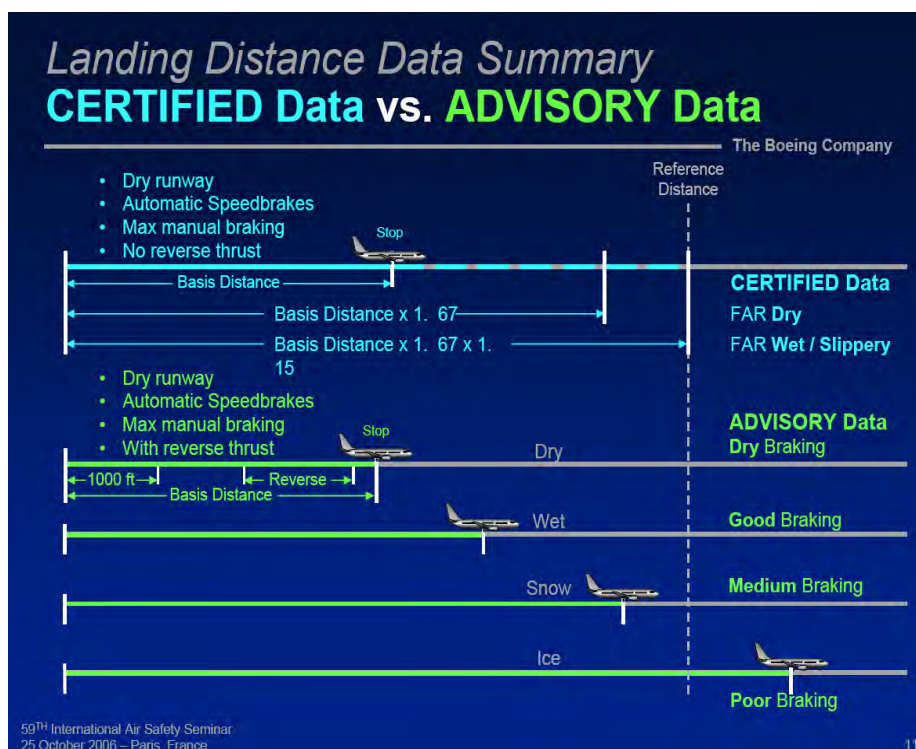


Figure 16: Boeing's Certified Data vs. Advisory Data (Boeing, 2006).

Figure 17 shows the effect of various autobrake settings combined with the use of both, or without thrust reversers. The data is from Southwest's runway excursion in the USA. The blue lines are for use of both thrust reversers, while the red lines are for use without thrust reversers. The figure shows that it was not possible to plan for landing with an ABC of 0.05 (Boeing POOR). However, it was possible to plan for landing without the use of thrust reversers with an ABC of 0.10 (Boeing MEDIUM). Landing with the use of one thrust reverser could be planned on a 2,400 m long runway. The figure also shows that, with an ABC of less than 0.10 (Boeing MEDIUM), it makes no difference to the braking distance whether autobrake setting 3 (7 ft/sec²) or Max (14 ft/sec²) is chosen. This is because the effective braking is friction limited.

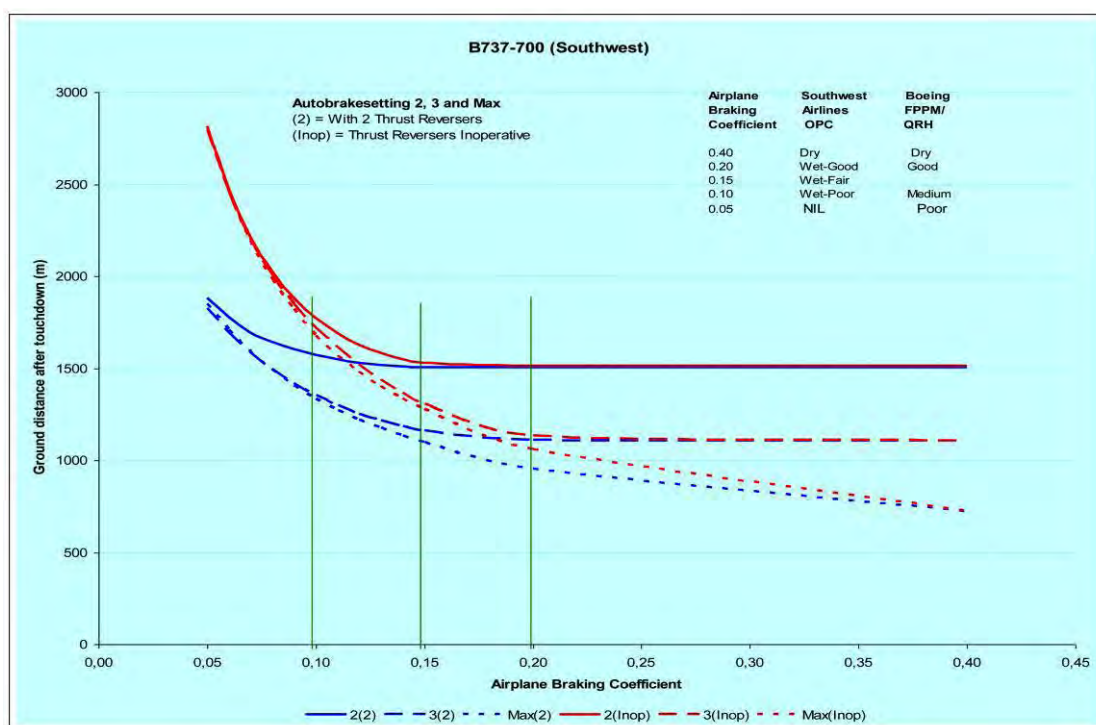


Figure 17: The effect of thrust reversers versus Airplane Braking Coefficients (NTSB).

Figure 11 shows the relative braking power that can be ascribed to the three braking forces air resistance, reverse thrust, and wheel braking, when braking on a contaminated runway with an „effective μ ” in the order of 0.05. At this low friction level the „effective μ ” and ABC are of the same order (Boeing POOR). The data concerns a relevant runway excursion in Norway (OY-VKA, RAP 2010/05, see 1.1.22). The graph shows that maximum reverse thrust accounts for approximately 20 % of the total braking power given the available POOR friction, and remains almost constant down to a ground speed of 20 kt. It also shows that the wheel brakes contribute 20-30 % during the first phase of the braking process. Although the FDR data is from an Airbus A321, it is considered relevant in general. The engine and reverser characteristics are similar if not identical, the anti-skid efficiency are of the same order and the aircraft aerodynamic layout are not much different.

Figure 12 shows the aircraft’s „effective μ ” * „anti skid efficiency” (μ * „ η ”, where „ η ” is max 0.92) during the same process as shown in Figures 10 and 11. The graphs show that the value was in the order of 0.05.

Boeing’s definition of Airplane Braking Coefficient (ABC) is shown in Figure 5 in Appendix G. It is important to emphasise that Boeing does not correlate its ABC values with ICAO’s SNOWTAM table. Such a correlation is permitted in Europe, conf. JAR OPS 1/EU OPS (Appendix C). For EU OPS operators Boeing’s published advisory data include an additional 15 % margin.

In this connection, it is also worth noting that Boeing does not make any finer distinction between friction levels than Dry, Wet, Good, Medium and Poor, and that these levels are published in the FCOM or AFM, and in the aircraft’s Quick Reference Handbook (QRH) so as to be readily available to pilots when planning landings on slippery runways. Norwegian airlines have had “their” correlation curves approved by the CAA Norway in accordance with JAR OPS 1. These correlation curves have been programmed into the

cockpit performance computers (CPC) which are used to calculate landing distances on the basis of reported (measured) FCs in accordance with ICAO's SNOWTAM table (see Figure 13 or Figure 9 in Appendix G, and Appendix O).

Table 2 in Appendix G shows Boeing's defined ABC versus runway contamination.

As far as crosswind limits on contaminated runways are concerned, reference is made to Boeing Flight Technical Services' *Guidelines for Narrow Runway Operations* (Reference 9):

„Boeing's Recommended Crosswind Guidelines are intended to address crosswind and engine failure... but they are based on a 45 m wide runway.“

Boeing publishes recommended crosswind limits in their Flight Crew Training Manual (FCTM).

1.6.3 Bombardier

Bombardier (formerly de Havilland Inc.) Supplement 37 (CAA Norway) to DHC-8-Model 103⁴⁶ and 311 Flight Manual, Supplementary Performance Information on Contaminated Runways (For Norwegian Operators Only) specify the conditions for operating on contaminated runways.

For the DHC-8-103/311, Bombardier has based its takeoff and landing calculations on the following criteria:

- Runway contaminated by compact snow
- Runway contaminated by ice
- Runway contaminated by standing water, slush or snow (maximum depth of 60 mm)
- Conversion of slush and snow depths to water equivalent depths (WED) based on the following estimated slush and snow relative densities (maximum WED of 15 mm).⁴⁷

- loose dry snow	0.20 – 0.35
- wet snow	0.35 – 0.50
- slush	0.50 – 0.85
- high water content slush	0.85 – 1.00
- in the case of unknown densities, maximum values are used for takeoff and the minimum values for landing.	
- Use of Braking Friction Index/Aircraft Mu (μ_{eff})

⁴⁶ PSM 1-81-1A. De Havilland Inc. DASH 8 Flight Manual Supplement 37 (NCAA) Model 103. Supplementary Performance Information for Operation on Contaminated Runways (For Norwegian Operators Only). Issue 5.

⁴⁷ The same values are used for Model 402.

- A combination of WED and aircraft μ is used for runways covered in water, slush or snow with WEDs of between 3 and 15 mm
- Aircraft μ is used for runways covered with compact snow or ice
- The aircraft μ_{ac} (μ_{ac}) is calculated using the formula:

$$\mu_{ac} = 0.6 \mu_{\text{measured cont}} / \mu_{\text{measured dry}}$$

where „ $\mu_{\text{measured cont}}$ “ is the measured friction coefficient (FC) on the contaminated surface

and „ $\mu_{\text{measured dry}}$ “ is the measured friction coefficient (FC) on the same airport's dry runway.

- If no measured friction coefficients are reported, fixed aircraft μ values are used:
 - Wet ice $\mu_{ac} = 0.05$
 - Compact snow $\mu_{ac} = 0.20$
 - Standing water, slush or loose snow $\mu_{ac} = 0.15$

For operations with the DHC-8-103/311 on contaminated runways exposed to crosswind, Bombardier has recommended the following values:

Table 3: Max crosswind vs. Aircraft μ /SNOWTAM FC.

Aircraft μ (μ_{ac})	Maximum Crosswind Component	ICAO SNOWTAM measured FC
≥ 0.30	32 kt	≥ 0.42
0.20 – 0.29	20 kt	0.28 – 0.41
0.10 – 0.19	8 kt	0.14 – 0.27
0.05 – 0.09	0 kt	0.07 – 0.13

Aircraft μ must be correlated with measured friction values (FC) based on the SNOWTAM friction table using the following formula: $\mu_{ac} = 0.6 \mu_{\text{measured cont}} / \mu_{\text{measured dry}}$

This means that the airlines prepare their own crosswind tables adapted to their own operations and submit these to the local aviation authorities for approval. In previous investigations (see 1.1.4 ([RAP 2002-23](#)), 1.1.9 ([RAP 2004-33](#)), 1.1.13 ([RAP 2009-06](#)) and 1.1.19), the AIBN has demonstrated that the crosswind limits for which Widerøe has obtained approval from the CAA Norway are more optimistic than the limitations recommended by Bombardier.

Furthermore, Table 3 shows that the limitations recommended by Bombardier are more optimistic than those that are recommended by, and published on Transport Canada's website. Conf. AIP Canada, AIR 1.6, Table 3:

<http://www.tc.gc.ca/publications/EN/TP14371/PDF/HR/TP14371E.pdf>

We quote from the table: „*The recommended minimum CRFI for a 13-kt crosswind component is 0.35. A takeoff or landing with a CRFI of 0.3 could result in uncontrollable drifting and yawing.*”

In its landing calculations, Bombardier assumes that discing is used for propeller braking, but not reverse thrust. Discing means that the angle of the propeller blades is set to zero so that they act as an air brake. The use of reverse thrust/negative propeller thrust (propeller blades set to a negative angle) is available as back-up braking power. This result in a considerable safety margin compared with jet aircraft, for which landing calculations are usually based on planned use of thrust reversers.

In connection with several of its investigations of runway excursions (see 1.1.4 [RAP 2002-23](#), 1.1.9 ([RAP 2004-33](#)), 1.1.13 ([RAP 2009-06](#)) and problems relating to control of DHC-8-103/300 aircraft after landing on slippery runways, the AIBN has found that Bombardier's conditions for use of the above-mentioned correlation formula have not been met in that “*µmeasured dry*” is not available in Norway. Wideroe's use of the factor 0.85 has been approved by the CAA Norway, but the AIBN has found it documented that the factor should be 1.115.⁴⁸

Reference is also made to Transport Canada's correlation curve as shown in Figure 18 (red curve). Based on these values, an FC of 0.40 (GOOD) corresponds to an aircraft Mu of 0.18, an FC of 0.30 (MEDIUM) corresponds to an aircraft Mu of 0.13 and an FC of 0.25 (POOR) corresponds to an aircraft Mu of 0.11. It is this correlation curve that is used as basis for the landing calculations published by TC on its website. Conf. AIP Canada, AIR 1.6, Table 1 (Recommended Landing Distances, No Discing/Reverse Thrust, and Table 2 (Recommended Landing Distances, Discing/Reverse Thrust):

<http://www.tc.gc.ca/publications/EN/TP14371/PDF/HR/TP14371E.pdf>

⁴⁸ CROW report 04-05 Correlation Trial of Self-Wetting Friction-Measuring Devices for Dutch Airfield Pavements. April 2004

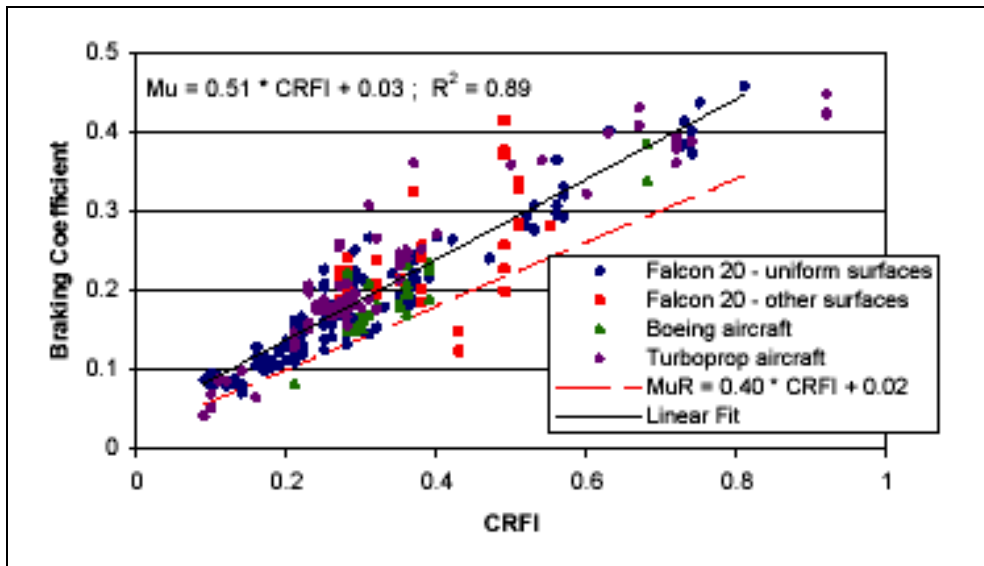


Figure 18: TC's correlation curve between CRFI and Braking Coefficient (aircraft μ).

For Norwegian operations with the DHC-8-103/311/402, the landing field length on contaminated runways is multiplied by a factor of 1.15.

For the DHC-8-Q400⁴⁹ Bombardier has based its takeoff and landing calculations on the following criteria:

- Runway contaminated with compact snow
- Runway contaminated with wet ice
- Runway contaminated by standing water, slush or snow (maximum depth of 60 mm)
- Conversion of slush or snow depth to water equivalent depth (WED) based on estimated densities of slush and snow (maximum WED of 15 mm) corresponding to those used for the DHC-8-100/300.

In 2004, the AIBN was informed by Transport Canada of Bombardier having adjusted the correlation formula for the DHC-8-Q400 (Model 402) to:

$$\mu_{ac} = 0.5 \mu_{\text{measured cont}} / \mu_{\text{measured dry}}^{50}$$

The current version of the Airplane Flight Manual Supplement 37 for Model 402, Supplementary Performance Information for Operation on Contaminated Runways, shows that Bombardier has discontinued its use of Aircraft μ for this model. This means that the calculation model has been simplified in that it uses fixed values for aircraft μ . It is not clear from Sup 37 what friction values Bombardier has used in its calculations, but it is anticipated that it has been used the same fixed values as for Model 103/311:

⁴⁹ PSM 1-84-1A. Q400 Airplane Flight Manual Supplement 37, Model 402. Supplemental Performance Information for Operation on Contaminated Runways. Issue 6.

⁵⁰ The measuring speed is not specified.

- Wet ice Aircraft $\mu_{ac} = 0.05$
- Compact snow Aircraft $\mu_{ac} = 0.20$

The friction values span the range POOR to GOOD as defined in the ICAO table in the SNOWTAM format (Appendix O).

The Q400 is subject to the following landing / crosswind limitations:

- For operations on runways covered by standing water, slush or wet snow with WED > 3 mm, the use of reverse thrust is not permitted
- For operations on runways covered by water, slush or wet snow, the maximum crosswind during takeoff and landing is 14 kt.
- For operations on runways covered by compact snow, the maximum crosswind limits is 20 kt.

1.6.4 Airbus

Some extracts from Airbus Industrie's document „Getting to Grips with Cold Weather Operations", Airbus Industrie, Flight Operations Support, Customer Services Directorate, 1999, are included in Appendix E (Reference 7). The document shows that Airbus is sceptical of the use of friction measurements:

„The main difficulty in assessing the braking action on a contaminated runway is that it does not depend solely on runway surface adherence characteristics.

What must be found is the resulting loss of friction due to the interaction tire/runway.

Moreover, the resulting friction forces depend on the load, i.e. the aircraft weight, tire wear, tire pressure and anti-skid system efficiency.

In other words, to get a good assessment of the braking action of an A340 landing at 150,000 kg, 140 kt with tire pressure 240 PSI, the airport should use a similar spare A340... Quite difficult and pretty costly!"

Airbus goes on to define contamination as „hard" or „fluid" in line with EASA's certification rules (see Appendices D and E):

A318/319/320/321 FLIGHT CREW OPERATING MANUAL	SPECIAL OPERATIONS FLUID CONTAMINATED RUNWAY	2.04.10	P 2
		SEQ 001	REV 37

2. CONTAMINATED RUNWAY

- R An equivalence between depth of slush and snow has been defined :
- 12.7 mm (1/2 inch) wet snow is equivalent to 6.3 mm (1/4 inch) slush
 - R – 25.4 mm (1 inch) wet snow is equivalent to 12.7 mm (1/2 inch) slush
 - 50.8 mm (2 inches) dry snow is equivalent to 6.3 mm (1/4 inch) slush
 - R – 101.6 mm (4 inches) dry snow is equivalent to 12.7 mm (1/2 inch) slush

Hard contaminants

For hard contaminants, namely compacted snow and ice, Airbus Industrie provides the aircraft performance independently of the amount of contaminants

on the runway. Behind these terms are some effective μ . These two sets of data are certified.

Fluid contaminants

Airbus Industrie provides takeoff and landing performance on a runway contaminated by a fluid contaminant (water, slush and loose snow) as a function of the depth of contaminants on the runway.

For instance, takeoff or landing charts are published for «1/4 inch slush», «1/2 inch slush», «1/4 inch water» and «1/2 inch water». For loose snow, a linear variation has been established with slush.

In other words, pilots cannot get the performance from reported μ or Braking Action. Pilots need the **type and depth of contaminant** on the runway.

CORRELATION BETWEEN REPORTED μ AND BRAKING PERFORMANCE

.....
To date, **there is no way to establish a clear correlation between the «reported μ » and the «effective μ ».** There is even a poor correlation between the «reported μ » of the different measuring vehicles.

It is then very difficult to link the published performance on a contaminated runway to a «reported μ » only. The presence of **fluid contaminants** (water, slush and loose snow) on the runway surface **reduces the friction coefficient**, may lead to **aquaplaning** (also called hydroplaning) and creates an **additional drag**. This additional drag is due to the precipitation of the contaminant onto the landing gear and the airframe, and to the displacement of the fluid from the path of the tire. Consequently, braking and accelerating performance are affected. The impact on the accelerating performance leads to a limitation in the depth of the contaminant for takeoff. **Hard contaminants** (compacted snow and ice) only affect the braking performance of the aircraft by a reduction of the **friction coefficient**. Airbus Industrie publishes the takeoff and landing performance according to the **type of contaminant**, and to the **depth** of fluid contaminants."

Table 4 shows applicable Airbus landing distances based on fluid-type contamination. It is interesting to note that Airbus considers friction on 12.7 mm water and 6.3 mm slush to be equivalent to the friction on compact snow (,effective $\mu^* = 0.20$), and friction on 12.7 mm slush as better than the friction on 6.3 mm slush. This is not in accordance with the AIBN's findings in its investigations relating to G-CRPH ([RAP 2007-25](#)) and OY-VKA ([RAP 2010-05-eng](#)).

Appendix P includes some examples of Airbus's friction curves for fluid-type contamination.

Table 4: Examples of Airbus's landing distances on fluid-type contamination.

ACTUAL LANDING DISTANCES										
1411										
CONFIGURATION FULL										
		ACTUAL LANDING DISTANCE (METERS)								
WEIGHT (1000 KG)		46	50	54	58	62	66	70	74	78
RUNWAY CONDITION	DRY	690	730	760	790	830	890	980	1070	1150
	WET	890	950	1010	1080	1150	1220	1290	1360	1420
	6.3 MM (1/4 INCH) WATER	1170	1250	1330	1420	1530	1630	1740	1850	1950
	12.7 MM (1/2 INCH) WATER	1140	1220	1290	1380	1470	1580	1680	1780	1860
	6.3 MM (1/4 INCH) SLUSH	1130	1210	1290	1370	1450	1530	1620	1720	1800
	12.7 MM (1/2 INCH) SLUSH	1100	1180	1250	1330	1400	1480	1560	1660	1730
	COMPACTED SNOW	1140	1220	1290	1360	1430	1500	1570	1650	1700
	ICE	2030	2170	2310	2450	2600	2740	2880	3030	3150

1.6.5 Summary

1.6.5.1 Boeing

Boeing complies with the FAA's regulations and guidelines which are mostly conservative. Boeing does not accept correlation between measured friction coefficients and airplane braking coefficients (ABC) and publishes ABC landing data in the categories GOOD, MEDIUM and POOR. For EU operators the landing data is multiplied by a factor of 1.15.

1.6.5.2 Bombardier

Bombardier adheres to Transport Canada's (TC) regulations and guidelines, which, in the case of DHC-8-100/300, are mainly based on measured friction coefficients correlated with the aircraft's braking friction index („Aircraft μ ") in accordance with TC's own correlation formula. In addition to this, Bombardier uses the principle of converting slush and snow depths to water equivalent depths (WED) based on defined densities for the various types of contamination.

In the case of DHC-8-Q400, applicable AFM data indicate that Bombardier has discontinued its use of measured friction coefficients correlated with „aircraft μ " and publishes landing data based on fixed „aircraft μ " values defined for wet ice, compact snow and standing water, slush and wet snow.

1.6.5.3 Airbus

Airbus's calculations are mainly based on the use of „hard contaminants" and „fluid contaminants" with fixed "effective μ ". Landing data is published in the Flight Crew

Operations Manual (FCOM) based on the „effective μ “ for various types and depths of contamination. In principle, this is in line with EASA’s certification rules.

Airbus does not trust the use of measured friction coefficients correlated with “effective μ ”; however, landing data based on friction is nevertheless included in FCOM as an alternative method for operators who wish to use it under the oversight of local aviation authorities.

1.7 Norwegian regulations and guidelines for winter operations.

1.7.1 Introduction

The Norwegian regulations and guidelines are based on ICAO’s and JAA/EASA’s recommendations and guidelines for winter operations.

1.7.2 Norwegian regulations relating to winter runway maintenance

- 1.7.2.1 The Norwegian regulations relating to winter maintenance of aerodromes are mainly based on ICAO Annexes 14/15 and JAA/EASA’s rules. Thus, winter preparation, friction measurements and reporting are carried out in accordance with international standards as described in Annexes 14 and 15 and ICAO Doc 9137 AN/898 Airport Services Manual, Part 2, Pavement Surface Conditions, Fourth Edition 2002 (Reference 4), and documented in AIP Norway and in CAR Norway (BSL) E (see Appendix F). Reference is made to the following links: [AIC I 03/08](#), [AIC I 08/09](#), [BSL E 4-1](#), [BSL E 4-2](#) and to AIP Norway AD 1.2, 2. Snow Plan, 28 August 2008 [AIP EN AD 1.2](#).

1.7.3 Meteorological personnel

- 1.7.3.1 During the latter half of the 1950s, the first meteorological consultants specialising in aviation weather services completed their education under the instruction of Aviation Meteorologist Petter Dannevig. The consultants were charged with the task of monitoring weather developments (making observations), among other things by checking that TAFs were in accordance with the weather at all times, as well as the task of monitoring the runway conditions and providing qualified advice to airport personnel and air crews. The consultants were not authorised to issue TAFs, but they could draft TAFs and brief aircraft crews on relevant meteorological conditions.
- 1.7.3.2 The AIBN has found that all Avinor’s meteorological consultants have been made redundant at all airports with the exception of Svalbard Airport Longyear and some of the RNoAF air bases by agreement with the Norwegian Armed Forces. The task of taking observations has been transferred to the air traffic services or automated. Aircraft crews are left with „self-briefing.“

1.7.4 The Norwegian Civil Aviation Administration's⁵¹ requirements for winter operations with DHC-8 on contaminated runways in 1996-97.

Appendices K-1 to K-3 show the Norwegian Civil Aviation Administration's requirements for winter operations with DHC-8 in 1996-97.

Appendix K-1 shows that the Norwegian Civil Aviation Administration's management held that DHC-8 required black runway for winter operations on runways shorter than ICAO recommended standard and friction not lower than equivalent to „wet“.

In its investigations, the Norwegian Civil Aviation Administration considered a „black“ runway to be equivalent to a „wet“ or contaminated runway with measured FC = 0.40 or higher (Reference 15).

Appendix K-2 (the Aeronautical Inspection Department's evaluation) states that:

*„AFM supplement 37 NCAA prescribes what to do when operating on „contaminated runways“. Great emphasis is placed on pointing out that the level of safety is reduced compared with that on black runways.
AFM DHC-8-103 supp. 37 NCAA 6.37.1 d):
„The level of safety is decreased when operating on contaminated runways and therefore every effort should be made to ensure that the runway surface is cleared of any significant contaminate.“
This is also stated in JAR 25 AMJ 25X1591 section 5.1.
An aerodrome must be adequately equipped so that the level of safety can be maintained, including during winter operations. This means that the aerodrome must be equipped so that the standard that forms the basis for the „black runway“ safety assessment can be maintained. Operating at a reduced level of safety as a result of „contaminated runways“ must only take place as an exception.
It should be noted that an acceptable total probability for incidents of the type „low speed overrun, failure to achieve net takeoff flight path etc.“ the consequence of which is „minor damage or possible passenger injuries“ lies in the region of $10^{-5} - 10^{-7}$. If we then accept a probability of „low speed overruns“ alone of 10^{-6} , such an incident, in the case of Widerøe, should only occur on average once every seven years given the current scope of operations (approx. 140,000 takeoffs + landings per year). (Ref. The Aircraft Performance Requirements Manual by R.V. Davies.)
In light of the above, it would seem reasonable to have a target whereby 95% of the operations on an annual basis and no less than 80 % of the operations in any one month should take place on black runways.
The issue of regularity should be considered in light of the above.“*

Appendix K-3 contains instructions to the relevant regions (1996-97) detailing the requirements, which are mainly based on 95 % of annual operations and 80 % of monthly operations taking place on „black“ runways (Reference 15).

⁵¹ On 1 January 2000, the Norwegian Civil Aviation Administration was split into an independent supervisory body – the Civil Aviation Authority of Norway (CAA Norway) – and the Civil Aviation Administration as airport owner and ATC service provider. The Norwegian Civil Aviation Administration was reorganised as a state-owned limited company under the name of Avinor on 1 January 2003.

The results of the Norwegian Civil Aviation Administration's investigations were compared with the Administration's requirements. On an annual basis, none of the aerodromes in the county of Finnmark met the requirements (95 % „black“ runways). It is evident from the Administration's report that the aerodrome of Hammerfest had 43 % „black“ runways ($FC \geq 0.40$) on an annual basis and maximum 63 % on a monthly basis, while the aerodrome of Hasvik had 72 % on an annual basis and maximum 76 % on a monthly basis. None of the aerodromes in the county of Nordland met the requirements on an annual basis, but the aerodromes in Narvik, Mosjøen, Sandnessjøen and Brønnøysund met the requirements during some individual months.

See also Appendix J, chapter 15.3, *„Table of estimated monthly mean number of days with sleet, snow or rain (1994-2009)“* which largely verifies the results of the Norwegian Civil Aviation Administration's investigations.

In comparison, Widerøe had 141,198 aircraft movements in 2009. Hence the probability of runway excursions has not changed since it was estimated by the Norwegian Civil Aviation Administration in 1996-97. Based on the accidents and incidents reported to the AIBN, two (2) cases of excursions were related to slippery runway surfaces in the past decade (see 1.1.4 and 1.1.9). This corresponds to an average of one runway excursion every five years. There were also two reported instances of loss of control after landing on slippery runways under crosswind conditions, but where the crew regained control and prevented excursion.

1.7.5 The Civil Aviation Authority (CAA Norway)'s work relating to winter operations and friction measurements

Based on several reported incidents and the AIBN's immediate recommendations⁵² (conf. 0.3.2) the CAA Norway issued an Aeronautical Information Circular (AIC) on the subject of friction and contaminated runways (AIC I 07/06 20 NOV). In the circular, the CAA Norway prescribed the use of a SNOWTAM table based on three friction categories. The CAA Norway also initiated a process to revise the Norwegian rules relating to measurement and reporting of friction on Norwegian runways (AIP Norway and CAR Norway (BSL) E 4-1 and 4-2).

In a subsequent circular (AIC I 03/08 03 JUL), the CAA Norway reversed position and went back to prescribing the use of a SNOWTAM table with five categories as from the winter season 2008/2009. This was a result of several meetings with three major airlines and Avinor, where AIBN attended as an observer. Two airlines and Avinor claimed that a three category SNOWTAM table would be too restrictive. One airline expressed that *„they could live with“* a three category table. Further, the decision was partly based on an incomplete pilot survey where many pilots were not aware of the ongoing evaluation.

The AIBN has been informed about the fact that the CAA Norway has postponed further revision, but it has not been issued information about a completion date for the Norwegian revision work.

„The Civil Aviation Authority Norway will continue to postpone the amendment of CAR Norway E 4-1, 4-2, and AIP Norway for the time being, because of the work being carried out by ICAO and EASA. A new AIC concerning friction reporting

⁵² The AIBN's letter to the CAA Norway, letter reference 06/362-1.

will be issued to replace the one that is currently in force before the start of the winter season 2009/2010." (The Civil Aviation Authority Norway, 2009)

AIC I 08/09 02 NOV replaced AIC I 03/08, by continuing the practice that was recommended in AIC I 03/08. The CAA Norway recommends that operators use correlation tables. This is in contrast to JAR OPS 1/EU OPS which requires the use of correlations approved by the authorities IEM OPS 1.485(b), (see Appendix C).

„If the performance data has been determined on the basis of measured runway friction coefficient, the operator should use a procedure correlating the measured runway friction coefficient and the effective braking coefficient of friction of the aeroplane type over the required speed range for the existing runway conditions."

The AIBN has not been presented with an overall risk assessment of operations on contaminated and slippery winter runways as the basis for maintaining "an equivalent level of safety" in connection with winter operations in Norway (see 1.5.5.1).

CAA Norway has informed AIBN that there will be no changes to the related Norwegian national regulations before EASA regulations are revised in 2013. CAA-N will be using the time period up to 2012 to review the experience based on AIC 08/09.

CAA-N is awaiting the outcome of the international work in ICAO and EASA before national regulations will be revised. CAA-N is participating in EASA working groups ADR 001 „Requirements for Aerodrome Operator Organisations and Competent Authorities", ADR 002 „Requirements for Aerodrome Operations", and ADR 003 „Requirements for Aerodrome Design". Collectively, these working groups are proposing the basis for new EASA regulations for airport layouts and operations, including winter operations and runway friction.

1.8 International and national research and test programmes

1.8.1 Introduction

This section refers to a selection of historical milestones and test programmes. The AIBN has collected documentation and information about test programmes relating to winter operations and friction measurements that span a period of 60 years. These test programmes have mainly aimed at finding better methods of measuring friction and developing new friction measuring devices.

1.8.2 Some international research and test programmes, reports and protocols relating to winter operations

Appendix I is a paper on landing on slippery runways by P. Giesman, Boeing. It is a paper covering operations with jet aircraft on slippery runways in general and Boeing aircraft in particular (attached with permission from Boeing). The paper includes FAA SAFO 06012.

Appendix J is a comprehensive document on micro meteorology and its influences on aircraft braking on runways contaminated by frozen water, by R. Mook, PhD. Reference is made to chapter 04 which explains why it is difficult to measure friction on contaminated runways.

Appendix L shows the historical development of the ICAO SNOWTAM table.

Appendix M shows some of the protocols from international work on friction measurements.

Appendix N shows Kollerud's report on friction measurements from Fornebu in 1954.

Appendix Q shows the historic development of friction measurements.

Appendix R shows an historic FAA NPRM 63-28 discussion paper about the requirement for landing distances for turbojets be scheduled with a factor of 0.5 when the runways at the airport of destination are apt to be wet (visible moisture) or icy. The landing runway length for dry runways would continue to be based on the 0.6 factor (1963).

Appendix S shows an historic FAA discussion paper on certification and operations of large turbojet transport aircraft operating on wet and slippery runways (1965).

Appendix T shows FAA Advisory Circular 91-6 advising airlines not to take off when standing water, slush or wet snow greater than 0.5 inch in depth covers an appreciable part of the runway. Further, the AC advises the airlines to add a 15 % correction factor to the clean, dry runway requirements (1965).

Appendix U shows FAA Advisory Circular 121-12 with advisory information for operations with large aircraft on Wet or Slippery Runways (1967).

Appendix V shows a Technical Report on Tire-Pavement Friction Coefficients from US Naval Civil Engineering Laboratory (1970). The report describes the challenges of measuring and correlating friction values on wet and contaminated runway surfaces (1970).

Appendix W shows an FAA Study of Normal Operational Landing Performance on Subsonic, Civil, and Narrow-Body Jet Aircraft during Instrument Landing System Approaches (2007). Figures 9 and 10 in the report shows the spread in threshold crossing heights, flare and touch down during routine landings. The landing data indicate the spread of touch down points which influences the braking distances on dry as well as on wet and contaminated runways. The difference is the lower friction and margins during winter operations.

Appendix X shows the FAA Order 1110.149 Takeoff/Landing Performance Assessment Aviation Rulemaking Committee (2007). The order established the mandate for the FAA TALPA Rule Making Committee.

Appendix Y shows the TALPA ARC recommendations (2009). The TALPA ARC recommended use of a matrix describing contamination types with the associated runway friction and braking conditions. At the end of Appendix Y is an updated version of the TALPA ARC matrix with associated ranges of friction coefficients (FC, μ , μ_u). It shows that these ranges of FC are approximately comparable to ICAO SNOWTAM table values of GOOD, MEDIUM and POOR.

Appendix Z shows the NTSB staff comments on the AIBN draft report on *Winter Operations, Friction Measurements and Conditions for Friction Predictions*. The letter is attached with permission from NTSB staff and describes common views on the present practice and challenges related to winter operations. In the letter NTSB staff is listing six

Safety Recommendations to FAA which reflects some of the AIBN Safety Recommendations listed under chapter 1.1 in this report. From the NTSB letter is quoted:

„During the Public Hearing for this accident⁵³, the NTSB had several witnesses from the research and operational communities detail the inconsistencies in runway measurement techniques, and the lack of any verifiable correlation to airplane braking coefficient, echoing the concern expressed in the AIBN”s report.

Many of the concerns expressed in the NTSB”s report on that accident are echoed in this comprehensive report examining these 30 incidents in Norway. Based on the Safety Board”s work during and since that accident investigation, the Safety Board supports the conclusions presented in the draft report regarding the inconsistencies and weak correlation of contaminated runway friction measurements to airplane braking coefficients. The NTSB staff firmly supports the publication of this report in its entirety, for the factual data, analysis and conclusions detail the current regulatory and operational factors that act to reduce the safety margins when operating on contaminated and slippery runways. This compilation will provide the various regulatory agencies a comprehensive framework for further research and regulation development to increase the safety margins for winter operations. The Safety Board staff appreciates the opportunity to review and comment on this report.”

Reference 23 show a study of runway excursions in Europe. It shows that wet or contaminated runway was a causal factor in 58.8 % of landing overruns and that the risk of a landing overrun is 13 times higher on a wet or contaminated runway than on a dry runway. From the report is quoted:

*„The most important factor identified is the condition of the runway being wet/contaminated⁵⁴. Such runway conditions are related to a reduction in braking friction between the aircraft tires and the runway compared to a dry runway. Whenever the runway condition wet/contaminated was identified as a factor in an excursion, it was related to a reduction in the runway friction levels. The runway condition (wet/contaminated) itself is not necessarily a causal factor. For instance on a runway with excellent macro- and microtexture⁵⁵, the friction levels can be relatively high even if the runway is wet. The analysed data showed that such occurrences were not limited to airports where wet/contaminated runways operations occurred frequently. Worldwide approximately 10 % of all landings are conducted on a wet/contaminated runway [Van Es, (2005)]. That means that the risk ratio is 13; **hence the risk of a landing overrun is about 13 times higher on a wet/contaminated runway than on a dry runway** (highlighted by AIBN). Crews aware of adverse runway conditions normally account for it when assessing the actual required landing distance.*

⁵³ The transcript for the Public Hearing on the SouthWest Airlines accident are available in the Public Docket on the NTSB website at <http://www.nts.gov>.

⁵⁴ Contaminated runway: A runway completely or partly covered with standing water (more than 3 mm), slush, snow (wet, dry), ice or a combination of these conditions. A runway is considered to be contaminated from a performance point of view if the percentage of the portion intended to be used exceed 25%. However, reporting of contamination could occur before this threshold is reached as is known from operational experience.

⁵⁵ The macrotexture encompasses the large-scale roughness of the surface whereas the microtexture is concerned with the sharpness of the fine grain particles on the individual stone particles of the surface.

Currently only those operators that fly according to EU-OPS are required to conduct an in-flight assessment of the landing distance using information contained in the operations manual⁵⁶.

This assessment should be conducted before commencing an approach to land (see EU-OPS 1.400). This assessment is required to ensure that the landing distance available is sufficient for the specific aircraft, and under the present weather and runway conditions at the airport, to make a safe landing."

Reference 24 shows an Australian Transport Safety Board (ATSB) report on runway excursions. Part 1 is describing the runway excursions and cause factors, while Part 2: describes recommended actions to minimise the likelihood and consequences of runway excursions.

Of other international work relating to winter operations, the following are worth referring to:

- 1950. The Kollerud method approved in Norway
- 1955. ICAO Circular 43-AN/38, which included the Kollerud method
- 1959 Today's SNOWTAM table was developed based upon tests at Bromma airport in cooperation with the Nordic Countries and Scandinavian Airlines⁵⁷
- 1964. ICAO-SNOWTAM format was developed
- 1967 ICAO-SNOWTAM format and specifications for Snowplan was adopted
- 1976. FFA BV-11 correlation trials with aircraft in Sweden
- 1987. ICAO working paper AN-WP/6081 – Runway braking action
- 1992. Dryden Report
- 1992-2000. Transport Canada/Boeing/ICAO Trials with friction measuring equipment and braking trials with aircraft
- 1995-2004. Joint Winter Runway Friction Measurement Program (JWRFMP)

1.8.3 Joint Winter Runway Friction Measurement Program (JWRFMP, Reference 10)

One important test programme was the Joint Winter Runway Friction Measurement Program (JWRFMP) carried out in Canada with the participation of several countries, including Norway. One of the objectives of this programme was the development of an

⁵⁶ FAA recently published Safety Alerts for Operators (SAFO), entitled "Landing Performance Assessments at Time of Arrival (Turbojets)", The FAA urgently recommends that operators of turbojet airplanes develop procedures for light crews to assess landing performance based on conditions actually existing at time of arrival, as distinct from conditions presumed at time of dispatch. Those conditions include weather, runway conditions, the airplane's weight, and braking systems to be used. Once the actual landing distance is determined an additional safety margin of at least 15 % should be added to that distance.

⁵⁷ The table was developed at an Inter-Nordic Meeting in Stockholm, 13–14 October 1959. (Finland, Denmark, Norway and Sweden).

- Skiddometer BV-11 (SKH) Tests at Oslo Fornebu from 1969 – in use from 1972.
- SAAB Surface Friction Tester Modified electronics/measuring wheel 1973. SFT in use with high pressure tyre 1976 (SFH).
- Tests with SKH, SFT and F-5B Tests at Kjeller Air Base with high pressure tyre 1978. (Reference 18).
- Griptester (GRT) Tested during 1994 and introduced later.

1.8.5 Kollerud trials

In 1949 O. Kollerud, airport manager at Oslo Airport Fornebu, started friction testing on snow and ice-covered runways, using a decelerometer mounted in a truck to measure the deceleration of the vehicle. Tests with accelerometers were complemented by tests to measure stopping distances and stopping times. The results were correlated with similar measurements in aircraft such as DC-4, and later extended to DC-6 and DC-6B.

In the ICAO Circular 43-AN/38 *Ice and Snow on Runways, Attachment B*, we find the *Report on the procedure for correction of minimum runway length under winter conditions at Oslo Airport Fornebu, by O. Kollerud, Airport Manager Fornebu, March 1954.* (Appendix N).

1.8.5.1 *General results*

Kollerud concluded that the effective braking action for the aircraft was found to be half the braking action measured for the vehicles during the tests.

- *Aircraft $\mu = 0.5$ Measured μ ⁵⁹.*
- *On snow and ice covered runways the braking effect varies from about 1,5 - 3,5 m/s² (FC = 0.15 - 0.30)⁶⁰.*

Braking effect 1.5 – 2.0 m/s² (FC = 0.15 - 0.20)

1. *Slush or rain on snow or ice covered runways*
2. *Change from frost to temperatures above zero*
3. *Change from mild to frost (not always)*
4. *The type of ice which is formed after long periods of cold*

⁵⁹ Kollerud used the expression “retardation”. ”These tests showed that by comparing the braking of the lorry and aircraft with the wheels skidding (to a full stop), the retardation of the aircraft was below half of the lorry.” This rule of thumb became generally accepted.

⁶⁰ AIBN has related the retardation (“a”) to “ μ ” according to the following relationship $a = \mu \cdot g$, $\mu = a/g$, e.g. $\mu = 2.00 \text{ m/s}^2 / 9.81 \text{ m/s}^2 = 0.20$. For the Full-Stop-Method Kollerud developed a correlation chart where RC=2.0 related to FC= 0.22 (Poor), RC=2.5 related to FC= 0.27 (Medium) and RC=3.3 related to FC= 0.42 (Good). Hence, the Kollerud FC (μ) are higher than the AIBN computed for the same RC.

5. *A thin layer of ice formed by frozen ground having been exposed to humidity or rain at zero degrees C or above*

Braking effect 2.0 - 2.5 (FC = 0.20 - 0.22)

6. *Snow conditions at temperatures just under zero*
7. *Snow covered runways at temperatures under zero, exposed to sun*

Braking effect 2.5 - 3.5 (FC = 0.22 - 0.35)

8. *Snow covered runways which have not been exposed to higher temperatures than about minus 2 - 4°C*

This classification is only meant as a guide based on our own experience and it must not be used for establishing the requirements for the braking effect. There are so many variations in runway conditions that each condition must be measured to be able to judge the braking possibilities. This classification has been included to give those who work with the problem an impression of what the figures which we give as braking effect represent with regard to the runway conditions."

1.8.6 Scandinavian trial project „Slippery Runways/Hala banor“

This was a Scandinavian trial involving the CAAs of Norway and Sweden and Scandinavian Airline Systems during the winter seasons of 1972-75 (Reference 14). The results showed large differences between the pilots' experienced braking action (airplane braking coefficient - ABC) and measured FC. The project report concluded that the differences were mainly caused by:

- The lapse of time between conducting the measurements and landing.
- Runways with smooth macro/micro textures.
- Use of Tapley meters on runways with snow, slush and hoar frost.
- Precipitation in the form of snow, super-cooled rain and hail at runway surface temperatures of just below zero °C.
- Short runways in combination with precipitation and low visibility⁶¹.

1.8.7 SWOP

The Safe Winter Operations Project (SWOP) was a contaminated runway friction research programme initiated and performed by Avinor during the period 2003-2008 (Reference 12). The objective was to look for correlation between measured meteorological conditions like precipitation, humidity, temperatures and experienced aircraft braking effects. A „weather model“ was developed as a basis for defining certain contamination scenarios. The data was compared to measured aircraft braking deceleration.

⁶¹ A perceived psychological reaction from pilots landing on short runways in low visibility.

The analysed results indicated a certain correlation between the „weather model“ and aircraft deceleration. It was concluded that the concept was worth developing further in a new research programme designated IRIS.

1.8.8 IRIS

The Integrated Runway Information System (IRIS) is based on the SWOP programme. The programme was initiated in 2008-2009 and is still ongoing.

The Project Status Report of 22 October 2009 (Reference 13) states:

„The objective of the project was to develop a system capable of assessing, predicting and communicating to the flight crew meaningful information relating to braking action in order to ensure that in-flight, landing and takeoff operations can be conducted with an appropriate margin of safety.

The campaign (IRIS and preceding work) has over the years collected substantial meteorological and runway condition data as well as flight data recorder information – and based on this – developed a link between prevailing weather conditions, type and degree of winter contamination and resulting runway braking action.

In addition to raising awareness of the challenge at hand, the IRIS project has developed a prototype tool for gathering and presenting runway and weather conditions to ground service personnel in real time. The tool consists of three parts:

- **Weather module** that alerts ground service personnel of potentially slippery runway due to changing weather conditions
- **Runway module**, which is a support tool related to the reporting of prevailing runway conditions
- **Weather information** (runway surface condition, air and dew point temperatures, precipitation, wind and radar images)

*In addition, and through most valuable support from flight operations experts at The Boeing Company in Seattle, the project has developed an **Aircraft module** which enables comparison of reported runway surface friction values against flight data recorder information from thousands of actual landings at Oslo Airport Gardermoen and Tromsø Airport Langnes.*

This development represents a breakthrough in regards to understanding how an aircraft „experiences“ actual frictional conditions on the runway during landing.

The development of a useful tool for ground service personnel has come a long way, but still needs further development and adjustments. It is therefore recommended that the work is continued in order to take the prototype tool through testing, commissioning and finally, certification for operational use.

The project has enjoyed considerable internal and external interest, including the major Norwegian airlines (SAS, Norwegian, Wideroe), the Norwegian Civil Aviation Authority, the Norwegian Accident Investigation Board and the Norwegian Air Force. The mentioned stakeholders express that they both hope and expect that Avinor will continue this important work to support safety of flight operations on contaminated runways."

The IRIS system has been evaluated and further developed over two winter seasons. The „weather model“ has been refined and a new „runway model“ has been developed and broken down into a number of contaminated runway scenarios. The two models were then correlated with an „aircraft model“ with actual braking data from landing aircraft. The analysed data indicated promising correlation results. Based on the positive results Avinor has decided to implement and develop the concept further in 2010-2011.

Figure 19 show measured ABCs from B737 during the IRIS program. It shows the spread in ABC in the ranges of GOOD ($ABC \geq 0.20$), MEDIUM ($ABC 0.10 - 0.19$) and POOR ($ABC < 0.10$) under wet or moist conditions..

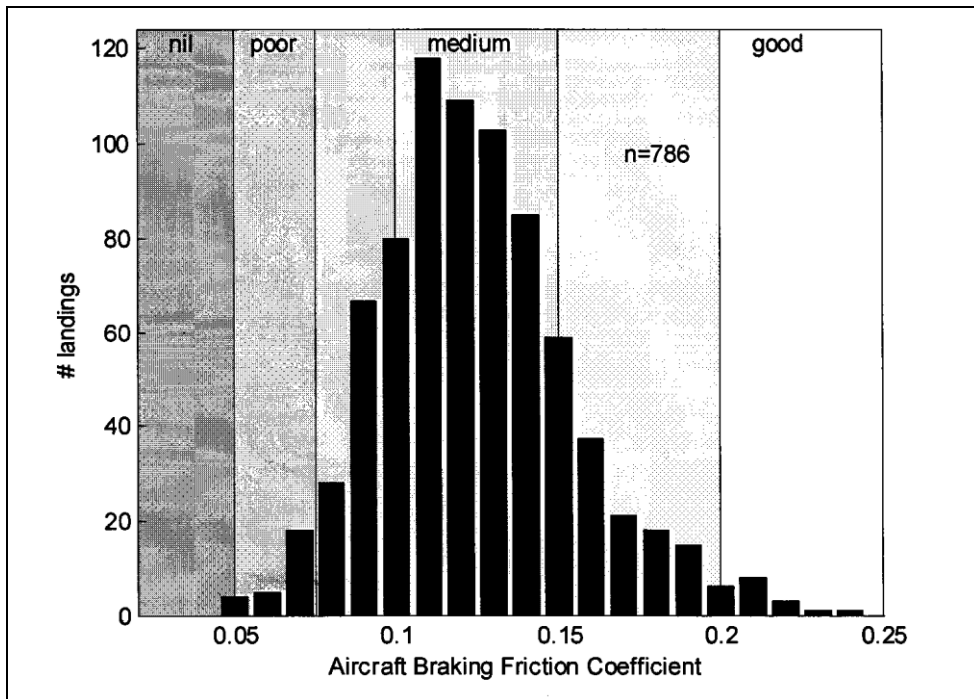


Figure 19: Aircraft Braking Coefficient measured under wet or moist conditions including Dew Point Spread ≤ 3 K.

1.8.9 Research project, Alex Klein-Paste, Norwegian University of Science and Technology (NTNU) 2007

The following is an excerpt from the report's summary and conclusions (Reference 17):

'Runway operability

The development of runway surface conditions in time and the consequences for the operability of the airport was investigated. Different situations were documented where the runway surface conditions changed due to snow fall, sand displacement by aircraft, ice deposition, snow compaction, and melting of the contamination layer. The main conclusion of the study is:

- *Practical constrains, such as time required for friction measurements and necessary clearance procedures to enter the runway, restrict the inspection frequency of the runway surface conditions. It therefore largely depends on the alertness and monitoring skills of maintenance personnel how quickly significant changes are detected, reported, or counteracted.*

- *There are currently limited possibilities to monitor runway surface conditions while the runway is open for air traffic. This hampers the objective to accurately report the actual surface conditions because significant changes cannot always be immediately detected.*

Warm, prewetted sanding

Wetting sand with hot water before its application on pavement provides new possibilities to improve pavement surface conditions. Lumps of sand freeze onto the pavement, creating a sand paper-like surface. This method is particularly interesting for airside applications because it provides a solution for the problem that loose sand is blown off the runway by the engine thrust of operating aircraft. The field studies identified the following operational aspects:

- *Proper cleaning the pavement prior to the application has been pointed out as an important requirement to avoid Foreign Object Damage. The application on thick, weakly bonded snow may cause the lumps to break loose in one piece, rather than disintegrating into individual sand particles.*
- *The high friction values that are typically measured on surfaces treated with warm pre-wetted sand can create a too optimistic picture of the prevailing conditions for aircraft. Cases are documented where pilots faced worse conditions than they expected from the provided friction numbers. In 66 % of the cases there were clear indications available that the situation was not as good as suggested by the friction measurements.*
- *The sand particles become bonded to the pavement as the added water freezes. However, observations showed that particles can break loose under the action of aircraft tires. Particles do also loosen as a result of ice sublimation.*

Tire-pavement friction on ice contaminated pavements

The level of friction that can be created between tire and pavement is determined by the whole interaction between the tire, the pavement, the contamination layer, and the atmosphere in which the interaction takes place. The presence of sand particles changes this interaction; it changes the way friction is generated. The total interaction takes place at different length scales.

Macroscopic observations of the tire-pavement interactions showed that:

- *Loose sand particles that enter the contact area can slide together with the rubber tread and plough into the ice layer.*
- *Loose sand particles can pile-up in front of, and under, locked tires (full skid)*
- *Tire lockups can occur in operational situations at low ground speed because aircraft anti-skid braking systems become disabled below a certain threshold speed (typically ranges between 30 and 45 Km/h, depending on the aircraft type).*
- *On freeze bonded sand, friction is provided by both loose particle interaction and fixed particle interaction.*

Microscopic observations by etching and replacing ice surfaces after the interaction revealed that:

- *Both rubber-ice and sand-ice sliding friction involved ice deformation as a mechanism of friction.*
- *During rubber-ice sliding friction, the original crystal structure of the ice remained intact during the interaction. However, small scale ice deformation was evident by the formation of dislocations, aligned in rows along the sliding direction.*
- *The ploughing of sand particles into the ice layer was accompanied by the formation of cells within the original crystal structure. This re-crystallization was observed both in the laboratory and in the field.*

The friction mechanisms occurring during rubber-ice and sand-ice sliding friction was investigated with a British Pendulum Tester in a cold laboratory. The experiments showed that:

- *The observed variability in friction measurements was significantly larger than the uncertainties introduced by the instrument itself. The variability may be caused by poorly controllable/reproducible, microscopic or nanoscopic surface properties of the ice and rubber.*
- *All friction measurements of rubber-ice friction at ice temperatures below -5 °C were about $\mu = 0.2$. However, the presence of less than 1 mm snow on the ice surface reduced the friction level dramatically; down to $\mu = 0.05$, even at temperatures below -20 °C. These low friction levels were in the range of the measurements on ice at 0 °C that was wetted by its own melt. It demonstrates that friction provided by rubber-ice interaction is very vulnerable to snow contamination.*
- *The sand-ice friction measurements did not show the dramatic drop in friction level by the presence of the same amount of snow (less than 1 mm). It demonstrates that friction provided by relatively large particles ploughing into the ice is more robust, compared to rubber-ice friction mechanisms.*

Concluding remark on winter maintenance at airports

Within winter maintenance at airports there is a large focus on the pavement's ability to provide friction to aircraft (shortly, the friction level of the surface conditions). This focus is also reflected in regulations, procedures, and in the public literature on tire-pavement friction or winter maintenance. Hence the common view is that „good“ surface conditions are surface conditions with a high friction level. Clearly, aircraft need tire-pavement friction for retardation and directional control. Hence, for pilots, a high friction level is indeed desirable.

But what kind of surface conditions do maintenance personnel need? Is a high friction level also desirable for them? Or are there also other quality factors that determine how good the surface conditions are for them? Any activity on a runway, whether it is a quick inspection, snow removal, or the application of sand

or chemicals, takes time. During this time runway is temporary closed for air traffic. As soon as the runway re-opens, (and pilots are updated with the latest information on the runway status), a period starts where there are currently little options but to trust that the surface holds its ability to provide friction. How long the surface conditions can be trusted upon depends on the local weather and traffic situation at the airport. But it depends also on the surface conditions itself. The surface conditions can have a high friction level, but may be very vulnerable to lose the ability to provide friction. A rapid deterioration of the surface conditions is difficult to detect due to the outlined practical constraints. Hence, for maintenance personnel, robust surface conditions are desirable."

1.8.10 International agreements

In 1959⁶², when the Nordic countries Finland, Sweden, Denmark and Norway agreed to use a standardised device, they chose a decelerometer of the type Tapley meter. However, there was a belief that more accurate and reliable results could be obtained by using a different measuring principle.

Representatives from Sweden⁶³ participated at the seventh session of the ICAO, Aerodromes, Air Routes and Ground Aids Division in 1962⁶⁴. Two of these representatives became central in the further development of friction measuring devices, procedures and regulations. From the report:

„One State reported that a vehicle had been developed which provided the incipient skidding friction coefficient in a graphical form with an accuracy of 0.01 and required a short runway occupancy time."

However, another state experienced that the use of different principles gave different results when measuring under the same surface conditions and the need for correlation and harmonization arose. Various states introduced new friction measuring devices of different makes and used them operationally with the best of intentions.

When Canada in 1970⁶⁵ introduced the use of friction measuring device, they chose the *James Brake Decelerometer*. Transport Canada developed the Kollerud method further⁶⁶ and the James Brake Index (JBI) tables were renamed the Canadian Runway Friction Index (CRFI) tables. These were further developed based on the findings of the JWRFP.

Based on the JWRFP findings⁶⁷ the „aircraft μ “ regardless of aircraft type, was plotted against the CRFI and it was found that the CRFI value could be used to predict the minimum aircraft braking coefficient (in general terms) using the equation: $MuR = 0.02 + 0.40 CRFI$.

⁶² Inter-Nordic meeting, Stockholm, 13 and 14 October, 1959.

⁶³ J. Wessel (Delegate), G. Antvik (Alternate), J-O Ohlson (Alternate), G. Kullberg (Advisor).

⁶⁴ ICAO Doc 8298-AGA/593, Aerodromes, Air Routes and Ground Aids Division, Report of the seventh session, Montreal, 13 November–14 December 1962.

⁶⁵ Department of Transport, Air Services, Civil Aviation Branch, Aerodromes, Information Circular 0/6/70, 23rd February–Use of James Brake Decelerometer.

⁶⁶ Transport Canada, Commercial and Business Aviation Advisory Circular No. 0164, 1999.11.03–Canadian Runway Friction Index.

⁶⁷ TP 13943E - Evaluation of Aircraft Braking Performance On Winter Contaminated Runways and Prediction of Aircraft Landing Distance Using the Canadian Runway Friction Index, June 2002.

The “recommended” aircraft braking coefficient, MuR^{68} , must be used in the equation for stopping distance, and is limited by a conservative maximum value of 0.34 on a bare and dry surface ($\text{CRFI} = 0.80$) and a minimum value (rolling resistance) of 0.02 on a surface with NIL braking action ($\text{CRFI} = 0.00$).

⁶⁸ $\text{MuR} = \text{Mu}_{\text{ac}} = \text{aircraft } \mu = \text{airplane braking coefficient}$.

2. ANALYSIS

2.1 Introduction

The findings of AIBN in its investigations relating to slippery winter runways and the related safety recommendations are described in section 1.1. The AIBN would like to stress the importance of understanding how such accidents and incidents can occur despite extensive international and national regulations. The AIBN believes that the rules and regulations may be so extensive that it is difficult to relate to. At the same time, pilots are given very little reliable factual guidance. Most regulations related to landing on contaminated and slippery runways are general guidelines and recommendations. The manufacturers landing performance data is not certified, but only advisory. In spite of this the data is used in exact landing performance computers giving the pilots a false impression of safety. It is left to the airline's and pilot's airmanship to add any safety factors. It follows that when there is a mishap the air crew are the first to blame, followed by the airline. Though airport staff and pilots do their best in their respective areas of knowledge and training based on their understanding of the rules, undesirable incidents still occur. At the same time, through interviews, observations and investigations, the AIBN has found that there is insufficient general knowledge about friction and limitations relating to the use of measuring devices and measuring techniques among air crews and ground staff.

The AIBN believes that incidents relating to contaminated runways are not the result of non-compliance with rules and procedures among the personnel in charge. They occur because the framework is based on very simplified physical conditions which are not necessarily scientifically founded, in addition to the existing rules and regulations being fragmented and not readily accessible. This analysis will discuss these matters in greater detail.

The aircraft crews seem to be as conscientious in their compliance with rules and procedures in connection with winter operations as they are in connection with summer operations. They are operating the same types of aircraft into the same airports and, in many cases, in accordance with the same timetables. The differences in operational conditions mainly relate to more challenging meteorological conditions such as poor lighting conditions and reduced visibility, higher air density, stronger and more gusty winds combined with contaminated and slippery winter runways.

The most important difference between summer and winter operations is the runway status and friction. The certified aircraft landing data are based on certification testing on bare and dry runways, using maximum manual braking and without use of the engine thrust reversers, with a safety factor of 1.67. For wet and contaminated runways the certified data are based on an additional safety factor of 1.15. These data are used as „dispatch data“ for planning purposes before departure and are meant to cover operational deviations during normal operations. For operational landing data it is approved to use reported runway status and uncertain friction data as basis for actual landing calculations, with autobrake, use of reverse thrust and no regulated safety factor. The regulations state that considerations must be given to engine (reverser) failure during landing, but this regulation is not enforced. This may indicate that the safety margins during winter conditions with contaminated and slippery runways are lower than during summer conditions, even though the operational deviations are the same. In this regard AIBN

refers to the EU/JAR OPS requirements and conditions for maintaining an “equivalent level of safety” during operations on contaminated and slippery runways.

2.2 Analysis of findings from 30 incidents and accidents

2.2.1 Introduction

In all the 30 incidents/accidents reported, the runways were slippery as a result of contamination in the form of dry or wet snow or ice. In most cases, runway friction (FC) was measured using approved measuring devices within the validity ranges, and considered to be satisfactory (MEDIUM or GOOD in the ICAO SNOWTAM table). The AIBN believes this is an indication of the high level of uncertainty that attaches to the stated measured friction values. It also indicates that there are differences between measured friction values and „aircraft μ “. The SNOWTAM table does not take into account these uncertainties. The many incidents/accidents linked to contaminated runways also suggest there is a safety potential in the use of friction-improving measures on runways. The AIBN’s findings also show that many of the incidents/accidents occurred where compact snow or ice was covered by a loose layer of slush or wet/dry snow (12 of 30 occurrences), and where there was wet/moist contamination (19 of 30 occurrences) and/or where the temperature-dew point spread was 3 K or less (21 of 30 occurrences). This is an indication that under certain conditions, the gap between measured friction values and „aircraft μ “ may be particularly wide. It should be noted that friction measurements under such conditions are particularly uncertain and that the assessment of runway conditions should rely less on friction measurements and more on safety indicators.

What is basic and essential, uncertain friction coefficients are reported to flight crews to an accuracy/uncertainty of hundredths (not in compliance with AIP Norway AD 1.2 which describe that an accuracy/uncertainty only in tenths can be of operational value). The flight crews use these uncertain friction coefficients in their landing calculations as input in their cockpit performance computer (CPC). Furthermore, crosswind conditions, which have a major impact on directional stability during the landing roll, is also a factor in the landing calculations. The fact that 19 of the 30 reported incidents/accidents occurred in strong crosswind conditions in combination with slippery runways, suggests that the landing calculations are not always reliable in this kind of operational situation. This might relate to the formulas/correlations/algorithms on which the calculations are based. It might also relate to the quality of the input wind data as well as the friction values used in the calculations. In five cases of strong crosswind conditions, the AIBN found that the flight crews based their landing calculations on instantaneous wind reports from TWR (average 30 seconds or 2-minute wind speed) and not on the most relevant METAR/ATIS wind speed (average 10-minutes wind speed). Another factor that further reduces the safety margins and increases the risk of losing control of the aircraft is the preparation of winter runways to a reduced width.

On the basis of these findings from the reported incidents/accidents, the AIBN decided to analyse the following:

- Friction conditions that result in gaps between measured friction values and „aircraft μ “ or „airplane braking coefficient“ (ABC)
- Friction-improving measures

- Validity ranges for friction measuring devices
- Friction measurements and uncertainty
- Correlation between various friction measuring devices and between friction coefficients and aircraft braking coefficients
- Crosswind conditions in combination with slippery runways
- Operational use of wind data in landing calculations
- Operational use of cockpit performance computers (CPC)
- The airport owner's (Avinor) friction measurement procedures
- Winter-prepared runways with reduced width

2.2.2 Friction conditions that result in gaps between measured friction values and „aircraft μ “

The AIBN's investigations of several incidents and accidents on contaminated runways show the gap between measured friction values (FC) and „aircraft μ “ or ABC (braking action) can be particularly great under the following conditions:

- Moist contamination in the form of compact snow or ice
- Sanded runway with sand on top of loose slush, wet or dry snow, or on moist ice/moist compact snow
- Moist contamination in the form of slush, wet or “dry” snow, compact snow or ice, with a measured temperature-dew point spread of ≤ 3 K
- Sanded runway covered by compacted dry snow or dry ice at below-zero temperatures down to minus 17 °C when the measured temperature-dew point spread is ≤ 3 K in strong crosswind conditions.

The investigation results show that moisture in combination with frozen water in the form of „dry” snow, compacted snow or ice has a more significant influence on „slipperiness” that previously understood (see Appendix J, chapters 02, 03, 04, 06, 09, and 12).

2.2.2.1 *Friction conditions on moist, compact snow or ice, and on sanded, loose, dry or moist contamination*

The use of friction meters on moist, compacted snow or ice, or on sanded, loose, dry or moist snow, measure higher friction values than can be achieved by the aircraft tyres. The pressure of the aircraft tyres will cause floating grains of sand in the water, or in the loose material on top of the compact material, to be pushed aside. A similar effect is achieved with sand in loose material on top of compact ice or snow when the temperature is above zero. An important factor in this connection is that the aircraft wheels exert much more pressure towards the ground than the friction measuring devices do.

Friction conditions on wet or moist contaminations seem to be very unpredictable. AIBN findings show that under certain conditions of temperature and moisture, friction measuring devices may measure friction coefficient in the MEDIUM or GOOD ranges

while the aircraft braking coefficient has been proved to be in the order of POOR (see 2.2.2.3). For a better understanding of the difficulty of measuring and prediction of the friction on the above mentioned types of contaminations it is recommended to study the Appendix J, chapters 02, 04 and 12.

2.2.2.2 *Friction conditions on sanded compact frozen snow or ice in strong crosswind and humid air conditions*

The investigations show that what normally could be regarded as good winter conditions can result in an extra slippery runway if the temperature-dew point spread is ≤ 3 K and there is a strong crosswind (see 1.3.6). This was the case when 19 of the 30 reported incidents / accidents occurred. It was also found that blizzards / ice particles can polish the snow and ice to make it more slippery, and leave a thin film under the aircraft tyres which could cause them to plane (see Appendix J, Chapter 11). This was the case when three of the incidents occurred. This is considered to be new knowledge about friction conditions relating to compacted snow, high air humidity, temperatures below zero and strong crosswind conditions. These matters can be misleading for both ground staff and flight crews. The reasons for uncertainties of friction measurements and predictions on these types of contaminations are described in Appendix J, chapters 02, 04, 07, 10 and 11.

2.2.2.3 *Friction conditions related to temperature and humidity/moisture*

The findings show that, in connection with friction measurements, reporting or with operational use of friction values, little attention is generally paid to temperatures, dew points (DP), air humidity and contaminant moisture. The AIBN found that in 21 of 30 occurrences (see 1.2.3) the spread between the air and dew point temperature as measured at 2 m above the runway surface (METAR), was ≤ 3 K. This is known as the „3-Kelvin-Spread-Rule“ (See 1.3.2 and Appendix J, chapter 09). The findings indicate that the braking action was POOR under such conditions.

In combination with runway reports, TAFs and METARs provide good indications relating to potentially slippery runways. Even though the METAR temperatures are measured two meters above the runway and therefore can deviate from the values immediately above the runway surface, they provide an indication of how slippery the runway might be. At surface temperatures of less than minus 9 °C, the difference between the dew point (DP) and the frost point (FP) will be more than 1 K. This is due to the fact that the saturation vapour pressure is lower above ice compared to over liquid water (see Appendix J, chapter 04). Therefore the FP above ice is higher (warmer) than the DP above water. This means that hoar frost may form even though the temperature-dew point spread as measured 2 m above the runway surface exceeds 3 K (see Appendix J, chapter 15.2 Frost point temperature). Infrared temperature and dew point measurements immediately above the contaminated layer on the runway may be a technique on which more accurate notification of hoar frost can be based in the future.

A small air temperature-dew point spread is an indication of high air humidity and hence the water contents of any snow. It should be made generally known that wet snow or slush result in poor friction. The findings also show that slippery conditions can be expected on contamination exposed to rain, or rain and snow showers, even if the measured friction values are in the order of 0.30-0.40 (30–40). For a deeper understanding of the challenges of measuring and predicting the correct aircraft friction

with these types of contaminations reference is made to Appendix J, chapters 02, 04 and 09.

With decreasing temperature, the frictional properties of ice or compacted snow improve considerable. At $-30\text{ }^{\circ}\text{C}$ the aircraft braking coefficient on pure ice may be as good as in cases with icebound sand. Therefore, at temperatures below $-15\text{ }^{\circ}\text{C}$, the 3 K-spread-rule may lose its practical meaning in dry and near calm weather. However, in the case of precipitation including debris from blowing snow, improved frictional properties cannot be expected due to an intermediate layer of loose frozen material. Very slippery conditions may prevail at ice or snow exposed to the polishing effect of blown particles of ice, especially at low temperatures.

2.2.2.4 *Safety indicators to evaluate friction conditions*

Based on the results of the AIBN's own investigations, it is believed that the measured friction coefficient should be considered (interpreted) in combination with the safety indicators; temperature, dew point or frost point, precipitation and the development of these parameters over time (weather history, see 1.2.3).

2.2.3 Friction-improving measures

2.2.3.1 *Sanding/gritting*

The AIBN has not found scientific basis for spreading loose sand on contaminated runways. It has not been the subject of separate approval by the authorities. It appears that current practice has mainly been developed on the basis of local trial and error and the experience at the various airports.

ICAO Airport Services Manual, Part 2 Pavement Surface Conditions, Chapter 7, contains a simple description of the use of sand on contaminated runways. However, nothing is stated about expected braking action associated with the use of different sand fractions or with the method of application on different types of contamination and at different temperatures. It has not been found that the aviation authorities have issued any specific regulated requirements relating to the use of sand over and above the guidance in the ICAO Doc 9137, Airport Services Manual, Part 2, Pavement Surface Conditions. AIBN is aware of that some research was performed in Canada as part of the JWRFMP and that Transport Canada has issued some guidance, but has not seen any national or international regulations regarding use of sand on runways.

The investigations show that sanding on wet and compact snow or ice, and sanding of loose layers of material in the form of slush, wet or dry snow on top of compact snow or ice, is not very effective. It has also been documented that friction measuring devices measure friction values that are too high when used on such surfaces (see 1.2.3 and 1.3.9.1). The AIBN's findings reveal that, under such conditions, the gap between measured friction and actual „aircraft μ “ becomes particularly wide. Reference is made to 1.8.9 which describes some research results regarding sanding of contaminated runways, and Appendix J, chapter 07 which describe the physical significance of sand on frozen contaminations.

2.2.3.2 *Chemicals*

It was found that the effect and use of chemicals are not adequately documented or regulated, with the exception of the environmental aspect. One challenge related to the use of chemicals is that when they melt the snow and ice, they cause the contamination to become wet or moist. Hence friction will be poorer until the melting process is completed. Attempts at sanding during the melting phase, can cause the sand in front of the wheels to be washed away. In addition, water from melted snow and ice can dilute the chemical liquid, so that it may freeze and become hard, often forming a clear ice ("black ice") in the process. This could lead to friction becoming poorer than it was before the chemical was applied, and it could also create difficulties in that any ice formation may be very difficult to discover. If the chemicals dry up and their concentration increases, a viscous slippery surface film may form, which could reduce friction.

In addition, the use of chemicals can create other aviation safety problems. Chemicals can be corrosive, this has led to grounding of aircrafts due to damage to flight systems in the wings and wheel wells.

Furthermore, chemicals can have an adverse effect on the actual runway structure (pavement and installations).

More effort should be put into international research initiatives to draw up specifications and guidelines for sanding and the use of chemicals to improve friction on contaminated runways.

AIBN's findings are based on own investigations, Reference 4, and Appendix J, chapter 08. Experience shows that chemical treatment of contaminated runways must be closely controlled. Otherwise wet runways may become slippery from freezing. A complicating issue for pilots is that the ICAO SNOWTAM code does not allocate a friction number for such conditions which are reported as UNRELIABLE or for „slippery when wet“. It was found that runways may be slippery with POOR friction under such conditions. Therefore the airport staff should report the friction for such conditions as either MEDIUM or POOR friction for air crews to base their landing calculations on.

2.2.4 Validity ranges for friction measuring devices

AIP Norway describes valid ranges of friction measuring devices (see Appendix F). Based on the AIBN's findings in its investigations relating to contaminated runways, which show that temperature and humidity play a major role in determining whether „aircraft μ “ is good or poor, it was concluded that there are reasons for raising doubts about the basis for the defined validity ranges (see 1.3.3). It was not found any international scientific data to document the basis for the friction measuring devices' validity ranges (other than the referred FAA Advisory Circular 150/5200-30C).

The Tapley meter (TAP) is a decelerometer. In Norway, the use of a Tapley meter is not permitted under so-called "wet conditions" (see Appendix F), while the use of continuous friction measuring devices⁶⁹ has not been subjected to any such limitations. However, the findings show that the values measured on moist contamination are too optimistic for all friction measuring devices used in Norway (see Table 1 and Figure 1 in Appendix G). Based on this, no friction measuring devices should be used on wet or moist

⁶⁹ Continuous Friction Measuring Devices (CFMD) or Equipment (CFME).

contamination. The findings show that friction on moist contamination is basically POOR, and can, at best, be improved to MEDIUM by special preparation.

Based on its own findings the AIBN believes that the definitions of various types of contaminations referred to in 1.3.3 and Appendix F, are not sufficiently fine-meshed to distinguish between degrees of "slipperiness". These definitions are currently used by ground staff and air crews as dividing lines between validity ranges for friction measuring devices and friction. The findings related to contaminated runways show that temperature and humidity play a major role in determining whether the „aircraft μ “ is good or poor. Hence, it was concluded that there is a justified doubt related to the basis (basic assumptions) for the defined validity ranges (see 1.3.3). With reference to Appendix F, it is believed that this partly explains why there is often a wide gap between measured or estimated friction values and „aircraft μ “. It therefore seems somewhat strange that the airlines, Avinor and the CAA Norway have not given more weight to the results of Norwegian investigations following accidents and incidents and regulated operational practice accordingly.

2.2.5 Friction measurements and uncertainty

In its investigation of accidents and incidents relating to contaminated and slippery runways, the AIBN has reviewed a large volume of documentation from national and international sources, including documents relating to operations on regional runways, sanding and chemical preparation of runways, measurement of friction coefficients (FC), correlation between friction coefficients (FC) and „aircraft μ “, correlation between various aircraft types and uncertainty attached to measurements. It has been concluded that the use of friction measuring devices can be justified if the following is also observed: friction must not be measured on wet/moist or loose contamination, the warning in AIP EN AD 1.2 and the uncertainty shown in Table 1 in Appendix G should be taken into account, and a table should be used instead of a curve (see Tables 3 and 4 in Appendix G). A slight increase in the ABC values in Table 4 should possibly be considered, but the AIBN's investigations indicate that the principle is a safe one.

The AIBN also refers to Transport Canada's experience, which shows that FC varies widely when compact snow or ice is covered by loose snow. See 1.3.4 and AIP Canada, AIR 1.6, Table 4a and Table 4b:

<http://www.tc.gc.ca/publications/EN/TP14371/PDF/HR/TP14371E.pdf>

The findings of TC, AIBN and Dr. R. Mook (see Appendix J, chapters 02, 03, 04, 06, 09 and 12) are also in accordance with the tests conducted by Mr. Kollerud at Oslo Airport Fornebu more than for 50 years ago (see Appendix N). The results of these early friction measurements showed measured FCs in the order of 0.15-0.35. On the basis of Kollerud's correlation curve (which bore a close resemblance to the one developed by TC, in particular) this corresponded to „aircraft μ “ of between 0.08 and 0.16. These values indicated ABCs from POOR to MEDIUM to GOOD. Once again, this confirms that uncertainty attached to such friction measurements.

Concerning the uncertainty of friction measurements, it is also referred to section 1.8.9. It is believed that the research results referred to in that section supports the AIBN view concerning the uncertainty that relates to friction measurements.

Reference is made to Table 1, Figure 10 and the extract from AIP EN AD 1.2⁷⁰ (see Appendix G) relating to the demonstrated uncertainty of friction measurements. If Table 1 is viewed in conjunction with Figure 9 in Appendix G, it can be concluded that if an uncertainty of ± 0.10 attaches to a measured FC of 0.30 (MEDIUM), the actual FC lies in the range from 0.20 (POOR) to 0.40 (GOOD).

Depending on which correlation curve is used (see Figure 13 in the report or Figure 9 in Appendix G), this can, in the worst case, result in an airplane braking coefficient/"aircraft μ " of between 0.05 (POOR) (Braathen's curve) and 0.13 (MEDIUM) (Widerøe's curve). This corresponds to something in the order of a doubling or more of the aircraft's retardation at speeds lower than 50-60 kt (when the effect of reverse thrust and air resistance is greatly reduced). The above leads to the conclusion that, depending on the correlation curve used, there may be a substantial difference in the calculated landing distance (Landing Distance Required - LDR) for jet aircraft and propeller aircraft. The investigations show that there may be grounds for using higher braking coefficients for propeller aircraft than for jet aircraft, but not to the degree that is currently practised in Norway (see AIBN's Table 4 in Appendix G and Figure 14 in 1.3.5.3).

Reference is also made to 1.8.8 (IRIS project). Figure 19 show some results from the tests. The figure indicates the spread in aircraft braking coefficient measured on runways covered by moist conditions, including Dew Point Spread ≤ 3 K. It shows that most readings are in the MEDIUM range ($\mu_{ac} = 0.10-0.20$), while some are in the POOR range $\mu_{ac} < 0.10$ based on Boeing ABCs. The results show the spread one might have for aircraft friction, but these are „after the fact figures“. Beforehand it is not known what the predicted aircraft friction might be, and what predicted figures one should base the landing calculations on. This would have been simple if we were able to predict the „real time aircraft friction coefficient“, but this is still not possible by any known methods.

AIBN's view is that the „acceptable level of safety“ should not be less than „an equivalent level of safety“. If it is accepted that the „acceptable level of safety“ may be lower during winter operations the discussion will be different. So far AIBN has not seen any international or national guidance to this effect. There is no scientific basis for using a scale of finer mesh than GOOD, MEDIUM and POOR when predicting a supposedly safe contaminated runway friction coefficient. This is in line with the present statement in the Norwegian AIP. If the prediction should be POOR based on the available meteorological information, and the real aircraft braking coefficient is MEDIUM or better, that should be considered a bonus and a safety factor just as when planning a landing on a wet runway which proves to be dry when landing. It is important to compare this with the certified aircraft landing data based on bare and dry runway friction without the use of thrust reversers and a safety factor of 1.67, while the actual landing distance calculations are based on estimated or assumed friction level and use of thrust reversers and no regulated safety margin. It will be up to the airport management and ground staffs to predict the contaminated friction coefficient as close to reality as possible. With a developed IRIS system the friction predictions should be closer to reality than seen from the investigation results. The data in figure 19 support the view regarding the difficulty of predicting contaminated friction levels and highlight the uncertainty of accurate friction predictions.

⁷⁰ https://www.ippc.no/norway_aip/current/AIP/EN_AD_1_2_en.pdf

Appendix O shows the ICAO SNOWTAM format. It is considered strange that ICAO has accepted a table of friction numbers expressed with two decimals when numerous test programs have shown that there is a relatively large measuring tolerance attached to the numbers. In fact, it has been found that the tolerance when measuring friction on wet contamination may be of the order of ± 0.20 . In practical terms this prohibits use of friction measuring devices on wet contamination.

During the consultation process it was received several comments requesting AIBN to recommend further research on friction measuring devices. Over the last 60 years there have been performed numerous friction measuring research programs to try to find a friction measuring device which can accurately measure the friction on winter contaminated runways. The specific challenge is to find a friction measuring device which not only can measure its own friction close to reality, but measure a friction coefficient which may be applied to aircraft wheel braking. Over the years there have been tried measurements both with decelerometers and CFMDs. The results show that regardless of type of friction meters used the results are basically the same, from the Kollerud's trial ca. 1950 to the JWRFMP trial ca. 2000. The physical explanations why it is difficult to measure friction on frozen water is explained in Appendix J, chapters 02, 03, 04, 06, 09 and 12.

2.2.6 Correlation between friction measuring devices, friction measuring devices and airplane braking coefficients (ABC)

The AIBN has been able to access a large volume of documentation relating to correlation – between various types of friction measuring devices as well as between friction measuring devices and airplane braking coefficients (ABC). Section 1.3.5.2 describes some examples of empirical correlation formulas developed on the basis of comparative tests between friction measuring devices and various aircraft types.

2.2.6.1 *Correlation curves*

In the 1970s and 1980s, NASA extrapolated a relationship between ABC as recorded by aircraft, on the one hand, and FC as measured using ground equipment, on the other. ICAO adopted a relationship for braking system efficiency established by NASA as part of the minimum friction level which relates to wet runways as described in the ICAO Doc 9137, Airport Services Manual, Part 2, Pavement Surface Conditions, Chapter 1 and Appendix 1 (Reference 4). ABC is expressed as the sum of a linear and a quadratic term, both related to measured FC. The result appears as an exponentially slightly increasing ABC and a Braking Action regression line. The basic assumptions behind the relationship between this curve and the friction measuring devices are detailed in a presentation by Walter Horne to Air Line Pilot's Association International in 1990 (see Figures 7 and 8 in Appendix G).

It is not surprising that there is a disparity between the formula as a mathematical model, on the one hand, and the AIBN's own empirical findings, on the other, since it is believed that NASA's assumptions can hardly be fulfilled in practice. Pressure melting can be disregarded, but melting due to heat released from friction and contact between warm tyres and the snow, and liquid water in newly fallen (recent) snow will to varying degrees contribute to the presence of liquid water and affect the „aircraft μ “.

One of NASA's assumptions is that the measuring wheel and the aircraft tyres have identical friction coefficients on ice and snow. In the light of the differences in rolling dynamics between ordinary aircraft and measuring equipment, such identity cannot be expected.

The formula which was developed by NASA (see 1.3.5.2) based on NASA Langley research data from the 1970's and 1980's as part of the Joint FAA/NASA Runway Friction Program (Report 1990, see 1.3.5), can give the impression that the scientific basis is better than for other correlation curves. The formula describes a non-linear correlation and hence creates the impression of being more correct than other correlation curves.

The investigations indicate that NASA's assumptions for use of the correlation formula represent a substantial over-simplification of the physical relationships (see Figure 8 in Appendix G.) The findings suggest that the aircraft tyre's friction coefficient is influenced by tyre dimension, vertical load and tyre pressure. The AIBN's investigations demonstrate that heat is generated in the aircraft tyres during braking (see Appendix J, chapter 03 and Appendix N). The increase in temperature will be affected by the above-mentioned factors. The increase in temperature will in turn have an impact on friction. Furthermore, it is believed that several of its investigations have demonstrated that aircraft tyres and friction measurement wheels have different friction coefficients. In addition it was found that moisture and strong crosswind effects (polishing, planing, see Appendix J, chapter 11) play a significant role and makes the correlation between ground friction measuring devices and aircraft tires difficult.

Transport Canada used the test results from the JWRFMP to develop its own friction index (CRFI) and its associated correlation curve, which were made applicable to all aircraft types (see Figure 3 in Appendix G). It is considered significant that TC's correlation curve closely resembles Kollerud's curve from 1954 (see Figure 18 in this report or Figure 9 in Appendix G). The Kollerud curve is based on the findings that the aircraft friction is less than half the friction measured by a truck (see Appendix N). This became the „rule of thumb“ that the aircraft experienced half the measured retardation/friction, and that this curve represents the upper range of relative safe correlation on compacted snow and ice provided a decelerometer type of friction measuring device was used. Furthermore, the obtained results required interpretation using tables, approved by Aviation Authorities, giving recommended landing distances.

With reference to section 1.3.5, it is believed that the coincidence between the results of the correlation tests of four different organisations (Kollerud, NASA, JWRFMP/TC, Bombardier) over 60 years is not incidental, and it concludes that the correlation between measured FC and „aircraft μ “ may be in the order of 0.5 of measured FC. Based on the investigations (1.3.5), the JWRFMP (Figure 18) and Appendix V (see Figure 14 in this report), it may be concluded that propeller aircraft may be credited with somewhat higher „aircraft μ “ than jet aircraft. It is suggested that such general correlation curves or tables for jet and propeller aircraft could be included in the ICAO Doc. 9137 AN/898 Airport Services Manual, Part 2 (Reference 4). However, the AIBN's investigations show that such correlations should only be used for advisory purposes and when measured on dry compacted snow or ice. Temperature, dew point, humidity, precipitation, strong crosswind conditions, use of chemicals, sanding, etc. must also be taken into account. Based on studies of research and test reports and own investigations, AIBN has concluded that friction measuring devices measure incorrect values when used on

runways contaminated by a layer of compact snow or ice covered by water, slush, wet or dry snow (layered contamination). This supports the test results that indicate that friction measuring devices should not be used on wet or moist contamination. The measured values are an indication of the friction between the measuring wheel and the surface, but are not representative for the aircraft tyres' friction coefficients.

2.2.7 Crosswind in combination with slippery runways

In 19 of the 30 investigated incidents relating to slippery runways difficulties in keeping control of the aircraft have arisen as a result of strong crosswind in combination with slippery runway conditions. In several of its reports, the AIBN has pointed to the uncertainty attached to friction measurements and the determination of „aircraft μ “ on contaminated runways and it has submitted several recommendations for improvements. It has been found that little has changed in the course of the past decade and believes that crosswind limits on contaminated runways should be more conservative.

Crosswind limits on slippery runways are not regulated by international certification rules, but based on the manufacturers' theoretical calculations and simulations. It is standard practice for the airlines to draw up their own detailed crosswind tables and submit them to the local aviation authorities for approval.

Based on the JWRFMP test results (see 1.5.4 and 1.8.3), Transport Canada (TC) developed a graph of crosswind limits versus CRFI (see 1.3.6 and Figure 5), which is more conservative than the ones used by Norwegian airlines. On the basis of its investigation results, the AIBN believes that TC's recommended wind limitations on slippery runways are more realistic than the limitations used by Norwegian operators, considering the total uncertainty attached to friction measurements, wind measurements and correlation with „aircraft μ “. This has been addressed on several occasions and been the subject of several safety recommendations in the AIBN's investigations relating to slippery runways (see 1.1.4 ([RAP 2002-23](#)), 1.1.13 ([RAP 2009-06](#)), 1.1.14 ([RAP 2009-07](#)) and Appendix J, chapters 10, 11 and 13.4).

The "Cornering friction" or „cornering effect“ is an important concept in connection with strong crosswind conditions (see 1.3.7). The investigations suggest that there is little knowledge of this concept among pilots. If the aircraft is to remain on the centreline, the cornering friction must be great enough to compensate for the crosswind action on the aircraft. This means that most of the friction available to the aircraft is spent as cornering friction to achieve directional stability and there is little friction left for braking. When the pilots start to brake, braking friction will be at the expense of cornering friction, the aircraft may start to skid sideways and the pilot may lose directional control of the aircraft. This can lead to the aircraft running off the side of the runway. The situation can be likened to driving a car through a curve on a slippery road. The friction between the car's tyres and the slippery surface is sufficient for the car to stay on the road as long as the brakes are not applied. If the driver tries to brake at the same time, the available cornering friction is reduced, the tyres lose their grip on the road and the car skids off the road.

2.2.8 Operational use of wind data in landing calculations

The AIBN has found that one of the factors relating to crosswind and slippery runway conditions is the use of wind data. Landing calculations shall be made well before landing (within 30 minutes), and be followed by a landing briefing. In five (5) of the 30 incidents investigated, the aircraft crew based their landing calculations on the average 2-minute or 3 sec wind speed received from TWR, which was more favourable for landing than the relevant average 10-minute wind speed in the applicable METAR. During the landing, the actual wind was similar to the reported and stronger METAR wind. This resulted in loss of directional control. This constitutes a safety risk, and has been demonstrated to be a cause factor in several of AIBN's investigations (see 1.3.10 and Appendix J, chapter 10).

Instantaneous wind read by TWR, is an indicator of possible changes in relation to METAR (average 10-minute wind speed). If a set of landing calculations is based on TWR's instant wind speed readings 10-20 minutes before landing, and these readings are better than the most recent METAR, METAR wind conditions could still prevail when landing takes place. Instant winds should therefore not be used for landing calculations if the values are more favourable than the METAR values. Landing calculations should be based on METAR/ATIS wind (10-minute average wind speed) while the actual TWR wind speed (average 2-minute, or in some cases 3 sec average as appropriate) speeds should be monitored during the approach to ensure that the wind speed does not exceed the landing limitations based on METAR as used during the previous landing calculations.

AIBN has found that runway excursion due to crosswind and low friction does not occur on the first third of the runway, but normally on the last third. At the landing point the aircraft is controlled by the aerodynamic control forces, while from 100 kt and lower the aircraft becomes a „ground vehicle“ and its directional control and braking is totally dependent on frictional forces. For airfields with known variations in wind condition due to hilly terrain, the operators could differentiate the minimum required friction on each third of the runway in combination with maximum crosswind.

2.2.9 Use of reverse thrust in landing calculations

It has been documented that the international guidelines for operation on contaminated runways are not in accordance with the strict requirements for certification of aircraft which are based on documented performance on dry runways without the use of thrust reversers. In spite of this, the same aviation authorities permit operations on contaminated runways based on use of thrust reversers and reduced safety margins (see Figure 16). Hence, the extra safety margin that the reverse thrust would constitute is not available on contaminated runways.

Appendix C contains the JAR/EU OPS 1.400 which covers the operational landing calculations. There is no specific regulated guidance regarding acceptable procedure, use of reversers or safety factor, etc. The wording is very general and leaves the rest to airlines and pilots.

JAR/EU OPS 1.485 regulates the planning of landings in general. It specifically states that the AFM landing data should include considerations for engine failure during all phases of flight, not excluding landing. These regulations may be interpreted as the

landing calculations should be based on planning with one reverser inoperative. As far as AIBN has understood, no European airline is doing that.

During the consultation process for this report AIBN received comments from Skandinavisk Tilsynskontor (STK) which is an office under „OPS-utvalget“ representing the CAA directors of the Scandinavian Civil Aviation Authorities (see 1.3.11). STK referred to an EASA interpretation received in an e-mail of 11 January 2008. EASA clearly states that landing calculations should be based on one reverser inoperative.

AIBN considers that the EASA interpretation would increase the safety margin by the effect of one additional thrust reverser when landing on slippery and contaminated runways.

2.2.10 Operational use of cockpit performance computers (CPC)

The pilots in most airlines use a cockpit performance computer for calculating landing distances (or maximum landing weight on the landing distance available). The airlines have detailed procedures for the pilots' calculation of landing distance/maximum landing weight and for determining limitations relating to measured and reported runway friction and crosswind conditions. There is much uncertainty attached to the accuracy of reported friction values. The same has proved to be the case with respect to reported wind speed and wind force. Several of the investigations have shown that this combination of two very uncertain parameters has been the cause of accidents and incidents.

Appendix H shows an example of one airline's crosswind limitations. It has been found that there is no scientific basis for the fine-meshed categorisation of runway conditions shown in Graph 1.9.3, whereby the friction coefficient is entered in the CPC with an accuracy of one hundredth (1/100). It is believed that such a graph may increase the probability of error in the landing calculations and constitute a risk factor.

At the time of several incidents, TAF, METAR, SNOWTAM, and runway reports have indicated conditions of wet precipitation on ice and temperatures above the freezing temperature. In spite of this, the friction values were entered uncritically in the CPC (or by use of tables) for the purpose of calculating landing data. Empirically, such conditions have resulted in POOR braking action. This can cause the aircraft to land under conditions of too strong a crosswind in relation to friction, whereby the pilot may lose directional control of the aircraft (see Table 1 in section 1.2.3).

The wide gap between measured friction and „aircraft μ “ (ABC) has increasingly contributed to the reduction of safety margins over the past decade in step with the airlines' growing use of cockpit performance computers (CPC). The pilots use FC as an input parameter to calculate optimum takeoff and landing weight for the landing distance available. We have seen that an FC of 0.30 may effectively be in the order of 0.20; this could increase the stop distance from 50-60 kt (when the thrust reversers are shut down and the air resistance is minimal) by up to 50 %⁷¹.

The investigations show that pilots are very loyal to their company's procedures. This means that the SNOWTAM table, with its fine mesh, and FC values are used uncritically as the basis for CPC calculations. It is therefore imperative that the procedures are well-

⁷¹ $S = V^2/2g\mu$, where S = stop distance, V = landing ground velocity, g = gravitational acceleration and $\mu = \mu_{ac}$.

founded. It often proves to be the case that pilots are very reluctant to re-examine landing data calculated using CPCs. The use of measured friction values and CPCs tend to give pilots a feeling that they are using scientific data, which lacks foundation.

2.2.11 The airport owners' (Avinor and private airports like Sandefjord and Moss) friction measurement procedures

The airport owners' procedures are, in whole or in part, based on ICAO's Doc. 9137 AN/898 Airport Services Manual and approved by the CAA Norway (see 1.5 and 1.7).

In several investigations of accidents and incidents, the AIBN has demonstrated the high degree of uncertainty that attaches to measurement equipment, measurement techniques and correlation with „aircraft μ “. This is also supported by the aircraft manufacturers and aviation authorities (e.g. FAA and the UK CAA). In connection with several incidents, friction measurements were carried out with FCs ranging from 0.30 to 0.40 and from 0.40 to 0.50, while the „aircraft μ “ was in the order of 0.05 (POOR).

Within the aviation community it has been known for a long time that wet ice and wet snow reduce the aircraft's braking action and increase the uncertainty attached to the correlation between measured values and „aircraft μ “. Despite this knowledge, the practice of trusting measured friction values continues, including under wet/moist conditions.

The investigations also show that the temperature-dew point spread is an indication of moist runway conditions. If the temperature-dew point spread is approximately equal to or less than 3K, the difference between FC and „aircraft μ “ has proved to be greater than normal. In such cases wet or moist conditions should be classified as POOR (FC = 0.20) regardless of measured FC. The same should apply in the case of wind-polished ice or compact snow in strong crosswind conditions (for example winds of more than 25 kt) at low temperatures and when there are dense layers of drifting snow and ice crystals, since such conditions could cause the aircraft's wheels to plane (an effect similar to water planning) and skid.

Friction coefficients are reported as being accurate to one hundredth (1/100). This is in conflict with AIP Norway AD 1.2, which states that only friction values stated in tenths to be of operational value. On this basis the friction assessment and reporting procedures should be reviewed (see 2.6.2).

Today, it is airport personnel who carry out weather observations or such observations have been automated (see 1.7.3). Hence the pilots are left with their own interpretations of METAR and TAF without benefiting from advice on runway conditions from professional meteorological personnel. The AIBN raises the question of whether the removal of meteorological consultants has adversely affected safety levels in connection with Norwegian winter operations.

2.2.12 Winter-prepared runways with reduced width

In two of its investigations, the AIBN found that Avinor and the airlines accepted operations on runways with reduced width in combination with contaminated surfaces / reduced braking action (see 1.3.8).

Reference is also made to Boeing's requirement for an acceptable runway width (see 1.6.2). This is believed to reduce the safety margins at Norwegian airports. The AIBN questions the CAA Norway's approval of a practice that permits safety margins to be reduced in winter compared with under summer conditions, and hence also compared with the criteria on which runway design and aircraft manufacturers' recommendations are based.

Reference is made to the CAA Norway's closing of the AIBN's safety recommendation 2009/15T relating to this matter, as described in section 1.1.14.3. CAA-N has informed AIBN that the practice of clearing runway widths to 30 m width in Norway is only permitted on longer runways, with operational limitations, in situations of critical ambulance missions where the time aspect is critical. On this basis it may seem odd that Avinor should permit, and that the airlines should accept, this practice (see 1.5.5.1 and EU-OPS requirement for maintaining an "equivalent level of safety" if one decides to operate on contaminated runways). The parties should reconsider their procedures for allowing reduced runway widths during winter operations. Based on Boeing's recommended crosswind guidelines (Reference 9), which are based on a runway width of 45 m, this constitutes an unnecessary risk factor which should be eliminated. This is a further reduction of the safety margins for aircraft operations that, in principle, are based on ICAO's rules and official regulations for certification of aircraft on runways of a specified length and width, with a dry surface, no crosswind and without the use of thrust reversers (see 1.6.2 and Figure 16). In international rules and regulations, operations on contaminated and slippery runways are regarded as involving reduced safety margins even with full runway widths. That is why ICAO and EASA recommend that operations on contaminated/slippery runways should only be carried out as an exception and that extra measures should be implemented to maintain "an equivalent level of safety" if one chooses to operate on runways with reduced friction on a regular basis (see Appendix C).

In spite of this, regular airline operations were performed at Evenes on 30 January 2005 (see 1.1.14). The airline involved in the incident stated in their response to CAA-N that they would continue to accept runway widths of 30 m. Hence, it seems that there might be different interpretations of the regulations. The minimum runway requirements are based on normal operations on bare and dry runways where the safety margins are higher, taking into considerations for engine failure during crosswind conditions. With contaminated and slippery runways where the safety margins are reduced, the runway width should not be any less.

2.3 Weather and runway conditions and use of safety indicators

2.3.1 Introduction

Today's winter operations are largely based on the aircraft crew and airport staff's own assessments of the weather and runway conditions. These assessments are made on the basis of TAF, METAR, SNOWTAM and prevailing weather and runway conditions.

The AIBN has chosen to present data from a typical Norwegian winter's day of snowfall in order to illustrate the type of information that is available to aircraft crews and air traffic controllers during winter operations in Norway. On the date in question (2 February 2010), aircraft landed at all the airports listed below without encountering any reported friction problems. This does not mean that the safety margins were as good as one would expect in aviation. The findings show that it is quite possible to land under

special conditions (landing distance available, headwind etc.) and brake to a halt within the landing distance available even if friction is POOR or below the estimated and reported value.

The findings in investigations from several accidents and incidents indicate that problems with low braking actions will only be apparent when there is a need for safety margins (i.e. long landing, soft touch down, late thrust reverser, late wheel braking, etc). The absence of aircrew remarks does not mean that an „equivalent level of safety“ was achieved. Appendix W, figures 9 and 10 show the spread in threshold crossing heights, flare and touch down recordings during normal landings with all kinds of runway conditions. During summer conditions the safety margins are quite large since the landing data are based on dry runways, 1.67 safety factor, max manual braking and no reverse thrust. Landing calculations for landing on contaminated runways however, is allowed based on actual, predicted friction coefficient, autobrakes and with all engines operating reverse thrust. Hence the safety margins are much reduced. However, as long as the flight crews are aware of the possibility of reduced friction and fly a stable approach, passes the threshold at exactly 50 ft, perform an ideal flare of less than 10 seconds, touch down firmly, and apply brakes and reverse thrust immediately, they may not need any safety margins, even though the friction is lower than predicted. To base safe landings on all types of winter contaminated runways on perfect piloting techniques at all times is not realistic taking into considerations the same variations in normal operating deviations during winter operations as when landing on bare and dry runways.

One should rely more on reporting runway friction conditions (“slipperiness”) based on measured meteorological conditions, and less on friction measurements or “estimates”, which entail a high degree of uncertainty. In the following, the AIBN will review TAF, METAR and SNOWTAM for the various airports in Norway on the chosen date and consider how runway friction properties could have been notified on the basis of that information. These assessments are made on the basis of knowledge about meteorological conditions that impact runway friction, including the safety indicators mentioned in the findings from the 30 reported incidents/accidents (see 1.2.3). The meteorological conditions and related safety indicators are described in more detail in Appendix J, chapter 13.

2.3.2 Oslo Airport Gardermoen (ENGM)

TAF and METAR forecasted and reported a light snowfall. METAR indicated humid air with a temperature of minus 11 °C and a temperature-dew point spread of 1 K. Based on the findings, this was, in principle, an indication of slippery runway conditions. SNOWTAM reported that runway 01L was 100 % covered with 8 mm dry snow on ice, and that the runway had recently been sanded. Friction was reported as being 4 (MEDIUM TO GOOD). The taxiways had a friction of 2 (MEDIUM TO POOR).

When air humidity is high, which in this case was indicated by the temperature-dew point spread, recently fallen snow may be very moist even with an air temperature of minus 11 °C. It was found that it is normal to classify snow as being dry at temperatures below zero, but that this is not always the case. As opposed to wet snow, dry snow is not normally regarded as producing slippery conditions. The findings indicate that sanding on loose snow and moist contamination results in a braking action of less than 3 (MEDIUM). This was confirmed in that the reported braking action for the taxiways was 2 (MEDIUM TO POOR).

Furthermore, the wording “slippery portions on central apron” was used. The term “slippery” is not clearly defined. The term indicates a slippery runway, but the degree of slipperiness is not defined. „Slippery” is not associated with a specific friction term, but has its origin from ICAO in relation to runways contaminated by rubber deposits, etc, which should be reported as „slippery when wet”. The expression is of no value to an aircrew who want to calculate the stopping distance or maximum landing weight on a designated runway. „Slippery when wet” indicates that friction is less than on a bare and wet runway which is of the order of GOOD, but how slippery? Friction, on the other hand, can vary between GOOD and POOR, i.e. across the whole SNOWTAM range. If an airport intends to report that patches of the runway or taxiways are slippery, it should use standard terms such as GOOD, MEDIUM and POOR as defined in the SNOWTAM friction table.

Based on AIBN findings, the friction value should at best have been reported as 3 (MEDIUM).

2.3.3 Sandefjord Airport Torp (ENTO)

TAF and METAR forecasted and reported a light snowfall, an air temperature of minus 9 °C and a temperature-dew point spread of 1 K. Slippery conditions should therefore be suspected. SNOWTAM reported compact snow in frozen wheel ruts (89)⁷² with estimated friction values of between 5 (GOOD) and 4 (MEDIUM TO GOOD). There was some old sand on the runway, probably underneath the recently fallen snow. METAR indicated snowfall, and SNOWTAM reported “drifting snow”, patchy contaminant and “slippery portions” on the runway. This suggests that SNOWTAM indicated runway status immediately after the preparation of the runway.

The term „slippery portions” is not defined and should not be used. To a pilot the friction terms MEDIUM or POOR should be used. See 2.3.2.

Based on continuing snowfall and “drifting snow”, it is probable that the contamination was at best 589 (dry snow on compact snow on frozen wheel ruts) with up to 8 mm dry snow. In this case it is believed that the reporting was too optimistic. Based on experience, the contamination is slippery under such conditions and sand in or under the loose contamination has little effect.

The friction value should at best have been reported as 3 (MEDIUM).

2.3.4 Kristiansand Airport Kjevik (ENCN)

TAF and METAR indicated a relatively dense snowfall, relatively strong wind, an air temperature of minus 7 °C and a temperature-dew point spread of 1 K. In principle, this indicated slippery conditions with recently fallen snow and moist contamination. SNOWTAM reported that the runway was 50 % covered with 8 mm dry snow on ice, and that the runway had recently been sanded. Friction was reported as being 3 (MEDIUM). There were also reports of „slippery” taxiways and apron.

Conditions like these can, at best, result in MEDIUM braking action, particularly when we take into account that the runway was 50 % covered by recently fallen snow. However, the investigations show that SNOWTAMs of this kind are based on fresh

⁷² [AIP Norway AD 1.2-4](#)

runway reports just after preparation of the runway, and that they are outdated shortly after being issued. In this case, METAR indicated that there was heavy snow in parts and wind, with a horizontal visibility of 1,200 m and a vertical visibility of 1,400 ft, and drifting snow. These conditions indicated that 100 % of the runway was covered with fresh new snow in high air humidity, and that the snow very probably contained a high proportion of liquid water, even though the air temperature was minus 7 °C. The investigations show that sanding on 8 mm loose contamination has limited effect.

It is believed that the prevailing friction conditions were less than 3 (MEDIUM).

2.3.5 Stavanger Airport Sola (ENZV)

TAF and METAR indicated no precipitation, an air temperature of minus 3 °C and a temperature-dew point spread of 4 K. SNOWTAM reported that runway 18 was 25 % covered with ice in frozen wheel ruts (79)⁷³ with an estimated friction of 4 (MEDIUM TO GOOD). Anti-icing agent was used. This could mean that there was wet ice in frozen wheel ruts (279). Runway 11 had 50 % of the same contamination while the friction value was estimated as being 3 (MEDIUM).

Conditions like these should not be reported as better than 3 (MEDIUM). ENZV also reported “slippery portions”, “slippery taxiways” and “slippery aprons” (see 2.3.2).

2.3.6 Bergen Airport Flesland (ENBR)

TAF and METAR indicated no precipitation, an air temperature of minus 4 °C and a temperature-dew point spread of 4 K. SNOWTAM reported that the runway was 25 % covered with wet ice (27). Friction was reported as being 4 (MEDIUM TO GOOD). The contamination and the degree to which it covered the runway suggested that chemicals had been used, without this having been reported. It is important to always report whether chemicals or sand have been used. The use of chemicals results in wet ice, which is slippery. Indications of use of chemicals were reported “slippery portions” of the runway and “slippery taxiways” (see 2.3.2).

The reported friction value of 4 (MEDIUM TO GOOD) was too optimistic and it should at best have been reported as 3 (MEDIUM).

2.3.7 Trondheim Airport Vaernes (ENVA)

TAF and METAR indicated no precipitation, an air temperature of minus 10 °C and a temperature – dew point spread of 4 K. SNOWTAM indicated that the runway was 10 % covered with patches of hoar frost on ice in frozen wheel ruts (379). Friction was reported as being 5 (GOOD). In this case, too, the runway, taxiways and apron were reported to have “slippery portions” (see 2.3.2).

The friction should at best have been reported as 3 (MEDIUM).

⁷³ [AIP Norway AD 1.2-4](#)

2.3.8 Bodø Airport (ENBO)

TAF and METAR indicated no precipitation, an air temperature of minus 5 °C and relatively dry air with a temperature-dew point spread of 6 K. SNOWTAM reported 100 % bare runway without stating any friction.

The reporting is considered correct in this case.

2.3.9 Bardufoss Airport (ENDU)

TAF and METAR indicated light precipitation in the form of snow showers, an air temperature of minus 13 °C and relatively humid air with a temperature-dew point spread of 3 K. This indicated that the runway was potentially slippery. SNOWTAM reported that the runway was 100 % covered with 8 mm dry snow on ice, and that it was covered by old sand („fixed sand“). Friction was estimated as being 4 (MEDIUM TO GOOD). In this case, the wet snow (57) should have been reported and that the friction was, at best, 3 (MEDIUM). This is based on there being 8 mm of recent snow on top of sanded ice, and on the temperature-dew point spread of 3 K being an indication of moist snow. The findings indicate that sand in or under loose contamination have little effect and that new (recent) snow in humid air contains a relatively high proportion of water, even though an air temperature of minus 13 °C apparently suggested “good winter runway conditions”.

The friction should at best have been reported as 3 (MEDIUM).

2.3.10 Alta Airport (ENAT)

TAF and METAR indicated temporary snow showers, an air temperature of minus 12 °C and relatively humid air with a temperature-dew point spread of 2 K. In principle, this indicated a slippery runway. SNOWTAM reported that the runway was 100 % covered by 8 mm deep dry snow on ice. The runway was covered in old “warm sand” („fixed sand“). This means that frozen sand was stuck to the underlying ice and covered by a layer of relatively moist new (recent) snow. The friction was estimated to be 3 (MEDIUM). The findings indicated that sand in/under loose contamination has little effect and that recent new snow in humid air contains a relatively high proportion of water. Under such conditions, the estimated friction could be poorer than 3 (MEDIUM). The AIBN’s findings indicate that measured friction coefficients (FC) on this type of contamination can be in the order of 4-5 (0.35 – 0.50), while the „aircraft μ ” may be in the order of 1-2 (0.05 - 0.08).

The friction value should at best have been reported as 3 (MEDIUM).

2.3.11 Kirkenes Airport Høybuktmoen (ENKR)

TAF indicated snow showers, while METAR indicated no precipitation, an air temperature of minus 10 °C and humid air with a temperature-dew point spread of 1 K. These conditions indicated that the runway could be covered by showers of moist recent new snow. SNOWTAM did not indicate any snow, but reported that the runway was 100 % covered by hoar frost on ice and that the runway was covered with old sand. Although it was not mentioned in SNOWTAM, this was probably “bonded sand” (warm, pre-wetted sand that bonds with the ice on coming into contact with it; „fixed sand“). This indicated that the sand grains were stuck to the ice and covered by hoar frost or ice. The friction was estimated to be 5 (GOOD).

In connection with incidents at ENVD and ENKR, the AIBN found that old "embedded sand" in humid air may be covered by ice and hence reduce ABC to 1 (POOR), while the measured friction (FC) may be 0.40-0.50 (5, GOOD). The findings indicate that, under such conditions, the estimated friction value should, at best, not be more than 3 (MEDIUM). If, in addition to this, there is a relatively strong crosswind, ice needles may smoothe the ice-covered sand grains, in addition to causing the aircraft to "plane" over a layer of flowing mass of ice needles.

Under such conditions, the friction value should be reported as 1 (POOR).

2.3.12 Summary

Based on available "safety indicators" (see 1.2.3), the interpretation of the TAF, METAR and SNOWTAM information on the date under consideration, compared with the AIBN's findings and experience of accidents and incidents, there are reasonable grounds for assuming that the actual friction was poorer than reported on some of the runways. In spite of this, no incidents were reported, and there were no reports of gaps between experienced friction and reported or expected friction values. This may indicate several things, including that the pilot corps has good training in handling routine operations on contaminated runways. It may also be an indication that none of the barriers were pushed to the limit and that even the reduced margins were just sufficient under the prevailing conditions. It reflects the fact that things go well most of the time and, hence, not enough weight is given to maintaining robust margins. An increase in the margins could be costly in terms of regularity and/or the direct costs of preparing the runways. Still, AIBN would point to the underlying requirement of public safety and the EASA requirement of an „*equivalent level of safety*“ during winter operations. Finally, AIBN recommends the term „*slippery when wet*“ and the general term „*slippery*“ should no longer be used as they are meaningless to pilots. If „*slippery*“ means POOR friction / braking action, it should be expressed as such.

2.4 **International guidelines for winter operations**

2.4.1 Introduction

The evaluation of the various international guidelines for winter operations is described below. The AIBN has related the analysis to its own findings in its investigations of incidents and accidents on contaminated runways, and to the corresponding Norwegian guidelines.

2.4.2 ICAO Annex 14/15 and ICAO Airport Services Manual, Part 2. DOC. 9137 AN/898

ICAO Annex 14 (See Appendix B) specifically states that the scientific data on which the SNOWTAM table was based was obtained from testing on compact snow and ice, and that it must therefore not be used indiscriminately under different conditions. The AIBN has written about this uncertainty in several previous investigation reports. ICAO describes that the term GOOD must not be understood to mean that the runway conditions correspond to those on a clean and dry runway (see Norwegian Aviation Administration's interpretation in Appendix K-3). This misconception has been mentioned in several AIBN reports without this having led to any apparent change of practice. Norwegian rules and procedures are based on reported friction values above 40

(FC > 0.40) corresponding to the friction of a „black“ (dry) runway (See Appendix K, the Norwegian Aviation Administration’s view of winter operations with DHC-8 in 1996-97).

The ICAO *Airport Services Manual*, Part 2. DOC. 9137 AN/898 (Reference 4) forms the basis for the Norwegian rules relating to friction measurements, reporting and use of friction data. The manual is generally outdated and not very appropriate as support for today's winter operations. The investigations show that the ICAO Airport Services Manual contains information that is not in accordance with more recent experience and research findings; among other things, the use of five levels in the SNOWTAM format lacks scientific basis. The guidance concerning the specifications for frictions measuring devices should be updated, description and limitations of newer types of friction measuring devices, the limitations that apply to measurement on moist contamination, requirements for sand, sand application, requirements for chemicals and the use of chemicals and updated information on expected friction on different types and depths of contamination, should be included. Annexes 14, Vol 1, Attachment A, Table A-1 as well as Doc 9137, Part 2 include a list of friction measuring devices. The inclusion of these devices means that they have been approved by local Aviation Authorities. Specifications for such friction measuring devices should be certified by an Aviation Certification Authority (FAA or EASA) and used in combination with correlation tables approved by the same agencies.

The ICAO Safety Management Manual, DOC. 9859 gives advice regarding the development of national safety standards. In this respect ICAO recommends that each State define an „acceptable level of safety“ (ALoS). Based on experience and knowledge gained from own investigations AIBN has concluded that the Norwegian climate and operating conditions requires adjustments to the general ICAO framework. Hence, Norway is required to establish national ALoS. Such a safety level should be based on a general safety analysis/assessment of routine operations on contaminated and slippery runways. A consequence from this may be that special measures must be taken in order to achieve „an equivalent level of safety“ as with „summer“ operations.

- 2.4.3 NASA-TM-82318. Joint Technical Conference on Slush Drag and Braking Problems. National Aeronautics and Space Administration. N81-74341. Unclas. 00/05 21663. December 19-20, 1961 (Reference 22).
http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19810069918_1981069918.pdf

Reference 22 and Appendix S contain some important historic information regarding the „state-of-the-art“ on winter operations in 1961-65. Much of the information in the referred papers is just as valid today and supports AIBN findings in this report. It is interesting to note that a common view was to increase the research efforts in trying to find better friction measurement devices. The papers in Reference 22 indicate that the uncertainties related to operations on contaminated and slippery runways and friction measurements are the same today.

- 2.4.4 USA/Federal Aviation Administration (FAA)

Chapter 1.5.3.1 and Appendix I refer to the FAA’s Safety Alert for Operators SAFO 06012. The SAFO 06012 may be viewed as a supplement to the ICAO Airport Services Manual and that it provides guidelines relating to the use of friction data and the relationship between measured FC data and how the data is used (Boeing, Appendix I).

Chapter 1.5.3.2 show some views from FAA regarding ICAO SNOWTAM table and friction measuring. AIBN has noted the FAA's views on friction measurements, which is in line with the data from the AIBN's own investigation. AIBN also agrees with most of the FAA's views in SAFO 06012. However, the FAA's description of braking action versus type of contamination in Table 1 in SAFO 06012 is not supported (see Appendix I).

It is evident from the table that the FAA assumes that dry snow (Dry Snow < 20 mm) results in GOOD braking action. However, data from the investigations show that dry snow results in a braking action of between POOR and MEDIUM depending on surface, temperature and dew point.

Furthermore, the table does not have a category for the condition „wet compacted snow“. The AIBN has found that this is a condition that often exists after sweeping of recent new snow. Investigations show that such conditions may have the same effect as „wet ice“, which corresponds to braking action NIL.

The values in the table apply to ploughed runways without the use of chemicals or sanding. In this context, it is worth mentioning that there are differences between the US and Norwegian climate, and that snow may have a different consistency in North America from what it has along the Norwegian coast. It has been demonstrated, for example, that salt particles in the air (from sea spray) can affect the „slipperiness“ of the snow. The FAA's estimated friction on dry snow < 20 mm may therefore be misleading (see Appendix J, chapters 02, 04, 06, 09, and 12).

The investigations show that it cannot be stated categorically that a particular type of contamination is associated with a specific friction value, and, in the AIBN's view, uncritical operational use of such a table can result in runway excursions. Friction is the result of a complex interaction of variables that may dominate to a different degree according to the framework conditions. Appendix J shows some of the results of measurements at Svalbard airport carried out by the AIBN's meteorological expert. It is also referred to the experience of Transport Canada, which shows that loose snow on compact snow or ice can have a wide range of FCs. See 1.3.4, and Appendices G and J, chapter 13.3).

SAFO 06012 shows that the FAA uses three descriptive terms for the Braking Action for contaminated runways: GOOD, MEDIUM, POOR (and NIL), rather than ICAO's SNOWTAM table. The uncertainties in the FC-measurements (standard deviations) are so large that the information given corresponds to a more coarse ranking scale of three categories (see 1.3.4). If it is desirable to view numerical values in relation to each other, then a common absolute zero is required in addition to the defined intervals.

The FAA's views on the use of friction coefficients (FC) is described in 1.5.3.2. It also shows that the FAA has not accepted any proven correlation between measured friction values and descriptive terms such as GOOD, MEDIUM and POOR. The FAA's view in that no strong correlation can be expected between two arbitrary scales, is supported.

It is also clear that the FAA does not support ICAO's view on the use of a correlation table (SNOWTAM) between measured FC and the pilot's subjective evaluation of braking action (Pilot Report, PIREP). The FAA claims that the „airplane braking coefficient“ is an objective quantity while the descriptive categories GOOD, MEDIUM

and POOR are subjective (a pilot's subjective assessment of experienced friction). Nor does the FAA support the use of correlation tables between measured FC and airplane braking coefficients.

FAA's policy of permitting landing calculations for operations on contaminated and slippery runways to be carried out on the basis of advisory data and use of reverse thrust can be questioned. FDR data from the investigations shows that reverse thrust contributes in the order of 20 % of the total braking effect (see 1.1.22) on POOR braking conditions. Figure 10 shows that total retardation (from spoilers, reverse thrust and wheel brakes) in connection with POOR braking action was in the order of 0.19 G. In the case in question, the braking action was much the same as the contribution from the reverse thrust, both of which were in the order of 0.05 G (together 0.10 G). Hence the contribution from air resistance was in the order of 0.09 G during the first stage of the braking process.

The evaluations and conclusions largely converge with what used to be the FAA's policy. However, it seems that this may be changed with the most recent developments in the USA and Europe. Reference is made to the TALPA ARC MATRIX in Appendix Y. The content of the Matrix deviates from the AIBN's findings in its investigations of runway excursions and seems to be based on opinion rather than scientific research data. It is not believed it is possible to simplify the matter to such a degree that a table may include all the meteorological variables which influence the slipperiness of a winter contaminated runway (see Appendix J, chapters 02, 04, 06, 09, 12, 13 and 14). However, with state-of-the-art technology and computer programmes AIBN believes that by use of actual measured meteorological data it will be possible to „nowcast“ the slipperiness of runways by use of systems like the Norwegian IRIS (see 1.8.8 and 2.7.5). The TALPA ARC MATRIX is based on the ICAO SNOWTAM table with its five descriptive categories, for which there is no documented scientific basis (see Appendices L and O). AIBN has previously submitted a recommendation to the CAA Norway to consider revising the table without success. The TALPA ARC MATRIX has other weaknesses in that it does not describe friction conditions relating to layered contamination, temperature and temperature-dew point spreads in connection with the various types of contamination, and in that it includes the general designation "slippery", which is not correlated with any friction. At the end of Appendix Y is included a proposed revised TALPA ARC matrix of 2010-11 where ranges of measured friction coefficients (FC) are included. As shown these ranges cover approximately the categories GOOD, MEDIUM, POOR and NIL and compares favourable with Boeing ABCs. The ultimate method of „nowcasting“ the predicted friction conditions on slippery and contaminated runways may be a fully developed IRIS system (see 1.8.8 and Reference 13).

Chapter 1.5.3.3 and Appendix L (at the end) refers to a special NTSB investigation report related to operations on contaminated runways (AIR/10/05 GPN/BAC, 1983). The report states that the airplane performance data used to establish operational limitations are obtained under ideally controlled conditions and are not representative of the performance actually attained during normal line operations, and that operational factors may not accurately reflect day to day operations. NTSB state that the most significant, is that all of the airplane acceleration and stopping performance data are for dry, smooth, hard runway surfaces; yet takeoff and landing operations are frequently conducted on runways covered with water, ice, slush or snow, or contaminated by rubber deposits. This is in line with AIBN's view.

Chapter 1.5.3.4 and Appendix R refer to an historic FAA NPRM 63-28 of 1963. The NPRM argues that the 0.60 factor for turbojet aircraft is meant to allocate for operational variations; i.e. excess threshold height and touch down speed, variations in piloting technique, adverse runway conditions, etc. The NPRM concludes that in order to have a similar safety margin when landing on wet (visible moisture) or icy runways the safety margin should be 0.5 in lieu of 0.6. AIBN find these views supportive of own investigation results, which indicate that the safety margins for operations on contaminated and slippery runways seem to have eroded over time.

Chapter 1.5.3.5 and Appendix S refer to an historic FAA discussion paper on Part 121 certification and operation of large turbojet transport aircraft landing on contaminated and slippery runways. The discussions are related to a requirement for adding 15 % the required landing distance of 60 % of the available dry runway in order to maintain the required safety level. This is the only reference AIBN has found which argues for increased runway length when landing on slippery runways, and seems to be the basis for today's regulations. It is interesting to note that this appears to mean that in addition to the 40 % margin on dry runways, which is meant to compensate for all possible deviations during normal operations, the added correction factor of 15 % is meant to compensate for reduced friction on slippery runways. Lastly, at that time thrust reverser was not part of the regulated landing performance calculations, but was considered an extra safety margin. It appears that lack of regulated requirements for operations on slippery runways, the practice of relying on „advisory“ information, actual landing distance with reduced friction, credit for reverse thrust, has over time resulted in reduced safety margins compared to the original requirements. These requirements seem to be relegated to „dispatch“ criteria, but once airborne it is allowed to reduce the margins. AIBN finds this rational contradictory to modern safety policies.

Chapter 1.5.3.6 and Appendix T refer to an FAA Advisory Circular, effective 21 January 1965. The AC contains FAA guidelines for operations on runways covered with standing water, slush or wet snow up to 0.5 inch in depth. The AC advises that the regulations are predicted on clean, dry runways, certain correction factors should be applied to the takeoff data when operating on wet snow, slush, or standing water in depths up to 0.5 inch. Therefore the runway length should be increased by 15 % in order to maintain the specified aircraft performance requirements as for dry runways. This comes in addition to operations on 60 % of the available dry runway. This tie in with the FAA discussion paper referred to in 1.5.3.4 and seems to mean an increased safety margin for actual landings. This includes no credit for use of thrust reverser, and gives the impression that the safety margins and the requirements for actual landings on slippery runways has gradually eroded over the years. AIBN suggests that with today's knowledge about safety barriers, human factors, organisational accidents and safety management systems, including safety assessments of operations, it is time to review the status of regulated operational requirements for operations on contaminated and slippery runways.

Chapter 1.5.3.7 and Appendix U refer to an FAA AC of 1967 with guidelines for establishing runway status for dry, wet or slippery. The guidelines may be just as valid today.

Chapter 1.5.3.8 and Appendix V refer to a US Navy report on tire-pavement friction coefficients. AIBN finds that the report results correlate well with own investigation results. Overall, these historic documents, together with the other historic documents listed under References and Appendices, show that there is not much new knowledge

related to operations on slippery and contaminated runways. Further, the investigation results correlate well with knowledge gained during the last 60 years.

Chapter 1.5.3.9 and Appendix W refer to an FAA report studying the normal operational landing performance on narrow body jet aircraft (B737 and A320) issued in 2007. Figures 9, 10 and 17 show the spread in threshold crossing heights, flare and touch down during routine landings. The data may indicate a lower safety level in today's operations on contaminated and slippery runways. The landing data indicate the spread of touch down points which influences the braking distances on dry as well as on wet and contaminated runways. During summer operations the requirement is to stop on 60 % of the available landing distance. Hence, there is a 40 % margin as well as reversers included in the margins. During winter operations with lower and uncertain friction the margins are smaller, dependent of thrust reversers and at best, a 15 % margin. AIBN does not consider this as an acceptable aviation safety standard.

Chapter 1.5.3.10 and Appendix X refers to an FAA order to establish a TALPA Aviation Rulemaking Committee which was tasked to forward recommendations to FAA regarding winter operations. The recommendations are shown in Appendix Y. AIBN's investigation findings do not agree with the TALPA ARC MATRIX recommended friction values which seems too optimistic. However, in the end of Appendix Y is a proposed revised friction matrix with indicated ranges of friction categories of GOOD, MEDIUM, POOR and NIL which are in line with the existing FAA and Boeing friction categories.

2.4.5 Canada

Runway excursions in connection with contaminated runways have also occurred in Canada. However, it is interesting to note that Canada has standardised its use of friction measuring devices on just one type (the ERD decelerometer, measuring friction coefficients defined as CRFI), abandoning the use of continuous friction measuring devices, and that it uses TC's own defined correlation curve as shown in Figure 18. The use of just one type of friction measuring device eliminates the element of uncertainty of measurement that is associated with the use of several types of friction measuring devices. In this context it is interesting to note that, in Norway, the use of as many as six different types of friction measuring devices are permitted (see Appendix F). All these measuring devices show different tendencies, in addition to the deviations between the individual friction measuring devices of each type.

During the consultation process AIBN has received comments indicating confusion between CRFI and IRFI (see 1.5.4 and 1.8.3). CRFI is just FC measured with an ERD and is comparable to FC's measured with other types of friction meters. The obvious benefit from standardizing on ERD and CRFI is the elimination of the uncertainties attached to the friction meters itself, and standardization between airports and airlines. Compare this with the Norwegian approval of not less than six different friction measuring devices, with measured FC's related to the same SNOWTAM table and using the same correlation curve (within the same airline). Hence the FC values have been used without any correlation between the types of measuring equipment.

2.4.6 JAR OPS 1/EU OPS⁷⁴

It may be in conflict with certified data when EU OPS/JAR OPS accepts operations on contaminated runways based on the use of measured friction coefficients that are correlated with the „aircraft μ “ for the relevant type of aircraft, without having defined corresponding safety margins. Operations based on the manufacturers“ advisory data are accepted instead, as mentioned in the FAA and Boeing“s regulations.

The climatic conditions in Norway make it difficult to limit operations on contaminated runways as something that should only take place infrequently as provided for in IEM OPS 1.490(c)(3). However, the accident and incident statistics pertaining to winter operations in the past ten years demonstrate that Norway has been unable to ensure an „equivalent level of safety“ for operations on contaminated runways. This suggests that the Norwegian rules and procedures („additional measures“) for winter operations do not ensure an „acceptable level of safety“ (ref. ICAO SMS Manual).

In this respect the attention is drawn to EU OPS 1.400, 1.485 and 1.520 which regulate European operations on contaminated and slippery runways (see 1.5.5.1). OPS 1.400 do not specify any safety factors for landing on slippery or contaminated runways. It leaves all the risks to the operators and flight crews. This is not in accordance with ICAO guidelines, or even in line with EASA“s own regulations (ref IEM OPS 1.490(c)(3)2, „...*ensuring an equivalent level of safety*“). It is suggested that EASA specify acceptable safety factors in order to achieve the goal.

OPS 1.485 (a)2 (see Appendix C and 1.3.11) requires consideration of engine failure during all phases of flight (not excluding landing). According to EASA“s own interpretation it is a requirement to plan all landings with one reverser inoperative. It has been found that this requirement is not implemented. This requirement, if implemented, would contribute to a higher safety level during landing on contaminated and slippery runways.

OPS 1.520 regulate landing on wet or contaminated runways. Compared to FAA regulations for dispatch (see 1.6.2 and Figure 16) EU dispatch criteria (OPS 1.520(b) allow airlines to deviate from the 60 % requirement as OPS 1.520(e) indicates, or base their dispatch data on „*at least 115 % of the landing distance determined in accordance with approved contaminated landing distance data or equivalent, accepted by the Authority, whichever is greater.*“ It may be questionable to base dispatch landing calculations on „approved contaminated landing distance data“, as investigations show that such data may contain gross errors. It is suggested that EU OPS dispatch criteria should be harmonized with FAA dispatch criteria.

These aspects underline the need to revise both the international and the national rules and regulations relating to winter operations.

2.4.7 JAR 25/EASA CS-25 certification requirements

The document shows that the basic data is uncertain and that both calculated and measured data should be used with care. What is meant by „care“ is not defined. It may be interpreted to mean „conservatively“ in the sense that friction should be stated as poorer than indicated by the figures.

⁷⁴ JAR OPS 1 has been changed to EU OPS.

It is believed that these reservations confirm the AIBN's own findings which indicate that ICAO and the Norwegian rules for operations on contaminated runways are not scientifically founded. The rules and guidelines are excessively based on very simplified physical models that lack sufficient basis in scientific facts.

Based on the findings in its investigations, the AIBN believes that the „default friction values“ in Table 2 in Appendix D are unrealistic. We see that EASA considers „standing water“ to be equivalent to „slush“ and defines a specific friction value using a speed-based formula. Effective $\mu = 0.12$ at a ground speed of 100 knots, 0.26 at a ground speed of 50 knots and 0.31 at a ground speed of 10 knots. The findings are in sharp contrast to EASA's default friction values for the relevant types of contamination, and has found that the „effective μ “ often lies in the area MEDIUM to POOR ($\mu_{ac} = 0.10$ to 0.05).

It is believed that the EASA formula is based on the aspect of acceleration during take-off in which the „displacement drag“ has a major impact on the achieved acceleration, and that friction during braking following an aborted take-off relates to wet friction and the phenomenon of aquaplaning. Airbus designates loose contamination as „fluid type contamination“ as opposed to „hard type contamination“ in the form of compact snow and ice. For braking when landing on a runway covered in slush („fluid type contamination“), the findings show that friction can be much poorer than is assumed by EASA and Airbus. Based on the probability of an aborted take-off being very small, the use of the formula can be justified for take-off calculations, but not for determining friction when landing on slush or loose wet or dry snow on top of a layer of compact snow or ice. In this connection, the picture is made even more complex by EASA's assumption that slush lies on top of bare asphalt, whereas slush, wet and dry snow are in actual fact most often found on top of an underlying layer of compact snow or ice. As mentioned above, the formula results in higher friction values at lower speeds under slippery runway conditions. In contrast to this, the tests carried out in JWRFP showed that friction on contaminated and slippery runways remained almost constant throughout the braking process (see Figure 4 in Appendix G).

As shown in section 1.8.5, as early as in the 1950s it was demonstrated that the „aircraft μ “ was approximately 50 % of the friction measured (FC) on the ground. This means that the values in Table 2 in Appendix D would have to be doubled in order to correspond to the measured friction coefficients (FC) for the stated types of contamination. If this is used as the basis, wet snow and dry snow of various depths are types of contamination that would result in MEDIUM braking action (FC = 0.30-0.34) while compact snow would result in GOOD (FC = 0.40) braking action, irrespective of temperature and dew point. Based on the findings it is believed that this is too optimistic. On the other hand, there seems to be international consensus that compact snow can result in good friction (FC = 0.40) with corresponding „aircraft μ “ = 0.20 at very low temperatures (below minus 15 °C), „aircraft μ “ = 0.05 for dry ice, and NIL for wet ice). The values of „aircraft μ “ = 0.20 for compact snow or 0.05 for dry ice should not be used when the conditions deviate from the assumption of low temperatures, dry compact snow or ice. This is shown in Figure 10 in Appendix G.

The EASA's certification requirements deviate from the AIBN's findings (see 1.1 and 1.2) and with the research data (see 1.8.9 and Appendix J) and thus provide misleading information.

2.4.8 UK

The UK CAA follows ICAO's guidelines. The British Airport Authorities (BAA) give priority to keeping the runways free of snow and ice. Even though it is difficult to introduce a similar policy in Norway, the BAA has considered the risk associated with operation on contaminated runways to be particularly high. This is in line with the EU OPS/JAR OPS 1 rules (see Appendix C).

However, not even the use of chemicals can solve all the problems. A time period arises during which the contamination accumulates before a decision to close/prepare the runway is taken. During this period, friction shall not be measured using friction measuring devices and a runway status of 9 or UNRELIABLE shall be reported pursuant to ICAO.

A period of uncertainty may arise immediately after the removal of snow and ice by means of chemicals/melting. At that time the runway is wet and must be reported as wet. If the air temperature is below zero and the chemical solution is diluted, the liquid can freeze to form hard transparent ice (so-called „black ice“) which is invisible to both airport staff and pilots. This is a concern expressed by British Airline Pilot Association (BALPA) and supported by the AIBN on the basis of a runway excursion at ENGM (see 1.1.3). With a reported runway status of 9, the flight commander is faced with a dilemma. Should this be interpreted as a wet runway with braking action GOOD, or as a winter contaminated runway with unknown runway friction. In the latter case he may be unable to land and have to fly to an alternative airport. For this reason, the runway conditions should be reported as 1 (POOR) in such cases, rather than 9 or UNRELIABLE.

AIBN has been informed by UK CAA that the reporting of 9 has been performed by some aerodromes in UK, but that this is contradicting to the UK policy. SNOWTAM Field (H) should only be used when friction coefficients measured on compacted snow and ice is available. Whether Field (H) is filled in with 9 or left blank does not help the pilots in any way. The aircrews are required to calculate the required landing distance or maximum landing weight on a specific runway. In order to calculate landing data they need a friction level GOOD, MEDIUM or POOR. The word „slippery“ is of no value to the pilots who have a requirement to correlate the „slippeness“ to known performance degradation.

2.4.9 Summary

AIBN's investigations into runway excursions due to contaminated and slippery runways show that different countries practise winter operations in different ways, even though each country has based their policies and procedures on common ICAO guidance. It has been found that USA, Canada, UK, and Norway differ in their local interpretations of the international framework for winter operations. Based on experience and knowledge gained from own investigations AIBN has concluded that different climate and operating conditions in different countries may constitute different adjustments to the general ICAO framework. This would be in line with the ICAO requirement for each State to establish its own „acceptable level of safety“. Such a safety level would have to be based on a general safety analysis/assessment of routine operations on contaminated and slippery runways in the national climactic and topographical conditions. A consequence from this may be that individual States may have to take special measures to achieve „an equivalent level of safety“ as with „summer“ operations.

AIBN has found that the expression „slippery“ is not defined and is not meaningful to pilots and should be deleted. A „wet“ runway has a friction level of the order of GOOD. „Slippery when wet“ must then have lower friction than „wet“ but the level of friction is not defined. If slippery means less friction than „wet runway“ the defined expressions MEDIUM or POOR braking action should be used. There is no performance data available for „slippery“ conditions. Hence, pilots receiving such information have to plan their landings on unknown friction.

2.5 Guidelines for winter operations for various aircraft types

2.5.1 Introduction

In the following, the various aircraft manufacturers' guidelines for operations on contaminated runways with their respective aircraft types is reviewed. The analysis is related to the AIBN's own findings in its investigations of incidents and accidents relating to slippery runways.

2.5.2 Boeing

Boeing's policy for operations on contaminated/slippery runways is described in section 1.6.2 and documented in Appendices G and I.

It is important to note the difference between the aircraft manufacturers' certified landing data and their 'advisory' data, and the ensuing differences in safety margins.

Based on the results of its own investigations, the AIBN believes that the present FAA and Boeing's policies for winter operations are in accordance with its own findings. However, the Boeing's ABC versus Runway Description as shown in Table 2 in Appendix G seem to be over-simplified and can therefore be misleading. The AIBN's findings based on its own investigations (see 1.1 and 1.2) and on research (see 1.8.9 and Appendix J) show that „aircraft μ “ (ABC) is influenced by temperature, dew point, precipitation and wind. Hence, such simplified descriptive contamination conditions can be seriously misleading.

FAA is presently reviewing a TALPA ARC matrix for reporting friction on contaminated and slippery runways (see 1.5.3.10 and Appendices X and Y). The proposed matrix for prediction of friction on contaminated and slippery runways has the same basic deficiencies as the beforementioned „Boeing description“ since it is not adequately including temperatures and moisture. However, it is a step in the right direction, and may be a basis for further refinement in combination with the Avinor IRIS system (see 1.8.8).

2.5.3 Bombardier

The correlation formula for DHC-8-103/311 is shown in section 1.6.3. The AIBN also refers to the comparison between Bombardier's correlation formula and the Kollerud curve in sections 1.3.5 and 1.6.3.

The above supports the AIBN's findings in its investigations of runway excursions with these aircraft models – that the correlation formula for the DHC-8-103/311 with the correction factor as used in Norway is optimistic.

The AIBN has studied AFM Supplement 37 for DHC-8-Q400. The supplement indicate that Bombardier has discontinued its use of friction coefficients and now bases landing data on fixed friction coefficients and fixed density values for the various types of contamination (see 1.6.3). Bombardier has based its calculations on the use of water equivalent depth (WED), where loose contamination (slush, wet and dry snow) is converted to water equivalent depths based on fixed density values and the associated Braking Friction Index (or „*aircraft μ* ”).

It is believed that the use of WEDs is an important factor in being able to estimate rolling resistance and acceleration in connection with takeoffs, while the associated friction values are highly uncertain. WED does not take account of variations in the friction properties of various contamination types compressed under the aircraft tyres, friction heating or of any impact on friction that can be ascribed to differences in water content and temperatures (see Appendix J, chapters 02, 04, 06, 09, 12 and 13). The investigations show that the use of fixed friction values based on WED and „fluid type contamination” is very uncertain in connection with landing calculations.

2.5.4 Airbus

An excerpt of an Airbus policy document relating to operations on contaminated runways was shown in section 1.6.4 and is included in Appendix E (Reference 7). In essence, Airbus argues that an aircraft „effective μ ” cannot be determined on the basis of measured friction coefficients. Airbus has therefore chosen to evaluate friction on the basis of the type and depth of contamination.

AIBN agrees with Airbus in that there is much uncertainty attached to the use of friction measurements. On the other hand, the investigations show that there is also much uncertainty attached to Airbus’ method of relating specific friction coefficients to specific types of contamination. The results of the investigations show that the friction of various types of contamination will vary greatly according to the water content and temperature.

Airbus has chosen to use two main categories of contamination, „hard contaminants” such as compact snow and ice, and „fluid contaminants” such as water, slush and loose snow, allocating different friction values as a function of the type and depth of the contamination.

For „hard contaminants”, Airbus uses EASA’s „default friction values” (shown in 1.5.5.2 and in Table 2 in Appendix D, and discussed in 2.4.2). However, the findings show that there are weaknesses associated with these values, too. The values seem to be acceptable at temperatures below minus 15 °C, but can hardly be correct at higher temperatures and water contents (see Figure 10 in Appendix G and Appendix J, chapters 02,04, 06, 09, 12 and 13).

For „fluid contaminants”, Airbus uses the formula for „default friction values” for water and slush. In principle, Airbus assumes „equivalence between water, slush and snow” based on density for these contaminants, where the density of water is 1.0 with relatively lower density for slush and snow. These values are based on differences in density, rolling resistance and precipitation drag and on tests, on the basis of which Airbus has arrived at different friction curves. Examples of such curves are shown in Appendix P.

Such calculations can be meaningful in describing resistance during acceleration in connection with takeoffs, but that the use of such data as the basis for estimating „effective μ “ will give incorrect results. Furthermore, the investigations show that the friction values obtained through the use of such formulas are too optimistic on various types of contaminants such as slush, wet snow and dry snow of various depths (see 1.2.3). In several of its investigations, the results show that friction has been much poorer than indicated by Airbus“ friction curves / landing data.

Table 4 in section 1.6.4 presents an example of Airbus“s landing data. The table indicates that 12.7 mm of water results in the same friction as compact snow. As far as compact snow at low temperatures ($< -15^{\circ}\text{C}$) is concerned, it has long been accepted that it can have an „aircraft μ “ of 0.20, which corresponds to GOOD. It is doubted that 12.7 mm water would result in GOOD braking action under all conditions. Furthermore, the table shows that 6.3 mm and 12.7 mm of slush result in approximately the same braking action as compact snow. Friction on compact snow will be reduced at higher temperatures and at low temperatures and high humidity. Further, it has been found that „aircraft μ “ on slush could be MEDIUM or POOR depending on the underlying surface, temperature and moisture conditions. Hence, it may be misleading to determine „aircraft μ “ on the basis of the type and depth of contamination without taking account of the underlying surface, temperature, dew point, and that this can contribute to runway excursions as demonstrated in the AIBN“s investigations.

Based on the results of the investigations, it is believed that Airbus“ method of determining friction on various contaminants is even more uncertain than the conservative use of measured friction coefficients in line with the AIBN“s own findings (see Appendices G and J, chapters 12 and 13).

The AIBN supports Airbus“ general scepticism to the use of measured friction coefficients. However, friction measurements and estimates can be used more conservatively than the current ICAO rules and the SNOWTAM table would suggest. Hence, AIBN does not fully agree with Airbus“ view that *“there is no way to establish a clear correlation between the «reported μ » and the «effective μ »”*.

It is referred to 1.3.5.2 and 1.3.5.3 and Appendix G, in which various correlation curves are discussed. Based on the evaluation of the various correlation curves, AIBN has concluded that, together with the TC curve from 2004, the Kollerud curve from 1954 indicates that 'aircraft μ ' is in the order of 50 % of the measured friction coefficient (FC). Given the correct assumptions, ICAO and Bombardier“s correlation curves will give much the same results as Kollerud and TC“s curves. Hence, it is believed that conservative use of measured or estimated friction values may give acceptable results.

AIBN has investigated two incidents in Norway involving runway excursions by Airbus aircraft. In both cases, the findings show that the results of Airbus“ policy of defining a specific friction value associated with the specific type and depth of contaminant were overly optimistic. This contributed to the aircraft skidding off the runway.

2.5.5 Summary

The investigations show that the various aircraft manufacturers use different methods of calculating landing data on contaminated and slippery runways. The Boeing“s method based on conservative use of airplane braking coefficients (ABC) seems the most reliable

method. Boeing publishes advisory landing data on the basis of its own defined ABCs for the friction conditions GOOD, MEDIUM, POOR. The experience of Norwegian operations with the B737 over several years demonstrates that these procedures are acceptable. The investigations show that there is no scientific basis for replacing the three categories of the Boeing's table with the five categories of ICAO's SNOWTAM table or the proposed TALPA ARC matrix in its present form.

2.6 Norwegian regulations and guidelines for winter operations

2.6.1 Introduction

The evaluation of the Norwegian regulations and guidelines for winter operations is described below. AIBN has related the analysis to its own findings in its investigations of incidents and accidents on contaminated runways, and to the corresponding international guidelines.

2.6.2 Norwegian application of the ICAO SNOWTAM format

Norwegian regulations relating to winter maintenance are described in 1.7. In particular, AIBN would like to emphasise the wording of AIP Norway AD 1.2-5, SNOWTAM format Field H, as shown in Appendix F. It is a general warning concerning the uncertainty attached to the use of friction measuring devices, included in AIP Norway for several years but not duly taken into account. The investigations show that pilots, airport staff and the CAA Norway's personnel who approve the companies' operational procedures are not familiar with the warning.

The warning in the SNOWTAM format Field H describes several important conditions for the use of friction values.

- The SNOWTAM table was developed based on data collected during the last part of the 1950's on the basis of friction measurements on compact snow and ice. In principle; it is therefore not valid for other forms of contaminant.⁷⁵
- The use of friction values measured on wet snow and slush of up to 3 mm using a continuous friction measuring device (not a Tapley meter or other decelerometers) has gradually been accepted.⁷⁶
- A numerical expression cannot be acquired for the quality of the friction levels reported in SNOWTAM.
- Tests show that the accuracy indicated by the table cannot be acquired with today's friction measuring equipment. While the table states values to an accuracy of 1/100 (one hundredths), tests show that only values to an accuracy of 1/10 (one tenths) can have any operational value.

AIBN also refers to JAR OPS 1 Subpart G Section 2 IEM OPS 1.490(c)(3), item 2, (Appendix C), which addresses additional measures in connection with routine operations on contaminated runways in order to achieve "*an equivalent level of safety*".

⁷⁵ The actual table was developed during the Internordic Meeting in Stockholm in October 1959.

⁷⁶ This was justified by the introduction of the high pressure measuring tyre of the AERO type. In AIBN's view this has not been scientifically verified.

The findings confirm these cautions (see 1.1 and 1.2). The fact that the CAA Norway, Avinor and Norwegian operators insist on using the five-category SNOWTAM table conflicts with the 'safety first' principle. In light of the many winter related accidents and incidents in Norway this practice should be reviewed.

2.6.3 The Norwegian Civil Aviation Administration (LV)'s requirements for winter operations with DHC-8 on contaminated regional runways

The Norwegian Civil Aviation Administration (LV)'s requirements for winter operations with DHC-8 on contaminated runways in 1996-97 are described in 1.7.4 and included in Appendices K-1 to K-3 (Reference 15).

Norwegian Civil Aviation Administration has stated that „*DHC-8 requires a black runway for winter operations on short runways*” and that „*the conditions must not be poorer than wet*”. By „black runway” was meant a bare runway without contamination with $FC > 0.40$, and „*wet condition*” signified a normal FC of 0.40 which corresponded to GOOD braking action (see Table 2 in Appendix G)

The Aeronautical Inspection Department has used international rules as the basis (ICAO Annex 14/15). See Appendix B, section 6.6, and JAR OPS 1, Annex C, IEM OPS 1.490(c)(3), item 2, which clearly cautioned against routine operations on contaminated runways:

„An aerodrome must be adequately equipped so that the level of safety can be maintained, including during winter operations. This means that the aerodrome must be equipped so that the standard that forms the basis for the „black runway” safety assessment can be maintained. Operating at a reduced level of safety as a result of „contaminated runways” must only take place as an exception.”

It is evident from section 1.7.4 and Appendix K-2 (the Aeronautical Inspection Department's evaluation) that the Aeronautical Inspection Department believed that for the probability of a „*low speed overrun*” on contaminated regional runways not to exceed 10^{-6} in connection with Widerøe's winter operations, such an incident (runway excursion) should not occur more often than once every 7 years⁷⁷. In order to achieve this goal, the Aeronautical Inspection Department believed that targets should be set to the effect that 95 % of all operations per year and a minimum of 80 % of all operations per month should be carried out on a „black” runway. The Norwegian Civil Aviation Administration's own investigations (1996-97, Reference 15) show that none of the airports in the Norwegian counties of Finnmark and Nordland met these requirements.

The AIBN does not know of any updated figures concerning the percentage distribution of „black” runways on Norwegian regional runways per year / month, but, based on the number of reported incidents relating to slippery runways in the past decade, the AIBN believes that the conditions are much the same today as they were in 1996-97. Appendix J, chapter 15.3 supports these findings.

Based on updated figures relating to the number of aircraft movements on the regional runway network in 2009 (see 1.7.4), the probability of runway excursions remains unchanged since 1996-97. However, the AIBN has investigated two runway excursions on regional runways in the course of ten years, and two incidents relating to control

⁷⁷ The figure should be updated in the CAA Norway's safety analysis of Norwegian winter operations.

problems after landing on a slippery runway in crosswind conditions. These investigations indicate that the level of risk is higher than required by the Norwegian Civil Aviation Administration in 1996-97. This is reflected in that more than 5 % of all operations on an annual basis and more than 20 % of all operations on a monthly basis are carried out on winter-contaminated runways with a lower friction than a wet runway (GOOD).

The AIBN has not found that these requirements from the Aeronautical Inspection Department have been followed up by the CAA Norway or Avinor. Nor has any documentation been provided to show that compensatory measures have been implemented, thereby cancelling the requirements. The requirements seem to have gradually been forgotten as Widerøe gained experience of operations on contaminated regional runways. Based on the Aeronautical Inspection Department's evaluations and the AIBN's investigations into incidents on regional airports, the actual risk of runway excursions may be in excess of 1×10^{-6} .

Seen in light of the investigated accidents and incidents relating to contaminated runways, it may seem that the Aeronautical Inspection Department and the Norwegian Civil Aviation Administration made a reasonable and correct assessment stating realistic requirements for winter operations on short runways in 1996-97. However, the assessment was incorrect on one point: namely, that a measured $FC > 0.40$ should reflect a „black“ (bare) runway. Experience has proved that, under special conditions, measurements in excess of 0.40 (GOOD) may be recorded while the „aircraft μ “ is POOR (see 1.1.9, 1.1.13 and 1.1.19). AIBN also refers to ICAO Annex 14 (Appendix B) concerning uncertainty associated with the reporting of friction coefficients.

The ICAO Safety Management Manual, DOC. 9859 gives advice regarding the development of national safety standards and recommends that each State define an „acceptable level of safety“ (ALoS). Hence, CAA Norway is required to establish national ALoS. Such a safety level should be based on a general safety analysis/assessment of routine operations on contaminated and slippery runways. A consequence from this may be that special measures must be taken in order to achieve „an equivalent level of safety“ as with „summer“ operations. The Norwegian ALoS is an essential baseline for the national safety programme and thereby a performance based regularity agency. The CAA Norway seems to lack an overall risk assessment of winter operations as part of the State Safety Program (SSP).

A risk assessment should include risk factors other than contamination, such as crosswind, turbulence and available approach aids. Such a risk assessment carried out by the CAA Norway could determine what the probability of a „low speed overrun“ on contaminated runways is today, and, hence, contribute to realising the vision of being a risk-based supervisory authority. This may contribute towards fulfilling the ICAO requirement for a State defined „acceptable level of safety“.

2.6.4 The Civil Aviation Authority Norway's work relating to winter operations and friction measurements

As mentioned in section 1.1, AIBN has submitted many recommendations relating to operations on contaminated runways in the past decade. So far this has not resulted in any significant changes to the rules for winter operations in AIP Norway and CAR (BSL) E 4-1 and E 4-2 (see 1.7).

ICAO and EASA guidelines and regulations dictate that operations on contaminated and slippery runways should only be performed on a limited basis. If such operations are to be performed on a regular basis, the authorities require the operators to take special measures in order to acquire an „equivalent level of safety“ (interpreted as the level of safety with summer conditions). AIBN has found that the CAA Norway has not performed safety analyses / assessments to quantify levels of safety in connection with winter operations in Norway; hence, an „equivalent level of safety“ is unknown. The large numbers of occurrences in connection with Norwegian winter operations indicate that an „equivalent level of safety“ is not achieved.

On behalf of the Norwegian Ministry of Transport and Communications, the CAA Norway has not publicised any facts that lower safety margins are accepted for operations on contaminated runways than for operations on “black” runways. Thus it is expected that the same margins shall apply to operations on contaminated runways as to operations under summer conditions. Since it appears that an overall risk assessment has not been carried out, the lack of safety margins only becomes manifest under unforeseen circumstances (see Appendix C, IEM OPS 1.490(c)(3), item 2).

The referred Reference 22, Appendices S and T as discussed under 2.4.3 and 2.4.4 indicate that the operational guidelines for maintaining the required safety level when operating on contaminated and slippery runways, gradually has shifted towards an operational policy with less safety margins. This is in spite of the stated official requirement of maintaining an „equivalent level of safety“ by EASA, or an „acceptable level of safety“ as recommended by ICAO.

2.6.5 Summary

Based on accidents and incidents that have occurred in Norway during the past decade, the documented findings of the investigations and the many previous recommendations, AIBN believes that Norway should consider the introduction of separate limits for winter operations just as USA, Canada and UK have done. The climatic conditions in Norway differ substantially from those in other countries, and each individual country’s aviation authorities are responsible for supervising aviation in a manner that ensures „an *acceptable level of safety*“ as specified in the Norwegian safety programme. The above-mentioned countries have taken the consequences of this. Based on experience, it can take several years to revise ICAO’s regulations. ICAO and EASA’s documentation relating to friction contains guidelines and adopted physical simplifications that lack the necessary foundation in scientific research, or do not take account of Norwegian climatic conditions. The AIBN is under the impression that, in general, there has not been much focus on winter operations in Europe. This may be the result of the reduced snowfall experienced in Europe in recent years. However, the heavy snowfall during the last two winter seasons have renewed the focus on contaminated runways and AIBN hopes that this report may contribute to safer winter operations.

2.7 **International and national research and test programmes**

2.7.1 Introduction

During the past 60 years, test and research programmes have been carried out in several countries in order to develop measuring instruments for the determination of friction on contaminated and slippery winter runways. So far, attempts at finding a measuring

instrument that measure representative and reliable „aircraft μ “ values have been unsuccessful. Based on its own investigations, the AIBN has little faith in the possibility of developing a perfect friction measuring device. On the other hand, it is believed that it should be possible to develop a prediction („nowcast“) system for runway friction based on relevant meteorological measurements in combination with aircraft flight data. The AIBN's evaluation of the results of some of the research programmes is summed up below.

2.7.2 The Kollerud method

As early as in 1954, Kollerud concluded that „aircraft μ “ was 50 % of measured friction (see 1.8.5 and Appendix N). What is notable is that, 50 years later, the test results from JWRFMP in Canada are virtually the same (see Figure 18 or Figures 3 and 9 in Appendix G, and Reference 10). This is an indication of the challenge to find a perfect device for measuring „aircraft μ “ on frozen water in the form of snow and ice. This can be explained by the contamination not being homogenous and by „aircraft μ “ being largely dependent on temperature and surface moisture. The picture is further complicated by the foot print and ground pressure of the aircraft wheel tyres on the surface, tyre pressure, elasticity, hysteresis, temperature increase during braking (see Appendix J, chapter 03), and aircraft braking systems that include anti-skid and auto-braking. There is no way in which a friction measuring device can simulate all the forces that come into play during braking of an aircraft's wheels.

Other interesting data from the Kollerud's tests are the measured friction coefficients (in actual fact deceleration values converted to FCs) described in 1.8.5. They correspond well with the findings of the investigations (see 2.2). It is significant that Kollerud found the best measured friction value to correspond with $FC = 0.35$. It was measured on compact snow at temperatures below minus 4 °C. Based on Kollerud's correlation curve, this would correspond to an „aircraft μ “ of 0.17. This can be compared to the „effective μ “ of 0.20 used by EASA for compact snow, irrespective of temperature. The results of Kollerud's trials as reported in 1954 may be more trustworthy than EASA's current “default values”.

2.7.3 The Joint Winter Runway Friction Measurement Program (JWRFMP)

The Joint Winter Runway Friction Measurement Program (Canada 1995-2004) was briefly described in section 1.8.3. This research programme may be the most important winter programme for friction testing on contaminated runways since Kollerud conducted his trials in Norway in the 1940s and 1950s.

One of the objectives of the JWRFMP was to find an International Runway Friction Index (IRFI) with which all types of friction measuring devices could be correlated. An IRFI was in fact developed, but it has so far not been adopted by any state. The reason for this is that there is much uncertainties attached to the reliability of such correlations. This is a result of uncertainties attached to the use of each type of friction measuring device, uncertainties related to each individual friction measuring device, and uncertainties about the correlation between types of friction measuring devices and IRFI, and „aircraft μ “. Based on available information it is not practicable to determine a friction value on a contaminated runway by means of an IRFI. Another consideration is that friction on contaminated runways is to some degree dependent on the climate. Runway contaminants may become more slippery than expected as a result of high water content in the snow, a

high salt content in precipitation or chemical residues on the runway, and by strong crosswinds. The method of the above-mentioned type could result in an even greater gap between measured FC and „aircraft μ “, compared with the current values based on conservative application of TC's and Kollerud's correlation curves.

2.7.4 SWOP

The Safe Winter Operations Project (SWOP) is briefly described in 1.8.7 (Reference 12). The CAA Norway and AIBN were observers to this Norwegian winter programme conducted by Avinor. AIBN took a positive view of the project, which, in principle, had great potential. However, the results were disappointing. The analysis of the data warranted some optimism in that a degree of correlation could be traced between the "weather model" and aircraft braking action. AIBN was very satisfied that the results of the project were used as the basis for a continued new Norwegian winter project; the Integrated Runway Information System (IRIS).

2.7.5 IRIS

The project Integrated Runway Information System (IRIS) is described in section 1.8.8 (Reference 13). As in the case of SWOP, the CAA Norway and AIBN were observers to the project. Based on what was achieved in 2009 and 2010, the project looks very promising. AIBN has concluded that a continued focus on development of friction measurements serve little purpose, and has long held the view that a method should be found whereby the runway's friction properties ("slipperiness") should be predicted („nowcasted“) on the basis of actual relevant measured meteorological conditions. The IRIS concept, which integrates three "models" – a weather model, a runway model and an aircraft model – could be a good basis for a "nowcast" model for the prediction of friction on contaminated runway surfaces on the basis of relevant meteorological real-time measurements. As indicated in 1.8.8 the project results as shown in Figure 19 the measured „aircraft μ “ from B737 during the IRIS trial show the spread in ABC in the ranges of GOOD ($ABC \geq 0.20$), MEDIUM ($ABC 0.10 - 0.19$) and POOR ($ABC < 0.10$) under wet or moist conditions. It is important to note that these are actual values recorded during the landing, and not the predicted values. The spread in actual ABC's is a confirmation of the uncertainties attached to the prediction of the friction on contaminated and slippery runways. These landings are based on advisory landing data from the manufacturers for predicted runway friction. Compare this to operations on bare and dry runways where the landing data are based on safety factor of 1.67, max manual braking and no reverse thrust. Hence, the safety margins are much higher during summer conditions. Figure 19 shows that most of the „aircraft μ “ values will be in the MEDIUM category (0.10-0.19), while comparatively smaller numbers will fall in the POOR (0.05-0.09) and GOOD (>0.20) categories. If the friction level was predicted as MEDIUM and proved to be GOOD during the landing, this should be valued as a safety margin just as when landing on bare and dry runways. Hence, the safety margins will be higher. The important point here is the uncertainty of friction prediction, while the data presented in Figure 19 is „after the fact“ (actual data). As referred to in chapter 1.1 runway excursions became the result when the friction predictions before landings were too optimistic. A developed IRIS system may facilitate a more accurate prediction („nowcast“) of the friction on contaminated and slippery runways.

2.7.6 Research project, Alex Klein-Paste, Norwegian University of Science and Technology (NTNU) 2007

This research project and some of the results are described in section 1.8.9 (Reference 17). The results of this research project are scientific confirmations of the AIBN's findings in its own investigations, and support Dr. Mook's theoretical analyses in Appendix J, chapters 02, 07, 12, 13 and 14.

The research project found that in 66 % of the cases in which runways had been treated with warm pre-wetted sand („fixed sand”), the „aircraft μ ” was poorer than indicated by the friction measurements.

In several of its investigations, the AIBN has stressed the uncertainty that is attached to friction measurements. The above-mentioned research findings reinforce this uncertainty as shown in Table 1 and in Figure 10 in Appendix G, and the basis for the caution in AIP Norway (Appendix F).

AIBN refers to three of its own investigations (see 1.1.9, 1.1.13 and 1.1.19) which showed how friction on runways on which friction was in principle good after preparation with warm pre-wetted sand („fixed sand”), could gradually deteriorate as a consequence of moisture settling on the sand grains or a strong crosswind on the runway. Crosswind conditions have proved to result in very slippery runways as a result of “polishing” of the runway and „planing” of the aircraft wheels on a layer of ice crystals (Appendix J, chapter 11).

What was significant about the three above-mentioned incidents was that these phenomena had not previously been known. What AIBN found alarming was that the friction measurements (BV-11/SKH) had shown values of more than 0.40 (GOOD), while the „aircraft μ ” was POOR. The consequences of such a disparity between reported friction values and „aircraft μ ” constitute a serious risk factor.

AIBN would also like to refer to the results of Dr. Klein-Paste's research, which demonstrated that „*friction provided by rubber-ice interaction is very vulnerable to snow contamination.*”

These research findings confirm the findings of the AIBN's own investigations and confirm Dr. Mook's theoretical analyses (and research at Svalbard) that all precipitation in the form of snow contains moisture, even at low temperatures (see Appendix J, chapter 04). A thin layer of snow on ice works as a lubricating layer, even if the snow is defined as being “dry”. This also corresponds to Table 1 and Figure 10 in Appendix G and to TC's link (see 1.3.4 AIP Canada).

2.8 **The AIBN's safety recommendations since 1999, relating to slippery runways**

Section 1.1 refers to the safety recommendations relating to contaminated/slippery runways submitted by AIBN since 1999. Of 36 safety recommendations including 9 immediate, 4 immediate and 4 regular safety recommendations remain open⁷⁸. Even though 28 recommendations have been closed, the risk of winter related occurrences seems unchanged. The many incidents investigated by the AIBN have not involved any

⁷⁸ In this context, “open” means that the AIBN has not received confirmation from the Norwegian Ministry of Transport and Communications' that the recommendations have been 'closed'.

fatalities. The parties involved may therefore have been lulled into overlooking the great risk potential of such incidents and accidents. Reference is made to the accident at Stord Airport (see the published intermediate factual report www.aibn.no/luftfart/rapporter/06-470) where an aircraft excursion from a bare, but moist, runway at slow speed had fatal consequences. The accident was not winter related but illustrates the potential of fatal accidents at runway excursions on some of the Norwegian runways located in uneven terrain.

The measures that have been implemented have not, so far, reduced the trend as far as incidents relating to contaminated and slippery runways are concerned. The safety of Norwegian winter operations can and should be improved.

The role of the CAA Norway has changed considerably since 1999. At present, the CAA Norway claims that its supervision is risk-based. Such supervision is conditional on the actual risk level being known, so that its acceptability can be evaluated and the development of the risk level monitored. AIBN is not aware of any risk levels having been defined for neither dry nor contaminated runways (ref. ICAO SMS Manual, State Safety Program (SSP) and Acceptable Level of Safety (ALoS)). In light of this, the process surrounding the closure of all the recommendations relating to contaminated runways seems to have been inadequate.

AIBN is aware of that Avinor, on its own initiative, conducted a risk analysis relating to Hammerfest Airport following the accident with the LN-WIK (AIBN Report 2009/07). That analysis showed that, under the prevailing conditions, operations were carried out at a significantly higher risk level than acceptable. The analysis described measures to reduce risk. It would be in accordance with the principles for risk-based supervision of aviation to conduct such risk analyses relating to Norwegian practice surrounding winter operations on both regional and main airports (including short and long runways).

AIBN has demonstrated that there are several conflicting international guidelines for winter operations on contaminated runways and believes that improvement should be based on international rules and regulations. On the other hand, Norway experiences special conditions during winter with frequently changing temperatures, a humid climate and strong winds, turbulence, gusty crosswinds and lack of precision approach guidance at many airports. These conditions are seen as contributory factors to the many incidents in Norway during winter operations. In the absence of international improvements, and supplemental to international guidelines, Norway should amend its national framework for winter operations pending a scientifically based revision of ICAO's guidelines and actual verified improvements.

As referred to in 1.7.5 CAA Norway has stated that they will not change the national regulations before EASA regulations are revised in 2013. In the mean time national winter operations will be guided by AIC 08/09, or „continue as usual“. Based on past experience and own investigations, AIBN believes this may not prevent further runway excursions from contaminated and slippery runways. The policy does not seem to be in line with ICAO SMS Manual with reference to a SSP and a state ALoS. AIBN interprets the ICAO SMS Manual as individual states are required to adjust the international (ICAO) guidelines and regulations (EASA) to fit national winter conditions. Based on experience and own investigations AIBN has seen that winter conditions differ largely between countries. Therefore it has been concluded that „one fits all“ type of winter regulations (EASA) may not lead to a national „*acceptable level of safety*“.

3. CONCLUSIONS

In the 30 investigated occurrences, the AIBN found that the aircraft braking coefficient (ABC) was not in accordance with the measured/estimated runway friction coefficients (FC). The AIBN has identified numerous common factors that have reduced the safety margins and factors that explain the differences between ABC and FC. These factors are related to meteorological conditions and friction measurement uncertainty, runway treatment, operational aspects and regulatory conditions:

3.1 Central findings

3.1.1 Meteorological conditions and friction measurement uncertainty

The '3-Kelvin-spread-rule': Moisture in combination with contaminated runways plays a more significant role in relation to „slipperiness“ than previously understood. In most occurrences the difference between the air temperature and dew point (at 2 m height above the runway surface - METAR values) was ≤ 3 Kelvin. This is referred to as the „3-Kelvin-spread-rule“ and indicates that the humidity is 80 % or more.

Correlation: The difference between measured/estimated runway friction coefficients (FC) and airplane braking coefficients (ABC) is particularly great under certain meteorological conditions. Layered contaminants, wet and moist conditions, air temperature, dewpoint temperature, sanding and strong crosswinds are important factors. The correlation, when measured on „dry“ compact snow or ice, between measured friction coefficient (FC) and experienced airplane braking coefficient (ABC) is in the order of 0.5 of measured FC. On all other types of contaminations there is no consistent correlation.

Friction measuring devices: Validity ranges for friction measuring devices lack the necessary scientific basis. The various types of friction measuring devices measure different friction values when used on the same surface. None of the internationally improved friction measuring devices are reliable on all types of contaminations. In particular, moisture and less than 3 K dew point spread and loose/layered contaminations increase the friction measurement uncertainty.

Safety indicators: There is an apparent correlation between the observed meteorological conditions and runway slipperiness. The measured friction coefficient should be considered on the basis of temperature, dew point, precipitation and the history of these parameter values (weather history). These factors can be used as practical „safety indicators“ for assessing runway friction.

3.1.2 Runway treatment

There has been limited scientific research and inadequate approval by the authorities concerning friction-improving means - both related to sanding and the use of chemicals.

Sanding on wet and compact snow or ice, and sanding of loose layers of material in the form of slush, wet or dry snow on top of compact snow or ice, is not very effective. Friction measuring devices measure friction values that are too high when used on such surfaces.

Chemicals: A challenge associated with the use of chemicals is that melting snow and ice results in wet and mixed contamination so that friction is reduced until the contaminant is fully melted. In addition water from melted snow and ice dilute the chemical liquid, so that it can freeze and form invisible ice ("black ice").

3.1.3 Operational aspects

Uncertainty: The airport owner, pilots, airport staff and the CAA Norway, who approve the airlines' and airports' procedures, do not take into account the uncertainty attached to the use of friction measurements and estimation of friction on contaminated runways. Independent of the friction measuring device used, included in wet/moist conditions, measured friction values are reported, trusted and used to an accuracy of one hundredths (1/100). This is in conflict with AIP Norway AD 1.2 which describes that an accuracy/uncertainty only in tenths can be of operational value.

Input to CPCs: The combined use of two very uncertain parameters (uncertain friction values stated in hundredths (1/100) and wind direction and wind force) when calculating landing distances by means of cockpit performance computers (CPCs) could cause aircraft to land in too strong crosswinds in relation to the available friction. The use of measured friction values and CPCs tends to give pilots a false feeling that they are using scientific data.

Instantaneous wind data: In five (5) of the 30 incidents investigated by the AIBN, the aircraft crew based their landing calculations on the TWR's instant wind speed readings (average 2-minute or 3 sec wind speed), which was more favourable for landing than the relevant METAR wind (average 10-minute wind). During the landing, the actual wind was similar to the reported and stronger METAR wind. This resulted in loss of directional control. Instantaneous wind data should not be used for landing calculations, but should be monitored during the approach to ensure that the wind speed does not exceed the basis for the landing calculations.

Crosswind: 19 of 30 investigated incidents occurred in conditions of crosswind in combination with slippery runways. Crosswind has a major impact on directional stability during the landing roll. The aircraft manufacturers have defined recommended crosswind limits which are not included in the basis for the certification of the respective aircraft. Transport Canada's table of crosswind versus friction values is far more conservative than the tables used by Norwegian airlines.

Correlation curves/tables: The various aircraft manufacturers have different policies for operations on contaminated runways and therefore the airlines use different correlation curves/tables. In several instances the curves/tables have an uncertain basis and result in highly unreliable braking coefficients for the relevant type of aircraft. Boeing's method, which is based on conservative use of airplane braking coefficients (ABC), provides the greatest safety margin compared with the methods of Bombardier and Airbus.

3.1.4 Regulatory conditions

International guidelines: ICAO's and EASA's documentation include guidelines and assumptions that are too optimistic and only to a limited degree founded on scientific evidence. International guidelines do not take into account the Norwegian climatic

conditions. Norway should consider introducing national limitations for winter operations, just as USA, Canada and UK have done.

Thrust reversers: Reverse thrust represents approximately 20 % of the total available braking force when braking on a slippery runway. The international guidelines for operation on contaminated runways are not in accordance with the strict requirements for certification of aircraft which are based on documented performance on dry runways without the use of thrust reversers. Nevertheless, operations on contaminated runways are permitted on the basis of „advisory“ (not „certified“) friction data and the use of thrust reversers. EASA has regulated that consideration of engine failure during landing should be considered, but this is not adhered to. Hence, the extra safety margin that the reverse thrust would constitute is not available.

The ICAO Safety Management Manual, gives advice regarding the development of national safety standards. In this respect ICAO recommends that each State define an „acceptable level of safety“ (ALoS). Based on experience and knowledge gained from own investigations AIBN has concluded that the Norwegian climate and operating conditions requires adjustments to the general ICAO framework. Hence, Norway is required to establish national ALoS. Such a safety level should be based on a general safety analysis/assessment of routine operations on contaminated and slippery runways. A consequence from this may be that special measures must be taken in order to achieve „an equivalent level of safety“ as with „summer“ operations. The Norwegian ALoS is an essential baseline for the national safety programme and thereby a performance based regularity agency. The CAA Norway seems to lack an overall risk assessment of winter operations as part of the State Safety Program (SSP).

The ICAO Airport Services Manual, on which the Norwegian rules relating to friction measurements, reporting and the use of friction data are based, is generally outdated and not very appropriate as support for today's winter operations. The manual should describe in more detail the newer types of friction measuring devices, the limitations that apply to measurement on moist contamination, requirements for sand, sand application, requirements for de-ice and anti-ice chemicals and the use of chemicals, and updated information on expected friction on different types and depths of contamination.

The ICAO SNOWTAM table: The uncertainty in predicting the correct friction level is also applicable to the estimation of the friction category from 1 to 5 as per ICAO SNOWTAM format. The figures in the ICAO SNOWTAM table showing measured friction values are in hundredths (1/100) and are independent of the type of friction measuring device that is used. AIP Norway describes the use of friction measuring devices in general and warns that the measurements are associated with such a high degree of uncertainty that the figures should not be reported to more than one decimal place (one tenth, 1/10). The figures from the SNOWTAM table are used in flight operations through the airlines' individual correlation curves/tables which further increases the uncertainty.

EASA's certification requirements are optimistic and not in accordance with the findings of the AIBN's investigations. They use default friction values for various contaminants, irrespective of temperature and dew point, and permit conversion between various types of depths of contamination on the basis of „water equivalent depth“ (WED) using a speed-based formula.

3.2 Conclusions

The AIBN believes that incidents relating to slippery runways occur because the involved parties do not realise that existing rules and regulations are based on a simplification of the actual physical conditions. The measured/estimated friction values are used as scientific truths and not compared to other meteorological conditions („safety indicators“). The safety margins are reduced by operational procedures which to a limited degree take into account the uncertainties connected to input parameters used for landing distance calculations. The AIBN’s findings are supported by research programmes and studies.

The AIBN findings show that the national regulations governing operations on contaminated and slippery runways are less strict than those that govern operations in summer conditions. This is in spite of the ICAO and EASA guidelines and regulations which prescribe that if winter operations are to be performed on a regular basis, the authorities require the operators to take special measures in order to attain an „*equivalent level of safety*“ to summer conditions.

The many incidents and accidents relating to contaminated and slippery winter runways, reveal that an “equivalent level of safety” is not achieved in connection with Norwegian winter operations. The CAA Norway seems to lack an overall risk assessment quantifying the level of safety of winter operations as part of the State Safety Program (SSP) and establishment of an Acceptable Level of Safety (ALoS).

4. SAFETY RECOMMENDATIONS

Based on the analyses presented in this theme report, the Accident Investigation Board Norway (AIBN) had decided to uphold its immediate recommendations from 2006 in a revised form.

The Accident Investigation Board Norway proposes the following safety recommendations.⁷⁹

Safety recommendation 2011/07T

The many incidents and accidents relating to contaminated and slippery winter runways, reveal that an “equivalent level of safety” to summer conditions is not maintained in connection with Norwegian winter operations. The CAA Norway seems to lack an overall risk assessment of winter operations as part of the State Safety Program (SSP) and establishment of an Acceptable Level of Safety (ALoS). The AIBN recommends that the CAA Norway carries out risk assessments and considers introducing national limitations of winter operations in order to ensure an „equivalent level of safety“.

Safety recommendation 2011/08T (replaces SL 06/1350-1).

In the investigated occurrences, the AIBN found that the aircraft braking coefficients were not in accordance with the measured and reported values. Validity ranges for friction measuring devices lack the necessary scientific basis. The various types of friction measuring devices measure different friction values when used on the same surface. None of the internationally approved friction measurements devices are reliable on all types of contaminations. In particular, moisture and less than 3 K dew point spread and loose/layered contaminations increase the friction measurement uncertainty. The AIBN recommends that ICAO, FAA, EASA and CAA Norway review and validate the permitted measuring (validity) ranges for approved friction measuring devices.

Safety recommendation 2011/09T (replaces SL 06/1350-2).

The figures in the ICAO SNOWTAM table showing measured friction values are in hundredths (1/100) and independent of the type of friction measuring device that is used. AIP Norway describes the use of friction measuring devices in general and warns that the measurements are associated with such a high degree of uncertainty that the figures should not be reported to more than one decimal place (one tenth, 1/10). The figures from the SNOWTAM table are used in flight operations through the airlines’ individual correlation curves/tables which further increases the uncertainty. Based on the above, the AIBN recommends that ICAO, FAA, EASA and CAA Norway consider revising the SNOWTAM table to reduce the degree of friction uncertainty.

Safety recommendation 2011/10T (replaces SL 06/1350-3).

Reverse thrust represents approximately 20 % of the total available braking force when braking on a slippery runway. Operations on contaminated runways are permitted on the basis of „advisory“ (not „certified“) friction data and the use of thrust reversers. EASA has regulated that consideration of engine failure during landing should be considered, but this is not adhered to. Hence, the extra safety margin that the reverse thrust would

⁷⁹ The Ministry of Transport and Communications takes due steps to ensure that safety recommendations are submitted to the aviation authorities and/or other relevant departments for evaluation and follow-up, cf. Regulations on public investigation of accidents and incidents in civil aviation, section 17.

constitute is not available. The AIBN recommends that FAA, EASA and CAA Norway consider, on the basis of risk assessments, whether all available reverse thrust should continue to be included in part or in whole when calculating the required landing distance on contaminated and slippery runways.

Safety recommendation 2011/11T (replaces SL 06/1350-4).

In 19 of 30 incidents, conditions of slippery runways combined with crosswind were present. The aircraft manufacturers have defined recommended crosswind limits which are not included in the basis for certification of the respective aircrafts. Transport Canada's table of crosswind versus friction values is far more conservative than the tables used by Norwegian airlines. The AIBN recommends that FAA, EASA and CAA Norway evaluate the airlines' crosswind limits in relation to friction values and consider whether they should be subject to separate approval by the authorities.

Safety recommendation 2011/12T.

EASA's certification requirements use default friction values for various contaminants, irrespective of temperature and dew point, and permit conversion between various types and depths of contamination on the basis of "water equivalent depth" (WED) using a speed-based formula. EASA's certification requirements are optimistic and not in accordance with the findings of the AIBN's investigations. The AIBN recommends that EASA considers a more conservative determination of friction values on various types and depths of contamination.

Safety recommendation 2011/13T.

The ICAO Airport Services Manual is generally outdated and not very appropriate as support for today's winter operations. The manual should describe in more detail the newer types of friction measuring devices, the limitations that apply to measurement on moist contamination, requirements for sand, sand application, requirements for de-ice and anti-ice chemicals and the use of chemicals, and updated information on expected friction on different types and depths of contamination. The AIBN recommends that ICAO initiate an updating and revision of the Airport Services Manual on the basis of the results of investigations of runway excursions and recent research findings.

The Accident Investigation Board Norway

Lillestrøm, 5 May 2011

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