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RuFAB - Runway friction characteristics measurement and aircraft braking

Volume 4

Operational Friction Measurement and Runway Condition Reporting.



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RUNWAY FRICTION CHARACTERISTICS MEASUREMENT
AND AIRCRAFT BRAKING (RuFAB)

DRAFT FINAL REPORT
VOLUME 4 – OPERATIONAL FRICTION MEASUREMENTS
AND RUNWAY CONDITION REPORTING

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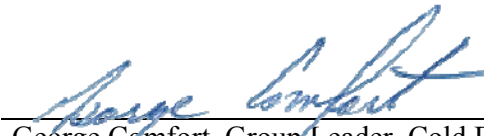
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ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ABS	Anti-Lock Braking System
AFM	Aircraft Flight Manual
AIP	Aeronautical Information Publication
AIS	Aeronautical Information Services
AMS	Aircraft Movement Surface
AMSCR	Aircraft Movement Surface Condition Report
AS	Aerospace Standard
ASTM	American Society for Testing and Materials
ATC	Air Traffic Control
ATS	Air Transport Services
BA	Braking Action
CAA	Civil Aviation Authority
CARAC	Canadian Aviation Regulatory Advisory Council
CAT	Clear Air Turbulence
CFM	Continuous Friction Measurement
CFME	Continuous Friction Measurement Equipment
cm	Centimetre(s)
COTS	Common Off The Shelf
CRFI	Canadian Runway Friction Index
DGAC	Direction Générale de l'Aviation Civile (France)
EASA	European Aviation Safety Agency
EFB	Electronic Flight Bag
ERD	Electronic Recording Decelerometer
ESDU	Engineering Sciences Data Unit
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAA	Federal Aviation Administration
FAST	Fixed Automated Spray Technology
FLI	Forward-Looking Interferometer
FOD	Foreign Object Debris
FOVE	Flight Operations Versatile Environment
FTF	Friction Task Force
FTS	Fourier Transform Spectrometry
GFMD	Ground Friction Measuring Device
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IFI	International Friction Index
IR	InfraRed
IRFI	International Runway Friction Index
IST	Information Society Technologies
ITTV	Instrumented Tire Test Vehicle
JWRFMP	Joint Winter Runway Friction Measurement Program
km	Kilometre(s)
km/h	Kilometre(s) per Hour
kPa	Kilopascal(s)

kts	Knot(s)
LAHSO	Land And Hold Short aircraft Operations
LD	Landing Distance
LLTT	Landing Loads Test Track
LPC	Less Paper in the Cockpit
LSoC	Loose Snow on Compact Snow
LSoCP	Loose Snow on Compact Snow Patches
LSoI	Loose Snow on Ice
LSoIP	Loose Snow on Ice Patches
m	Metre(s)
MAL	Maintenance Action Level
MPL	Minimum Planning Level
MIRA	Motor Industry Research Association
mm	Millimetre(s)
mph	Miles Per Hour
MTO	Ministry of Transportation of Ontario
NASA	National Aeronautics and Space Administration
NCAA	Norwegian Civil Aviation Authority (Avinor)
NOTAM	NOTice to AirMen
NRC	National Research Council
NTSB	National Transportation Safety Board
OBC	OnBoard Computer
PIARC	Permanent International Association of Road Congresses
PIREPS	Pilot Reports
psi	Pounds per Square Inch
R&D	Research and Development
RCR	Runway Condition Reading
RFT	Runway Friction Tester
RI	Runway Inspector
ROAR	Road Analyzer and Recorder
RuFAB	Runway Friction Characteristics Measurement and Aircraft Braking
RWIS	Runway Weather Information System
SAE	Society of Automotive Engineers
SCRIM	Sideway-Force Coefficient Routine Investigation Machine
SFT	Surface Friction Tester
SNIC	Snow Removal and Ice Control
SNOWTAM	Snow Warning To Airmen
SoIP	Slush on Ice Patches
SPAR	Spectral Analysis Imaging
STBA	Société Technique des Base Aérienne (France)
SWIFT	Summer Winter Integrated Field Technologies
TALPA ARC	Takeoff And Landing Performance Assessment Aviation Rulemaking Committee
TC	Transport Canada
TP	Technical Publication
TWO	Traction Watcher One
UHF	Ultra High Frequency
UK	United Kingdom
US	United States

USA	United States of America
VHF	Very High Frequency
WiFi	Wireless Fidelity (IEEE 802.11b/g/n wireless networking)
WoC	Water on Compact Snow
WoCP	Water on Compact Snow Patches
WSDDM	Weather Support to De-icing Decision Making

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EXECUTIVE SUMMARY

Introduction

This report constitutes the final submission under EASA Contract No. EASA.2008.C46 for the Runway Friction Characteristics Measurement and Aircraft Braking (RuFAB) study, which was sponsored by the European Aviation Safety Authority (EASA) to investigate and harmonize:

- (a) Terminologies for runway surface conditions, related to functional and operational friction characteristics;
- (b) Functional characteristics as they relate to friction measurement reporting; and
- (c) Operational characteristics as they relate to runway surface condition assessment and reporting, friction measurement, and aircraft braking.

The overall objective of the work was to provide recommendations regarding the assessment of runway friction characteristics and Runway Condition Reporting (RCR). This is a broad subject, and thus, the project had several specific objectives, as generally summarized below:

- (a) To conduct a broad information-gathering effort to determine the current state-of-practice.
- (b) To compare the various approaches and definitions used for RCR and to suggest approaches for harmonizing them.
- (c) To compare the various approaches used for assessing functional friction characteristics and to suggest approaches for harmonizing them. This included an evaluation of past approaches for harmonizing the readings from ground friction-measuring devices, and recommendations for an updated device equivalency table (to Table A-1 in ICAO Annex 14, Volume 1).
- (d) To compare the various approaches used for assessing operational friction characteristics and to suggest approaches for harmonizing them.

This is Volume 4 of a four-volume series of reports describing the project as follows: (a) Volume 1 – Summary of Findings and Recommendations; (b) Volume 2 - Documentation and Taxonomy; (c) Volume 3 - Functional Friction; and (d) Volume 4 - Operational Friction.

It should be noted that recommendations are only presented in Volume 1.

Runway Surface Condition Assessment

The TALPA ARC concept for operational performance on winter contaminated runways is a major condition reporting and interpretation initiative which will result in significant changes to current airport operations if it is put into practice. If this were adopted by EASA, its member-states, air carriers, and airports would be directly affected and there would be a direct influence on the standards used.

There is a deficiency at airports regarding the information that aircraft operators require to effectively manage landing and take-off manoeuvres on contaminated runways. Airports try to err on the side of providing too much information rather than too little.

Current regulations lack sufficient detail for unambiguous interpretation. Enhancement of regulations addressing the following aspects of condition inspection would provide clearer direction to airports and improve the consistency and accuracy of operational condition reporting:

- (a) Contaminant definitions (addressed in detail in Volume 2 of this report) – Clear direction to airport operating authorities and RIs is required on the source of contaminant definitions to be used in operational condition reports.
- (b) AMS assessment frequency – Clearer direction is needed regarding the permissible intervals between operational inspections, especially during rapidly changing conditions.
- (c) RI qualifications - Restricting AMS inspection and reporting duties to qualified staff would significantly increase confidence in reported information.
- (d) Condition estimating techniques - Few if any references can be found regarding runway condition estimating techniques. Documented requirements would promote uniformity in reporting.
- (e) RI training and testing - Having RIs complete training that meets specific standards and providing direction on training content, retention of records, requirements for cyclical requalification, and other related issues would help to standardize inspection procedures and address some of the human factor issues discussed elsewhere in this report.
- (f) Auditing of airports' internal directions on runway inspection procedures - Auditing by regulators of airport operating authorities' internal procedures, systems and other related components of the inspection and reporting process would promote compliance with common standards.

Improved direction and advice is required to airport operating authorities regarding interpretation and accuracy of reporting terminology, contaminant measurement and location, and the reporting of layered contaminants.

Human factors have a significant influence on the accuracy and timeliness of condition reports. Direction and advice to airports would assist them in recognizing and managing the related issues.

Clear direction to airports is required regarding the need to close contaminated runways for maintenance purposes and to act in consort with the air navigation service provider to ensure there is sufficient runway access and time to perform complete, uninterrupted runway inspections, especially during inclement weather.

Runway Condition Reporting

In the overwhelming majority of cases, formal operational condition reporting takes place only in winter. Airports structure their operations on the premise that this is when the requirement exists; however the requirement for reporting of contaminants, etc. exists year-round. Direction is required on year-round reporting of contaminated runways.

There is inconsistency in direction to airports and in airports' interpretation of the reportable condition parameters, the required degree of accuracy, the reporting frequency, report scheduling, and the criteria for issuing new reports.

The current ICAO SNOWTAM format and related directions for its completion should be updated to bring them in line with current definitions and condition reporting requirements for consistency and clarity.

Norway has instituted direct electronic issuance of SNOWTAMS by RIs from the runway inspection vehicle, including data verification. Although checks are provided by the ANS through an intelligent computer program, air traffic controllers and flight service specialists are not required to handle the reports. This has resulted in SNOWTAMS being published within 20 seconds of the RCR being filed, which is a major improvement in timeliness. Sweden is currently trialing the process.

Technologies for Runway Condition Measurement

At present, there is a strong need for accurate reporting of the runway condition itself, with respect to parameters such as the contaminant type, the contaminant depth, cleared width, etc. This is evident from various sources, including the surveys done by questionnaire in this project (which are described in Volume 2). The TALPA ARC initiative is trending towards de-emphasizing ground friction measurements and recommending that instead RCR be focussed on descriptions of the runway. The ICAO FTF was unable to reach consensus regarding the most appropriate role for ground friction measurements although the FTF agreed that a global reporting format is required. This will produce an even stronger need for accurate reporting of the runway conditions.

Currently, there are few if any tools available to airports to assist them in quantifying runway conditions. The only measuring tools at present are crude instruments, such as rulers or threshold gauges to measure contaminant depth. Consequently, a long time is required to make measurements, which makes this approach unsuitable at a high-volume operational airport. As a result, practically all information related to the runway surface condition is estimated visually at present.

The credibility of the runway surface condition assessment process would be improved if equipment were available which could identify the contaminants on the runway and which could quantify the contaminants in terms such as depths, cleared widths, contaminant patches, etc.

A technology review was conducted. No off-the-shelf equipment was found that would allow the important runway surface condition parameters (contaminant type, contaminant depth, cleared width, contaminant location, cleared width offset, area coverage, etc.) to be measured with sufficient accuracy and rapidity to fulfill operational runway condition reporting requirements.

With regard to availability of systems related to condition measurement and reporting, with few exceptions, the historical practice has been for manufacturers to independently develop a product that they consider would be beneficial to airports. This product would then be field-tested by staff at airports to determine the effectiveness and usefulness of the product. The result is general a product which works to some extent. It is perhaps time for airports and the aviation community to clearly define requirements and work jointly with the manufacturers in development of new products.

A number of relevant research programs have recently been conducted, which offer potential (Table Ex-1). These should be monitored and perhaps encouraged.

Table Ex-1: Potential Applicability of Sensing Technologies

	Maintained Path Width	Maintained Path Offset	Contaminant Type	Contaminant Location	Contaminant Depth
Spectral analysis imaging (SPAR)	Yes	Yes	Yes	Yes	
Near infrared imaging (Vaisala DSC111)	Yes	Yes	Yes	Yes	
Infrared temperature sensing (Vaisala DST111)			Yes	Yes	
Lateral laser scanning (IST ALASCA)	Yes	Yes	Yes	Yes	Yes
Vehicle mounted radar (IST or similar)	Yes	Yes		Yes	
Differential GPS (COTS)		Yes		Yes	
Stereo polarization imaging (IST Road Eye sensor or similar)	Yes	Yes	Yes	Yes	
Contaminant Impact energy measurement (Vestabill modified Mu-meter)			Yes		Yes
Forward Looking Interferometer (NASA/Georgia Tech/Hampton University)	Yes	Yes	Yes	Yes	
Laser Depth Profiling (SnowMetrix)					Yes

Friction-Related Information

The Friction-Related Information that Is Reported

Countries differ with respect to the type of information that is provided to pilots. Some countries provide the measured friction values while others only provide general indications of braking action according to the ICAO scale. It is noteworthy that the results from the questionnaire survey assigned a lower priority to general braking action indications compared to the measured friction values themselves.

The AIPs of many countries contain warnings regarding the limitations of ground friction-measuring devices. It is generally recognized that (a) that they are most suitable for “solid” surfaces (such as compacted snow and ice); and (b) that they are unreliable for “liquid-type” surfaces (water, slush, de-icing chemicals, wet snow, etc.).

Pilot REports (PIREPs) were also identified during the questionnaire survey as important information, with high priority. PIREPS provide good information on the aircraft's ability to brake on that particular surface. These reports however, are subjective and aircraft- and time-dependent. The TALPA ARC has recognized the value of PIREPS formally, albeit not as a primary information source, but as information that can be used to downgrade assessments based on the surface conditions.

General Views of the Aviation Community Regarding Friction Measurements

It was found that there is a divergence of views regarding the role that friction measurements can play for operational applications:

- (a) The TALPA ARC's recommendations are headed towards de-emphasizing friction measurements and, instead, they are recommending that RCR efforts be focused on defining the runway surface itself for operational evaluations of aircraft performance. This indicates that a large part of the general aviation community feels that RCR emphasis should be refocused from friction measurement to observations of physical condition parameters.
- (b) The ICAO FTF agreed that a global reporting format is required although consensus could not be reached regarding the methods to reach this goal. There was a divergence of views regarding the role that friction measurements should play for operational assessments. As a result, the option was left open for States to report the friction coefficient. The use of this option would require additional information in the State's AIP describing the approved friction-measuring system and the basic parameters associated with the ground friction measurement.
- (c) Some airlines utilize ground friction measurements as an important input for making operational assessments of aircraft performance. It is noted though, that these airlines use the friction data in an advisory role only. Also, they only include one device; and they limit their usage to data on surfaces where the readings are considered to be reliable. This leaves a gap as the current devices are not suitable for all surfaces.

In summary, many stakeholders are reluctant to accept friction-measurements as a primary information source, or as a useful information source. On the other hand, some pilots, carriers and regulators consider friction measurements from a single device family to be of significant value.

It should be noted that this situation refers to friction measurements as they are performed at present. This should not necessarily be construed to mean that friction measurements are not useful potentially.

Past Test Programs Related to Operational Friction Measurements

The Joint Winter Runway Friction Measurement Program (JWRFMP) was the most extensive test program conducted to date for winter surfaces, although tests were done prior to it by NASA:

- (a) The JWRFMP showed that the presently-available devices produced different friction numbers when operated on the same contaminated surfaces at the same time. A common reporting index (i.e., the International Runway Friction Index – IRFI) was established for the devices for a limited range of surfaces (i.e., compacted snow and ice), although it contained scatter.
- (b) The JWRFMP showed that a ground friction measurement could be related to aircraft braking performance, although the correlations contained scatter. The scatter from the JWRFMP tests was generally similar to that seen from the NASA tests.
- (c) The JWRFMP showed that there are different concerns related to the correlation, consistency, and repeatability of measurements taken by different families of ground friction measurement devices, such as continuous friction measurement devices versus decelerometers.

The results from the JWRFMP contributed greatly to the state-of-knowledge. They have been implemented to a limited extent in a regulatory capacity. However, the IRFI produced during the JWRFMP has not been used widely, partly because the infrastructure for it is lacking at present.

The JWRFMP also identified serious issues with the present ground friction-measuring devices, related to (a) the limited number of surfaces on which they can provide reliable data; (b) the repeatability and reproducibility of the devices; and (c) the stability of the device readings over time, etc. Until such time that these concerns are addressed, questions will remain regarding the value of these devices for operational friction assessments.

It is apparent that the current friction devices available on the market are not satisfying the needs of the aircraft manufacturers, air carriers, and civil aviation authorities. Until such time that this changes, there will continue to be strong resistance to any attempt to have them relate a ground friction number to aircraft braking performance, particularly in a regulatory capacity.

Issues Limiting the Application of Operational Friction Measurements

There are many issues which can be categorized as follows:

- (a) Regulatory and certification issues;
- (b) Issues associated with the technical performance of the friction-measuring devices;
- (c) Complexities regarding the process of friction measurements; and
- (d) Lack of high-level performance criteria for friction-measuring devices.

The available devices differ widely with respect to practically all design parameters, including the measurement principle, the tire used, and the vertical load and tire contact pressure. This leads to differing parameter dependencies among the devices and, with respect to an aircraft, given that (a) many processes occur in the tire contact zone and (b) they differ depending on the design of the device.

This limits the degree of correlation that can be achieved, as has been seen from the various correlation attempts that have been made to date.

Need for High-Level Criteria for a Device for Operational Friction Measurements

Except for decelerometers, the current ground friction measuring devices were initially designed to assess surface friction characteristics for maintenance purposes. The attempts to date have focussed on utilizing these existing devices for operational use for correlation with aircraft performance on contaminated runways.

Experience has shown that this approach is not generally producing acceptable results. For friction measurements to be useful, a fresh approach is needed starting with “first principles”, with the objective of producing a device that would correlate well with an aircraft on the full range of contaminated surfaces of concern.

A high level definition of requirements (performance specification) for a continuous-measuring ground friction device specifically targeted for operational friction measurement would be beneficial for advancing the current state of the art. This is presently lacking, and as a result, suppliers develop improved designs using their best judgments. A high-level performance requirement would provide direction (a) to the most suitable device type for correlation with an aircraft and (b) to suppliers of friction devices regarding the criteria for the device.

Research and investigation is required to develop a high-level performance specification. The performance specification should, at a minimum, address the following:

- (a) The measurement principle, starting with the GFMD type (fixed-slip vs. variable slip vs. side force vs. locked-wheel tester, etc.). As well, the JWRFMP tests showed that different readings were produced on some surfaces (mainly loose snow) from devices that used torque measurements versus ones that used force measurements.
- (b) The tire design (tread and ribbing, carcass design, properties, etc.). Also, investigation is needed to establish whether or not an aircraft tire is required as the measurement tire.
- (c) The vertical load on the tire, the tire inflation pressure, and the tire contact pressure – the results presented in this section suggest that a contact pressure in the range of about 750 kPa is probably required, although it is cautioned that more detailed testing is necessary.
- (d) The slip ratio(s) and the slip speed(s) that is (are) required.
- (e) The requirement for an anti-skid system that has similar performance to those on aircraft also needs to be investigated.

1 INTRODUCTION, OBJECTIVES, AND GENERAL SCOPE

1.1 Background Regarding Aircraft Operations on Contaminated Runways

1.1.1 Introduction

Aircraft operations under inclement weather conditions is considered a hazardous operation because these aircraft routinely take off and land on runways that may have contaminants on them. In winter, the contaminants may include snow, ice, wet ice, frost, slush, and liquids. These contaminants significantly reduce the runway surface friction, which affects the ability of the aircraft to stop safely within the runway available length and/or to take off. Of course, this poses potential safety concerns.

At the same time, there are financial issues, recognizing that airlines are in business to transport people and goods. Operational delays due to weather are a financial concern to air carriers; and therefore, it is important for them to adhere to their operational schedules. In order to maintain this schedule, air carriers take off and land on surface conditions that are less than ideal.

Because aircraft may be operating on hazardous surfaces, airports implement procedures to reduce the safety hazard to a minimum. Three main activities are typically carried out:

- (a) Efforts are made to increase the friction of the surfaces. In winter, snow removal and ice control operations are conducted to either remove the surface contaminants quickly, or to increase the friction level (e.g., by sanding). Acceptable friction levels in summer are typically achieved by a combination of (i) pavement design to promote rapid surface drainage and (ii) pavement restoration work, such as rubber removal.
- (b) Inspections are carried out to identify the condition of the aircraft movement surfaces. This information is reported to the aeronautical services provider for onward transmission to pilots.
- (c) In winter, unless liquids, slush, or deep snow are present, measurements are made of the surface friction using a ground vehicle and the information is provided to pilots in various forms as appropriate.

1.1.2 Snow Removal and Ice Control in Wintertime

The objective of Snow Removal and Ice Control (SNIC) operations is usually to remove the winter contaminants from the aircraft movement surfaces as quickly as possible in order to restore the runway surface to a bare and dry condition. This objective cannot always be achieved, such as during a snowstorm or during freezing rain, as airports have limited resources (i.e., equipment and staff) for SNIC operations. Depending upon the storm intensity and the available resources at an airport, airports find it necessary to establish priority areas for the clearing of contaminants. Commonly, this leads airports to reduce the operational width on the runway in order to provide a runway surface which is acceptable for aircraft operations. It also leads to aircraft operations on contaminated runways.

1.1.3 Runway Condition Reporting in Wintertime

In order to minimize the risk for aircraft operations on contaminated runways, airports put in place runway surface condition inspection and reporting procedures. Such information is intended to aid the pilot in determining whether the runway is considered acceptable for use or not and if so, the landing and takeoff procedures. The key element of the runway condition reporting process is the inspection and identification of the conditions of the runway surfaces and deterioration of surface friction due to contaminants present on the runway. This typically involves two major components:

1.1.3.1 Inspection of the Runway Surface Condition

Inspections are conducted on the aircraft movement surfaces with runways as the first priority, to determine the presence of contaminants on the runway surface, the need for snow removal and ice control, and following snow removal and ice control, the availability of the runway for aircraft operations.

The process involves driving the length of the runway and visually assessing what is on the surface. The visual inspection is aimed at determining what are the winter contaminants (ice, slush, wet snow, compacted snow, ice and snow patches, etc.) left on the runway surface, what depths of contaminants are present, available cleared width, presence of snow banks, etc.

1.1.3.2 Surface Friction Measurements

Surface friction measurements are taken on winter contaminated runway surfaces as a means of providing information to pilots on the friction condition that may be present on the runway surface. These measurements are made using a Ground Friction Measuring Device (GFMD) that travels the length of the runway. Practices vary among countries regarding whether the actual friction numbers are provided to the pilot or they are used to categorize the potential ‘braking action’ on the surface, for example, as being good, medium-good, medium, poor-medium, or poor.

Over the years, efforts have been made to improve the runway surface friction assessment process, with the general emphasis being on developing different, improved GFMDs. This has contributed to the current situation in which a range of GFMDs are presently used, which report different friction values when operated on the same surface at the same time.

1.2 Objectives

Ground friction measurements are made to meet various objectives, which may be broadly categorized as follows.

1.2.1 Functional Friction Measurements

These measurements are done to aid in planning and undertaking runway pavement maintenance, and for setting criteria for the design of new pavements. They are intended to identify potential hazards related to rubber deposits or “worn” surfaces (i.e., ones polished by repeated aircraft operations or SNIC activity).

1.2.2 Operational Friction Measurements

This relates to operations on contaminated surfaces, such as aircraft takeoffs and landings, and possible actions by the aerodrome such as the closure of a runway.

1.2.3 Organization of Report

The reports for the work in this project have been organized in four volumes as follows:

- (a) Volume 1 – Summary of Findings and Recommendations – for simplicity, recommendations are only presented in Volume 1;
- (b) Volume 2 - Documentation and Taxonomy;
- (c) Volume 3 - Functional Friction; and
- (d) Volume 4 - Operational Friction.

This report is Volume 4 of a four-part series and is focussed on operational friction measurements and runway condition reporting. Operational friction measurements and runway surface condition reports are not made in summer. They are presently only carried out in winter when the contaminants may include snow, ice, frost and slush. However, it is recognized that there are some applications for operational friction assessment in summertime. Examples follow:

- (a) Operational friction assessment is applicable for the determination of whether or not a runway is “slippery when wet”. Presently, conditions are considered to be “slippery when wet” when the runway’s friction level falls below the minimum friction level specified by the State before pavement restoration is required. A NOTAM is typically issued when “slippery when wet” conditions exist.
- (b) Land and Hold Short aircraft Operations (LAHSO) are being allowed as a means to increase airport capacity, which imposes another potential requirement for reliable runway friction data. LAHSO operations require that an acceptable runway surface condition be present. Pilots currently do not use runway friction information as an input for determining whether they can land safely on a wet runway surface. Instead, they are typically forced to assume that the friction of the existing runway surface condition falls within that which was used in developing the Aircraft Flight Manual (AFM) for their particular aircraft for a contaminated runway.

1.3 **Content of Volume 4**

This report documents the work that was done in relation to operational friction measurements and runway condition reporting. It was comprised of the following general tasks.

1.3.1 Definition and Characterization of Wet and Contaminated Runways

This work was undertaken to meet the following objectives:

- (a) Define the terminologies used to describe surface contamination by distinct term of contaminant and level of contaminant;
- (b) Specify the physical characteristics of the contaminant (nature, depth, extent of contamination along the runway);

- (c) Investigate and define a methodology to determine the runway surface conditions based on visual observations by aerodrome operation staff;
- (d) Assess the feasibility of methods to forecast short term (i.e., within tens of minutes) changes in runway conditions, termed “now-casting”;
- (e) Characterize the effects of contamination in terms of drag and surface friction; and
- (f) Assess the feasibility of ways for harmonizing the different methods of friction characteristics measurement or estimation used in Europe and globally.

1.3.2 Compatibility of Friction Measurement Techniques

This work was comprised of the following sub-tasks:

- (a) Document the current state of the art, taking into account current initiatives;
- (b) Review and assess past attempts to harmonize ground friction readings on contaminated surfaces, including the difficulties that have arisen; and
- (c) Provide recommendations.

1.3.3 Runway Condition Information to be Transmitted

This work was comprised of the following sub-tasks:

- (a) Summarize the differences of the currently applied runway contamination reports and appraise the pros and cons, taking the specific needs of airports and states into consideration as appropriate.
- (b) Define what kind of information must be transmitted to the pilots through ATS.
- (c) Determine if the information given by present SNOWTAM format is sufficient. If appropriate, identify improvement to SNOWTAM.
- (d) Identify a methodology to improve and harmonize the use of SNOWTAMs, and identify ‘best practices’ in the transmission of runway condition information.
- (e) Assess current R&D associated with transmission of runway condition information and identify areas of future work.

1.3.4 Notice Regarding Definition of Depth

To avoid confusion, it should be noted that unless specifically stated in the text, all depths defined in this report series refer to the actual depth of material and not the water-equivalent depth.

2 PRACTICES FOR CHARACTERIZING WET & CONTAMINATED RUNWAYS

Primarily, Runway Condition Reporting (RCR) for operational purposes is done for winter conditions. Practices for characterizing wet and contaminated runways for operational applications vary considerably among countries and airports. Equipment and procedures for surveying and reporting the Aircraft Movement Surface (AMS) conditions during winter conditions vary within the global community of airports. However, RCR can be divided into two general tasks as follows:

- (a) Observations and descriptions of the runway surface conditions, such as the contaminant type and depth – this subject is discussed in Section 2; and
- (b) Measurements of the runway friction using a ground vehicle – this is discussed in Section 3.

2.1 Surface Condition Assessment for Operational Inspections

2.1.1 Introduction

Runways, taxiways, and aprons are regularly inspected by airport personnel year-round. Inspections are conducted for a number of reasons, all of which are concerned with maintaining a safe environment for aviation. For the purposes of this report, inspections can be categorized as being conducted either for runway maintenance purposes or for purposes related to aircraft operations. Often, though, there is overlap between these two general types of inspections.

Inspections related to aircraft operations are done to determine the presence of contaminants that could impact aircraft operations. The goals of inspections for runway maintenance purposes vary somewhat between summer and winter. In winter, they are done to determine what snow removal and ice control activities should be undertaken.

For inspections related to either runway maintenance or aircraft operations, the surfaces are visually surveyed as the inspector drives across the surfaces. During near-zero and sub-zero temperatures, the potential contaminants include slush, liquid, snow, ice and, frost. At other times, water is the primary concern. Inspections in winter pose the greatest challenges for locating, categorizing, and recording the presence of frozen contaminants and their residue (run-off, sand or remaining ice control chemical, etc.).

As shown in the survey that was conducted (described in Volume 2), air carriers and pilots always require surface condition reports during winter to determine the acceptability of the surface for aircraft operations. Under certain conditions and in some jurisdictions, the surface condition survey is combined with measurements of the runway friction or a subjective estimation of friction based on the inspection vehicle's braking performance.

During all AMS inspections, the inspector also checks for the presence of Foreign Object Debris (FOD) material, bird and wildlife activity or any other condition that may present a hazard to aircraft operations.

2.1.2 Objectives of Operational Inspections

Operational inspection condition reports are used not only by pilots to make landing and take-off decisions, they are the major contributor to AMS maintenance decisions. Less detail is required for such decisions, but current knowledge is as important for maintenance decisions as for aircraft performance input.

2.1.3 Reportable Conditions

2.1.3.1 *Summer Versus Winter*

For the purposes of this discussion and for organizing the material in this report, it is convenient to separate contaminants and operations by season as being either “summer” or “winter”. However, it is recognized that in practice, this distinction is an artificial one as:

- (a) Liquid precipitation and liquid surface contaminants also occur during winter when the surface temperature is approaching, at or below 0°C; and
- (b) Frozen precipitation often occurs during summer months in the form of hail or snow, and sometimes frost, particularly at sites in the northern hemisphere.

It is noted that various agencies and presently-ongoing initiatives (i.e., TALPA ARC, ICAO) do not explicitly distinguish between “summer” or “winter” contaminants. This is considered to be logical in our opinion.

However, at the same time, runway condition reporting practices at airports generally vary between “summer” and “winter”, in response to for example, the need to establish “snow plans” over certain parts of the year. As a result, often, there are variations in reporting procedures between “summer” and “winter”, with respect to parameters such as the contaminant type and depth. This issue is re-visited subsequently in this section.

2.1.3.2 *Functional Inspection Parameters for Summer*

During summer, the primary safety issue is the potential for hydroplaning by aircraft caused by water build-up on a polished or rubber-contaminated runway. In this case, the reportable parameters are:

- (a) The longitudinal extent of rubber build-up or surface deterioration on the runway surface; and
- (b) The lateral extent of rubber build-up or surface deterioration on the runway surface.

Runway Inspectors (RIs) also make note of the locations and the extent of areas of water ponding which could lead to localized hydroplaning, loss of directional stability or ingestion of water into jet engines. RIs also inspect the aircraft movement surfaces for general maintenance requirements noting needs for crack sealing, patching, etc.

2.1.3.3 Reportable Conditions for Winter

Air carriers are not unanimous in stating their requirements for the reporting of specific runway surface condition parameters. This is probably because their internal instructions on use and interpretation of specific parameters in adjusting aircraft operations are not universal. Civil aviation authorities and airport operating authorities often take the conservative position of providing extensively detailed reports that they hope will respond to everyone's needs, or they emulate the ICAO Annex 14 SNOWTAM requirements although some base this on a broad interpretation of reporting requirements.

The following contaminants and parameters present the greatest risk of loss of directional control, reduced braking capability, and damage to aircraft in winter:

Water

In temperatures where frozen contamination is considered the predominant threat but there is still a possibility of aircraft hydroplaning on a wet surface, standing or ponded water, the reportable parameters for water on the runway are:

- (a) The percentage coverage on the surface;
- (b) The average depth; and
- (c) The location, either by runway third or specific location, reported as distance from a geographic feature.

Frozen Contaminants

In most jurisdictions, the following parameters, or a combination of them, must be addressed in aircraft movement surface condition reports for the runway:

- (a) The width of the maintained path down the runway available for aircraft operations;
- (b) The offset of the maintained path compared with the centerline;
- (c) The type of contaminant on the maintained path;
- (d) The percentage distribution of contaminant on the maintained path;
- (e) The location of contaminant on the maintained path;
- (f) The depth of contaminant on the maintained path;
- (g) The length of windrows;
- (h) The height of windrows;
- (i) The width of windrows;
- (j) The type of contaminant on the un-maintained path;

- (k) The percentage distribution of contaminant on the maintained path;
- (l) The location of contaminant on the un-maintained path; and
- (m) The depth of contaminant on the un-maintained path

2.1.3.4 Threshold Values for Airport Operations Such as the Closure of a Runway

In some jurisdictions, threshold values such as the width of runway available for aircraft operations (maintained width) or the depth of contaminant are used to close the runway for maintenance. This direction can come from a civil aviation authority or it can result from the airport authority's policies. In other jurisdictions, airport staff must report the surface conditions but they have the discretion to close the runway for maintenance. This is a fundamental difference in airport maintenance and reporting policy and direction.

Threshold values are used to determine compliance with operational criteria such as air carriers requiring a specific minimum cleared path width for operations or airports closing runways for snow removal and or ice control when a specified contaminant accumulation is reached.

2.1.3.5 Layered or Underlying Contaminants

One of the main principles for the “winter” condition reporting process is that “observable” contaminants (i.e. the material that is visible to the observer) are to be reported. Often, there is an underlying material that should also be addressed in condition reports, such as ice under loose snow. This is especially important when friction measurements are not provided as part of the condition report. Currently, there is little direction or advice from regulators to airports on reporting layered contaminants.

2.1.3.6 Runway Condition Report Renewal

Usually, a new report must be issued as soon as there is a “significant change” in conditions in order to maintain currency. This is a regulated requirement in some jurisdictions but there is little guidance from civil aviation authorities on what constitutes a significant change.

2.1.3.7 Other Aircraft Movement Surfaces

Often there is an explicit requirement to report conditions on taxiways and other aircraft movement surfaces (as referenced in the ICAO SNOWTAM reporting format) but the information is not usually included in wide distribution NOTAMS. It is normally provided to pilots within the airport vicinity for local usage and often has a lower degree of detail than that for runways.

2.2 Human Factors and Runway Surveying

Several factors influence the ability of an airfield inspector to successfully survey a runway visually so that sufficient information is gathered and reported without delay, such as the following:

- (a) Visibility of the surface conditions – this is affected by many factors including:
 - (i) Visual field of range;
 - (ii) Ambient visibility, which is affected by factors such as precipitation, illumination of the surface at night, and fog/freezing fog;

- (iii) Depth perception;
 - (iv) Contaminant feature contrast, which is affected by items such as (i) low light reducing shadows, (ii) bright sunlight creating glare, and (iii) contaminant reflectivity, which is reduced for 'black' ice, and by refraction in frost; and
 - (v) Eyesight.
- (b) Vehicle speed.
- (c) Proximity to contaminant – this is affected by whether a single traverse is made, or an “up & back” runway inspection is made.
- (d) Perception of urgency, for example due to ATC or supervisory time constraints.
- (e) Perception of personal safety, which may be affected by the proximity of aircraft, the proximity of maintenance vehicles, the surface traction, and the vehicle condition.
- (f) Distractions, such as UHF/cellular communications, monitoring of VHF aeronautical traffic, operation of friction measurement equipment, vehicle and/or equipment malfunction, FOD, bird or wildlife activity, edge light and centreline lighting condition.
- (g) Training.
- (h) Experience.
- (i) Fatigue.
- (j) Contaminant definitions.
- (k) Reporting formats.

With all of these factors influencing the ability of the RI to concentrate and assess the surface conditions, it is difficult to maintain consistent quality, even under ideal surveying conditions. The challenge is compounded where there is no institutionalized AMS inspection and reporting training, or regulated performance standards, in which case, the requirements become subject to an individual's interpretation.

All of the above factors play a part in the quality and consistency of reports for operational reporting, especially in locations where frozen contaminants occur. The challenges are compounded in temperate climates where frozen contaminants are experienced infrequently but must be reported accurately when they do occur. At these sites, inspectors have few opportunities and reduced motivation to maintain their skills and knowledge for reporting winter contaminants.

2.3 Runway Condition Observation

2.3.1 Parameters for Runway Condition Observation

Although it is generally true that RIs develop estimating accuracy with experience, it is a challenge to maintain consistency among inspectors given the variety and intensity of factors influencing their perception of conditions and therefore, the accuracy of their reports. Obviously, reports of surface conditions must be accurate to be useful or to maintain safety at an operational airport.

The reportable conditions listed above can be reduced to the following short list of measurable parameters for the purposes of describing the data collection process:

- (a) Maintained path width;
- (b) Offset of the maintained path from the centreline (if any);
- (c) Contaminant type;
- (d) Contaminant depth;
- (e) Contaminant location; and
- (f) Contaminant spread.

In general, the only data that are consistently “measured” objectively at present during operational aircraft movement surface inspections are the surface temperature, the air temperature and in some jurisdictions, the coefficient of friction. None of the [six](#) reportable surface condition parameters listed above are normally measured. Rather, they are usually observed and an estimated value is reported. This is due to various factors such as limited time being available for runway inspections and a lack of technology for rapidly measuring these parameters in an operational environment.

2.3.2 Runway Condition Estimation

The tools for estimating runway conditions vary but the following are common:

- (a) Maintained width of the runway from the centreline or edge is estimated based on such values as multiples of the perceived width of the path cleared by maintenance equipment or in relation to surface markings; estimates rarely exceed increments of 6 m at best.
- (b) Maintained path offset, if any, is estimated in much the same way as the width of the maintained path.
- (c) Surface contaminant type is assessed against descriptions provided by the CAA.

- (d) Contaminant depths are usually estimated. The accuracy exceeds increments of 6 mm. On some occasions a gauge is used to measure contaminant depth. The gauge may be marked with increments (ruler) such that a precise measurement can be made and, in some cases, the gauge is a device of known thickness that can be used to determine compliance with “go/no-go” criteria for aircraft operations (for example a pound coin, which happens to be 3 mm thick). Whenever depth measurements are taken, they consist of a small number of “spot” measurements that are averaged. Such measurements can only be made in liquid or permeable contaminants such as water, loose snow and slush.
- (e) The location of surface contaminants is estimated and is described as either a macro percentage coverage of a defined area (entire runway, entire maintained path, runway third, etc.), or as a feature (patch, snow drift, etc.) located a specified distance from a known runway mark (threshold, intersection, etc.). Sometimes, it is simply identified as being present. The estimated longitudinal distances often do not exceed an accuracy of 300 m increments.
- (f) Contaminant spread is a general estimate of the amount of an area that is covered by a specific contaminant type. Estimates of spread coverage do not usually exceed increments of 20 percent or 10 percent at best.

Of course, a shift from estimating these condition parameters to measuring them with instrumentation will significantly enhance the consistency and accuracy of condition reports by minimizing the potential for human error. A discussion of the potential for moving towards contaminant measurements is presented later in this report but it is clear that the status quo of visual condition assessment will remain the norm for the immediate future.

2.3.3 Direction and Guidance to Airports

Airport operating authorities require Runway Inspectors (RIs) to perform inspections and file reports based on the broad assumption that the information they provide is what air carriers and pilots need to ensure safe operation of aircraft on contaminated surfaces. It is widely believed at airports that the reported information is both needed and must be as accurate as possible to enable accurate calculations of aircraft drag impingement, stopping distance, etc.

This assumption has often lead to detailed and demanding runway inspection procedures that are resource-intensive and not always obviously directly linked to aircraft performance, as described by aircraft manufacturers or even civil aviation authorities. A realignment of the runway condition reporting requirements for contaminated runways with the needs of air carriers and pilots would ‘streamline’ procedures for all and provide the necessary linkage to help correctly match information “supply” to “demand”.

A reassessment of runway condition reporting requirements would be advantageous. Specifically, clear direction and guidance is needed regarding runway inspection criteria, accuracy and in some cases terminology. There are various items where there is a “disconnect” between airport reporting, the direction to pilots, and the performance stated by the aircraft manufacturer, including the following:

Cleared Width

- (a) The term “cleared” is ambiguous. Although it is used to describe the width of the maintained path, it implies that contaminants have been removed from the given width. In fact, the maintained path width reported as “cleared” may only have been treated with sand or ice control chemical. The use of the word “cleared” may also lead an inexperienced reader to assume that all ground vehicles (maintenance and inspection) have been removed from the surface.
- (b) CAAs do not provide direction or guidance to airports on the required accuracy of the reported runway maintained path width. Consequently there are variations in reporting practices and accuracy.

Cleared Width Offset

- (a) RIs report the off-set of the maintained path believing that pilots need to know this so that they can adjust their landing approach path, but the required accuracy is unknown.
- (b) Some CAAs are silent on the reporting requirement while others specify the reporting need but are silent on required accuracy.

Contaminant Type

- (a) Although contaminant definitions are provided by CAAs (discussed elsewhere), there are some gaps in definitions such as including melt water brine with “water”.
- (b) Definitions for reportable contaminant as provided to airports by CAAs do not align with those used to describe effects on aircraft ground performance. As discussed in Volume 2, the TALPA ARC recommendations indicate that relatively few contaminant type categories (wet snow, slush, etc.) would suffice. Considerably more categories are used at airports, which may indicate they are using too many categories at present. This issue needs to be monitored in association with the field trials that are planned for the TALPA ARC system this coming winter.

Contaminant Depth

- (a) There is no uniform direction on whether the mean or the maximum contaminant depths should be reported for water, snow, or slush.
- (b) Some civil aviation authorities require an “average” depth for each third of the runway while others require the average for the runway with exception reporting for the maximum height of snow drifts and snow “windrows”.

- (c) Often, CAAs provide differing directions on the required accuracy for reporting the depth of different types of contaminants. This may be because of the variations in aircraft performance sensitivity to different types of contaminant but RIs need clear instruction on the required accuracy of their estimates (or measurements) and a uniform procedure in order to give consistent reports.
- (d) Some CAAs provide little direction on reporting the depth of contaminants outside the maintained path as they leave this for airports or RIs to make assumptions about the required accuracy.
- (e) In some jurisdictions, depths only have to be assessed as meeting or not meeting threshold values that trigger runway closures or reporting actions. This simple go/no-go criterion also requires a degree of accuracy – i.e., \pm 'X' mm.

Contaminant Location

- (a) Some jurisdictions require the location of contaminants on runways to be reported only by their presence or lack thereof on each third while others require the location of contaminants to be reported in terms of distance from a specific feature, i.e. runway threshold or intersection. The two methods have different accuracies and simultaneous reporting is difficult. Alignment with aircraft performance reporting requirements could result in more uniform directions to airports.
- (b) RIs use a variety of terms to report contaminant location. Guidance and standardized terms such as “scattered”, “ponding”, etc. would contribute to uniformity.

Contaminant Distribution Spread

- (a) While some CAAs require an estimate of the percentage coverage of an area by a contaminant or several contaminants, others require only that their presence be reported. If the percentage of coverage is a factor in determining aircraft performance, RIs require guidance on the required accuracy, which affects appropriate methods for evaluating coverage.
- (b) For some directions to airports, there is a lack of clarity regarding whether reporting of percentage coverage is required on the maintained path or on the full width of the runway. The implication of a misinterpretation could be significant.

2.3.4 Variations in Reporting Procedures between Winter and Summer: Contaminant Depth

2.3.4.1 Seasonal Distinctions

Separating contaminants by season – i.e., “summer” and “winter” – is convenient for discussing the general scientific/engineering and operational implications of liquid and frozen contamination. However, this distinction is an artificial one. Liquid precipitation and liquid surface contaminants also occur during winter when the surface temperature is approaching, is at or is below zero. Frozen precipitation routinely occurs during summer months in the form of hail or snow at various northern hemisphere airports.

When the assignment of conditions to seasons is carried through to detailed discussions and deliberations, the artificial distinction may impede a comprehensive evaluation of all of the relevant issues. Because most flight operations issues regarding ground contamination occur with frozen contamination, “operational” condition reporting by airports is focused on winter. There is virtually no systematic reporting of surface contaminants during summer months for the purposes of aircraft operations.

The implications of inaccurate reporting of water film depths on runways during summer and of them not being taken into consideration in landing/take-off decisions have been in some cases catastrophic. Rain conditions are usually transitory and runway water depths are constantly changing as well as sometimes varying across surfaces because of runway depressions. This leads air carriers and airports to try to avoid landings and take-offs in the worst of rain/water conditions rather than attempting to report and account for “current” conditions that are constantly in flux. This strategy is not perfect and accidents and incidents result from aircraft hydroplaning on liquid-contaminated runways.

Like frozen permeable contaminants, water induces drag as well as hydroplaning; and there is a requirement for airports to report water depths as well as frozen contaminants on runways for the purposes of flight operations during winter. These concerns exist year-round for water-contaminated runways.

In conclusion, it can be seen that there is as much need for systematic, operational reporting of water depths on runways in summer months as there is in winter periods.

2.3.4.2 Reporting of Contaminant Depth

It is well known that one of the major influences on aircraft hydroplaning is the depth of liquid or permeable contaminants on runway surfaces.

There is significant data to indicate that aircraft can hydroplane on very thin films of water on runways. Current direction and guidance to airports on operational reporting of contaminant depths (including water) is not precise and concentrates on distinguishing between depths below and above 3 mm. It appears from available data that this distinction is inadequate for the purposes of predicting aircraft hydroplaning.

Another major challenge is that there are varying opinions on the value of extrapolating the impact on aircraft hydroplaning of a given depth of a permeable frozen contaminant based on its water depth equivalent. Some aircraft manufactures use “water equivalent” values to estimate the impact of frozen contaminants on aircraft hydroplaning while other methods are employed elsewhere. There appears to be little direct measurement of the impact of permeable frozen contaminants on aircraft hydroplaning.

2.3.4.3 Assessment Regarding Reporting of Contaminant Depth

In order to provide carriers and pilots with sufficient information for them to assess the risk of hydroplaning, airports should be reporting the depth of contaminants with an accuracy determined by aircraft manufacturers that is sufficient for the purposes of evaluating potential hydroplaning. This requirement exists for all liquid and permeable surface contaminants including brine, slush, loose snow, possibly deep frost and water, regardless of the time of year.

2.3.4.4 Operational Challenges of Depth Measurements for Airports

All surface contaminant conditions that impose a requirement for depth reporting are transitory in nature, whether they are liquid or solid. Liquids present the greatest problem as the depth on the runway changes almost constantly during rain. Furthermore, localized depressions and changes in runway topography create differences in depths across runways. Runway intersections with other runways and taxiways are particularly troublesome.

RIs have few tools to accurately measure contaminant depths under operational conditions; however their impact on flight safety is significant.

2.3.4.5 Overall Comments

Airports should receive direction regarding the required accuracy of contaminant depth and operational procedures for measurement and reporting.

As well, R&D should be conducted to produce reliable mechanisms for contaminant depth measurements. This work should be sponsored by regulators.

2.3.5 Variations in Reporting Procedures Between “Winter” and “Summer”

2.3.5.1 Summer

The approach to reporting of water depths on runways in summer conditions is generally “ad-hoc” in all jurisdictions with little variation. Variations are minor and exist in the airport authorities instructions to airfield maintenance and runway inspection staff on runway patrol frequencies in inclement weather and criteria for triggering reporting conditions to Air Traffic Control or Aeronautical Information Services (ATC/AIS). Where an airport has posted that a runway may be “slippery when wet”, it appears that notice of weather conditions is considered sufficient to warn pilots of potentially hazardous circumstances. The exception is where there is standing water (or “flooding”) is at, or in excess of 3 mm depth. Airfield maintenance staff or RIs will relay the current surface state directly to ATC/AIS for furtherance to pilots via voice NOTAM or directly during voice communications between ATC/AIS and local air traffic.

2.3.5.2 Winter

All jurisdictions with regular winter conditions have formal reporting procedures. CAAs provide direction to airports based on the ICAO Annex 14 SNOWTAM requirements. The SNOWTAM input format as shown in Annex 14, Figure 6a, is not ideally suited for completion in the field, nor does it facilitate ease of reporting of all relevant conditions (Figure 2.1). It is therefore common to find localized condition reporting forms tailored to airports requirements that provide for reporting of the required data elements as described in the ICAO SNOWTAM format. This does not constitute a significant change in reporting practice. Reporting practices vary only in localized interpretation of criteria thresholds that trigger a report – i.e., what is a ‘significant change in conditions’ – and in the means of transmitting the report contents to ATC/AIS (radio, fax, computer/modem, etc.).

2.3.5.3 Material in ICAO Documents

The ICAO documents listed in Volume 2 of this report series were reviewed to obtain further information regarding the general issue of reporting for “summer” versus “winter”. ICAO, 2002 contains the following definitions:

- (a) “A contaminant is considered to be a deposit (such as snow, slush, ice, standing water, mud, dust, sand, oil and rubber) on an airport pavement, the effect of which is detrimental to the friction characteristics of the surface”.
- (b) “Debris is fragments of loose material (such as sand, stone, paper, wood, metal, and fragments of pavements) that are detrimental to airplane structures or engines or that might impair the operation of airplane systems if they strike the structure or are ingested into engines.

It is evident that the above definitions are broad enough that they encompass contaminants likely to occur in either “summer” or “winter”.

ICAO, 2002 also describes two general forms of runway condition reporting:

- (a) The issuance of a NOTAM that the runway may be “slippery when wet” when the friction level of a wet runway falls below the minimum set by the State’s National Aviation Authority; and
- (b) The SNOWTAM, which is intended to convey “snow-, slush-, or ice-covered surface state information”.

Again, these two types of reporting formats are broad enough to capture variations in “summer” versus “winter” conditions. For example, a SNOWTAM could be issued in “summer” should hail or other frozen contaminants occur. Similarly, a NOTAM could be issued in “winter” for wet conditions.

In summary, the general focus of the ICAO material is that RCR should be based on the type of contaminant rather than on the time period. This is considered to be logical.

It is believed that the present variations in RCR for summer versus winter result mainly from historical practices with respect to regulatory variations for these two time periods.

2.3.6 Condition Assessment Technologies

Currently, there are few if any tools available to RIs to assist them in assessing current runway conditions. In-surface sensors give an indication of the presence of water, chemical, or ice and temperature but reliability is always an issue so RIs will always inspect the surface to assess conditions. Where edge-of-runway Runway Weather Information System (RWIS) sensors are in place they provide supplementary information to that from in-surface sensors to add in predicting impending conditions. The only measuring tools currently available to RIs to assist in measuring surface conditions are rulers or gauges to measure contaminant depth. Vehicle mounted surface temperature sensors are widespread; but again, they are used primarily to assist in predicting surface condition trends so that decisions can be made about sweeping and application of ice control chemicals and/or sand, etc.

This issue is discussed further in Section 4, with respect to Research and Development (R&D) activities that are currently taking place.

2.4 Runway Condition Reporting for Layered Contaminants

2.4.1 Introduction

The conventional approach to runway condition surveying in frozen contaminant conditions is for Runway Inspectors (RIs) to report “what they see”. This principle results in RIs being directed to report specific contaminant parameters such as percentage coverage, etc. for the “observed” material. Where numeric descriptions of the surface are provided in RCRs and there are any underlying materials (e.g., ice under loose snow), they are not reported in terms of percentage distribution. The condition will either be reported using a narrative comment, or it will be revealed through a low friction reading.

2.4.2 Requirement

It is imperative that underlying contaminants with the potential to affect aircraft performance differently than the observed layer be reported by RIs, especially for the case where friction measurements are not reported for the purposes of aircraft operations.

2.4.3 Challenge

It is currently perceived as being impractical to require RIs to report conditions of the underlying layer, if present, to the same level of detail as the top layer of contaminants. There are two main reasons for this viewpoint. Firstly, the runway condition report would be so complex that it would be impractical to file either by voice, written form, or electronic reporting system. The second is that if such a complex report were filed, the potential for confusion and/or misinterpretation by either ATC/FSS or a pilot would increase considerably.

2.4.4 Suggested Approach for Resolution

To obviate the necessity for definitive but potentially confusing reporting of details for more than one layer of contaminant on a runway, it is suggested that a set of acronyms for standard remarks be made available to RIs for reporting of one contaminant on another.

As a possible way forward, the following phrases are suggested as additions to an RCR where such layered conditions exist. It is noted that many of these conditions are rare but a standardized process for reporting them would greatly reduce the potential for misinterpretation of reports. Of course, consultation is required with the various stakeholders to ensure that the reporting system eventually adopted is acceptable.

2.4.4.1 *Loose Snow on Ice*

- (a) Runway covered with ice with loose snow fully covering the ice.
- (b) Details of the loose snow to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: LSoI

2.4.4.2 *Loose Snow on Ice Patches*

- (a) Runway partially covered with ice with loose snow on top of the ice and possible on top of the rest of the runway.

- (b) Details of the loose snow to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: LSoIP

2.4.4.3 Loose Snow on Compact Snow

- (a) Runway covered with compact snow with loose snow fully covering the compact snow.
- (b) Details of the loose snow to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: LSoC

2.4.4.4 Loose Snow on Compact Snow Patches

- (a) Runway partially covered with compact snow with loose snow on top of the compact snow and possible on top of the rest of the runway.
- (b) Details of the loose snow to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: LSoCP

2.4.4.5 Slush on Ice

- (a) Runway covered with ice with slush fully covering the ice.
- (b) Details of the slush to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: SoI

2.4.4.6 Slush on Ice Patches

- (a) Runway partially covered with ice with slush on top of the ice and possible on top of the rest of the runway.
- (b) Details of the slush to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: SoIP

2.4.4.7 Water on Compact Snow

- (a) Runway covered with compact snow with water fully covering the compact snow.
- (b) Details of the water to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: WoC

2.4.4.8 *Water on Compact Snow Patches*

- (a) Runway partially covered with compact snow with water on top of the compact snow and possible on top of the rest of the runway.
- (b) Details of the water to be reported in the numerical columns of the AMSCR.
- (c) Abbreviation: WoCP

2.5 Runway Condition Reporting Practices

The means of recording and transmitting runway condition reports is a reasonably straight forward process to document. However interpretation of instructions by RIs can become clouded where there are few details or there is ambiguity in regulation or advice. One of the primary issues is “what is the definition of a Runway Condition Report?” This may be left to the discretion of RIs. The process of providing the Aeronautical Information Service (AIS) provider with status updates (usually addressing a single aspect of AMS conditions) throughout a snow or ice event may be interpreted as, or substituted for, a formal condition report. Another major issue that has already been highlighted is what specifically triggers the need for a new report.

2.5.1 Runway Condition Notation and Transmission to Air Navigation Service Provider

CAAs choose either to apply the ICAO Annex 14 SNOWTAM logic (as depicted in the ICAO SNOWTAM form, Figure 2.1) of reporting runway conditions in discrete thirds – i.e. touchdown, centre and roll-out – or they require reporting of the overall runway conditions with specific annotations for extra ordinary conditions by specific location. The FAA currently interprets this requirement in their AC 150-520-30C (FAA, 2008) with the form in Figure 2.2. The FAA may well revise this guidance based on the outcome of the TALPA ARC process.

6-2

Airport Services Manual

(COM heading)	(PRIORITY INDICATOR)		(ADDRESSES)		≪≡
	(DATE AND TIME OF FILING)		(ORIGINATOR'S INDICATOR)		≪≡
(Abbreviated heading)	(SWAA* SERIAL NUMBER)		(LOCATION INDICATOR)	DATE/TIME OF OBSERVATION	(OPTIONAL GROUP)
	S	W	.	.	

SNOWTAM	(Serial number)	→
(AERODROME LOCATION INDICATOR)	A)	→
(DATE/TIME OF OBSERVATION (<i>Time of completion of measurement in UTC</i>))	B)	→
(RUNWAY DESIGNATORS)	C)	→
(CLEARED RUNWAY LENGTH, IF LESS THAN PUBLISHED LENGTH (<i>m</i>))	D)	→
(CLEARED RUNWAY WIDTH, IF LESS THAN PUBLISHED WIDTH (<i>m</i> ; if offset left or right of centre line add "L" or "R"))	E)	→
(DEPOSITS OVER TOTAL RUNWAY LENGTH (<i>Observed on each third of the runway, starting from threshold having the lower runway designation number</i>) NIL — CLEAR AND DRY 1 — DAMP 2 — WET or water patches 3 — RIME OR FROST COVERED (<i>depth normally less than 1 mm</i>) 4 — DRY SNOW 5 — WET SNOW 6 — SLUSH 7 — ICE 8 — COMPACTED OR ROLLED SNOW 9 — FROZEN RUTS OR RIDGES	F)	→
(MEAN DEPTH (<i>mm</i>) FOR EACH THIRD OF TOTAL RUNWAY LENGTH)	G)	→
(FRICTION MEASUREMENTS ON EACH THIRD OF RUNWAY AND FRICTION-MEASURING DEVICE MEASURED OR CALCULATED COEFFICIENT or ESTIMATED SURFACE FRICTION 0.40 and above GOOD — 5 0.39 to 0.36 MEDIUM/GOOD — 4 0.35 to 0.30 MEDIUM — 3 0.29 to 0.26 MEDIUM/POOR — 2 0.25 and below POOR — 1 9 — unreliable UNRELIABLE — 9 (<i>When quoting a measured coefficient, use the observed two figures, followed by the abbreviation of the friction-measuring device used. When quoting an estimate, use single digit</i>)	H)	→
(CRITICAL SNOWBANKS (<i>If present, insert height (cm)/distance from the edge of runway (m) followed by "L", "R" or "LR" if applicable</i>))	J)	→
(RUNWAY LIGHTS (<i>If obscured, insert "YES" followed by "L", "R" or both "LR" if applicable</i>))	K)	→
(FURTHER CLEARANCE (<i>If planned, insert length (m)/width (m) to be cleared or if to full dimensions, insert "TOTAL"</i>))	L)	→
(FURTHER CLEARANCE EXPECTED TO BE COMPLETED BY . . . (UTC))	M)	→
(TAXIWAY (<i>If no appropriate taxiway is available, insert "NO"</i>))	N)	→
(TAXIWAY SNOWBANKS (<i>If more than 60 cm, insert "YES" followed by distance apart, m</i>))	P)	→
(APRON (<i>If unusable, insert "NO"</i>))	R)	→
(NEXT PLANNED OBSERVATION/MEASUREMENT IS FOR) (<i>month/day/hour in UTC</i>)	S)	→
(PLAIN LANGUAGE REMARKS (<i>Including contaminant coverage and other operationally significant information, e.g. sanding, de-icing</i>))	T)) ≪≡
NOTES: 1. *Enter ICAO nationality letters as given in ICAO Doc 7910, Part 2. 2. Information on other runways, repeat from C to P. 3. Words in brackets () not be transmitted.		
SIGNATURE OF ORIGINATOR (<i>not for transmission</i>)		

Figure 2.1: ICAO SNOWTAM

DATE OF SURVEY	TIME	RUNWAY-TAXIWAY DESIGNATOR	DESCRIPTION OF SURFACE CONDITION(S)	TYPE OF CONTAMINANT REMOVED		TEMPERATURE	
				METHOD(S) EMPLOYED	TIME	AMBIENT	PAVE-MENT

TYPE OF FRICTION MEASURING DEVICE USED	DATE OF LAST CALIBRATION	VEHICLE SPEED (MPH)	LOCATION OF TEST RUN FROM RUNWAY CENTERLINE (FEET)	AVERAGED μ READING BY ZONE			REMARKS
				TOUCHDOWN ZONE	MIDPOINT ZONE	ROLLOUT ZONE	

FAA Runway Contamination Mitigation Record (top) and Runway Friction Survey Record (bottom)

Figure 2.2: FAA Reporting Format (FAA, 2008)

Transport Canada employs the latter logic. The TC AMSCR form (Figure 2.3) typifies the reporting protocol used by Canadian airports to generate the NOTAMJ used in Canada in place of the SNOWTAM.

AIRCRAFT MOVEMENT SURFACE CONDITION REPORT CANADIAN RUNWAY FRICTION INDEX (CRFI)														COMPTÉ-RENDU DE L'ÉTAT DES AIRES DE MOVEMENT POUR AÉRONES COEFFICIENT CANADIEN DE FROTTEMENT SUR PISTE (CRFI)													
AIRPORT-AÉROPORT														REPORT NO - COMPTÉ-RENDU N°													
SURFACE CONDITION DATA - RENSEIGNEMENTS SUR L'ÉTAT DE LA SURFACE														AVERAGE CRFI - CRFI MOYEN													
RUNWAY PISTE	PORTION PARTIE	WIDTH LARGEUR	BARE & DRY NUÉ ET SECHE	BARE & WET NUÉ ET MOUILLEE	LOOSE SNOW NEIGE POUDREUSE		COMPACTED NEIGE DURE	SNOW DRIFTS CONGÈRES		SLUSH/WET SNOW NEIGE FONDANTES/ NEIGE MOUILLEE		FROST GIVRE	ICE PATCHES PLAQUES DE GLACE	ICE CONTROL MATERIAL APPLIED AGENT DE FUSION EMPLOYÉ	REMARKS REFERENCES TO ANY SURFACE CONDITION WEATHER REMOVAL IS IN PROGRESS AND ESTIMATED COMPLETION TIME	OBSERVATIONS MENTIONNER TOUT ÉTAT DE LA SURFACE PRÉCISER SI LE DÉGAGEMENT EST EN COURS ET LE TEMPS D'ACHÈVEMENT ESTIMÉ	RUNWAY PISTE	AMBIENT TEMP (°C) AMBIANTE	TOTAL RUNWAY AVERAGE MOYENNE POUR TOUTE LA PISTE	TIME ZULU HEURE ZULU							
					%	IN POUNCES		%	IN POUNCES	%	IN POUNCES										%	SAND SABLE	CHEMICAL CHIM.				
	CLEARED DÉGAGÉE																										
	REMAINING RESTANTE																										
	CLEARED DÉGAGÉE																										
	REMAINING RESTANTE																										
	CLEARED DÉGAGÉE																										
	REMAINING RESTANTE																										
NOTE: IF THE CLEARED PORTION OF THE RUNWAY IS OFF CENTER THE REMAINING WIDTH ON BOTH SIDES IS TO BE REPORTED														À NOTER : SI LA PARTIE DÉGAGÉE DE LA PISTE N'EST PAS CENTRÉE, LA LARGEUR RESTANTE DES DEUX CÔTÉS DOIT ÊTRE RAPPORTÉE.													
TAXIWAYS AND APRONS																											
VOIES DE CIRCULATION ET AIRES DE TRAFIC																											
VOICE REPORT TO - COMPTÉ-RENDU ORAL A														HOUR (LOCAL) HEURE (LOCALE)													
														DAY-JOUR													
														MONTH-MOIS													
														YEAR-ANNÉE													
														SIGNATURE													
														TAXIWAY/APRON INFORMATION FOR LOCAL DISTRIBUTION													
														ONLY													
														LES DONNÉES RELATIVES AUX VOIES DE CIRCULATION ET AUX AIRES DE TRAFIC SONT													
														RESERVEES A LA DIFFUSION LOCALE SEULEMENT													

Figure 2.3: Transport Canada AMSCR Form

The AMSCR/NOTAMJ protocol employed by Canadian Airports and NAVCAN, the Canadian AIS, responds to the demands of Canadian carriers and pilots for standardized descriptions of runway conditions with detailed information about contaminant location that is not easily found in the ICAO SNOWTAM protocol.

There are a variety of ways in which runway conditions are recorded by the RI prior to transmission of the information. Not all regulatory authorities provide detailed direction and guidance on the matter.

2.5.1.1 Ad Hoc Notation

At some (usually small) airports, RIs may make ad-hoc notes on conditions immediately after inspecting the runway in preparation for radio transmission of the condition report to the AIS provider. This may be the norm when there is no direction on using means other than voice radio to transmit reports. It may also be the case at larger airports for communicating frequently changing conditions when it is impractical to use other means.

2.5.1.2 Paper Forms

Where there is direction, either from the regulator or the airport authority, the RI will record conditions on a paper form immediately after the inspection and fax the report to the AIS provider and other interested parties. The report may also be transmitted by radio in anticipation of receipt by the AIS. Paper forms will reflect the mandated or advised ICAO Annex 14 requirements wherein the runway conditions are reported in one third sections or they will respond to nationally mandated requirements for reporting details such as with the Transport Canada format in Figure 2.3.

2.5.1.3 Computerized Information Recording and Transmission

RIs may use in-vehicle computerized systems to record the conditions and transmit the resulting computerized report to the AIS via cellular modem, WiFi, dedicated frequency, or other radio medium. Computerized reports usually contain the same report elements as written forms but may be received in plain text, as a form or as a data element sequence.

Commercial computerized aircraft movement surface condition reporting systems such as the “Winter OPS PRO” and “TRACR II” systems have been in widespread use for many years and have several advantages over paper or voice reporting:

- (a) Graphical interface for ease of use;
- (b) Reporting terminology is uniform and consistent;
- (c) Time to receipt is minimized;
- (d) Reports can be transmitted to multiple destinations simultaneously;
- (e) System can ‘interrogate’ peripheral sensors such as friction measurement and temperature measuring equipment to collect and transmit information;
- (f) ‘Tombstone’ (unchanging) data, date, time and other non-condition information is automatically added; and
- (g) Logic checks are built in to reduce the potential for error.

The disadvantages of such systems include cost and a time lag when amendments have to be made. It is believed that such systems can be improved with further development to ensure they fully accommodate the informational needs of carriers and pilots and are fully compatible with evolved SNOWTAM formats. A major advancement in the use of such systems is the automatic translation and dissemination of condition reports into the SNOWTAM format. As will be discussed elsewhere, this has been achieved for one system in Norway. The results of the Norwegian experience should be closely monitored.

2.5.2 Information Distribution

Within each national jurisdiction, it is the AIS provider that is responsible for providing carriers and pilots with information about services available at each airport, including runway condition reports. The local air navigation office, usually Air Traffic Control or a Flight Service Station or equivalent, will receive reports of runway conditions directly from RIs for distribution. With smaller airports, there may not be a local air navigation office and airport staff have to transmit reports to a remote Flight Service Centre for distribution.

The receiving AIS office translates airport reports of conditions into a proscribed NOTAM format prior to transmission over the distribution network. For reports of transitory winter runway conditions, the SNOWTAM format is used in most jurisdictions and the NOTAMJ format is used in Canada. These specialized forms of NOTAM are tailored for the issuance of multiple iterations.

Upon receipt of the report of runway conditions by the AIS, the report is checked for logic, manually (except for the automatic one in Norway – to be described subsequently) translated into the appropriate NOTAM format and submitted to the distribution networks. These steps are time consuming and can result in intervals of 30 minutes or more between the receipt of a runway condition report and the publication of a NOTAM. This weakness in the distribution system contributes significantly to out-of-date surface condition reports being received by pilots, which is one of the most commonly expressed concerns from pilots.

2.6 Issues for Runway Condition Reporting: Access to the Runway and the AMSs

2.6.1 The Problem

Airports are charged by Civil Aviation Authorities with the responsibility of providing accurate and timely reports of aircraft movement surface conditions to the air navigation service provider for distribution to air carriers and pilots. At the same time, they are affected by the very real (at times) challenge of gaining access to the runway to conduct the inspections. At times, this affects the ability to obtain accurate measurement and or estimation of runway surface conditions.

It is paradoxical that, as aviation traffic increases for a given airport, there is increasing pressure on airport staff (Runway Inspectors) to limit their interruption of traffic. Of course, RIs interrupt aviation traffic when they survey the runways in order to deliver condition reports for the purposes of aircraft landing and take-off operations.

This paradox reaches its peak when airport staff repeatedly ask air traffic controllers for runway access and are told to wait or are finally given permission for “expedited” inspections which are often rushed or only partially completed. Under such circumstances, safety may be compromised due to factors such as (a) the recommended inspection vehicle speeds are exceeded, (b) the surface is not adequately viewed, and (c) friction measurement procedures that are compromised or (d) out-of-date reports are not superseded or cancelled.

Air traffic controllers are often powerless to provide adequate and/or immediate access or time for runway inspections without significantly delaying or diverting air traffic because of preset flight schedules. At busy airports with snow and ice control in progress, traffic is often “stacked” waiting for the runway to be “cleared”. As a result, significant pressure is placed on airport staff to produce the best possible maintenance in the least time, and RIs sometimes get little opportunity to view the runway unless it is concurrent with maintenance in progress.

Some busy airports deal with the challenge of limited runway access for the purposes of winter maintenance by closing the surface via NOTAM. This action is most often considered a last resort because of the impact on aircraft landing and departure timing and is rarely taken for the purposes of conducting inspections alone. RIs are often made fully aware of the disruptive impact they will have on aircraft traffic should they close a runway and are therefore reluctant to action a closure.

2.6.2 Recommendations

Regulators should direct airports to discuss their winter condition aircraft movement surface maintenance and inspection requirements with their air navigation service provider and agree upon processes for providing adequate aircraft movement surface access for the purposes of maintenance and particularly runway condition surveying, including runway friction measurement where relevant.

2.7 **Condition Forecasting and Role of Short-Term Forecasting**

Meteorological forecasting information sources are available to airports to assist them in predicting the severity of impending adverse weather conditions. These can be divided into three groupings as follows:

- (a) National weather forecasting services;
- (b) Commercial weather information-gathering, dissemination and prediction services; and
- (c) Short-term forecasting or “now-casting”.

Each level of service has different accuracy and requirements for financial investment and interpretive skills. Their advantages and disadvantages vary depending upon factors such as local conditions and the consistency of localized weather trends. When they are used in combination, these technologies can be a very effective tool for accurate weather prediction, but interpretive skills and monitoring resources are required to achieve the best advantage.

2.7.1 National Weather Forecasting Services

Most countries either have their own service or subscribe to another country's national meteorological weather reporting and prediction service. These services can be very sophisticated and have considerable resources at their disposal. For an example, see the US National Oceanic and Atmospheric Administration's website which includes satellite imaging: <http://www.noaa.gov/index.html>. The European EUMETSAT website is another such example (<http://www.eumetsat.int/Home/Main/AboutEUMETSAT/index.htm?l=en>).

Often, there is meteorological instrumentation belonging to these services at airports. Airports can subscribe to service websites or dedicated information telephone lines and get general predictions of impending weather conditions with a reasonable level of accuracy.

For a fee, some governmental services provide an enhanced level of weather prediction with specific, localized predictions and access to more recent information. Detailed satellite and trending imaging for local vicinities covering a current time minus 20 minutes time frame is possible.

Highly detailed information including infrared, satellite and radar images, atmospheric temperature, wind direction and strength, and weather system formation are available but skill and knowledge are required for detailed interpretation.

2.7.2 Commercial Weather Information-Gathering, Dissemination and Prediction Services

Commercial services are available which tailor the information provided to specific needs of the user. These services interpret and predict localized conditions removing the need for the customer to have such skills. Information regarding a typical service may be found at: <http://www.weatheronline.co.uk/>

RWIS (Runway Weather Information Service) system manufacturers provide installations to roadway and airport authorities in many jurisdictions for the purposes of "now-casting". Some system manufactures can collect the localized information using phone or internet lines, collate it and make it available to other clients within the vicinity. This can be very useful when weather trends are consistent and predictable and an airport can expect to experience a given weather condition based upon the current conditions at a specified nearby location.

2.7.3 Short-Term Forecasting, or "Now-Casting"

2.7.3.1 *General Description*

"Now-casting" is the term given to prediction of immediately impending localized weather conditions based on data received from instrumentation in the immediate vicinity. For airside applications, instrumentation is typically installed with three or four in-runway sensors and one or two edge-of-runway installations per runway:

- (a) In-surface sensors typically provide information regarding (i) surface temperature, (ii) sub-surface temperature, (iii) the presence of moisture, and (iv) the presence of ice control chemical.
- (b) Edge-of-runway stations typically provide information regarding (i) wind direction, (ii) wind speed, (iii) dew point, (iv) air temperature, and (v) humidity

Now-casting uses localized RWIS stations and predictive software to provide an estimation of impending conditions and or to control ice control chemical applications by in-ground or mobile sprayers. The Boshung FAST system (<http://www.boschungamerica.com/pages/FAST.php>) is typical. Systems can be configured to automatically notify airport staff of impending adverse conditions using e-mail, cellular message “push” services, etc. Such notifications are sent when predetermined criteria are reached or when automated ice control application system action is taken.

2.7.3.2 Feasibility of “Now-Casting” for Runway Condition Reporting

RWIS and “now-casting” is integral in automatic ice control chemical application systems that are currently in use or on test at roadway locations and bridge installations. Such systems offer an invaluable tool for predicting localized imminent conditions. For full effectiveness, more than one installation would probably be required for large airfield areas. Because of the immediacy of the information, RWIS and now-casting can supplement other meteorological forecasting, but it cannot replace it.

Advanced now-casting systems incorporate intelligent system software that interprets data from RWIS and other sources to produce prediction and advice on snow and ice control. The FAA refers to such systems as Weather Support to De-icing Decision Making (WSDDM) Systems and minimum specifications for such systems are described in Society of Automotive Engineers (SAE) Aerospace Standard (AS) 5537.

With respect to the role of “now-casting” for Runway Condition Reporting (RCR), it must be noted that the role of RCR is to report present runway conditions and not ones that may potentially occur in the future. Thus, while “now-casting” can be an important tool, especially for runway maintenance operations, it can never replace runway surveying as the primary process for documenting runway surface conditions.

3 OPERATIONAL FRICTION MEASUREMENTS

The overall objectives of the work were to:

- (a) Document the current state of the art, taking into account current initiatives such as the TALPA ARC and the ICAO FTF;
- (b) Review and assess past attempts to harmonize ground friction readings on contaminated surfaces, including the difficulties that have arisen; and
- (c) Provide recommendations – these are presented in Volume 1.

3.1 Operational Friction Measurement

This is one method of assessing the acceptability of runways for aircraft operations in winter. There are few if any regulatory requirements to measure friction under operational conditions in other Aircraft Movement Surfaces (AMSs). Runway friction measurements are routinely used to assess runway surface friction characteristics due to winter contaminant conditions such as snow, ice, etc. Some airports, in common with some road authorities, have been known to publish Levels of Service based upon surface friction values.

3.1.1 Methods for Measuring Friction

A detailed review of the available methods and devices for measuring surface friction is presented in Volume 3 of this report series, in relation to functional friction measurements. In brief, the available methods may be divided into four categories as shown in Table 3.1. All four types of testers are promoted as being suitable for operational friction measurements.

The types in common use at airports for operational friction assessments include fixed-slip devices, side-force devices and locked wheel decelerometers.

Table 3-1: Methods of Measurement for Surface Friction Measurement

Device Type	Sampling Provided	Available Configurations
Locked-wheel testers	Spot Measurement	Decelerometer mounted in a vehicle Trailer with locked wheel towed by vehicle
Side-force testers	Continuous record	Trailer towed by vehicle
Fixed-slip testers	Continuous record	Trailer towed by vehicle Fifth wheel in vehicle
Variable-slip testers	Continuous record	Trailer towed by vehicle Instrumented wheel under a truck body

3.1.2 The Form of the Friction-Related Information that is Reported

The friction-related information that is reported to pilots may be either:

- (a) The average of the measured friction values themselves, which are collected with various ground friction-measuring devices; or
- (b) General indications of braking action. Only one scale is in active use, that being the one in ICAO Annex 14, Volume 1 (ICAO, 2004 - Figure 3.1).

It is noted that, in the past, the FAA has had a general braking action scale in its 150/5200-30C Advisory Circular. However, their previous scale is not discussed here because the FAA no longer recommends relating friction coefficient measurements to scales of braking action (FAA, 2008), and its AC presently does not contain a scale.

<i>Measured coefficient</i>	<i>Estimated braking action</i>	<i>Code</i>
0.40 and above	Good	5
0.39 to 0.36	Medium to good	4
0.35 to 0.30	Medium	3
0.29 to 0.26	Medium to poor	2
0.25 and below	Poor	1

Figure 3.1: Braking Action Scale in ICAO Annex 14, Volume 1 (ICAO, 2004)

Note: ICAO, 2004 contains a warning that the above table was “developed from friction data collected only in compacted snow and ice and should not, therefore, be taken to be absolute values applicable in all conditions”.

Countries differ with respect to the type of information that is provided (Table 3.2). Some countries (e.g., Canada, Finland, Germany, and France) provide the measured friction values to pilots.

Other countries only provide them with a general indication of the braking action according to the ICAO scale (Figure 3.1). Many of these countries include statements in their AIP regarding the limitations of this scale, and some include a code in the reporting format to signify that the runway conditions are unsuitable for measurement with a friction device thereby rendering the results from the ICAO scale inaccurate.

In the past, the FAA recommended providing friction values to pilots, but without any accompanying indication of the braking action. The FAA’s position has recently changed such that it considers it “permissible” for airports to provide measured friction values, but it is “not recommended” (FAA, 2008). See Table 3.2 for further information.

Table 3-2: Type of Friction Information or Braking Action Reported to Pilots

Country	Measured Friction Values	General Braking Action Index
United States	“Permissible” to be reported but not recommended ²	Not recommended or reported ²
Finland	Reported ³	Only when friction data not available ³
Norway	Not recommended to be reported & not reported ⁴	Reported Using ICAO Scale ⁴
United Kingdom	Not recommended to be reported & not reported	Reported Using ICAO Scale ^{1,5}
France	Varies among airports ⁶	Varies - Reported Using ICAO Scale ^{1,6}
Germany	Reported ⁷	Only when friction data not available ⁷
Canada	Reported ⁸	Not reported

Country	Measured Friction Values	General Braking Action Index
Italy	Not recommended to be reported & not reported	Reported Using ICAO Scale ¹
Sweden	Not reported	Reported Using ICAO Scale ¹
Netherlands	Not reported	Reported Using ICAO Scale ¹

Notes:

1. See Figure 5.3 for the ICAO Scale.
2. The FAA has recently taken a strong position against friction measurements in its recently-updated Advisory Circular (FAA, 2008) which advises that:
“Airport operators must not attempt to correlate friction readings (Mu numbers) to Good/Medium (Fair)/Poor or Nil runway surface conditions, as no consistent, usable correlation between Mu values and these terms has been shown to exist to the FAA’s satisfaction. It is important to note that while manufacturers of the approved friction measuring equipment may provide a table that correlates braking action to Mu values, these correlations are not supported by the FAA”.
“Although the FAA no longer recommends providing friction measurements to pilots for the reasons stated in the paragraph above, some airport users still consider runway friction measurement values to be useful information for tracking the trend of changing runway conditions. Therefore continued transmittal of Mu values is permissible with the understanding that the particular numerical value has no particular significance other than to provide changing runway condition trend information when associated with previous or subsequent runway friction measurement values. Airport operators are cautioned against using Mu values as their sole indicator of winter runway slipperiness”.
3. Finland’s AIP states that the general braking action should only be reported when friction data are not available. In this case, the estimated braking action should be reported. It is noted that Finnair uses friction measurements made by a BV-11 as an input for operational assessments for its aircraft (Puronto, 2004).
4. In November, 2008, Norway amended its AIC to state that PIREPS are an acceptable means for establishing the braking action. The Norwegian AIP also notes that:
“In general there is great uncertainty related to measurement taken on a winter contaminated surface. A measured friction level is associated with the measuring device used and can not be used as an isolated number ... The table used in the SNOWTAM format item H, with associated descriptions, was developed in the early 1950’s from friction data collected only on compact snow and ice. The friction levels should not be regarded as absolute values and they are generally not valid for other surfaces than compact snow or ice”.
5. The United Kingdom’s AIP states that:
“It is important to remember that the braking action assessment obtained from the Snow and Ice Table is only a rough indication of the relative slipperiness of a contaminated runway in conditions of compact snow and ice only. The description ‘Good’ is used in comparative sense – good for an icy surface – and is intended to indicate that aircraft generally, but not specifically, should not be subject to undue directional control or braking difficulties, but clearly a surface affected by ice and/or snow is not as good as a clean dry or even a wet runway. The description ‘Good’ should not be used for braking action on untreated ice but may be used, where appropriate, when ice has been gritted. ‘Poor’ will almost invariably mean that conditions are extremely slippery, and probably acceptable only, if at all, to aircraft needing little or no braking or steering. Where ‘Poor’ braking assessment exists, landings should only be attempted if the Landing Distance Available exceeds the Landing Distance Required on a ‘very slippery’ or icy runway as given in the aircraft Flight Manual. The intermediate values of ‘Medium/Good’, and ‘Medium/Poor’ have been included only to amplify the description when conditions are found to be Medium. The procedure is insufficiently refined to be able to discriminate accurately in the narrow numerical bands as set out in the table”.

6. France – a variety of responses were received from French airports. One stated that friction measurements are made where appropriate based on the limitations of the device, and information is reported to pilots according to ICAO. Another French airport stated that previously they only provided general braking indications but now, in response to requests from pilots, they provide the measured friction values. Another French airport stated that they routinely report the actual friction readings to pilots and would only give a general indication of braking action if data were not available from a friction-measuring device.
7. Germany – the measured friction values are reported unless the conditions are outside the operational limits of the device. In that case, only general indications of the braking action are provided, based on a matrix that has been developed which provides guidance to the ground friction device operator.
8. Canada has a system based on the Canadian Runway Friction Index (CRFI), as described in its AIM. Also, as part of the regulatory regime in Canada, airports are required to report the CRFI. The CRFI is routinely reported to pilots. The Canadian system is described in detail in Volume 4.

3.1.3 Currency of Operational Friction Measurements

Snow and icing events tend to be transitory, particularly during a snowstorm or freezing rain, which are critical conditions. As a result, runway surface conditions, including friction, vary significantly with time. In order for friction measurements to be of value to flight operations, they must be as current as possible and reported as quickly as possible.

Although only the most recent report of runway friction can be of value in calculating the effects on aircraft ground performance, to date, regulators have only required air carriers to take runway friction into account in calculating aircraft stopping distances at the time of dispatch. It is noted that there are indications that the FAA is considering addressing this discrepancy, through the proposed TALPA ARC system.

As a result, many air carriers provide their own instructions to pilots. These instructions can vary from training briefings to aircraft flight operations manual instructions to computerized or manual processes for calculating landing distances. However, such instructions are not required by regulation and they vary considerably among airlines.

3.1.4 Perceived Value and Reliability of Operational Friction Measurements

There appears to be a divergence of views regarding this. Introductory information is presented below. This issue is revisited in subsequent sections.

3.1.4.1 General Results from Test Programs and Experience from Air Carriers

Previous Test Programs

As will be discussed in a subsequent section, various previous test programs such as tests done by NASA (Yager et al, 1990) and the Joint Winter Runway Friction Measurement Program (e.g., Andrassy, 1999) have demonstrated that correlations can be established between aircraft performance and ground friction readings, although they contained scatter.

Inclusion of Ground Friction Readings by Air Carriers for Operational Assessments

A number of airlines are currently using ground friction readings as part of their process for assessing aircraft takeoff and landing performance. Examples are provided in Hollands, 2004, and Puronto, 2004, for Westjet and Finnair, respectively. It is noted though that these airlines limit their usage of friction information to the readings from a single device (i.e., a decelerometer and the BV 11 respectively). They do not attempt to incorporate the readings from all the different devices into their procedures, which considerably simplifies the problem.

Canada is one jurisdiction that has maintained a consistent approach to measuring and reporting runway friction for the purposes of flight operations in winter conditions. This has been done over several decades with virtually no criticism of the supporting Government policy. Canada is an example of a jurisdiction employing a single friction measurement method with highly standardized procedures and a clear interpretation of runway operational friction measurements as a description of ground vehicle performance.

Support has been expressed repeatedly for maintaining and advancing operational friction measurement by carriers and pilots alike at formal forums. The same views have been declared by air carrier and pilots association representatives in the Canadian Aviation Regulatory Advisory Council (CARAC) Airport Winter Maintenance and Planning Working Group convened by Transport Canada to draft updated airport regulations (as described in Transport Canada's ASC 2001-011). A formal survey of Canadian airline pilots found that they have positive perceptions of the value of runway friction measurements (Biggs and Hamilton, 2002).

It may be speculated that the stability and consistency inherent in the Canadian approach to operational friction measurement has contributed to the domestic support. While regulators and industry are often at odds, there is a significant degree of harmony in Canada on this issue with debate limited to and focused on technical issues and how to advance the state of the art.

Much of the general debate regarding the value of friction measurement on contaminated runways seems to rest in defining reported friction as either a predictor of aircraft braking action or solely as an indicator of surface slipperiness as experienced by a ground vehicle. The distinction is significant and sometimes overlooked in debate.

3.1.4.2 General Trends Being Exhibited by the Aviation Community

At the same time, the general aviation community appears to be expressing a lack of confidence in ground friction readings as evidenced by a number of items, which are discussed in more detail subsequently:

- (a) The FAA has recently updated its 150/5200-30C Advisory Circular (FAA, 2008) to:
 - (i) Strongly advise against correlating ground friction readings with aircraft performance; and
 - (ii) Advise that while it is "permissible" for airports to report ground friction readings, it is "not recommended".

See Note 2 in Table 3.2

- (b) The Takeoff/Landing Performance Assessment Aviation Rulemaking Committee (TALPA/ARC), which has been led by the FAA, is de-emphasizing ground friction readings as a means for assessing aircraft performance. Instead, descriptions of the runway surface condition itself form the primary basis for assessing aircraft performance in the TALPA ARC Runway Assessment Matrix. Although ground friction readings are part of this matrix, they can only be used to downgrade the assessment based on surface conditions, presumably on the premise that it is “better to be safe than sorry” and not to upgrade it. This expresses a reduced confidence in the value of runway friction measurements from ground vehicles.
- (c) The ICAO FTF has also considered the issue of ground friction readings for operational applications. Although there was consensus that a global format is required for runway condition reporting, there was disagreement regarding the path to be taken to achieve this goal and the role of ground friction measurements.

3.1.5 Operational Friction Measurement Procedures

Although friction measurement requirements and procedures vary across jurisdictions and even in some jurisdictions from airport to airport, operational friction measurements are always taken along the path expected to be traversed by the aircraft’s outboard landing gear.

In some jurisdictions, RIs are permitted great latitude in selecting the exact friction measurement path, vehicle speed and even, in the case where decelerometers are used, the number of readings to be taken to obtain an average value. This inconsistency alone will produce variable levels of reliability for average runway readings.

Averages are reported for the entire runway length and, depending upon jurisdiction, averages are also reported for each of the three zones (touchdown, centre, and rollout) or detailed information is given for locations of lower than average friction.

3.1.6 Operational Friction Measurement Limitations

Regardless of the degree of support for operational friction measurement, there is consensus among all parties involved that the available friction-measuring devices are most suitable for “solid” surfaces such as ice or compacted snow. Furthermore, they are all generally considered to be unreliable on fluid or fluid-like surfaces (slush, wet, de-icing chemicals, etc). This is reflected in the AIPs of many countries which contain warnings regarding the limitations of friction-measuring devices. These warnings have been listed in Volume 2 of this report series, and this subject is discussed in further detail in a subsequent section.

This limitation is a major restriction given that fluid or fluid-like surfaces often represent a major challenge to flight operations. This needs to be taken into account in evaluating the value of ground vehicle friction measurements.

3.2 **Previous Harmonization Attempts**

For obvious reasons, ground friction-measuring devices should all report the same friction number on the same surface. For some time, the aviation community has recognized that there is a need for harmonization of the outputs from all the friction measuring devices so that

they all report according to a similar friction index. As part of efforts to harmonize the outputs from ground friction devices, various major research initiatives have taken place, including the following:

- (a) The Permanent International Association of Road Congresses (PIARC) international harmonization study was conducted in 1992 (Wambold et al., 1995) by representatives from many countries. It was focussed on the harmonization of continuous ground friction measurement devices under wet conditions.
- (b) Tests and research conducted by NASA spanning the period from about 1970 to 1990 – the most recent tests were conducted by Yager et al., 1990 with Boeing 727 and 737 aircraft, as well as several ground vehicles, on various surfaces including dry, wet, ice, snow-and-slush, and surfaces that had been treated with chemical de-icers.
- (c) the Joint Winter Runway Friction Measurement Program (JWRFMP), initiated by Transport Canada (e.g., Andrassy, 1999) which concentrated on:
 - (i) Harmonization of ground friction measurement devices under winter contaminated surfaces; and
 - (ii) Relating a ground friction measured number to aircraft braking performance.

3.2.1 The PIARC Research Program

The Permanent International Association of Road Congresses (PIARC) initiated a harmonization research program in 1992 (Wambold et al., 1995) that consisted of a series of field tests to compare pavement texture and friction measurements. The PIARC research program concentrated on testing on “wet” surfaces only, which for the purposes of this study, relates more to runway maintenance than to operational measurements, especially for winter-contaminated runways. Consequently, only an outline is presented for the PIARC program here, as it has been discussed in Volume 3, in relation to functional friction measurements.

Nevertheless, since similar ground friction devices are used for winter operations, a brief description of the PIARC research program is relevant, along with a synopsis of the program’s outcome and achievements:

- (a) The field tests were conducted at over 50 sites along with over 40 different measuring systems.
- (b) The overall objective was to compare and harmonize surface texture and skid resistance measurements.
- (c) The participating friction-measuring devices were fixed-slip and locked wheel systems that operated at different speeds.
- (d) A series of relationships were developed from comparisons made using the measurements.

- (e) A common harmonized index was produced (Wambold et al., 1995) for wet pavements, which was termed the International Friction Index (IFI).
- (f) An American Society for Testing and Materials (ASTM) standard was developed for the IFI index (ASTM, 1998 - ASTM E1960-98: “Standard Practice for Calculating International Friction Index of a Pavement Surface”).
- (g) The ASTM IFI standard has not been adopted by ICAO or by civil aviation authorities.

3.2.2 Test Programs Conducted by NASA

Test programs were conducted by NASA over a period of about 20 years, from about 1970 to 1990. Yager et al., 1990s tests were the most recent ones. They were carried out at several sites including NASA’s Wallops Flight Facility; the FAA’s Technical Centre; the Langley Air Force base; the Pease Air Force base; the Naval Air Station at Brunswick, Maine; and the Portland International Jetport.

Two aircraft were used: (a) NASA’s B-737 and (b) the FAA’s B-727. In parallel, test data were obtained with seven ground-friction measuring devices (a) the Diagonal Braked Vehicle; (b) the Mu-Meter; (c) the RFT; (d) the BV-11 Skiddometer; (e) the Tapley Decelerometer; (f) the Bowmonk Decelerometer; and (g) the SFT.

Tests were conducted on a wide range of surfaces including dry, wet, ice, snow-and-slush, and surfaces that had been treated with chemical de-icers.

The tests showed that different parameter dependencies were observed depending on the device and contaminant with respect to, for example, (a) speed or (b) the general relation between the friction coefficient measured for the aircraft versus the one measured by the ground vehicles (e.g., with respect which was larger). See Figure 3.2 for sample results.

Yager et al., 1990, hypothesized that the different trends reflected significant variations in the governing processes, as presented below:

- (a) Compacted snow and ice – they believed that the friction coefficient on these surfaces was controlled by the relatively low shear strength of these materials. This hypothesis was confirmed during parametric tests conducted later as part of the JWRFMP (described subsequently).
- (b) Loose dry snow and slush – they believed that the observed differences in trends could be attributed to the higher pressure aircraft tires being pushed through the loose dry snow and slush, such that they regained contact with the pavement below. In contrast, the lower pressure tires used on the ground vehicles behaved differently.

Temperature was identified as another significant factor, especially for surfaces near the melting point. In these cases, it is expected that a thin water film would be produced, which could lead to slippery conditions, due to lubrication and possibly viscous hydroplaning.

Yager et al., 1990, concluded that ground friction data had been shown to correlate with aircraft braking coefficients. However, more data and investigation was required to define the governing processes and to quantify the functional relations appropriately.

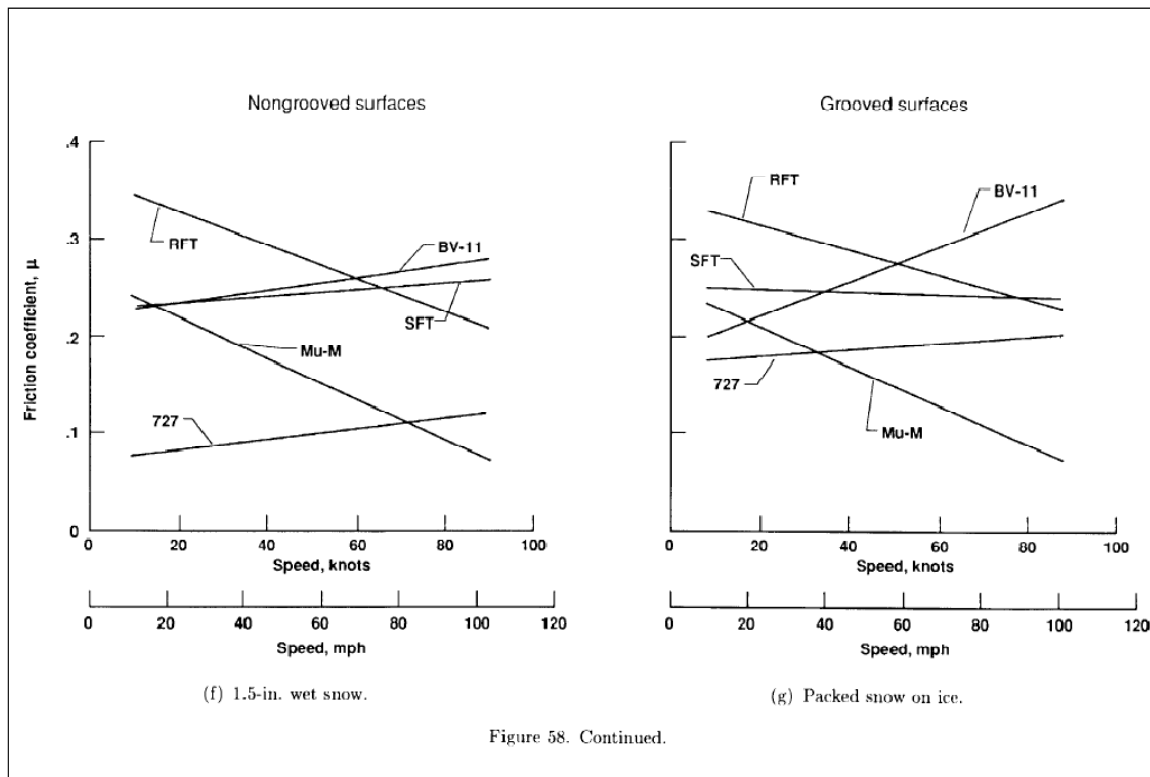


Figure 3.2: Sample Results for B727 Aircraft and GFMD Data (Yager et al., 1990)

Predictors were developed by Yager et al., 1990, for aircraft braking coefficients. It was found that:

- (a) For wet runway conditions, the estimated aircraft braking performance from the ground vehicle measurements was within ± 0.1 friction coefficient value of the measured values, except for some rain-wet data; and
- (b) 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, except for some rain-wet data.

It is seen that the degree of correlation achieved was coarse. These observations provide some indication of the limits to which harmonization is possible for friction-measuring devices that differ significantly in design.

3.2.3 The Joint Winter Runway Friction Measurement Program

The Joint Winter Runway Friction Measurement Program (e.g., Andrassy, 1999) has been the most extensive program conducted to date on winter-contaminated surfaces.

The JWRFMP research program dealt with harmonization of friction measuring devices in use at airports to measure and report friction on winter contaminated surface and to relate a ground friction measurement to aircraft braking performance. Because this research was very relevant to this part of the project, its activities and results will be discussed in more detail.

3.2.3.1 Program Objectives

There were two main objectives for the program:

- (a) To establish reliable correlation between ground vehicle friction measurements and aircraft braking performance; and
- (b) To harmonize ground vehicle friction measurements such that they report a consistent friction value or index for similar contaminated runway conditions, such as, for example, compacted snow, and ice.

It is BMT's opinion that the first objective is the more important one, as a reliable correlation with aircraft performance is essential for ground friction measurements to be useful. Without this, there is little point in establishing a wide-ranging harmonization among the devices.

3.2.3.2 Program Scope

NASA and Transport Canada (TC) led this study with support from the NRC, FAA, NCAA, and STBA. Organizations and equipment manufacturers from North America, France, Norway, Sweden, Scotland, Germany, and the United Kingdom also participated in the JWRFMP by providing aircraft, and ground friction vehicles.

The program spanned 1996 to 2003. A wide variety of instrumented test aircraft and ground friction measuring vehicles were used. Field tests were conducted at different sites in the US, Canada, Norway, Germany, and the Czech Republic.

In 1996, tests were conducted using NASA's B-737 aircraft, and the NRC's Falcon-20 aircraft. The tests were conducted on winter-contaminated surfaces at Jack Garland Airport in North Bay, Ontario, Canada. Seven ground friction measuring devices from six different countries collected comparable friction data from several winter runway conditions including dry, wet, solid ice, dry loose snow, and compacted snow.

Similar tests were performed at North Bay airport during the 1997 winter season. The participating aircraft were FAA's B-727, the NRC's Falcon-20 and De Havilland's Dash-8. Thirteen (13) ground friction measuring devices also participated by measuring surface friction. The data obtained helped to define a methodology to harmonize the friction measurements obtained with the different ground test vehicles to a common scale. The common scale was given the term the "International Runway Friction Index" (IRFI).

During the 1998 winter season, additional data were collected at North Bay with the Falcon-20 and Dash-8 aircraft, together with 11 different ground test vehicles. This helped to further refine the IRFI methodology, and to develop a methodology to relate a ground friction measurement to aircraft braking performance.

In March 1998, tests were conducted with several different ground friction measuring devices on compacted snow and ice at a test track facility at Gardermoen Airport, near Oslo, Norway.

Work also commenced to develop an index relating the friction measurements made by the Electronic Recording Decelerometer (ERD) to the measurements made of aircraft braking coefficient, which was termed the Canadian Runway Friction Index (CRFI).

More data were collected in 1999 with the Falcon-20 aircraft and with ground vehicles at North Bay airport. Also, the 1999 program included tests with NASA's B-757 aircraft and ground vehicles data at Sawyer Airbase, Gwinn, MI. These tests were followed with additional tests with ground vehicles at the Gardermoen test track in Oslo, Norway. The data from these tests were used (a) to further refine and improve the IRFI methodology, (b) to define the present correlation constants in the IRFI standard, and (c) to further refine the aircraft braking performance/ground friction measurement relationship methodology.

During the 2000 winter season, testing was done at North Bay, Ontario, with the Falcon-20 aircraft and ten ground friction measuring vehicles. As well, tests were conducted at Munich Airport, Germany, with an Aero Lloyd A320, Sabena Airlines A320, Deutsche British Airways B-737-300, and a Fairchild/Dornier 328 aircraft. Thirteen ground test vehicles participated in the Munich testing which totalled 60 test runs with five aircraft, and over 1,000 runs with the ground vehicles.

In 2001, three weeks of testing took place at North Bay, Ontario, involving a NAVCAN Dash-8 aircraft and six ground vehicles. As well, more tests with the Fairchild/Dornier 328 aircraft were conducted at Erding Airbase in Germany. Ten different ground friction measuring devices participated in the tests at the Erding Airbase. Nearly 80 test runs were completed with the two aircraft, and over 2,000 test runs were made with the ground vehicles.

During 2002, seven ground vehicle devices participated in over 2,200 test runs at North Bay, Ontario. These tests were aimed at improving the accuracy of the IRFI methodology. In addition to tests at North Bay, over 1,200 ground vehicle tests were also conducted during the first week in March at Prague Airport, Czech Republic, to determine the repeatability of friction data measured by similar devices operated under self-wetting conditions.

During 2003, tests were conducted in Japan using a Boeing 767 in combination with ground friction-measuring devices.

In parallel, development of the CRFI continued by incorporating the data from the additional aircraft tests into the methodology.

3.2.3.3 Test Summary

The JWRFPMP produced a large amount of data. Ten (10) aircraft and forty-four (44) different ground devices participated in the program. A total of 442 aircraft runs and close to 15,000 ground vehicle runs were conducted on nearly 50 different runway surfaces. The data set included:

- (a) Eight (8) weeks of NASA Aircraft Tire/Runway Friction Workshop data;
- (b) Over 19 weeks of winter testing at North Bay;
- (c) One week at Sawyer Airbase, Gwinn, MI;
- (d) Two weeks at Oslo, Norway;
- (e) One week at Munich Airport, Germany;

- (f) One week at the Airbase at Erding, Germany; and
- (g) One week at Prague Airport.

Over 400 individuals from nearly 60 organizations in 15 different countries participated with personnel, equipment, facilities, and data reduction/analysis efforts.

3.2.3.4 Results and Achievements

These are summarized below:

- (a) Over 45 technical reports were produced during the course of the JWRFMP. These reports cover all major topics including:
 - (i) The field testing that was done for the aircraft and the ground friction-measuring devices on the different winter-contaminated surfaces at various locations;
 - (ii) A technical analysis of the data and the development of a methodology in the development of the ASTM IRFI standard;
 - (iii) The development of a methodology to establish a relationship between aircraft braking performance and ground friction measurements; and
 - (iv) The performance of ground friction-measuring devices. The reports provide correlations of ground friction devices, data regarding the reliability and reproducibility of the devices, and recommendations regarding where further studies should be considered.

Abstracts and summaries for 47 of the JWRFMP reports are provided in Appendix C of Volume 2.

- (b) Aircraft braking coefficients were compared with runway friction indices measured by various devices, including the Transport Canada Electronic Recording Decelerometer (ERD), the SAAB Surface Friction Tester and a reference vehicle providing an interim IRFI. The correlation between aircraft braking coefficients and the Canadian Runway Friction Index (CRFI) provided by the ERD was considered to be good enough by Transport Canada to be used for the prediction of aircraft braking performance based on the measured CRFI. As a result, tables of recommended landing distance, independent of specific aircraft type, were developed as a function of the CRFI and published in Transport Canada's Aeronautical Information Publication (AIP).
- (c) An ASTM standard was developed for the International Runway Friction Index (IRFI) using the data from field testing. The ASTM IRFI standard describes how to calculate IRFI for winter surfaces. The ASTM IRFI standard is a harmonized reporting index that is intended to provide aircraft operators with information on the tire-surface friction characteristics of a runway.
- (d) International aviation conferences were held in Montreal to disseminate the test results, to try to obtain user acceptance of the findings, and to obtain recommendations for future developments.

- (e) A substantial database was established incorporating all the tests that were carried out with both ground vehicles and aircraft. Each friction value is stored along with the corresponding name/type of ground friction device, the test location, the test speed, the tire specifications, the surface conditions, the ambient weather conditions, and any other relevant data.
- (f) At all test sites, the National Research Council of Canada (NRC) provided an ice and snow researcher who classified the winter contaminants. Typically, the water content, density, temperature of air, contaminant and pavement, and the contaminant depth were measured, along with observations of the surface conditions during the aircraft and ground vehicle test runs. These data, along with the hourly flight weather, are included in the database.
- (g) The JWRFMP data were used to establish a relationship between the contaminant type and the expected friction coefficient on that surface, as defined by the CRFI (Figure 3.3). That relationship was put into Transport Canada's AIP.

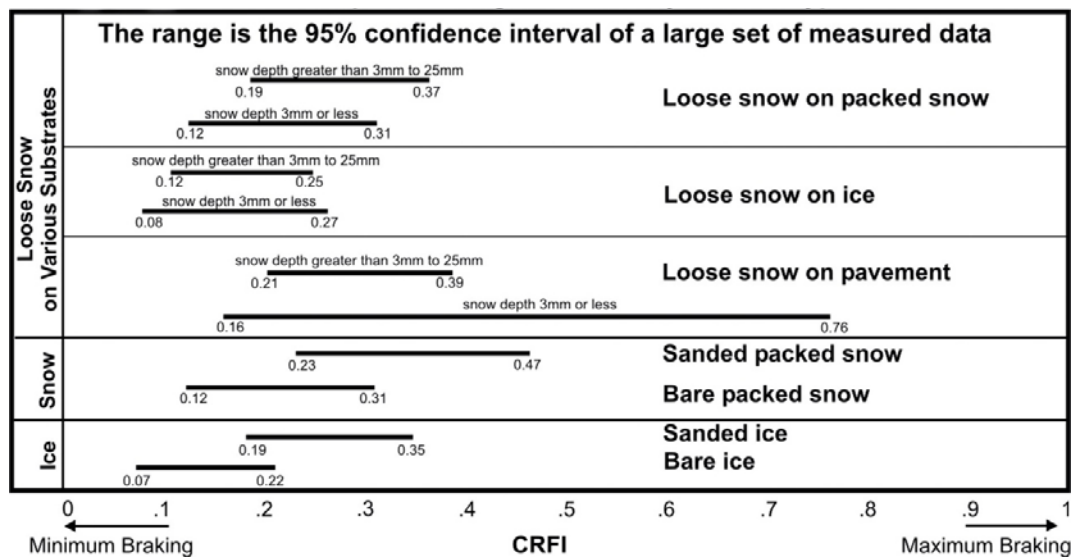


Figure 3.3: Effect of Contaminant Type (Transport Canada AIP)

- (h) The effectiveness of the ASTM IRFI was established. Table 3-3 compares the zero intercepts and slope multiplier values of each Ground Friction-Measuring Device (GFMD) before and after IRFI was applied. Table 3-2 shows that the IRFI did reduce the differences of each GFMD when compared to the IRFI reference. The average error of the difference of the slope multipliers from the reference is 0.14 without IRFI and 0.05 with IRFI (absolute error of 0.1), which is a reduction in the error of 64 percent.
- (i) The data showed that aircraft braking performance could be correlated to the friction coefficients measured by ground vehicles (Croll et al., 2002; Wambold et al., 2003) as illustrated in Figures 3.4, 3.5, and 3.6 for the ASTM IRFI, the ERD (i.e., the CRFI) and the IMAG, respectively.

It is noted though that the range of variation is about +/- 0.1 friction coefficient values, which is generally similar to the correlation that was achieved by Yager, et al., 1990, based on the tests conducted by NASA (described in Section 3.2.2).

- (j) The data identified items where changes to regulations are required, such as:
- (i) An analysis of the Falcon 20 landing distances, using the braking coefficients obtained during tests on wet surfaces indicated that the current operational dispatch factor of 1.92 for turbojet aircraft does not provide an adequate safety margin for landings on wet runways, particularly those with low texture or rubber contamination; and
 - (ii) An analysis of the DHC-8-100 and DHC-8-400 aircraft landing distances obtained during tests on wet surfaces indicates that the current operational dispatch factor of 1.43 for turbo-propeller aircraft does not provide an adequate safety margin for landings on wet runways.

Table 3-3: Effect of Application of IRFI (Wambold et al, 2003)

	Device			IRFI (Device)		
Device	Zero Intercept	Slope Multiplier	R ²	Zero Intercept	Slope Multiplier	R ²
Reference	0.016	0.148	0.7	0.016	0.48	0.7
ERD	0.03	0.5	0.81	-0.023	0.64	0.8
IMAG	-0.005	0.49	0.73	-0.005	0.52	0.73
RUNAR	0.07	0.26	0.56	0.103	0.36	0.51
GT-TC	0.064	0.33	0.62	0.108	0.32	0.6
RFT	0.06	0.33	0.87	0.04	0.64	0.88
SFT79	0.07	0.34	0.6	0.08	0.39	0.61
SFT85	0.126	0.25	0.75	0.119	0.3	0.71
SFT212	0.178	0.23	0.52	0.13	0.37	0.89
SFT99	0.08	0.37	0.81	0.13	0.54	0.94

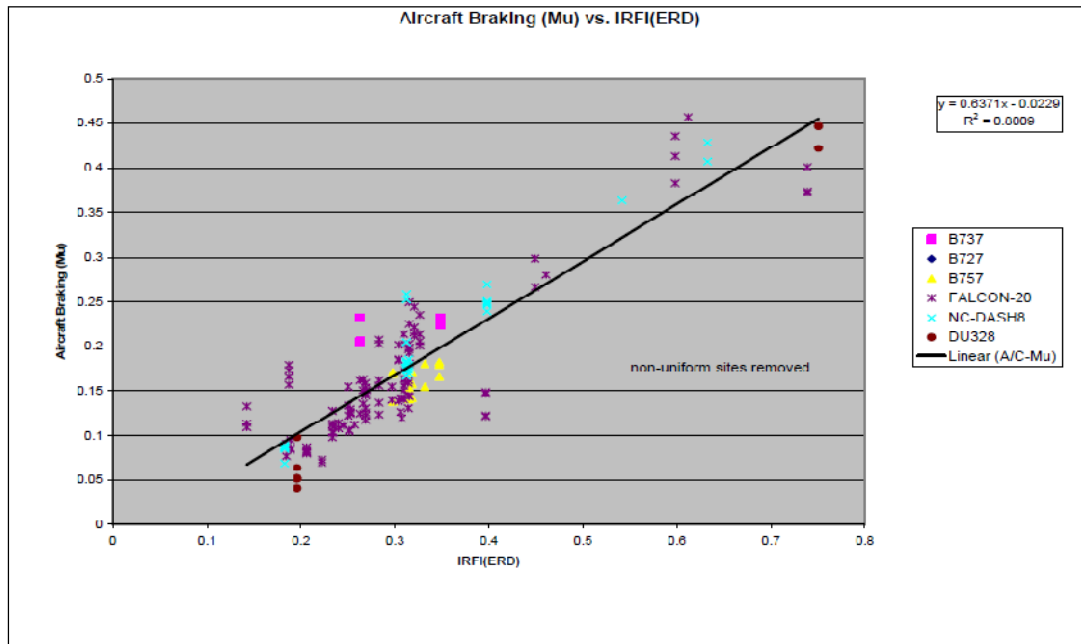


Figure 3.4: Aircraft Braking Coefficient vs. IRFI (Wambold et al, 2003)

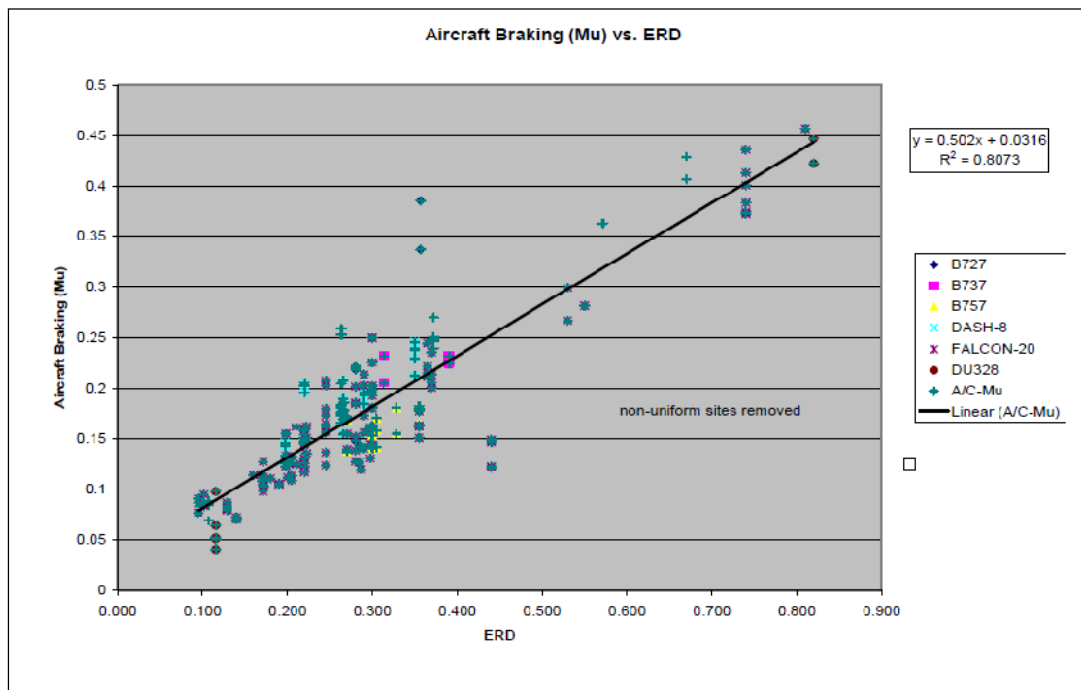


Figure 3.5: Aircraft Braking Coefficient vs. CRFI (Wambold, et al, 2003)

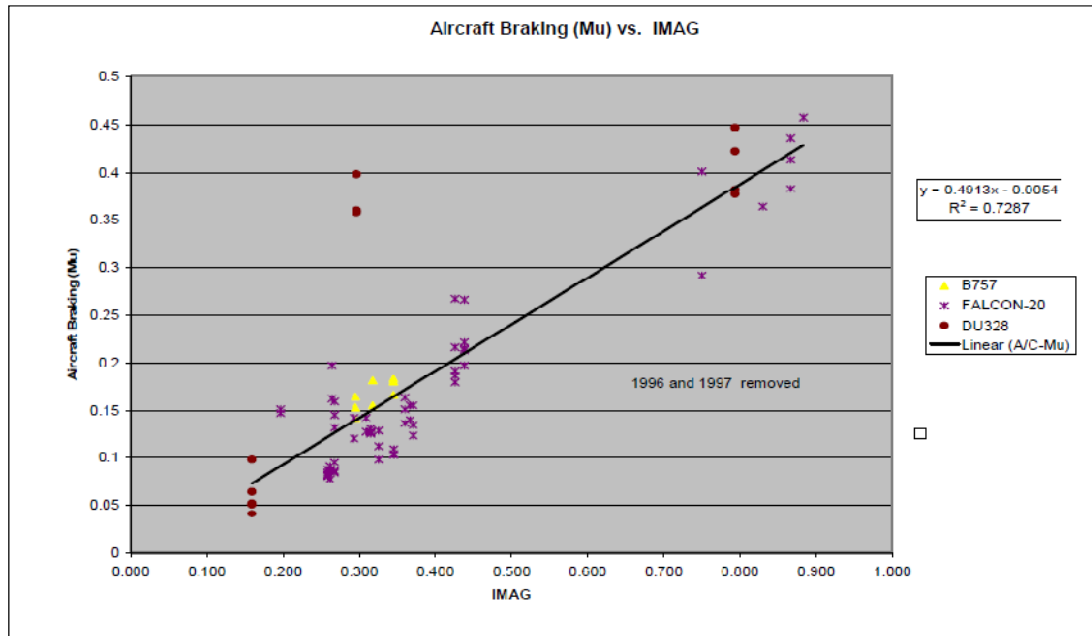


Figure 3.6: Aircraft Braking Coefficient vs. IMAG (Wambold et al, 2003)

3.2.3.5 Concluding Comments Regarding the Overall Outcome of the JWRFMP

The JWRFMP identified shortcomings with the friction measuring devices which raise questions concerning the credibility of using these devices for operational friction measurements. For example, it was found that there are reproducibility and repeatability concerns with various device families (e.g., Avinor, 1999; 2001; Rado and Radone, 2003).

Although the results of the JWRFMP have not been implemented in certification requirements, they have contributed to the overall state-of-knowledge. The JWRFMP has contributed to the current regulatory regime in Canada in that airports are required to report the CRFI, which is routinely done at present. Some airlines in Canada utilize CRFI measurements in an advisory role as an aid in determining aircraft landing performance. This is similar to the results of the information surveys that were done in this project, which identified a number of airlines that use the results of ground friction readings as an aid to determine aircraft landing performance. It is noteworthy, though, that all airlines utilizing ground friction readings limit their usage to a single friction-measuring device and develop approaches that are specific to their operations.

The IRFI has not been implemented partly because the infra-structure for it is lacking at present.

This situation reflects reluctance on the part of the aviation community to accept ground friction measurements for defining aircraft performance in a regulated capacity. An extensive survey conducted as part of the JWRFMP (Biggs and Hamilton, 2002) found that a large majority of pilots felt that flexibility was required, and that the measured CRFI values should only be used to provide recommended landing distance values, as opposed to being a regulated requirement. This is also shown by the TALPA ARC initiatives, which is trending towards de-emphasizing friction measurements for operational applications. Instead, the

TALPA ARC made the recommendation that efforts be focussed on defining the runway surface itself for operational evaluations of aircraft performance.

3.3 Issues Limiting the Application of Operational Friction Measurements

This section discusses the issues that presently limit the application of friction measurements for operational purposes. This is a multi-faceted problem which includes:

- (a) Regulatory and certification issues;
- (b) Issues associated with the technical performance of the friction-measuring devices;
- (c) Complexities regarding the process of friction measurements; and
- (d) Lack of high-level performance criteria for friction-measuring devices

3.3.1 Regulatory and Certification Issues

3.3.1.1 *Aircraft Certification and Regulation*

Aircraft manufacturers are only required by regulators to specify aircraft performance with respect to basic runway surface conditions as summarized briefly below:

- (a) EASA: The requirement is to supply data for certification for dry, wet, ice, snow, slush, and standing water surface conditions.
- (b) FAA: The requirement is to only supply data for certification for dry and wet surfaces.

No requirement is imposed by either EASA or FAA for aircraft manufacturers to provide certified aircraft performance data in relation to the friction coefficients measured by ground vehicles. This, to a large extent, reflects a lack of confidence in the current generation of friction devices. In fact, the FAA has recently taken a stronger position against friction-measuring devices in its recently-updated Advisory Circular (FAA, 2008) which advises that:

- (a) *“Airport operators must not attempt to correlate friction readings (Mu numbers) to Good/Medium (Fair)/Poor or Nil runway surface conditions, as no consistent, usable correlation between Mu values and these terms has been shown to exist to the FAA’s satisfaction. It is important to note that while manufacturers of the approved friction measuring equipment may provide a table that correlates braking action to Mu values, these correlations are not supported by the FAA”.*

- (b) *“Although the FAA no longer recommends providing friction measurements to pilots for the reasons stated in the paragraph above, some airport users still consider runway friction measurement values to be useful information for tracking the trend of changing runway conditions. Therefore, continued transmittal of Mu values is permissible with the understanding that the particular numerical value has no particular significance other than to provide changing runway condition trend information when associated with previous or subsequent runway friction measurement values. Airport operators are cautioned against using Mu values as their sole indicator of winter runway slipperiness”.*

3.3.1.2 Operational Assessments of Aircraft Landing and Takeoff Performance

In the absence of certified data, airlines develop additional information to define aircraft performance on specific surfaces. As part of this process, aircraft manufacturers can and do supply aircraft performance information to air carriers upon request as advisory material. Table 3.4 summarizes information received during this study from airlines regarding the methods by which they make operational aircraft performance assessments.

Furthermore, regulatory authorities require Landing Distance (LD) assessments to be made at takeoff, but do not require that these be checked at the aircraft’s destination. It is understood that the FAA is considering addressing this gap within the framework of the TALPA ARC initiative, although detailed information is not yet available.

As a result, airlines are forced to make their own assessments at the time of landing. There is considerable variability among airlines with respect to the methods used for determining landing distance requirements, as illustrated by Table 3-4. The methods used by the airlines generally ranged between those based on (i) ground friction readings; (ii) surface condition information, principally contaminant type and depth; or (iii) a combination of the two information sources.

Table 3-4: Sampling of Methods Used by Airlines to Establish Aircraft Performance

Question ¹	Listing of the Five Responses Received (Numbered 1 to 5)
What information is contained in the AFM?	<ol style="list-style-type: none"> For new certification aircraft (A320/A330 and E190), the wet runway takeoff performance data are included in the AFM. For our older aircraft (B737/B757/B767), the engine-inop wet takeoff performance is found in the Operations and Performance Engineers Manuals. The contaminated runway data for takeoff are found as non FAA-certified data. Certified wet landing performance is found in the AFM for all aircraft. Operational landing performance data (not certified by the FAA) are found for all runway conditions for all aircraft within the Operations Manuals and QRH. We are flying Boeing 737Classics and 737NG. The classics are certified on dry runways only, as the NGs are certified on dry, wet and wet skid resistant runways. For operation on contaminated runways, Boeing has published “Advisory Information”. Boeing has also published aircraft databases that includes this advisory information, and we are using these databases in our electronic flightbag (EFB). The respective AFMs include information only needed for certification.

Question ¹	Listing of the Five Responses Received (Numbered 1 to 5)
	<p>4. The Airbus Aircraft Flight Manual states that for the "Determination of Performance" at Takeoff, Final Takeoff and Landing Performance, the Performance Engineering Program/AFM Approved (OCTOPUS) Flight Manual Modules are used which use the stated approved aircraft database. Note that only the PC version of this program is approved. Furthermore the Performance Engineers Program provides some further guidance on the Tire/Runway Friction coefficients used for the performance calculations.</p> <p>Information for an A319 is listed below. The data differ of course for each aircraft type and Flight Manual (i.e. whether it is an OCTOPUS Flight Manual or not).</p> <p><u>Dry runways</u> On a dry runway an ETA MU is the result of the modelling of the flight test data. (ETA) represents the anti-skid efficiency.</p> <p><u>Wet runways</u> The WET braking coefficient is defined in compliance with CRI F4012.</p> <p>The WET braking friction coefficient is based on ESDU (Engineering Science Data Unit) data. It is determined with 200 PSI tire inflate pressure, UK wear limit, runway surface effect intermediate between B-type and C-type runways and ETA = 92% antiskid efficiency (demonstrated through flight tests).</p> <p><u>WET</u> = <u>WET</u> (ESDU) and Airbus provides the <u>WET</u> (ESDU) equation used in the program.</p> <p><u>Contaminated runways</u> On standing water and slush, the braking friction coefficient results from an amendment based on flight test campaign defined in CRI F4012.</p> <p>The SNOW braking coefficient = 0.2</p> <p>The ICY braking coefficient is = 0.05.</p> <p>The aquaplaning phenomenon is taken into account.</p> <p>A graph is also provided which plots mu vs. ground speed (m/s) for the 3 rwy conditions for each aircraft type.</p> <p>5. The AFM contains the data required to comply with EU-OPS for operations on contaminated runways.</p>
Contaminant types on which aircraft performance assessments are based.	<p>1. Dry, wet, wet snow and/or slush in ¼-inch increments, dry snow in 1-inch increments, ice</p> <p>2. We use DRY, WET, STANDING WATER, SLUSH, SNOW and DEGRADED BRAKING ACTION. We differ between contaminants that give roll-resistance in takeoff (Standing water, slush, snow) and contaminants that give no roll-resistance (ice, compact snow). On landing we only use slippery data – i.e., no roll-resistance in addition to DRY and WET. When using roll-resistance we need to input how thick the layer is in addition to a braking action value (3 mm slush, braking action MEDIUM).</p> <p>3. Performance calculations are based on the most critical contaminant type covering the runway. The options available in their performance software are Dry, Wet, Compacted snow, Ice wet, Standing water (mm), Slush (mm), Snow (mm), Loose Snow (mm), Reported friction. For take-off the most critical contaminant is usually a thick contaminant, and for landing usually slippery runway.</p>

Question ¹	Listing of the Five Responses Received (Numbered 1 to 5)
	<p>4. The flight crew use the onboard computer (Less Paper in the Cockpit) to carry out the Takeoff performance calculations. The following contaminants are available for use in the calculations: Dry, Wet, Water ¼ inch, Water ½ inch, Slush ¼ inch, Slush ½ inch, compacted snow and Icy.</p> <p>5. All contaminants</p>
Are performance assessments based on ground friction readings?	<p>1. We do not provide performance based on readings from ground friction vehicles.</p> <p>2. “Yes” and “No”. The National Airport Authority uses friction readings as an aid for estimating braking action. However, their AIP advises that friction readings are not accurate under certain conditions.</p> <p>3. Yes, in most cases the runway condition is given as reported friction, based on reading provided by Skiddometer BV 11 equipment. Also when runway friction is given as Braking Action (BA), the runway inspector usually uses the readings obtained in measurement with Skiddometer equipment for his/her estimation of friction level (BA). When we are given BA, the ICAO BA-friction table is used to get corresponding friction value for BA level (the most conservative friction value for each level is used).</p> <p>4. FODCOM 200906 states that CAP 683 has been revised to warn aerodrome licence holders NOT to promulgate friction readings in periods of runway contamination, whilst paragraph 4 explains the limitations of operational use of Continuous Friction Measuring Equipment and friction readings, also relevant to aeroplane operation. We have included similar instructions in our SOPs for crews NOT to use if provided any runway friction coefficient readings. In cases of slippery when wet runways we instruct crews to reduce rwy length accordingly and then calculate takeoff performance.</p> <p>5. “If these are available”</p>
Source of aircraft performance data	<p>1. It is not provided by the manufacturer.</p> <p>2. Boeing uses braking action 0.05 for poor, 0.1 for medium and 0.2 for good. The airline defines a friction vehicle value .20 to be poor (0.05) and value .30 to be medium (0.1) and finally value .40 to be good. They do not use values above .40 and below .20. They define all other values linearly between these points. They also point out that the airport authority no longer reports the measured friction value, and only provides the SNOWTAM format (1-5) or the phrasing GOOD, MEDIUMtoGOOD, MEDIUM, MEDIUMtoPOOR, and POOR.</p> <p>3. The manufacturers have provided only dry/wet/water covered rwy/compacted snow and ice wet runways. The sources for development of reported friction calculation has not been provided by manufacturers. The friction model has been developed by Antti Puronto, TopPOY. (toppoy@dnainternet.net<mailto:toppoy@dnainternet.net>, Mob. +35850 3935186) and the sources for development have been JAR OPS 1 AMC; NPA friction model; ICAO Doc 9137; experimental research at EFHK, EFTP, EFTU and EFOU and Transport Canada-JAA-NASA friction program results.</p> <p>See also Note 2 below.</p> <p>4. See previous answers.</p> <p>5. Supplied by the manufacturer.</p>

Question ¹	Listing of the Five Responses Received (Numbered 1 to 5)
Is there an onboard computer for calculating landing or takeoff performance?	<ol style="list-style-type: none"> 1. No. Data adjusted by Dispatch are used to calculate performance. 2. Yes. We are now introducing the EFB in our aircraft. For the aircraft not yet having the EFB, we are using gross weight charts. These charts are produced by the same software used in the EFB. 3. Yes, all aircraft are using an onboard cockpit computer for performance calculations as well as for mass and balance calculations. All performance calculations are done for the actual take-off weight/landing weight in actual conditions (OAT, QNH, wind, lineup, runway, obstacles, de-ice fluid effects, flap setting, engine rating etc) considering the actual runway condition (dry/wet/water/slush/snow/loose snow/BA or reported friction). The program used (EGAR, provided by TopP Oy) is fast to use and calculations can be made during lineup using up-to-date contamination information. The program calculations optimum speeds to be used with a safety-centric logic; a low V1 speed for slippery runways and a high V1 speed in relation to the optimized V2 speed for runways covered by a thick contaminant. 4. We have the <u>Airbus</u> Less Paper in the Cockpit (LPC) concept implemented across our Airbus fleet; The Flight Operations Versatile Environment (FOVE) software runs amongst other Takeoff & Landing applications that flight crew use to carry such calculations. Our <u>Boeing</u> fleet uses paper Takeoff Performance Manuals. 5. No. All our calculations are done by a ground based application that is available to connect to from the aircraft using ACARS.

Notes:

1. See Appendix A, Section A.4, in Volume 2 for a listing of the questions that were asked.
2. The information above related to the “Source of aircraft performance data” for respondent 3 is a direct quote. It is believed that the FAA was also a major participant in the research.

3.3.1.3 Operational Assessments of Aircraft Performance: Southwest Airlines

Because relatively little information is publicly available regarding the approaches used by airlines for operational assessments of aircraft landing and takeoff performance, further information is presented in subsequent sections for three airlines.

A description of the process used by SouthWest Airlines is included in the NTSB report for the Chicago Midway accident (NTSB, 2005). Southwest Airlines provides an OnBoard Computer (OBC) to pilots (Figure 3.7), and their Flight Operations Manual provides guidance regarding its usage.

Airport Identifier: MDW KMDW Elev./Pressure Altitude: 620 / 482 FT Maximum OAT: 53 °C / 128 °F		Runway Condition: WET_POOR Air Conditioning: BLEEDS ON Anti-Ice: ENGINE ON												
Wind: 090/11 MAGN-KTS Temp/DP: -3 / -5 °C (27 / 23 °F) Altimeter: 30.07 In Hg	Landing Weight: 119.7 LB Landing Flaps: 40 Quick Turn: <input type="checkbox"/> App Clb: 151.2 LB													
Clk Wing Frost if Fuel Temp < <input type="checkbox"/> +0 °C														
<table border="1"> <thead> <tr> <th>Rwry</th> <th>Length</th> <th>Winds</th> <th>Min(2)</th> <th>Med(3)</th> <th>Max (M)</th> </tr> </thead> <tbody> <tr> <td>31C</td> <td>5826 - DT</td> <td>8T / 7X</td> <td>-730</td> <td>-30</td> <td>40</td> </tr> </tbody> </table>		Rwry	Length	Winds	Min(2)	Med(3)	Max (M)	31C	5826 - DT	8T / 7X	-730	-30	40	Approx Stop Margin V Ref: 125 V App: <input type="text"/> 15° MMS: 145 5° MMS: 155 1° MMS: 175 0° MMS: 195 Go-Around: 91.3
Rwry	Length	Winds	Min(2)	Med(3)	Max (M)									
31C	5826 - DT	8T / 7X	-730	-30	40									
Wind limits: 5T/10X.														
<div> <input type="button"/> <input type="button"/> <input type="button" value="MEL/CDL"/> <input type="button" value="Module Menu"/> <input type="button" value="Return"/> </div>														

Note: the white "8T" with a red background and the "Wind limits: 5T/10X" remark in white with a black background near the bottom of the display indicate that the tailwind limits for poor braking action were exceeded.

Figure 3.7: Onboard Computer Used by Southwest Airlines (NTSB, 2005)

With regard to landing performance and stopping margins, their pilots enter current data regarding the landing runway, wind speed and direction, airplane gross weight at touchdown, ambient temperature, altimeter setting, and reported runway braking action into the OBC. The program user is also required to enter the level of deceleration desired from the braking system. The OBC calculates the airplane's landing performance. The Flight Operations Manual includes the following with respect to braking action and the available selections in the program:

- (a) Wet-fair, which is to be used when the braking action is reported as fair; and
- (b) Wet-poor which is to be used when the braking action is reported as poor

3.3.1.4 Operational Assessments of Aircraft Performance: Finnair

Puronto, 2004, provided information regarding how friction measurements are incorporated into the process used by Finnair for operational landing distance assessments. He noted that JAR-OPS 1 must be adhered to, and that the Finnish CAA requires friction-based performance calculations in addition to JAR contaminants (which include wet, compacted snow, wet ice, water, slush, wet snow, and dry snow). The Finnish CAA performs runway maintenance using friction measurements made with BV-11 friction testers as criteria.

Finnair has synchronized friction data with observations of contaminant type such as wet, compacted snow and wet ice (Figure 3.8).

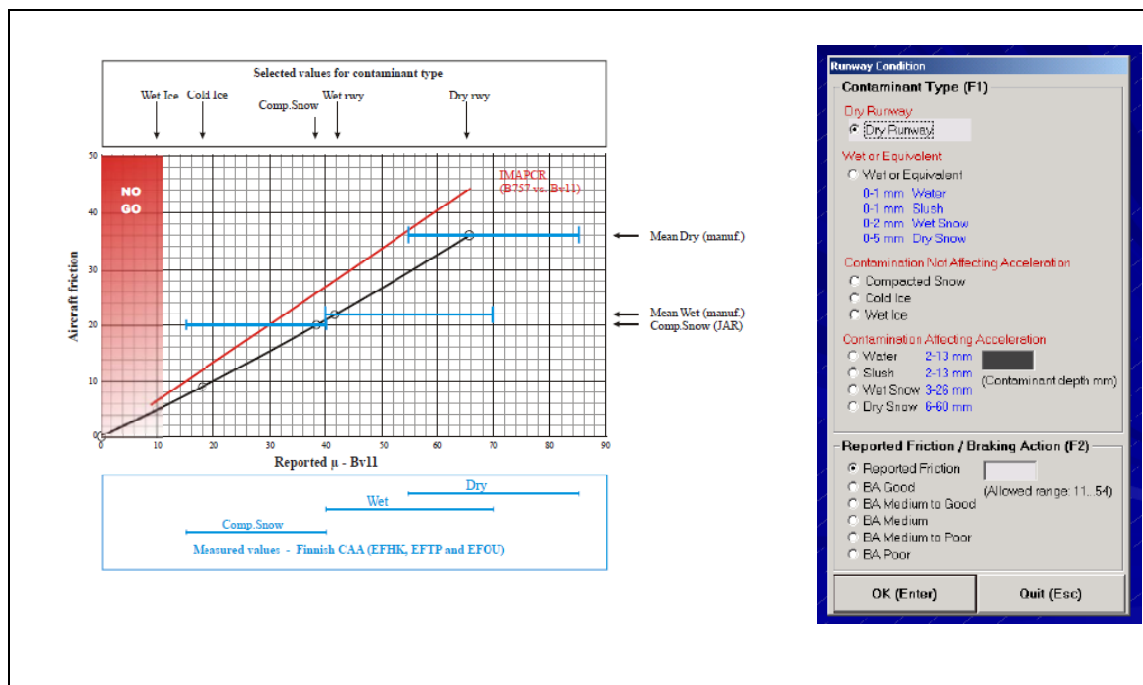


Figure 3.8: Operational Landing Distance Assessments by Finnair (Puronto, 2004)

The Finnish CAA has produced data on the reported frictions with a BV-11, giving a data band for various surfaces. Finnair use manufacturer data to evaluate the friction value area covered by these data bands. Finnair uses a cockpit PC (Figure 3.8), which enables the pilot to perform calculations with the latest information and to perform updates. The user interface includes the types of contaminant and the reported friction or braking action. Puronto, 2004, emphasized that the program is intended to be a tool for decision-making and not the tool making the decisions. The pilot is the decision maker.

3.3.1.5 Operational Assessments of Aircraft Performance: Westjet

Hollands, 2004, presented information regarding Westjet's approach for operational landing distance assessments. He commenced by noting that manufacturers provide very little information for slippery and contaminated runways, and furthermore, any information provided is advisory. In response, Westjet has developed a system based on CRFI measurements, given that 8 percent of their take-offs and landings occur on contaminated runways. Hollands, 2004, provided a step-by-step description of their approach. Their approach with respect to braking action is illustrated in Figure 3.9. For operational purposes, Westjet places a limitation on take-offs and landings of 0.25 CRFI, unless optimum conditions exist (meaning any condition that increases the margin of safety). Westjet has produced a calculation program in Excel (Figure 3.10) that is in the cockpit.

When questioned about the issue of the correlation of the LD values inferred from CRFIs versus the manufacturer's recommended LDs, Hollands, 2004, noted that if one takes the "poor" braking action numbers, they coincide with 0.20 or 0.25 CRFI. "Good" braking

action compares to about 0.4 CRFI. “Dry” is about 0.6 which is the maximum CRFI. He further commented that there is correlation, and building the link is important, but it needs to be put together to make it effective.

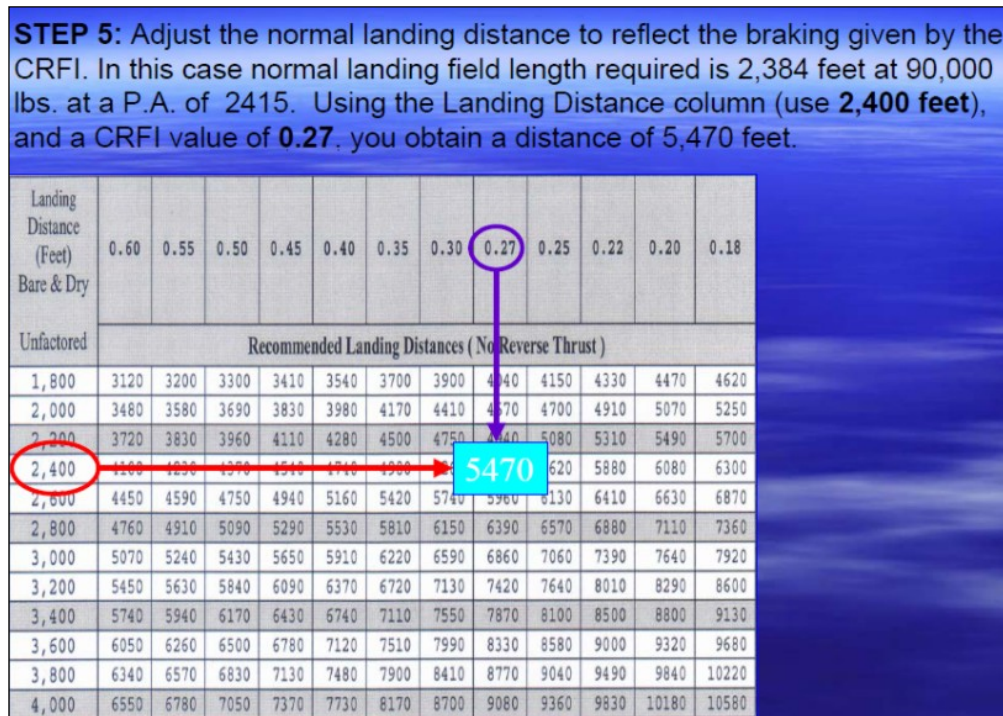


Figure 3.9: Operational Landing Distance Assessments by Westjet (Hollands, 2004)

Excel Quick Calculator


Aircraft Type	700
Gross Weight (1000lbs)	120
Field Altitude 	2700
Current Altimeter Setting	29.78
Runway Friction Index	0.24
Flaps 30 or 40	40
Headwind Speed	0
Tailwind Speed	0
Antiskid Inop	No
Manual Speed Brakes	No
Condition	Antiskid, Brakes, Reversers
Landing Distance	Antiskid, Brakes, Auto Speedbrakes, Reversers
Landing Distance with CFRI	Antiskid, Brakes, Reversers
	Antiskid, Brakes
	Brakes w/o Antiskid, Manual Speedbrakes
	CFRI Chart

Figure 3.10: Westjet Quick Calculator Program (Hollands, 2004)

3.3.1.6 Concluding Comments

This report has outlined several studies that have been done in the past to compare aircraft performance with the readings from ground friction measurements including:

- (a) Tests conducted over the 1996-2003 period with several aircraft and several GFMDs during the Joint Winter Runway Friction Measurement Program (JWRFMP); and
- (b) Various tests conducted by NASA of which the most recent ones were done by Yager et al., 1990.

Correlations were developed from these test programs between aircraft braking coefficients and ground vehicle friction readings. Also, examples have been presented in this report where ground friction readings are an integral part of the process used by airlines for operational assessments of aircraft performance for takeoff and landing.

Despite this work, the aviation community is not fully convinced that ground friction readings correlate with aircraft performance in an acceptable manner, as illustrated by various indicators, such as:

- (a) The recent update to FAA Advisory Circular 150/5200-30C (FAA, 2008);
- (b) The trends being exhibited by the TALPA ARC's recommendations; and
- (c) The fact that the ICAO FTF could not reach a consensus on this issue.

As a result, there is a reluctance on the part of the aviation community to make friction measurements part of a regulatory process. There is general support for the view that friction readings are useful as advisory material, as an input for determining aircraft performance in an operational manner. Of course, the correlation and overall performance requirements are considerably more stringent if the readings from GFMDs are to be used as part of a regulatory process.

3.3.2 Technical Performance of the Available Devices

3.3.2.1 Lack of Harmonization

Numerous studies have shown that the various devices report different readings when operated at the same time on the same surface. For an illustration, the reader is referred to Figure 3.11 and Figure 3.12, which present comparative results on compacted snow and ice, respectively.

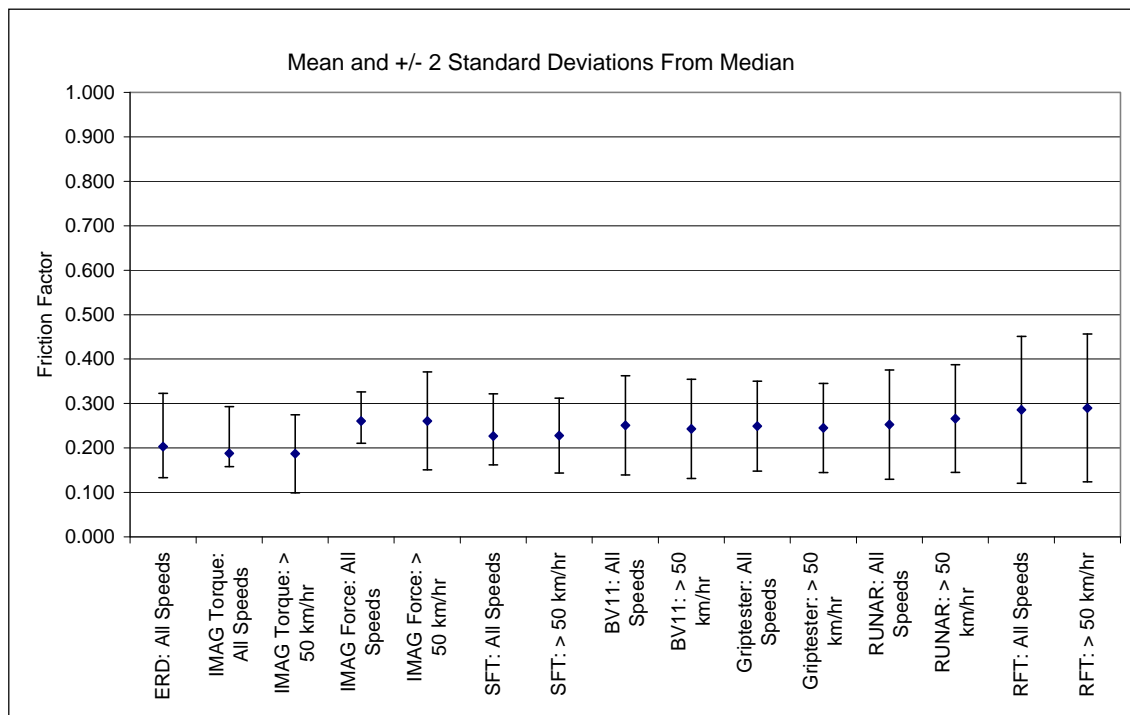


Figure 3.11: Friction Factors on Bare Packed Snow for GFMDs (Comfort, 2006)

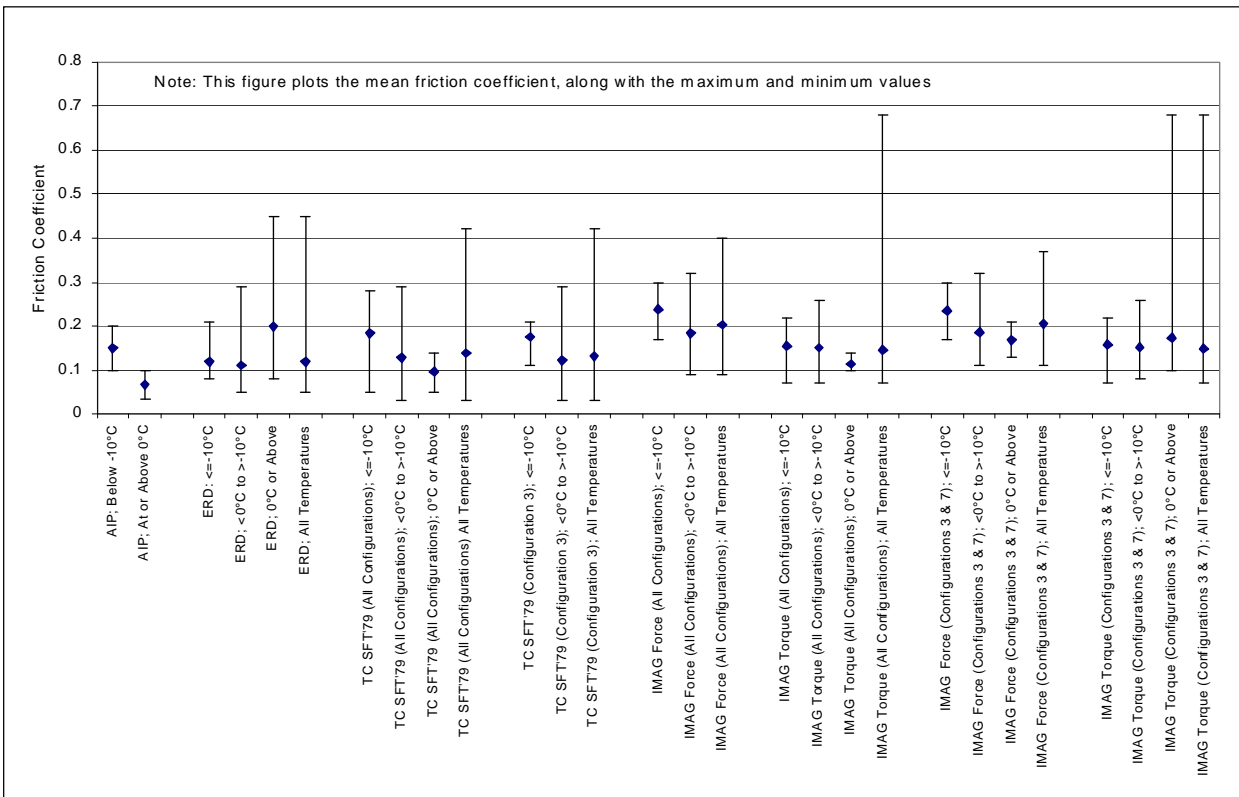


Figure 3.12: Friction Factors on Bare Ice (Comfort and Mazur, 2004)

As well, attempts to harmonize the readings from the different devices have only shown limited success with respect to both (a) the range of applicable surfaces and (b) the degree of correlation that could be established among the devices.

3.3.2.2 Limited Range of Applicability Regarding the Surfaces that Can Be Measured

Ground Friction-Measuring Devices (GFMDs) can only function effectively on a limited range of surfaces. This is borne out by warnings in the AIPs of many countries regarding the limitations of GFMDs, which are listed and summarized in Volume 2 of this report series.

It is generally recognized that GFMDs are most suitable for solid surfaces such as ice and compacted snow. They are generally not suitable for “loose” or wet contaminants (e.g., loose or dry snow, slush, wet ice, wet snow). Given that these surfaces can pose a significant safety hazard, this gap in capabilities is a serious concern.

This limitation is partly due to the fact that the GFMD readings on “loose” or wet surfaces are affected by contaminant drag. Also, tests during the JWRFMP showed that the GFMD readings were affected by the measurement principle. Significantly different readings were obtained on loose snow from devices that determined the friction coefficient based on torque measurements versus those that used force measurements on the test tire.

This gap is reflected in the limitations associated with the available friction indices:

- (a) ASTM IRFI – the IRFI is only applicable to ice and compacted snow.
- (b) CRFI – the Canadian Runway Friction Index is only applicable to surfaces on which decelerometers are considered to be reliable, which occur when (Transport Canada, 1998; 2001; ASTM, 2000):
 - (i) There is a layer of ice or frost on the runway;
 - (ii) There is wet ice (ice covered with a thin film of water) on the runway;
 - (iii) There is a thin layer of slush over ice on the runway;
 - (iv) Sand, aggregate material, anti-icing or de-icing chemicals have been applied to the runway;
 - (v) There is a layer of compacted snow on the runway; and
 - (vi) There is a layer of loose snow not exceeding 1 in. (2.5 cm) in depth on the runway

Transport Canada, 1998; ASTM, 2000 consider decelerometers to be unreliable when:

- (i) The runway surface is simply wet with no other type of contamination present;
- (ii) There is a layer of slush on the runway surface with no other type of contamination condition present; and
- (iii) There is loose snow on the runway surface exceeding 1 inch (2.5 cm) in depth.

3.3.2.3 Practical Limitations

It is well known that operational conditions can make friction readings difficult as:

- (a) Limited time is often available to survey a runway;
- (b) Conditions are often non-uniform, as illustrated by Figure 3.13; and
- (c) Conditions can change rapidly, especially for the cases of most concern such as during a snowstorm or during freezing rain.

3.3.2.4 Device Performance: Time-Stability

Tests within the JWRFMP have shown that the calibrations obtained for the devices were not time-stable as significant variations occurred over time (e.g., Wambold et al, 2001; Wambold and Henry, 2003). See Figure 3.14.



Figure 3.13: Non-Uniform Surface Conditions on a Runway in Canada

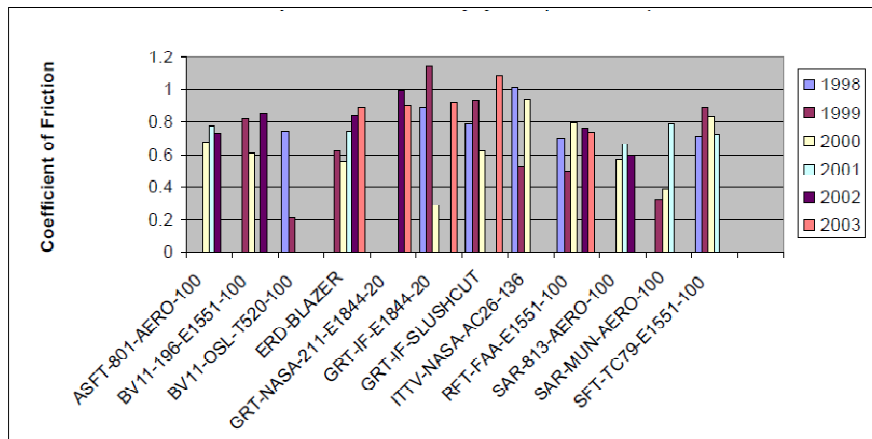


Figure 1 – Multiplier b vs. years (1998-2003) by device

Figure 3.14: Time-Stability of the Devices (Wambold et al, 2003)

Note: “ b ” in the above figure is defined as follows: $IRFI = a + b * \text{Device}$
 where: $IRFI$ = the IRFI friction index; and Device = the friction coefficient measured by a particular device

3.3.2.5 Device Performance: Variability within Device Families

Tests within the JWRFMP (Wambold and Henry, 2003) and in Norway (Avinor, 1999; Avinor, 2001) have shown that significant variations in friction coefficient were measured for individual devices of the same device family. Results are shown in Figure 3.15, Figure 3.16, and Figure 3.17, shown for the SFT, the Griptester, and the BV-11 respectively, for artificially-wetted pavement surfaces.

Similar data are not available for winter-contaminated surfaces.

Because this issue has been discussed in detail in Volume 3, it is not considered further here. However, this variability is a serious concern as it degrades the confidence that can be placed in ground friction measurements and the factors causing the observed variations are not fully understood.

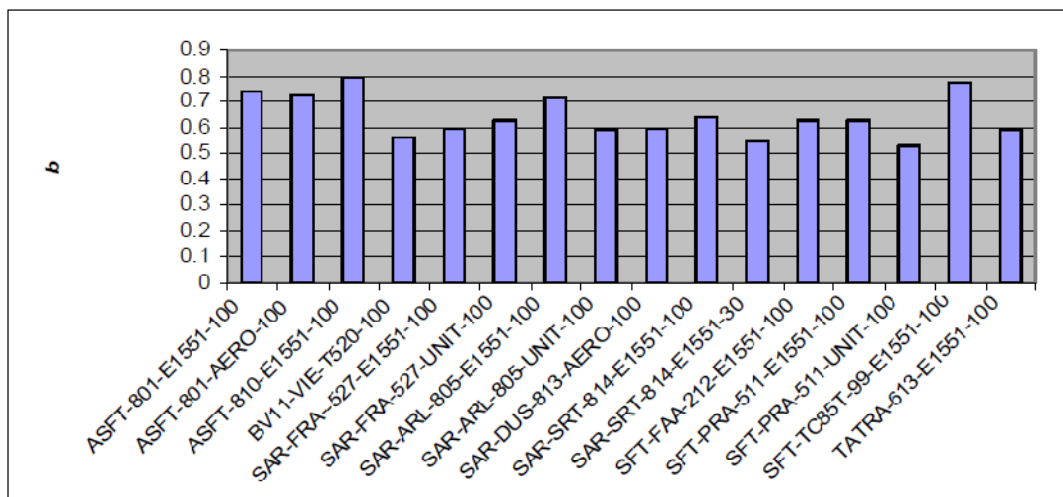


Figure 3.15: Variability for SFT Device Family (Wambold and Henry, 2003)

Note: “b” in the above figure is defined in the same manner as for Figure 3.14.

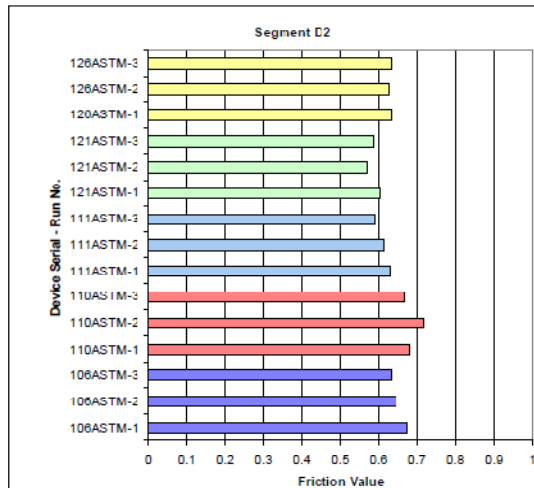


Figure 2 - A sample collection of runs for a segment for the same devices in project 1. The segment was traversed 3 times. Each bar represent the average of 10 reported friction values of a run. The average of all runs by a device over a segment in a project constitute one observation.

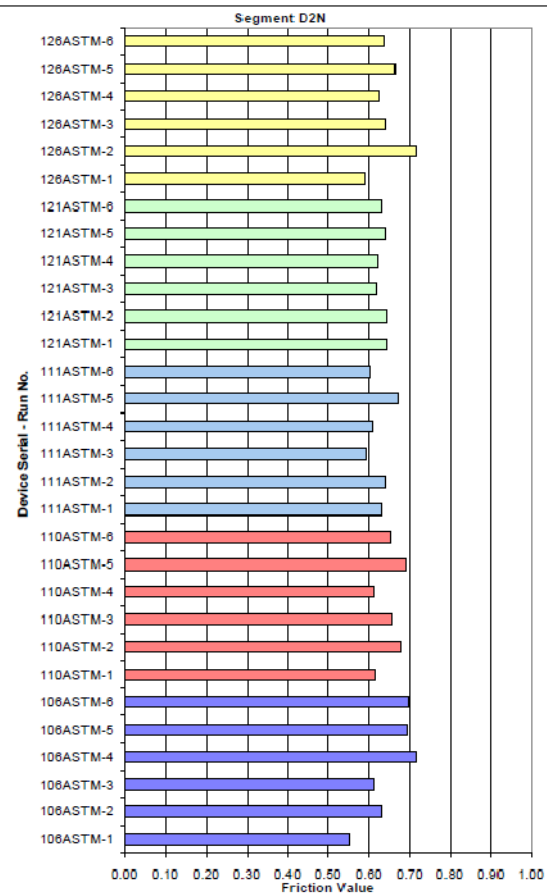


Figure 3 - A sample collection of runs for a segment for the same devices in project 2. The segment was traversed 6 times. Each bar represent the average of 10 reported friction values of a run. The average of all runs by a device over a segment in a project constitute one observation.

Figure 3.16: Variability within the Griptester Device Family (Avinor, 1999)

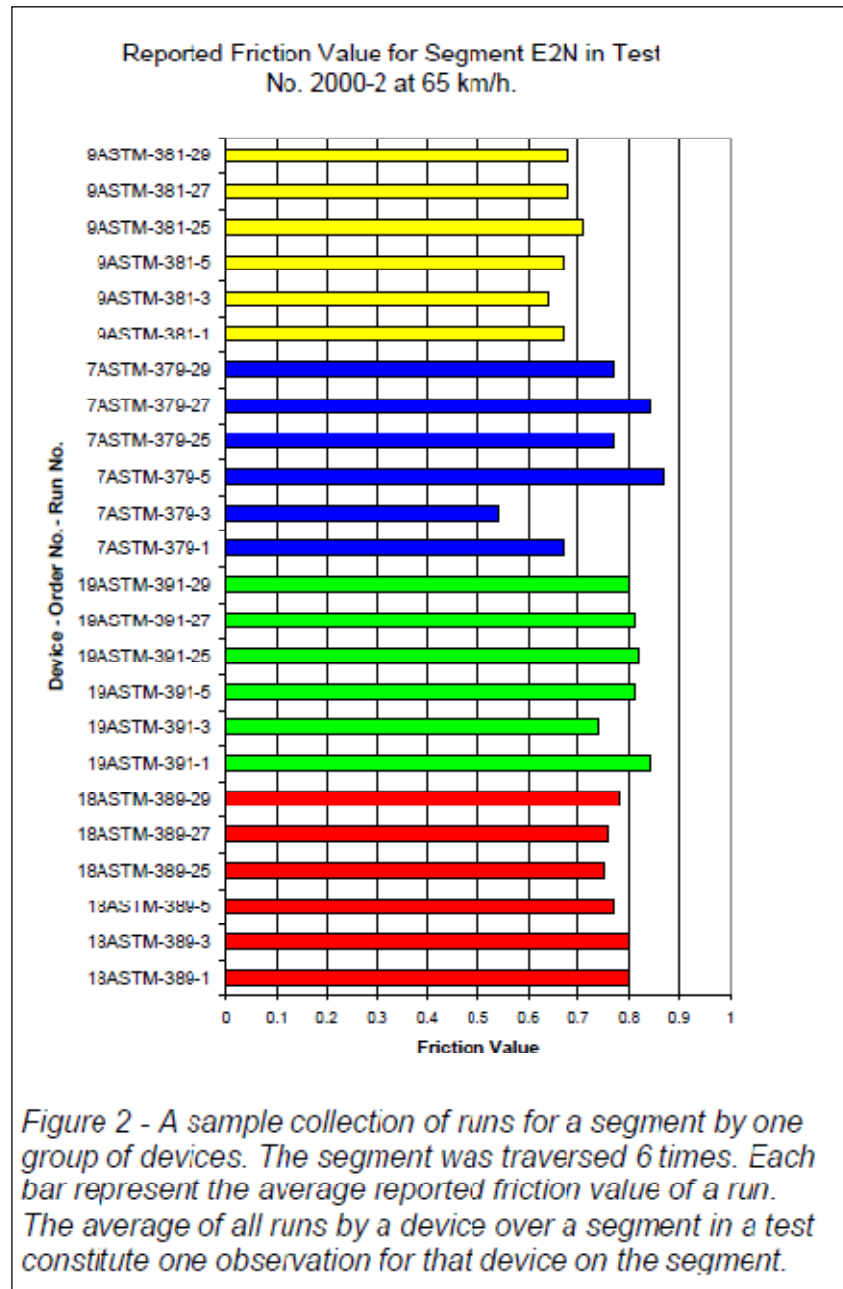


Figure 3.17: Variability within the BV 11 Device Family (Avinor, 2001)

3.3.3 Complexities Regarding Friction Measurement

3.3.3.1 Basic Overview of the Processes during a Ground Friction Measurement

Probably, the most important item to recognize is that the friction coefficient is a “system” measurement, rather than an intrinsic property of say, the pavement, the tire, or the material on the surface of the pavement. The result of a friction measurement is governed by the interaction of all the components of the system which include the tire, the pavement, the material on the pavement, and the atmospheric conditions (Figure 3.18).

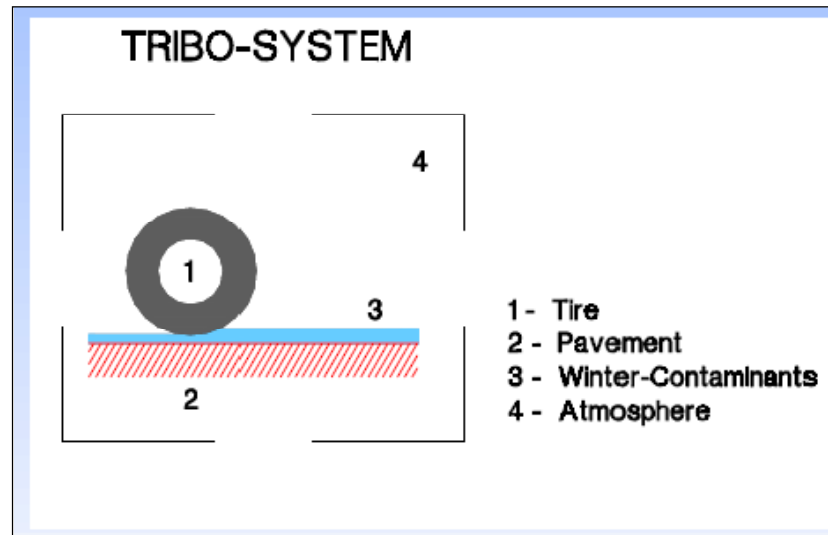


Figure 3.18: The Systems Affecting the Measured Friction (Norheim, 1999)

Many processes typically occur within the contact zone, and the friction coefficient recorded reflects which component of the interaction becomes the “sacrificial surface” (to use a term coined by Walter Horne). Some of the processes that may occur are listed below:

- (a) The material on the surface may fail, for example, by shear. This process is most likely to occur for solid contaminants such as compacted snow or ice. Examples are presented subsequently where this mechanism has been shown to control the frictional forces that can be developed. For other cases, such as a tire on dry, well-textured pavement, failure/deformation of the tire is likely to be the controlling process.
- (b) Metamorphosis of the material on the surface – as an example, experience has shown that in some cases, “dry” snow may become “wet” under the pressure exerted in the contact zone, which has a significant effect on the frictional forces that can be developed. This is discussed further subsequently.
- (c) Contaminant drag – loose contaminants (such as slush or snow) are likely to cause contaminant drag forces to be developed, which affects the measured friction coefficient. Some ground friction-measuring devices, such as locked-wheel tester or side-force testers, are more susceptible to contaminant drag than others that “process” the contaminant more effectively by rolling over them.
- (d) Liquid contaminants may cause thin film lubrication, leading to partial or full hydroplaning. This interaction is significantly affected by the degree of drainage that occurs from under the tire. The degree of hydroplaning depends on the tire pressure and perhaps the tire aspect ratio as well. It also depends on the viscosity of the contaminant as viscous contaminants (such as slush or solutions with de-icing chemicals in them) are more likely to cause hydroplaning. Hydroplaning is discussed further subsequently.

This variety of interaction processes is of great significance for:

- (a) Relating the readings from a Ground Friction Measuring Device (GFMD) to the braking coefficient experienced by an aircraft; and
- (b) Harmonizing the readings from different GFMDs.

Because the devices all differ significantly with respect to the key design parameters (vertical load and contact pressure, slip ratio, tire type, measurement principle, etc.), different parameter dependencies occur with respect to, for example:

- (a) Speed;
- (b) Contaminant depth;
- (c) Contaminant type; and
- (d) Contaminant physical properties such as shear strength, density, and viscosity.

This significantly limits the degree of correlation that can be achieved by an empirical approach, consisting of the following steps (which is the approach typically used to date):

- (a) Conducting many comparative runs; and
- (b) Correlating the measured friction factors using linear regression analyses.

This is evidenced by the fact that correlations produced in this manner tend to have varying degrees of “scatter”, as seen in the work to date.

3.3.3.2 Example: Friction Factor Limited by the Shear Strength of the Surface

A “Load and Pressure” Study was undertaken within the JWRFMP in 1998, in which friction factors were measured on various surfaces using NASA’s Instrumented Tire Test Vehicle (ITTV) as well as other test vehicles. Parametric tests were done with different types of tires which had different inflation pressures, which were loaded with different vertical loads. This produced a range of contact pressures. The following is indicated by the results (Figure 3.19):

- (a) Tests on “rough ice” – the friction coefficient reduced with increasing contact pressures up to about 750 kPa. At contact pressures above about 750 kPa, the friction coefficient was essentially independent of the contact pressure. This trend can be explained by the limited shear strength of the “rough ice”, which appears to have been exceeded at a contact pressure of about 750 kPa.
- (b) Tests on “loose snow over a packed snow base” – the friction coefficient decreased steadily with increasing contact pressure. This result can be explained by a combination of the following:
 - (i) At increasingly higher contact pressures, the tire “saw” more of the packed snow base, as it was pushed through the loose snow; and
 - (ii) The friction was limited by the shear strength of the packed snow base.

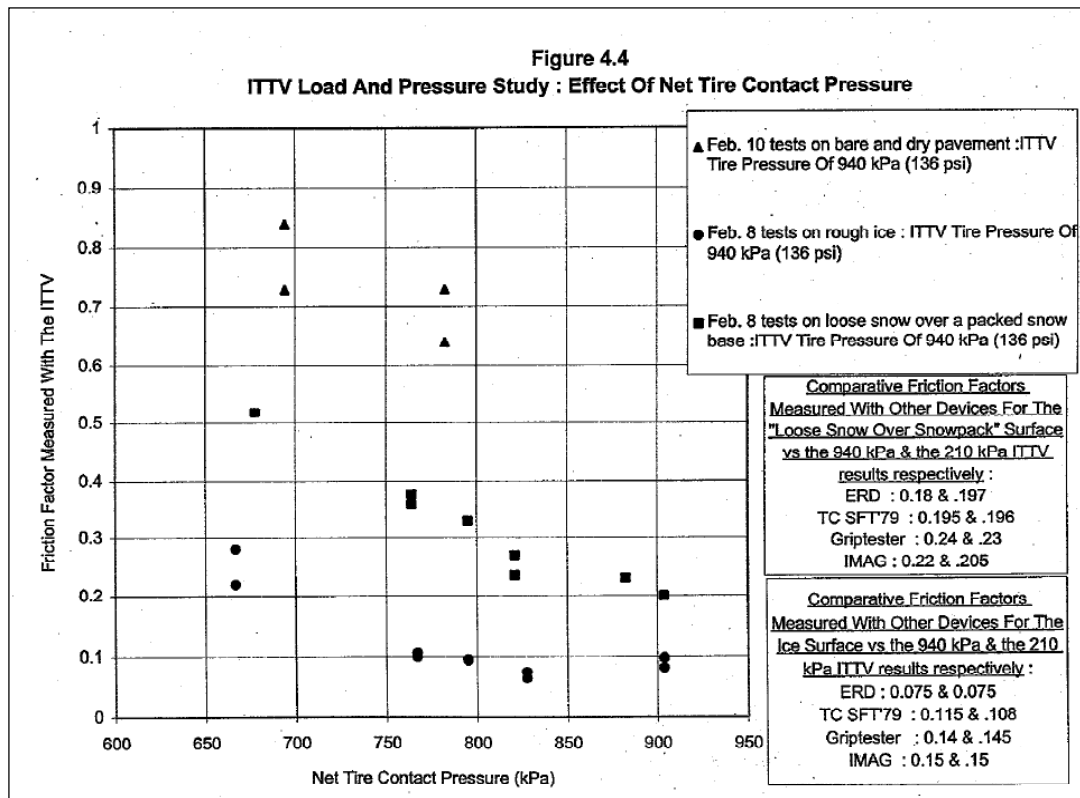


Figure 3.19: Friction Factor Limited by Material Shear Strength (Comfort et al., 1998)

These findings provide quantitative support for the hypotheses put forward by Yager et al, 1990, (described in a previous section) that the friction coefficient on packed snow and ice may be governed by the limited shear strength of these materials.

3.3.3.3 Example: Changes in Snow Properties in the Contact Zone (Snow Metamorphosis)

It is well known that snow exhibits a wide range of properties depending on the contact pressure, the temperature, and the snow's moisture content and density. The taxonomies reviewed in Volume 2 contained definitions for different snow types, which were generally for dry or loose snow, compacted snow, or wet snow.

Little information is available to account for the fact that snow metamorphosis occurs under various degrees of temperature, pressure and moisture. Aircraft data collected during the Joint Winter Runway Friction Measurement Program provide some insight, as they did not support using different friction coefficients for dry versus wet snow, nor did they support using a different friction coefficient depending on the snow depth (Transport Canada, 2004). It is believed that this finding resulted from snow metamorphosis in the tire contact zone, which may have turned the "dry" snow into "wet" snow. As a result, EASA CS-25 (EASA, 2008) contains the same default friction coefficients for both dry and wet snow.

It is not clear whether or not the friction coefficients measured by ground vehicles would exhibit the same trends (with respect to dry versus wet snow) given that ground vehicle tires have considerably lower tire inflation and ground contact pressures than do aircraft tires.

3.3.3.4 Example: Differences Caused by Tire Pressure Variations

Many previous studies have been done to investigate pressure effects on the measured friction coefficients. This section discusses one example.

The introduction of more viscous aircraft de-icing fluids initiated considerable research. The Federal Aviation Administration (FAA) conducted comparative tests in 1992 at LaGuardia airport using a B-727 aircraft and a Saab SFT friction-measuring ground vehicle (Agarwal, 1992; 1993; FAA, 1992). These tests showed that both the aircraft and the SFT experienced a drop in friction in going from a wet surface to one coated with Type II aircraft de-icing fluid. However, the SFT experienced a substantially larger drop than did the B-727 aircraft (Figure 3.20).

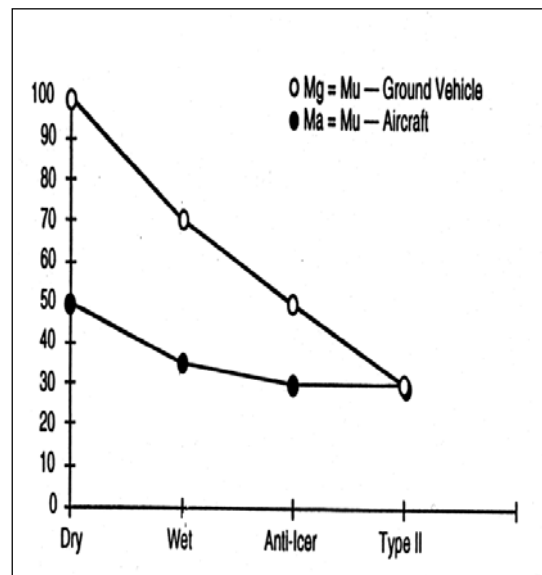


Figure 3.20: Results from the FAA Tests (Agarwal, 1993)

Notes to Figure 3.20:

1. The “anti-icer” tested was potassium acetate.
2. The Type II fluid tested was Octagon 40.

This issue was investigated further by Cowper, Comfort and Horne, 1994, at the 1994 NASA Tire/Friction Workshop at the Wallops Flight Facility. Parametric tests were done using NASA’s Instrumented Tire Test Vehicle (ITTV) and an SFT-type ground vehicle (the KJ Law) with a range of tire contact pressures, and surface conditions including wet surfaces, and ones coated with Type II de-icing fluid. These tests showed that the variations observed by Agarwal, 1992, 1993, could be attributed to differences in tire pressure (Figure 3.21), and hence contact pressure. It was concluded that the variation between the SFT and the aircraft results was due to the difference in tire pressure and viscous effects related to differences in drainage under the respective tires.

Hence, different trends can be expected to be produced by variations between ground vehicle and aircraft tires and also between ground vehicles with significantly different designs. This has significant implications for harmonizing the readings from ground vehicles operating at different vertical loads and inflation pressures.

Figure 4 - Friction Coefficients at Low Speeds For The K.J. Law And The ITTV Results

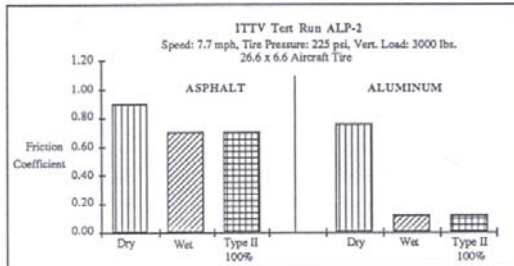
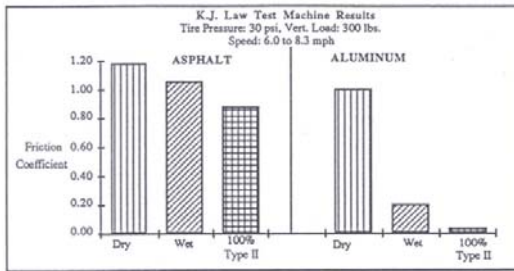


Figure 5 - Friction Coefficients for 100 psi K.J. Law Tire

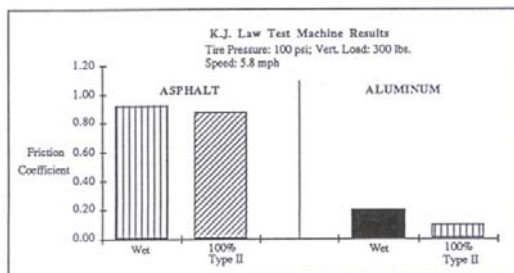


Figure 6 - Friction Coefficient vs Tire Pressure (ITTV Data ; Aluminum Plate Surface ; Speed: 7.0-7.7 mph)

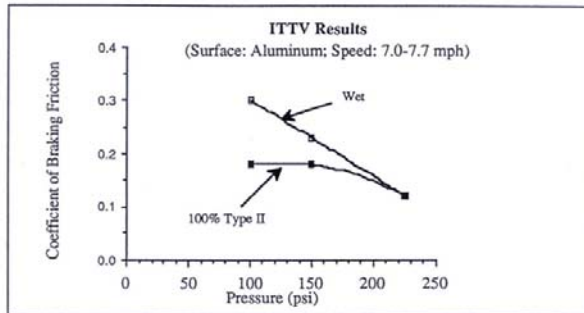


Figure 7 - Difference in Friction Coefficient vs Tire Pressure ITTV and K.J. Law Data; Aluminum Plate Surface; Speed: 5.8-7.7 mph)

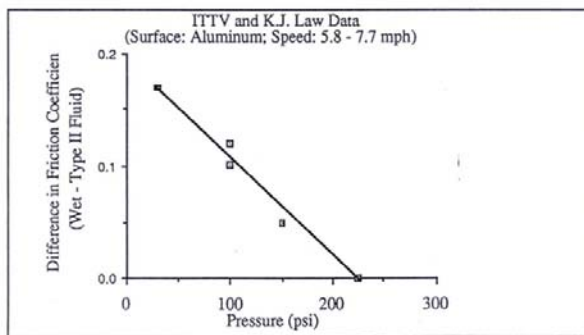


Figure 3.21: Parametric Tests at 1994 NASA Friction Workshop (Cowper et al., 1994)

3.3.3.5 Hydroplaning and Drainage under the Instrumented Tire

A brief review of hydroplaning follows as this may be a factor contributing to the observed variations among ground vehicles given that some of them operate at different tire pressures.

Hydroplaning is defined as the condition when a rolling or sliding tire on wet pavement is lifted away from the pavement surface as a result of water pressures built up under the tire. Horne et al., 1985, described four manifestations of hydroplaning that are useful identifying the minimum speed at which hydroplaning commences, as follows:

- Detachment of the tire footprint from the pavement;
- Tire spindown;
- Peaking of the fluid displacement drag; and
- Loss in tire braking/cornering traction.

Three types of hydroplaning have been identified (i.e., viscous hydroplaning, dynamic hydroplaning, and reverted rubber hydroplaning). See Figure 3.22, and also Horne, 1974.

Viscous hydroplaning is the dominant mechanism contributing to friction loss on damp or wet runways, typically with low texture, at low speeds, for:

- (a) Thin water films less than 0.25 mm (0.01 in) thick (Leland, Yager, and Joyner, 1968; Yager, Phillips, and Horne, 1970; Yeager, 1974);
- (b) Smooth pavements – Horne, Yager, and Taylor, 1968, commented that “fortunately, the texture existing on most runway surfaces is sufficient to break up and dissipate the thin viscous film which leads to this type of hydroplaning”; and
- (c) Low speed – as speed increases, inertial effects become more important than viscous effects with the result that the dynamic hydroplaning mechanism becomes predominant. See also Figure 3.23.

Fluid pressures produced by viscous hydroplaning develop quickly as the ground speed is increased from a low value. They then tend to “level off” as the speed is increased towards the full hydroplaning speed (Figure 3.23). Thus, the majority of the friction loss associated with viscous hydroplaning occurs at low speeds.

An opposite trend occurs with dynamic hydroplaning. The majority of the friction loss associated with dynamic hydroplaning occurs at high speeds (Figure 3.23). This occurs on flooded pavement. Typically, this occurs on thick water films when the water depth on the runway exceeds 2.5 mm (Leland, Yager, and Joyner, 1968; Yager, Phillips, and Horne, 1970).

Reverted rubber hydroplaning occurs when the tire fails to spin up, which results in a non-rotating, tire being slid over the surface. High temperatures are produced, which can generate steam in the tire footprint causing re-vulcanization of the rubber. The factors contributing to the occurrence of reverted rubber hydroplaning are (see also Figure 3.22):

- (a) Poor pavement texture;
- (b) High speed;
- (c) A wet or flooded pavement, (although it can also occur on very smooth non-wetted surface, such as ice); and
- (d) A deficient brake system

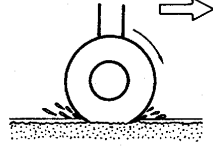
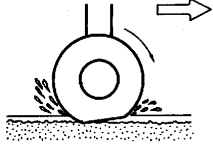
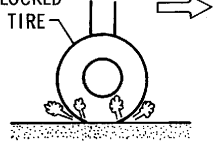
CAUSES	HYDROPLANING		REVERTED RUBBER SKIDDING
	VISCOUS	DYNAMIC	
			
CONTRIBUTING FACTORS	DAMP OR WET PAVEMENT MEDIUM TO HIGH SPEED POOR PAVEMENT TEXTURE WORN TIRE TREAD	FLOODED PAVEMENT HIGH SPEED LOW TIRE PRESSURE WORN TIRE TREAD	WET OR FLOODED PAVEMENT HIGH SPEED POOR PAVEMENT TEXTURE DEFICIENT BRAKE SYSTEM
ALLEVIATING FACTORS	PAVEMENT MICROTTEXTURE PAVEMENT GROOVING GOOD TREAD DESIGN	PAVEMENT MACROTTEXTURE PAVEMENT GROOVING INCREASED TIRE PRESSURE GOOD TREAD DESIGN	GOOD PAVEMENT TEXTURE PAVEMENT GROOVING IMPROVED ANTISKID

Figure 3.22: Conditions for Hydroplaning on Wet Pavement (Yager, 1983)

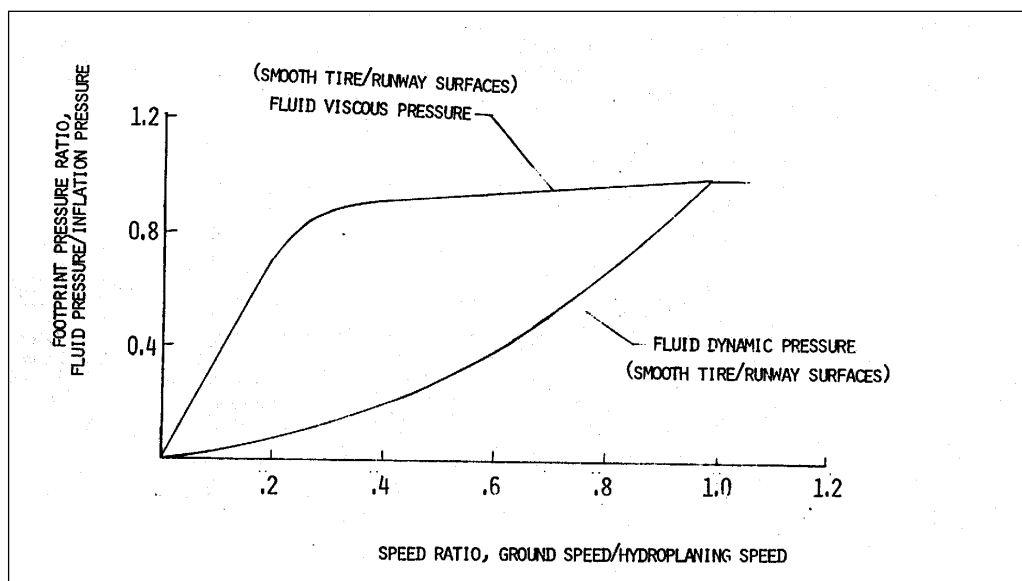


Figure 3.23: Fluid Pressure Development Due to Hydroplaning (Horne, 1974)

Differences between aircraft and ground vehicle tires are exhibited in the minimum speed for dynamic hydroplaning (for a flooded runway), which is related to the tire pressure and aspect ratio (Horne, Yager, and Ivey, 1985; Horne, 1974; and Figure 3.24) as follows:

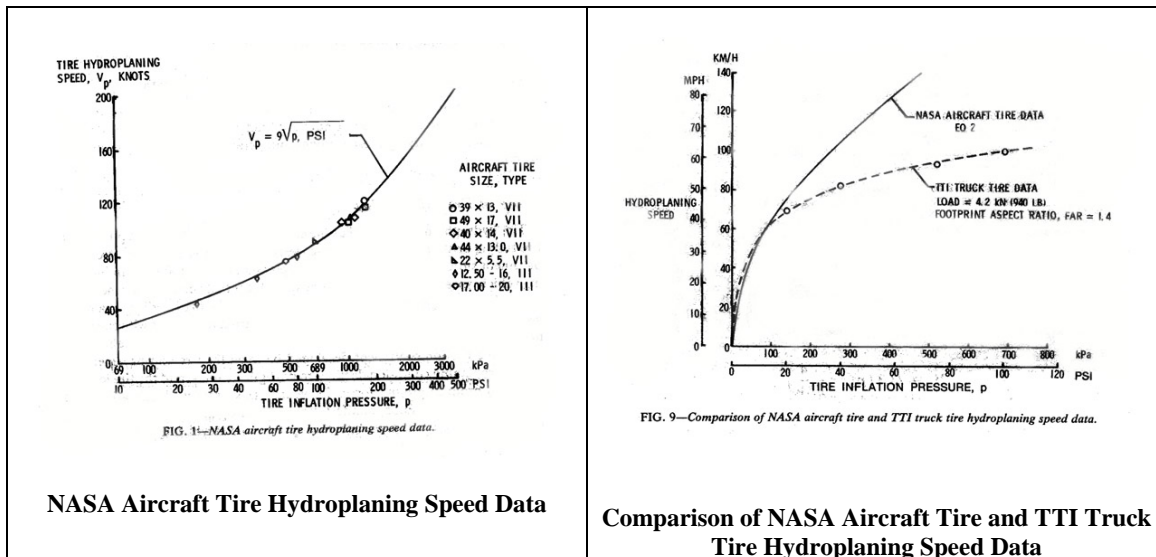


Figure 3.24: Hydroplaning Speed (Horne et al., 1985)

Aircraft Tires

Horne et al., 1985; Horne, 1974 developed Equations 3.1 and 3.2 to define the minimum hydroplaning speeds for aircraft tires during wheel spin-up and wheel spin-down. It is important to note that hydroplaning occurs at slower speed during wheel spin-up; and thus, for the same runway conditions, hydroplaning is more likely to occur for aircraft landings than takeoffs.

For aircraft tires, Horne et al., 1985; Horne, 1974, found that their hydroplaning speed data could be well defined based on only the tire inflation pressure (Figure 3.23) as follows:

$$\text{Wheel Spin-down:} \quad V \text{ (kts)} = 9 \sqrt{p \text{ (psi)}} \quad [3.1]$$

$$\text{Wheel Spin-up:} \quad V \text{ (kts)} = 7.7 \sqrt{p \text{ (psi)}} \quad [3.2]$$

where: p = tire inflation pressure, in psi

It should be noted that Equations 3.1 and 3.2 apply only to the following cases (Horne and Joyner, 1965):

- (a) “Smooth or closed pattern tread tires which do not allow escape paths for water”; and
- (b) “Rib tread tires on fluid-covered runways where the depth of the fluid exceeds the groove depths in the tread of these tires”.

Horne and Joyner, 1965, and also Horne and Dreber, 1963, cautioned that some cases have been observed where a complete loss in braking traction occurred at ground speeds “considerably less than the tire hydroplaning speed” predicted by Equation 3.1. They noted that these special cases occurred on smooth surfaces and inferred that “thin film lubrication” (i.e., viscous hydroplaning) was taking place.

Ground Vehicle or Truck Tires

Investigations of truck accidents on highways (Horne, 1984; Horne et al., 1985) showed that truck tires may have a wide range of tire footprint aspect ratios in contrast to aircraft tires for which the tire footprint aspect ratio remains relatively constant. These investigations showed that the footprint aspect ratio needed to be included as a parameter in the predictor equation for truck tires. Equation 3.3 was developed based on tests at Texas Transportation Institute (Horne et al., 1985):

$$\text{Spin-down: } V \text{ (mph)} = 23.3 * [p(\text{psi})]^{0.21} (1.4/\text{Footprint Aspect Ratio})^{0.5} \quad [3.3]$$

where Footprint Aspect Ratio is defined as:

$$\frac{\text{tire footprint width}}{\text{tire footprint length}}$$

In conclusion, it should be noted that the above discussion is applicable to wet surfaces. There may be greater potential for hydroplaning on “liquid” contaminated surfaces such as slush or solutions with de-icing chemical in them as these solutions are more viscous than water. This makes it more likely that design differences among ground vehicles (which tend to operate at different tire pressures and vertical loads) or between ground vehicles in general and aircraft may contribute to differences in the readings obtained.

3.3.3.6 Influence of Differences in Aircraft Type

A number of studies have shown that variation in aircraft type affect aircraft performance on contaminated surfaces, and the correlations achieved with Ground Friction-Measuring Devices (GFMDs).

For example, a close examination of Figure 3.4 to Figure 3.6 shows that the relationships between the GFMD readings and the corresponding aircraft braking coefficients varied by aircraft type, which produced “scatter” in the resulting correlations.

Research carried out during the CONTAMRUNWAY project (Dassault, 1999) also showed that aircraft braking performance was affected by aircraft type. Dassault, 1999 concluded that AMJ 25x1591 was not applicable (in its state at that time) to small and commuter aircraft.

Dassault, 1999 also found that the contaminant type was important, and that the results had to be classified into two categories:

- (a) Standing water and slush down to a specific gravity of about 0.5; and
- (b) Natural dry snow with a specific gravity lower than 0.2.

These findings contributed to the information and methodologies in EASA CS-25.

These results highlight an added difficulty for developing correlations between GFMD readings and aircraft performance.

3.3.3.7 Concluding Comments: Implications for Harmonizing the Readings from Devices

This section has highlighted the fact that many different processes may occur in the tire contact zone during a friction measurement. The number and type of processes depends on factors such as:

- (a) The design of the ground friction-measuring device, including its measurement principle;
- (b) The tire contact pressure, which depends on the vertical load and the tire inflation pressure;
- (c) Drainage under the tire;
- (d) The contaminant type, depth and properties, especially if it is a “solid” one like ice or compacted snow, versus a “liquid” one like slush or wet snow; and
- (e) The pavement properties

The fact that the available friction-measuring devices have a wide range of designs contributes to different trends and parameter dependencies among the devices. This makes it very difficult for an empirical correlation process to produce results with high confidence or low scatter. This limits the degree of correlation that can be achieved as has been seen from the various calibration attempts that have been made to date.

3.3.4 Lack of High-Level Performance Criteria

3.3.4.1 Historical Perspective

There has been a relatively long “history” over which Ground Friction-Measuring Devices (GFMDs) have been developed for functional friction applications. During this process, GFMDs have evolved as the significance of various parameters (tire type and rubber properties, self-wetting system, water film depth, etc.) has become better known with continued testing and investigation. This is reflected in the numerous ASTM standards that have been developed over the years. This process is continuing today.

In contrast, the usage of GFMDs for surfaces with winter contaminants is much less-developed. In general, efforts have been made to apply the existing continuous friction-measuring devices to these surfaces with the objective of obtaining data that is meaningful for aircraft performance assessments. Decelerometers are an exception as they have been developed for operational applications on winter surfaces (related to maintenance assessments). However, they suffer from some drawbacks too such as (a) the fact that they are spot measurements, (b) they are only suitable for a limited number of surfaces, and (c) the readings are affected by the host vehicle used (Comfort and Ryan, 2002; Comfort and Verbit, 2003).

During the Joint Winter Runway Friction Measurement Program (JWRFMP), the available GFMDs were assembled and tested comparatively on various winter surfaces. As shown previously, this empirical approach did produce correlations although they contained scatter. The JWRFMP contributed greatly to the state-of-knowledge. However, it has only contributed to friction-measuring devices being incorporated in a regulated capacity to a limited extent. Also, it is noted that some airlines do use friction readings from a single device in an advisory role as part of the inputs for their operational assessments. This also demonstrates that airlines recognise the potential value of readings from GFMDs.

This illustrates the limits of such an empirical technique, which started with existing devices that were not primarily developed for winter applications for correlation with aircraft performance. For an improvement, it is believed that one would need to start with an assessment of the problem from “first principles”.

As an example, the usage of a smooth tire has generally become standard for CFME tests on artificially-wetted pavement surfaces. This is done to ensure that the readings are primarily controlled by the pavement texture and characteristics with minimal influence from the tire itself. This best meets the objectives of the measurements, which are to evaluate the functional friction characteristics of the pavement and whether or not pavement maintenance actions need to be planned or undertaken.

In contrast, for operational friction evaluations, the usage of a smooth tire can be questioned as the goal of these measurements is to obtain data that are meaningful in relation to aircraft performance. Aircraft tires are longitudinally grooved to allow drainage from under the tire, and the expulsion of fluid (water, slush, etc.) from the contact zone is an important part of the overall tire-surface-pavement interaction process for some surfaces. The use of a smooth tire on a GFMD affects the degree to which fluid expulsion occurs, and this variation contributes to a fundamental difference between GFMDs and aircraft tires for some surfaces.

Little fundamental research or investigation has been done. Wahi et al, 1977 undertook a numerical study to develop a model for airplane braking distance requirements on wet and dry runways which included ground friction readings as an input (Figure 3.25). This work included sensitivity studies to identify the most critical inputs. It should be noted that this work did not include physical testing although the simulations produced were compared with aircraft landing data on wet runways for the B-52, the KC-135, and the F-111.

To our knowledge, similar work has not been done for winter-contaminated surfaces, particularly with the aim of evaluating the most appropriate configuration for a GFMD intended to operate on these surfaces with the end goal of correlating to aircraft performance.

As a result, there is a lack of information for use as an overall design basis for developing GFMDs that would have good correlation with aircraft performance for the range of surfaces of concern.

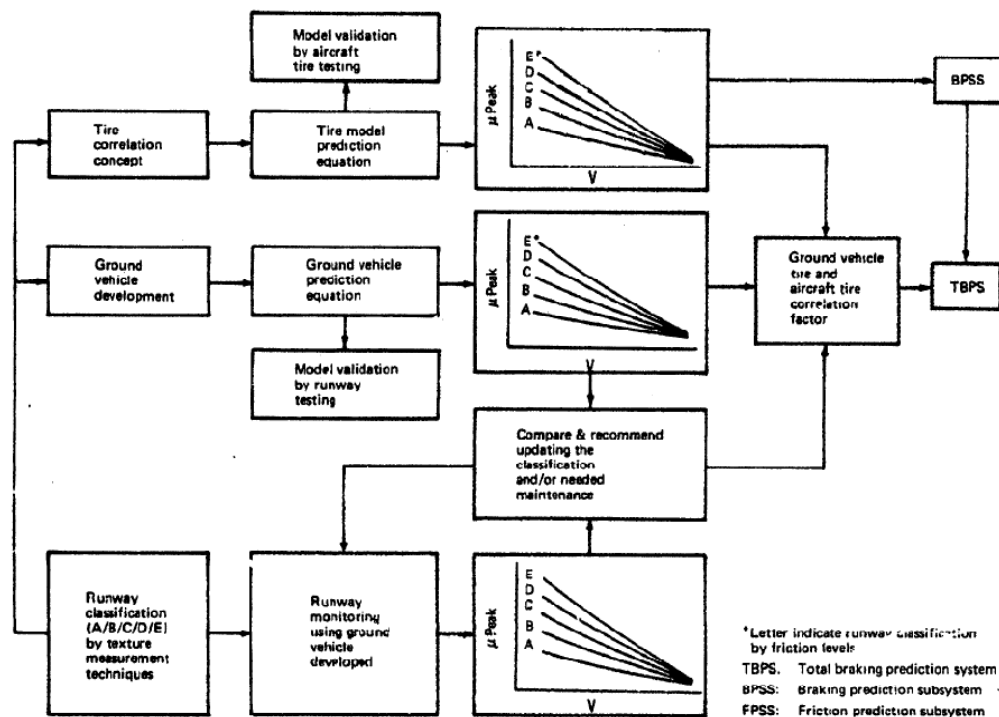


Figure 27.—Friction Prediction Subsystem (FPSS)

Figure 3.25: Friction Prediction Subsystem (Wahi et al, 1977)

3.3.4.2 Possible Approaches

As described in Volume 3 of this report series, the ground friction-measuring devices differ widely with respect to items such as:

- The measurement approach – four general classes of device are available, as listed in Table 3.1; and
- The design details – within the same class of device (e.g., fixed-slip testers), the available Ground Friction-Measuring Devices (GFMDs) differ among each other with respect to practically every design parameter (measurement principle, vertical load, inflation pressure, contact area and pressure, slip ratio, test tire, etc.).

Furthermore, all of the devices have designs that differ substantially from that for an aircraft.

This wide variation makes harmonization very difficult, recognizing that the friction coefficient recorded by a given GFMD is the outcome of a complex set of processes. Widely-varying designs will lead to different parameter dependencies which introduces “scatter” in empirical correlations produced by comparative testing. As well, testing has identified repeatability and reproducibility concerns for individual devices within the same family of devices.

In principle, various approaches, such as the two listed below, might be used to resolve this problem:

- (a) Correlations might be done taking into account the physical differences among the devices and the effect that these would produce on the readings obtained. An approach of this type was suggested by Andresen and Wambold, 1999, who proposed that, in essence, a deterministic IRFI be developed. This pre-supposes that a good, quantitative, mechanics-based, physical understanding can be developed of the processes that occur in the tire contact zone. This is a major challenge given the complexity of the problem, and it is beyond the current state of the art. This approach is not recommended.
- (b) Harmonization might be achieved by limiting the design options for ground friction-measuring devices. In principle, this approach would not try to achieve acceptable correlation among all existing (and future) devices. Instead, it would set out basic, high-level criteria that identify the key overall design requirements for friction-measuring devices from which manufacturers could design and build improved friction devices.

It is our opinion that this approach merits consideration.

It is noted that this approach has not been tried before. To date, device manufacturers have not been constrained by regulatory authorities with respect to the overall design features for devices, although some consideration has been given to the requirements for a reference device (Wambold and Henry, 2003).

At present, there are no performance-based criteria for GFMDs although a step in this direction is being made by Transport Canada (Comfort, Rado, and Mazur, 2009). Thus, GFMD manufacturers are free to develop designs for devices based upon their perception of what is needed. If a clear definition of requirements could be established, it is believed that manufacturers would likely respond and design equipment to meet these goals.

3.3.4.3 High-Level Performance Criteria

Research is required to quantitatively define the parameters that should be incorporated into a GFMD that would show good correlation to an aircraft on winter surfaces, although there is a general understanding at present regarding the ones that are probably important.

As a start, it is useful to review the criteria proposed by Wambold and Henry, 2003 for a reference friction-measuring device (Figure 3.26).

- Measure both force and torque;
- Have a high footprint contact pressure, greater than 500 kPa;
- Have variable or adjustable slip ratios up to 100%;
- Have a standard tire that is reproducible from tire to tire;
- Be equipped with an anti-skid system; and
- Be a trailer device that is compact for shipping and can be towed with most any truck.

Figure 3.26: Criteria for a Reference Device (Wambold and Henry, 2003)

For an improved correlation between GFMDs and aircraft, high-level performance criteria need to be developed with respect to many items such as those below:

- (a) The measurement principle, starting with the GFMD type (fixed-slip vs. variable slip vs. side force vs. locked-wheel tester, etc.). As well, the JWRFP tests showed that different readings were produced on some surfaces (mainly loose snow) from devices that used torque measurements versus ones that used force measurements.
- (b) The tire design (tread and ribbing, carcass design, properties, etc.). Also, investigation is needed to establish whether or not an aircraft tire is required as the measurement tire.
- (c) The vertical load on the tire, the tire inflation pressure, and the tire contact pressure – the results presented in this section suggest that a contact pressure in the range of about 750 kPa is probably required, although it is cautioned that more detailed testing is necessary.
- (d) The slip ratio(s) and the slip speed(s) that is (are) required.
- (e) The requirement for an anti-skid system that has similar performance to those on aircraft also needs to be investigated.

4 OVERALL COMMENTS REGARDING RUNWAY CONDITION REPORTING

Runway Condition Reporting (RCR) for operational purposes can be divided into two main activities as follows:

- (a) The collection of friction-related information, and its dissemination. The potential forms of this information include:
 - (i) The values measured by ground vehicles;
 - (ii) General indications of braking action, within the context of a general scale such as the one in ICAO Annex 14, Volume 1;
 - (iii) Friction information deduced based on the surface conditions;
 - (iv) Pilot REports (PIREPs); and/or
 - (v) Friction information derived from aircraft data obtained from previous landings.
- (b) Runway surface condition observations and measurements.

4.1 Overall Comments Regarding Friction-Related Information

4.1.1 Operational Friction Assessment

4.1.1.1 Value of Friction Information

There is discussion and disagreement regarding the value of friction measurements on runways and the value of attempting to relate this friction number to aircraft braking performance and an implied braking action. However, it should be recognized that there is no disagreement that runway surface friction information is not potentially valuable.

The concerns and disagreement being expressed lie with the ability of the current friction measuring devices to provide credible data and how this information should be used. Until such time that ground friction devices are developed which meet the requirements of aircraft manufacturers, airlines, and CAAs, the aviation industry will continue to rely on other means to infer braking action on winter-contaminated runways.

4.1.1.2 PIREPS (Pilot Reports)

Pilots provide subjective assessments of braking action immediately after landing. Given the number of aircraft landings on contaminated surfaces, PIREPS are a potentially valuable information source. The proposed TALPA/ARC system formally recognizes the value of such reports.

This process could be enhanced by building a database of perceived aircraft braking performance on various winter contaminated surfaces in conjunction with surface condition reports. With the collection of sufficient data, conclusions could be drawn regarding the effects of such variables as aircraft type, loading, cross-winds, surface conditions, etc. and appropriate guidelines could be developed for using PIREPs most effectively. Standardization of airport condition assessment and studious recording of pilots' observations could yield a growing database that would provide a basis for conclusions that grows in strength with time. Such information could be cross-referenced with other processes for determining and predicting aircraft performance on contaminated runways with a view to establishing correlations.

It is understood that a process of this type is intended to be done within the scope of the proposed TALPA ARC program.

4.1.1.3 Braking Action Inferred from Surface Contaminant Conditions

Some airlines utilize this as an input for, or in some cases, the primary method for, assessing operational aircraft performance, as shown in the questionnaire survey that was done (described in Volume 2 of this report series) and in Section 3 of this report.

It is further noted that this is the primary approach being advocated by the proposed TALPA ARC system, which has developed an assessment matrix relating aircraft performance to various surface conditions. Field trials will be conducted during the 2009-2010 winter using the TALPA ARC system at some American airports. EASA is advised to monitor these trials closely.

4.1.1.4 Friction Information Derived from Measured Aircraft Data from Previous Landings

A potential exists for utilizing aircraft data collected during previous landings for near real-time determinations of the friction coefficient of the surface. Field trials will be conducted at an airport this winter using one system. This is an emerging technology that should be monitored, evaluated, and perhaps encouraged.

4.2 Operational Condition (Contaminant) Measurement or Observation

As a general rule, reliable measured data are always better than estimated values or observations. This avoids subjectivity and also provides tangible evidence when questions arise or in cases where liability becomes an issue.

This requirement will become even more important should the proposed TALPA ARC system become enacted into regulation as surface condition assessments (which are all done visually at present) will become the primary basis for making aircraft performance assessments.

4.2.1 Harmonization

Consistency and reliability of condition reports may be expected to improve if harmonization brings about standardization of measureable parameters, requirements for accuracy, frequency of inspection, contaminant definitions and reporting procedures.

4.2.2 Human Factors Including Training and Testing

The negative influence of distractions, work pressure, demanding work environment, fatigue, and other human factors on the accuracy and value of condition reports is documented elsewhere and can only be managed effectively if they are understood. Regulators can assist airports in managing human factor challenges by providing information and guidance on managing negative influences on the inspection process.

Airport staffs are often required to be qualified in a wide variety of subjects, yet there are few CAA references to airport RI performance criteria and qualifications. Some CAAs advise airports to ensure that inspecting staff are trained or qualified but leave airports to determine the required qualifications. There is a need for suitable direction and guidance to airports on the type of training required, testing, retesting, and retention of qualifications for RIs. A strong CAA auditing function would reinforce the process. Training is also seen as an additional cost by airports and some airports organizations have lobbied for CAA financial assistance for such safety related training. If CAA financial assistance were provided for such training CAAs would naturally have an enhanced audit role.

4.2.3 Operational Condition (Contaminant) Measurement

Measuring rather than estimating runway contaminant parameters holds significant potential for enhancing condition report accuracy, reliability and timeliness. However, significant work must be done in order to realize a system that provides consistent, accurate, cost-effective measurements of the previously discussed contaminant condition parameters. Various technologies hold promise for the future (as described in Section 5), and it may be pragmatic to adopt a strategy of supporting technology development and fostering staged introduction into the operational environment as trials demonstrate accuracy and reliability of various measuring systems.

As with ground friction devices, it is believed that equipment manufacturers would be greatly assisted if a set of basic requirements were available to define the device(s) that are required to identify and quantify runway contaminants. This would contribute to an efficient device-development process.

4.2.3.1 *Requirements*

For practical application during aircraft operations, measurement of contaminant parameters in aircraft movement surface condition inspection and reporting should meet the following requirements:

- (a) Critical AMS must be monitored, either with adjacent and/or imbedded instrumentation or via inspection vehicle instrumentation or a combination of both of these methods and/or others.
- (b) Sensor accuracy must meet or exceed levels required to confirm presence, spread, distribution, type, and depth of contaminants.
- (c) Instruments must be capable of continuously sampling data in all potential contaminant conditions over long, uninterrupted periods.
- (d) Instrumentation should comply with relevant standards for accuracy, durability, mean-time-between-failure, etc.

- (e) Vehicle based data sampling speeds must be sufficient to sustain a reasonable vehicle inspection speed, ostensibly at or above 50 km/h.
- (f) Interpretive software should be capable of averaging the sensed data in real time such that it is of value in estimating aircraft performance during current aircraft operations and is available in real-time in the vehicle.
- (g) Conditions sensing systems should employ sensors and other hardware that are accurate, robust, reliable and cost effective.

4.2.3.2 Performance Accuracy

For AMS condition reports to be of value in aircraft operations, the accuracy of the reported values must match or exceed that used to differentiate aircraft operational performance as determined by aircraft manufacturers and/or Civil Aviation Authorities (CAAs). Direct sensor data or values derived through analysis of sensed data from one or more sensors should provide values with accuracies as summarized in Table 4-1.

Table 4-1: Sensed Data Accuracy

Measurable Parameter	Suggested Minimum Accuracy
Runway maintained path	.5 m
Offset of the runway maintained path from the centreline	.5 m
Contaminant surface distribution as a percentage of each third of the entire maintained path	10%
Contaminant surface distribution as a percentage of the entire maintained path	10%
Runway full width and maintained path contaminant depth - liquid	1 mm
Maintained path contaminant depth - dry (loose) snow	2 mm ¹
Maintained path contaminant depth - wet snow	1 mm ¹
Maintained path contaminant depth - slush	.5 mm ²
Contaminant type differentiation	Liquid, slush, wet snow, dry snow, compact snow, ice, frost, sanded (gritted) ice, sand (grit), ice control chemical (liquid, prill or granular)
Windrow maximum height	≥ 5 cm
Windrow maximum width	≥ 10 cm
Contaminant boundary location	± 3 m

Notes:

1. Ten percent of ICAO Recommended mean depth assessment accuracy (dry snow – 2cm, wet snow – 1 cm) reference ICAO Annex 14 Vol. 1, 2.9.11.
2. Fifteen percent of ICAO Recommended mean depth assessment accuracy (Slush – .3cm), reference ICAO Annex 14 Vol. 1, 2.9.11.

4.2.3.3 Suggested Confidence Level Requirements

Although it appears to date that no CAA has commented on confidence levels for the accuracy of estimated surface conditions, at least one CAA has advised a 95 percent

confidence level for estimated runway friction derived from ground vehicle measurements. It is, therefore, suggested that confidence levels should meet or exceed 95 percent.

4.2.3.4 Condition Sensing Objectives

Several groups have investigated the potential for instrumented measurement of the surface contaminant parameters previously listed. There has been some research into, and development of, instrumentation specifically for use on runways. However, most of the investigative work to date has been based on sensing some of the same conditions on highways and roadways to enhance driver safety through better management of vehicle safety systems and driver information delivery. This is described in Section 5.

Much of this work is directly relevant to AMSs and, if combined with other measuring techniques and technologies, may provide answers to many of the challenges RIs and flight crews face in determining surface conditions.

Road authorities also have an interest in determining compliance with predetermined maintenance standards. This requirement often results in focusing sponsored R&D projects on the determination of compliance with ‘threshold’ limits such as clearing contaminants from a surface to reveal pavement over a set percentage of a given area. Measurement of go/no-go status (threshold values) may be applicable on runways under certain circumstances (e.g., close/open runway) but reporting of actual condition measurements would be more useful for aircraft operations. Therefore, refocusing of some of this work would be of value to the aviation community.

4.3 Reporting Formats Including the ICAO SNOWTAM

4.3.1 SNOWTAM

4.3.1.1 Discussion

There are advantages in unifying the format in which winter runway conditions are provided to carriers and pilots by AIS NOTAM. SNOWTAM, NOTAMJ (Canada), and other NOTAM formats referring to transient winter runway conditions have varying degrees of detail. CAAs’ differing interpretation of condition reporting requirements have resulted in varying instructions to airport and AISs regarding content and structure of airport reports and NOTAMS. The fundamental differences are in the level of detail to be reported and in the requirement to report conditions either by runway third or for the entire runway with locational exceptions reported in detail. A unified interpretation of air carriers’ and pilots’ need for information would be required to completely harmonize the reporting format and provide a practical output. The following steps are recommended:

- (a) Such a harmonizing process should have, as its first step, a definitive declaration of the runway information required by carriers and pilots to assess aircraft performance. Once the required information is defined the reporting formats used in various jurisdictions can be tailored to address them.
- (b) One methodology for achieving such a harmonization goal would include the following steps:
 - (i) Define the reportable contaminant parameters such as type, depth, location, etc.;

- (ii) Mandate the reporting of location of conditions by runway third or for entire runway with exceptions or to allow for either;
- (iii) Choose to provide for reporting of runway friction (mandatory or advised) or not;
- (iv) Review the international SNOWTAM protocol to confirm or amend the required runway condition data elements and accuracy;
- (v) Provide a sample runway condition reporting format, including all required data elements, for airport use or interpretation;
- (vi) Require all airports to report conditions to AISs using as a minimum, the sample runway condition reporting format;
- (vii) Provide detailed guidance to airports on minimum runway condition report requirements, structure, interpretation, preparation and frequency; and
- (viii) Provide detailed guidance to AISs on transposing airport runway condition reports to SNOWTAM.

4.3.1.2 Potential Changes to the Current SNOWTAM Format

The current ICAO SNOWTAM reporting requirements (Figure 2.1, in Section 2) do not fully respond to those as stated by carriers and pilots to date, nor are they consistent with definitions and requirements stated elsewhere in ICAO for determination of aircraft performance or with direction to airports for reporting of conditions.

As part of the response to many of the project requirements, this report recommends that aircraft manufactures and aircraft operators should state their requirements for runway condition information. For the SNOWTAM format to be fully in tune with these requirements, the preceding step must be completed. In the absence of fully definitive requirements information from aircraft manufacturers and based upon current knowledge the following changes are recommended to SNOWTAM submittal instructions to airports:

- (a) Change wording of items ‘D’ and ‘E’ from ‘CLEARED’ to ‘MAINTAINED’ to better reflect status.
- (b) Within item ‘E’, provide format for defining runway centreline off-set (if any).
- (c) Within item ‘E’, change off-set direction indicator from L/R to magnetic heading to reduce potential for confusion.
- (d) Subdivide item ‘F’ to provide the following information:
 - (i) Deposits over each third of maintained width of runway; and
 - (ii) Deposits over un-maintained width, subdivide runway sides by magnetic heading if significantly different conditions exist on each.
- (e) Substitute current list of conditions in item ‘F’ with agreed definitions as listed elsewhere in ICAO Annex 14.
- (f) Harmonize friction/braking action values in item ‘H’ with outcome from ICAO Friction Task Force findings, if different.

- (g) Substitute designation magnetic headings in place of ‘L’, ‘R’, and ‘LR’ for location of snowbanks in item ‘J’.
- (h) Provide means to describe longitudinal location of snowbanks in relation to thresholds or other geographic locators in item J.
- (i) Updated guidance should be provided on reporting layered contaminants.
- (j) Updated guidance should be provided on completion of each section.
- (k) Updated guidance should be provided on distinguishing between the type of information to be entered into items ‘N’, ‘P’ and ‘R’ and that entered into item ‘T’.

An example graphical depiction of a practical information collection form to be completed by RIs at the end of an inspection together with suitable direction on interpretation would be of value to airports as guidance in amending their surveying and reporting protocols.

4.3.2 Currency of Information

4.3.2.1 *Definition of a Significant Change*

Most agencies require an updated report of runway condition whenever “conditions change”. Usually, a significant change is not defined although the ICAO SNOWTAM does have some information regarding this.

More quantitative criteria would be beneficial though, particularly if the trends being advocated by some groups to de-emphasize friction measurements become enacted. Table 4.2 provides recommendations regarding what might be considered to be a “significant change”.

Table 4-2: Recommendations Regarding the Definition of a Significant Change

Measurable Parameter	Estimated Change in Condition
Maintained path width	$\geq \pm 3\text{m}$
Offset of the maintained path from the centerline (if any)	$\geq \pm 3\text{m}$
Contaminant type	Reclassification of $\geq 10\%$ of reportable path surface
Contaminant depth	$\geq \pm 10\%$
Contaminant location	$\geq \pm 100\text{m}$ for $\geq 25\%$ of contaminant deposition
Contaminant spread	$\geq \pm 10\%$
Friction measurement	$\geq \pm .05$ of measurement scale (μ , g, CRFI, etc.)

4.3.2.2 *NOTAMS - System for Automatic Distribution of NOTAMs in Norway*

One of the most frequent concerns expressed by pilots and airlines regarding AMS reporting is the lack of currency of reports they receive due to the time lag between RIs filing reports and NOTAMS being distributed. Norway has implemented a report distribution system that builds on current and widely used computer based condition reporting technology.

This system (Figure 4.1) has been developed by Tradewind Scientific Ltd. This system is unique and offers the very real advantage that RCR information can be disseminated faster.

4.3.2.3 Discussion of Norwegian Automatic NOTAM System

The Norwegian winter NOTAM (SNOWTAM) transmission and distribution process represents a significant step forward. RIs record surface conditions using in-vehicle computers that perform first level logic checks, input base data such as time, RI identification etc. The RI reviews the computerized report in text format and then transmits the report. The report is transmitted to a centralized AIS computer where it is checked for errors using intelligent software. If errors are found, the report is immediately transmitted back to the RI with guidance for corrections. The RI makes the required corrections and retransmits. The report is then formatted by computer for NOTAM distribution and submitted to the NOTAM distribution network.

The time from transmission of report by RI from the inspection vehicle to NOTAM distribution has been reduced to the order of 20 seconds.

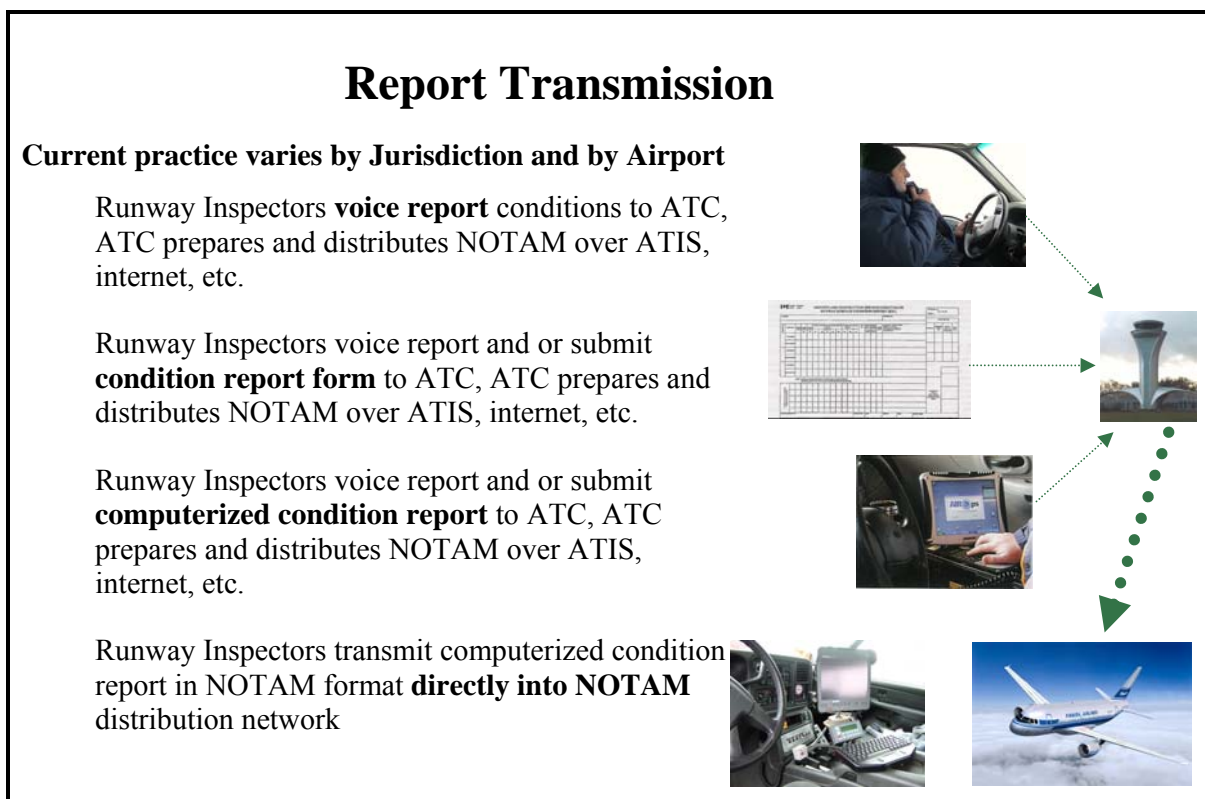


Figure 4.1: System for Automatic Dissemination of NOTAMs in Norway

4.4 Summary of Findings

4.4.1 Operational Friction Assessment

A number of options are possible and are being followed to various degrees by the aviation community, as follows:

- (a) Friction measurements made using ground vehicles – a lack of confidence is being expressed by various groups within the aviation community with respect to the value of friction measurements by ground vehicles, and it is being recommended that RCR efforts be refocused towards defining the runway surface condition itself. It is the opinion of the project team that this statement is specific to friction data as they are being collected at present. This is not necessarily applicable to all friction data. Friction measurements are discussed further subsequently.
- (b) Friction information as provided by general scales of braking action, such as the one in ICAO Annex 14, Volume 1 – this option is losing favour. Only one scale is presently in active use, that being the ICAO one. Also, the survey conducted in this project showed that braking-scale information is considered to be of lesser value compared to surface condition assessments, friction measurements or PIREPs.
- (c) Friction information inferred from surface contaminant conditions – this method is in common use by airlines for operational aircraft performance assessments. Furthermore, this is the primary approach being advocated by the proposed TALPA ARC system for aircraft performance assessments.
- (d) Pilot REports (PIREPs) – the proposed TALPA/ARC system formally recognizes the value of such reports. Also, it is understood that efforts will be made as part of the TALPA ARC process to develop guidance material to aid in using PIREPs which would probably enhance their value.
- (e) Friction information determined from measured aircraft data collected during previous landings – this is a potentially valuable emerging technology that should be monitored.

4.4.2 Aircraft Movement Surface Condition Assessment

4.4.2.1 *General*

Referencing the following subjects in regulation and providing related guidance will promote harmonization and uniformity of report content:

- (a) Contaminant definitions;
- (b) Assessment frequency;
- (c) Runway Inspector qualifications;
- (d) Estimating techniques for reportable conditions;
- (e) Training and testing of RIs; and
- (f) Auditing of airports' runway inspection instructions and procedures.

4.4.2.2 Items Where Direction and Guidance Are Required

Direction and advice should be provided to airport operating authorities regarding interpretation and accuracy in assessing the following contaminant criteria:

- (a) Interpretation of the term ‘cleared’ when reporting the width of the runway available for aircraft operations;
- (b) Required accuracy for reporting the ‘cleared’ runway width;
- (c) Required accuracy and methodology for reporting the ‘cleared’ width off-set if any;
- (d) Definitions of contaminants as used to estimate aircraft performance;
- (e) Uniform measurements for reporting depths including increments, number of sample measurements if required, estimating techniques, required accuracy;
- (f) Requirement for reporting contaminant depths outside of the ‘cleared’ path;
- (g) Required method for describing contaminant location(s) including terminology, increments (if any) for describing distances and required accuracy; and
- (h) Required accuracy and terminology for reporting contaminant percentage distribution on the maintained “cleared” path and remaining areas of the runway and direction on distinguishing the two.

4.4.2.3 Underlying Contaminants

Where no friction measurement is provided and reporting the uppermost layer of contaminant would not provide a complete description of the potential for loss of friction (such as with loose snow on ice), direction, guidance, and training should be provided to RIs in reporting underlying contaminants.

4.4.2.4 Runway Closure for Maintenance

An investigation should be undertaken and suitable direction provided into the advisability of directing that runways be closed for maintenance if a predetermined transitory condition (water, snow, etc.) threshold is reached.

4.4.2.5 Human Factors

Airports should be advised of the influence of human factors on the accuracy of AMS reports and of means to negate negative influences.

4.4.3 Aircraft Movement Surface Condition Reporting

The artificial categorization of surface conditions by season has lead to airports in some jurisdictions implementing different reporting protocols for different calendar periods. Clarification of the reporting of required surface conditions, regardless of season, by CAAs would enhance airports’ understanding of the universal requirements.

4.4.3.1 Operational Condition Reporting Requirements

Airports should be advised of operational condition reporting requirements including:

- (a) Reportable parameters;
- (b) Required accuracy;
- (c) Reporting frequency;
- (d) Timeliness of report transmission; and
- (e) Criteria for issuance of new reports.

4.4.3.2 ICAO SNOWTAM Updates

For jurisdictions using the ICAO SNOWTAM reporting protocols, format updates as detailed in 4.3.1.2 above would promote consistency, accuracy and harmonization.

4.4.3.3 Automatic Transmission of Runway Condition Reports

The results of the Norwegian and Swedish civilian and military experiences with automatic translation of runway condition reports into SNOWTAMs and automatic dissemination over NOTAM distribution networks offer significant advantages over current winter NOTAM distribution methodologies:

- (a) Significant delay reduction;
- (b) Full empowerment of RIs for NOTAM content; and
- (c) Harmonization of reporting formats.

5 TECHNOLOGIES FOR MEASURING SURFACE CONDITIONS

5.1 Purpose of Investigation

At present, there is a strong need for accurate reporting of the runway condition itself, with respect to parameters such as the contaminant type, the contaminant depth, cleared width, etc. This is evident from various sources, including the surveys done by questionnaire in this project (which are described in Volume 2).

Presently-ongoing initiatives such as the TALPA ARC are trending towards de-emphasizing ground friction measurements, and recommending that instead, RCR be focussed on describing the runway itself. This will produce an even stronger need for accurate reporting of the runway condition itself for a number of reasons. Examples follow:

- (a) Surface condition descriptions will constitute the main basis for operational decisions.
- (b) There will probably be a need to document additional parameters. For example, the proposed TALPA ARC system requires that the surface temperature be measured, which is not normally done at present.

As discussed previously and shown in the results from the questionnaire surveys (described in Volume 2), at present, the key parameters (i.e., contaminant type, contaminant depth, cleared width, contaminant location, cleared width offset, area coverage, etc.) are either:

- (a) Estimated visually, rather than measured; or
- (b) Measured using relatively crude procedures such as a ruler for contaminant depth, or a depth indicator for assessing threshold exceedence (i.e., a pound coin which happens to be 3 mm thick). These procedures are time-consuming and not suitable for large area surveys, on the scale of a large-volume, operational runway.

These trends will impose a requirement for rapid, large-scale, accurate descriptions of the runway surface itself.

5.2 Synopsis of Currently-Available Technology

No off-the-shelf equipment was found that would allow the important runway surface condition parameters (contaminant type, contaminant depth, cleared width, contaminant location, cleared width offset, area coverage, etc.) to be measured remotely with sufficient accuracy and rapidity on the scale of the area of an operational runway.

However, a number of relevant research programs have recently been conducted, which are reviewed in the next section.

5.3 Technology Review and Relevant Research and Development Work

Most of the work has been related to investigations for highways. Although it has relevance to airports, Aircraft Movement Surfaces (AMSs) at airports have their own unique requirements; and thus, in general, adaptations would be necessary to apply this technology to airports.

5.3.1 Relevant R&D – Width of Maintained Path

Of all the RCR parameters of concern, the measurement of the maintained path has had the least attention with respect to R&D; and thus, this runway condition parameter presents a significant challenge. This issue is not a major one for highways because roadway drivers are limited to a narrow (lane) path. The expectation for highways is that conditions sensed directly in front of a vehicle will be the same across the highway lane. This is not the case on an aircraft movement surface.

Thus, relatively little R&D was found with respect to the measurement of the width of a path with less contaminant on it than on the remaining longitudinal area. Some relevant R&D programs are reviewed below.

5.3.1.1 SPAR Aerospace Spectral Analysis

A technology development project was carried out in the mid 1990s by SPAR Aerospace that was sponsored by Transport Canada, which had the potential to allow determination of the maintained path. The project was commissioned to investigate the potential for sensing various winter contaminants and employed spectral analysis cameras. The project was in large part successful, but the lateral range of imaging is currently unclear. It may be possible to determine the maintained path by developing image analysis algorithms that can quantify the lateral component of the image that is less contaminated or treated with sand and/or chemical. A synopsis of the project is reproduced from the Transport Canada website (www.tc.gc.ca) in Appendix A, Annex 1. Further R&D work was not sponsored by Transport Canada regarding this.

It should be noted that it has not been possible to obtain additional information despite requests to Transport Canada and other sources, as this technology is considered proprietary to SPAR Aerospace.

5.3.1.2 DSC111 Vaisala Remote Road Surface State Sensor

The DSC111 Vaisala Remote Road Surface State Sensor was examined during a field trial conducted during the 2007 winter that was sponsored by the Ministry of Transportation of Ontario (MTO) on a major highway in Ontario, Canada (Feng and Fu, 2008). See Figure 5.1.

A review of this evaluation project is provided in Appendix A, Annex 2.

These tests indicated that the system has potential. Although it would be impractical for AMS installations in its current state due to, for example, the excessive mounting height that is required, it may be possible for a modified system to be used at airports. The system uses near-infrared sensors or a sensor array in combination with associated software to determine differences in ground conditions across a pavement surface. Again, algorithms might be developed that would use sensed differences in surface conditions to calculate a maintained path. The DST111 infrared Remote Temperature Sensor may also be of value in this regard.



Figure 5.1: Vaisala Remote Road Surface State Sensor (Feng and Fu, 2008)

5.3.1.3 Other Technologies or Approaches with Potential for Measuring Maintained Path

Laser scanning and radar have both been demonstrated to be capable of detecting contaminant across a specified width in the IST Fricti@n project conducted in Finland (Koskinen, and Peussa, 2009). These tests were conducted with three vehicles that were extensively instrumented (Figures 5.2 and 5.3). The Information Society Technologies (IST) Program 2009 Fricti@n Project is discussed in Appendix A, Annex 3.

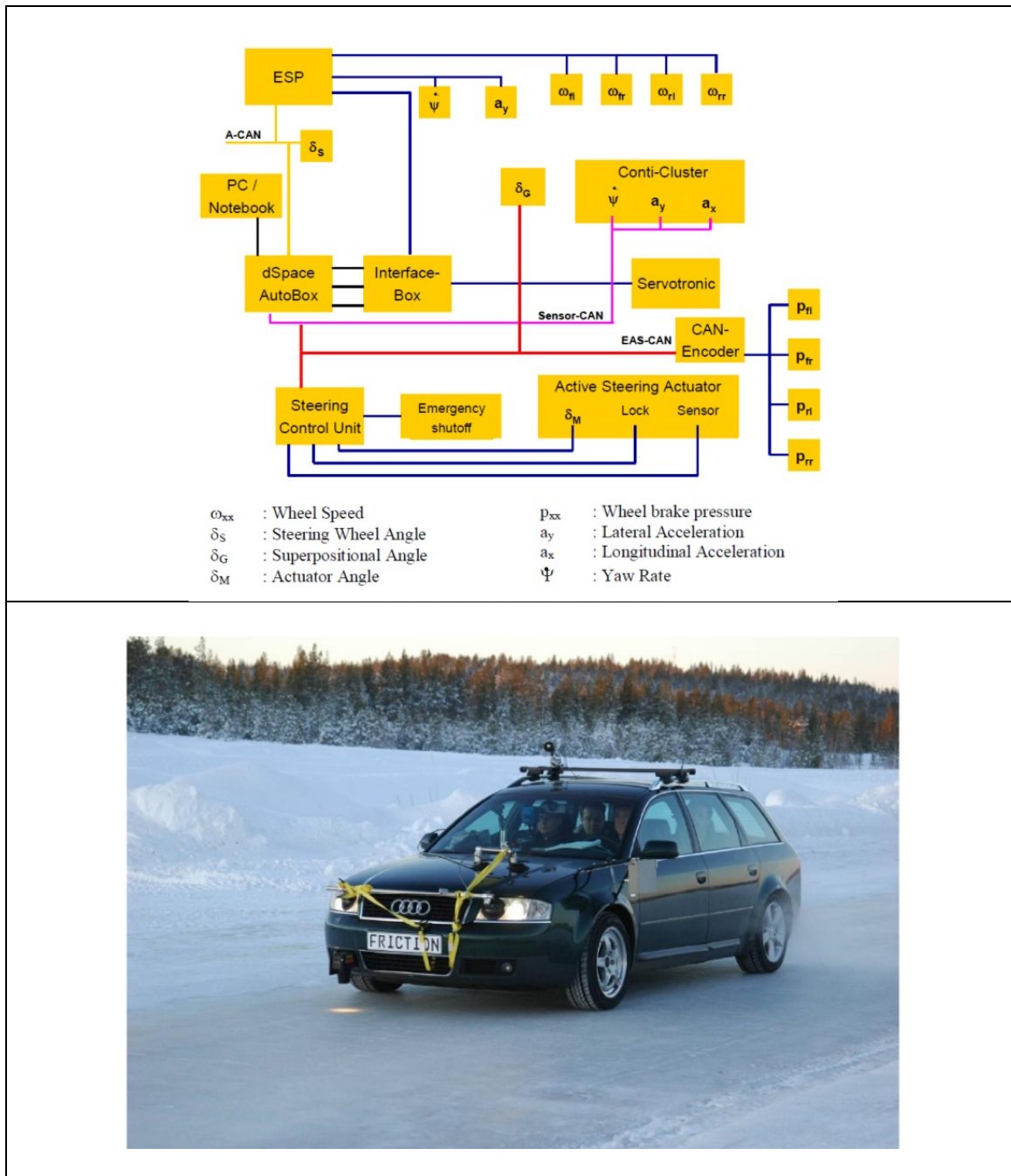


Figure 5.2: Instrumented Vehicle in Friction Project (Koskinen and Peussa, 2009)

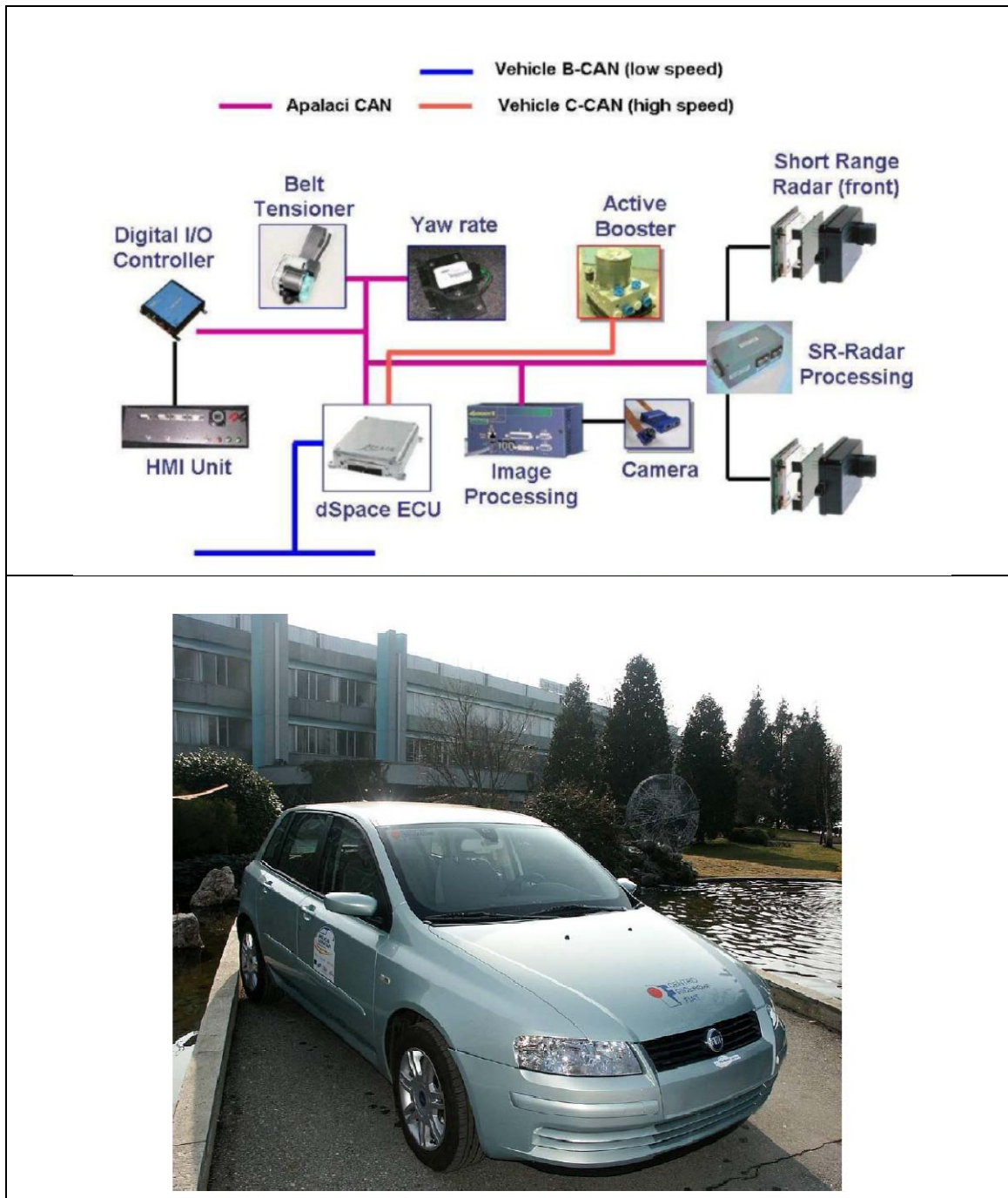
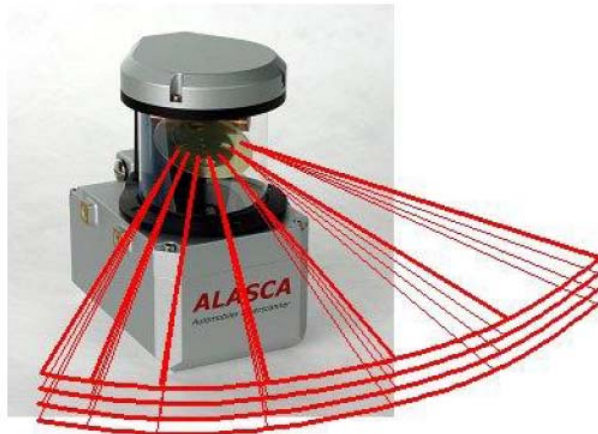


Figure 5.3: Instrumented Vehicle in Friction Project (Koskinen and Peussa, 2009)

The sensors used in the Friction@ project included (Figure 5.4) (a) a Road Eye sensor (which is a laser/infrared spectroscopy based sensor developed by Optical Sensors and (b) Lux and ALASCA laser scanners developed by IBEO.



ALASCA Laser Scanner with Schematic of 4-Layer Laser Beam



Road Eye Sensor



LUX Laser Scanner Attached to ika Audi

Figure 5.4: Some Sensors Used in Friction Project (Koskinen and Peussa, 2009)

Similar methodologies to those discussed above might be employed to determine the path width at an airport, although some modifications would be necessary.

5.3.2 Relevant R&D – Maintained Path Offset

The lateral position of the maintained path relative to the runway centreline is important to pilots, especially for approaches in low visibility conditions or significant cross-winds.

The maintained path of the runway is often offset from the centerline when winter maintenance activities are conducted in parallel with aircraft operations. The runway's maintained path is also usually offset when snowfall occurs during aircraft operations while maintenance operations clear snow from one side of the runway to the other. This is particularly true at smaller airports when the operations are done in the presence of a crosswind.

While the offsets are usually temporary at larger airports, they may last for the duration of the storm at smaller airports due to the limited resources that they have to maintain the runway during the storm. Offsets are currently normally estimated by AMS inspectors.

There seems to have been no formal investigations into methods to measure the maintained path offset using sensors. However, there is potential for determining the position of maintained path of the AMS (usually the runway) by combining data derived from the maintained path measurements with differential GPS or other positional inputs. Differential GPS can provide levels of positional accuracy down to centimetres with the installation of locators on the airport.

However, at present, a system of this type is not commercially available for this application.

5.3.3 Relevant R&D – Contaminant Type

The surface contaminant type is very critical to aircraft operations. This is reflected in the varying tolerances of aircraft performance to various contaminant types. For example, the aircraft performance codes within the proposed TALPA ARC Runway Condition Matrix (described in Volume 2 of this report series) vary from '5' for frost, to '1' or '0' for ice depending on whether the ice is wet or not.

Currently, contaminants are categorized by RIs using criteria provided by their CAA or another source. Even though training (where available) focuses on a unified interpretation of the documented descriptions, personal determinations are subjective.

Several projects, including those listed below, have exhibited potential for matching surface condition measurements with pre-determined parameters.

- (a) The SPAR camera, which is described in Appendix A, Annex 1;
- (b) The Vaisala near-infrared camera, which is described in Appendix A, Annex 2; and
- (c) A combination of the layered ALASCA laser, infrared spectroscopy and polarization sensors in the Fricti@n project, which is described in Appendix A, Annex 3

As well, recently, a project was conducted by NASA project (West et al., 2008) using aircraft mounted forward looking interferometers for real-time detection of flight hazards such as birds, volcanic ash and precipitation conditions during flight. This shows potential for the accurate detection of contaminants on the ground, although that was not the objective of the NASA project. A project synopsis from the NASA website is reproduced in Appendix A, Annex 4.

None of these technologies are presently sufficiently-developed for operational use at an airport, as further development would be required. Nevertheless, they show potential and should be monitored, or perhaps encouraged, given the current emphasis on focussing on defining runway surface conditions.

5.3.4 Relevant R&D – Contaminant Location

A knowledge of the longitudinal location of contaminants along both the maintained path, and to a lesser extent, the remainder of the runway, permits pilots to adjust landing and take-off procedures. Where the aircraft Accelerate-Stop-Distance-Available is significantly less than the runway length, the pilot may be able to select a longitudinal section of the runway that presents better braking if it is reported. Contaminant location is currently estimated, in the best case, using edge lights, to approximate distance from AMS features such as the runway threshold and runway/taxiway intersections.

No R&D work was found that has been specifically focused on using instrumentation to determine the location of contaminants on AMS, but this may be achievable by positively identifying the contaminants and fixing their location using differential GPS.

5.3.5 Relevant R&D – Contaminant Depth

The contaminant depth is a very critical parameter for evaluating aircraft performance. As an example, the aircraft performance codes within the proposed TALPA ARC Condition Matrix (described in Volume 2 of this report series) for slush, dry snow or wet snow drop from '5' to '2' if the depth is less than, or more than, $\frac{1}{8}$ inch respectively.

The following technologies were found for contaminant depth measurements.

5.3.5.1 *Vestabill Ltd. Modified Mu Meter*

After a number of runway contamination-related aircraft incidents beginning in 2003, the UK CAA commissioned Vestabill Ltd. to determine (a) the correlation of friction measurements from a Mu-meter CFME and aircraft performance, (b) the effects of drainage on friction readings, and (c) other related issues. Extracts from the study are reproduced in Appendix A, Annex 5.

As part of the study, experiments were conducted to investigate whether the depth of runway surface water could be determined by measuring the contaminant drag forces generated as contaminants impacted the instrumented wheel. The results were sufficiently positive to conclude that further experimentation was warranted.

5.3.5.2 *SnoMetrixTM*

SnoMetrixTM, which is marketed by Tradewind Scientific Ltd., is a patented laser imaging device that is mounted on an airfield inspection vehicle and is capable of measuring contaminant depth with an estimated accuracy of 2 mm at speeds up to 80 km/h. The device has been tested at airports in operational conditions with some success. The SnoMetrixTM unit is not currently commercially available, but previous marketing material is reproduced in Appendix B. Tradewind Scientific Ltd. is reviewing the product market potential and expects to once again make the SnoMetrixTM available to airports.

5.3.6 Summary of Potential for the Reviewed Technologies

Table 5-1 summarizes the potential applicability of the reviewed sensing technologies for measuring the AMS parameters of concern.

Table 5-1: Potential Applicability of Sensing Technologies

	Maintained Path Width	Maintained Path Offset	Contaminant Type	Contaminant Location	Contaminant Depth
Spectral analysis imaging (SPAR)	Yes	Yes	Yes	Yes	
Near infrared imaging (Vaisala DSC111)	Yes	Yes	Yes	Yes	
Infrared temperature sensing (Vaisala DST111)			Yes	Yes	
Lateral laser scanning (IST ALASCA)	Yes	Yes	Yes	Yes	Yes
Vehicle mounted radar (IST or similar)	Yes	Yes		Yes	
Differential GPS (COTS)		Yes		Yes	
Stereo polarization imaging (IST Road Eye sensor or similar)	Yes	Yes	Yes	Yes	
Contaminant Impact energy measurement (Vestabill modified Mu-meter)			Yes		Yes
Forward Looking Interferometer (NASA/Georgia Tech/Hampton University)	Yes	Yes	Yes	Yes	
Laser Depth Profiling (SnowMetrix)					Yes

It is noted that multiple sensing may have a role in producing a useful overall system. Although accuracy, reliability, operating range, cost and other parameters must all be taken into account in deploying systems to determine AMS conditions, the most accurate AMS sensing system may employ complementary technologies with a combination of sensor inputs to examine a given parameter. This approach can take advantage of the reduced cost of Common-Off-The-Shelf (COTS) technologies and increase overall system reliability and accuracy. Such advantages have been documented in the IST 2009 Friction Project, as described in Koskinen and Peussa, 2009, and discussed in Appendix A, Annex 3.

5.4 General Findings: Aircraft Movement Surface Condition Measurement – Sensing R&D

- (1) Given that the accuracy of reported AMS contaminant values and other conditions is paramount for safe aircraft operations, especially in adverse weather, there is ample justification for devoting significant resources to refining the determination of AMS physical conditions using sensing technologies, just as there has been to advance the art of friction measurement.

- (2) There is real potential for building on previous extensive R&D work to develop cost-effective sensing for AMS inspection that would significantly improve the accuracy of operational AMS condition reports.
- (3) Given that relevant condition sensing R&D is currently being conducted by a variety of organizations, focuses on different aspects of the subject, adopting a strategy of monitoring development, reviewing performance authorizing deployment would likely encourage transition from estimating conditions to measurement.

Improving the accuracy of operational runway reports will provide air carriers with the opportunity to improve landing and take-off safety and the overall cost-effectiveness of aircraft operations on contaminated runway surfaces by taking advantage of more accurately calculated performance for declared distances

5.5 Specific Recommendations with Respect to the Technologies Reviewed

5.5.1 General Recommendations

- (1) An extended review and assessment of roadway and AMS condition sensing technologies should be undertaken to determine the features, benefits, relevance, and potential of each. If there is consensus, a formal program of development and testing would provide the foundation for a common approach by CAAs to the issue of contaminant measurement.
- (2) The Fricti@n project strategy of using inputs from various condition sensors to increase overall condition identification accuracy demonstrated tangible advantages and should be applied in exploring the combined potential of various technologies through concurrent testing.
- (3) The principles applied to runway friction measuring equipment of standards compliance, CAA approval, calibration, etc. should be equally applied to runway surface contaminant measuring equipment. Formal parameters should be established and compliance confirmed before equipment is approved for use in operational condition reporting. The general requirements outlined in previous sections should be considered.

5.5.2 SPAR Aerospace Spectral Analysis System

This system is described in Appendix A, Annex 1.

Although it appears that Transport Canada did not follow up on the initial project findings, the technology demonstrated promise and has been used as the foundation for development of a commercial aircraft surface ice detection system. An exploration of the further potential should be undertaken with the current technology holder, MD Robotics.

The estimated soonest possible operational deployment for this system is two to three years.

5.5.3 Vaisala Active Near Red Infrared and Remote Temperature Sensors

This system is described in Appendix A, Annex 2. Feng and Fu, 2008, described field trials conducted with it on a major highway in Canada.

Discussions should be opened with the manufacturer to determine:

- (a) The potential for mounting the sensors on a vehicle;
- (b) The ability of the sensors to collect and interpret data while moving over a target surface at speeds greater than 50 km/hr; and
- (c) The potential for significantly increasing the sensed target area.

If discussions with the manufacturer indicate that the sensors have potential to provide accurate data from a moving vehicle over a reasonable target area, evaluation of the DSC111 sensor's determination of runway conditions in wet and winter conditions should be undertaken.

The estimated soonest possible operational deployment for this system is two years.

5.5.4 IST Program Which Incorporated Various Technologies

This system is described in Appendix A, Annex 3.

The Information Society Technologies (IST) (Finland) Program European Union "Fricti@n" Project (Koskinen and Peussa, 2009) incorporated various technologies as described in Appendix A, Annex 3). A study should be undertaken to determine the potential for adapting the Fricti@n project technologies for sensing and differentiating runway surface contaminants.

The estimated soonest possible operational deployment for this system is one to three years.

5.5.5 Forward Looking Interferometer

This technology is described in West et al., 2008, and in Appendix A, Annex 4.

Discussions should be held with the research team to evaluate the potential for the technology to identify and categorize ground contaminants from an approaching aircraft. If there is such, potential testing should be undertaken and a methodology developed and tested for integrating outputs into surface condition status reports.

The estimated soonest possible operational deployment for this system is three to four years.

5.5.6 Measurement of Water Depth Using a Modified Mu Meter

The UK CAA contracted Vestabill Ltd. to investigate the measurement of water depth using a Modified Mu-Meter as described in Appendix A, Annex 5. This evaluation should be continued to evaluate potential for the modified Mu-Meter to determine water depths under operational conditions. Trials should be conducted to determine the system's performance should it be determined that the system has potential.

5.5.7 TSL SnoMetrix Snow Depth Profiling System

This system is described in Appendix B.

This is the only known contaminant parameter measurement technology to be commercially available to airports. The product has been temporary withdrawn from the market for additional development; but when again available, it should be tested in field trials and, if found accurate and reliable, incorporated into testing of combinations of technologies.

6 SUMMARY AND CONCLUSIONS

The conclusions from this study are presented and grouped into the following categories:

- (a) Runway surface condition inspection and reporting process;
- (b) Technologies for Runway Condition Reporting; and
- (c) Runway friction measurement

6.1 Runway Surface Condition Inspection and Reporting Process

- (1) The runway surface condition inspection and reporting process provides critical information to air carriers to enable them to operate aircraft safely on winter contaminated runways.
- (2) The runway surface condition reports identify the contaminants on the surface in terms of what they are, where they are, and in many instances, an indication of the runway surface friction.
- (3) The determination of the contaminants on the runway surface is not measured but, rather, is done visually. Assessments as to extent of coverage, locations, etc. are also not measured but are estimated.
- (4) A shift from estimating these condition parameters to measuring them with instrumentation would significantly enhance the consistency and accuracy of condition reports by minimizing the potential for human error.
- (5) A variety of different definitions for the same winter contaminant exists.
- (6) There is a lack of user consensus on what are the critical contaminants that should be identified, what accuracy is needed when giving the information, and on the extent of detail necessary. A consistent definition of a “significant change” (which would trigger the need for an updated RCR) is not available, and recommendations are provided in section 4.
- (7) Consensus and standardization of the winter surface contaminants to be reported would enhance aviation safety. The minimum list of winter contaminants necessary should be agreed to, following which appropriated definitions would be established.
- (8) Air carriers (the users of this information) are not unanimous in stating their requirements for airport reporting of specific runway surface condition parameters.
- (9) Standardization of the runway surface condition surveying process (format, definitions, including guidance material, training requirements, etc.) would ensure that the same information will be given to the users of this information, regardless what airport they are flying into.

- (10) The reportable conditions for runway surface condition reporting can be categorized as follows for describing the data collection process:
- (a) Maintained path width;
 - (b) Offset of the maintained path from the centerline (if any);
 - (c) Contaminant type;
 - (d) Contaminant depth;
 - (e) Contaminant location; and
 - (f) Contaminant spread.
- (11) It is widely believed at airports that the reported information is both needed and must be as accurate as possible to enable accurate calculations of aircraft drag impingement, stopping distance, etc. This has resulted in a variety of surface conditions being reported (such as, loose snow, wet snow, hard compact snow, medium compact snow, ice, rough ice, wet ice, ice with sand, wet ice with sand, slush, etc.) and the need to try to establish definitions for all these conditions in terms which can be understood and used by the airport and users of the information. The need for such detail is questionable. The type of contaminants should coincide with the information provided by aircraft manufacturers and air carriers that relate to aircraft braking performance.
- (12) A realignment of the runway condition reporting requirements for contaminated runways which coincide with the needs of carriers would ‘streamline’ procedures for all, reduce confusion, and increase overall aviation safety.
- (13) The availability of runway occupancy time is a major influence on airports’ runway inspection procedures and by default, accuracy. Where there is a potential for inspections to be rushed because of the perceived interruption of aviation traffic there are real risks of RIs cutting corners, either because of institutionalized direction or because of their own perception of priorities. The lack of inspection time on runways can be addressed by CAAs giving clear direction to air navigation Service providers and airports to ensure adequate inspection time under all weather conditions.
- (14) Human factors and training have a significant influence on the ability of RIs to provide accurate condition reports. CAAs can provide advice to airports that would assist them in managing these issues.

6.2 Technologies for Runway Condition Assessment

- (1) At present, there is a strong need for accurate reporting of the runway condition itself, with respect to parameters such as the contaminant type, the contaminant depth, cleared width, etc. This is evident from various sources, including the surveys done by questionnaire in this project (which are described in Volume 2).
- (2) The TALPA ARC is trending towards de-emphasizing ground friction measurements, and recommending that, instead, RCR be focussed on describing the runway itself. The ICAO FTF was unable to reach consensus regarding the most appropriate role for ground friction measurements, although it agreed that a global reporting format is required. These initiatives and others, if enacted, will produce an even stronger need for accurate reporting of the runway condition itself.
- (3) Currently, there are few if any tools available to airports to assist them in quantifying runway conditions. The only measuring tools at present are crude instruments, such as rulers or threshold gauges to measure contaminant depth. Consequently, a long time is required to make measurements, which makes this approach unsuitable at a high-volume operational airport. As a result, practically all information related to the runway surface condition is estimated visually at present.
- (4) The credibility of the runway surface condition assessment process would be improved if equipment were available which could identify the contaminants on the runway and which could quantify the contaminants in terms such as depths, cleared widths, contaminant patches, etc.
- (5) A technology review was conducted. No off-the-shelf equipment was found that would allow the important runway surface condition parameters (contaminant type, contaminant depth, cleared width, contaminant location, cleared width offset, area coverage, etc.) to be measured remotely with sufficient accuracy and rapidity on the scale of the area of an operational runway.
- (6) The historical practice has been to let manufacturers, on their own, develop a product that the manufacturers consider would be beneficial to airports. This product would then be field-tested by staff at airports to determine the effectiveness and usefulness of the product. The result is general a product which works to some extent. It is perhaps time for airports and the aviation community to clearly define the requirements and work jointly with the manufacturers in development of new products.
- (7) A number of relevant research programs have recently been conducted, which offer potential (Table 6-1). These should be monitored and perhaps encouraged.

Table 6-1: Potential Applicability of Sensing Technologies (copied from Section 5)

	Maintained Path Width	Maintained Path Offset	Contaminant Type	Contaminant Location	Contaminant Depth
Spectral analysis imaging (SPAR)	Yes	Yes	Yes	Yes	
Near infrared imaging (Vaisala DSC111)	Yes	Yes	Yes	Yes	
Infrared temperature sensing (Vaisala DST111)			Yes	Yes	
Lateral laser scanning (IST ALASCA)	Yes	Yes	Yes	Yes	Yes
Vehicle mounted radar (IST or similar)	Yes	Yes		Yes	
Differential GPS (COTS)		Yes		Yes	
Stereo polarization imaging (IST Road Eye sensor or similar)	Yes	Yes	Yes	Yes	
Contaminant Impact energy measurement (Vestabill modified Mu-meter)			Yes		Yes
Forward Looking Interferometer (NASA/Georgia Tech/Hampton University)	Yes	Yes	Yes	Yes	
Laser Depth Profiling (SnowMetrix)					Yes

6.3 Runway Friction Measurement and Information

- (1) Countries differ with respect to the type of information that is provided to pilots. Some countries provide the measured friction values to others while others only provide them with general indications of braking action according to the ICAO scale.
- (2) Pilot REports (PIREPs) were also identified during the questionnaire survey as important information, with high priority. PIREPS provide good information on the aircraft's ability to brake on that particular surface. These reports, however, are subjective and are aircraft- and time- dependent. The TALPA ARC has recognized the value of PIREPS formally as information that can be used to downgrade assessments based on the surface conditions but not as a primary information source.
- (3) The AIPs of many countries contain warnings regarding the limitations of ground friction-measuring devices. It is generally recognized (a) that they are most suitable for "solid" surfaces (such as compacted snow and ice) and (b) that they are unreliable for "liquid-type" surfaces (water, slush, de-icing chemicals, wet snow, etc).

- (4) There is a divergence of views regarding the role that friction measurements can play for operational applications:
 - (a) The TALPA ARC's recommendations are headed towards de-emphasizing friction measurements and, instead, they are recommending that RCR efforts be focused on defining the runway surface itself for operational evaluations of aircraft performance. This indicates that a large part of the general aviation community feels that RCR emphasis should be refocused from friction measurement to observations of physical condition parameters.
 - (b) The ICAO FTF agreed that a global reporting format is required although consensus could not be reached regarding the methods to reach this goal. There was a divergence of views regarding the role that friction measurements should play for operational assessments. As a result, the option was left open for States to report the friction coefficient. The use of this option would require additional information in the State's AIP describing the approved friction-measuring system and the basic parameters associated with the ground friction measurement.
 - (c) Some airlines utilize ground friction measurements as an important input for making operational assessments of aircraft performance. It is noted though that these airlines use the friction data in an advisory role only. Also, they only include one device, and they limit their usage to data on surfaces where the readings are considered to be reliable. This leaves a gap as the current devices are not suitable for all surfaces.
- (5) In summary, many stakeholders are reluctant to accept friction-measurements as a primary information source, or as a useful information source. On the other hand, some pilots, carriers and regulators consider friction measurements from a single device family to be of significant value.
- (6) It should be noted that this situation refers to friction measurements as they are performed at present. This should not necessarily be construed to mean that friction measurements are not useful potentially.
- (7) The Joint Winter Runway Friction Measurement Program (JWRFMP) was the most extensive test program conducted to date for winter surfaces, although tests were done prior to it by NASA.
 - (a) The JWRFMP showed that the presently-available devices produced different friction numbers when operated on the same contaminated surfaces at the same time. A common reporting index was established for the devices for a limited range of surfaces (i.e., compacted snow and ice), although it contained scatter.
 - (b) The JWRFMP showed that a ground friction measurement could be related to aircraft braking performance, although the correlations contained scatter. The scatter from the JWRFMP tests was generally similar to that seen from the NASA tests.

- (c) The JWRFMP showed that there are different concerns related to the correlation, consistency and repeatability of measurements taken by different families of ground friction measurement devices, such as continuous friction measurement devices versus decelerometers.
- (8) The JWRFMP contributed greatly to the current state-of-knowledge. The results from the JWRFMP have been implemented to a limited extent in a regulatory capacity. The IRFI (International Runway Friction Index) produced during the JWRFMP has not been used widely, partly because the infra-structure for it is lacking at present.
- (9) The JWRFMP also identified serious issues with the present ground friction-measuring devices, related to (a) the limited number of surfaces on which they can provide reliable data; (b) the repeatability and reproducibility of the devices; (c) the stability of the device readings over time, etc. Until such time that these concerns are addressed, the acceptance of these devices for operational friction measurement will continue to be questioned.
- (10) It is apparent that the current friction devices available on the market are not satisfying the needs of the aircraft manufacturers, air carriers, and civil aviation authorities. Until such time that this changes, there will continue to be strong resistance to any attempt to have them relate a ground friction number to aircraft braking performance, particularly in a regulatory capacity.
- (11) There are many issues which can be categorized as follows:
 - (a) Regulatory and certification issues;
 - (b) Issues associated with the technical performance of the friction-measuring devices;
 - (c) Complexities regarding the process of friction measurements; and
 - (d) Lack of high-level performance criteria for friction-measuring devices
- (12) The available devices differ widely with respect to practically all design parameters, including the measurement principle, the tire used, and the vertical load and tire contact pressure. This leads to differing parameter dependencies among the devices and with respect to an aircraft given that (a) many processes occur in the tire contact zone and (b) they differ depending on the design of the device.

This limits the degree of correlation that can be achieved, as has been seen from the various calibration attempts that have been made to date.
- (13) Except for decelerometers, the current continuous friction-measuring devices were initially designed to assess surface friction characteristics for maintenance purposes. The attempts to date have focussed on utilizing these devices for operational use for correlation with aircraft performance on contaminated runways. Experience has shown that this approach is not producing acceptable

results for most stakeholders. For friction measurements to be useful, a fresh approach is needed starting with “first principles”, with the objective of producing a device that would correlate well with an aircraft on the full range of contaminated surfaces of concern.

- (14) A high level definition of requirements (performance specification) for a ground friction device specifically targeted for operational friction measurement would be beneficial for advancing the current state of the art. This is presently lacking and, as a result, suppliers develop improved designs using their best judgments. A high-level performance requirement would provide direction (a) to the most suitable device for correlation with an aircraft and (b) to suppliers of friction devices regarding the criteria for the device.
- (15) Research and investigation is required to develop a high-level performance specification. The performance specification should, at a minimum, address the following:
 - (a) The measurement principle, starting with the GFMD type (fixed-slip vs. variable slip vs. side force vs. locked-wheel tester, etc.). As well, the JWRFMP tests showed that different readings were produced on some surfaces (mainly loose snow) from devices that used torque measurements versus ones that used force measurements.
 - (b) The tire design (tread and ribbing, carcass design, properties, etc). Also, investigation is needed to establish whether or not an aircraft tire is required as the measurement tire.
 - (c) The vertical load on the tire, the tire inflation pressure, and the tire contact pressure – the results presented in this section suggest that a contact pressure in the range of about 750 kPa is probably required, although it is cautioned that more detailed testing is necessary.
 - (d) The slip ratio(s) and the slip speed(s) that is (are) required.
 - (e) The requirement for an anti-skid system that has similar performance to those on aircraft also needs to be investigated.

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APPENDIX A –
RECENT R&D PROJECTS RELATED TO REMOTE SURFACE CONDITION
MEASUREMENT

APPENDIX A, ANNEX 1 –
AUTOMATED SYSTEM FOR MONITORING THE CONDITION OF RUNWAY
SURFACES

(Study commissioned by Transport Canada and conducted by SPAR Aerospace)

Objective

To develop a method of rapidly conveying to aircraft pilots useful and timely information on runway condition.

Description

In this work, a prototype high-speed remote ice detection system, initially designed to inspect aircraft surfaces, was applied to runway surface monitoring. Developed by SPAR Aerospace of Brampton, Ontario, the innovative infrared spectral camera images a surface and automatically detects both the presence and thickness of ice. It was tested for operation on a vehicle moving at up to 60 km/h to measure cleared width, identify surface contamination, and determine the depth of snow, water, or ice on the runway.

The project involved three phases: surface measurement processing, camera concept development, and modifications and trials.

Results

All three phases of the project have been completed. The final phase, which included trial tests at Lester B. Pearson Airport, demonstrated the following:

- (1) Successful detection of ice and snow contamination in the day and the night at speeds greater than 70 km/h and 40 km/h respectively;
- (2) A minimum detectable ice thickness of approximately 0.5 mm;
- (3) A contamination detection range significantly exceeding 30 m in daylight, but at night limited to about 10 m for thin ice and approximately 15 m for snow;
- (4) Night ranges primarily determined by light orientations and beam widths; and
- (5) Capability of the camera to detect the transition of water to slush and finally to ice.

The testing also demonstrated that, because the surface measurement processing is lengthy, the mobile system tested is not practical for busy airports. An alternative approach would be to place a series of stationary cameras on towers adjacent to the runway. Data would be accumulated by each individual camera and sent to the maintenance facility. A stationary system would offer real-time runway inspection for contamination and improved safety due to fewer runway incursions by inspection personnel.

A concept feasibility study to consider the technical and regulatory issues affecting a stationary system was recommended.

Project Officer:

Barry B. Myers

Contractor:

SPAR Aerospace, Brampton, Ontario

Schedule: November 1996 – June 1998

Transport Canada Transportation Development Centre Project number: 9107

APPENDIX A, ANNEX 2 –
ONTARIO MINISTRY OF TRANSPORTATION EVALUATION OF TWO NEW
VAISALA SENSORS FOR ROAD SURFACE CONDITION MONITORING
(Conducted by Feng Feng, and Liping Fu of the Department of Civil & Environmental
Engineering at the University of Waterloo, Ontario. August 2008)

REPORT REVIEW

Short Project Description

The roadside installation based project investigated the potential for using pole mounted road surface sensors for measuring surface contaminate conditions and estimating tire-surface friction using an empirical model.

Project Summation

The project evaluated the performance of a Vaisala Remote Road Surface State Sensor designated DSC111 and a Vaisala Remote Road Surface Temperature Sensor designated DST111 and the accuracy of the sensors compared to an in-surface Lufft IRS-20 sensor for temperature and presence of contaminants, visual observations for contaminant state and a Traction Watcher One (TWO) friction measurement device for derived μ .

The DSC111 is an active near-infrared band ($\sim 1 \mu\text{m}$) remote sensor which sends infrared light beams to the road surface and detects the backscattered signals at selected wavelengths to differentiate surface contaminants and measure depth. Surface state determination includes dry, moist, wet, icy, snowy/frosty, or slushy.

The following data are reported:

- (1) Pavement states: dry, wet (thin water layer), slushy (thick water layer, no ice or snow), snow or frost (white ice), ice (black ice);
- (2) Pavement contaminant depth in equivalent liquid water amount (in mm); and
- (3) Estimated surface grip level (0.01-1.00).

The DST111 is an infrared temperature sensor which measures the difference of long wave infrared radiation between the sensor instrument itself and the road surface to a claimed accuracy of 0.3 °C.

The following data are reported:

- (1) Pavement surface temperature in °C;
- (2) Air temperature in °C;
- (3) Dew point temperature in °C; and
- (4) Relative humidity in percentage.



Figure A2-1: DSC 11 (Spectro Sensor)



Figure A2-2: DST111 (Cyclo Sensor)

The sensors were installed on a pole at the roadside vertically 8.3 m over the road monitoring a 20 cm-diametered road surface area near the right wheel track of the lane and video cameras were used to record surface conditions.

Data was collected during four winter storms in 2007 and 2008 on a newly surfaced road section. Significant calibration was required prior to data collection.

Achievements

There was sufficient data collected to determine conclusions.

Observations

- (1) The DST111 reported different surface temperatures from those reported by the IRS-20 sensor but the reported values correlated. The differences were either positive or negative, depending upon surface temperature. Differences did not exceed 2°C and diminished as the surface temperature approached 0°C.
- (2) Surface conditions as reported by the DSC111 correlated well with interpretations from the video camera images but in some cases the DSC111 reported a lower level of severity. The project team concluded that is was due to the small monitoring patch and temporary high variations in road conditions during the storms.
- (3) Correlation between the DSC111 reported 'grip level' and μ as measured with a TWO device was poor although there was limited data available from the TWO device.

Conclusions

- (1) Sensor mounting position at 8.3 m above the monitored surface is impractical for use in monitoring the surface conditions of aircraft movement surfaces.
- (2) The sensing technology employed in the DSC111 holds potential for accurate sensing of runway conditions and possible inclusion in a measured condition reporting system.

- (3) As with other conditions sensors, the ability to sense surface conditions over a wide path must be realized before practical application on aircraft movement surfaces can be realized. This may possibly be accomplished either by broadening the target area or by using multiple sensing instances.
- (4) The Vaisala DST111 temperature sensor performed well, especially in the critical 'near 0°C' range but improved calibration would be desirable if the device were to be used as part of a runway surface condition reporting system.

APPENDIX A, ANNEX 3 –
INFORMATION SOCIETY TECHNOLOGIES (IST) (FINLAND) PROGRAM
(European Union Project “Fricti@n” Final Report FP6-IST-2004-4 – 027006)

FINAL REPORT REVIEW

Short Project Description

The road going vehicle oriented project investigated the potential for using vehicle on-board systems for estimating tire-road friction and using the determined values to enhance the performance of vehicle integrated and safety cooperative systems.

Project Summation

The project focused on developing, demonstrating and verifying a real-time, tire-road friction sensing process that would assist in compensating for the average driver's inability to accurately assess adverse road conditions and correctly manage vehicle handling on contaminated surfaces. Dry, wet, snow, and ice surfaces were included in the study.

The project consisted of building the friction estimation mathematical model, determining the required sensor inputs, building and testing the system and integrating the system with other vehicle safety systems, either existing or under development. Chassis based input sensors included xyz axis acceleration, steering wheel angle, etc. Environmental sensors included ambient and surface temperature, laser spectroscopy, and radar. A previously developed tire deformation sensor was also employed. The vehicle chassis test beds were a sub-compact hatchback, a mid-sized development platform station wagon and a commercial truck.

Achievements

Project goals were achieved as follows:

- (1) Within the test parameters, there was a near continuous estimation of friction potential in changing road conditions.
- (2) New sensing technology was developed to detect and differentiate ice, snow and water.
- (3) The developed sub-system was successfully integrated with existing collision mitigation and other safety enhancing vehicle systems with improved performance of anti-lock braking and traction control systems.

Observations

- (1) While there is extensive use of both added and original equipment on-board sensors and advanced integration of data with other sources such as environmental and external data to determine current conditions, the system as a whole requires predictive mechanisms to adjust vehicle performance. In essence the system calculates the probability that conditions are going to be similar or worse in the immediate future than they currently are as the vehicle moves forward and adjusts vehicle safety system responses accordingly.

- (2) The Fricti@on project has sought out and employed COTS (common-of-the-shelf) and state-of-the art sensors of a wide variety. Integration of these technologies with intelligent and learning software has yielded remarkable sensing capabilities such as determining the density of falling snow, the presence of thin (.5 mm) layers of ice in front of the vehicle and lack of tire sidewall deformation (expected when cornering without slip). The development and in some cases, evolution of these technologies could aid in the challenge of determining the state of runway contamination but adaptation would be required.
- (3) While the Fricti@n project is focused on aiding a driver and or vehicle safety system(s) in dealing with adverse surface conditions by sensing the conditions in close proximity and providing warnings and or adjustments to handling, the challenge with runway condition surveying is different. The runway must be surveyed over a much wider path to determine the specific conditions of the contaminants with the information categorized and transmitted for use in aircraft manoeuvring calculations. To employ the discussed systems in their current configuration in runway surveying would require multiple vehicle runs that would consume runway occupancy time to an unacceptable point.
- (4) However, many of the sensing technologies are fundamentally capable of sensing conditions across a wide path from a vehicle and could quite possibly be adapted to the task:
 - (a) Laser scanning – precipitation particle size and rate;
 - (b) Laser and infrared spectroscopy – surface contaminant density;
 - (c) Stereo camera measurement of contaminant polarization (reflectivity and granularity);
 - (d) Radar – contaminant detection and distribution;
 - (e) Tire deformation – slip; and
 - (f) Ambient and surface temperature sensors – contaminant properties and potential change.

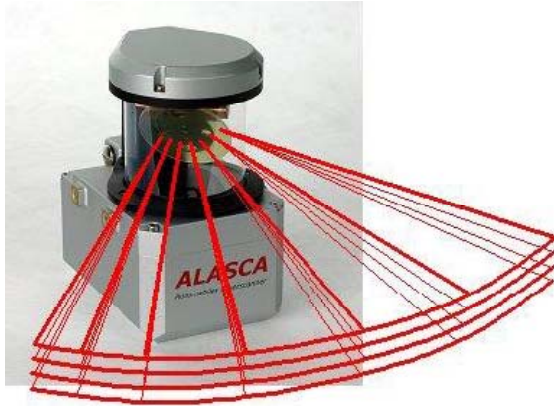


Figure A3- 1: Laserscanner ALASCA with Schematic Drawing of 4-Layer Laser Beam



Figure A3- 2: Road Eye sensor

The dimensions of casing are
51*53*45 mm

- (5) Even without concern for measurement of runway/tire μ , new (and probably simpler) analytical algorithms could be written to interpret sensed data as contaminant density, deposition rate, depth and distribution. The major challenge would be sensor range with a close second being processing power for real-time reporting at reasonable speed.
- (6) Data from these vehicle based systems could be integrated with stationary runway surveying systems employing “Optical, acoustic, ultrasonic and radio frequency based environmental sensors for changes in the reflectance, polarization and absorption properties of the road [runway] surface” as is discussed for highway application. Current runway sensors that detect presence of chemical, moisture, liquid and temperature could further enhance a database that would feed contaminant confirmation algorithms.
- (7) Derived “friction” was validated using distance over time deceleration/acceleration calculations.
- (8) The system cannot at present derive ‘friction’ during constant velocity straight line driving.

Conclusions

The study aspired to determine friction between tire and surface by combining inputs from various sensors and using ‘learning’ software and demonstrate the usefulness of such technology by enhancing the performance of vehicle safety systems. These objects were achieved and demonstrated. The available friction estimation process maintained a correct value with an approximate error of 0.15 in normal driving.

The study demonstrated that refining and integrating various sensing technologies could accurately and repeatedly sense and differentiate surface contaminants. Adaptation to the runway environment seems entirely possible and would significantly enhance the condition reporting process with increased accuracy by replacing estimation of contaminant type, depth and distribution with measurement. These technologies hold real potential for enhancing runway condition.

The study objective of providing a ‘friction’ value input to vehicle warning and control systems was achieved within the boundaries of the study; but it appears that the process of ‘measuring’ friction, when defined as the outcome of the project work, would be of little use as a deliverable to pilots as a measurement of tire/runway μ at present. There does however appear to be significant potential for adapting the technology to give a μ output that corresponds to that provided by airport CFMEs today.

APPENDIX A, ANNEX 4 –
NASA FORWARD-LOOKING INTERFEROMETER REPORT SYNOPSIS FROM NASA
WEBSITE

Title:	Applications of a Forward-Looking Interferometer for the On-board Detection of Aviation Weather Hazards
Author(s):	West, Leanne; Gimmetstad, Gary; Smith, William; Kireev, Stanislav; Cornman, Larry B.; Schaffner, Philip R.; Tsoucalas, George
Abstract:	The Forward-Looking Interferometer (FLI) is a new instrument concept for obtaining measurements of potential weather hazards to alert flight crews. The FLI concept is based on high-resolution Infrared (IR) Fourier Transform Spectrometry (FTS) technologies that have been developed for satellite remote sensing, and which have also been applied to the detection of aerosols and gases for other purposes. It is being evaluated for multiple hazards including clear air turbulence (CAT), volcanic ash, wake vortices, low slant range visibility, dry wind shear, and icing, during all phases of flight. Previous sensitivity and characterization studies addressed the phenomenology that supports detection and mitigation by the FLI. Techniques for determining the range, and hence warning time, were demonstrated for several of the hazards, and a table of research instrument parameters was developed for investigating all of the hazards discussed above. This work supports the feasibility of detecting multiple hazards with an FLI multi-hazard airborne sensor, and for producing enhanced IR images in reduced visibility conditions; however, further research must be performed to develop a means to estimate the intensities of the hazards posed to an aircraft and to develop robust algorithms to relate sensor measurables to hazard levels. In addition, validation tests need to be performed with a prototype system.
NASA Center:	Langley Research Center
Publication Date:	October 2008
Document Source:	CASI
Document ID:	20080045836
Publication Information:	Number of Pages = 107
Report Number:	L-19522; NASA/TP-2008-215536
Contract-Grant-Task Number:	WBS 609866.02.07.07.04

On-line reference:

<http://naca.larc.nasa.gov/search.jsp?R=577138&id=7&as=false&ts=false&q=No%3D30%26Ns%3DHarvestDate%257c1%26N%3D4294714880>

APPENDIX A, ANNEX 5 –
UK CAA/VESTABILL LTD. CONTRACT NO: 1141 TO DEVELOP MEASUREMENTS
OF BRAKING ACTION ON RUNWAYS CONTAMINATED WITH WATER, WET
SNOW, OR SLUSH
(May 2006)

Objectives

- (1)to demonstrate the feasibility of using the ESDU methods to formulate a correlation between a proposed modified Mu-meter and aircraft ...
- (2)to demonstrate the effects of runway drainage times on braking action. This study is germane to the next objective....
- (3)to study the database constructed for Transport Canada for the International Reference Vehicle on snow and ice. To augment these data with information from NASA Technical Report 2917 pertaining to aircraft and ground-vehicle operations on wet, flooded, ice-covered and snow-covered runways.
- (4)with the agreement of Douglas Engineering, to formalize the reporting of the trials partly funded by the CAA.
- (5)to develop a “top level” specification for a generic ground vehicle that is capable to deliver appropriate data to aircraft and airfield operators concerning conditions on contaminated runways.

Summary – Mu-meter Development Analysis of Experiments in Water and Snow

- (1) A set of experiments conducted on the Straight-line Wet Grip track at the Motor Industry Research Association’s (MIRA) facility is analyzed to show that it is possible to use the Mu-meter to measure the depth of water on a runway.
- (2) Measurements of the forces generated by impact of fluid on the third wheel have been shown to correlate with kinetic pressure and water depth. By inverting this correlation, water depth can, therefore, be inferred from force measurements.
- (3) This particular form of correlation is valid only for fluids. In a series of tests run on the United States Naval Air Station at Keflavik the modified version of a Mu-meter Mk6 has been used to show that it is feasible to infer snow properties from measurements of the decelerating force on the third (stabilizing) wheel.
- (4) Depth of snow cover has been deduced from measured forces and specific gravity of freshly fallen snow. These deduced values compare well with direct measurements.
- (5) In the light of these preliminary findings, it is concluded that a production version of the modified installation is a realistic proposition.

Conclusions – Mu-meter Development Analysis of Experiments in Water and Snow

- (1) There is no statistically significant difference between snow depth as deduced from the Mu-meter and that measured directly with a ruler.
- (2) In an operational context, a modified Mu-meter is, therefore, usable as a predictor of snow properties given an estimate of depth.

- (3) The device can be used to separate the effects of decelerating force due to contaminant “drag” and that due to braking friction in the event that operations are required to continue on a marginally contaminated runway.
- (4) In the light of these conclusions, there seems to be no reason to delay the engineering of a production item.

Vestibill Report Recommendations – Mu-meter Development Analysis of Experiments in Water and Snow

- (1)that the data collected on the airbase at Keflavik be studied in greater detail. Such a study is needed to define the software necessary for inclusion in a production version. It will also help to consolidate the information collected in other contaminants and so enable the construction of a viable mathematical model of the (modified) Mu-meter.

APPENDIX B –
SNOWMETRIX BROCHURE

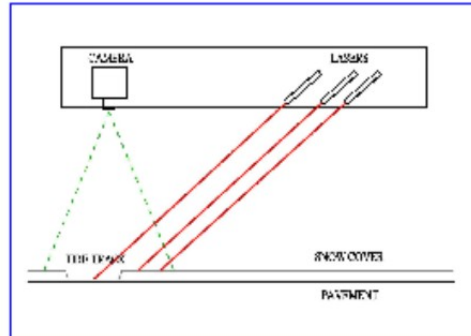


SnoMetric™

NEW SNOW DEPTH PROFILING TECHNOLOGY

SnoMetric™ is a rugged instrument system designed and manufactured by Tradewind Scientific Ltd. for mobile surveying of pavement surfaces. The system is configured to measure the depth profiles of runway and road contaminants, such as snow and slush, over long distances.

The design of the instrument is based on proprietary (*patent pending*) optical technology. It allows operation and high-speed data acquisition under harsh weather conditions as well as real time (wireless) transmission and display of the results.



Specifications

Power Requirements: USB

Data Acquisition and Control: USB PC and/or Wireless PDA

Power Consumption: less than 5W

Depth Resolution: better than 1mm (0.04")

Measurement Accuracy: better than 2mm (0.08")

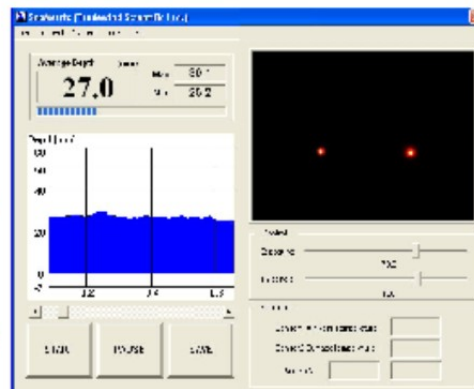
Sampling: up to 12 measurements per second

Measurement range: 0 – 100 mm (0 – 4 inches)

Operating Temperature: -30° C to 40° C
(-20° F to 100° F)

Dimensions: approx. 90 x 15 x 15 cm (36 x 6 x 6")

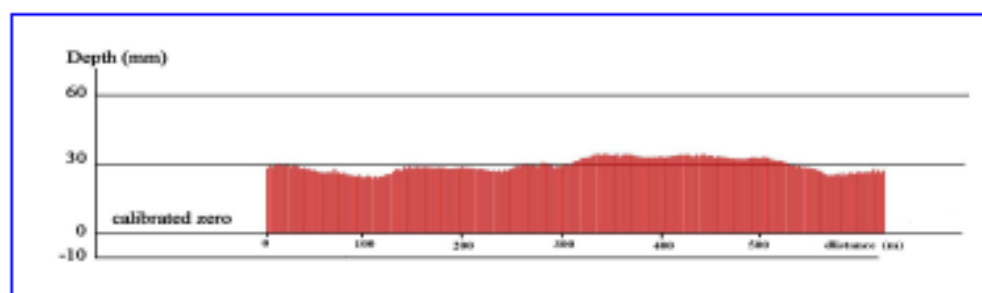
Weight: 7 kg (15 lbs)



Airfield snow condition reporting is one of the primary applications of the *SnoMetrix™* profiling system. Accurate knowledge of the actual runway and taxiway surface conditions is vital for airport operations. Take off and landing procedures depend strongly on the type and depth of surface contaminants. Current manual snow depth measurement methods are inconvenient, inaccurate and time consuming especially when average values are needed.



The *SnoMetrix™* system can be easily attached to any surveying vehicle and driven over the pavements of interest under a wide range of weather and day or night conditions. Measurements are recorded every few meters (dependent on the speed of the vehicle) then averaged and displayed on the operator's screen in real time. Furthermore, a profile of the whole surveyed path can be displayed, as shown in the sample graph. While fully functional as a stand-alone unit, *SnoMetrix™* can also be integrated with Tradewind Scientific Ltd's TRACR II® airfield condition reporting system.



Ordering Information

The *SnoMetrix™* System is available in two configurations: Standard, Part # TSM910 and Wireless, Part # TSM920

For detailed specifications and quoting please contact:

Tradewind Scientific Ltd.
1280 Merivale Rd., Suite 201
Ottawa, ON, K2G 4B5
(613) 238-1246
(613) 832-2721 facsimile
support@tradewindscientific.com
www.TradewindScientific.com

Visible light emitting lasers are used in the *SnoMetrix™* system for depth sensing. These are low-powered lasers, similar to those used in laser pointers. For safety reasons, a warning label is attached (Laser Class IIIa).
FDA Accession #: 0411571-00

