



European Aviation Safety Agency

Research Project EASA.2008/4

RuFAB - Runway friction characteristics measurement and aircraft braking

Volume 2

Documentation and Taxonomy

Disclaimer

This study has been carried out for the European Aviation Safety Agency by an external organization and expresses the opinion of the organization undertaking the study. It is provided for information purposes only and the views expressed in the study have not been adopted, endorsed or in any way approved by the European Aviation Safety Agency. Consequently it should not be relied upon as a statement, as any form of warranty, representation, undertaking, contractual, or other commitment binding in law upon the European Aviation Safety Agency.

Ownership of all copyright and other intellectual property rights in this material including any documentation, data and technical information, remains vested to the European Aviation Safety Agency. All logo, copyrights, trademarks, and registered trademarks that may be contained within are the property of their respective owners.

Reproduction of this study, in whole or in part, is permitted under the condition that the full body of this Disclaimer remains clearly and visibly affixed at all times with such reproduced part.

RUNWAY FRICTION CHARACTERISTICS MEASUREMENT
AND AIRCRAFT BRAKING (RuFAB)

FINAL REPORT
VOLUME 2 – DOCUMENTATION AND TAXONOMY

Submitted in response to
Contract: EASA.2008.C46

March 2010

Submitted to:

Mr. Werner Kleine-Beek
Research Project Manager
Safety Analysis and Research Department
Executive Directorate
European Aviation Safety Agency (EASA)
Ottoplatz 1
D-50679 Cologne
Germany

Submitted by:

BMT FLEET TECHNOLOGY LIMITED
311 Legget Drive
Kanata, ON
K2K 1Z8

BMT Contact: George Comfort
Tel: 613-592-2830, Ext. 226
Fax: 613-592-4950
Email: GComfort@fleetechnology.com

BMT DOCUMENT QUALITY CONTROL DATA SHEET

REPORT: Runway Friction Characteristics Measurement and Aircraft Braking (RuFAB): Volume 2 – Documentation and Taxonomy

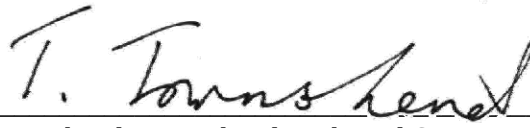
DATE: March 2010

PREPARED BY:


George Comfort, Group Leader, Cold Regions and Materials Technology, BMT Fleet Technology Ltd.



Dr. Zoltan Rado, Pennsylvania State University, State College, PA, USA



Terry Townshend, Townshend Technical Services, Bolton, ON, Canada


A. Mazur, BMT Fleet Technology Limited

REVIEWED BY:


Razek Abdelnour, Ing, Senior Consultant

APPROVED BY:


George Comfort, BMT Fleet Technology Ltd.

ACRONYMS AND ABBREVIATIONS

AC	Advisory Circular
AIP	Aeronautical Information Publication
AIM	Aeronautical Information Manual
AIMSG	Aeronautical Information Management Study Group
AIS	Aeronautical Information Service
AMSCR	Aircraft Movement Surface Condition Report
ASC	Aerodrome Safety Circular
ASTM	American Society for Testing and Materials
BAA	British Aviation Authority
BV 11	Swedish Friction Measuring Device
CAA	Civil Aviation Authority
CFME	Continuous Friction Measuring Equipment
COF	Coefficient Of Friction
DGAC	Direction Generale de l'Aviation Civile
DOL	Design Objective Level
EAD	EUROCONTROL Aeronautical Database
EASA	European Aviation Safety Agency
ECCAIRS	European Coordination Centre for Accident Incident Reporting Systems
ERD	Electronic Recording Decelerometer
FAA	Federal Aviation Administration
FTF	Friction Task Force
GT	GripTester
ICAO	International Civil Aviation Organization
IFI	International Friction Index
IRFI	International Runway Friction Index
JWRFMP	Joint Winter Runway Friction Measurement Program
MAL	Maintenance Action Level
MFL	Minimum Friction Level
MPL	Maintenance Planning Level
MTD	Mean Texture Depth
MUM	Mu-meter
NAA	National Airport Authority
NASA	National Aeronautics and Space Administration
NCAA	Norwegian Civil Aviation Administration
NLR	National Aerospace Laboratory
PIREP	Pilot REPort
PSC	Project Steering Committee
RCR	Runway Condition Reporting
RFT	Runway Friction Tester
RUN	Runar
SAFO	Safety Alert for Operations
SFH	Surface Friction tester high pressure tire
SFL	Surface Friction tester low pressure tire
SFT	Surface Friction Tester
SKH	Skiddometer

STAC-ACE	French acronym for STAC – ACE (Service Technique de l'Aviation Civile)
STBA	French acronym for the French Civil Aviation Administration
TALPA ARC	Takeoff And Landing Performance Assessment Aviation Rulemaking Committee
TAP	Tapley Meter
TC	Transport Canada
UK CAA	United Kingdom Civil Aviation Administration
VIN	Vertec Inspector

TABLE OF CONTENTS

ACKNOWLEDGEMENTS.....	x
EXECUTIVE SUMMARY	xi
1 INTRODUCTION AND OBJECTIVES	1
1.1 Introduction	1
1.1.1 Background	1
1.1.2 Seasonal Distinctions, Terminology and Reporting Practices	3
1.2 Project Scope and Objectives.....	3
1.3 Volume 2	4
1.3.1 Content of Volume 2	4
1.3.2 Notice Regarding Definition of Depth.....	4
2 INFORMATION-GATHERING: SCOPE AND TECHNICAL APPROACH	5
2.1 Contacts Made and Information Received	5
2.1.1 Questionnaires.....	5
2.1.2 Questionnaire Distribution and Responses Received	5
2.2 References Reviewed	7
3 INVENTORY OF REFERENCE DOCUMENTS	17
3.1 Objectives.....	17
3.2 Approach Used for Archival	17
3.3 Potential Platforms and Distribution Methods for the Archived References.....	17
4 OTHER INITIATIVES	20
4.1 Takeoff and Landing Performance Assessment Aviation Rulemaking Committee.....	20
4.1.1 Introduction.....	20
4.1.2 Direction from the Project Steering Committee.....	22
4.1.3 Relative Priorities of the Information Used for the TALPA ARC Table ...	22
4.1.4 Runway Surface Condition Classification and Conclusions Indicated by TALPA ARC.....	22
4.1.5 Concluding Comments Regarding the TALPA ARC System	25
4.2 ICAO Friction Task Force	25
4.3 French DGAC/STAC Study.....	27
4.3.1 General Objectives and Approach	27
4.3.2 General Scope	27
4.3.3 Summary Results from Air Traffic Control.....	28
4.3.4 Summary Results from Airport Operators	29
5 Information-Gathering Results	30
5.1 Operational Friction Characteristics: Air Carriers	30
5.1.1 The Contaminants Encountered During Operations	30
5.1.2 Relative Value of Various Types of Information for “Summer” Conditions	30
5.1.2.1 Friction Readings, Braking Action Indications or PIREPs	30
5.1.2.2 Descriptions of the Runway Surface Condition	31
5.1.3 Relative Value of Various Types of Information for “Winter” Conditions	32
5.1.3.1 Friction Readings, Braking Action Indications or PIREPs	32
5.1.3.2 Descriptions of the Runway Surface Condition	33
5.1.4 Most Significant Contaminants.....	34

5.1.5	Comparisons of Survey Results: Non-Winter vs. Winter Contaminants	35
5.1.6	The Methods Used to Establish Operational Data Regarding Aircraft Performance	35
5.2	Operational Friction Characteristics: Aircraft Manufacturers	35
5.2.1	Non-Winter (Wet) Contaminants	36
5.2.2	Winter (Ice, Snow and Slush) Contaminants	36
5.2.3	Additional Information regarding Aircraft Performance on Contaminated Runways	37
5.3	Operational Friction Characteristics: Airports	38
5.3.1	The Parameters That Are Measured or Estimated	38
5.3.1.1	Summer Conditions	38
5.3.1.2	Winter Conditions	40
5.3.2	Relative Priorities for the Information Collected	41
5.3.2.1	Summer Conditions	41
5.3.2.2	Winter Conditions	41
5.4	Overview of the Information That is Reported to Pilots	44
5.4.1	Friction Readings and General Indications of Braking Action	44
5.4.2	Descriptions of the Runway Surface Condition	46
6	RELEVANT ICAO DOCUMENTS AND ICAO DEFINITIONS	49
6.1	Relevant ICAO Documents	49
6.2	Relevant ICAO Definitions	49
6.3	Gaps or Discrepancies	52
6.3.1	Contaminant Types	52
6.3.2	Contaminant Types Not Included	53
7	COMPARISON OF DEFINITIONS	54
7.1	Summer Contaminants	54
7.1.1	Definitions of Contaminant and Contaminated Runways	54
7.1.2	Definitions Related to Water on the Runway	56
7.1.3	Comparison of Definitions for “Summer” Conditions	56
7.2	Winter Contaminants	58
7.2.1	Definitions of Contaminant and Contaminated Runways	58
7.2.2	Definitions Related to Snow, Slush and Ice on the Runway	60
7.2.3	Comparison of Definitions for Winter Contaminants	64
7.3	Definitions and Classifications for Aviation Incident and Accident Reporting	66
8	RUNWAY CONDITION REPORTING PRACTICES	67
8.1	Operational Friction Characteristics: Reporting of Friction Measurements and Braking Action	67
8.1.1	Reporting for Summer Contaminants	67
8.1.2	Friction Measurement Devices for Operational Purposes	68
8.1.3	Limitations Regarding the Reliability of Friction Measurements	70
8.2	Operational Friction Characteristics: Reporting of Surface Conditions	71
8.2.1	General Information: Forms and Formats for Runway Surface Descriptions	71
8.2.2	Forms and Formats Used for Runway Surface Description	71
8.2.3	Summary Comparisons: Runway Surface Description	72
9	FUNCTIONAL FRICTION CHARACTERISTICS	74
9.1	Criteria Used by ICAO and Various Civil Aviation Authorities	74
9.1.1	Information Sources	74

9.1.2	General Comments.....	74
9.1.3	Comparisons.....	74
9.1.3.1	General Basis.....	80
9.1.3.2	Number of Devices Accepted.....	80
9.1.3.3	Other Criteria for Runways Based on Texture and Pavement Characteristics.....	80
9.1.3.4	Test Parameters: Testing at One versus Two Speeds	82
9.1.3.5	Test Parameters: Water Film Depth	82
9.1.3.6	Test Parameters: Tire Types and Pressure.....	83
9.2	Information Obtained from Airports from the Questionnaires	83
10	METHODS FOR HARMONIZING DIFFERENT TAXONOMIES.....	84
10.1	Issues Related to Harmonization.....	84
10.2	Introduction and Contexts for Reporting	85
10.2.1	Contexts for Runway Surface Condition Reporting	85
10.2.2	RCR in the Context of Functional Friction	85
10.2.3	RCR in the Context of Operational Friction	86
10.3	Potential Methods for Harmonization and Assessments of Their Feasibility	87
10.3.1	General Objectives	87
10.3.2	General Options	88
10.3.3	Taxonomies for Aviation Accident and Incident Investigations	88
10.3.4	Harmonization Strategy Based on Relationships to Aircraft Performance.....	89
10.4	Fundamental Definitions: Contaminant and Runway Condition Categories.....	89
10.4.1	Runway Condition Categories	89
10.4.2	Similarities and Differences Among the Various Definitions	92
10.4.2.1	Runway Condition Categories.....	92
10.4.2.2	Contaminated Runway.....	93
10.4.2.3	Wet Runway	94
10.4.2.4	Dry Runway.....	94
10.5	Surface Condition Definitions for Runways With Water on Them.....	94
10.5.1	Damp Conditions	94
10.5.2	Wet Conditions	95
10.5.3	Flooded or Standing Water	95
10.6	Surface Condition Definitions for Runways with Winter Contaminants.....	96
10.6.1	Introduction and General Comments	96
10.6.2	Loose and Liquid Contaminants	97
10.6.3	Solid Contaminants Such as Frost, Ice or Compacted Snow	97
10.6.4	Layered Contaminants	98
10.6.5	Other Contaminants	98
10.7	Reporting Formats for Operational Friction Applications.....	99
10.7.1	General Requirements for Operational Descriptions of the Runway Surface	99
10.7.2	Contaminant Types	100
10.7.3	Scales of Braking Action vs. Friction Coefficient	101
10.8	Reporting Formats for Functional Friction Applications.....	101
10.8.1	Functional Friction Characteristics	101
10.8.2	Basis for Functional Criteria	102
10.8.3	Overlap With Operational Requirements: “Slippery When Wet”	102
10.8.4	Other Variations.....	102
11	CONCLUSIONS	103

11.1	General Conclusions and Basis for Harmonization	103
11.2	Operational Friction: Runway Classifications and Significant Parameters	103
11.3	Operational Friction: Detailed Taxonomies and Reporting Formats	107
11.4	Preliminary Recommendation for a Harmonized Format	109
11.5	Functional Friction Assessments	111
12	REFERENCES	112

APPENDIX A – BLANK QUESTIONNAIRES

Appendix A, Annex 1 – Functional Friction Characteristics (Sent to Civil Aviation Authorities and Airports)

Appendix A, Annex 2 – Operational Friction Characteristics (Sent to Civil Aviation Authorities and Airports)

Appendix A, Annex 3 – Operational Friction Characteristics (Sent To Air Carriers And Aircraft Manufacturers)

Appendix A, Annex 4 – Email with Follow-Up Questions

APPENDIX B – LITERATURE REVIEW OF RUNWAY FRICTION STANDARDS

Appendix B, Annex 1 – Survey of Civil Aviation Authorities

Appendix B, Annex 2 – Literature Review of Runway Friction Standards

Appendix B, Annex 3 – Runway Friction Standards for the Former Yugoslavia (taken from their AIP)

APPENDIX C – LITERATURE REVIEW OF PERFORMANCE SPECIFICATIONS, CORRELATION METHODS, AND CORRELATION TRIALS

Appendix C, Annex 1 – Literature Review of CFME Performance Specifications

APPENDIX D – RUNWAY CONDITION REPORTING FORMS AND FORMATS

LIST OF FIGURES

Figure 3.1: General Directory Structure	18
Figure 3.2: User Interface for Navigating the Directory Structure for the References.....	19
Figure 4.1: TALPA ARC Paved Runway Assessment Table (Ostronic, 2009)	21
Figure 5.1: Aircraft Braking Coefficients on Contaminated Runways (ref: Avinor)	37
Figure 5.2: Aircraft Braking Coefficients on Contaminated Runways (ref: Avinor)	38
Figure 5.3: Braking Action Scale in ICAO Annex 14, Volume 1 (ICAO, 2004).....	44
Figure 5.4: ICAO SNOWTAM Format	47
Figure 5.5: Transport Canada AMSCR Form.....	48
Figure 6.1: Contaminant Types Listed in the ICAO SNOWTAM	52
Figure 9.1: Changes to Norwegian Regulations (G. Lange, Avinor, pers. comm'n)	81
Figure 10.1: RCR in the Context of Functional Friction	86
Figure 10.2: RCR in the Context of Operational Friction.....	87

LIST OF TABLES

Table Ex 1:	General Contexts for Runway Surface Condition Reporting.....	xii
Table 1.1:	General Contexts for Runway Surface Condition Reporting	1
Table 1.2:	Definitions for Functional and Operational Friction Assessments.....	2
Table 2.1:	Questionnaire Distribution and Quantity of Responses Received	6
Table 2.2:	Partial Listing of References and Information Reviewed	8
Table 2.3:	Reports Reviewed Regarding Runway Friction Standards	11
Table 2.4:	Literature Review of CFME Performance Specifications.....	12
Table 2.5:	Literature Review of CFME Correlation Methods.....	13
Table 2.6:	Correlation Trials of Continuous Friction-Measuring Equipment	14
Table 2.7:	Reports from the Joint Winter Runway Friction Measurement Program.....	15
Table 2.8:	Methods for Remotely Measuring the Surface Condition.....	16
Table 4.1:	Equivalent Runway Surface Conditions Based on TALPA ARC.....	23
Table 5.1:	Contaminants Encountered.....	30
Table 5.2:	Friction or Braking Action Information for Summer Conditions	31
Table 5.3:	Runway Surface Condition Information for Summer Conditions.....	32
Table 5.4:	Friction or Braking Action Information for Winter Conditions	33
Table 5.5:	Runway Surface Condition Information for Winter Conditions	33
Table 5.6:	Most Significant Contaminants and Other Comments.....	34
Table 5.7:	Parameters that Are Measured or Estimated for Operational Purposes	39
Table 5.8:	Parameters That Are Measured or Estimated for Operational Purposes	40
Table 5.9:	Information Requested by Pilots for Summer Conditions	42
Table 5.10:	Information Requested by Pilots for Winter Conditions	43
Table 5.11:	Type of Friction Information or Braking Action Reported to Pilots.....	45
Table 6.1:	Summary of Relevant ICAO Documents	49
Table 7.1:	Comparison of Definitions Regarding Summer Contaminants.....	57
Table 7.2:	Comparison of Definitions Regarding Winter Contaminants	61
Table 7.3:	Comparison of Definitions Regarding Winter Contaminants	63
Table 7.4:	ICAO Classifications for Aviation Incident and Accident Investigations	66
Table 8.1:	Limitations Regarding the Reliability of Friction Measurements.....	70
Table 8.2:	Forms and Formats Used for Runway Surface Description	72
Table 8.3:	Specified Accuracies for Contaminant Depth Measurements.....	73
Table 9.1:	Runway Friction Criteria: Design Objective Level.....	75
Table 9.2:	Runway Friction Criteria: Maintenance Planning Level.....	76
Table 9.3:	Runway Friction Criteria: Maintenance Action Level	77
Table 9.4:	Runway Friction Criteria Specified in ICAO Annex 14, Volume 1	78
Table 9.5:	French Maintenance Action Criteria (STBA Journal 159 – 2006 Annex 1)	78
Table 9.6:	Runway Friction Levels Specified in FAA AC 150/5320-12C (FAA, 2008).....	79
Table 9.7:	Runway Friction Levels Specified in the Yugoslavian AIP.....	79
Table 9.8:	Information Obtained From Questionnaires.....	83
Table 10.1:	General Contexts for Runway Surface Condition Reporting	85
Table 10.2:	Required Elements of an Operational Description of the Runway Surface	100
Table 10.3:	Contaminant Types in the ICAO SNOWTAM Form.....	101
Table 11.1:	Preliminary Listing of Recommended Definitions.....	110

ACKNOWLEDGEMENTS

Werner Kleine-Beek of EASA was the Project Officer. He is thanked for his efforts throughout to administer and facilitate the work.

The contributions of the Project Steering Committee (listed below) are acknowledged as well. Their contributions included attending project meetings, providing guidance regarding the approach(es) for the project, providing information and references, reviewing the questionnaires that were sent out, and facilitating contacts.

Jean Baril, EASA;
Rachel Daeschler, EASA;
Xavier Vergez, EASA;
Chris Gash, CAA-UK;
John Matthews, EASA;
Herbert Meyer, EASA;
Ivan-David Nicolas, EASA;
Armann Norheim, Avinor (Norway);
Jerry Ostronic, FAA (USA);
Vincenzo Pennetta, EASA;
Francis Richards, Eurocontrol;
Maria Algar Ruiz, EASA;
Filippo Tomasello, EASA; and
François Watrin, DGAC-France.

Acknowledgements are made to various members of the Project Steering Committee for providing advance information regarding various ongoing initiatives as follows:

Jerry Ostronic, for information regarding the TALPA ARC recommendations;
François Watrin, for information regarding the French DGAC study; and
Armann Norheim, for information regarding the ICAO FTF.

Acknowledgements are also made to the various individuals and organizations who responded to the questionnaires which were sent out as part of the project. Although they cannot be named (to maintain their anonymity), their support is collectively acknowledged.

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 2 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 for clarity, all recommendations are presented in Volume 1.

Scope for Volume 2: Documentation and Taxonomy

The work included the following general tasks:

- (a) Extensive information-gathering was done to establish the current state-of-practice.
- (b) The relevant ICAO documents were reviewed and compared.

- (c) Detailed lists were produced and comparisons were made regarding the definitions and taxonomies used at present.
- (d) An inventory of the main reference documents was produced.
- (e) Current trends within the aviation community were identified.
- (f) Assessments were made regarding the feasibility of potential methods for harmonizing the taxonomies used, and recommendations were made regarding the preferred approach.

General Contexts for Runway Condition Reporting

RCR is undertaken in various contexts and conditions as summarized in the table below.

Table Ex 1: General Contexts for Runway Surface Condition Reporting

Type of Contaminants	Functional Friction Assessment ³	Operational Friction Assessment ⁴
Summer ² (e.g., wet)		not done in practice, except for evaluations of “slippery when wet”
Winter ¹ (snow, slush, ice, etc)	not done in practice	

Notes:

1. “Winter” - this refers to conditions or contaminants for below-freezing situations. The types of contaminants to be encountered in “winter” conditions include ice, wet ice, all types of snow, slush, frost in all forms, and de-icing chemical residues.
2. “Summer” - this refers to conditions or contaminants for above-freezing situations, and is often termed “wet” in the literature. The types of “summer” contaminants or conditions include damp, wet, flooded, standing water, dirt, and rubber buildup.
3. Functional friction measurements are mainly intended for planning and undertaking runway pavement maintenance, and for setting criteria for the design of new pavements.
4. Operational friction measurements relate to operations on contaminated surfaces, such as aircraft operations or manoeuvres, including possible actions by the aerodrome such as the closure of a runway

Information-Gathering

Information-gathering was done by: (i) conducting surveys using questionnaires that were sent to many airports, airlines, aircraft manufacturers and national civil aviation authorities; (ii) personal contacts; and (iii) an extensive literature review.

Other Current Initiatives

A number of initiatives are currently ongoing that are relevant to this project, and initial information was received regarding them. Because reports or technical documentation are not available at present regarding them, the conclusions and recommendations made in this report regarding them should be considered to be preliminary.

The TALPA ARC (Takeoff And Landing Performance Assessment Aviation Rulemaking Committee) Process

This was led by the FAA with representation from aircraft manufacturers, airlines, airports, and regulatory authorities. The TALPA ARC has defined an overall system such that all the key components of information gathering and employment are linked, ranging from the runway reporting process to assessments of aircraft performance. If implemented, the proposed TALPA ARC system would bring about significant changes to the current state-of-practice in the US and other countries duplicating or emulating the process.

The TALPA ARC defined a Runway Assessment Matrix which relates aircraft performance using a scale of 7 codes to primarily, a combination of the contaminant type, the contaminant depth, and the contaminant temperature. Friction measurements are downgraded in significance, as they are not the primary source of information, and they can only be used to downgrade the aircraft performance code. With this system, the primary information source and emphasis for RCR is on descriptions of the surface conditions of the runway itself.

The ICAO Friction Task Force

The FTF has a broad mandate to recommend technical directions regarding many friction-related issues. There was consensus within the FTF that a common reporting format is required but consensus was not reached regarding the method(s) to reach this goal.

Based upon the uncertainties involved, the ICAO FTF made a recommendation of not to report the measured friction coefficient and consequently to remove that option from the existing SNOWTAM format item H. In this case, the use of friction measurement devices would be downgraded to an internal tool to be used by the ground staff.

However, because consensus was not reached within the FTF regarding the reporting of friction measurements, the option was left open for States to use item T for such information provided that they have established and approved a system using the reported friction coefficient, and that they wish to use the existing SNOWTAM format for information dissemination. The use of this option will require additional information in the State's AIP describing the approved friction-measuring system and the basic parameters associated with the ground friction measurement.

The ICAO FTF also believes that a clear distinction must be made between runway friction measurements done in a functional context versus an operational one.

With respect to the term "Slippery when wet", the ICAO FTF's recommendation is to stop using this term based upon the fact that a relationship between the term and aircraft performance has not been established. Having said this, consensus was not reached on the subject.

Also, the FTF did not agree upon topics related to Table A1 (in ICAO Annex 14) and the uncertainty of friction measurements. It was agreed to await the outcome from the EASA RuFAB project. The following is part of the ICAO Rapporteur's report when the FTF handed over its recommendations:

The FTF could not agree upon revision of Table A-1 and associated text in Attachment A, Section 7 (Green pages) to Annex 14, Vol I. There is agreement on the need for revision, but not on how. There is disagreement on how to proceed on the subject related to uncertainty of measurement vs. the narrow band between maintenance planning level and minimum friction level.

It was agreed at FTF/5 to await the outcome of the EASA RuFAB project which might bring new information on how to proceed on the subject.

Information-Gathering Study by the French DGAC

A questionnaire study is in progress regarding: (i) the nature of the information to be transmitted; (ii) the assessment of operational friction characteristics; and (iii) the best approach for organizing and processing the data collected. The initial results from the French DGAC study generally support the results obtained in this project.

Review of Relevant ICAO Documents

Relevant information is contained in: (i) Annex 6; (ii) Annex 14, Volume 1; (iii) Annex 15; (iv) the Airport Services Manual; and (v) the ICAO ADREP 2000 Taxonomy document.

Taxonomies for Functional Friction or Operational Friction Applications

The first four ICAO documents listed above contain information for these applications. Annex 6 contains definitions for dry, wet, and contaminated runways. Annex 15 also has information regarding the definition of a wet runway, which differs from that in Annex 6. This discrepancy should be addressed by ICAO.

Annex 6 does not contain definitions for the contaminants themselves (snow, slush, ice, etc) nor does it reference the definitions in the other ICAO Annexes (i.e., Annex 14 and 15). Also, Annexes 14 and 15 do not reference Annex 6 for a definition of a contaminated runway. These documents should be updated by ICAO to include cross-referencing.

Taxonomies for Aviation Accident and Incident Investigations

These are described in the ICAO ADREP 2000 Taxonomy document. They are intended for use as general classifications within the context of an overall database (ECCAIRS). The definitions used in this context are much more general than those used for RCR for operational applications.

Practices for Functional Friction Applications and Taxonomies

Different reporting requirements are imposed for function friction characteristics versus operational applications, and thus, the need for taxonomies.

For the most part, functional friction characteristics are presently used by airports and regulators for maintenance purposes only in the context that they identify targets for airports action as necessary. It is widely recognized that the functional friction maintenance criteria used by national civil aviation authorities are not related to aircraft performance. The only operational applications is when a runway is approaching a level indicating that the minimum maintenance level is being approached or reached, a notice is sent out indicating that the runway may be “slippery when wet”. The ICAO Friction Task Force (FTF) is studying this

issue in detail. Because a report from the FTF is not yet available, detailed recommendations are premature. It is recommended that EASA maintain close contact with the ICAO FTF, and develop policies accordingly.

With respect to functional friction characteristics, most countries use friction measurements as the basis for their runway maintenance criteria for maintenance planning and action. The Norwegian civil aviation authority appears to be the lone exception as it has implemented criteria based on the runway texture and pavement characteristics. This is considered to be the most significant deviation among those found from the surveys and investigations. This variation would impose the most significant difference in requirements for reporting and taxonomies.

Practices also vary among countries using friction measurements as the basis for their functional friction criteria. There are differences regarding: (a) the device(s) accepted; (b) the tire types used; (c) the test speeds used, and; (d) the measurement water film depth used.

Functional friction characteristics are discussed in detail in Volume 3.

Runway Condition Reporting Practices for Operational Friction Applications

“Summer” Versus “Winter”

RCR varies between “summer” and “winter”, which is roughly divided along the lines of liquid versus frozen contaminants. This distinction is an artificial one though as:

- (a) Liquid precipitation and liquid surface contaminates also occur during winter when the surface temperature is approaching, is at, or is 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 FTF) do not explicitly distinguish between “summer” or “winter” contaminants. This is considered to be logical.

However, at the same time, runway condition reporting practices at airports vary between “summer” and “winter”. Parameters such as the contaminant type and depth are not reported in “summer” in contrast to “winter”. This is an important issue. It has been considered further in Volume 4, which discusses operational friction characteristics and runway condition reporting.

“Summer”

Operational reporting for summer conditions can be briefly summarized as:

- (a) Friction is not measured on an operational basis (e.g., during a rainstorm) although functional friction measurements are made at regular intervals; and
- (b) NOTAMs are issued when a runway may be “slippery when wet”.

“Winter”

Operational reporting for winter conditions involves two main activities: (a) the collection of friction-related information; and (b) observations of the runway surface conditions.

With respect to friction-related information, the information that is transmitted to pilots varies among countries. It can include: (i) the measured friction values; (ii) general indications of the braking action (based on the scale in ICAO Annex 14, Volume 1), and/or; (iii) PIREPs.

Different countries use different Ground Friction-Measuring Devices (GFMDs), which report different values when operated on the same surface. There is general consensus that GFMDs are most suitable for “solid” surfaces such as compacted snow and ice. Furthermore they are all generally considered to be unreliable on fluid or fluid-like surfaces (slush, wet, de-icing chemicals, etc). This is borne out by warnings in the AIPs of many countries.

Observations of the runway surface conditions include defining parameters such as the contaminant type, the contaminant depth, the cleared width, and others. This information is usually estimated visually, or in the case of the contaminant depth, it might be measured using crude instruments such as a ruler. Runway condition reporting for operational applications is discussed further in Volume 4.

General Nature of Present Definitions and Options for Harmonization

The definitions used at present are typically a mix between criteria that can be applied easily in the field, and ones that are quantitative, which are intended to avoid subjectivity. For example, the ICAO definition for compacted snow contains practical/subjective descriptions such as “will hold together or break up into lumps if picked up” as well as the scientific/quantitative criterion that the specific gravity is be greater than 0.5.

The harmonization process involves both technical and policy issues. Only technical ones have been investigated here. Various options for harmonization were considered:

- (a) Maintaining the status quo – this is not considered to be acceptable, as it would not address the safety concerns being expressed.
- (b) Making the definitions more scientific/quantitative – this would have the advantage that they would be defined using measurable parameters. This would probably reduce the variability among observers, but, in all probability, this approach would be impractical in an operational airport environment.
- (c) Making the definitions more practical/subjective – this would probably not meet the requirements of all user groups.
- (d) Utilizing the taxonomies in place for aviation accident and incident investigation – these are considerably more general than those used or considered to be needed for operational RCR. Hence, this approach would not provide a feasible way forward for harmonizing the different taxonomies.
- (e) Basing harmonization efforts on relationships to aircraft performance – this is considered to be the most appropriate basis for harmonization, and it is the one

that is most closely linked to the overall goal of maintaining a high level of safety. The TALPA ARC system is the only one that has been developed taking aircraft performance into account explicitly. This gives it a very strong advantage, and as a result, this has been used as the basis for many recommendations in this project. It is noted though, that field trials related to the TALPA ARC reporting process will be taking place during the 2009-2010 winter at some American airports which may potentially lead to some changes. Consequently, the recommendations made here are preliminary. EASA is advised to monitor these field trials closely.

Definitions Related to Various Runway States and What Constitutes a Contaminant

These are the basic definitions, and it is fundamental that these be harmonized first. It was found that the aviation community is trending towards a three-point scale for the runway state (i.e., dry, wet and contaminated), and that the definitions for these three states are generally similar. This trend will help encourage harmonization.

For dry and wet runways, the various definitions are essentially equivalent.

For contaminated runways, the only difference of significance is considered to be which contaminants are specifically named or listed. None of the definitions specify whether the contaminant lists they contain is intended to be all inclusive or not, which leaves open the question of where materials not specifically named would fit. Some other contaminants of concern include:

- (a) Sanded surfaces or sand itself;
- (b) De-icing chemicals, whether they be in liquid form or in mixtures with materials such as slush or snow;
- (c) Layered contaminants such as loose snow over compacted snow or ice; and
- (d) Various other materials, such as dirt or debris, rubber build-up, and other infrequent frozen contaminants, such as frozen airborne residue from industrial processes.

Contaminant Definitions: Water on the Runway

There are three basic cases: (a) damp, (b) wet, and (c) flooded. The definitions for each case are essentially equivalent.

Because the aviation community is heading towards a three-point scale for runway state (i.e., dry, wet, or contaminated), the need for a definition of damp can be questioned, as a damp runway would be considered to be wet. However, there are a number of performance standards and advisory circulars presently in force that would require a definition for damp. Consequently, a definition for damp is still believed to be required until consistency is achieved with respect to the associated performance standards.

Contaminant Definitions: Winter Contaminants

A very large number of surface conditions occur in winter. A precise classification system would involve a multitude of categories and parameters which would probably produce an unworkable system in an operational airport environment.

The TALPA ARC process has indicated that there is no need to define a large number of contaminant types as there is not a corresponding effect on aircraft performance. The TALPA ARC has resulted in only seven aircraft performance codes being defined, in relation to various surface contaminants. This is considered to be a very important outcome of the TALPA ARC process, as it helps to identify the key surfaces while offering potential for simplifying the overall reporting process.

The contaminant types can be broadly defined as follows:

- (a) Loose contaminants such as dry snow or wet snow;
- (b) Liquid contaminants such as water or slush;
- (c) Solid contaminants such as frost, ice, or compacted snow; and
- (d) Layered contaminants, such as wet ice, water on compacted snow, and dry or wet snow over ice.

Definitions are available from various sources for all of the above contaminants. The most serious gap in the present set of definitions is in relation to frost. Only Transport Canada has a definition for it at present. This is problematic because the TALPA ARC code varies greatly depending on whether the surface is frost (in which case the code is 5) or ice (in which case the code is 1 or 0 for ice or wet ice, respectively).

Further Inferences from TALPA ARC Regarding Important Winter Contaminants

An examination of the TALPA ARC Runway Assessment Matrix shows that the same aircraft performance code is produced by various types of contaminants (e.g., dry vs. wet snow for all contaminant depths and temperatures), which suggests that it is not necessary to distinguish all of the listed surfaces for RCR. Thus, some further simplification for RCR might be possible, but recommendations are reserved pending the results of the field trials that will be undertaken during the 2009-2010 winter.

1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

1.1.1 Background

Numerous studies have found that the runway surface condition has an important effect on the safety of aircraft operations on contaminated runways. In an effort to improve aviation safety, efforts are made regularly at aerodromes to document and report the runway surface condition. Runway Condition Reporting (RCR) is undertaken in various contexts and conditions as depicted in Table 1.1.

Table 1.1: General Contexts for Runway Surface Condition Reporting

Type of Contaminants (see notes)	Objective: Functional Friction Assessment (Table 1.2)	Objective: Operational Friction Assessment (Table 1.2)
Summer (e.g., wet)		not done in practice, except for evaluations of “slippery when wet”
Winter (e.g., snow, slush, ice)	not done in practice	

Note regarding definitions in this report:

1. “Winter” - this refers to conditions or contaminants for below-freezing situations. The types of contaminants to be encountered in “winter” conditions include ice, wet ice, all types of snow, slush, frost in all forms, and de-icing chemical residues.
2. “Summer” - this refers to conditions or contaminants for above-freezing situations, and is often termed “wet” in the literature. The types of “summer” contaminants or conditions includes damp, wet, flooded, standing water, dirt, and rubber buildup.

The most appropriate RCR approach(es) depend on, among other factors:

- (a) the end objective (i.e., functional vs. operational friction measurements), as defined in Table 1.2; and
- (b) the type of contaminant and conditions – in winter, the main contaminants of concern are snow, ice, and slush. In summer, the most significant contaminants include water, rubber build-up, and general debris (e.g., dirt).

The amount and type of RCR information varies between countries and even airports themselves, which is a safety issue. A major matter of concern is that lack of harmonization leads to surface condition information provided by airports to air carriers and aviators, especially for operational reporting, being generated using a variety of inspection methods and friction measurement procedures with no uniform quality standards. Airplane manufacturers and air carriers therefore have a limited ability to provide precise airplane landing and take-off performance instructions to pilots for contaminated runways. This in turn may lead to greater than necessary safety margins which financially penalize operators through operational limitations or, it may lead to misinterpretation of condition reports resulting in incidents and or accidents.

Table 1.2: Definitions for Functional and Operational Friction Assessments

Type of Assessment	General Conditions & Type(s) of Contaminants
<u>Functional Friction Characteristics</u> – these measurements are mainly intended for planning and undertaking runway pavement maintenance, and for setting criteria for the design of new pavements. This is intended to be in the context of Clause 2.9.6 in ICAO Annex 14 (which is repeated in the notes below for reference).	Water, dirt, rubber, worn surfaces
<u>Operational Friction Characteristics</u> – this relates to operations on contaminated surfaces, such as aircraft operations or manoeuvres, including possible actions by the aerodrome such as the closure of a runway. This is intended to be in the context of Clause 2.9.9 in ICAO Annex 14 (which is repeated in the notes below for reference).	“Summer”; Water, dirt, rubber “Winter”; Ice, snow, slush

Notes to Table 1.2: Copy of Clauses in ICAO Annex 14:

1. 2.9.6 (Standard): A runway or portion thereof shall be determined as being "slippery when wet" when the measurements specified show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.
2. 2.9.9 (Recommendation): Whenever a runway is affected by water & snow, slush or ice, and it has not been possible to fully clear the precipitant fully, the condition of the runway should be assessed, & the friction coefficient measured.

Presently, harmonization does not exist with respect to the reporting and friction measurement practices. The information provided can include or range from:

- (a) observations of the runway surface condition including the contaminants on the runway
- (b) friction measurements made with a ground vehicle - In some countries, the friction number is given to the pilot, along with a descriptive report of the surface conditions. Other states only provide pilots with a general indication of the braking action.
- (c) Pilot REports (PIREPs) from previous landings.

Among other variations, countries also use different: (a) RCR forms; and (b) friction-measuring devices. As a result, they report friction characteristics and runway surface conditions differently. This safety concern is significantly worsened by the fact that different friction-measuring devices give different friction numbers when operated on the same surface at the same time.

It is generally recognized that the safety of aircraft operations on contaminated runways would be increased if runway condition reporting and friction measurement were internationally harmonized. The overall objective of this project is to promote common RCR procedures.

1.1.2 Seasonal Distinctions, Terminology and Reporting Practices

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 contaminates 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 periods 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 considered in Volume 4, which discusses operational friction characteristics and runway condition reporting.

1.2 Project Scope and Objectives

The overall objective of the work was to provide recommendations regarding the assessment of runway friction characteristics and runway condition reporting. This is a very broad subject, and thus the project had several specific objectives, which may be summarized as follows:

- (a) To conduct a broad information-gathering effort to determine the current state-of-practice. This included conducting surveys using questionnaires; personal contacts, and an extensive literature review.
- (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.

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 clarity, all recommendations are only presented in Volume 1;
- (b) Volume 2 - Documentation and Taxonomy;

- (c) Volume 3 - Functional Friction; and
- (d) Volume 4 - Operational Friction.

1.3 Volume 2

1.3.1 Content of Volume 2

This report (i.e., Volume 2) provides the following:

- (a) Documentation of the information-gathering that was done, which included a combination of questionnaires, personal contacts, and literature reviews.
- (b) Synopses of other key initiatives that have been ongoing in parallel (i.e., the TALPA ARC, the ICAO FTF, and the French DGAC/STAC study).
- (c) Detailed descriptions of:
 - (i) The different taxonomies presently used for RCR by various practitioners including: (i) international legal regulations and State documents, operational documentation such as SNOWTAM and NOTAM, and (iii) incident/accident reports/databases; and
 - (ii) The practices presently used by organizations for reporting the surface conditions at aircraft movement surfaces.
- (d) Documentation for an inventory of the main reference documents that was produced.
- (e) Syntheses of the results particularly with respect to trends, tendencies, and exceptions.
- (f) Assessments regarding the feasibility of potential methods for harmonizing the different taxonomies used and recommendations regarding the preferred ones.

1.3.2 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 INFORMATION-GATHERING: SCOPE AND TECHNICAL APPROACH

This was accomplished using the following general approaches:

- (a) Questionnaires were sent to representatives of several Civil Aviation Authorities (CAAs), airports, air carriers, and aircraft manufacturers.
- (b) Reports and other information sources were reviewed.
- (c) The collected information was synthesized.

2.1 Contacts Made and Information Received

2.1.1 Questionnaires

The following types of questionnaires were prepared and sent out:

- (a) Functional Friction Characteristics – this type of questionnaire was sent out to Civil Aviation Authorities (CAAs) and airports; and
- (b) Operational Friction Characteristics – two types of questionnaire were prepared regarding Operational Friction Characteristics, which sought different information depending on which type of organization it was sent to as follows:
 - (i) Civil Aviation Authorities (CAAs) and airports.
 - (ii) Air carriers, associations, and aircraft manufacturers.

Blanks are provided in Appendix A for each type of questionnaire that was sent out.

2.1.2 Questionnaire Distribution and Responses Received

This is summarized in Table 2.1. Because all recipients of the questionnaires were promised anonymity, no information can be presented here regarding which organizations were contacted. The responses received are summarized below:

- (a) Airports – fifteen and seventeen responses were received regarding functional and operational friction characteristics respectively. These include generic responses that were prepared: (i) by Paul Fraser-Bennison of the UK CAA and (ii) by the project team for major Canadian International airports as a group, based on the project team's experience and working knowledge.

- (b) Civil Aviation Authorities (CAAs) – a total of six responses were received, of which only three were direct responses to the questionnaires. The other CAAs provided indirect responses which: (i) indicated that the responses received from the airport authorities in their countries would reflect their policies or (ii) directed the project team to their AIPs and other reference material. The following was done to fill this information gap:
- (i) Information was sought from publicly-available Aeronautical Information Publications (AIPs), Advisory Circulars (ACs), and other reports for several countries. Advisory Circulars and AIPs for Canada, Germany, Belgium, Denmark, Finland, Yugoslavia, France, Iceland, Japan, the Netherlands, Norway, Poland, Sweden, the USA, and the UK were reviewed.
 - (ii) Reference was made to an extensive review of CAAs that was done by the project team for a recently-completed project (Comfort, Rado, and Mazur, 2009).
 - (iii) A literature review was carried out.
- (c) Aircraft Manufacturers – three responses were received.
- (d) Air Carriers – twelve responses were received to the questionnaires. Follow-up questions were sent by email to the air carriers that responded to the initial questionnaire. See Appendix A for a copy of the email with the questions that were asked. Five (5) responses were received in response to these follow-up emails.

Table 2.1: Questionnaire Distribution and Quantity of Responses Received

Questionnaire Type	Type of Organizations Contacted	Number of Organizations Contacted	Number of Responses Received
Functional Friction Characteristics	Civil Aviation Authorities	14	6 ³
	Airport Operating Authorities	45 ^{1,2}	15 ^{1,2}
Operational Friction Characteristics	Civil Aviation Authorities	13	6 ³
	Airport Operating Authorities	39 ^{1,2}	16 ^{1,2}
Operational Friction Characteristics	Air Carriers	23	12, and 5 ⁵
	Associations ⁴	3	0
	Aircraft Manufacturers	6	3

Notes:

1. This includes a response that was prepared regarding functional and operational friction characteristics by Paul Fraser-Bennison of the UK CAA as a response on behalf of the UK CAA.

2. This includes a response that was prepared regarding functional and operational friction characteristics by the project team as a generic response on behalf of Canadian airports.
3. This includes informal responses from 3 CAAs which stated that the responses received from the airport authorities would reflect their policies, or which directed the project team to AIPs and other material.
4. This included associations of pilots and air traffic controllers.
5. Follow-up questions were sent by email to each of the air carriers that responded to the initial questionnaire. Five (5) responses were received in response to these follow-up emails.

2.2 References Reviewed

Many references and information sources were reviewed, of which a partial listing is provided in Table 2.2. Other reports that were reviewed included those listed below:

- (a) Runway Friction Standards – see Table 2.3 and Appendix B for summary reviews.
- (b) CFME Performance Specifications – see Table 2.4 and Appendix C for summary reviews.
- (c) CFME Correlation Methods – see Table 2.5 and Appendix C for summary reviews.
- (d) Correlation Trials of Continuous Friction Measuring Equipment – see Table 2.6 and Appendix C for summary reviews.
- (e) The Joint Winter Runway Friction Measurement Program (JWRFMP) – see Table 2.7, and Appendix C for summary reviews.
- (f) Methods for remotely measuring the surface condition – see Table 2.8. Report summaries for the relevant reports are presented in Appendix A of Volume 4.

Table 2.2: Partial Listing of References and Information Reviewed

Source & Category	Reference
Airports Council International	Winter Services Yearbook, 2003
Australia: Standards & Guidelines	Manual of Standards Part 139 – Aerodromes; Version 1.4, 2008
Australia: Australia Transport Safety Bureau	Runway Excursions Part 1 – A Worldwide Review of Commercial Jet Aircraft Runway Excursions
Belgium: Standards and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport - Introduction
Denmark: Standards and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport - Introduction
EASA	Certification Specifications for Large Aeroplanes, EASA CS-25
Eurocontrol	EAD Database – accessed for AIPs AICM Manual Integrity of Aeronautical Information – Data Exchange Human Factors: Training Development Guidelines Common AIS Staff Profiling Operating Procedures for AIS Dynamic Data
FAA: Airport Cooperative Research Program	Analysis of Aircraft Overruns and Undershoots for Runway Safety Areas
FAA: Standards and Advisory Circulars	Improved Standards for Determining Rejected Landing and Takeoff Performance Airport Winter Safety and operations (Advisory Circular 150/5200/30C)
FAA: TALPA ARC	Recommendations from the TALPA ARC
Finland	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport – Introduction Seasonal Snow Plan for the Winter Season 2008/2009
France: Manuals and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport - Introduction Guide Particulier Relatif Aux Mesures d’Adherence Sur Chaussees Aeronautiques
France: CFME Acceptance and General Papers	IMAG – Skid Resistance Friction Trailer Numerous calibration test reports with the IMAG, the SARYS STFT, and the SFT Program d’Essais, PRO/STAC/IA/SAC/PR2/006, March 11, 2009 Analyse des Résultats d’Essais, PRO/STAC/IA/SAC/PR2/007, March 11, 2009 CFME Certification Procedure and Programme, personal communications Les Mesures de l’Adherence des Chaussees en France et leur Interprétation Friction Variation Due to Speed and Water Depth
France: DGAC RCR Study (In Progress)	Blank questionnaires that were sent out Project Description and Presentation of the DGAC/STAC Study on Operational Friction (personal communications)
General References: Snow	The 2008 International Classification of Seasonal Snow on the Ground The International Classification of Seasonal Snow on the Ground
General References: Tribology	A New Retrospect of Snow and Ice, Tribology, and Aircraft Performance

Source & Category	Reference
Germany	AIP: Section AD 1.2-1 Snow Plan AIP: Section AD 1.1-1 Aerodrome Availability
ICAO: Accident Investigation Group (AIG)	ICAO ADREP 2000 Taxonomy AIG Divisional Meeting Notes (Oct 2008) - Management of Safety Data AIG Divisional Meeting Notes (Oct 2008) - Accident/Incident Reporting System
ICAO: Manuals and Standards	Airport Services Manual, Doc 9137 Aerodromes, Volume 1, Annex 14, 4 th Edition Supplement to 3 rd Edition of Aerodromes, Volume 1, Annex 14 Aeronautical Information Services Manual, Doc 8126 Amendment 3 to Aeronautical Chart Manual, Doc 8697 Manual on the Quality Management System for the Provision of Meteorological Service to International Air Navigation, Doc 9873 Procedure for Air Navigation Services: Training, Doc 9868 World Geodetic System – 1984 (WGS-84) Manual, Doc 9674
ICAO: Aeronautical Information Management Study Group (AIS-AIMSG)	Numerous Information Papers (7) Produced by the AIS-AIMSG Numerous Study Notes (25) and Presentations (2) Produced by the AIS-AIMSG Quality Management System for AIS/MAP
ICAO: European Coordination Centre Accident Reporting System (ECCAIRS)	Development and Implementation of Safety Recommendations Taxonomy Associated With Aircraft Accident and Incident Investigations ECCAIRS 4.2.6 Data Definition Standard
Iceland: Standards and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport - Introduction
Japan	NOTAM Example AD 1.2 Rescue, Fire Fighting and Snow Plan (Gives Format, Definitions & Info)
NASA: Reports	Behaviour of Aircraft Anti-Skid Braking Systems on Dry and Wet Runway Surfaces, NASA Technical Note TN-D-8332 Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements Obtained for Various Runway Surface Types and Conditions, NASA Technical Paper 2917
National Aerospace Laboratory (NLR) Reports	Test and Evaluation of Precipitation Drag ... (NLR Report NLR-TP-2001-490) CRspray Impingent Drag Calculations ... (NLR Report NLR-TP-2001-204) Safety Aspects of Aircraft Performance ... (NLR Report NLR-TP-2001-216) Safety Aspects of Aircraft Operations ... (NLR Report NLR-TP-2001-217) Hydroplaning of Modern Aircraft Tires (NLR Report NLR-TP-2001-242) Correlation of Self-Wetting Friction Measuring Devices (NLR-TP-2004-121) Running Out Of Runway – Analysis of ... (NLR Report NLR-TP-2005-498) A Method for Predicting the Rolling Resistance ... (NLR Report NLR-TP-99240)

Source & Category	Reference
Netherlands: Standards and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport - Introduction
Norway: Reports	Results from a Calibration Workshop Held 25-29 May 1998 Harmonizing Friction Measures of Avinor-Operated Griptesters 1999 Harmonizing Friction Measures of Avinor-Operated BV-11s in June 2000 Friction Profiles of Avinor-Operated Friction Measuring Devices 1998-2000
Norway: Standards and Guidelines	AIP Friction on Contaminated Runways AIC-1 03/08, 03.Jul Cancel'n of AIC-1 07/06, Concerning Friction on Contaminated Runways, 27.Oct Amended Procedure for Pilot Reports on Estimated Braking Action, AIC 1 11.Nov
Poland: Standards and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport - Introduction
Sweden: Standards and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport – Introduction
Transport Canada: Reports	Friction Fundamentals, Concepts and Methodology Airport Operations Under Cold Weather Conditions: Operations on Operative Runways in Norway Study of Warm, Pre-Wetted Sanding Method at Airports in Norway Runway Operability Under Cold Weather Conditions
Transport Canada: Forms, Standards and Guidelines	AIP Numerous Advisory Circulars Form: Aircraft Movement Surface Condition Report (AMSCR)
UK: Standards and Guidelines	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport – Introduction The Assessment of Runway Surface Friction Characteristics, CAP 683
UK: Reports and Other	Report on Research into the Measurement of Contaminated Runway Friction Air Accidents Invest'n Branch: Aircraft Incident Report 1/2009 (EW 1/C2006/12/05) Consultancy to Develop Measurement of Braking Action on Runway Contaminated with Water, Wet Snow, and Slush, Contract 1141
Yugoslavia	AIP: Section AD 1.2-1 Rescue and Fire Fighting Services, and Snow Plan AIP: Section AD 1.1-1 Aerodromes/Heliport - Introduction

Table 2.3: Reports Reviewed Regarding Runway Friction Standards

Report	Status¹
Comfort, G., Rado, Z., and Mazur, A., 2009, Correlation of Continuous Friction Measuring Equipment and Development of Runway Friction Standards, BMT FTL report 6176 submitted to Transport Canada.	Included
Comfort, G “Investigation of Friction Standards for Wet Runway Pavements”, Fleet Technology report 4793 submitted to Transport Canada, July 1998	Included
County Surveyor Society Guidance Note, “Skidding resistance”, Wiltshire, May 2005	Not applicable
TRL Report 510 : “A guide to levels of skidding resistance for roads”, Salt, GF, Szatkowski, WS, 1973	Not applicable
“Traffic Standards and Guidelines 1999 Survey RSS 10 Skid Resistance”, Land Transport Safety Authority, October 1999	Not applicable
Highway Research Board: “Recommendations for an international minimum skid resistance standard for pavements”, Highway Research Board Special Report 101, 1969	Not applicable
Safety Regulation Group: “The Assessment of Runway Surface Friction for Maintenance purposes “CAP 683, Civil Aviation Authority, 2008	Included
ICAO International Standards and Recommended Practices: Annex 14, Aerodromes: Volume 1 – Aerodrome Design and Operations, Fourth Edition, ICAO, July 2004	Included
Aerodrome Standards and Recommended Practices (TP 312), 4 th Edition, Transport Canada, Civil Aviation, March 1993	Included
Aerodrome Safety Circular ASC 2004-024 Runway Friction Testing Program (Appendix A), Transport Canada, Civil Aviation, Aerodromes and Air Navigation, April 1994	Included
AK-68-35-000 Airport Pavement Evaluation – Surface Friction, Transport Canada, Airports and Construction, July 1984.	Included
Regeling stroefheid start- en landingsbanen (Skid resistance regulation for Dutch runways and taxiways), Staatscourant nr. 23, 1998	Included
Information and standards from other Civil Aviation Authorities	Included

Note: This refers to whether or not a summary of the reference is included in this report series.

Table 2.4: Literature Review of CFME Performance Specifications

Reports and Standards	Status ¹
Comfort, G., Rado, Z., and Mazur. A., 2009 Proposed Performance Specifications and Standard Correlation Method for Continuous Friction Measurement Equipment, TP 14825.	Included
Arnberg P. W., Sjogren L.; "Nordiska friktionsmätare". VII Meddelande 333. Statens Väg- och Trafikinstitut. Linköping. 1983.	Not available
Nordström O., "Development and validation of BV14, a new twin track fixed slip friction tester for winter road maintenance monitoring in Sweden." Xth PIARC International Winter Road Congress. Luleå Sweden. 1998.	Not applicable
Giles C. G., Sabey B. E., Cardew K. H. F., 1964, "Development and Performance of the Portable Skid-Resistance Tester." Road Research Technical Paper No. 66. Road Research Laboratory. London.	Not applicable
Meyer, W E; Hegmon, R R; Gillespie, T D "LOCKED-WHEEL PAVEMENT SKID TESTER CORRELATION AND CALIBRATION TECHNIQUES", National Cooperative Highway Research Program Report 151, Transportation Research Board, Washington, D.C. 1974	Not applicable
Choubane B., Holzshuher C.R., and Gokhale S., 2003, "Precision of Locked Wheel Testers for Measurement of Roadway Surface Friction Characteristics." Research Report FL/DOT/SMO/03-464.	Not applicable
The performance specifications for Continuous Friction Measurement Equipment (CFME) part of the FAA Advisory Circular 150/5320-12C, titled "Measurement, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces."	Included
ICAO "Airport Services Manual, Part 2: Pavement Surface Conditions, Chapter 5– Runway Friction-Measuring Devices, 5.2 Criteria for new Friction-measuring devices"	Included
New ASTM E17 Standard: "Standard Test Method for Measuring the Skid Resistance of Pavements and other Trafficked Surfaces using a Continuous Reading, Fixed Slip Technique"	Included
ASTM E 274-97 (2002). "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire". American Society for Testing and Materials.	Not applicable
ASTM E 303-93 (2002). "Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester". American Society for Testing and Materials.	Not applicable
ASTM E 501-94 (2002). "Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests". American Society for Testing and Materials.	Not applicable
ASTM E 524-88 (2002). "Standard Specification for Standard Smooth Tire for Pavement Skid Resistance Tests". American Society for Testing and Materials.	Not applicable
ASTM E 670-94 (2002). "Standard Test Method for Side Force Friction on Paved Surfaces Using the Mu-Meter". American Society for Testing and Materials.	Included
ASTM E 867-02 (2002). "Terminology Relating to Vehicle Pavement Systems".	Not applic.
ASTM E 965-96 (2002). "Standard Measuring Pavement Macrotexture Depth Using a Volumetric Technique". American Society for Testing and Materials.	Not applicable
ASTM E 1859-97 (2002). "Standard Test Method for Friction Coefficient Measurements Between Tire and Pavement Using a Variable Slip Technique".	Included
ASTM E 1911-98 (2002). "Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester". American Society for Testing and Materials.	Not applicable
ASTM E 1960-98 (2002). "Standard Practice for Calculating International Friction Index of a Pavement Surface". American Society for Testing and Materials.	Included
BS 7941-1 : 1999 : Methods for measuring the skid resistance of pavement surfaces - Part 1 : Side-way force coefficient routine investigation machine	Not available
BS 7941-2 : 2000 : Surface friction of pavements - Part 2 : Test method for measurement of surface skid resistance using the GripTester braked wheel fixed slip device	Not available
ASTM E1551 "Standard Specifications for a Special Purpose, Smooth-Tread Tire, Operating on Fixed Braking Slip Continuous Friction Measuring Equipment", ASTM International	Included

Reports and Standards	Status ¹
ASTM E1844 “Standard Specification for a Size 10x4-5 Smooth Tread Friction Test Tire”	Included
Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields”, CROW Report D06-05	Included

Note: This refers to whether or not a summary of the reference is included in this report series.

Table 2.5: Literature Review of CFME Correlation Methods

Report	Status ¹
Comfort, G., Rado, Z., and Mazur, A., 2009 Proposed Performance Specifications and Standard Correlation Method for Continuous Friction Measurement Equipment, BMT FTL report 6176 submitted to Transport Canada.	Included
Van Es, G.W.H. “Correlation of self wetting friction measuring devices”, National Airspace Laboratory, April 2004	Included
Wambold J. C., Antle C. E., Henry J. J. & Rado Z.; “International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements.” 01.04.T. PIARC. 1995.	Included
Horne, W.B., Buhlmann, F. :“A Method for Rating the Skid Resistance and Micro/Macrotexture Characteristics of Wet Pavements“, Frictional Interaction of Tire and Pavement, ASTM SRP 793, 1983	Not available
Van Es, G.W.H, Giesberts: “A Literature Survey on Tire Surface Friction on Wet Pavements: Application of Surface Friction Testers”, CROW, Report 03-06, Ede, The Netherlands, 2003	Included
Merritt L.R.: “Concorde Landing Requirements Evaluation Tests”, FAA, FS-160-74-2, 1974	Not available
Van ES, G.H.W.: “Correlation of Self-wetting Friction Measuring devices: Evaluation of the ESDU method”, CROW, Report 03-10, Ede, The Netherlands, 2003	Separate review not done – same reference as #1
ICAO “Airport Services Manual, Part 2: Pavement Surface Conditions”, Appendix 3, NASA Certification Test Procedure for New Continuous Friction-Measuring Equipment Used at Airport Facilities”	Included
Aerodrome Safety Circular ASC 2004-024 Runway Friction Testing Program, Appendix A, Section 2.1 Alternative Device Requirements, Transport Canada, Civil Aviation, Aerodromes and Air Navigation, April 2004.	Included
“Correlation Trial of Self-Wetting Friction-Measuring Devices for Dutch Airfield Pavements”, CROW Report 04-05, Ede, The Netherlands, 2004	Separate review not done – same reference as #1
“Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields”, CROW Report D06-05.	Separate review not done – same reference as #1

Note: This refers to whether or not a summary of the reference is included in this report series.

Table 2.6: Correlation Trials of Continuous Friction-Measuring Equipment

Report
Comfort, G., Rado, Z., and Mazur, A., 2009 Proposed Performance Specifications and Standard Correlation Method for Continuous Friction Measurement Equipment, BMT FTL report 6176 submitted to Transport Canada.
Lund B, "Friction test. Comparative testing with 3 different equipments carried out during the summer 1996." Report 82. Road Directorate, Danish Road Institute. 1997.
Nordström, O.; "Correlation test between SARSYS Saab 9-5 Wagon Surface Friction Tester and VTI Safegate Saab 9000 SFT." Test Report Dnr 605/99-8. Swedish Road and Transport Research Institute. Linköping.
Schmidt B.; "Friktionsmålinger. Sammenlignende målinger mellem ROAR och Stradograpf." Rapport 90. Vejdirektoratet, Vejteknisk Institut. Denmark 1999. (Translation: "Friction measurements. Comparative measurements between the ROAR and the Stradograpf." Report 90. Road Directorate, Danish Road Institute. 1999.
"Measuring systems for evaluation of Skid-Resistance and Texture, Part 1: Comparison of repeatability standard deviation", Road Directorate, Danish Road Institute. March 1998
Wambold J. C., Antle C. E., Henry J. J. & Rado Z.; "International PIARC experiment to compare and harmonize texture and skid resistance measurements." 01.04.T. PIARC. 1995.
TP 14498E, "Friction coefficients for various winter surfaces", BMT Fleet Technology Limited, 2004
TP 14318E, "Joint Winter Runway Friction Measurement Program (JWRFMP): International Runway Friction Index (IRFI) versus aircraft braking coefficient (μ)", CDRM Inc., 2003
TP 14083E, "Repeatability and reproducibility of Saab friction measurement devices in self-wet mode", Transportation Infrastructure Consulting and Services Ltp., 2003
TP 14065E, "Comparison of the IRV and the ERD on winter contaminated surfaces", CDRM Inc., 2001
Comparison of GripTester and Saab SFT Measurements, Interim report
Runway Friction Monitoring with the SFT - 0.5mm versus 1.0mm Water Depths,
Runway Friction Monitoring with the GripTester - 0.5mm versus 0.25mm Water Depths
TP 14190E NASA Wallops Tire/Runway Friction Workshops: 1993-2002
Meyer, W.E; Hegmon, R.R.; Gillespie, T.D.: "LOCKED-WHEEL PAVEMENT SKID TESTER CORRELATION AND CALIBRATION TECHNIQUES", National Cooperative Highway Research Program Report 151, Transportation Research Board, Washington, D.C. 1974
Reliability and Performance of Friction Measuring Tires and Friction Equipment Correlation. - Final report <i>Federal Aviation Administration, Washington, DC. Office of Airport Safety and Standards</i> Mar 1990, T. H. Morrow, DOT/FAA/AS-90-1
Van ES, G.H.W.: "Correlation of self-wetting Friction Measuring devices: Evaluation of the ESDU method", CROW, Report 03-10, Ede, The Netherlands, 2003
"Correlation Trial and Harmonization Modeling of Friction Measurements on Runways 2005", CROW Report 06-02, Ede The Netherlands, 2006
Friction Workshop held at LCPC Centre de Nantes, France (June 2004)
"Correlation Trial of Self-Wetting Friction-Measuring Devices for Dutch Airfield Pavements", CROW Report 04-05, Ede, The Netherlands, 2004
"Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields", CROW Report D06-05
Results From A Calibration Workshop Held 25-29 May 1998, Avinor Report OKK 1998-3
Harmonizing Avinor-Operated Griptesters 1999, Avinor Report OKK 1999-1
Harmonizing Friction Measures of Avinor-Operated BV-11s in June 2000, Avinor Report OKK 2000-1
OKK Friction Profiles of Avinor-Operated Friction-Measuring Devices 1998-2000, Avinor Report OKK 2000-2
Comparison of Pavement Texture Measurement Systems, Avinor Report OKK 2003-1
Results from the International Texture Workshop, Avinor Report OKK 2003-2

Note: Summaries for all of the listed references are included in the appendices.

Table 2.7: Reports from the Joint Winter Runway Friction Measurement Program

Report
Aircraft tire braking friction under winter conditions: Laboratory testing (TP 12584E)
Proceedings of the international meeting on aircraft performance on contaminated runways, IMAPCR '96 (TP 12943)
Characteristics of winter contaminants on runway surfaces in North Bay – January and February-March 1997 tests (TP 13060E)
Braking friction coefficient and contamination drag of a B727 on contaminated runways (TP 13258E)
Falcon 20 aircraft performance testing on contaminated runway surfaces during the winter of 1997/1998 (TP 13338E)
Analysis of the friction factors measured by the ground vehicles at the 1998 North Bay trials (TP 13366E)
Laboratory testing of tire friction under winter conditions (TP 13392E)
Measuring tires for harmonized friction measurements of runway surfaces and prediction of aircraft wheel braking (TP 14005E)
Overview of the joint winter runway friction measurement program (TP 13361E)
Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the winter of 1998-1999 (TP 13557E)
Proceedings of the 2nd International Meeting on Aircraft Performance on Contaminated Runways, IMAPCR '99 (TP 13579)
Joint Winter Runway Friction Measurement Program (JWRFMP): 1997-98 testing and data analysis (TP 13836E)
Winter contaminants on surfaces during friction tests at Munich Airport – February 2000 (TP 13658E)
Runway surface and environmental conditions during friction tests at K.I. Sawyer Airbase, Michigan, USA – February 1999 (TP 13672E)
Friction factor measurements on non-uniform surfaces: sampling frequencies required (TP 13784E)
Comparison of the IRV and the IMAG on winter contaminated surfaces (TP 13791E)
First Air B727 aircraft landing performance on contaminated arctic runway surfaces during the winters of 1998-1999 and 1999-2000 (TP 13800E)
Falcon 20 aircraft performance testing on contaminated runway surfaces during the winter of 1999/2000 (TP 13833E)
Friction fundamentals, concepts and methodology (TP 13837E)
Wet runway friction: literature and information review (TP 14002E)
Runway friction accountability risk assessment: Results of a survey of Canadian airline pilots (TP 13941E)
Evaluation of aircraft braking performance on winter contaminated runways and prediction of aircraft landing distance using the Canadian Runway Friction Index (TP 13943E)
Dash 8 aircraft braking performance on winter contaminated runways (TP 13957E)
Effect of vehicle parameters on the friction coefficients measured by decelerometers on winter surfaces (TP 13980E)
Dornier DU328 aircraft braking performance on winter contaminated runways (TP 13983E)
International Runway Friction Index (IRFI): Development technique and methodology (TP 14061E)
Joint winter runway friction measurement program (JWRFMP): 2000 Testing and data analysis (TP 14062E)
Evaluation of IRFI calibration procedures for new and existing devices (TP 14063E)
Repeatability of friction measurement devices in self-wetting mode (TP 14064E)
Comparison of the IRV and the ERD on winter contaminated surfaces (TP 14065E)

Report
Joint Winter Runway Friction Measurement Program (JWRFMP): 2001 testing and data analysis (TP 14192E)
Environmental and runway surface conditions during friction tests at North Bay Airport: Jan-Feb 2002 (TP 14158E)
NASA Wallops Tire/Runway Friction Workshops: 1993-2002 (TP 14190E)
Benefit-cost analysis of procedures for accounting for runway friction on landing (TP 14082E)
Repeatability and reproducibility of Saab friction measurement devices in self-wet mode (TP 14083E)
Decelerometer tests: CRFI quality assurance tests and the effect of the vehicle's ABS system (TP 14176E)
Joint Winter Runway Friction Measurement Program (JWRFMP): 2002 testing and data analysis (TP 14193E)
Joint Winter Runway Friction Measurement Program (JWRFMP): 2003 testing and data analysis (TP 14194E)
Joint Winter Runway Friction Measurement Program (JWRFMP): International Runway Friction Index (IRFI) versus aircraft braking coefficient (Mu) (TP 14318E)
Development of a comprehensive method for modelling performance of aircraft tyres rolling or braking on dry and precipitation-contaminated runways (TP 14289E)
Meeting on Aircraft Performance on Contaminated Runways, IMAPCR 2004 (TP 13579)
Effect of surface conditions on the friction coefficients measured on winter surfaces (TP 14220E)
Effect of surface conditions on the friction coefficients measured on winter surfaces (TP 14220E)
Evaluation of wide-body aircraft braking performance with the determined runway friction index from tests conducted in Japan in 2003 (TP 14399E)
Friction coefficients for various winter surfaces (TP 14498E)
Evaluation of Falcon 20 turbojet and DHC-8 series 100 and 400 turbopropeller aircraft safety margins for landings on wet runway surfaces (TP 14627E)
Airport operations under cold weather conditions: Observations on operative runways in Norway (TP 14648E)
Study of warm, pre-wetted sanding method at airports in Norway (TP 14686E)

Note: Summaries for all of the listed references are included in the appendices.

Table 2.8: Methods for Remotely Measuring the Surface Condition

Report	Status ¹
Friction @, report produced through the Information Society Technologies (IST) Program	Included
Evaluation of Two New Vaisala Sensors for Road Surface Conditions Monitoring	Included
Final Report for Aurora Program Project 2002-01: Phase I: Final Report on Signal and Image Processing for Road Condition Classification Phase II : Intelligent Image-Based Winter Road Condition Sensor	Not Included
Probabilistic Models for Discriminating Road Surface Conditions Based on Friction Measurements, August 2008, report to MTO by Feng and Fu	Not Included
Probabilistic Models for Discriminating Road Surface Conditions based on Friction Measurements, 2008 TRB paper by Feng and Fu	Not Included
Report On Research Into The Measurement Of Contaminated Runway Friction, Report By Vestabill For the UK CAA	Included
Spectral Analysis of Continuous Friction Measurements for Winter Road Surface Condition Discrimination, paper by Feng and Fu, Univ. of Waterloo, Ontario, Canada	Not Included

Note: This refers to whether or not a summary of the reference is included in this report series.

3 INVENTORY OF REFERENCE DOCUMENTS

3.1 Objectives

A wide range of documents were obtained and reviewed. A system was produced to:

- (a) Provide a means for archiving them electronically; and
- (b) Facilitate the future use and retrieval of these documents.

3.2 Approach Used for Archival

The archived references were organized by general source, as depicted in Figure 3.1. The archival system has a two-level directory structure as follows:

- (a) First-level directory: this identifies the general source for the documents (e.g., Australia, ICAO, FAA, Eurocontrol, etc.).
- (b) Second-level directory: at this level, the information from each source is subdivided by general type (e.g., Standards and Guidelines versus Reports versus Information from Working or Study Groups, etc.).

An HTML, web-enabled interface/browser was produced to provide a user-friendly means for navigating the directory structure for the archived references.

Figure 3.2 shows the initial screen that is presented to the user. Sub-directories and reports within those directories can be accessed by clicking on the appropriate boxes.

3.3 Potential Platforms and Distribution Methods for the Archived References

The references have been supplied to EASA with a separate communication.

The possible approaches for distributing and accessing the archived references include the following:

- (a) All files would be put on a DVD that may be downloaded onto someone's hard drive. In this case, the archived documents would be resident on that person's computer.
- (b) All files would be loaded onto a website, such as perhaps, EASA's Sinapse website, where they may be accessed.

In either case, the directory/document navigation system would be launched by double-clicking on the "TOC.htm" file within the system.

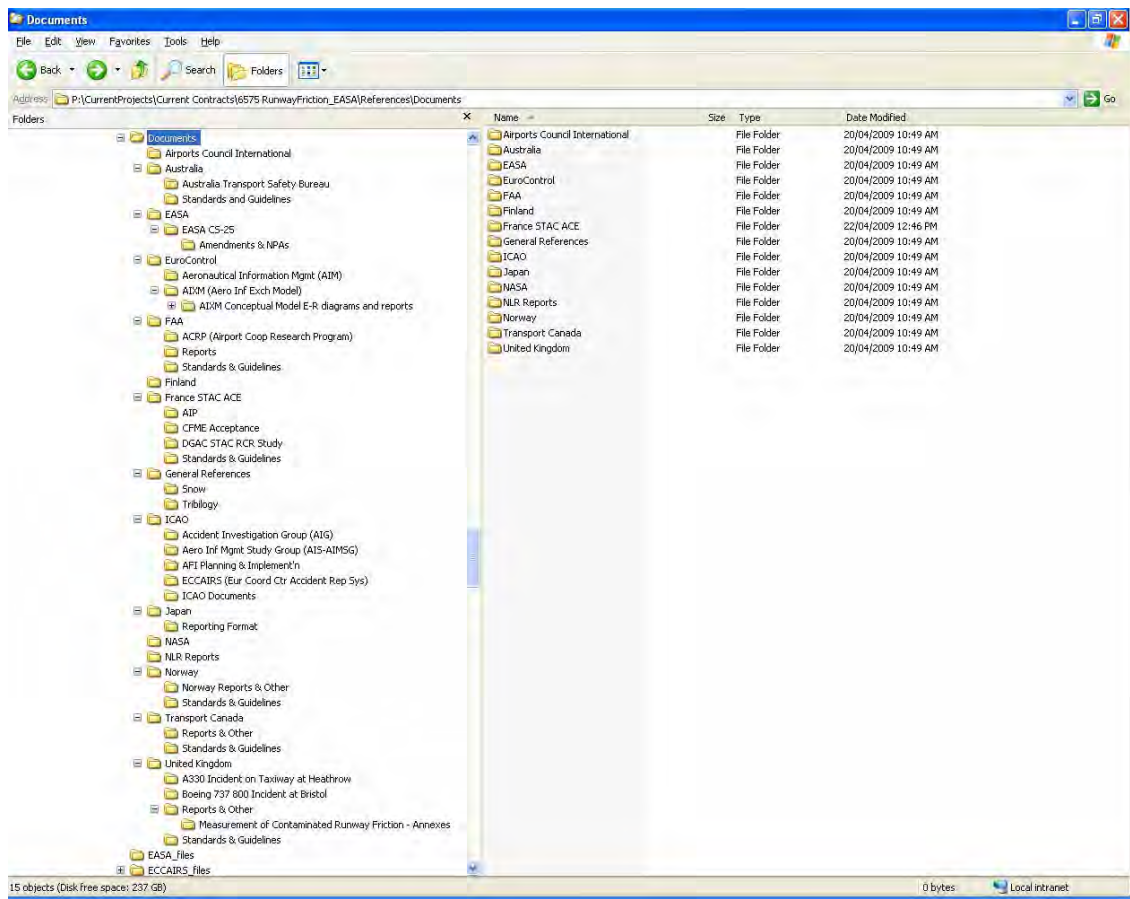


Figure 3.1: General Directory Structure



Figure 3.2: User Interface for Navigating the Directory Structure for the References

4 OTHER INITIATIVES

4.1 Takeoff and Landing Performance Assessment Aviation Rulemaking Committee

4.1.1 Introduction

An extensive investigation has recently been led by the FAA regarding aircraft performance on contaminated runways, and the relationship of runway surface conditions, including runway friction measurements, to aircraft performance. The Takeoff And Landing Performance Assessment Aviation Rulemaking Committee (TALPA ARC) had wide representation, including aircraft manufacturers, airline representatives, airports, and regulatory bodies.

The TALPA ARC produced extensive recommendations which have not yet been formally published, although the FAA intends to commence the rulemaking process regarding them soon. Initial information regarding the TALPA ARC's recommendations was presented to the project team (Ostronic, 2009). To test and further develop the recommendations, trials are intended to be carried out at some airports in the USA during the 2009-2010 winter.

The TALPA ARC defined an overall system such that all the key components are linked:

- (a) Runway Surface Condition Observation and Definition – A Runway Condition Assessment Table was developed (Figure 4.1) which defined seven categories (termed “codes”) for classifying the prevailing runway conditions. The “codes” were selected to represent the expected range of conditions, and to be meaningful with respect to aircraft performance.
- (b) Runway Surface Condition Reporting – Ground personnel at aerodromes will be expected to report the runway surface conditions according to the Runway Condition Assessment Table and the codes that have been defined. It is recognized that training will be an important aspect of the proposed system.
- (c) Aircraft Performance – Aircraft manufactures will establish aircraft landing and takeoff performance data for their aircraft in relation to the specified seven runway surface condition categories.
- (d) Pilots – Pilots will receive the reported runway surface condition information, and will also have information regarding aircraft performance for that type of condition. There is also flexibility in the proposed system for pilots to apply judgment. This will allow the reported codes (defining a particular type of runway surface condition) to be interpreted with respect to aircraft performance, and for pilots to apply judgment.

PAVED RUNWAY CONDITION ASSESSMENT TABLE

Airport Estimated Runway Condition Assessment				Pilot Reports (PIREPs) Provided To ATC And Flight Dispatch
Runway Condition Assessment – Reported		Downgrade Assessment Criteria		
Code	Runway Description	Mu (μ)	Deceleration And Directional Control Observation	PIREP
6	• Dry	-	-	Dry
5	• Wet (Smooth, Grooved or PFC) • Frost <i>1/8" or less of:</i> • Water • Slush • Dry Snow • Wet Snow	40μ or higher	Braking deceleration is normal for the wheel braking effort applied. Directional control is normal.	Good
4	<i>At or below -13°C:</i> • Compacted Snow	39-36μ	Brake deceleration and controllability is between Good and Medium.	Good to Medium
3	• Wet (Slippery) <i>At or below -3°C:</i> • Dry or Wet Snow greater than 1/8" <i>Above -13°C and at or below -3°C:</i> • Compacted Snow	35-30μ	Braking deceleration is noticeably reduced for the wheel braking effort applied. Directional control may be slightly reduced.	Medium
2	<i>Greater than 1/8" of:</i> • Water • Slush <i>Above -3°C:</i> • Dry or Wet Snow greater than 1/8" • Compacted Snow	29-26μ	Brake deceleration and controllability is between Medium and Poor. Potential for hydroplaning exists.	Medium to Poor
1	<i>At or below -3°C:</i> • Ice	25-21μ	Braking deceleration is significantly reduced for the wheel braking effort applied. Directional control may be significantly reduced.	Poor
0	• Wet Ice • Water on top of Compacted Snow • Dry or Wet Snow over Ice <i>Above -3°C:</i> • Ice	20μ or lower	Braking deceleration is minimal to non-existent for the wheel braking effort applied. Directional control may be uncertain.	Nil

Notes:

- **Contaminated runway.** A runway is contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the reported length and the width being used is covered by water, slush, frost or snow greater than 0.125 inches (3 mm), or any compacted snow or ice.
- **Dry runway.** A runway is dry when it is not contaminated and at least 75% is clear of visible moisture within the reported length and width being used.
- **Wet runway.** A runway is wet when it is neither dry nor contaminated.
- Temperatures referenced are average runway surface temperatures when available, OAT when not.
- While applying sand or liquid anti ice to a surface may improve its friction capability, no credit is taken until pilot braking action reports improve or the contaminant type changes (e.g., ice to water).
- Compacted Snow may include a mixture of snow and imbedded ice.
- Compacted Snow over Ice is reported as Compacted Snow.
- Taxi, takeoff, and landing operations in Nil conditions are prohibited.

Figure 4.1: TALPA ARC Paved Runway Assessment Table (Ostronic, 2009)

Note to Figure 4.1 regarding the definition of “depth” (J. Ostronic, FAA, personal communication):

1. The depths specified in Figure 4.1 are actual depths, and not water-equivalents.
2. The runway condition codes are for each third of the runway. The depths are to be the highest measured depth within that third of the runway length within the cleared width of the runway if the runway is not cleared full width.

4.1.2 Direction from the Project Steering Committee

Only limited information has been published regarding the TALPA ARC's recommendations, which are still under consideration by several organizations including EASA. Thus, it was not possible for the Project Steering Committee (PSC) to provide specific direction to the project team. BMT FTL was directed that it should consider the TALPA ARC proposal to be a good foundation, but it should recognize that the final outcome may vary with respect to detail. It is also recognized that testing will be undertaken during the 2009-2010 winter regarding the TALPA ARC system, and that potentially, this could lead to some changes.

For example, a representative from Norway stated that, although Norway agrees with the broad principles incorporated in TALPA ARC, it has some differences with respect to detail:

- (a) Norway's general philosophy for runway condition assessment is to start with the position that the runway is slippery, and the net result of runway condition actions/reporting is to bring the runway's assessed friction level up. In contrast, TALPA ARC starts with a runway assessment based on the surface condition, and then, any additional information (e.g., PIREPs, ground friction readings) act to downgrade this. This is a fundamental difference.
- (b) Sanding – this is used regularly in Norway, and is an example of a method by which the runway friction level is increased. Sanding is not considered by TALPA ARC.

Overall, BMT FTL was directed to give strong consideration to the TALPA ARC's recommendations. This report has been prepared accordingly. It is focused on the part of the TALPA ARC system that is related to runway surface condition definition, observation/measurement, and reporting, as this is most relevant to this project's objectives.

4.1.3 Relative Priorities of the Information Used for the TALPA ARC Table

It is evident from the TALPA ARC Runway Condition Assessment Table (Figure 4.1) that:

- (a) Surface condition evaluations constitute the main basis for runway surface condition assessments. Thus, these are considered to be highest priority.
- (b) other information sources (i.e., ground friction measurements, PIREPs, qualitative surface friction assessments by the ground crew) may be used to downgrade the code, but not to upgrade it, presumably on the premise that it is better to be "safe than sorry".

4.1.4 Runway Surface Condition Classification and Conclusions Indicated by TALPA ARC

It is well known that a very wide range of surface conditions may be found in practice on a runway or on other aircraft movement surfaces. In isolation, this presents a major problem for classifying runway surface conditions, as a multitude of classification categories could be produced. The categories in the TALPA ARC system provide a logical basis for classifying runway surface conditions, as they have been developed taking into account their relative effect on aircraft performance.

It is evident that clear definitions would only be needed for the cases that produce variations in the runway surface code for the TALPA ARC system. The TALPA ARC's Runway Condition Assessment Table (Figure 4.1) was sorted to define the cases that would and would not lead to a variation in Code (Table 4.1).

Table 4.1: Equivalent Runway Surface Conditions Based on TALPA ARC

Code	Contaminant	Temperature	Depth
6	Dry	Any	n/a
5	Wet Surface	Any	
	Frost	Any	
	Water	Any	$\leq 1/8''$
	Slush	Any	$\leq 1/8''$
	Dry Snow	Any	$\leq 1/8''$
	Wet Snow	Any	$\leq 1/8''$
4	Compacted Snow	$\leq -13\text{ C}$	
3	Wet (Slippery When Wet)	Any	
	Dry Snow	$\leq -3\text{ C}$	$>1/8''$
	Wet Snow	$\leq -3\text{ C}$	$>1/8''$
	Compacted Snow	$-3\text{ to }-13\text{ C}$	
2	Water	Any	$>1/8''$
	Slush	Any	$>1/8''$
	Dry Snow	$> -3\text{ C}$	$>1/8''$
	Wet Snow	$> -3\text{ C}$	$>1/8''$
	Compacted Snow	$> -3\text{ C}$	
1	Ice	$\leq -3\text{ C}$	
0	Wet Ice	Any	
	Water on Compacted Snow	Any	
	Dry or Wet Snow Over Ice	Any	
	Ice	$\geq -3\text{ C}$	

This led to the following conclusions with respect to contaminant type:

- (a) It is important to distinguish the following conditions:
 - (i) Frost vs. Ice – the TALPA ARC Code is 5 for frost, versus 1 or 0 for ice, depending on whether or not the ice is wet. Of all the cases, the variation for frost is most significant as it produces the largest difference in code.
 - (ii) Compacted Snow vs. Ice - the TALPA ARC Code ranges from 2 to 4 for compacted snow, depending on temperature, while it ranges from 0 to 1 for ice, depending on wetness and temperature.

- (iii) Compacted Snow vs. Slush – the TALPA ARC Code varies depending on depth and temperature.
- (b) It is NOT important to distinguish the following conditions:
 - (i) Dry vs. Wet Snow.
 - (ii) Slush vs. Water, in most cases, except when “Slippery When Wet” conditions exist.
 - (iii) Slush vs. Wet Snow, in most cases, except for depths exceeding 1/8” and temperatures less than or equal to -3°C)

The conclusions with respect to contaminant depth depend on the contaminant type and the depth range as follows:

- (a) It is VERY important to distinguish whether or not the contaminant depth is greater than, or less than, 1/8” for water, slush, wet snow, and dry snow.
- (b) The Runway Surface Condition Code is NOT affected by depth for ice, compacted snow or frost.

The conclusions with respect to contaminant temperature depend on the contaminant type and the depth as follows:

- (a) It is VERY important to measure or distinguish the temperature ranges (i.e., $\geq -3^{\circ}\text{C}$; -3°C to -13°C ; $\leq -13^{\circ}\text{C}$) for compacted snow, and ice, for all contaminant depths.
- (b) It is VERY important to measure or distinguish the temperature ranges (i.e., $\geq -3^{\circ}\text{C}$; -3°C to -13°C ; $\leq -13^{\circ}\text{C}$) for wet snow, and dry snow, for contaminant depths $> 1/8$ ”
- (c) It is NOT important to measure or distinguish the temperature ranges (i.e., $\geq -3^{\circ}\text{C}$; -3°C to -13°C ; $\leq -13^{\circ}\text{C}$) for wet snow, and dry snow, for contaminant depths $< 1/8$ ”
- (d) It is NOT important to measure or distinguish the temperature ranges (i.e., $\geq -3^{\circ}\text{C}$; -3°C to -13°C ; $\leq -13^{\circ}\text{C}$) for frost, water, and slush for all contaminant depths

With respect to contaminant layering, the TALPA ARC system indicates that it is important to distinguish: (a) wet ice; (b) water on top of compacted snow, and; (c) dry or wet snow over ice.

It is obvious that the significance of the various parameters varies. In general, it can be seen that, for the purpose of runway condition reporting, one would have to define all of the ones below to determine whether or not they are significant:

- (a) Contaminant type;
- (b) Contaminant depth;
- (c) Temperature; and
- (d) Contaminant layering

4.1.5 Concluding Comments Regarding the TALPA ARC System

The TALPA ARC recommendations have the strong advantage that they provide a coherent system that extends from the ground crew conducting runway inspections to the pilot making operational decisions. This is a major step forward.

With respect to runway condition reporting, they offer the potential for simplification over existing practices as they limit the number of cases that are of significance. This has been kept in mind in formulating recommendations for this study.

The TALPA ARC recommendations present an opportunity for harmonizing the process of surveying runways for the purposes of reporting contaminant conditions with a framework that facilitates further enhancement where they are considered necessary.

4.2 ICAO Friction Task Force

A working group has been formed by ICAO, termed the Friction Task Force (FTF), with a broad mandate to recommend technical directions regarding many friction-related issues. Because the FTF has not yet completed its work, formal documents were not available to the project team. Nevertheless, preliminary inputs were received through the Project Steering Committee, some of whom were also on the ICAO FTF.

There was consensus within the FTF that a common reporting format is required. The FTF's phase 2 activity related to **a global reporting format** will address pilots' need for determining aircraft performance. The reporting format is the language that ground personnel will use for reporting surface conditions, and the pilots when determining aircraft performance. To be useful for the pilots, it is important that a common format is used, which is understood by both the ground personnel and the flight crew. This reporting format, coupled with the information provided in the AIP, must be in a form that flight crews can relate to. The AIP information should be incorporated in the documentation provided to the flight crew by aircraft operators.

It is most important that the ground crew are able to describe the runway surface condition in a manner such that the flight crew can go to the appropriate aircraft performance data to determine key parameters such as the maximum weight available for that runway for that day, the required takeoff or landing distance, the required flap settings, the takeoff speeds (as well as power setting) that should be used at that time, etc. Of course, this varies between takeoff and landing operations as well as for the specific set of circumstances at that time.

The definitions of the runway contaminants and deposits are a key element. A concept of **two harmonized sets of definitions** was discussed to a certain degree by the FTF. One set would be aimed at the ground personnel responsible for identifying the different contaminants and deposits, and significant changes thereof. The other set would be developed in relation to the application of evaluating aircraft performance. Probably, the most practical approach for a global reporting format would be amalgamation of existing

reporting formats. This is an important future activity that should be reflected in the report for the EASA RuFAB project.

The information put together by the FTF for phase 1 (which is its current delivery) can to a certain extent be regarded as defining the conceptual approach that is needed, and as providing an understanding of the processes and parameters involved. A key element from the airport side (with respect to ICAO Annex 14) is the FTF's new recommendation related to **training of the personnel** reporting the conditions at the movement area. The FTF strongly believes that training is an important issue for personnel involved in runway surface reporting and measuring.

While there was agreement within the FTF that a unifying global format is needed, consensus was not reached regarding the method(s) to reach this goal. This was identified as a future activity and thus, not discussed within the FTF to the degree that detailed recommendations were produced. These discussions are yet to come and are a subject under discussion within the ICAO Secretariat. The outcome of these discussions, and how the activity will be organized, is still an open question.

Based upon the uncertainties involved, the ICAO FTF made a recommendation of not to report the measured friction coefficient and consequently to remove that option from the existing SNOWTAM format item H. In this case, the use of friction measurement devices would be downgraded to an internal tool to be used by the ground staff.

However, consensus was not reached within the FTF regarding the reporting of friction measurements. As a result, the option was left open for States to use item T for such information provided that they have established and approved a system using the reported friction coefficient, and that they wish to use the existing SNOWTAM format for information dissemination. The use of this option will require additional information in the State's AIP describing the approved friction-measuring system and the basic parameters associated with the ground friction measurement.

With respect to a clear distinction between runway friction measurements in a functional context versus an operational one, the ICAO FTF was given quite clear guidance from the AOSWG when it was established. The ICAO FTF believes that a clear distinction must be made between runway friction measurements done in a functional context versus an operational one. The ICAO FTF has followed up on that.

With respect to the term "Slippery when wet", the ICAO FTF's recommendation is to stop using this term based upon the fact that a relationship between the term and aircraft performance has not been established. Having said this, consensus was not reached on the subject, and the ICAO FTF will monitor the TALPA ARC process which is making an attempt to bridge this gap.

The FTF would also like to bring to attention the fact that it, at the FTF/5 meeting, did not agree upon topics related to Table A1 (in ICAO Annex 14) and the uncertainty of friction measurements. It was agreed to await the outcome from the EASA RuFAB project. The following is part of the ICAO Rapporteur's report when the FTF handed over its recommendations:

The FTF could not agree upon revision of Table A-1 and associated text in Attachment A, Section 7 (Green pages) to Annex 14, Vol I. There is agreement on the need for revision, but not on how. There is disagreement on how to proceed on the subject related to uncertainty of measurement vs. the narrow band between maintenance planning level and minimum friction level.

It was agreed at FTF/5 to await the outcome of the EASA RuFAB project which might bring new information on how to proceed on the subject.

4.3 French DGAC/STAC Study

4.3.1 General Objectives and Approach

The French DGAC/STAC has been conducting an information-gathering study, by sending out questionnaires, to investigate the information needed regarding operational frictional characteristics. The overall aims of the study are to investigate:

- (a) The nature of information to be transmitted;
- (b) The assessment of runway operation frictional characteristics; and
- (c) How the data collection should be organized and processed.

It should be noted that because this study is still ongoing, only preliminary information can be presented in this report.

4.3.2 General Scope

Questionnaires were sent to: (a) 12 French Airport air traffic control services, with 10 replies being received, and; (b) to 12 French airport operators, with 7 replies being received. The following questions relating to operational friction and contaminants were asked:

Airport Air Traffic Control Services:

- (a) Who informs the ATC that the runway is likely to be contaminated (multiple answers possible)?
- (b) Does the ATC ask for an assessment of runway surface friction (measured coefficient or estimated surface friction) in case of contaminated runway (with WATER, SNOW,...)?
- (c) What are the means used to inform pilots in case of a contaminated runway?
- (d) Do some pilots make specific requests in order to assess the runway surface friction characteristics in the case of a runway contaminated with WATER?
- (e) Do some pilots make a specific request in order to assess the runway surface friction characteristics in case of a runway contaminated with SNOW or ICE?
- (f) Do you have all information and necessary data to inform with SNOWTAM?
- (g) In case of contamination with water, do you transmit by NOTAM or SNOWTAM?

Airport Operator:

- (a) Do you own a device to measure contaminant DEPTH?
- (b) Do you implement a process in order to assess the type of contaminant (dry snow, wet snow ...)?
- (c) Do you own a device to assess runway surface friction (measured coefficient or estimated surface friction)?
- (d) Who takes the decision to assess runway surface conditions (type of contaminant, friction ...)?
- (e) Do you perform a friction assessment after de-icing or snow clearing?

4.3.3 Summary Results from Air Traffic Control

General results are summarized below:

- (a) ATC is in 90 percent cases informed that contaminated conditions are present by a pilot, the meteorological service, or the airport operator. Other services happen to inform ATC too.
- (b) ATC may ask for an assessment of runway surface friction (measured coefficient or estimated surface friction) in case of contaminated runway (with, SNOW, but seldom with WATER ...).
- (c) In the case of a contaminated runway, pilots are routinely informed by NOTAM or SNOWTAM and in 90 percent cases by ATC or by ATIS.
- (d) In the case of a runway contaminated with WATER, pilots often make specific requests to assess the runway surface friction characteristics. Information is most commonly requested regarding the contaminant depth.
- (e) In the case of a runway contaminated with SNOW or ICE, all respondents indicated that pilots make specific requests regarding the runway surface friction characteristics. Information is most commonly requested regarding the contaminant depth, the type of contaminant, and the percentage of runway contaminated.
- (f) All respondents indicated that they get all of the necessary data required through the ICAO SNOWTAM. Format.
- (g) In the case of a runway contaminated with WATER, most respondents indicated that they do not transmit by NOTAM or SNOWTAM.

4.3.4 Summary Results from Airport Operators

General results are summarized below:

- (a) Most operators own a manual device for measuring contaminant depth, which is used primarily for snow and slush. A large number of respondents indicated that contaminant depth measurements require more than 20 minutes.
- (b) Most respondents implement a process to assess the type of contaminant.
- (c) All respondents owned a device to assess the runway surface friction, of which about half indicated that the device is a CFME. The other half indicated that decelerometers are used.
- (d) In all cases, ATC undertakes the decision to have a runway surface friction assessment made. In a large number of cases, the airport operator also makes this decision.
- (e) All respondents stated that a runway surface friction assessment is made after de-icing or snow clearing.

5 INFORMATION-GATHERING RESULTS

5.1 Operational Friction Characteristics: Air Carriers

Information was received from responses to: (a) the questionnaires that were sent out, and; (b) the follow-up questions that were asked. The information has been organized with respect to:

- (a) The contaminants encountered during operations;
- (b) Assessments of the relative value of various types of runway surface condition information for “summer” conditions;
- (c) Assessments of the relative value of various types of runway surface condition information for “winter” conditions;
- (d) Assessments of the contaminants of most concern; and
- (e) The methods used to establish aircraft takeoff and landing performance.

5.1.1 The Contaminants Encountered During Operations

The results are summarized in Table 5.1.

Table 5.1: Contaminants Encountered

“Summer” Operations	“Winter” Operations
Percentage of Total Operations conducted with <u>any</u> type of “summer” contaminant on the runway: Range: 5% to 60%; Mean: 23%	Percentage of Total Operations conducted with <u>any</u> type of “winter” contaminant on the runway: Range: 0% to 60%; Mean: 10%
Relative frequency of contaminant type: most frequent: damp without rubber on runway 2 nd most frequent: wet without rubber on runway	Relative frequency of contaminant type: generally equally split between dry or loose snow; wet snow; compacted snow, or; slush

Of course, the results differed between “summer” and “winter”. In summer, damp surfaces were encountered most often, with wet being next with respect to frequency of encounter.

“Winter” contaminants were encountered less often, which partially reflected the fact the sample survey encompassed some airlines that did not operate in winter conditions. The types of winter contaminants encountered were generally evenly divided between dry or loose snow; wet snow; compacted snow, or; slush.

5.1.2 Relative Value of Various Types of Information for “Summer” Conditions

5.1.2.1 *Friction Readings, Braking Action Indications or PIREPs*

Table 5.2 summarizes the survey results with respect to friction measurements, braking action indications or PIREPs. PIREPs and ground friction readings were considered valuable by the largest number of respondents, in that order. General indications of braking action were considered to be of lesser value.

Table 5.2: Friction or Braking Action Information for Summer Conditions

Parameter	Information Valuable?	Priority
Runway friction values, as measured and produced using a ground friction vehicle	Yes: 75 % of replies No: 25 % of replies	High: 60 % of replies Medium: 10 % of replies Low: 30 % of replies
Summary braking action reports (e.g. good, medium-good, medium, medium-poor, poor)	Yes: 58 % of replies No: 42 % of replies	High: 50 % of replies Medium: 25 % of replies Low: 25 % of replies
Runway braking action reports, as given by pilots of previous flights (PIREPs)	Yes: 92 % of replies No: 8 % of replies	High: 50 % of replies Medium: 37 % of replies Low: 13 % of replies

Only about half of the respondents provided information regarding the required accuracy or reporting frequency, and thus, these results are based on a smaller sample. The survey results with respect to the required accuracy can be generally summarized as follows:

- (a) Runway Friction Readings: The measured data should be as accurate as possible. Only one respondent specified a quantitative value, in that they stated that friction measurements should be accurate within a friction coefficient of 0.01. One respondent stated that often airports declare friction readings to be unreliable to avoid liability.
- (b) Summary Braking Action Indications: Again, the respondents most commonly indicated that these should have high accuracy, or be as accurate as possible. Two respondents indicated that the current five-point ICAO scale (i.e., good, medium-good, medium, medium-poor, poor) was acceptable.
- (c) PIREPs: It was most commonly indicated that these should also have high accuracy, or be as accurate as possible. Two respondents indicated that the current five-point ICAO scale (i.e., good, medium-good, medium, medium-poor, poor) was acceptable.

With respect to the required frequency of reporting, similar responses were received for all three types of information (i.e., runway friction readings, summary braking action indications, and PIREPs), in that the respondents stated that this information is required whenever significant conditions exist, or whenever conditions change.

5.1.2.2 Descriptions of the Runway Surface Condition

Table 5.3 summarizes the survey results with respect to runway surface condition. Information regarding the type and depth of contaminant was considered to be most valuable.

With respect to required accuracy, similar responses were received for all four types of information (i.e., contaminant type; contaminant location; presence of rubber, and; contaminant depth), in that the respondents stated that this information should have high accuracy, or be as accurate as possible. Only respondent gave a quantitative response, indicating that the depth should be accurate to 1 mm. The following other comments were made:

- (a) Location of contaminants: one respondent stated that they consider the runway to be either fully contaminated, or not.
- (b) Contaminant type: one respondent stated that terms such as dry, damp, wet, or flooded were unusable to them.

With respect to the required frequency of reporting, the results can be generally summarized by stating that information should be required often; whenever significant conditions exist, or; when conditions change. One respondent stated that information regarding the contaminant type and depth was required for every takeoff and landing.

Table 5.3: Runway Surface Condition Information for Summer Conditions

Parameter	Information Valuable?	Priority
Contaminant Type (e.g., damp, wet, flooded)	Yes: 100 % of replies No: 0 % of replies	High: 100 % of replies Medium: 0 % of replies Low: 0 % of replies
Location of contaminants on runway, sub-divided by type	Yes: 67 % of replies No: 33 % of replies	High: 56 % of replies Medium: 22 % of replies Low: 22 % of replies
Presence of rubber deposits (if this affects the braking performance), and their location on runway	Yes: 83 % of replies No: 12 % of replies	High: 56 % of replies Medium: 22 % of replies Low: 22 % of replies
Contaminant depth	Yes: 92 % of replies No: 8 % of replies	High: 89 % of replies Medium: 0 % of replies Low: 11 % of replies

Only about half of the respondents provided information regarding the required accuracy or reporting frequency, and thus, these results are based on a smaller sample.

5.1.3 Relative Value of Various Types of Information for “Winter” Conditions

5.1.3.1 *Friction Readings, Braking Action Indications or PIREPs*

Table 5.4 summarizes the survey results with respect to friction measurements, braking action indications or PIREPs. All three types of information were considered to be valuable with high priority. Generally, the respondents assigned higher value and priority to this type of information for “winter” conditions than for “summer” conditions. Compare Tables 5.2 and 5.4.

Table 5.4: Friction or Braking Action Information for Winter Conditions

Parameter	Information Valuable?	Priority
Runway friction values, as measured and produced using a ground friction vehicle	Yes: 91 % of replies No: 9 % of replies	High: 78 % of replies Medium: 11 % of replies Low: 11 % of replies
Summary braking action reports (e.g. good, medium-good, medium, medium-poor, poor)	Yes: 91 % of replies No: 9 % of replies	High: 78 % of replies Medium: 11 % of replies Low: 11 % of replies
Runway braking action reports, as given by pilots of previous flights (PIREPs)	Yes: 100 % of replies No: 0 % of replies	High: 88 % of replies Medium: 12 % of replies Low: 0 % of replies

Only about half of the respondents provided information regarding the required accuracy or reporting frequency, and thus, these results are based on a smaller sample.

With respect to the required accuracy, similar responses were generally received for all three types of information (i.e., friction readings; braking action indications on a general scale, and; PIREPs), in that the respondents stated that this information should have high accuracy, or be as accurate as possible. Two respondents gave a quantitative response, indicating that the friction coefficient should be accurate to 0.01. With respect to the present 5-point ICAO braking action scale (i.e., good; medium-good; medium; poor-medium, and; poor) one respondent stated that a finer resolution was required, while another stated that the current number of categories was acceptable.

Relatively few responses were received regarding the required frequency of reporting. Similar responses were received for all three types of information (i.e., runway friction readings, summary braking action indications, and PIREPs), in that the respondents stated that this information is required whenever significant conditions exist, or whenever conditions change.

5.1.3.2 Descriptions of the Runway Surface Condition

Table 5.5 summarizes the survey results with respect to requirements regarding runway surface condition. Information regarding the type and depth of contaminant was considered to be most valuable.

Table 5.5: Runway Surface Condition Information for Winter Conditions

Parameter	Information Valuable?	Priority
Contaminant Type (e.g., snow, ice, slush)	Yes: 100 % of replies No: 0 % of replies	High: 100 % of replies Medium: 0 % of replies Low: 0 % of replies
Location of contaminants on runway, subdivided by type	Yes: 80 % of replies No: 20 % of replies	High: 56 % of replies Medium: 33 % of replies Low: 11 % of replies
Contaminant depth	Yes: 100 % of replies No: 0 % of replies	High: 100 % of replies Medium: 0 % of replies Low: 0 % of replies

Only about half of the respondents provided information regarding the required accuracy or reporting frequency, and thus, these results are based on a smaller sample.

With respect to required accuracy, similar responses were received for contaminant type and depth, in that the respondents stated that this information should have high accuracy, or be as accurate as possible. Two respondents gave a quantitative response, indicating that the depth should be accurate to 1 mm. With respect to contaminant location, various results were obtained. One respondent stated that they consider the runway to be either contaminated or not. Another stated that only medium accuracy was required for this, versus high accuracy for contaminant type and depth.

With respect to the required frequency of reporting, the results can be generally summarized by stating that information should be required often; whenever significant conditions exist, or; when conditions change. One respondent stated that information regarding the contaminant type and depth was required for every takeoff and landing.

5.1.4 Most Significant Contaminants

Respondents were asked to identify the contaminant(s) of most concern to them, as well as for any other comments. Because these cannot be analyzed easily, they are listed in Table 5.6.

Table 5.6: Most Significant Contaminants and Other Comments

Summer Conditions	Winter Conditions
1 - Wet/flooded	1- Slush
2 - Sand/water	2 - No operations on winter surfaces
3 - wet (very slippery), standing water/flooded	3 - slippery runway: reported friction values are invaluable for winter operations. Also, slush, snow, loose snow information significant
4 - wet	4 – snow, ice, slush
5 – anything that significantly degrades braking including wet and standing water	5 – snow, slush, ice
6 – wet with rubber buildup, making runway “slippery when wet”, and no published braking coefficients	6 – slush, snow, ice
7 - rubber deposits, newly-laid runway surface	7 – snow, slush
8 – wet runways	8 – wet runway > 3mm depth, dry snow, wet snow, slush
9 – water on a non-grooved surface, of a short-field airport	9 – any kind of snow or ice contamination
10 – a damp runway is neither DRY nor WET. It is often treated as DRY, but does not meet the DRY friction. A runway should either DRY or WET.	10 – several contaminants on top of each other, i.e., dry snow on ice. Also, wet conditions, wet snow/slush on ice.
11 – rubber deposits	11 – snow, slush, standing water, ice
12 – reduced braking coefficient due to any contamination	12 – slush in combination with reported braking coefficients, because this results in mistakes and errors

Note: The numbers are the number assigned to the respondent by BMT FTL.

These results are considered further in subsequent sections of this report series.

5.1.5 Comparisons of Survey Results: Non-Winter vs. Winter Contaminants

In general, there were more similarities than differences from the survey results with respect to winter versus summer contaminants. Some comparisons are made below:

- (a) Description of the runway surface condition, in particular the type of contaminant and its depth - in both cases, most or all of the respondents indicated that these were valuable, and all respondents put a high priority on this information.
- (b) Runway braking action reports, as given by pilots of previous flights (PIREPS) – these scored high for both contaminant types, as respondents considered these to be valuable, and put a high priority on this information. PIREPS were considered to be of higher value and priority for winter-contaminated surfaces.
- (c) Runway friction measurements - these were considered to be of high value and priority for both contaminant types.
- (d) General indications of braking action (e.g., the categories in ICAO, Annex 14, Volume 1) - these were considered to be of medium-to-high value and priority for non-winter contaminants. This information was considered to be of somewhat higher value and priority for winter-contaminated surfaces.

5.1.6 The Methods Used to Establish Operational Data Regarding Aircraft Performance

Information was obtained from responses to follow-up questions that were sent to the airlines that responded to the initial questionnaire (see Appendix A for the questions asked). Five responses were received. This was supplemented with published information for a few airlines (i.e., Southwest Airlines, Finnair, Westjet).

This information-gathering showed that there is considerable variability among airlines with respect to the methods used for determining landing distance requirements. 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.

This information is presented and discussed subsequently in Volume 4 (Operational Friction) of this report series.

5.2 **Operational Friction Characteristics: Aircraft Manufacturers**

Because only three responses were received, a detailed analysis is not warranted. Instead, this section only presents the main points from the survey results.

5.2.1 Non-Winter (Wet) Contaminants

The following points were made:

- (a) Generally, aircraft performance data are provided by the manufacturers in relation to the contaminant (e.g., wet, flooded), and the expected braking action for the airplane on that surface. This is in accordance with methods accepted by regulatory/certification authorities. Generally, though, information is provided in the AFM for relatively few surfaces. One manufacturer commented that the only non-winter charts in its AFM would be for wet or for standing water (which they group in with other winter contaminants – equivalent water depths).
- (b) The information supplied varies depending on the regulatory agencies, the type of aircraft, and the operating requirements. One respondent commented that for JAA/EASA operators, the current practice is to supply data for certification for wet, ice, snow, slush, and standing water in its AFM, and for wet only in its AFM for the FAA. They further commented that advisory data is supplied to airline operators on a case-by-case basis. Aircraft performance data are not provided in relation to the friction coefficients measured by ground vehicles. There was a general consensus that there is no reliable correlation between the ground vehicle readings and aircraft braking action. One manufacturer commented that ground vehicle friction readings would score a higher priority if they could be proven to provide consistent results.
- (c) One manufacturer commented that the information in its AFM is based on the type and depth of contamination and that getting this information consistently is challenging.
- (d) It was further commented that ground vehicle readings do not address other important factors such as the consequences of contaminants, which include potential hydroplaning, or the drag resulting from spray build-up or impingement.
- (e) The reported braking action (i.e., good, fair, poor, nil) is an input for determining the maximum cross wind at take-off or landing.
- (f) The accuracy of the reported contaminant depth should be about one to a few millimetres.
- (g) One manufacturer commented that its performance data do not take rubber build-up into account, and thus, this information is not required for them from RCRs.

5.2.2 Winter (Ice, Snow and Slush) Contaminants

The following points were made:

- (a) Aircraft manufacturers provide performance data in relation to the surface itself (e.g., slush, compacted snow, wet ice) and not the friction readings obtained from ground vehicles on that surface. There was a general consensus that there is no reliable correlation between the ground vehicle readings and aircraft braking action.

- (b) One respondent commented that for JAA/EASA operators, the current practice is to supply data for certification for wet, ice, snow, slush, and standing water in its AFM. However, data are not supplied for these surfaces in its AFM for the FAA.
- (c) Another respondent commented that: (i) its AFM provides contaminated data in terms of the type and depth of contaminant, and; (ii) getting this information consistently is challenging. Furthermore, they commented that their AFMs do not provide a correlation between the braking action or friction reports and type/depth of contaminant.
- (d) The practices used and the surfaces considered vary among the manufacturers, and regulatory requirements at the time of certification. Also, there are variations with respect to whether the information is supplied only as advisory material, or it is supplied as part of a certification/regulatory process.
- (e) The reported braking action (i.e., good, fair, poor, nil) is an input for determining the maximum cross wind at take-off or landing.
- (f) The accuracy of the reported contaminant depth should be about one to a few millimetres.

5.2.3 Additional Information regarding Aircraft Performance on Contaminated Runways

Figures 5.1 and 5.2 provide responses from Airbus and Boeing respectively regarding aircraft certification on contaminated runways.

AIRBUS

Until recently, regulations stated that, for a wet runway and for a runway covered with standing water or slush, the aircraft's friction coefficient could be deduced from the one obtained on a dry runway, as follows:

$$\mu_{\text{wet}} = \mu_{\text{dry}}/2 \text{ (limited to 0.4)}$$

$$\mu_{\text{floods}} = \mu_{\text{dry}}/4$$

This concerns A300, A300-600, A310, A320 (except A320-233), A321-100 (JAA certification only), A330-300 (JAA certification only) and A340 basic versions.

As of today, a new method, known as ESDU, has been developed and introduced by post-amendment 42 in JAR/FAR 25.109. The proposed calculation method of the μ_{wet} accounts for the tire pressure, the tire wear state, the type of runway and the anti-skid efficiency demonstrated through flight tests. The μ_{floods} (water and slush) results from an amendment based on a flight test campaign. The ESDU model concerns all aircraft types which are not mentioned above.

For snow-covered or icy runways, the following values are considered, whatever the aircraft type:

$$\mu_{\text{snow}} = 0.2$$

$$\mu_{\text{icy}} = 0.05$$

Getting to grips with aircraft performance, Airbus, January 2002

Figure 5.1: Aircraft Braking Coefficients on Contaminated Runways (ref: Avinor)

BOEING

Question: Does Boeing have a position on how to relate runway friction chart information to reported braking action?

Response: There are many different runway friction vehicles, which have not been calibrated to a standard measurement system nor the airplane. At this point Boeing does not correlate runway friction measurements to pilot reported braking actions or airplane braking coefficient.

Question: Then how does (is) flight operations (to) determine what to use?

Response: The slippery runway (landing and takeoff) data provided by Boeing is a function of airplane braking coefficient. Airplane braking coefficient is the percentage of the airplane's weight on the wheels ($W - L$) which is converted into an effective stopping force. For example, for a reported airplane braking coefficient of 0.20, an airplane with a ($W - L$) of 100,000 lbs would create 20,000 lbs of stopping force.

Boeing provides slippery runway data based on an airplane braking coefficient of 0.05 to 0.2 (Poor to Good reported braking action). Please review the following guidance for relating commonly used terms of reporting runway condition to airplane braking coefficient:

Airplane Braking Coefficient	Pilot Reported Braking Action	Runway Description
0.4	Approximates dry runway	Friction limited certification values
0.2	Good	Wet Runway, Jar certification for compact snow
0.1	Medium/Fair	Ice, Compacted Snow
0.05	Poor/Nil	Wet Ice, Slush, Melting Compacted Snow, Standing Water

On a runway covered with wet ice, slush, melting compacted snow, or standing water the possibility of hydroplaning exists, which can result in nil braking capability. For that reason we recommend that the flight crew use the operational landing distance for POOR Braking Action in such conditions to determine the acceptability of landing on such a runway.

2003 Boeing Performance and Flight Operations Engineer Conference, Seattle, Washington USA

Figure 5.2: Aircraft Braking Coefficients on Contaminated Runways (ref: Avinor)

5.3 Operational Friction Characteristics: Airports

5.3.1 The Parameters That Are Measured or Estimated

5.3.1.1 Summer Conditions

The survey revealed that there is general similarity among airports, as listed in Table 5.7, and summarized below:

- (a) Friction measurements are not made for operational purposes in summer conditions.
- (b) The contaminant type and depth, and the rubber build-up are usually observed, although there are some differences.

Table 5.7: Parameters that Are Measured or Estimated for Operational Purposes

Country	Summary of Results
<u>United Kingdom</u> : 4 responses were received ¹	<u>Friction measurement</u> : friction is not measured for operational purposes. <u>Runway condition assessment</u> : (a) Contaminant type – assessed visually (b) Contaminant depth – estimated visually or measured with a ruler. One airport stated that this information is not provided unless they are specifically asked for it. (c) Rubber deposits – assessed visually
<u>Germany</u> : 5 responses were received	<u>Friction measurement</u> : friction is not measured for operational purposes. <u>Runway condition assessment</u> : (a) Contaminant type – assessed visually (b) Contaminant depth – estimated for most airports. One airport stated that this is not observed. (c) Rubber deposits – assessed visually for most. Two airports stated that this is not observed.
<u>France</u> : 4 responses were received	<u>Friction measurement</u> : friction is not measured for operational purposes. <u>Runway condition assessment</u> : (a) Contaminant type – assessed visually (b) Contaminant depth – estimated visually for most airports. One airport stated that this is not observed (c) Rubber deposits - assessed visually for most. One airport stated that this is not observed
<u>Netherlands</u> : generic response from CAA	<u>Friction measurement</u> : friction is not measured for operational purposes. <u>Runway condition assessment</u> : the ICAO form in Annex 15 is used. (a) Contaminant type – assessed visually (b) Contaminant depth – estimated visually (c) Rubber deposits – observed visually
<u>Switzerland</u> : 1 response was received	<u>Friction measurement</u> : friction is not measured for operational purposes. <u>Runway condition assessment</u> : (a) Contaminant type – not observed (b) Contaminant depth – not observed (c) Rubber deposits – observed
<u>Canada</u> ² : 1 response was prepared	<u>Friction measurement</u> : friction is not measured for operational purposes. <u>Runway condition assessment</u> : (a) Contaminant type – estimated visually (b) Contaminant depth – estimation or measurement (c) Rubber deposits - not observed
<u>USA</u> : 1 response was received	<u>Friction measurement</u> : friction is not measured for operational purposes. <u>Runway condition assessment</u> : (a) Contaminant type – assessed visually (b) Contaminant depth – measured with a ruler (c) Rubber buildup – assessed visually

Notes:

1. This includes a generic response produced by Paul Fraser-Bennison of the UK CAA.
2. This was a generic response prepared by the project team on behalf of Canadian airports.

5.3.1.2 Winter Conditions

The survey results are summarized in Table 5.8.

Table 5.8: Parameters That Are Measured or Estimated for Operational Purposes

Country	Summary of Results
<u>United Kingdom</u> : 4 responses were received ¹	<u>Friction measurement</u>: this is measured using either the Griptester or the Mu Meter. <u>Runway condition assessment</u>: (a) Contaminant type - observed for all responses; assessed visually; SNOWTAM format used. (b) Contaminant depth – observed for all responses; estimated visually. One airport uses a pound coin as a visual check for wet snow to determine if the depth exceeds 3 mm or not. (c) Cleared width – observed for most airports; assessed visually
<u>Germany</u> : 5 responses were received	<u>Friction measurement</u>: this is measured using either the SFT or the Griptester. <u>Runway condition assessment</u>: (a) Contaminant. type – observed for all responses; assessed visually; SNOWTAM format used. (b) Contaminant depth – observed for all responses; estimated visually. (c) Cleared width – observed for most airports. One airport stated that this is not observed. The cleared width is assessed visually.
<u>France</u> : 4 responses were received	<u>Friction measurement</u>: this is measured using either the IMAG or the ERD decelerometer. <u>Runway condition assessment</u>: (a) Contaminant type - observed for all responses; assessed visually; SNOWTAM format used. (b) Contaminant depth – observed for all responses; estimation or measurement using a ruler. (c) Cleared width - observed for most airports. One airport stated that this is not observed. The cleared width is assessed visually.
<u>Netherlands</u> : generic response from CAA	<u>Friction measurement</u>: this is measured using either the ASFT, the SFT, or the BV 11. <u>Runway condition assessment</u>: (a) Contaminant type - observed for all airports - assessed visually. The ICAO format in Annex 15 is used. (b) Contaminant depth – observed for all responses; this estimated visually. (c) Cleared width – this is not observed for airports.
<u>Switzerland</u> : 1 response was received	<u>Friction measurement</u>: friction is measured for operational purposes using an ASFT Saab 9000. <u>Runway condition assessment</u>: (a) Contaminant type – observed visually. The types reported include ice; dry snow; wet snow; compacted snow; slush; frost, and these others: de-iced, damp, rime, frozen ruts, ridges, wet. (b) Contaminant depth – observed visually. (c) Cleared width - estimated visually.
<u>Canada</u> ² : 1 response was prepared	<u>Friction measurement</u>: friction is measured for operational purposes using decelerometers. <u>Runway condition assessment</u>: (a) Contaminant type – observed visually. Ice, wet snow, compacted snow, loose snow, slush and frost are identified as per Transport ASC 2001-011. Other contaminants that are identified include sanded and chemical-treated. Dry snow is not identified. (b) Contaminant depth – estimation or measurement. (c) Cleared width – estimated visually.
<u>USA</u> : 1 response was received	<u>Friction measurement</u>: friction is measured using a NAC DFT, or a decelerometer. <u>Runway condition assessment</u>: (a) Contaminant type – observed visually. The contaminants that are identified include ice, dry snow, wet snow, compacted snow, loose snow, slush, sanded, and chemical-treated. (b) Contaminant depth – measured with a ruler. (c) Cleared width – estimated visually.

Notes:

1. This included a generic response produced by Paul Fraser-Bennison of the UK CAA.
2. This was a generic response prepared by the project team on behalf of Canadian airports.

The following general observations can be made:

- (a) Friction Measurements: All respondents stated that these are made for operational purposes. A variety of measuring devices are used as summarized in Table 5.8.
- (b) Runway Surface Condition Reporting: All respondents stated that the contaminant type and depth are observed. The ICAO SNOWTAM format is used as the basis for RCR for the European airports that responded, although several of them have customized it to suit their needs. The contaminant type is determined by visual assessments. The contaminant depth is assessed visually or using simple tools such as a ruler, for contaminant depth. Most, but not all, respondents stated that the cleared width is assessed. The cleared width is estimated visually in all cases.

5.3.2 Relative Priorities for the Information Collected

The responses regarding the information that was requested by pilots, and the relative frequencies, were used as an indicator of the relative priorities for the collected information.

5.3.2.1 *Summer Conditions*

Table 5.9 summarizes the results for the whole data set for summer conditions.

The following general statements can be made:

- (a) Most often, pilots request information regarding the runway surface condition, such as contaminant type and depth. Pilots ask for the measured friction values least often.
- (b) Relatively few special requests are made by pilots for additional information.

5.3.2.2 *Winter Conditions*

Table 5.10 summarizes the results for the whole data set for summer conditions.

The following general statements can be made:

- (a) Almost all of the respondents indicated that pilots request information for: (i) the runway surface condition, such as contaminant type and depth and (ii) the measured friction values. Pilots ask for general indications of braking action (i.e., good, medium-good, medium, poor-medium, poor) only about half of the time.
- (b) Pilots make more special requests for information for winter conditions than for summer conditions.

Table 5.9: Information Requested by Pilots for Summer Conditions

Parameter			% of Replies
Measured Friction Values	Information Requested ?	Yes	29
		No	71
	Relative Frequency of Requests	Rarely	25
		Depends ^{See Notes}	75
		Regularly	0
Braking Action Index (e.g., Good, Medium-good, Medium, Medium-Poor, Poor)	Information Requested ?	Yes	44
		No	56
	Relative Frequency of Requests	Rarely	33
		Depends ^{See Notes}	67
		Regularly	0
Runway surface conditions (e.g., contaminant type and depth)	Information Requested ?	Yes	100
		No	0
	Relative Frequency of Requests	Rarely	20
		Depends ^{See Notes}	70
		Regularly	10
Number of special requests made by pilots versus the total number of aircraft movements		< 20%	88
		20 to 50 %	12
		50 to 80 %	0
		> 80 %	0

Notes: The following notes and comments were provided:

- Nothing during summer if not needed.
- Sometimes, pilots ask for depth and location of water. Requests are rare and vary by aircraft type.
- Very few requests have been received. Generally, pilots work on the principle that contaminants will be removed from the runway.
- Pilots may make requests (for friction values) but no actual data is ever passed.
- Pilots often request runway friction characteristics after or when raining, to measure the friction and the depth of water. But the instrument of measure used is not able to give these types of information.
- Qualifier for “Depends”: If, for example, you have heavy rain, pilots will sporadically radio a request for runway surface conditions.
- Qualifier for “Depends”: When situation changes, if PIREPs differ from published friction values.

Table 5.10: Information Requested by Pilots for Winter Conditions

Parameter			% of Replies
Measured Friction Values	Information Requested ?	Yes	93
		No	7
	Relative Frequency of Requests	Rarely	8
		Depends ^{See Notes}	77
		Regularly	15
Braking Action Index (e.g., Good, Medium-good, Medium, Medium-Poor, Poor)	Information Requested ?	Yes	62
		No	38
	Relative Frequency of Requests	Rarely	12
		Depends ^{See Notes}	88
		Regularly	0
Runway surface conditions (e.g., contaminant type and depth)	Information Requested ?	Yes	100
		No	0
	Relative Frequency of Requests	Rarely	0
		Depends ^{See Notes}	77
		Regularly	23
Number of special requests made by pilots versus the total number of aircraft movements		< 20%	67
		20 to 50 %	8
		50 to 80 %	0
		> 80 %	25

Notes: The following notes and comments were provided:

1. Friction not measured on wet surfaces. Arriving pilots often request latest surface conditions and friction value as they approach airport. Departing pilots often request same just prior to departure under adverse weather conditions.
2. Very few requests have been received. Generally, pilots work on the principle that contaminants will be removed from the runway.
3. Pilots may make requests (for friction values) but no actual data is ever passed.
4. Pilots still request friction values as they receive them in other countries, but UK airports are not permitted to provide the information.
5. Pilot requests often depend on aircraft type – aircraft without reverse thrust (e.g., older Lear jets) do ask more often for braking action values.
6. Usually, pilots make requests when snow clearing operations are being conducted.
7. Qualifier for “Depends”: When situation changes, if PIREPs differ from published friction values.
8. Pilot requests don’t vary with aircraft type.
9. Pilots prefer measured friction but measurements depend on contaminant type, from instrument to instrument. The most requested information is about ice, snow, rime, or frost.

5.4 Overview of the Information That is Reported to Pilots

5.4.1 Friction Readings and General Indications of Braking Action

The information obtained from the questionnaires was supplemented by reviewing AIPs and advisory circulars for several countries including Belgium, Canada, Denmark, Finland, France, Germany, Iceland, Italy, Japan, Norway, Poland, Sweden, Yugoslavia, the UK, and the USA. This revealed some fundamental differences with respect to the type of “friction” or “braking action” information that is reported to pilots. There are two general types of information:

- (a) The measured friction values themselves, which are collected with various ground friction-measuring devices.
- (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 5.3). 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 5.3: 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 what information is provided to pilots (Table 5.11). Some countries provide the measured friction values to pilots, while others only provide them with a general indication of braking action, according to the ICAO scale (Figure 5.3). Many of these countries include statements in their AIP regarding the limitations of this scale, and some include a code in the 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 5.11 for further information.

Table 5.11: 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
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:
 - (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. 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 cannot 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.

For most of the countries reporting according to the ICAO scale, the braking action is determined based on friction measurements made with a ground vehicle. These countries generally use different friction-measuring devices which is a source of inconsistency, given that the various devices report different values when operated on the same surface. Warnings are present in the AIPs of many countries with respect to the range of applicability of the friction-measuring devices, and hence, the associated braking action index. Some countries include a specific code in their reporting format to signify that the runway surface conditions are unsuitable for measurement with a friction-measuring device.

Some countries use, or allow, other means to establish the braking action index, such as:

- (a) Recently, Norway amended its Aeronautical Information Circular (AIC) to state that PIREPS are an acceptable means for establishing the braking action (Avinor, 2008).
- (b) 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.

5.4.2 Descriptions of the Runway Surface Condition

Most countries and airports reported that the ICAO SNOWTAM format (Figure 5.4) is used as a basis for RCR, although they have developed forms based on it to suit their specific needs. Sample airport-specific forms are contained in Appendix D. Transport Canada uses the AMSCR (Aircraft Movement Surface Condition Reporting) form (Figure 5.5), which it developed to suit its specific needs, such as the requirement to report conditions for the whole runway versus runway thirds for the ICAO format.

A detailed description of Runway Condition Reporting (RCR) practices is provided in Section 7. Appendix D provides copies of the forms used by several agencies, as well as a tabular comparison of RCR practices. RCR practices are discussed further in Section 8, and also, in Volume 4 of this report series.

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 (Time of completion of measurement in UTC)}	B)	→
{RUNWAY DESIGNATORS}	C)	→
{CLEARED RUNWAY LENGTH, IF LESS THAN PUBLISHED LENGTH (m)}	D)	→
{CLEARED RUNWAY WIDTH, IF LESS THAN PUBLISHED WIDTH (m; if offset left or right of centre line add "L" or "R")}	E)	→
{DEPOSITS OVER TOTAL RUNWAY LENGTH (Observed on each third of the runway, starting from threshold having the lower runway designation number)} NIL — CLEAR AND DRY 1 — DAMP 2 — WET or water patches 3 — RIME OR FROST COVERED (depth normally less than 1 mm) 4 — DRY SNOW 5 — WET SNOW 6 — SLUSH 7 — ICE 8 — COMPACTED OR ROLLED SNOW 9 — FROZEN RUTS OR RIDGES	F)	→
{MEAN DEPTH (mm) 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 (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)	H)	→
{CRITICAL SNOWBANKS (If present, insert height (cm)/distance from the edge of runway (m) followed by "L", "R" or "LR" if applicable)}	J)	→
{RUNWAY LIGHTS (If obscured, insert "YES" followed by "L", "R" or both "LR" if applicable)}	K)	→
{FURTHER CLEARANCE (If planned, insert length (m)/width (m) to be cleared or if to full dimensions, insert "TOTAL")}	L)	→
{FURTHER CLEARANCE EXPECTED TO BE COMPLETED BY ... (UTC)}	M)	→
{TAXIWAY (If no appropriate taxiway is available, insert "NO")}	N)	→
{TAXIWAY SNOWBANKS (If more than 60 cm, insert "YES" followed by distance apart, m)}	P)	→
{APRON (If unusable, insert "NO")}	R)	→
{NEXT PLANNED OBSERVATION/MEASUREMENT IS FOR} (month/day/hour in UTC)	S)	→
{PLAIN LANGUAGE REMARKS (Including contaminant coverage and other operationally significant information, e.g. sanding, de-icing)}	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 (not for transmission)

Figure 5.4: ICAO SNOWTAM Format

AIRCRAFT MOVEMENT SURFACE CONDITION REPORT
CANADIAN RUNWAY FRICTION INDEX (CRFI)

COMPTÉ-RENDU DE L'ÉTAT DES AIRES DE MOUVEMENT POUR AÉRONEFS
COEFFICIENT CANADIEN DE FROTTEMENT SUR PISTE (CRFI)

AIRPORT / AÉROPORT														REPORT NO. / COMPTÉ-RENDU N°		AVERAGE CRFI / CRFI MOYEN				
SURFACE CONDITION DATA - RENSEIGNEMENTS SUR L'ÉTAT DE LA SURFACE																				
RUNWAY PISTE	PORTION PARTIE	WIDTH LARGEUR FEET / MÈTRES	BALE DRY SÈCHE %	BALE & WET MOULÉE %	LOOSE SNOW / NEIGE POUDREUSE		COMPACTED SNOW / NEIGE DURÉE	SNOW DRIFTS / COUVERTS		SLUSHY / NEIGE MOULÉE		FROST / GIVRE	ICE PATCHES / PLAQUES DE GLACE	ICE CONTROL MATERIAL APPLIED / AIDE À LA FUSION EMPLOYÉE	REMARKS REMARQUES	OBSERVATIONS OBSERVATIONS	RUNWAY PISTE	AMBIENT TEMP. / C° AMBIANTE	TOTAL RUNWAY AVERAGE MOYENNE POUR TOUTE LA PISTE	TIME (ZULU) HEURE (ZULU)
					%	IN POUCHES		%	IN POUCHES	%	IN POUCHES									
CLEANED / DÉGAGÉE																				
	REMAINING RESTANTE																			
CLEANED / DÉGAGÉE																				
	REMAINING RESTANTE																			
CLEANED / 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 APPROXS																				
VOIES DE CIRCULATION ET AIRES DE TRAFIC																				

VOICE REPORT TO / COMPTÉ-RENDU ORAL À

HOUR (LOCAL)
HEURE (LOCALE)

DAY / JOUR

MONTH / MOIS

YEAR / ANNÉE

SIGNATURE

TAXIWAY/APPROX
INFORMATION FOR LOCAL
DISTRIBUTION
ONLY

LES DONNÉES
RELATIVES AUX
VOIES DE
CIRCULATION ET
AUX AIRES DE
TRAFIC SONT
RESERVÉES À LA
DIFFUSION
LOCALE
SEULEMENT

Figure 5.5: Transport Canada AMSCR Form

6 RELEVANT ICAO DOCUMENTS AND ICAO DEFINITIONS

6.1 Relevant ICAO Documents

As a first step, a search was made for ICAO documents that are relevant to this project, which identified the ones listed in Table 6.1.

Table 6.1: Summary of Relevant ICAO Documents

ICAO Document	Relevance to Project
Airport Services Manual (ICAO, 2002)	Contains sections regarding basic factors affecting friction and terms (Chapters 1 & 2) Contains section regarding friction characteristics of wet paved surfaces (Chapter 3) Contains section regarding the measurement of paved surface friction characteristics for surfaces covered by compacted snow or ice (Chapter 4) Contains section regarding friction-measuring devices (Chapter 5) Contains section regarding runway condition reporting, including the SNOWTAM format (Chapter 6) Contains section regarding a method for determining the minimum friction level (Appendix 1) Contains sections regarding runway friction assessments (Appendices 2, 3, 4, 5, and 6)
Aerodromes - Annex 14, Volume 1 (ICAO, 2004)	Contains definitions for contaminants, etc , (Chapter 1) Contains section regarding the determination of friction characteristics on compacted snow-and ice-covered surfaces, including their relation to aircraft braking action (Attachment A) Contains section regarding the friction characteristics of wet paved runways, including an equivalency table for various ground friction-measuring devices (Attachment A)
Operation of Aircraft - Annex 6 (ICAO, 2001)	Contains definitions for runway surface conditions (Attachment C).
Annex 15, Document 8126 (ICAO, 2003)	Discusses organization of an Aeronautical Information Service (AIS) and of an Aeronautical Information Publication (AIP) Presents and discusses SNOWTAM format, including definitions
ICAO ADREP 2000 Taxonomy (ICAO, 2006a)	Presents formats, terminologies and definitions used for aviation incident and accident investigations
ECCAIRS Definition Standard (ICAO, 2006b)	Presents formats, terminologies and definitions used for aviation incident and accident investigations

6.2 Relevant ICAO Definitions

The above documents were searched for definitions relevant to this project. These are listed below, except for those related to aviation incident and accident investigations (i.e., ICAO, 2006a; 2006b). These were excluded from the list below because the project team was instructed by the PSC that close coordination with the taxonomies used for aviation incident and accident investigations was not required. This is discussed further in Section 7.

Braking Action

No specific definition was found in any of the ICAO documents although a table is provided in the Airport Services Manual and in Annex 14, Volume 1 which relates the measured friction coefficient on compacted snow- and ice-covered runways to a 5-point scale of good, medium-good, medium, poor-medium, and poor. That table is copied as Figure 5.3 (in Section 5) of this report.

However, Annex 14, Volume 1 contains the following information:

The friction conditions of a runway should be expressed as “braking action information” in terms of the measured friction coefficient, μ , or estimated braking action. Specific numerical values are necessarily related to the design and construction of each friction measuring device as well as to the surface being measured and the speed employed.

Contaminant

Annex 14, Volume 1, and the Airport Services Manual, Part 2, do not contain a specific definition for the word contaminant. Annex 6 contains include some material in its description of a contaminated runway, which is presented below.

Contaminated Runway

This is included in the definition in Annex 6 for runway surface condition (below).

Runway surface condition: The state of the surface of the runway: either dry, wet, or contaminated.

- (a) *Contaminated runway: A runway is contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the required length and width used is covered by:*
 - (i) *water, or slush more than 3 mm (0.125 in) deep;*
 - (ii) *loose snow more than 20 mm (0.75 in) deep, or;*
 - (iii) *compacted snow or ice, including wet ice.*
- (b) *Dry runway: A dry runway is one which is clear of contaminants and visible moisture within the required length and the width being used.*
- (c) *Wet runway: A runway that is neither dry nor contaminated.*

Annex 6 also contains the following notes regarding runway surface condition definitions:

- (1) *In certain conditions, it may be appropriate to consider the runway contaminated even when it does not meet the above definition. For example, if less than 25 per cent of the runway surface area is covered with water, slush, snow, or ice, but it is located where rotation or lift-off will occur, or during the high speed part of the take-off roll, the effect will be far more significant than if it were encountered early in the take-off while at low speed. In this situation, the runway should be considered to be contaminated.*
- (2) *Similarly, a runway that is dry in the area where braking would occur during a high speed rejected take-off, but damp or wet (without measurable water depth) in the area where acceleration would occur, may be considered to be dry for computing take-off*

performance. For example, if the first 25 percent of the runway was damp, but the remaining runway length was dry, the runway would be wet using the definitions above. However, since a wet runway does not affect acceleration, and the braking portion of a rejected take-off would take place on a dry surface, it would be appropriate to use dry runway take-off performance.

Annex 15 contains the following information:

When ice, snow or slush is present on 10 percent or less of the total area of a runway, the friction coefficient will not be measured and braking action will not be estimated. If in such a situation water is present, the runway will be reported WET. Where only water is present on a runway and periodic measurements so indicate, the runway will be reported as “WET”.

It is noted though, that the relevant ICAO documents do not reference each other as listed below, which may lead to confusion.

- (a) Annex 14, Volume 1, Annex 15, and the Airport Services Manual make no reference to the general definitions in Annex 6 regarding a contaminated runway, and;
- (b) Annex 6 does not reference the definitions in Annex 14, Volume 1, Annex 15, and the Airport Services Manual regarding the contaminants themselves.

Damp

The surface shows a change of colour due to moisture (Annex 14, Volume 1).

Wet

The surface is soaked but there is no standing water (Annex 14, Volume 1).

Water Patches

Significant patches of standing water are visible (Annex 14, Volume 1).

Flooded

Extensive standing water is visible (Annex 14, Volume 1).

Slippery when Wet

A runway or portion thereof shall be determined as being slippery when wet when the measurements specified in 10.2.3 (listed below) show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State (Annex 14, Volume 1).

Clause 10.2.3 in Annex 14, Volume 1: Measurements of the friction characteristics of a runway surface shall be made periodically with a continuous friction measuring device using self-wetting features.

Dry Snow

Snow which can be blown if loose or, if compacted by hand, will fall apart again upon release; specific gravity: up to but not including 0.35 (Airport Services Manual; Annex 14, Volume 1, and Annex 15).

Compacted Snow –

Snow which has been compressed into a solid mass that resists further compression and will hold together or break up into lumps if picked up; specific gravity: 0.5 and over (Airport Services Manual; Annex 14, Volume 1, and Annex 15).

Wet Snow

Snow which, if compacted by hand, will tend to or form a snowball; specific gravity: 0.35 up to but not including 0.5 (Airport Services Manual; Annex 14, Volume 1, and Annex 15).

Slush

Water-saturated snow with a heel-and-toe slapdown motion against the ground will be displaced with a splatter; specific gravity from 0.5 to 0.8 (contained in the Airport Services Manual; Annex 14, Volume 1, and Annex 15).

Annex 14, the Airport Services Manual, and Annex 15 include the following note as well:

Combinations of ice, snow, and/or standing water may, especially when rain, rain and snow, or snow is falling, produce substances with specific gravities in excess of 0.8. These substances, due to their high water/ice content, will have a transparent rather than a cloudy appearance and, at the higher specific gravities, will be readily distinguishable from slush.

Annex 14, Volume 1, and Annex 15 contain the recommendation below regarding snow, slush or ice on a runway:

Whenever dry snow, wet snow or slush is present on a runway, an assessment of the mean depth over each third of the runway should be made to an accuracy of approximately 2 cm for dry snow, 1 cm for wet snow, and 0.3 cm for slush.

6.3 Gaps or Discrepancies

6.3.1 Contaminant Types

The contaminant types listed in the ICAO SNOWTAM are shown in Figure 6.1. The complete SNOWTAM format is shown in Figure 5.4, in Section 5.

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)

Figure 6.1: Contaminant Types Listed in the ICAO SNOWTAM

The following comments are made in relation to the definitions listed in the previous section (from the ICAO documents):

- (a) “Clear and dry” – there is no corresponding definition for this.
- (b) “Damp” – there is a corresponding definition for damp. However, there is a discrepancy with respect to the definitions of dry, wet, and contaminated runways, as a “damp” surface would be classified as a “wet” one.
- (c) “Wet or water patches” – there is no corresponding definition for “water patches”.
- (d) “Rime or frost covered” – there is no corresponding definition for this.
- (e) “Compacted or rolled snow” – there is no corresponding definition for “rolled snow”.
- (f) “Frozen ruts or ridges” – there is no corresponding definition for this.

Also, the term “standing water” is part of the definition for a contaminated runway (Section 6.2) but no corresponding definition is provided for it the ICAO documents.

6.3.2 Contaminant Types Not Included

The ICAO SNOWTAM format and definitions do not include the following, which are common types of contaminants:

- (a) Layered contaminants such as loose snow over compacted snow;
- (b) Wet ice;
- (c) Sanded surfaces, such as sanded ice, sanded dry ice, sanded wet compacted snow and sanded dry compacted snow; and
- (d) Surfaces with de-icing chemicals on them, or with de-icing chemical residues. It is further noted that de-icing chemicals may be ones for aircraft de-icing or runway de-icing.

7 COMPARISON OF DEFINITIONS

Sections 7.1 and 7.2 present information related to operational and functional friction for the non-winter (wet) and winter contaminants, respectively. Classifications used by aviation accident/incident investigators are presented separately in Section 7.3.

7.1 Summer Contaminants

7.1.1 Definitions of Contaminant and Contaminated Runways

As a first step, a search was made for the definition of “contaminant” for the summer case. The results are summarized below. Although the definitions are similar in intent, they differ in detail, and many references to contamination discuss “summer” and “winter” contaminants together.

ICAO

None of the ICAO documents reviewed contained a specific definition for the word “contaminant”, although this is discussed in Annex 6 in relation to dry, wet and contaminated runways. See Section 6 for information.

FAA

FAA Advisory Circular 150-5200-30C (FAA, 2008) defines a contaminant as:

Any substance on a runway. For the purposes of this AC, references to contaminants mean winter contaminants such as snow, slush, ice or standing water.

It should be recognized though, that this advisory circular was developed for the winter case, and as such, contaminants mean winter contaminants such as snow, slush, ice or standing water.

Transport Canada

Its Advisory Circular (which is also intended to be applicable to the winter case) defines a contaminant to mean the presence of any uncontrolled material on the surface of a movement area including water, snow, frost, ice, slush, sand, and ice control chemicals.

Next, a search was made for the definition of “contaminated runway”. The results are summarized below.

ICAO

This is defined in Annex 6, as described in Section 6.

Transport Canada

Its Advisory Circular considers a runway to be contaminated when any portion of the runway surface within the published length and width is covered or partially covered by a contaminant.

FAA

Various FAA documents describe runway contamination. From a flight operations perspective, the following is of interest. Summer and winter contaminants are discussed together. FAA Safety Alert for Operations (SAFO)#06012 directed to air carriers regarding landing performance of turbojets on contaminated runways contains the following description:

Runway Surface Conditions. The state of the surface of the runway: either dry, wet, or contaminated. A dry runway is one that is clear of contaminants and visible moisture within the required length and the width being used. A wet runway is one that is neither dry nor contaminated. For a contaminated runway, the runway surface conditions include the type and depth (if applicable) of the substance on the runway surface, e.g., standing water, dry snow, wet snow, slush, ice, sanded, or chemically treated.

JAR-OPS and EU-OPS

They do not differentiate between winter and non-winter contaminants:

Contaminated Runway: A runway is considered to be contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the required length and width being used is covered by the following:

Surface water more than 3.0mm [millimetres] (0.125in[inch]) deep, or by slush or loose snow, equivalent to more than 3.0mm (0.125in) of water;

Snow which has been compressed into a solid mass which resists further compression and will hold together or break into lumps if picked up (compacted snow); or,

Ice, including wet ice.”

JAR-OPS also state the following:

- (a) *For JAR-OPS performance, runways reported as DRY, DAMP or WET should be considered as NOT CONTAMINATED.*
- (b) *For JAR-OPS performance purposes, runways reported as WATER PATCHES or FLOODED should be considered as CONTAMINATED.*

UK

UK AIP Section AD 1.1.1 contains the following statement:

Patches of standing water covering more than 25 percent of the assessed area will be reported as WATER PATCHES and should be considered as CONTAMINATED.

TALPA ARC:

A contaminated runway is defined as follows:

A runway is contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the reported length and the width being used is covered by water, slush, frost or snow greater than 0.125 inches (3 mm), or any compacted snow or ice.

7.1.2 Definitions Related to Water on the Runway

The relevant definitions in various ICAO documents have already been reviewed in Section 6.

Table 7.1 compares the definitions used for various important terms related to summer contaminants.

The literature also provides some information regarding definitions. Yager, Phillips, and Horne, 1970, provided the following definitions for the “runway wetness categories in common use”, as follows:

- (a) *Damp* – This is defined as “having a moist (discoloured) surface where the average water depth is 0.01 inch or less on the pavement, as measured by the NASA water depth gauge”;
- (b) *Wet* – This is defined as “having a moist surface where the average water depth lies between 0.01 and 0.1 inch as measured by the NASA water depth gauge”; and
- (c) *Flooded* – the water depth on the pavement exceeds 0.1 inch, as measured by the NASA water depth gauge.

7.1.3 Comparison of Definitions for “Summer” Conditions

With respect to the definitions used for the surface conditions, the survey showed that the definitions in ICAO Annex 14, Volume 1 are generally used as the standard, and that any deviations with respect to definition were small. Comparisons are made below with respect to the definitions in ICAO Annex 14, Volume 1:

Damp

All definitions were based on discoloration. Although there are differences with respect to the descriptions used, the differences are small, and follow the same general intent.

Wet

No significant differences were found. In most cases, a “wet” pavement is one that is neither dry nor contaminated. A pavement covered by water exceeding 3 mm depth is considered to be contaminated. The FAA is somewhat of an exception to these statements at present, as they only require certification data from manufacturers for dry and wet runways. However, they are heading towards a three-point scale (i.e., dry, wet, contaminated) through, for example, the proposed TALPA ARC system.

Flooded or Standing Water

Although the same criteria is applied (namely, depth exceeding 3 mm), differences exist as to whether the condition is termed “flooded” or “standing water”.

Table 7.1: Comparison of Definitions Regarding Summer Contaminants

Parameter	Definitions Used
Bare and Dry (Transport Canada); Dry Runway (EU)	Transport Canada: Means no observed contamination on the movement areas JAR OPS and EU OPS: A dry runway is one which is neither wet nor contaminated, and includes those paved runways which have been specially prepared with grooves or porous pavement and maintained to retain “effectively dry” braking action even when moisture is present UK: The surface is not affected by water, slush, snow or ice. NOTE: Reports that the runway is dry are not normally passed to pilots. If no runway surface report is passed, the runway can be assumed to be dry. TALPA ARC: A runway is dry when it is not contaminated and at least 75% is clear of visible moisture within the reported length and width being used.
Bare and Wet	Transport Canada: Means when the movement area is contaminated by the observed presence of a thin layer of water and the layer is less than 3mm or 1/8 inch in depth; or water drips from an outstretched hand just raised from contact with the surface; or the surface is covered with sufficient moisture to cause it to appear reflective.
Damp	JAR OPS and EU OPS: A runway is considered damp when the surface is not dry, but when the moisture on it does not give it a shiny appearance. Transport Canada: A condition that cannot be described as wet or dry due to the fact that the surface appears wet, but moisture cannot be detected and the surface is non-reflective. Transport Canada: TC also defines “damp” as: “means that the surface appears wet but that the moisture depth cannot be readily determined”. UK: The surface shows a change of colour due to moisture. NOTE: If there is sufficient moisture to produce a surface film or the surface appears reflective, the runway will be reported as WET.
Flooded	UK: Extensive patches of standing water are visible. NOTE: Flooded will be reported when more than 50% of the assessed area is covered by water more than 3 mm deep.
Slippery When Wet	Finland: A runway is determined as being slippery when wet when the runway is wet and the friction coefficient is less than 0.50
Standing Water (TC; EASA CS-25); Associated Standing Water (UK)	Transport Canada: Water in pools or puddles with a depth in excess of 3 mm or 1/8 inch on a movement areas EASA CS-25: Water of a depth greater than 3mm. A surface condition where there is a layer of water of 3mm or less is considered wet for which AMC 25.1591 is not applicable. UK: Standing water produced as a result of melting contaminant in which there are no visible traces of slush or ice crystals
Wet	JAR OPS and EU OPS: A runway is considered wet when the runway surface is covered with water, or equivalent, less than specified in subparagraph (a)2. above or when there is sufficient moisture on the runway surface to cause it to appear reflective, but without significant areas of standing water. UK: A runway that is soaked but no significant patches of standing water are visible. Note: standing water is considered to exist when water on the runway surface is deeper than 3mm. Patches of standing water covering more than 25% of the assessed area will be reported as WATER PATCHES and should be considered as CONTAMINATED. EASA CS-25: Included in definition above for standing water TALPA ARC: A runway is wet when it is neither dry nor contaminated.
Water Patches	Poland: Patches of standing water are visible UK: Significant patches of standing water are visible. NOTE: Water patches will be reported when more than 25% of the assessed area is covered by water more than 3mm deep

7.2 Winter Contaminants

7.2.1 Definitions of Contaminant and Contaminated Runways

As a first step, a search was made for the definition of “contaminant”. The results are summarized below. Although the definitions are similar in intent, they differ in detail.

ICAO

None of the ICAO documents reviewed contained a specific definition for the word “contaminant”, although this is discussed in Annex 6 in relation to dry, wet, and contaminated runways. See Section 6 for information.

FAA:

FAA Advisory Circular 150-5200-30C (FAA, 2008) defines a contaminant as:

Any substance on a runway. For the purposes of this AC, references to contaminants mean winter contaminants such as snow, slush, ice or standing water.

This advisory circular was developed for the winter case, and as such, contaminants mean winter contaminants such as snow, slush, ice or standing water.

Transport Canada

Its Advisory Circular (which is also intended to be applicable to the winter case) defines a contaminant to mean the presence of any uncontrolled material on the surface of a movement area including water, snow, frost, ice, slush, sand, and ice control chemicals.

Norway:

Rime, snow, slush, ice, etc.

EASA CS-25

This refers to runways that are contaminated by standing water, slush, snow, ice or other contaminants.

Next, a search was made for the definition of “contaminated runway”. The results are summarized below.

ICAO:

This is defined in Annex 6, as described in Section 6.

Transport Canada

Means when any portion of the runway surface within the published length and width is covered or partially covered by a contaminant. Transport Canada further states that, in the context of winter contaminants, the airport operator shall provide a friction measurement when the area within 10m of either side of centreline, for the full length of the runway has more than 25 percent of its surface contaminated.

FAA

Various FAA documents describe runway contamination. From a flight operations perspective the following is of interest. Summer and winter contaminants are discussed together. FAA Safety Alert for Operations (SAFO)#06012 directed to air carriers regarding landing performance of turbojets on contaminated runways contains the following description:

Runway Surface Conditions. The state of the surface of the runway: either dry, wet, or contaminated. A dry runway is one that is clear of contaminants and visible moisture within the required length and the width being used. A wet runway is one that is neither dry nor contaminated. For a contaminated runway, the runway surface conditions include the type and depth (if applicable) of the substance on the runway surface – e.g., standing water, dry snow, wet snow, slush, ice, sanded, or chemically treated.

France:

Une piste est dite contaminée (suivant les termes du § 1.480 de l'OPS1) quand au moins 25% de sa surface est recouverte de contaminant sur des épaisseurs supérieures aux valeurs suivantes qui varient en fonction de la nature du contaminant:

- (a) une épaisseur équivalente à 3 mm d'eau pour de la neige fondante, de la neige sèche ;
- (b) 3 mm pour de l'eau (pour mémoire);
- (c) en cas de présence de neige compactée;
- (d) en cas de présence de glace.

JAR-OPS and EU-OPS

They do not differentiate between summer and winter contaminants. Their definitions have already been provided in the previous section.

TALPA ARC

A contaminated runway is defined as follows:

A runway is contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the reported length and the width being used is covered by water, slush, frost or snow greater than 0.125 inches (3 mm), or any compacted snow or ice.

7.2.2 Definitions Related to Snow, Slush and Ice on the Runway

The definitions in the ICAO documents have already been presented in Section 6. Table 7.2 lists the definitions used by various organizations and agencies for winter contaminants. For brevity, Table 7.2 only lists the cases for which the definitions differ from those in the ICAO documents. The following should be further noted:

- (a) In some cases, the AIPs for various CAAs do not list a definition for a particular contaminant. These cases have not been listed for the sake of brevity.
- (b) Also, several countries use the ICAO definitions. These have not been listed for brevity.

It is noted that continued consideration of taxonomies has led to different and changing definitions, as:

- (a) Regulations and guidance regarding operation of aircraft on contaminated runways have evolved;
- (b) The issue has been addressed by more and more agencies;
- (c) Issues related to aircraft performance have been examined in greater detail by airplane manufacturers, air carriers, regulators, pilots and airports, sometimes collectively and sometimes independently; and
- (d) Research, testing, and discussion have been ongoing for many years.

Inevitably, this has led to different and changing definitions. The benefits of harmonization are obvious, but will require concerted efforts to achieve.

Table 7.2: Comparison of Definitions Regarding Winter Contaminants

Parameter	Definitions Used
Associated Standing Water	UK: standing water produced as a result of melting contaminant, in which there are no visible traces of slush or ice crystals
Standing Water	UK (NATS Limited, Aeronautical Information Service – AIP Section AD 1.1.1): 1.00 Sp. Gravity UK CAP 683: Standing water is considered to exist when water on the runway surface is deeper than 3 mm. EASA CS-25: Water of a depth greater than 3mm. A surface condition where there is a layer of water of 3mm or less is considered wet for which AMC 25.1591 is not applicable.
Compacted Snow	FAA: Snow that has been compressed into a solid mass that resists further compression and will hold together or break up into lumps if picked up Transport Canada: means snow that through wind, wheel traffic or rolling, has compacted or bonded to a movement area and cannot be compacted further when walked on EASA CS-25: Snow which has been compressed into a solid mass such that the aeroplane wheels, at representative operating pressures and loadings, will run on the surface without causing significant rutting. Denmark: Snow compacted to a solid snow layer by traffic, etc Japan: Snow which has been compressed and hardened by snow removal equipment or such others. UK (NATS Limited, Aeronautical Information Service – AIP Section AD 1.1.1): over 0.50 Specific Gravity TALPA ARC: Compacted snow may include a mixture of snow and imbedded ice. Also, TALPA ARC defines snow over ice as compacted snow.
Dry Snow	FAA: Snow that has insufficient free water to cause cohesion between individual particles. This generally occurs at temperatures well below 32°F (0°C). If when making a snowball, it falls apart, the snow is considered dry. EASA CS-25: Fresh snow that can be blown, or, if compacted by hand, will fall apart upon release (also commonly referred to as loose snow), with an assumed specific gravity of 0.2. The assumption with respect to specific gravity is not applicable to snow which has been subjected to the natural ageing process. Denmark: Loose powdery snow which, if compacted by hand, will not stick together. Japan: Normal snow, which is dry, or not so watery. The Japanese AIP also refers to the definitions in it for wet snow, slush, and compacted snow. UK (NATS Limited, Aeronautical Information Service – AIP Section AD 1.1.1): less than 0.35 Specific Gravity
Frost	Transport Canada: a condition where ice crystals formed from air borne moisture condense on a surface whose temperature is below zero. Frost differs from ice in that the frost crystals grow independently and therefore have a more granular texture
Ice	FAA: The solid form of water consisting of a characteristic hexagonal symmetry of water molecules. The density of pure ice is 57 lb/ft ³ (913 kg/m ³), which is 9 percent less dense than water. Compacted snow becomes ice when the air passages become discontinuous at a density of about 50 lb/ft ³ (800 kg/m ³). Transport Canada: a frozen liquid with a continuous surface and includes the term "black ice" and the condition where compacted snow transitions to a polished surface with the density of ice. EASA CS-25: Water which has frozen on the runway surface, including the condition where compacted snow transitions to a polished ice surface. UK: water in its solid state, it takes many forms including sheet ice, hoar frost and rime (assumed specific gravity 0.92)
Sand	Transport Canada: (a) small particles of crushed angular mineral aggregates or natural sand material used to improve friction; (b) sand is a contaminant.

Parameter	Definitions Used
Loose Snow	Transport Canada: the presence of fresh falling dry snow, drifting or old standing snow that is not compacted nor bonded to the movement areas.
Snow on the Ground (FAA, France); Snow – generic (ICAO ADREP 2000)	FAA: A porous, permeable aggregate of ice grains, which can be predominately single crystals or close groupings of several crystals. France: Refers to any combination of dry snow, wet snow, compacted snow or slush ICAO ADREP 2000 Taxonomy: Snow is precipitation in the form of feathery ice crystals or large agglomerations in the form of flakes. Snow is composed of millions of star-shaped hexagonal ice crystals.
Wet Snow	FAA: Snow that has grains coated with liquid water, which bonds the mass together, but that has no excess water in the pore spaces. A well-compacted, solid snowball can be made, but water will not squeeze out. Transport Canada: snow which will stick together when compressed, but will not allow water to flow from it when squeezed. EASA CS-25: Snow that will stick together when compressed, but will not readily allow water to flow from it when squeezed, with an assumed specific gravity of 0.5. Denmark: Moist snow which, if compacted by hand, will stick together Japan: Snow which is rather watery and oozes out water if compacted by gloved hand UK (NATS Limited, Aeronautical Information Service – AIP Section AD 1.1.1): 0.35 to 0.050 Specific Gravity
Slush	FAA: Snow that has water content exceeding its freely drained condition such that it takes on fluid properties (e.g., flowing and splashing). Water will drain from slush when a handful is picked up. This type of water-saturated snow will be displaced with a splatter by a heel and toe slap-down motion against the ground. Transport Canada: saturated snow caused by a mixture of water and/or ice control chemicals from which a liquid can flow or be readily squeezed. EASA CS-25: Partly melted snow or ice with a high water content, from which water can readily flow, with an assumed specific gravity of 0.85. Slush is normally a transient condition found only at temperatures close to 0°C. Denmark: Water-saturated snow which with a slap with the foot will be displaced and splash up. Japan: Water-saturated snow, which with a heel and toe slapdown motion against the ground will be displaced with a splash. UK (NATS Limited, Aeronautical Information Service – AIP Section AD 1.1.1): 0.50 to 0.80 Specific Gravity
Trace	Transport Canada: depth of a contaminant on a movement surface which cannot be reasonably measured.
Cleared Width	Transport Canada: means the narrowest portion of the runway width which has been cleared of contaminants and can be estimated by making reference to known widths such as plow blades, sweeper brooms or pavement markings. Finland, France, and Iceland: At least 30 m
Remaining Width	Transport Canada: the portion of the runway width that has not yet been cleared of contaminants.
Windrow	Transport Canada: a continuous ridge of snow varying in height and width created as snow falls off the outer edge of the plow or sweeper. . The maximum height of any point along a windrow is reported as the height of the windrow in its entirety.
Contaminated Depth	Transport Canada: means the mean or average depth of the contaminant as measured by a tape or yardstick
Percentage of Contaminant	Transport Canada: means the estimated amount of contamination present on the surface of the aircraft movement area is reported as a percentage (%). The top layer of contaminant and /or surface is viewed as one "unit" or 100%. The amount of each contaminant is reported separately as a percentage of the whole surface; (e.g., 60% Bare and Dry 40% Loose Snow.)

Parameter	Definitions Used
Patchy Conditions (FAA); Percentage of Contaminant (Transport Canada)	FAA: Areas of bare pavement showing through snow and/or ice covered pavements. Patches normally show up first along the centerline in the central portion of the runway in the touchdown areas. Transport Canada: the estimated amount of contamination present on the surface of the aircraft movement area is reported as a percentage (%). The top layer of contaminant and /or surface is viewed as one "unit" or 100%. The amount of each contaminant is reported separately as a percentage of the whole surface; (e.g. 60% Bare and Dry 40% Loose Snow.)
Specially Prepared Winter Runway	EASA CS-25: A runway, with a dry frozen surface of compacted snow and/or ice which has been treated with sand or grit or has been mechanically or chemically treated to improve runway friction. The runway friction is measured and reported on a regular basis in accordance with national procedures.

Notes:

1. UK (NATS Limited, Aeronautical Information Service – AIP Section AD 1.1.1 contains the following statement:
(a) *Note: Specific Gravity values are stated here to assist in the correlation of conditions with aircraft data, and not necessarily to assist in the determination of conditions as found*
2. Other Definitions – Specific Gravity (in EASA CS-25): the density of the contaminant divided by the density of water.
3. Other Contaminants (in EASA CS-25): EASA CS-25 gives Table 7.3 as the contaminants that are commonly found. It comments that the complete range of conditions or specific gravities has not been covered. It further comments that applicants may wish to consider other, less likely, contaminants in which case such contaminants should be defined in a manner suitable for using the resulting performance data in airplane operations.

Table 7.3: Comparison of Definitions Regarding Winter Contaminants

Contaminant Type	Range of Depths to Be Considered mm	Specific Gravity Assumed for Calculation	Is Drag Increased?	Is Braking Friction Reduced Below Dry Runway Value?	Analysis Paragraphs Relevant
Standing water, Flooded runway	3-15 (see Note 1)	1.0	Yes	Yes	7.1, 7.3, 7.4
Slush	3-15 (see Note 1)	0.85	Yes	Yes	7.1, 7.3, 7.4
Wet Snow (see Note 2)	Below 5		No	Yes	7.3, 7.4
Wet Snow (see Note 3)	5-30	0.5	Yes	Yes	7.1, 7.3, 7.4
Dry Snow	10-130	0.2	Yes	Yes	7.2, 7.3, 7.4
Compacted Snow	0 (see Note 4)		No	Yes	7.3, 7.4
Ice	0 (see Note 4)		No	Yes	7.3, 7.4
Specially Prepared Winter Runway	0 (see Note 4)		No	Yes	7.3, 7.4

Notes:

1. Runways with water depths or slush less than 3 mm are considered wet, for which AMC 25.1591 is not applicable.

2. Contaminant drag may be ignored.
3. For conservatism the same landing gear displacement and impingement drag methodology is used for wet snow as for slush.
4. Where depths are given as zero, it is assumed that the airplane is rolling on the surface of the contaminant.

7.2.3 Comparison of Definitions for Winter Contaminants

The definitions are typically a combination of practical/subjective and scientific/quantitative descriptions. Some definitions are more practical/subjective, while others tend to be more scientific/quantitative. This is illustrated by the example below for compacted snow.

ICAO

The ICAO definition contains practical/subjective descriptions such as “will hold together or break up into lumps if picked up”, as well as the scientific/quantitative criterion that the specific gravity is to be greater than 0.5.

Transport Canada Definition:

This definition is entirely practical/subjective, as it defines compacted snow as:

snow that through wind, wheel traffic or rolling, has compacted or bonded to a movement area and cannot be compacted further when walked on

Comparisons are made below with respect to the definitions in ICAO Annex 14, Volume 1:

Slush

The definitions are all primarily subjective. References to the specific gravity constitute the only quantitative parameter in them, and although this provides a specific parameter that can be measured, this cannot be measured easily in an operational context. The definitions are all generally similar, and are sufficiently broad that they would all encompass the same surface condition. However, except for references to specific gravity, which is not measured in an operational context, and the ability to drain a liquid from the material, the definitions are not sufficiently “tight” that they would preclude a surface being classified as say, wet snow, instead of slush.

Wet Snow

The definitions are all primarily subjective and are generally similar. The overall intent is that the snow is sufficiently moist, but not too wet, that a snowball can be formed. In Canada, a simple field test is used, in that wet snow will compact whereas loose (dry) snow will not. This is a practical test that can be done in the field. References to the specific gravity constitute the only quantitative parameter in the definitions, although as stated above, this cannot be measured easily. The definitions are sufficiently broad that they would all encompass the same surface condition, but also, the definitions are not sufficiently “tight” (except for references to specific gravity) that they would preclude a given surface from being classified in different ways – e.g., material that is at the edge where a snowball can or cannot be formed or where the snow can be compacted or not.

Compacted Snow

The definitions are all primarily subjective and are generally similar. The overall intent is that an airplane or vehicle would be able to drive on this surface without breaking through or displacing it, although the definition in EASA CS-25 is the only one that captures this intention specifically. This is the test used in Canada in that the snow is considered to be compacted if it will support traffic without further compaction. References to the specific gravity constitute the only quantitative parameter in them, although as stated above, this cannot be measured easily. The definitions are sufficiently broad that they would all encompass the same surface condition, but also, the definitions are not sufficiently “tight” (except for references to specific gravity) that they would preclude a given surface from being classified in different ways – e.g., ice vs. compacted snow.

Dry Snow

The definitions are all primarily subjective and are generally similar. Transport Canada has a definition for “loose snow” rather than “dry snow”, but its definition is generally similar to that for “dry snow” for other countries. In Canada, loose snow is snow that is neither compacted nor bonded. References to the specific gravity constitute the only quantitative parameter in them, although as stated above, this cannot be measured easily. The definitions are sufficiently broad that they would all encompass the same surface condition, but also, the definitions are not sufficiently “tight” (except for references to specific gravity) that they would preclude a given surface from being classified in different ways.

Ice

ICAO, Annex 14, Volume 1 does not contain a definition for ice. Definitions were found for ice from the FAA, Transport Canada, EASA CS-25, and the UK CAA, which essentially state that ice is frozen liquid on a runway surface. The definitions are sufficiently broad that they would all encompass the same surface condition, but also, the definitions are not sufficiently “tight” (except for references to specific gravity and density) that they would preclude a given surface from being classified in different ways – e.g., ice vs. compacted snow.

Frost

The proposed TALPA ARC Runway Assessment Matrix (Section 4) indicates that frost is a very significant contaminant, as the associated aircraft performance code varies from 5 for frost, to 1 or 0 for ice, depending on whether or not the ice is wet. Despite this, very few definitions were found for frost. ICAO, Annex 14, Volume 1 does not contain a definition for frost, although its SNOWTAM indicates that frost is typically 1 mm thick or less. Transport Canada was the only source found with a definition for frost. Although the Transport Canada definition for frost is a general, scientific one, it is supplemented in Canadian training materials with the following notes which make it usable operationally.

Frost is differentiated from ice and compact snow by its refraction of light giving it an opaque presentation. The crystalline nature of frost is readily apparent to the viewer because it does not uniformly reflect light, presenting instead a “sparkle” or “glitter” effect. This is true of all forms of frost and for all depths.

7.3 Definitions and Classifications for Aviation Incident and Accident Reporting

ECCAIRS (European Coordination Centre for Accident Incident Reporting Systems) is a database system (ICAO, 2006b) developed by the European Commission that supports the ICAO ADREP 2000 taxonomy (ICAO, 2006a). This was investigated because it is another application for Runway Condition Reporting. Table 7.3 lists the classifications defined by ICAO, 2006a for use for aviation accident and incident investigation. Although there is some linkage between the definitions and classifications in ICAO Annex 14, Volume 14 (ICAO, 2004), it can be seen that the ICAO ADREP 2000 Taxonomy classifications are more general.

The project team was instructed by the PSC that the ECCAIRS system is intended primarily to aid in classifying accidents and incidents for use in a database. More detailed investigations would likely use more specific definitions such as those in the other ICAO annexes. Thus, close coordination of the taxonomies used was not considered to be required.

Table 7.4: ICAO Classifications for Aviation Incident and Accident Investigations

Id#	Description	#
8	<u>Section: Helicopter Landing Area Surface Type:</u> Ice (The surface of a helicopter landing area is solid ice) Snow (The surface of a helicopter landing area is snow- see note 2 below)	4 5
430	<u>Section: Classification: Occurrence Category:</u> LOC-G Loss of Control - Ground (Loss of aircraft control while the aircraft is on the ground) Usage Notes: The loss of control may result from a contaminated runway or taxiway (e.g., rain, snow, ice, slush)	12
120	<u>Runway Surface (General):</u> Description of the surface of the runway used by this aircraft. This includes information on the type of surface as well as on information related to runway contamination and braking action.	
504	<u>Section: Runway Surface Contamination (Contamination):</u> Ice (The runway surface was contaminated by ice) Slush (The runway surface was contaminated by slush - see note 3 below) Snow (The runway surface was contaminated by slush - see note 2 below) Water (The runway surface was contaminated by water)	3 2 4 1
506	<u>Section: Runway Surface Type (Surface Type):</u> Ice (The runway surface was ice) Snow (The runway surface was snow – see Note 2 below)	5 6

Notes:

- Source: ICAO ADREP 2000 Taxonomy; ECCAIRS 4.2.6 Data Definition Standard
- ICAO ADREP 2000 Taxonomy has the following definitions regarding snow:
 - Snow is precipitation in the form of feathery ice crystals or large agglomerations in the form of flakes. Snow is composed of millions of star-shaped hexagonal ice crystals.
 - Snow (on the ground): Dry snow can be blown if loose, or if compacted by hand, will fall apart upon release. Wet snow if compacted by hand, will stick together and tend to or form a snowball. Compacted snow has been compressed into a solid mass that resists further compression and will hold together or break into lumps if picked up.
 - Snow should be differentiated from ice.
- ICAO ADREP 2000 Taxonomy references the definition in ICAO Annex 14, Volume 14 for slush, which is included in Table 7.2.

8 RUNWAY CONDITION REPORTING PRACTICES

8.1 Operational Friction Characteristics: Reporting of Friction Measurements and Braking Action

Section 8 presents an overview. More detailed information is included in Volume 4 (Operational Friction Characteristics) of this report series.

8.1.1 Reporting for Summer Contaminants

Operational reporting for summer contaminants can be summarized as follows:

- (a) Friction is not measured on an operational basis (e.g., during a rainstorm) although functional friction measurements are made at regular intervals.
- (b) NOTAMs are issued when a runway may be “slippery when wet”.

The following information was found regarding the conditions for issuance of a NOTAM regarding “slippery when wet”:

ICAO Annex 14, Volume 1

A runway or portion thereof shall be determined as being slippery when wet when the measurements specified in 10.2.3 (in ICAO) show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.

Transport Canada

When friction measurements are below any one of the minimum levels specified, a NOTAM will be issued by the airport operator identifying the runway and the portion of the runway (by runway thirds) that may be slippery when wet. The measured friction value will not be reported in the NOTAM. The NOTAM will remain in effect until such time as subsequent measurements demonstrate the friction levels have improved to meet or exceed the specified minimums.

Australia

If the measured friction level falls below the relevant minimum friction level, the aerodrome operator must promulgate by NOTAM that the runway pavement falls below minimum friction level when wet.

Finland

A runway is determined as being slippery when wet when the runway is wet and the friction coefficient is less than 0.50.

United Kingdom

UK CAA, 2008a defines the Minimum Friction Level (MFL) as the State-set friction level below which a runway shall be notified as may be “slippery when wet”. UK CAA, 2008a provides further guidance which includes the following:

- (a) if the friction level is below the MFL, maintenance should be arranged urgently in order to restore the friction readings to an acceptable level.
- (b) if the lowest 100 m rolling average by portion is below MFL, a NOTAM shall be issued advising that the runway 'may be slippery when wet', which is in accordance with ICAO Annex 14 Volume 1.
- (c) the NOTAM should contain information to assist aircraft operators to adjust their performance calculations where possible. This should include the location and extent of where friction values are below MFL.
- (d) if the friction level is significantly below the MFL, the aerodrome operator should withdraw the runway from use for take-offs and/or landings when wet and inform the UK CAA.

8.1.2 Friction Measurement Devices for Operational Purposes

Different devices are accepted for use as summarized below.

Belgium

The following devices are used at the indicated aerodromes:

- (a) Surface Friction Tester: EBAW, EBBR, ELLX, and EBOS
- (b) Skiddometer: ELLX
- (c) Mu-meter: EBCI and EBLG

Canada

Friction measurements are only made for operational purposes in wintertime. These are made using decelerometers, most typically with the Electronic Recording Decelerometer (ERD).

Denmark

CFMEs:

- (a) Surface Friction Tester, high pressure tire (SFH) – SFH is used at Bornholm/Rønne, Esbjerg, København, Kastrup and København/Roskilde,
- (b) Surface Friction Tester, low pressure tire (SFL) – SFL is used at Odense
- (c) Mu-meter (MUM) – MUM is used at Vojens/Skrydstrup
- (d) Skiddometer (SKH) – SKH is used at Aalborg, Aarhus, Billund, and Karup

Decelerometers are also used. The Tapley meter is used at various aerodromes as indicated in the Danish AIP.

Finland

The Skiddometer BV-11 measuring equipment with a high pressure tire is used for the measurement of friction coefficients at all aerodromes.

France:

The French AIP lists the Tapley meter. France also uses the IMAG.

Germany

Germany's AIP lists the Skiddometer, the SFT, and the Tapley meter.

Iceland:

The SFT is used at Akureyri, Egilsstradir, Keflavik, and Reykjavik. Deceleration measurements made using the Tapley meter are also listed in Iceland's AIP.

Yugoslavia

Two types of instruments were used:

- (a) Continuous method, whereby the friction coefficient is recorded continuously by means of special devices constructed for this purpose; SAAB friction tester (SFT) and skidometer (SKH or SKL).
- (b) Retardation measurements with the use of an instrument that only indicates the peak value of the retardation reached during each braking; Tapley-meter (TAP).

Poland

A variety of devices is used as summarized below:

- (a) The SFT is used at aerodromes EPBY, EPGD, and EPWA.
- (b) The Griptester is used at EPKT, EPKK, EPPO, and EPSC.
- (c) The Bowmonk decelerometer is used at EPKT, EPKK, EPLL, and EPSC.
- (d) The VERICOM VC 3000 decelerometer is used at EPPO.

Norway

Norway's AIP lists the following devices:

- (a) GRT – Grip Tester;
- (b) SFH – Surface Friction Tester, High pressure tire;
- (c) SKH – Skiddometer BV 11, High pressure tire;
- (d) RUN – Runar;
- (e) VIN – Vertec Inspector; and
- (f) TAP – Tapley meter

Sweden

The devices listed in the Swedish AIP include the Skiddometer, the SFT (with a high pressure tire) and the Tapley meter.

United Kingdom

The devices listed in UKCAA, 2008a include the Mu-Meter, the Griptester, and the ASFT.

USA

The FAA accepts the following continuous friction measurement devices:

- (a) Mu Meter;
- (b) Runway Friction Tester;
- (c) Skiddometer;
- (d) Airport Surface Friction Tester;
- (e) Griptester;
- (f) Tatra Friction Tester; and
- (g) Norsemeter RUNAR.

The following decelerometers are also accepted: (i) Bowmonk; (ii) Tapley; (iii) TES ERD MK3 ; (iv) Vericom VC3000RFM,; and (v) NAC DFD.

8.1.3 Limitations Regarding the Reliability of Friction Measurements

Statements regarding this were found in the AIPs and ACs of many countries, including those listed in Table 8.1.

Table 8.1: Limitations Regarding the Reliability of Friction Measurements

	Summary
ICAO	A continuous friction measuring device (e.g. Skiddometer, Surface Friction Tester, Mu-meter, Runway Friction Tester or Grip Tester) can be used for measuring the friction values for compacted snow and ice covered runways. Decelerometers may be used on certain surface conditions e.g. Compacted snow, ice and very thin layers of dry snow. A decelerometer should not be used in loose snow or slush.
Belgium	"Unreliable" will be reported when more than 10% of a RWY surface is covered by wet ice, wet snow and/or slush. Measuring results and estimates are considered absolutely unrealistic in such situations. In reports "Unreliable" will be followed by either the friction number given by the instrument used or the estimated braking action.
Canada (for friction readings with decelerometers)	Surfaces Acceptable: (i) ice on runway; (ii) wet ice on runway surface (thin film of water on ice); (iii) compacted snow on runway surface; (iv) slush on ice; (v) loose snow on runway surface not exceeding 2.5 cm in depth; (vi) de-icing chemical solution on ice; and (vii) frost Surfaces for Which Unreliable Readings will be Obtained: friction readings with decelerometers shall not be included in the aircraft movement surface condition report where the following surface conditions exist: (i) wet runway surface (water); (ii) damp runway surface; (iii) slush on runway surface; and (iv) loose snow on runway exceeding 2.5cm in depth.

USA (FAA)	Research by the FAA at one time indicated that measurements using approved friction measuring devices would provide pilots with an objective assessment of the braking action that could be expected on the runway, but later research has not been able to identify a consistent and usable correlation between those measurements and airplane braking performance. Currently, there is no objective type of measurement of runway surface condition that has been shown to consistently correlate with airplane performance in a usable manner to the satisfaction of the FAA. The FAA no longer recommends providing friction measurements to pilots. 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.
Finland	The level of friction on a runway may be reported as a measured coefficient or an estimated level. The friction coefficient can only be reported when the conditions are within the limits appropriate to the measuring device and when the deposits on the runway do not prevent the use of the measuring device.
UK	Deployment of CFME on contaminated runways for the purpose of obtaining friction value readings is not permitted because contaminant drag on the equipment's measuring wheel, amongst other factors, will cause readings obtained in these conditions to be unreliable. A runway is termed contaminated when water deeper than 3 mm, or wet snow or slush, is present over 25% or more of the assessed area. Additionally, it must be borne in mind that, in the time taken to pass measurements to pilots, conditions may have changed. With the exception of compacted snow and ice table (Paragraph 4.4), friction value readings must not be passed to aircrew as pilots do not have the means to interpret the readings for the purpose of calculating take-off or landing performance.

8.2 Operational Friction Characteristics: Reporting of Surface Conditions

8.2.1 General Information: Forms and Formats for Runway Surface Descriptions

For reference, several reporting forms and formats are presented in Appendix D, as listed below:

- (a) The ICAO SNOWTAM Form;
- (b) Instructions for completing the ICAO SNOWTAM;
- (c) Transport Canada's Aircraft Movement Surface Condition Report (AMSCR) Form;
- (d) The form used by Geneva Airport;
- (e) The form used by Nurnberg Airport;
- (f) SNOCLO (from German AIP); and
- (g) The format from the Japanese AIP.

Appendix D also contains a detailed comparison (Table D.1) of the Runway Condition Reporting (RCR) that is done for winter contaminants by various countries.

8.2.2 Forms and Formats Used for Runway Surface Description

The reporting formats used by various countries are summarized in Table 8.2. Most use the ICAO SNOWTAM as the basis for their RCR, although individual airports customize it to suit their needs.

Table 8.2: Forms and Formats Used for Runway Surface Description

	Summary
Belgium	uses the ICAO SNOWTAM - see Appendix D for sample
Canada	uses the AMSCR form – see Appendix D for sample
Germany	the ICAO SNOWTAM (see Appendix D for sample) is incorporated in the German AIP. The responses from the questionnaires indicated that the forms used by individual airports may vary somewhat as evidenced by the sample received (Appendix D). However, the general information content is similar to the ICAO SNOWTAM. uses the SNOCLO Code – see Appendix D
Denmark	uses the ICAO SNOWTAM - see Appendix D for sample uses the SNOCLO Code – see Appendix D
Finland	uses the ICAO SNOWTAM - see Appendix D for sample uses the SNOCLO Code – see Appendix D
France	uses the ICAO SNOWTAM - see Appendix D for sample uses the SNOCLO Code – see Appendix D
Iceland	uses the ICAO SNOWTAM - see Appendix D for sample uses the SNOCLO Code – see Appendix D
Japan	has reporting format that is similar – see Appendix D
Netherlands	uses the ICAO SNOWTAM - see Appendix D for sample
Norway	uses the ICAO SNOWTAM - see Appendix D for sample
Poland	uses the ICAO SNOWTAM - see Appendix D for sample uses the SNOCLO Code – see Appendix D
Sweden	uses the ICAO SNOWTAM - see Appendix D for sample
UK	uses the ICAO SNOWTAM - see Appendix D for sample

Some inconsistencies were noted regarding the ICAO SNOWTAM and documents, as described in Section 6.

Transport Canada has its own form, the AMSCR (Appendix D). Although its RCR is similar to ICAO, there are differences. For example, Transport Canada conducts RCR for the whole runway, rather than runway thirds, which is the basis for RCR using the ICAO method. Transport Canada's procedures require reporting the conditions and average friction for the runway as a whole, for the reporting of the specific location of contaminants and for the specific location of lower friction points.

8.2.3 Summary Comparisons: Runway Surface Description

The ICAO documents state that, whenever a runway is affected by snow, slush or ice and it has not been possible to clear the precipitant fully, the condition of the runway should be assessed and the friction coefficient measured.

Summary comparisons of practices for various countries for runway surface description are presented in Table 8.3 with respect to the required accuracies for contaminant depth measurements.

Table 8.3: Specified Accuracies for Contaminant Depth Measurements

	Summary
ICAO	Whenever dry snow, wet snow or slush is present on a runway, assessment of the mean depth over each third of the runway should be made to an accuracy of approximately 2 cm for dry snow, 1 cm for wet snow and 0.3cm for slush
Norway ¹	Norway uses the following intervals for reporting the depth of the contamination on the runway: (i) Dry snow: 0.8 cm; (ii) Wet snow: 0.6 cm, and; (iii) Slush: 0.3 cm
Finland	Precision: 20 mm for dry snow, 10 mm for wet snow and 3 mm for slush

Notes:

1. This was stated as a deviation as a Supplement to the 3rd edition of ICAO, Annex 14, Volume 14.

9 FUNCTIONAL FRICTION CHARACTERISTICS

This section provides an introduction by presenting the results of the information-gathering that was done. This subject is discussed further in Volume 3 (Functional Friction Characteristics) of this report series.

9.1 Criteria Used by ICAO and Various Civil Aviation Authorities

9.1.1 Information Sources

Information was obtained by the following means:

- (a) Reviewing the ICAO documents, in particular the 4th Edition of Annex 14, Volume 1 (ICAO, 2004) and the Airport Services Manual (ICAO, 2002). As well, the Supplement to the 3rd Edition of ICAO Annex 14, Volume 1 (ICAO, 2005) was reviewed. These functional friction criteria are summarized in Appendix B.
- (b) Reviewing the AIPs of many countries. The EUROCONTROL Aeronautical Database was used as the information source for this work.
- (c) Conducting an extensive literature and information search. This included:
 - (i) Web-based searches – summary information is presented in Appendix B
 - (ii) Utilizing the results of a previous survey of Civil Aviation Authorities (CAAs) that was done recently by the project team (Comfort, Rado, and Mazur, 2009a; 2009b). Because this material is recent and relevant to this project, the relevant section of that report is copied in Appendix B.
 - (iii) Reviewing relevant reports – summary reviews are presented in Appendix B.

9.1.2 General Comments

Ideally, functional friction criteria should be based on acceptable runway friction levels for the safe operation of aircraft on wet runways. Historically, though, acceptable runway friction levels (as measured by a ground vehicle) have not been defined by the air carriers or manufacturers. As a result, countries have been forced to set up their own criteria and to assume that the level of service provided is adequate, since they have not been directed otherwise.

Consequently, there is not a direct relation between the runway maintenance criteria used by various States and aircraft performance. This gap has been recognized as an important issue by many groups, including the presently-ongoing ICAO Friction Task Force.

9.1.3 Comparisons

The runway friction criteria that are in use by Civil Aviation Authorities (CAAs) for the Design Objective Level (DOL), the Maintenance Planning Level (MPL), and the Maintenance Action Level (MAL), are listed in Tables 9.1, 9.2, and 9.3 respectively. Other criteria are listed in Tables 9.4 to 9.7.

Table 9.1: Runway Friction Criteria: Design Objective Level

	Device	Film Depth, mm	Speed = 65 km/hr Reading	Speed = 95 km/hr Reading
ICAO	Many Devices, 1 film depth (1.0 mm) and 2 speeds (65 & 95 km/h) – See Table 7.4			
Australia	Mu-Meter	1.0	0.72	0.66
	Skiddometer	1.0	0.82	0.74
	SFT	1.0	0.82	0.74
	RFT	1.0	0.82	0.74
	Tatra	1.0	0.76	0.67
	Griptester	1.0	0.74	0.64
Canada	No Criteria			
Germany	SFT	1.0	0.82	0.78
Hong Kong	Griptester	1.0	0.74	0.64
Netherlands	Skiddometer LP ¹	1.0	0.82	0.74
	Skiddometer HP ²	1.0	0.70	0.60
	DWW Trailer	1.0	0.80	0.60
UK	See note 3			
USA (FAA)	Many Devices, 1 film depth (1.0 mm) and 2 speeds (65 & 95 km/h) – See Table 7.6			
Former Yugoslavia	Many Devices, 2 film depths and 3 speeds – See Table 7.7			

Notes:

1. Skiddometer LP refers to the Skiddometer BV11 being operated with the smooth AST E1551 tire at 210 kPa.
2. Skiddometer HP refers to the Skiddometer BV11 being operated with the ribbed aero tire at 700 kPa.
3. The table below is taken from UK CAA, 2008a.

Table 3 Friction Level Values

	Test speed	Test water depth	Test tyre type	DOL	MPL	MFL
Mu-Meter	65 kph	0.50 mm	ASTM E670 ¹	0.72 or greater	0.57	0.50
Grip Tester	65 kph	0.25 mm	ASTM E1844 ²	0.80 or greater	0.63	0.55
ASFT	65 kph	1.00 mm	ASTM E1551 ³	0.74 or greater	0.47	0.34

1. This is the Standard Test Method for Side Force Friction on Paved Surfaces Using the Mu-Meter, which includes the specification for the Mu-Meter test tyre.
2. This is the Standard Specification for A Size 10 x 4-5 Smooth-Tread Friction Test Tire, which is the tyre used by the GripTester.
3. This is the Standard Specification for Special Purpose, Smooth-Tread Tire, Operated on Fixed Braking Slip Continuous Friction Measuring Equipment, which is the tyre used by the CFMEs like the ASFT.

Table 9.2: Runway Friction Criteria: Maintenance Planning Level

	Device	Film Depth, mm	Speed = 65 km/hr Reading	Speed = 95 km/hr Reading
ICAO	Many Devices, 1 film depth (1.0 mm) and 2 speeds (65 & 95 kmh) – See Table 7.4			
Australia	Mu-Meter	1.0	0.52	0.38
	Skiddometer	1.0	0.60	0.47
	SFT	1.0	0.60	0.47
	RFT	1.0	0.60	0.54
	Tatra	1.0	0.57	0.52
	Griptester	1.0	0.53	0.36
Canada: Whole Runway	SFT Griptester ³ Griptester ³	0.5 0.5 0.25	0.60 0.48 0.60	
Canada: Lowest 100 m	SFT: treaded tire SFT: smooth tire Griptester ³	0.5 0.5	0.50 0.40	
Germany	SFT	1.0	0.60	0.51
Hong Kong	Griptester	1.0	0.53	0.36
Netherlands	Skiddometer LP ¹	1.0	0.60	0.47
	Skiddometer HP ²	1.0	0.50	0.40
	DWW Trailer	1.0	0.60	0.40
UK	See note 4			
USA (FAA)	Many Devices, 1 film depth (1.0 mm) and 2 speeds (65 & 95 kmh) – See Table 9.6			
Former Yugoslavia	Many Devices, 2 film depths and 3 speeds (65, 95 and 130 kmh) – See Table 9.7			

Notes:

1. Skiddometer LP - Skiddometer BV11 operated with the smooth ASTM E1551 tire at 210 kPa.
2. Skiddometer HP - Skiddometer BV11 operated with the ribbed aero tire at 700 kPa.
3. Transport Canada's ASC contains cautionary notes about using the Griptester, and states that in the event of a discrepancy, readings from the SFT would govern.
4. The table below is taken from UK CAA, 2008a.

Table 3 Friction Level Values

	Test speed	Test water depth	Test tyre type	DOL	MPL	MFL
Mu-Meter	65 kph	0.50 mm	ASTM F670 ¹	0.72 or greater	0.57	0.50
Grip Tester	65 kph	0.25 mm	ASTM E1844 ²	0.80 or greater	0.63	0.55
ASFT	65 kph	1.00 mm	ASTM E1551 ³	0.74 or greater	0.47	0.34

1. This is the Standard Test Method for Side Force Friction on Paved Surfaces Using the Mu-Meter, which includes the specification for the Mu-Meter test tyre.
2. This is the Standard Specification for A Size 10 x 4-5 Smooth-Tread Friction Test Tyre, which is the tyre used by the Griptester
3. This is the Standard Specification for Special Purpose, Smooth-Tread Tyre, Operated on Fixed Braking Slip Continuous Friction Measuring Equipment, which is the tyre used by the CFMEs like the ASFT.

Table 9.3: Runway Friction Criteria: Maintenance Action Level

	Device	Film Depth, mm	Speed = 65 km/hr Reading	Speed = 95 km/hr Reading
ICAO	Many Devices, 1 film depth (1.0 mm) and 2 speeds (65 & 95 km/h) – See Table 9.4			
Australia	Mu-Meter	1.0	0.42	0.26
	Skiddometer	1.0	0.50	0.34
	SFT	1.0	0.50	0.34
	RFT	1.0	0.50	0.41
	Tatra	1.0	0.48	0.42
	Griptester	1.0	0.43	0.24
Canada: Whole Runway	SFT Griptester ³ Griptester ³	0.5 0.5 0.25	0.50 0.37 0.50	
Canada: Lowest 100 m	SFT Griptester ³ Griptester ³	0.5 0.5 0.25	0.30	
France	Many Devices, 1 film depth (1.0 mm), 3 tire types, and 2 speeds – See Table 9.5			
Germany	SFT	1.0	0.50	0.35
Hong Kong	Griptester	1.0	0.43	0.24
Netherlands	Skiddometer LP ¹	1.0	0.50	0.34
	Skiddometer HP ²	1.0	0.40	0.32
	DWW Trailer	1.0	0.50	0.32
UK	See note 4			
USA (FAA)	Many Devices, 1 film depth (1.0 mm) and 2 speeds (65 & 95 km/h) – See Table 9.6			
Former Yugoslavia	Many Devices, 2 film depths and 3 speeds (65, 95 and 130 km/h) – See Table 9.7			

Notes:

1. Skiddometer LP - Skiddometer BV11 operated with the smooth ASTM E1551 tire at 210 kPa.
2. Skiddometer HP - Skiddometer BV11 operated with the ribbed aero tire at 700 kPa.
3. Transport Canada's ASC contains cautionary notes about using the Griptester, and states that in the event of a discrepancy, readings from the SFT would govern.
4. UK CAA, 2008a contains the following table.

Table 3 Friction Level Values

	Test speed	Test water depth	Test tyre type	DOL	MPL	MFL
Mu-Meter	65 kph	0.50 mm	ASTM E670 ¹	0.72 or greater	0.57	0.50
Grip Tester	65 kph	0.25 mm	ASTM E1844 ²	0.80 or greater	0.63	0.55
ASFT	65 kph	1.00 mm	ASTM E1651 ³	0.74 or greater	0.47	0.34

1. This is the Standard Test Method for Side Force Friction on Paved Surfaces Using the Mu-Meter, which includes the specification for the Mu-Meter test tyre.
2. This is the Standard Specification for A Size 10 x 4-5 Smooth-Tread Friction Test Tire, which is the tyre used by the Griptester
3. This is the Standard Specification for Special Purpose, Smooth-Tread Tire, Operated on Fixed Braking Slip Continuous Friction Measuring Equipment, which is the tyre used by the CFMEs like the ASFT.

Table 9.4: Runway Friction Criteria Specified in ICAO Annex 14, Volume 1

Test equipment	Test tire		Test speed (km/h)	Test water depth (mm)	Design objective for new surface	Maintenance planning level	Minimum friction level
	Type	Pressure (kPa)					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Mu-meter Trailer	A	70	65	1.0	0.72	0.52	0.42
	A	70	95	1.0	0.66	0.38	0.26
Skiddometer Trailer	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Surface Friction Tester Vehicle	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Runway Friction Tester Vehicle	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.54	0.41
TATRA Friction Tester Vehicle	B	210	65	1.0	0.76	0.57	0.48
	B	210	95	1.0	0.67	0.52	0.42
GRIPTESTER Trailer	C	140	65	1.0	0.74	0.53	0.43
	C	140	95	1.0	0.64	0.36	0.24

Table 9.5: French Maintenance Action Criteria (STBA Journal 159 – 2006 Annex 1)

Dispositif de mesure	Pneu d'essai		Vitesse durant l'essai (km/h)	Epaisseur d'eau durant l'essai (mm)	Niveau minimal de frottement
	Type	Pression (kPa)			
Mumètre MK6	A	70	65	1,0	0,30
	A	70	95	1,0	0,20
Skiddomètre BV11	B	210	65	1,0	0,41
	B	210	95	1,0	0,28
SFT	B	210	65	1,0	0,40
	B	210	95	1,0	0,27
RFT	B	210	65	1,0	0,42
	B	210	95	1,0	0,28
SARSYS STFT	B	210	65	1,0	0,37
	B	210	95	1,0	0,24
DMAG	C	150	65	1,0	0,30
	C	150	95	1,0	0,20

(A) Pneu d'essai ASTM (American Society for Testing and Materials), à bande de roulement lisse conforme à la spécification E670

(B) Pneu d'essai ASTM (American Society for Testing and Materials), à bande de roulement lisse conforme à la spécification E1551

(C) Pneu d'essai AIPCR (Association Internationale des Congrès de la Route) à bande de roulement lisse

Table 9.6: Runway Friction Levels Specified in FAA AC 150/5320-12C (FAA, 2008)

	40 mph			60 mph		
	Minimum	Maintenance Planning	New Design/ Construction	Minimum	Maintenance Planning	New Design/ Construction
Mu Meter	.42	.52	.72	.26	.38	.66
Dynatest Consulting, Inc. Runway Friction Tester	.50	.60	.82	.41	.54	.72
Airport Equipment Co. Skiddometer	.50	.60	.82	.34	.47	.74
Airport Surface Friction Tester	.50	.60	.82	.34	.47	.74
Airport Technology USA Safegate Friction Tester	.50	.60	.82	.34	.47	.74
Findlay, Irvine, Ltd. Griptester Friction Meter	.43	.53	.74	.24	.36	.64
Tatra Friction Tester	.48	.57	.76	.42	.52	.67
Norsemeter RUNAR (operated at fixed 16% slip)	.45	.52	.69	.32	.42	.63

Table 9.7: Runway Friction Levels Specified in the Yugoslavian AIP

Test Equipment	Design objective for new Runway	Surface Maintenance Level	Water film depth (mm)	Test speed (km/h)
MU-meter method 1	0.7	0.5	1	65L
method 2	0.64	0.4	1	95L
	0.65	0.45	0.5	130L
Skidometer and	0.7	0.5	1	65H
Surface Friction	0.6	0.4	1	95H
Tester	0.6	0.35	1	130H
Skidometer	0.8	0.67	1	65L
Surface Friction Tester and	0.8	0.6	1	65L
Runway Friction Tester	0.7	0.5	1	95L

Notes:

1. The values in columns 2 and 3 are averaged values representative of the runway or significant points thereof.
2. L : with low pressure tire
3. H : with high pressure tire

In general, the National Airport Authorities (NAAs) follow the criteria set out in ICAO, Annex 14, Volume 1, although they tend not to implement them fully, and there are differences. One airport authority commented that the ICAO guidelines are followed to the extent that they agree with them. Some of the differences encountered are listed in the subsequent sections.

9.1.3.1 General Basis

ICAO, Annex 14, Volume 1 specifies the following runway friction criteria:

- (a) The Design Objective Level (DOL) for new or re-surfaced pavements;
- (b) The Maintenance Planning Level (MPL) – maintenance actions must be planned when the runway friction falls below this level; and
- (c) The Maintenance Action Level (MAL) – maintenance actions must be carried out when the runway friction falls below this level.

All countries presently follow this general approach in that they base their runway friction standards on friction measurements made with a ground vehicle.

The most significant deviation is that one CAA (i.e., Norway - Avinor) has recently established regulations for runway maintenance that are not based on friction measurements. This is discussed subsequently.

Other differences are that while all countries have a MPL and a MAL, not all of them utilize a DOL. Also, there is some variation among the CAAs with respect to the runway length being considered. Transport Canada is the only CAA to have different criteria for the average friction reading for the whole runway, versus the average friction regarding for the lowest 100 m section. Other CAAs utilize various definitions regarding the applicable length of the runway (Appendix B).

9.1.3.2 Number of Devices Accepted

Typically, CAAs only accept one CFME (Continuous Friction Measuring Equipment) device, or perhaps two to three. Most often, the SFT was identified as the CFME on which the criteria were based. Transport Canada accepts two devices (i.e., the SFT and the Griptester) but states that in the event of a discrepancy, readings by the SFT would govern. The UK has standards (CAP 683 - UK CAA, 2008a) that are based on: (a) the Griptester at 0.25 mm water film depth; (b) the ASFT at 1.0 mm water film depth; and (c) the Mu-Meter at 0.5 mm water film depth.

9.1.3.3 Other Criteria for Runways Based on Texture and Pavement Characteristics

One CAA (i.e., the Norwegian Civil Aviation Administration – Avinor) has developed criteria based on the texture and pavement characteristics of the runway, which were implemented into regulations on July 1, 2009 (ref.: G. Lange, Avinor, personal communication). Figure 9.1 summarizes the changes that are specified. It should be recognized that this is in progress and some work remains such as (G. Lange, Avinor, personal communication):

- (a) Criteria for rubber removal need to be developed; and
- (b) Criteria need to be established to define the cases where grooves are not functioning properly, such as for depth, polishing, rutting, etc.

It should be further noted that the material shown in Figure 9.1 is an unofficial translation, and that, when available in the future, official translations should be referenced.

Guidance material to the paragraphs (BSL E 3-2 design)



§ 2-6 Strength and surface on runways

- (3) Guidance material for surface texture measurements are given in ICAO Doc 9137 Aerodrome Services Manual Part 2.

Grooves that shall comply with the requirement of good breaking action should be perpendicular to the runway centre line. The grooves should be scored with suitable equipment that avoid any damage to the corners groove/surface.

The width and depth of the grooves should be 5-7mm and the in-between spacing should be less than 125 mm. If the longitudinal slope of any part of the runway is less than 0,3%, additional longitudinal grooves should be constructed for each 1,5 m.

Guidance material (to BSL E 4-2 Airport services)



B. Note (same as for BSL E 3-2)

Grooves that shall comply with the requirement of good breaking action should be perpendicular to the runway centre line. The grooves should be scored with suitable equipment that avoid any damage to the corners groove/surface.

The width and depth of the grooves should be 5-7mm and the in-between spacing should be less than 125 mm. If the longitudinal slope of any part of the runway is less than 0,3%, additional longitudinal grooves should be constructed for each 1,5 m.

Figure 9.1: Changes to Norwegian Regulations (G. Lange, Avinor, pers. comm'n)

Evenness— New recommendations in Annex 14, oct 2009



- Evenness: 3 mm / 3 m straight edge
- 0,45 G (ie 25-30 mm / 45 m "straight edge").
- New Annex 14 Attachment A item 5 from autumn 2009. Recommendation for maximum unevenness with different straight edge lengths:
 - 8 cm / 45 m straight edge
 - 6 cm / 20 m straight edge
 - 4 cm / 9 m straight edge

Guidance material to NCAA's regulation Aerodrome operations (BSL E 4-1)



B. Note to § 8

If a runway is not grooved, the macrotexture shall be measured periodically in order to be sure that the macrotexture is not below 1,0 mm. On a majority of the norwegian airports it is sufficient to measure the macrotexture once a year, but on some runways, rubber deposit can reduce the wet friction. In such occasions wet friction measurements can be added to the texture measurements.....

If the runway is grooved, the operator have to inspect the grooves periodically to make sure that the grooves has the proper function. Hence, evenness, width and depth of the grooves are important in addition to rubber deposit or other materials. On a majority of the norwegian airports it is sufficient to control the grooves once a year.

Figure 9.1 (cont'd): Norwegian Regulations (G. Lange, Avinor, pers. comm'n)

9.1.3.4 Test Parameters: Testing at One versus Two Speeds

Most countries require tests at two speeds (i.e., 65 and 95 km/hr), although some only test at one speed. For example, Hong Kong and Canada only conduct tests at 65 km/hr.

9.1.3.5 Test Parameters: Water Film Depth

Most countries use 1.0 mm film depth. Canada is one exception as it conducts testing at 0.5 mm film depth. The water film depths used by the UK CAA vary from 0.25 mm to 1.0 mm depending on the device used (Table 9.1 – note 3). The standards for the former Yugoslavia (Table 9.7) contain criteria for depths of both 1.0 mm and 0.5 mm.

9.1.3.6 Test Parameters: Tire Types and Pressure

The CAA for the Netherlands has different criteria for different tires for the same device, as follows (Appendix B):

- (a) Skiddometer BV-11 with the ribbed aero tire at 700 kPa; and
- (b) Skiddometer BV-11 with the smooth ASTM E1551 tire at 210 kPa.

The standards for Yugoslavia (Table 9.7) also contain criteria for high pressure and low pressure tires.

9.2 Information Obtained from Airports from the Questionnaires

Table 9.8 summarizes information received from the questionnaires regarding the criteria used for runway maintenance (i.e., functional friction), and the specifics of the friction measurements used. The airports follow the regulations set forth by the State (i.e., the CAA), which generally follow the ICAO guidelines, subject to the observations and comments made in the previous section.

Table 9.8: Information Obtained From Questionnaires

Parameter	Speed, kmh	A Swiss Airport	A USA Airport	A German Airport	A German Airport	A German Airport	Canadian Airports ²
Runway Friction Criteria							
Design Objective Level	65		0.82			ICAO	See
	95			0.78 speed ¹ ?	0.74	Annex 14	Section
Maint. Planning Level	65	0.60	0.60			Volume 1	9.1
	95			0.51 speed ¹ ?	0.47	Followed	
Maint. Action Level	65	0.50	0.50				
	95			0.35 speed ¹ ?	0.34		
Test Details							
Speed, km/h		65	65	65 & 96	96	65 & 96	
Device Used		ASFT, Saab 9000	NAC DFT	SARYS SFT	SAAB 9-5 SFT with SARYS	SFT	note 2
Water Depth		1.0 mm	1.0 mm	1.0 mm	1mm	1mm	050 mm
Tire Type		Swiss Standards	ASTM		ASTM E1844	ICAO Annex 14	note 2
Tire Pressure		210 kPa	30 psi	210 kPa	210 kPa	700 kPa	note 2

Notes:

1. The test speed for the various criteria was not specified by the survey respondent.
2. This is a generic response that was prepared by the project team. The devices used are the Saab SFT, the SARYS SFT, and the Griptester. The test tires used for these devices vary.

10 METHODS FOR HARMONIZING DIFFERENT TAXONOMIES

10.1 Issues Related to Harmonization

These include the following:

- (a) In the past, airline operators/aircraft manufacturers have not clearly defined their minimum operational requirements for safe aircraft takeoffs and landing on wet and/or winter contaminated runway surfaces.

The work that has been ongoing through the TALPA ARC is considered to be a major step forward as input was obtained from a wide range of groups including aircraft manufacturers, airlines, and regulatory bodies. This has led to the proposed TALPA ARC Runway Assessment Matrix (described in Section 4), which if implemented, would provide a direct relationship between aircraft performance and the reported runway conditions.

- (b) In the absence of clear direction from airline operators and aircraft manufacturers in the past, airport governing bodies and the airports section within ICAO have made their best efforts to establish criteria. This process has resulted in a “history” with different devices and approaches being used by various countries. Tests have shown that the various devices give different readings on the same surface, which is to be expected given that they employ different measurement principles and approaches. Previous attempts at harmonization have not produced a satisfactory or universally-accepted outcome for either summer contaminants or winter contaminants.

- (c) This has led to outcomes and views such as the following:

- (i) There is a divergence of views regarding whether or not the readings from friction-measuring devices can be correlated with aircraft performance, at least to a sufficient degree of reliability and accuracy that would be considered to be of operational value. Recent initiatives are trending towards de-emphasizing friction measurements for operational applications. However, some airlines utilize ground friction measurements as a basis for making operational assessments of aircraft performance. It is noted though, that these airlines limit their approaches to measurements made using a single ground friction-measuring device. They do not attempt to accommodate the many friction-measuring devices that presently exist.
- (ii) The role of friction-measurement devices should perhaps be limited to maintenance evaluations. This view leaves a gap for operational runway condition reporting.
- (iii) Runway Condition Reporting (RCR) for operational purposes may perhaps be best done based solely on descriptions of the surface condition and the runway pavement characteristics.

- (iv) Runway friction measurement for operational purposes is most useful to air carriers and pilots when readings are provided from a single make of device when used in accordance with detailed, specified procedures.
- (d) Harmonization is a combined technical and political process. The work conducted in this project has concentrated on technical aspects of the problem. However, for harmonization to be achieved, policy decisions must also be made, recognizing that the overall goal of runway condition reporting, and harmonization of the practices thereof, is to enhance aviation safety.

10.2 Introduction and Contexts for Reporting

10.2.1 Contexts for Runway Surface Condition Reporting

It is important to recognize that friction measurements and Runway Condition Reporting (RCR) is done in various contexts as summarized in Table 10.1. Comments regarding differences among the taxonomies used must be made with respect to the various contexts for RCR, and the criteria they impose in regard to type of contaminant, accuracy, frequency of reporting and measurement, etc.

Table 10.1: General Contexts for Runway Surface Condition Reporting

General Type of Contaminants	Objective: Functional Friction Assessment	Objective: Operational Friction Assessment
Non-Winter (e.g., wet)		not done in practice, except for evaluations of “slippery when wet”
Winter (e.g., snow, slush, ice)	not done in practice	

10.2.2 RCR in the Context of Functional Friction

The overall goal in this case is to help define the aerodrome operations necessary for maintaining a runway pavement surface with adequate friction. This can potentially be accomplished by a variety of means, such as those illustrated in Figure 10.1.

The approach on the left hand column of Figure 10.1 (i.e., based on runway friction measurements) is the current state-of-practice for almost all countries. As described in Section 9, one country (i.e., Norway) has established functional criteria based on measurements of the runway texture and pavement characteristics. The information-gathering done in this project showed that the option depicted in the right hand column of Figure 10.1 (i.e., a combined approach) is not part of the established procedures for any country at present, with respect to maintenance planning or maintenance action. However, some countries do include texture criteria in their specifications for new or re-surfaced pavements.

Obviously, the relative significance of items such as those below depend greatly on which general approach is being utilized to achieve the overall goal of defining the actions required:

- (a) Friction measurements;
- (b) Measurements of runway texture and pavement characteristics

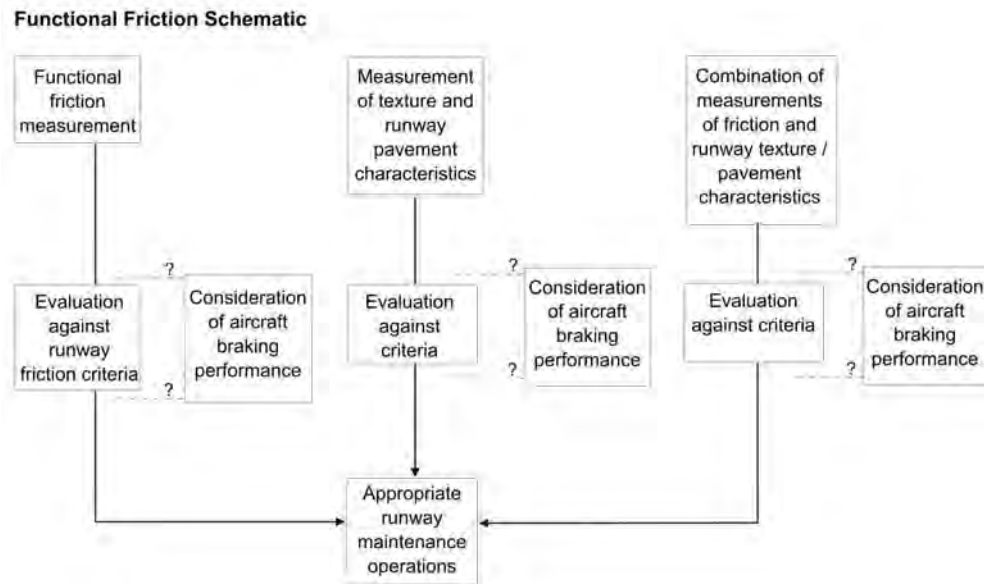


Figure 10.1: RCR in the Context of Functional Friction

10.2.3 RCR in the Context of Operational Friction

The overall goal in this case is to provide information that is useful to aircraft operations such as take-offs or landings on a given runway, and aerodrome operations in that context as well, such as runway maintenance and the potential closure of a runway. Again, this can be potentially accomplished by a variety of means, such as those illustrated in Figure 10.2.

As shown in previous sections of this report, a variety of information is transmitted to pilots at present, depending on the type of contaminant and the country, as generally described below:

- (a) Runway surface descriptions, including the contaminant type and depth;
- (b) Friction information in some form, whether it be general indications of the braking action or the actual measurements from ground vehicles; and
- (c) Reports from pilots for previous landings (PIREPs)

The above options are generally captured in the approaches illustrated in the left-hand and in the centre columns of Figure 10.2. The third option on the right hand column of Figure 10.2 (i.e., a combined approach using for example, an index based on both surface descriptions and friction measurements) is not done, and is beyond the current state-of-the-art.

Obviously, the relative significance of items such as those below depends greatly on which general approach is being utilized.

- (a) Friction measurements, or general indications of the braking action; and
- (b) Measurements or observations of the runway surface condition, such as the contaminant type and depth

With respect to PIREPs, it is recognized that while they may form a useful component of the overall information package, they are not sufficient as a standalone measure to provide runway condition reports. This is evident by inspection because:

- (a) They are unavailable to the first pilot landing on a given surface;
- (b) They are aircraft-specific.
- (c) They may not be current.

Thus, there is a need for runway condition reporting as well, whether it be based on surface condition descriptions, or friction information, or both.

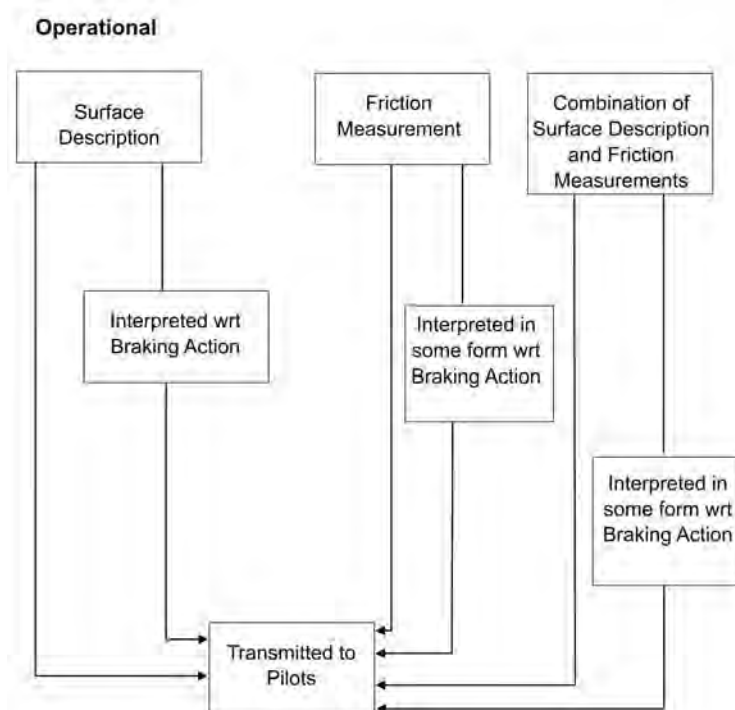


Figure 10.2: RCR in the Context of Operational Friction

Legend: “wrt” indicates with respect to

10.3 Potential Methods for Harmonization and Assessments of Their Feasibility

10.3.1 General Objectives

Primarily, the harmonized taxonomies must be suitable for the intended purposes. This implies that they are sufficiently accurate, measurable, and quantitative that they are usable for functional or operational reporting of conditions, taking into account the constraints that this imposes such as timeliness, accuracy, and reproducibility. As well, the harmonized taxonomies must ensure that different observers consistently and accurately report the same runway surface conditions in the same way.

Of course, as discussed in the previous section, the taxonomies are likely to get used in various ways, which imposes differing constraints, so it may not be feasible or advisable to have one set of definitions for all cases. This option has been considered.

While this work concentrates on terms used to describe the implications of runway coefficient of friction, it is recognized that terminology must also address aircraft ground performance as it is affected by physical obstacles such as windrows and snow drifts and by impingement drag.

10.3.2 General Options

Fundamentally, the options for developing harmonized definitions include the following, or combinations of them:

- (a) One approach would be to maintain the status quo. This maintains consistency with current practices, but does not address the concerns that are being raised regarding safety issues that may result from variations in RCR practices among different groups.

A related approach would be to develop a definition for each surface condition using terms that are commonly found in existing definitions. This solution offers the most potential for “common ground”, with the advantage that it offers the best opportunity for maintaining consistency with existing practices. However, this would not necessarily address the inconsistencies that are present today, or the fundamental needs of practical application.

- (b) A second general method would be to make the definitions for each condition more scientific/quantitative, perhaps by using inputs from existing definitions that include measurable parameters such as density, temperature or specific gravity. A precise value, or range of values, would then define the condition. This approach has the advantage of precision and reproducibility, but in all probability, it would be impractical at airports during flight operations.

- (c) A third, contrary approach would be to have primarily practical/subjective definitions that are determined by a “most qualified” user group. The primary user groups include aircraft manufacturers, air carriers, pilots, ATC, airfield inspection staff, and accident/incident investigators. This method has the advantage of incorporating “expert” opinion, but it may miss the mark by not addressing the requirements of all user groups, regardless of the consultation processes used. This reflects the diversity of uses for the taxonomies. Again, it may not be feasible or advisable to have one set of definitions for all cases.

10.3.3 Taxonomies for Aviation Accident and Incident Investigations

The taxonomies used for aviation accident and incident investigation, which are described in ICAO ADREP 2000 Taxonomy (ICAO, 2006a), were investigated in this project as well. It was found that these are more general than the ones in operational or functional use for RCR at airports. The project team was advised by the PSC that these definitions are primarily intended to serve as part of a basic classification system, and they do not need to be harmonized with the ones in use for RCR at airports. A more precise set of definitions is believed to be required for operational or functional use for RCR at airports.

Consequently, they are not discussed further here, as this will not provide a feasible way forward for harmonizing the taxonomies used.

10.3.4 Harmonization Strategy Based on Relationships to Aircraft Performance

This is considered to be the most appropriate basis for any harmonization of taxonomies, whether it be for the purpose of either functional friction characteristics or operational friction. Given that the end objective of any Runway Condition Reporting (RCR) is to enhance aviation safety, it is obvious that the RCR must be done in a way that is meaningful to aircraft performance. It is equally important that the requirements for RCR can be fully complied with at airports during operational conditions.

It is noted that the proposed TALPA ARC system is the only one that has been developed taking into account the relative effect on aircraft performance explicitly. This is a very strong advantage. As a result, the proposed TALPA ARC system has been considered to be a good basis on which to develop recommendations in this study, recognizing that the TALPA ARC will be undergoing testing during the 2009-2010 winter, which may lead to some changes.

10.4 **Fundamental Definitions: Contaminant and Runway Condition Categories**

The fundamental definitions are those used for:

- (a) A contaminant; and
- (b) Dry, wet and contaminated runways

10.4.1 Runway Condition Categories

Obviously, the cases used should match those used for aircraft certification, and for assessments of aircraft performance. The information-gathering survey showed that aircraft certification requirements vary between EASA and the FAA as outlined below:

EASA

Aircraft manufacturers are required to provide certification data for aircraft for:

- (a) Dry;
- (b) Wet; and
- (c) Contaminated runways, which include standing water, slush, ice, wet snow, dry snow, and compacted snow.

FAA

Currently, aircraft manufacturers are only required to provide certification data for aircraft for dry and wet surfaces. It is noted however, that the FAA intends to proceed with the rulemaking process for the proposed TALPA ARC system, which would require aircraft manufacturers to supply certification data for dry, wet, and contaminated runways. Contaminated runways would be defined within the TALPA ARC system as listed below (Ostronic, 2009):

A runway is contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the reported length and the width being used is covered by water, slush, frost or snow greater than 0.125 inches (3 mm), or any compacted snow or ice.

The above three runway condition categories, and definition, are generally aligned with the information in FAA Safety Alert for Operations (SAFO) #06012 which is directed to air carriers regarding landing performance of turbojets on contaminated runways. It contains the following information:

Runway Surface Conditions. The state of the surface of the runway: either dry, wet, or contaminated. A dry runway is one that is clear of contaminants and visible moisture within the required length and the width being used. A wet runway is one that is neither dry nor contaminated. For a contaminated runway, the runway surface conditions include the type and depth (if applicable) of the substance on the runway surface, e.g., standing water, dry snow, wet snow, slush, ice, sanded, or chemically treated.

Hence, the first basic requirement for a harmonized set of definitions should be to:

- (a) Follow the same set of generic runway condition categories; and
- (b) Contain the same definitions for them, including what constitutes a contaminant.

With respect to the first requirement, the survey showed that the aviation community is trending towards the same set three types of runway condition cases (i.e., dry, wet, and contaminated). It is noted that ICAO Annex 6 also defines these same three categories of runway surface condition, as follows:

Runway surface condition: The state of the surface of the runway: either dry, wet, or contaminated.

- (a) *Contaminated runway: A runway is contaminated when more than 25 per cent of the runway surface area (whether in isolated areas or not) within the required length and width used is covered by:*
 - (i) *water, or slush more than 3 mm (0.125 in) deep;*
 - (ii) *loose snow more than 20 mm (0.75 in) deep; or*
 - (iii) *compacted snow or ice, including wet ice.*
- (b) *Dry runway: A dry runway is one which is clear of contaminants and visible moisture within the required length and the width being used.*
- (c) *Wet runway: A runway that is neither dry nor contaminated.*

Various definitions were found from other sources for each case as listed below:

Contaminated Runway

The definitions found include those listed below:

Transport Canada

Its Advisory Circular considers a runway to be contaminated when any portion of the runway surface within the published length and width is covered or partially covered by a contaminant.

Furthermore, Transport Canada's Advisory Circular (which is intended to be applicable to the winter case) defines a contaminant to mean the presence of any uncontrolled material on the surface of a movement area including water, snow, frost, ice, slush, sand, and ice control chemicals.

JAR-OPS and EU-OPS

They do not differentiate between winter and non-winter contaminants, and have the following definition:

Contaminated Runway: A runway is considered to be contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the required length and width being used is covered by the following:

Surface water more than 3.0mm [millimetres] (0.125in[inch]) deep, or by slush or loose snow, equivalent to more than 3.0mm (0.125in) of water;

Snow which has been compressed into a solid mass which resists further compression and will hold together or break into lumps if picked up (compacted snow); or,

Ice, including wet ice.

TALPA ARC

A runway is contaminated when more than 25 percent of the runway surface area (whether in isolated areas or not) within the reported length and the width being used is covered by water, slush, frost or snow greater than 0.125 inches (3 mm), or any compacted snow or ice.

Wet Runway

The definitions found include those listed below:

JAR OPS and EU OPS

A runway is considered wet when the runway surface is covered with water, or equivalent, less than specified in subparagraph (a)ii or when there is sufficient moisture on the runway surface to cause it to appear reflective, but without significant areas of standing water.

UK

A runway that is soaked but no significant patches of standing water are visible. Note: standing water is considered to exist when water on the runway surface is deeper than 3mm. Patches of standing water covering more than 25 percent of the assessed area will be reported as WATER PATCHES and should be considered as CONTAMINATED.

TALPA ARC

A runway is wet when it is neither dry nor contaminated.

Dry Runway

The definitions found include those listed below:

Transport Canada

Means no observed contamination on the movement areas

JAR OPS and EU OPS

A dry runway is one which is neither wet nor contaminated, and includes those paved runways which have been specially prepared with grooves or porous pavement and maintained to retain “effectively dry” braking action even when moisture is present.

UK

The surface is not affected by water, slush, snow or ice. NOTE: Reports that the runway is dry are not normally passed to pilots. If no runway surface report is passed, the runway can be assumed to be dry.

TALPA ARC

A runway is dry when it is not contaminated and at least 75 percent is clear of visible moisture within the reported length and width being used.

10.4.2 Similarities and Differences Among the Various Definitions**10.4.2.1 *Runway Condition Categories***

The above discussion shows that there is considerable uniformity with respect to the runway surface condition categories (i.e., dry, wet or contaminated). It is recommended that this 3-point subdivision be maintained, particularly since there are parallel efforts to align the aircraft certification process along these same lines (through the proposed TALPA ARC system).

With respect to the definitions for each runway surface condition class, there are considerably more similarities than differences among the definitions above.

10.4.2.2 Contaminated Runway

10.4.2.2.1 Contaminants Included

For a contaminated runway, the only difference of significance among the definitions is believed to be which surfaces are specifically named or listed. Transport Canada is the only agency that lists sand as a contaminant. Transport Canada and the FAA (SAFO Alert # 06125) are the only ones to include ice control chemicals as contaminants. Other ones of concern that are not listed include:

- (a) Other layered contaminants such as loose snow over compacted snow or ice; and
- (b) Various sanded surfaces, such as sanded ice, sanded dry ice, sanded wet compacted snow and sanded dry compacted snow; and
- (c) Various other materials, such as dirt or debris, rubber build-up, and other infrequent frozen contaminants, such as frozen airborne residue from industrial processes.

It is well known that a very large number of surface conditions occur in practice, especially for winter contaminants. Definitions utilizing precise quantitative scientific criteria based on the properties of these various conditions would generate a huge number of cases. This would lead to a system that would be unworkable in an operational airport environment for defining runway surface conditions.

Furthermore, the trends indicated from the TALPA ARC process are that fewer categories, rather than more, would suffice, as the same aircraft performance code would be produced by the presently-proposed TALPA ARC matrix for several different contaminant types. (See Section 4 for further information).

To avoid confusion and variations among the reported conditions, some flexibility is believed to be preferable with respect to the surface condition classes that are considered to be contaminants. The use of more generic terms which encompass a broad range of surface types would probably be easier to implement in practice, and would involve less chance for variations among the runway inspection ground crew. This might lead to more uniformity, and simplify training issues. This is discussed further subsequently.

10.4.2.2.2 Contaminant Depths

There is agreement among the various definitions with respect to 1/8" or 3 mm as being the critical depth above which contaminated conditions exist.

10.4.2.2.3 Runway Coverage Required to Produce Contaminated Conditions

There is general agreement among the various definitions that runways with coverage by contaminants of at least 25 percent of the reported runway length and the width being used would be considered to be contaminated.

The following exceptions were found though:

ICAO Annex 15 (ICAO, 2003) is the only exception to this statement as it contains the following information:

When ice, snow or slush is present on 10% or less of the total area of a runway, the friction coefficient will not be measured and braking action will not be estimated. If in such a situation water is present, the runway will be reported WET. Where only water is present on a runway and periodic measurements so indicate, the runway will be reported as “WET”.

Transport Canada define a runway to be contaminated when:

any portion of the runway surface within the published length and width is covered or partially covered by a contaminant

10.4.2.3 Wet Runway

The same fundamental criteria are used in the definitions from many sources:

- (a) A wet surface is one that is neither dry nor contaminated – this criterion is present in the definitions in ICAO Annex 6, the FAA’s SAFO Alert, and the proposed TALPA ARC system.
- (b) A wet surface shows discoloration due to moisture, which, along with reflection, is the traditional definition for a damp surface.

These are simple definitions to implement. For consistency, it is recommended that they be maintained.

10.4.2.4 Dry Runway

Again, the same fundamental criteria are used in the definitions from many sources. The basic criterion is that the runway is clear of visible moisture.

10.5 Surface Condition Definitions for Runways With Water on Them

There are three basic cases:

- (a) Damp;
- (b) Wet; and
- (c) Flooded, which is termed standing water by some agencies

10.5.1 Damp Conditions

The general runway surface condition classes in ICAO Annex 6, the FAA’s SAFO Alert, and the proposed TALPA ARC system (i.e., dry, wet or contaminated) remove the need for a definition of “damp”, as a damp runway would fall into the “wet” category, and would be reported as such.

However, some criteria were found where a need for a definition of damp is still required:

- (a) EASA CS-25 – this specifies that, for testing to define an aircraft’s anti-skid efficiency, the surface must be “well-soaked (i.e., not just damp)”.
- (b) EU-OPs contains the statement (in OPS 1.475 – General): *For performance purposes, a damp runway, other than a grass runway, may be considered to be dry.*
- (c) JAR-OPs and EU-OPs include an allowance for paved runways which have been specially prepared with grooves or porous pavement and maintained to retain “effectively dry” braking action even when moisture is present.
- (d) CAP 168 (UK CAA, 2008b) states that: *In wet conditions the runway surface state should be reported to pilots as “Damp”, “Wet”, “Water Patches” or “Flooded” as laid down by the CAA in the Manual of Air Traffic Services.*

Consequently, it is believed that a definition for damp should be retained, until consistency is achieved with respect to the associated performance standards.

10.5.2 Wet Conditions

The definitions for this condition are generally consistent. Wet is one of the three general runway surface condition classes in ICAO Annex 6, the FAA’s SAFO Alert, and the proposed TALPA ARC system. The basic criteria are that:

- (a) There is moisture on the surface, which is generally defined based on visibility; and
- (b) The depth of the moisture is less than 1/8 inch or 3 mm.

10.5.3 Flooded or Standing Water

These terms are used to identify water deposits exceeding 1/8” or 3 mm in depth.

Flooded or standing water conditions are considered to be a contaminated surface within the context and definitions in ICAO Annex 6, the FAA’s SAFO Alert, and the proposed TALPA ARC system for the three general runway surface condition classes (i.e., dry, wet, or contaminated). It is noted that the definitions used in these documents avoid the need for a specific definition of flooded or standing water, as they simply state define it as water exceeding 1/8 inch or 3 mm depth.

This is a simpler approach.

10.6 Surface Condition Definitions for Runways with Winter Contaminants

10.6.1 Introduction and General Comments

It is well known that a very large number of surface conditions occur in practice in winter. A precise classification system based on the physical properties of each type of condition would involve a multitude of categories and parameters, which would lead to a system that would be unworkable in an operational airport environment. Many problems would likely result such as:

- (a) For a system based on visual assessments, different runway inspectors may classify the same surface differently, depending on their perception and experience. This may result in non-uniformity and variability among runway inspection reports.
- (b) For a system based on precise, scientific measurements, operational personnel would probably not be able to measure the required physical properties rapidly enough with sufficient accuracy, to use this to distinguish different types of contaminant.

It is recognized that this issue may be potentially resolved through extensive training. The extent to which this will alleviate the problem will be partially revealed by the results of the FAA's planned tests for the proposed TALPA ARC system for the winter of 2009-2010. EASA is advised to monitor these tests closely. Nevertheless, given that most of the critical parameters in TALPA ARC (i.e., contaminant type and depth, and possibly surface temperature if the airport is not equipped with in-pavement runway sensors) will be estimated rather than measured, there is considerable potential for non-uniformity.

It is noted though, that the TALPA ARC process has shown that there is no need to define a large number of types of winter contaminants because there is not a corresponding effect on aircraft performance. The same aircraft performance code is generated by several different contaminant types in the proposed TALPA ARC Runway Assessment Matrix. This is a very important outcome of the TALPA ARC process. It represents an important step forward as it helps to define the key surfaces while at the same time offering potential for simplifying the overall reporting process.

The TALPA ARC process has resulted in only seven aircraft performance codes being defined, as described in Section 4. In fact, a close examination of the runway assessment matrix proposed by TALPA ARC leads to the conclusion that fewer surface condition classes would suffice as the same aircraft performance code is produced by several contaminant types. The contaminant types can be broadly defined as follows:

- (a) Loose contaminants such as dry snow or wet snow;
- (b) Liquid contaminants such as water or slush;
- (c) Solid contaminants such as frost, ice or compacted snow; and
- (d) Layered contaminants

10.6.2 Loose and Liquid Contaminants

A detailed review of the TALPA ARC Runway Assessment Matrix is presented in Section 4. It showed the following:

A – Different Categories or Types of Loose Snow

The same aircraft performance code would be generated for all depths and temperatures for dry snow and wet snow. This suggests that there is no need to distinguish between dry snow and wet snow. A simple generic category of, say, “loose snow” would suffice.

Only one definition was found for “loose snow”, that being the one developed by Transport Canada below. See Section 7 for further information.

Loose snow means the presence of fresh falling dry snow, drifting or old standing snow that is not compacted nor bonded to the movement areas.

It is noted that the above definition would not encompass all possible forms of “loose snow”, such as wet snow.

B – Slush vs. Dry or Wet Snow

The only cases where it is necessary to distinguish between slush from any type of loose snow (i.e., dry or wet), based on whether or not the TALPA ARC aircraft performance code is changed, occur when:

- (a) The depth exceeds 1/8”; and
- (b) The surface temperature of the snow is warmer than -3°C.

This suggests that an elimination process might be developed in the field based on the contaminant depth and temperature such that the number of cases where it is necessary to distinguish between slush and loose snow is minimized.

C – Water vs. Slush

The TALPA ARC Runway Condition Assessment Matrix suggests that it is not necessary to distinguish between slush and water for most combinations of temperature and depth, with the sole exception being for cases where the runway may be “slippery when wet”.

Requirement for a Precise Definition of Slush

Items (B) and (C) suggest that a precise definition for slush is not required. The only requirement is to distinguish between water and dry and wet snow.

10.6.3 Solid Contaminants Such as Frost, Ice or Compacted Snow

With respect to solid contaminants, a detailed review of the TALPA ARC Runway Assessment Matrix (presented in Section 4) showed the following:

Frost vs. Ice

The TALPA ARC aircraft performance code changes greatly depending on whether the contaminant is ice or frost (Section 4), which indicates that it is very important to distinguish between frost and ice. Very few definitions were found for frost, as Transport Canada (TC) is the only agency with a detailed one (Section 7). Specific components of the TC definition can be used for effective differentiation between ice and frost in the field.

The ICAO documents did not contain a specific definition for frost although inferences can be made from the ICAO SNOWTAM, which refers to rime and frost as having depths that are “normally less than 1 mm”.

This is considered to be the most serious gap in definitions for solid contaminants.

Ice vs. Compacted Snow

The TALPA ARC aircraft performance code changes depending on whether the contaminant is compacted snow or ice, which indicates that it is important to distinguish between these two surfaces. Thus, definitions are required for each of them.

Wet ice vs. Ice

The TALPA ARC aircraft performance code changes depending on whether the ice is wet or not. Hence, a definition is required to distinguish wet ice from ice.

10.6.4 Layered Contaminants

The proposed TALPA ARC Runway Assessment Matrix only addresses two types of layered contaminants as follows:

- (a) Water on compacted snow; and
- (b) Dry or wet snow over ice.

Both of these cases generate the lowest aircraft performance code, which is effectively, “nil” braking.

10.6.5 Other Contaminants

Other contaminants that may be of concern include the following:

- (a) De-icing chemicals – these may be present in various forms such as:
 - (i) Liquid residues from aircraft de-icing chemicals;
 - (ii) Liquid residues from runway de-icing chemicals; or
 - (iii) In mixtures with winter materials such as slush or snow.
- (b) Sanded surfaces or sand itself.

- (c) Various other materials, such as dirt or debris, rubber build-up, and other infrequent frozen contaminants, such as frozen airborne residue from industrial processes.

These surfaces are not included in the TALPA ARC Runway Condition Assessment Matrix.

The project team has not been involved in the TALPA ARC process. Furthermore, reports or detailed documentation are not available describing the TALPA ARC process, or the material supporting its conclusions. Thus, specific comments cannot be made at present regarding the reasons why these other contaminants that are not included in the TALPA ARC Matrix. EASA is advised to obtain as much background information as possible regarding the TALPA ARC process so that informed decisions can be made.

10.7 Reporting Formats for Operational Friction Applications

Ideally, an assessment of the runway surface should include:

- (a) Path available for aircraft operations;
- (b) Observations and measurements of the surface contaminants, including their type, depth and location;
- (c) Measurements of the friction coefficient, indications of the braking action, or PIREPs;
- (d) Observations and measurements of the surface texture and pavement characteristics; and
- (e) Visual observations of the weather conditions, such as when it is raining, snowing, etc

The requirements and priorities vary somewhat depending on whether the runway assessment is being done for functional or operational purposes

Two issues are discussed in this section.

- (a) The ICAO SNOWTAM format in relation to reporting requirements, and the contaminant types of concern; and
- (b) The method used to provide friction information (i.e., the measured friction values versus general indications of braking action based on the measured friction coefficients).

10.7.1 General Requirements for Operational Descriptions of the Runway Surface

These are discussed in detail in Volume 4 (Operational Friction). In summary, a description of the runway surface should contain the elements listed in Table 10.2.

The ICAO SNOWTAM was referred to by most authorities as the one that is the basis for their RCR, although the actual RCR form used by airports varied somewhat as they have customized it to suit their needs. For example, Canadian airports conduct RCR for the whole

runway, rather than runway thirds, which is the basis for RCR using the ICAO method. Thus, Transport Canada uses its own form, the AMSCR, which is also shown in Section 5. Hence, harmonization would only be possible if, for example, all airports used the same reporting basis (i.e., thirds versus the whole runway). It is noted that the proposed TALPA ARC system includes reporting based on runway thirds.

The ICAO SNOWTAM is discussed in Section 5. Table 10.2 shows that it meets some of the requirements for an operational description of the runway surface but not all of them.

Table 10.2: Required Elements of an Operational Description of the Runway Surface

Parameter	Comments in relation to SNOWTAM Form
Contaminant type	Contaminant list included in the SNOWTAM BUT the contaminants in the list are not fully defined, or aligned with other reporting requirements. This is discussed further in the next section
Contaminant depth	Included in the SNOWTAM
Contaminant location	Not included in the SNOWTAM
Contaminant spread (i.e., the area coverage of the contaminant)	Not included in the SNOWTAM
Cleared width, which is also termed maintained path width	Included in the SNOWTAM
Offset of the maintained path from the runway centreline	Not included in the SNOWTAM
Surface temperature	Not included in the SNOWTAM. It is noted that the runway assessment matrix proposed by the TALPA ARC would add the requirement to measure/observe this parameter.

10.7.2 Contaminant Types

It is noted that many of the contaminants listed in the ICAO SNOWTAM are not defined, which is a potential source of confusion. Also, many of them are not relevant within the context of the various reporting systems being considered, such as the TALPA ARC Runway Condition Assessment Matrix (Table 10.3).

Table 10.3: Contaminant Types in the ICAO SNOWTAM Form

Contaminant Type and Code Number in the ICAO SNOWTAM	Assessment
Nil — Clear And Dry	no corresponding definition for this, although dry is a defined case
1 — Damp	not clear that “damp” is required, as discussed previously
2 — Wet Or Water Patches	no corresponding definition for “water patches”
3 — Rime Or Frost-Covered (<i>Depth Normally Less Than 1 Mm</i>)	no corresponding definition for this in the ICAO documents. However, frost is a very significant contaminant in the proposed TALPA ARC Runway Assessment Matrix.
4 — Dry Snow	
5 — Wet Snow	
6 — Slush	
7 — Ice	
8 — Compacted or Rolled Snow	no corresponding definition for “rolled snow” in the ICAO documents or elsewhere
9 — Frozen Ruts or Ridges)	no corresponding definition for “frozen ruts or ridges” in the ICAO documents or elsewhere

10.7.3 Scales of Braking Action vs. Friction Coefficient

Only one general braking action scale is in active use, that being the one in ICAO Annex 14, Volume 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.

Given that the survey respondents assigned lower priorities to general indications of braking action versus friction measurements or PIREPs (Section 5), the need for a harmonized scale of general braking action versus friction coefficient is questionable.

This is supported by the form of the Runway Assessment Matrix proposed by TALPA ARC, which does not include a general braking action scale based on friction measurements in its list of inputs. However, the proposed TALPA ARC matrix does include general indications of braking action (from sources such as subjective assessments based on the experience of the runway inspection crew), as one of the inputs that may be used to downgrade assessments based on the runway surface condition.

10.8 Reporting Formats for Functional Friction Applications

10.8.1 Functional Friction Characteristics

Different reporting requirements are imposed for function friction characteristics versus operational applications, and thus, the need for taxonomies. Functional friction is discussed in detail in Volume 3.

10.8.2 Basis for Functional Criteria

It was found that most countries use friction measurements as the basis for their runway maintenance criteria for maintenance planning and action. The Norwegian CAA (Avinor) appears to be the lone exception as it is in the process of implementing criteria based on the runway texture and pavement characteristics.

This is considered to be the most significant deviation among those found from the surveys and investigations. Of course, this variation would impose the most significant difference in requirements for reporting and taxonomies.

10.8.3 Overlap With Operational Requirements: “Slippery When Wet”

At present, functional friction characteristics play a role in determining whether or not a runway is “slippery when wet”. It is recognized though, that the functional friction criteria used by National Aviation Authorities are not related to aircraft performance.

The project team has been informed that the ICAO Friction Task Force (FTF) is studying this issue in detail. Because a report from the FTF is not yet available, detailed recommendations are premature. It is recommended that EASA maintain close contact with the ICAO FTF, and develop policies accordingly.

10.8.4 Other Variations

Differences exist with respect to items such as the device(s) accepted, the test speeds used, and the water film depth used. These are outlined in Section 9, and discussed in detail in Volume 3 (Functional Friction).

11 CONCLUSIONS

Extensive information-gathering has been done, that included broad surveys using questionnaires, some personal contacts, and an extensive literature review. The conclusions and recommendations presented here are limited to the taxonomies involved and methods for harmonizing them. Conclusions related to functional friction characteristics and operation friction characteristics are presented in Volumes 3 and 4 respectively. Recommendations regarding all parts of the work are presented in Volume 1.

11.1 General Conclusions and Basis for Harmonization

- (1) The harmonization process includes both technical and policy issues. The scope of this study was limited to technical issues.
- (2) A wide range of taxonomies are in use at present. They are used in various contexts such as (a) operational friction assessments, (b) functional friction assessments, and (c) aviation accident and incident investigations.
- (3) The taxonomies used for aviation accident and incident investigations are intended primarily as general classifications for use within a database. They are much more general than those required for operational or functional assessments, and they would not provide a logical basis for a way forward for harmonizing the various taxonomies used.
- (4) The most suitable basis for harmonizing taxonomies, for either functional friction or operational friction applications, is considered to be one based on relationships with aircraft performance. In this respect, the Runway Assessment Matrix proposed by TALPA ARC is a major step forward as it provides a means by which aircraft performance can be related to the reported runway conditions. This approach also provides the most direct link to the overall goal of enhanced aviation safety.
- (5) For this reason, the runway condition definitions used in TALPA ARC merit the strongest consideration as a basis for harmonized taxonomies. It is noted though, that the TALPA ARC process is still ongoing, with field testing being planned for the 2009-2010 winter. Recognizing that this may lead to some changes, the recommendations made in this study should be considered to be preliminary. EASA should monitor these field trials closely as well as any other developments related to the TALPA ARC process.
- (1) Valuable input to this problem will likely be provided by the ICAO Friction Task Force (FTF), which has not yet completed its investigations. The results and conclusions from the FTF should be reviewed in detail when they become available.

11.2 Operational Friction: Runway Classifications and Significant Parameters

- (1) The first step for achieving harmonization is to establish common definitions for: (a) what constitutes a contaminant and (b) the general runway state classifications. This has a fundamental effect on the definitions that are required, and their relative priorities.

- (2) With respect to runway state classifications, there is general agreement among the aviation community for a three-point system (i.e., dry, wet, and contaminated runways).
 - (a) It was found that there is similarity among the various definitions for dry and wet runways.
 - (b) For contaminated runways, the only major difference among the definitions is believed to be the conditions which are named as contaminants and whether or not other ones would be considered to be contaminants too (which is not specified in the definitions). Some surfaces that should also be considered contaminants (in our opinion) include sanded surfaces, layered contaminants, and ice control chemicals.
 - (c) The need for any changes to existing taxonomies is affected by whether or not the contaminant list in the definition for a contaminated runway is intended to be an all-inclusive/exclusive list, or just to provide examples of surfaces considered to be contaminants. The latter is the simpler approach as a multitude of surface conditions occur in practice, particularly in winter. A system that included a large number of surface conditions would probably prove to be unworkable in an operational airport environment.
 - (d) It was found that the relevant ICAO documents do not cross-reference each other with respect to the definition of a contaminated runway and the contaminants themselves (i.e., Annex 6 vs. Annex 14, Volume 1, Annex 15 and the Airport Services Manual). This could potentially lead to confusion. It is recommended that this be addressed by ICAO.
 - (e) It was also found that there is inconsistency between ICAO Annex 15 and the other ICAO documents with respect to the area coverage threshold for defining a wet runway. This should be addressed by ICAO.
- (3) Definitions for a dry, wet, and contaminated runway: the definitions in the TALPA ARC matrix are recommended, with the cautionary comments that:
 - (a) They should be considered to be preliminary pending the results of the field testing that will be carried out to evaluate the TALPA ARC system; and
 - (b) Clarification should be made regarding the contaminant list that is included in the definition, with respect to whether it is intended to be an all-inclusive/exclusive list, or to just provide examples of contaminants. It is our recommendation that the latter is preferred as flexibility is required.

- (4) The proposed TALPA ARC runway assessment matrix provides very valuable insights regarding Runway Condition Reporting (RCR) requirements, as the surface condition categories in it have been developed in relation to aircraft performance. This matrix provides information regarding the cases where it is important, and not important, to distinguish the various contaminants, based on whether or not the associated aircraft performance code would be changed:
- (a) Contaminant type, depth, temperature and layering (for a few cases) – the aircraft performance code is affected by all of these parameters. This has significant implications for RCR as clearly, all parameters would have to be defined to determine the associated TALPA ARC code.
 - (b) With respect to contaminant type, it is important to distinguish the following conditions, as the associated aircraft performance code would be changed:
 - (i) Frost vs. ice – it is most important to distinguish frost from ice, or wet ice, as there is a very large variation in aircraft performance code between frost and ice.
 - (ii) Compacted snow vs. ice
 - (iii) Compacted snow vs. slush
 - (c) It is NOT important to distinguish the following conditions, as the associated aircraft performance code would be unchanged:
 - (i) Dry vs. wet snow
 - (ii) Slush vs. water in most cases (i.e., depths and temperatures). The only exception to this statement is when “slippery when wet” conditions exist.
 - (iii) Slush vs. wet snow, except for depths exceeding 1/8”, and surface temperatures less than or equal to -3°C.
 - (d) With respect to contaminant depth, the following is seen from the matrix
 - (i) It is very important to determine whether or not the contaminant depth is greater than or less than 1/8 inch for water, slush, wet snow and dry snow. It is not important to measure the actual depth other than in relation to a threshold of 1/8 inch.
 - (ii) It is not important to measure the depth for solid contaminants such as ice, frost and compacted snow.
 - (e) The significance of contaminant temperature depends on the contaminant type and depth, and whether the surface temperature varies from one range to another (i.e., $\geq -3^{\circ}\text{C}$, -3°C to -13°C , and $\leq -13^{\circ}\text{C}$).

(f) With respect to contaminant layering, the TALPA ARC system indicates that it is important to distinguish:

- (i) Wet ice;
- (ii) Water on top of compacted snow; and
- (iii) Dry or wet snow over ice.

All of these cases are important as they generate the lowest aircraft performance code, which is effectively, “nil” braking.

(5) A further examination of the proposed TALPA ARC runway assessment matrix showed that fewer surface conditions might be employed as the same aircraft performance code is produced for some contaminants (e.g., dry vs. wet snow, or slush vs. water). Generally, the categories could be divided into:

- (a) Loose contaminants, such as dry snow or wet snow;
- (b) Liquid contaminants such as slush or water;
- (c) Solid contaminants, such as frost, ice, or compacted snow; and
- (d) Layered contaminants such as loose snow over compacted snow.

Potentially, this could simplify RCR as well as the need for harmonized taxonomies. However, given that field tests will be conducted with the TALPA ARC system over the 2009-2010 winter, there is a potential that changes might be made to the TALPA ARC system. Thus, any recommendations for changes are premature at present. Instead, EASA is advised to monitor the field tests closely, and to re-visit this issue subsequently.

(6) There are other contaminants than those listed in the TALPA ARC matrix that may be of concern such as:

- (a) De-icing chemicals, which may be present in various forms such as:
 - (i) Liquid residues from aircraft de-icing chemicals;
 - (ii) Liquid residues from runway de-icing chemicals; or
 - (iii) In mixtures with winter materials such as slush or snow.
- (b) Sanded surfaces, or sand itself.
- (c) Various other materials, such as dirt or debris, rubber build-up, and other infrequent frozen contaminants, such as frozen airborne residue from industrial processes.

Because the project team has not been involved in the TALPA ARC process nor have reports regarding it been made available, further comments cannot be made regarding this. EASA is advised to obtain as much background information as possible regarding the TALPA ARC process so that informed decisions can be made.

- (7) Views regarding friction measurements from ground vehicles – these include the following:
 - (a) There is a divergence of views regarding whether or not the readings from friction-measuring devices can be correlated with aircraft performance. Recent initiatives are trending towards de-emphasizing friction measurements for operational applications. However, some airlines utilize ground friction measurements for making operational assessments of aircraft performance. It is noted though, that these airlines limit their approaches to measurements made using a single ground friction-measuring device. They do not attempt to accommodate the many friction-measuring devices that presently exist.
 - (b) Other than where airlines limit their use of airport determined friction to the use of a single friction-measuring device, the role of friction-measurement devices should perhaps be limited to maintenance evaluations. This view leaves a gap for operational runway condition reporting.
 - (c) Other than where airlines limit their use of airport determined friction to the use of a single friction-measuring device, RCR for operational purposes may perhaps be best done based solely on descriptions of the surface condition and the runway pavement characteristics.

11.3 Operational Friction: Detailed Taxonomies and Reporting Formats

- (1) Required Parameters for RCR – it is believed that RCR reports should include:
 - (a) The contaminant type;
 - (b) The contaminant depth;
 - (c) The contaminant location;
 - (d) The area coverage by contaminant;
 - (e) The cleared width; and
 - (f) The offset. The TALPA ARC matrix would impose a further information requirement, that being the surface temperature.

The ICAO SNOWTAM does not allow all of these parameters to be reported. It is recommended that it be updated, following the completion of the initiatives that are currently ongoing (i.e., TALPA ARC, ICAO FTF).

- (2) Many of the contaminants listed in the ICAO SNOWTAM are not defined, which is a potential source of confusion. Also, many of them are not relevant within the context of the various reporting systems being considered, such as the TALPA ARC Runway Condition Assessment Matrix. It is recommended that the ICAO SNOWTAM be updated, following the completion of the initiatives that are currently ongoing (i.e., TALPA ARC, ICAO FTF).
- (3) The format of reported friction information:
 - (a) The survey showed that pilots consider general indications of braking action based on friction measurements to be of lower value than the actual friction measurements themselves or PIREPs.
 - (b) At the same time, the recent initiatives (i.e., TALPA ARC; ICAO FTF) have shown that there is a divergence of views in the aviation community. The recommendations from the TALPA ARC are headed towards de-emphasizing friction measurements compared to descriptions of the runway surface itself. The ICAO FTF did not reach a consensus regarding this issue, although it agreed that a common reporting format is required.
- (4) RCR for runways with water on them – it was found that:
 - (a) Three condition classes (i.e., damp, wet, and flooded or standing water) are generally specified by the various agencies;
 - (b) The definitions for each condition class are similar, and there are no technical reasons that would favour one over another; and
 - (c) The general runway surface condition classes in ICAO Annex 6, the FAA’s SAFO Alert, and the proposed TALPA ARC system (i.e., dry, wet or contaminated) remove the need for a definition of “damp”, as a damp runway would fall into the “wet” category, and would be reported as such.

However, a number of performance standards and advisory circulars were found which would require a definition for a damp surface. These discrepancies should be harmonized.
- (5) RCR for runways with winter contaminants - a multitude of possible surface conditions can occur in winter, and a classification system that distinguished between all of them would probably prove to be unworkable in an operational airport environment.

This issue should be deferred until there is consensus regarding the fundamental definition of a contaminated runway, and the contaminants of concern. To this end, the TALPA ARC system should be monitored closely.

- (6) Taxonomies for winter contaminants –
- (a) The need for definitions is governed by the surfaces that are considered to be contaminants and whether or not an all-inclusive/exclusive list is required.
 - (b) The TALPA ARC system necessitates the need for definitions for frost, slush, ice, wet ice, compacted snow, wet snow, and dry snow. Although various definitions exist for most of these contaminants, there are no technical reasons that would favour one over another. Recognizing this, it is recommended that the current definitions in ICAO be retained for consistency with the following refinements.
 - (c) Very few definitions were found for frost. This is considered to be the most serious gap in the present set of definitions, especially because the TALPA ARC process has assigned great importance to distinguishing frost from ice.

ICAO does not contain a specific definition for frost, and the ICAO SNOWTAM makes an indirect reference to frost by noting that its depth is “normally less than 1 mm”.

Transport Canada is the only agency that has a definition for frost at present. The Canadian training material includes the following explanatory notes, which should be considered to be part of the definition for frost.

Frost is differentiated from ice and compact snow by its refraction of light giving it an opaque presentation. The crystalline nature of frost is readily apparent to the viewer because it does not uniformly reflect light, presenting instead a “sparkle” or “glitter” effect. This is true of all forms of frost and for all depths.

11.4 Preliminary Recommendation for a Harmonized Format

Recommendations regarding the various taxonomies are provided in Table 11.1, regarding:

- (a) the values and relevance to aircraft performance evaluations (Column 2); and
- (b) the characteristics that would be used by runway inspection personnel to describe the runway surface condition (Column 3).

In many cases, there was no technical reason that would favour one definition over another as they all have the same intent. For the purpose of establishing the recommendations listed in Table 11.1, priority was given to:

- (a) the classifications and definitions in the TALPA ARC system, as this system has been developed taking aircraft performance into account; and
- (b) the definitions in ICAO Annex 14, Volume 1, to maintain consistency with past definitions.

It is recognized that definitions are also required for other parameters such as cleared width, contaminant depth, etc. Definition lists are contained in the main body of the report.

Table 11.1: Preliminary Listing of Recommended Definitions

Frozen Contaminants		
<u>Term</u>	<u>For Aircraft Performance</u>	<u>Recognizable Characteristics</u>
Slush	Assumed SG: .85 (source: EASA CS25.1583)	Water-saturated snow with a heel-and-toe slapdown motion against the ground will be displaced with a splatter (source: ICAO)
Frost	Higher friction than Ice (source: BMT Project Team)	A condition where ice crystals formed from air borne moisture condense on a surface whose temperature is below zero. Frost differs from ice in that the frost crystals grow independently and, therefore, have a more granular texture (source: TC)
Loose Snow	Assumed SG: .34 (source: ICAO)	Sometime called “Dry” snow. Snow which can be blown if loose or, if compacted by hand, will fall apart upon release (source: ICAO & EASA CS25.1583). Snow that is not bonded to the AMS and will compact under vehicular traffic (source: BMT Project Team)
Wet Snow	Assumed SG: .5 (source: EASA CS25.1583)	Snow that will stick together when compressed but will not readily allow water to flow from it when squeezed (source: EASA CS25.1583)
Compact Snow	Assumed SG: .8 (source BMT Project Team)	Snow which has been compressed and will not compress further under vehicular traffic or aircraft wheels, at representative operating pressures and loadings (sources: EASA CS25.1583 & BMT Project Team)
Ice	Lower friction than Frost (source: BMT Project Team)	A frozen liquid with a continuous surface and includes the term “black ice” and the condition where compacted snow transitions to a polished surface with the density of ice (sources: Transport Canada & EASA CS25.1583)
Non-Frozen Contaminants		
Damp	Required in various standards	A surface is Damp when it is non-reflective and moisture is present (source: TC & BMT Project Team)
Wet	Liquid depth no more than 3mm	A Wet surface has liquid present and is reflective (Source: EASA CS25.1583 & BMT Project Team)
Standing Water	Liquid depth greater than 3mm (source: EASA CS25.1583)	Sometimes called ‘Flooded’. Includes localized and continuous surface coverage, whether during precipitation or not (source: BMT Project Team)

Notes:

1. SG: Specific Gravity
2. Transport Canada is the only agency that has a definition for frost at present. The Canadian training material includes the following explanatory notes, which should be considered to be part of the definition for frost.

Frost is differentiated from ice and compact snow by its refraction of light giving it an opaque presentation. The crystalline nature of frost is readily apparent to the viewer because it does not uniformly reflect light, presenting instead a “sparkle” or “glitter” effect. This is true of all forms of frost and for all depths.
3. Caveat: to date, NO technical documentation has been published regarding the rationale that led to the TALPA ARC’s recommendations, and definitive recommendations can NOT be made regarding the TALPA ARC’s recommendations. The TALPA ARC’s recommendations are presented in Table 11.1 in recognition of the fact that they have been developed by a large group with representation from aircraft manufacturers, airlines, and regulatory bodies. EASA is strongly advised to obtain as much supporting material as possible regarding the TALPA ARC, and to review it in detail in formulating positions and policies.

11.5 Functional Friction Assessments

The overall goal in this case is to define the general actions for aerodrome operations necessary for maintaining a runway pavement surface with adequate friction. This can potentially be accomplished by a variety of means, such as friction measurements and/or texture measurements. Almost all countries use friction measurements as criteria for establishing runway maintenance programs for maintenance planning and action. However, one country (i.e., Norway) has established functional criteria based on measurements of the runway texture and pavement characteristics.

The degree to which taxonomies need to be harmonized is affected by which approach is used to establish the criteria.

12 REFERENCES

- [1] Avinor, _, Runway – Wet and Contaminated, Certification Limitations, available as “Note 110106 Wet Runway.pdf” at www.ippc.no
- [2] Avinor, 2008, Amended Procedure for Pilot Reports on Estimated Braking Action, AIC-1, 07/08, 11-Nov.
- [3] Transport Canada, 1993 (revised 2005), Aerodrome Standards and Recommended Practices, 4th Edition, TP 312.
- [4] Comfort, G., Rado, Z., Rado, E., and Mazur, A., 2009a, Correlation of Continuous Friction Measuring Equipment and Development of Runway Friction Standards, TP 14823E.
- [5] Comfort, G., Mazur, A., Rado, Z., and Rado, E., 2009b, Proposed Performance Specifications and Standard Correlation Method for Continuous Friction Measurement Equipment, TP 14825E.
- [6] FAA, 2008, Airport Winter Safety and Operations, FAA Advisory Circular 150/5200-30C, updated Dec. 9, 2008.
- [7] International Civil Aviation Organization, 2002, Airport Services Manual, Part 2 Pavement Surface Conditions, Chapter 5, 5.2, “Criteria for New Friction-Measuring Devices”.
- [8] ICAO, 2001, Annex 6: Operation of Aircraft: Part 1 – International Commercial Air Transport - Aeroplanes, 8th edition, International Civil Aviation Organization.
- [9] ICAO, 2002, Airport Services Manual: Part 2 – Pavement Surface Conditions, 4th edition, International Civil Aviation Organization.
- [10] ICAO, 2003, Aeronautical Information Services Manual, 3rd edition, Annex 15 – Document 8126, International Civil Aviation Organization.
- [11] ICAO, 2004, Aerodromes, Annex 14, Volume 1: Aerodrome Design and Operations, 4th edition, International Civil Aviation Organization.
- [12] ICAO, 2005, Supplement to 3rd edition of Annex 14, Volume 1: Aerodrome Design and Operations, , International Civil Aviation Organization.
- [13] ICAO, 2006a, ADREP 2000 Taxonomy, International Civil Aviation Organization, 12 January 2006.
- [14] ICAO, 2006b, ECCAIRS (European Co-ordination Centre for Accident Incident Reporting Systems) 4.2.6 Data Definition Standard, Input to ADREP 2000 Taxonomy, International Civil Aviation Organization, 12 January 2006.
- [15] Ostronic, J., 2009, FAA TALPA ARC Runway Surface Condition Matrix, PowerPoint presentation provided to the Project Team.

- [16] Puronto, A., 2004, One Solution to Include Friction in Performance Calculation (Finnair), minutes of IMPACR meeting held in Montreal, Canada, available from Transport Canada.
- [17] Transport Canada, 2004, Guidelines Respecting the Measurement, Evaluation and Maintenance of Airfield Pavement Surface Friction - Appendix A to ASC 2004-024, available at www.tc.gc.ca.
- [18] UK CAA, 2008a, The Assessment of Runway Surface Friction Characteristics CAP 683, published by the Safety Regulation Group of the United Kingdom Civil Aviation Authority.
- [19] UK CAA, 2008b, Licensing of Aerodromes, CAP 168, published by the Safety Regulation Group of the United Kingdom Civil Aviation Authority.
- [20] Yager, T., Phillips, W., and Horne, W., 1970, A Comparison of Aircraft and Ground Vehicle Stopping Performance on Dry, Wet Flooded, Slush-, Snow-, and Ice-Covered Runways, NASA Technical Note TN 6098.

APPENDIX A – BLANK QUESTIONNAIRES

Contents:

- Appendix A.1: Functional Friction Characteristics (Sent to Civil Aviation Authorities and Airports)
- Appendix A.2: Operational Friction Characteristics (Sent to Civil Aviation Authorities and Airports)
- Appendix A.3: Operational Friction Characteristics (Sent to Air Carriers and Aircraft Manufacturers)
- Appendix A.4: Email with Follow-Up Questions

APPENDIX A, ANNEX 1 –
FUNCTIONAL FRICTION CHARACTERISTICS (SENT TO CIVIL AVIATION
AUTHORITIES AND AIRPORTS)



BMT Fleet Technology Ltd
 311 Legget Drive
 Kanata, Ontario
 Canada K2K 1Z8
 Tel: +1 613 592 2830
 Fax: +1 613 592 4950
www.fleetech.com

FUNCTIONAL SURFACE FRICTION ASSESSMENT: SURVEY OF AIRPORT OPERATORS AND CIVIL AVIATION AUTHORITIES

Background and Objectives

BMT Fleet Technology Limited has been contracted by EASA (European Aviation Safety Agency) to gather information on regulations, procedures, standards, and guidelines that various Civil Aviation Authorities have in place that regulate and/or provide guidance to airports on maintenance of runways as related to providing acceptable runway surface conditions for aircraft landing and take-off.

An introductory letter from EASA is attached separately.

This survey is being conducted in the following parts:

Type of Assessment	General Conditions & Type(s) of Contaminants
<u>Functional Friction Characteristics</u> – these measurements are mainly intended for planning and undertaking runway pavement maintenance, and for setting criteria for the design of new pavements. The general intent is that this part of the survey would be in the context of Clause 2.9.6 in ICAO Annex 14 (which is repeated in the notes below for reference)	Water, dirt, rubber, worn surfaces
<u>Operational Friction Characteristics</u> – this relates to operations on contaminated surfaces, such as aircraft operations on contaminated surfaces, including possible actions by the aerodrome such as the closure of a runway. The general intent is that this part of the survey would be in the context of Clause 2.9.9 in ICAO Annex 14 (which is repeated in the notes below for reference)	• “Non-Winter”; Water, dirt, rubber • “Winter”; Ice, snow, slush

Notes: Copy of Clauses in ICAO Annex 14:

2.9.6: A runway or portion thereof shall be determined as being “slippery when wet” when the measurements specified show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.

2.9.9 Whenever a runway is affected by water & snow, slush or ice, and it has not been possible to fully clear the precipitant fully, the condition of the runway should be assessed, & the friction coefficient measured.

This questionnaire requests information regarding Functional Friction Characteristics.

Registered Office:
 311 Legget Drive,
 Kanata, ON Canada K2K 1Z8
 Registered in Canada No 10181 9602RC



Functional Friction Characteristics SurveyBMT Fleet Technology Ltd.

The answers given in this survey will be analyzed with all the responses received. The overall results will be presented in summary form in our report. However, the individual responses from the various organizations contacted will remain confidential. Please advise us if you have any special requirements.

We thank you for your assistance and cooperation. If you have any questions, please contact me at the contact coordinates below. Please transmit this document by fax or electronic mail to:

George Comfort, BMT Fleet Technology Ltd.

Phone number: +1 613 592 2830 ext 226

Fax: +1 613 592 4950

Email: gcomfort@fleetech.com

Functional Friction Characteristics Survey

BMT Fleet Technology Ltd.

AIRPORT DESCRIPTION

Country/Airport's name :

Length of the longest runway :

What are the predominant runway surfaces? : Concrete? ; Asphalt? ; Combination?

Are the runway surfaces grooved (Y/N)? : Concrete?; Asphalt?

Other Information:

.....

.....

Contact coordinates

Last name:

First name:

Duties:

Phone number:

Email:

SURVEY – FUNCTIONAL FRICTION CHARACTERISTICS

1- What policies and or standards does the airport operating authority follow for maintenance of runways in order to provide acceptable functional friction surfaces for aircraft operations on non-frozen surfaces contaminated with water, rubber, dirt, as well as surfaces with reduced texture?

- Regulatory requirement? Please specify regulation, or attach
- Airport operating authority requirement? Please specify regulation, or attach
- CAO Standards/Recommendations? Y/N
- Other?

.....

.....

.....

2- What are the criteria used for functional friction characteristics? Please attach a copy of the applicable regulations, if available.

- Are the criteria entirely based on friction measurements, or are other parameters measured and considered as well (e.g., texture)? Y/N
- if No, please explain in the Other Information box below.
- Are different criteria specified for the whole runway versus parts of it (e.g., thirds)? Y/N
- if Yes please specify in the boxes below.
- Device(s) Accepted for Friction Measurement:
- Required Friction Level for New Pavement (i.e., Design):
- Friction Level at Which Maintenance Actions Must be Planned:
- Friction Level at Which Maintenance Actions Must be Conducted:
- Other Information

.....

3- Are Functional Friction Characteristics evaluated using measurements conducted with Continuous Friction Measurement Equipment (CFMEs)? Y/N

If yes, please answer the following questions:

- Device Manufacturer and Model
- Requirements for the Measuring Tyre:
 - Compliance to a Standard (e.g., ASTM)? Y/N.....; If Yes, Which one?
 - Tyre Inflation Pressure (kPa):
- Other Test Conditions:
 - Test Speed(s)
 - Water Film Depth (mm):
- Information regarding test runs:
 - Distance from centerline (m):
 - Number of Runs:
 - Test Path (e.g., single run, "up and back", other):
- Frequency of measurement:
 - How often are surfaces measured?:
- Other Information

.....

4- Are pavement texture measurements made? Y/N.....; If yes, please answer the following questions:

■ Device Manufacturer and Model

■ Other Information:

.....
.....
.....
.....

5- Please describe the actions taken to rectify low runway surface friction:

■ How is rubber removed?

- High pressure water used? Y/N
- Softening agent plus high pressure water? Y/N
- Rubber solvent plus runway sweeping? Y/N
- Shot blasting with steel shot? Y/N
- Blasting with abrasive medium? Y/N

Other (please explain):

■ How is the surface re-textured?

- High pressure water used? Y/N
- Shot blasting with steel shot? Y/N
- Blasting with abrasive medium? Y/N
- Other (please explain):

SUBMIT



European Aviation Safety Agency

Werner Kleine-Beeck • Research Project Manager - Executive Directorate

Cologne, 23 January 2009
EASA.WKB/hka E.2 2009(D)52720

To airlines, airport authorities, regulators,
ANSPs, airframe manufacturer contacted
by:
BMT Fleet Technology Limited
311 Legget Drive Kanata
Kanata ON K2K 1Z8
Canada

**Subject: Letter of Introduction for EASA Contract EASA.2008.C46
(RuFChaMaAB - Runway friction characteristics measurement and
aircraft braking)**

Dear Sir or Madam,

The European Aviation Safety Agency (EASA) is starting a project regarding the above subject to review existing and previous research as well as pertinent literature, providing a sound basis for the evolution of a road map for further development and regulatory or R&D actions, namely to contribute to the progress of the ICAO action plan and European (EASA) rulemaking.

After a tendering process, BMT Fleet Technology Ltd (BMT FTL) was selected to carry out the project. During the course of their work, BMT FTL will be contacting various organizations and agencies for information.

Should BMT FTL contact your organization, EASA appreciates your support and cooperation to the extent possible. Please feel free to contact me should questions arise.

Your cooperation is much appreciated.

Yours sincerely,

A handwritten signature in blue ink, reading 'Kleine-Beeck', is positioned above the printed name.

W. KLEINE-BEEK
Research Project Manager
Safety Analysis & Research Department
Executive Directorate

Postal address: Postfach 10 12 53 • D-50452 Cologne, Germany – Visiting address: Ottoplatz, 1 • D-50679 Cologne, Germany
Tel.: +49 (0)221 8999 0000 • Fax: +49 (0)221 8999 0999 • E-mail: info@easa.europa.eu • www.easa.europa.eu

APPENDIX A, ANNEX 2 –
OPERATIONAL FRICTION CHARACTERISTICS (SENT TO CIVIL AVIATION
AUTHORITIES AND AIRPORTS)



BMT Fleet Technology Ltd
 311 Legget Drive
 Kanata, Ontario
 Canada K2K 1Z8
 Tel: +1 613 592 2830
 Fax: +1 613 592 4950
www.fleetech.com

OPERATIONAL SURFACE FRICTION ASSESSMENT: SURVEY OF AIRPORT OPERATORS AND CIVIL AVIATION AUTHORITIES

Background and Objectives

BMT Fleet Technology Limited has been contracted by EASA (European Aviation Safety Agency) to gather information on regulations, procedures, standards, and guidelines that various Civil Aviation Authorities have in place that regulate and/or provide guidance to airports on maintenance of runways as related to providing acceptable runway surface conditions for aircraft landing and take-off.

An introductory letter from EASA is attached separately.

This survey is being conducted in the following parts:

Type of Assessment	General Conditions & Type(s) of Contaminants
<u>Functional Friction Characteristics</u> – these measurements are mainly intended for planning and undertaking runway pavement maintenance, and for setting criteria for the design of new pavements. The general intent is that this part of the survey would be in the context of Clause 2.9.6 in ICAO Annex 14 (which is repeated in the notes below for reference)	Water, dirt, rubber, worn surfaces
<u>Operational Friction Characteristics</u> – this relates to operations on contaminated surfaces, such as aircraft operations on contaminated surfaces, including possible actions by the aerodrome such as the closure of a runway. The general intent is that this part of the survey would be in the context of Clause 2.9.9 in ICAO Annex 14 (which is repeated in the notes below for reference)	• “Non-Winter”; Water, dirt, rubber • “Winter”; Ice, snow, slush

Notes: Copy of Clauses in ICAO Annex 14:

- 2.9.6: A runway or portion thereof shall be determined as being "slippery when wet" when the measurements specified show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.
- 2.9.9 Whenever a runway is affected by water & snow, slush or ice, and it has not been possible to fully clear the precipitant fully, the condition of the runway should be assessed, & the friction coefficient measured.

Registered Office:
 311 Legget Drive,
 Kanata, ON Canada K2K 1Z8
 Registered in Canada No 10181 9902RC



Operational Friction Characteristics: Airports & CAAs

BMT Fleet Technology Ltd.

This questionnaire requests information regarding Operational Friction Characteristics.

The answers given in this survey will be analyzed with all the responses received. The overall results will be presented in summary form in our report. However, the individual responses from the various organizations contacted will remain confidential. Please advise us if you have any special requirements.

We thank you for your assistance and cooperation. If you have any questions, please contact me at the contact coordinates below. Please transmit this document by fax or electronic mail to:

George Comfort, BMT Fleet Technology Ltd.

Phone number: +1 613 592 2830 ext 226

Fax: +1 613 592 4950

Email: gcomfort@fleetech.com

AIRPORT DESCRIPTION

Country/Airport's name :

Length of the longest runway :

What are the predominant runway surfaces? : Concrete?.....; Asphalt?.....; Combination?.....

Are the runway surfaces grooved (Y/N)? : Concrete?.....; Asphalt?

Other Information:

.....

.....

Contact coordinates

Name:

Duties:

Phone number:

Email:

SURVEY**1. What policies or standards does the airport operating authority follow for the maintenance of operational runways to provide acceptable friction?****“Non-Winter” Contaminants (water, dirt, rubber):**

- ICAO Standards/Recommandations? Y/N
- Regulatory Requirement? Please specify regulation
....., or attach.
- Airport operating authority requirement? Please specify regulation
....., or attach.
- Other?
.....
.....
.....

Winter Contaminants (water, dirt, rubber):

- ICAO Standards/Recommandations? Y/N
- Regulatory Requirement? Please specify regulation
....., or attach.
- Airport operating authority requirement? Please specify regulation
....., or attach.
- Other?
.....
.....
.....

2. What information is observed or measured, and how often?

“Non-Winter” Contaminants (water, dirt, rubber):

- Runway friction (Y/N)?
 - What is the frequency of these measurements?
Use the Other Information Box if necessary.
- Runway surface condition:
 - What is observed? Please provide a list, or a blank runway surface condition form
 - contaminant type and condition (e.g., damp, wet, flooded)
Y/N?
 - contaminant depth, Y/N?
 - What scale do you use (e.g., light, medium or heavy)? Please explain.
.....
.....
 - rubber deposits, Y/N?
 - % coverage, Y/N?
 - is the surface condition report sub-divided by runway thirds,
Y/N? or is it only applicable to the full runway?
Y/N?
 - other?
 - What is the frequency of these observations?

monthly	☐	hourly	☐
weekly	☐	when conditions change	☐
daily	☐	other	☐

 Use the Other Information Box if necessary.
 - What reporting format is used? Please explain, or attach a blank Runway Surface Condition Form
.....
.....
 - Definitions Used – Please provide a listing for the items below as well as any other categories used:
 - damp:
 - wet:
 - flooded:
 - Other Information
.....
.....

Winter Contaminants (water, dirt, rubber):

- Runway friction (Y/N)?
 - What is the frequency of these measurements?
Use the Other Information Box if necessary
- Runway surface condition:
 - What is observed? Please provide a list, or a blank runway surface condition form
 - o contaminant type and condition (e.g., ice, snow, slush, etc.)
Y/N?
 - o contaminant depth, Y/N?
 - o cleared width, Y/N?
 - o is the surface condition report sub-divided by runway thirds,
Y/N? or is the surface condition generalized for the full
runway? Y/N?
 - o how are non-uniform conditions reported, e.g., within a runway third?
.....
 - o other?
 - What is the frequency of these observations?

monthly	☐	hourly	☐
weekly	☐	when conditions change	☐
daily	☐	other	☐

 Use the Other Information Box if necessary.
- Format used? Please explain, or attach a blank Runway Surface Condition Form or copy of electronic report printout.
.....
.....
- Definitions used for recording the surface contaminate – Please provide a listing for the items below as well as any other categories used:
 - ice:
 - dry snow:
 - wet snow:
 - compacted snow:
 - loose snow:
 - any other categories:
 - slush:
 - frost:
 - sanded:
 - chemical-treated:

- Other Information

.....

.....

.....

3. What information is transmitted to ATC?

“Non-Winter” Contaminants (water, dirt, rubber):

- Runway friction (Y/N)? If yes, please provide further information:
 - are the measured friction values provided? Y/N
 - if Yes, please describe the frequency of these reports (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
 - are summary braking action categories (e.g. good, fair, poor, nil) provided?
Y/N
 - if Yes, please describe the frequency of these reports (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Description of runway surface condition (e.g., damp, wet, flooded)
Y/N
 - if Yes, please describe the frequency of these reports (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Other Information

.....

.....

.....

.....

.....

.....

.....

.....

Winter Contaminants (water, dirt, rubber):

- Runway friction (Y/N)?; If yes, please provide further information:
 - are the measured friction values provided? Y/N
 - if Yes, please describe the frequency of these reports (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
 - are summary braking action categories (e.g. good, fair, poor, nil) provided? Y/N
 - if Yes, please describe the frequency of these reports (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Description of runway surface condition (e.g., damp, wet, flooded) Y/N
 - if Yes, please describe the frequency of these reports (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Other Information

.....

.....

.....

.....

.....

.....

.....

.....

4. (a) What method is used to send information to ATC?**“Non-Winter” Contaminants (water, dirt, rubber):**

- ☐ Radioed condition reports
- ☐ Telephoned condition reports
- ☐ Faxed condition reports
- ☐ Electronically transmitted condition reports
- ☐ ATIS (Automatic Terminal Information Service)

Winter Contaminants (water, dirt, rubber):

- ☐ Radioed condition reports
- ☐ Telephoned condition reports
- ☐ Faxed condition reports
- ☐ Electronically transmitted condition reports
- ☐ ATIS (Automatic Terminal Information Service)

(b) What method is used to send information to pilots?**“Non-Winter” Contaminants (water, dirt, rubber):**

- ☐ NOTAM or SNOWTAM issued by ATC
- ☐ NOTAM or SNOWTAM issued by airport staff
- ☐ by ATIS (Automatic Terminal Information Service)

Winter Contaminants (water, dirt, rubber):

- ☐ NOTAM or SNOWTAM issued by ATC
- ☐ NOTAM or SNOWTAM issued by airport staff
- ☐ by ATIS (Automatic Terminal Information Service)

5. Do ATC or pilots ask for Runway Friction Characteristics?

“Non-Winter” Contaminants (water, dirt, rubber):

- Runway friction (Y/N)?; If yes, please provide further information:
 - are the measured friction values requested? Y/N
 - if Yes, please describe the frequency of these requests (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
 - are summary braking action categories requested (e.g. good, fair, poor, nil)?
Y/N
 - if Yes, please describe the frequency of these requests (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Description of runway surface condition (e.g., damp, wet, flooded) Y/N.....
 - if Yes, please describe the frequency of these requests (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Special requests - Do pilots make special or specific requests at times in order to assess the runway surface condition, and its friction characteristics?
Y/N
 - if Yes, please explain in the Other Information space below.
 - For example, how many specific requests are received from the pilot versus the total number of passes on water-contaminated runways?

(i) more than 80%; ☐	(iii) between 20% and 50%; ☐
(ii) between 50% and 80%; ☐	(iv) less than 20%; ☐

Also, do pilot requests vary with respect to the aircraft type (e.g., manufacturer, size, type)? Y/N

- Other Information

.....

.....

.....

.....

.....

.....

.....

.....

Winter Contaminants (water, dirt, rubber):

- Runway friction (Y/N)?; If yes, please provide further information:
 - are the measured friction values requested? Y/N
 - o if Yes, please describe the frequency of these requests (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
 - are summary braking action categories requested (e.g. good, fair, poor, nil)? Y/N
 - o if Yes, please describe the frequency of these requests (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Description of runway surface condition (e.g., damp, wet, flooded) Y/N
 - if Yes, please describe the frequency of these requests (use the Other Information space below if necessary):
systematically ☐; depends on conditions ☐; rarely ☐
- Special requests - Do pilots make special or specific requests at times in order to assess the runway surface condition, and its friction characteristics? Y/N
 - if Yes, please explain in the Other Information space below.
 - For example, how many specific requests are received from the pilot versus the total number of passes on water-contaminated runways?

(i) more than 80%; ☐	(iii) between 20% and 50%; ☐
(ii) between 50% and 80%; ☐	(iv) less than 20%; ☐
 - Also, do pilot requests vary with respect to the aircraft type (e.g., manufacturer, size, type)?
- Other Information

.....

.....

.....

.....

.....

.....

.....

.....

6. Is feedback received from pilots?

“Non-Winter” Contaminants (water, dirt, rubber):

- Is feedback received (Y/N)? - if Yes, please describe this in the Other Information space below.
 - For example, are complaints or recommendations logged? If Yes, can this information be provided?
 - Also, what actions are taken to address complaints or recommendations? Can this information be provided?
 - Would feedback from pilots be useful to confirm the data provided? (Y/N)
- Other Information
.....
.....
.....
.....
.....

Winter Contaminants (water, dirt, rubber):

- Is feedback received (Y/N)? - if Yes, please describe this in the Other Information space below.
 - For example, are complaints or recommendations logged? If Yes, can this information be provided?
 - Also, what actions are taken to address complaints or recommendations? Can this information be provided?
 - Would feedback from pilots be useful to confirm the data provided? (Y/N)
- Other Information
.....
.....
.....
.....
.....

7. Friction measurements made for evaluating Operational Friction Characteristics in “winter” or “non-winter” conditions – Are these done (Y/N)? If yes, please provide the following information

“Non-Winter” Contaminants (water, dirt, rubber):

- Device Manufacturer and Model
- Requirements for the Measuring Tyre:
 - Compliance to a Standard (e.g., ASTM)? Y/N; Which one?
 - Tyre Inflation Pressure (kPa):
- Other Test Conditions:
 - Test Speed(s)
 - Water Film Depth (mm):
- Test Runs Information
 - Distance from centerline (m):
 - Number of Runs:
 - Test Path (e.g., single run, “up and back”, other)
- Other Information

.....

.....

.....

.....

.....

.....

.....

.....

.....

.....

Winter Contaminants (water, dirt, rubber):

- Device Manufacturer and Model
- Requirements for the Measuring Tyre:
 - Compliance to a Standard (e.g., ASTM?)? Y/N.....;
 - Which one?
 - Tyre Inflation Pressure (kPa):
- Other Test Conditions:
 - Test Speed(s)
 - If decelerometers are used for friction measurement, please provide information:
 - Conditions where decelerometer tests are considered unreliable (e.g., loose snow, slush):
 - Test speed:
 - Device manufacturer:
 - Host vehicle used, and any criteria for it (weight, tires, type, etc):
 - Whether or not the vehicle's ABS must be disabled for friction measurement (Y/N):
 - How often is the equipment calibrated and/or tested by the manufacture to confirm its operating performance?
- Test Runs Information
 - Distance from centerline (m):
 - Number of Runs:
 - Test Path (e.g., single run, "up and back", other)
- Other Information
.....
.....
.....
.....
.....
.....
.....
.....
.....
.....

8. Observations made regarding runway surface conditions - Are these done (Y/N)? If yes, please provide the following information.

“Non-Winter” Contaminants (water, dirt, rubber):

- Surface condition (e.g., bare & dry, damp, wet, flooded): How are these conditions determined?
- Extent, or % coverage, of various contaminants on the runway
 - What is assessed, e.g., are reports divided by contaminant type and by thirds?
 - How is the uniformity of the runway surface condition assessed and reported? :
 - Using Detailed mapping?
 - Using a general description in a NOTAM?
 - other?
- Contaminant depth: How is this determined?
- Rubber deposits: are these mapped or noted? Y/N
 - if Yes, please explain how these are reported
- Other Information

Winter Contaminants (water, dirt, rubber):

- Surface condition (e.g., bare & dry, damp, wet, flooded): How are these conditions determined?
- Extent, or % coverage, of various contaminants on the runway
 - What is assessed, e.g., are reports divided by contaminant type and by thirds?
 - How is the uniformity of the runway surface condition assessed and reported? :
 - Using Detailed mapping?
 - Using a general description in a NOTAM?
 - other?
- Contaminant depth: How is this determined?
- Cleared width: How is this determined?
- Other Information

9. Does the airport have in pavement sensors (Y/N)?**“Non-Winter” Contaminants (water, dirt, rubber):**

- How is this information used as an aid for preparing runway condition reports for “non-winter” contaminants?

.....

.....

.....

.....

.....

Winter Contaminants (water, dirt, rubber):

- How is this information used as an aid for preparing runway condition reports for “winter” contaminants?

.....

.....

.....

.....

.....

10. Any Other Remarks

“Non-Winter” Contaminants (water, dirt, rubber):

.....

.....

.....

.....

Winter Contaminants (water, dirt, rubber):

.....

.....

.....

.....

SUBMIT



European Aviation Safety Agency

Werner Kleine-Beek • Research Project Manager – Executive Directorate

Cologne, 23 January 2009
EASA WKB/hka E.2 2009(D)52720

To airlines, airport authorities, regulators,
ANSPs, airframe manufacturer contacted
by:

BMT Fleet Technology Limited
311 Legget Drive Kanata
Kanata ON K2K 1Z8
Canada

**Subject: Letter of Introduction for EASA Contract EASA.2008.C46
(RuFChaMaAB – Runway friction characteristics measurement and
aircraft braking)**

Dear Sir or Madam,

The European Aviation Safety Agency (EASA) is starting a project regarding the above subject to review existing and previous research as well as pertinent literature, providing a sound basis for the evolution of a road map for further development and regulatory or R&D actions, namely to contribute to the progress of the ICAO action plan and European (EASA) rulemaking.

After a tendering process, BMT Fleet Technology Ltd (BMT FTL) was selected to carry out the project. During the course of their work, BMT FTL will be contacting various organizations and agencies for information.

Should BMT FTL contact your organization, EASA appreciates your support and cooperation to the extent possible. Please feel free to contact me should questions arise.

Your cooperation is much appreciated.

Yours sincerely,

A handwritten signature in blue ink, reading 'Kleine-Beek', is positioned above the printed name.

W. KLEINE-BEEK
Research Project Manager
Safety Analysis & Research Department
Executive Directorate

Postal address: Postfach 10 12 53 • D-50452 Cologne, Germany – Visiting address: Ottoplatz, 1 • D-50679 Cologne, Germany
Tel.: +49 (0)221 8999 0000 • Fax: +49 (0)221 8999 0999 • E-mail: info@easa.europa.eu • www.easa.europa.eu

APPENDIX A, ANNEX 3 –
OPERATIONAL FRICTION CHARACTERISTICS (SENT TO AIR CARRIERS AND
AIRCRAFT MANUFACTURERS)



BMT Fleet Technology Ltd
 311 Legget Drive
 Kanata, Ontario
 Canada K2K 1Z8
 Tel: +1 613 592 2830
 Fax: +1 613 592 4950
www.fleetech.com

OPERATIONAL SURFACE FRICTION ASSESSMENT: SURVEY OF AIRCRAFT MANUFACTURERS AND AIR CARRIERS

Background and Objectives

BMT Fleet Technology Limited has been contracted by EASA (European Aviation Safety Agency) to gather information on regulations, procedures, standards, and guidelines that various Civil Aviation Authorities have in place that regulate and/or provide guidance to airports on maintenance of runways as related to providing acceptable runway surface conditions for aircraft landing and take-off.

An introductory letter from EASA is attached separately.

This survey is being conducted in the following parts:

Type of Assessment	General Conditions & Type(s) of Contaminants
<u>Functional Friction Characteristics</u> – these measurements are mainly intended for planning and undertaking runway pavement maintenance, and for setting criteria for the design of new pavements. The general intent is that this part of the survey would be in the context of Clause 2.9.6 in ICAO Annex 14 (which is repeated in the notes below for reference)	Water, dirt, rubber, worn surfaces
<u>Operational Friction Characteristics</u> – this relates to operations on contaminated surfaces, such as aircraft operations on contaminated surfaces, including possible actions by the aerodrome such as the closure of a runway. The general intent is that this part of the survey would be in the context of Clause 2.9.9 in ICAO Annex 14 (which is repeated in the notes below for reference)	• “Non-Winter”; Water, dirt, rubber • “Winter”; Ice, snow, slush

Notes: Copy of Clauses in ICAO Annex 14:

- 2.9.6: A runway or portion thereof shall be determined as being “slippery when wet” when the measurements specified show that the runway surface friction characteristics as measured by a continuous friction measuring device are below the minimum friction level specified by the State.
- 2.9.9 Whenever a runway is affected by water & snow, slush or ice, and it has not been possible to fully clear the precipitant fully, the condition of the runway should be assessed, & the friction coefficient measured.

Registered Office:
 311 Legget Drive,
 Kanata, ON Canada K2K 1Z8
 Registered in Canada No 10181 9902RC



The answers given in this survey will be analyzed with all the responses received. The overall results will be presented in summary form in our report. However, the individual responses from the various organizations contacted will remain confidential. Please advise us if you have any special requirements.

We thank you for your assistance and cooperation. If you have any questions, please contact me at the contact coordinates below. Please transmit this document by fax or electronic mail to:

George Comfort, BMT Fleet Technology Ltd.

Phone number: +1 613 592 2830 ext 226

Fax: +1 613 592 4950

Email: gcomfort@fleetech.com

DESCRIPTION OF SURVEY RESPONDENT

Name of Company:

Air Carrier? or Aircraft Manufacturer? (please specify):

Location and Address:

Type and Number of Aircraft Manufactured, or in the Fleet – please attach a list or summarize below.....

Types of Declared Contaminated Runway Surfaces Encountered* – please enter approx. percentages

- Contaminant type – “Non-Winter” (wet, dirt, rubber):%
 - Approximate Subdivision by contaminant type, or predominant contaminant type:
 - Please specify if possible:
 - Damp Pavement *without* Significant Rubber Buildup:%
 - Wet Pavement *without* Significant Rubber Buildup:%
 - Flooded Pavement *without* Significant Rubber Buildup:%
 - Damp Pavement *with* Significant Rubber Buildup:%
 - Wet Pavement *with* Significant Rubber Buildup:%
 - Flooded Pavement *with* Significant Rubber Buildup:%
 - Other (please specify):
- Contaminant type – “Winter” (ice, snow, slush)
 - Approximate overall percentage per year with any form of “winter” contaminant%
 - Approximate overall percentage per year with ice:%
 - Approximate overall percentage per year with dry or loose snow:%
 - Approximate overall percentage per year with wet snow:%
 - Approximate overall percentage per year with compacted snow:%
 - Approximate overall percentage per year with slush:%
 - Other (please specify):

Other Information:

.....

Contact coordinates

Name:

Duties:

Phone number:.....

Email:

*Explanatory Note: Information is being sought regarding the types of contaminated runway surfaces, as defined by runway surface condition reports, on which your aircraft operations are conducted.

Operational Friction Characteristics: Air Carriers & Manufacturers

BMT Fleet Technology Ltd.

SURVEY PART 1 – “NON WINTER” CONDITIONS

1- What information is required or valuable, and at what frequency?

- Runway friction reports – Please complete the table below.

Parameter	How Often Is This Information Supplied?	Is This Information Valuable? (Y/N)	How is the Information Used?	Priority (1 [highest] to 5 [lowest])	Required Accuracy for the Information	Required Reporting Frequency
Runway friction values, as measured and produced using a ground friction vehicle	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Summary braking action reports (e.g. good, fair, poor, nil)	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Runway braking action reports, as given by pilots of previous flights	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Other parameters?	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			

Use this space if additional room required:

.....

.....

.....

Operational Friction Characteristics: Air Carriers & Manufacturers

BMT Fleet Technology Ltd.

■ Description of runway surface condition - Please complete the following table.

Parameter	How Often Is This Information Supplied?	Is This Information Valuable? (Y/N)	How is this Information Used?	Priority (1 [highest] to 5 [lowest])	Required Accuracy for the Information	Required Reporting Frequency
Contaminant Type (e.g., damp, wet, flooded)	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Location of contaminants on runway, sub-divided by type	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Presence of rubber deposits (if this affects the braking performance), and their location on runway	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Contaminant depth	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Other parameters?	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			

Use this space if additional room required:

.....

.....

.....

Operational Friction Characteristics: Air Carriers & ManufacturersBMT Fleet Technology Ltd.

2- What types of contaminant are of most concern to your operations?

- Which “Non-Winter” contaminants do you consider to be of most concern? Please specify below if possible

.....

3- What information format would you prefer?

- ☐ by NOTAM or SNOWTAM
- ☐ by ATC
- ☐ by ATIS (Automatic Terminal Information Service)
- ☐ Other

.....

.....

.....

4- Any Other Remarks

.....

.....

SURVEY PART 2 – WINTER CONDITIONS

1 - What information is required or valuable, and at what frequency?

■ Runway friction reports - Please complete the table below

Parameter	How Often Is This Information Supplied?	Is This Information Valuable? (Y/N)	How is this Information Used?	Priority (1 [highest] to 5 [lowest])	Required Accuracy for the Information	Required Reporting Frequency
Runway friction values, as measured and produced using a ground friction vehicle	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Summary braking action reports (e.g. good, fair, poor, nil)	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Runway braking action reports, as given by pilots of previous flights	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Other parameters?	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			

Use this space if additional room required:

.....

.....

.....

Operational Friction Characteristics: Air Carriers & Manufacturers

BMT Fleet Technology Ltd.

■ Description of runway surface condition – Please complete the following table.

Parameter	How Often Is This Information Supplied?	Is This Information Valuable? (Y/N)	How is This Information Used?	Priority (1 [highest] to 5 [lowest])	Required Accuracy for the Information	Required Reporting Frequency
Contaminant Type (e.g., snow, ice, slush)	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Location of contaminants on runway, sub-divided by type	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Presence of rubber deposits (if this affects the braking performance), and their location on runway	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Contaminant depth	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			
Other?	☐ Usually ☐ Sometimes ☐ Seldom		☐ As Advisory Material only? ☐ For aircraft manufacturers – A governing input into flight certification? (If yes, explain below.) ☐ For air carriers – A governing input into aircraft operations? (If yes, explain below.) ☐ Information not used?			

Use this space if additional room required:

.....

.....

.....

2 - What types of contaminant are of most concern to your operations?

- Which “Winter” contaminants do you consider to be of most concern? Please specify below if possible

.....

3- What information format would you prefer?

- ☐ by NOTAM or SNOWTAM
☐ by ATC
☐ by ATIS (Automatic Terminal Information Service)
☐ Other

.....
.....
.....

4- Any Other Remarks

.....
.....

SUBMIT



European Aviation Safety Agency

Werner Kleine-Beeck • Research Project Manager - Executive Directorate

Cologne, 23 January 2009
EASA WKB/hka E.2 2009(D)52720

To airlines, airport authorities, regulators,
ANSPs, airframe manufacturer contacted
by:
BMT Fleet Technology Limited
311 Legget Drive Kanata
Kanata ON K2K 1Z8
Canada

**Subject: Letter of Introduction for EASA Contract EASA.2008.C46
(RuFChaMaAB - Runway friction characteristics measurement and
aircraft braking)**

Dear Sir or Madam,

The European Aviation Safety Agency (EASA) is starting a project regarding the above subject to review existing and previous research as well as pertinent literature, providing a sound basis for the evolution of a road map for further development and regulatory or R&D actions, namely to contribute to the progress of the ICAO action plan and European (EASA) rulemaking.

After a tendering process, BMT Fleet Technology Ltd (BMT FTL) was selected to carry out the project. During the course of their work, BMT FTL will be contacting various organizations and agencies for information.

Should BMT FTL contact your organization, EASA appreciates your support and cooperation to the extent possible. Please feel free to contact me should questions arise.

Your cooperation is much appreciated.

Yours sincerely,

A handwritten signature in blue ink, reading 'Kleine-Beeck', is positioned above the printed name.

W. KLEINE-BEEK
Research Project Manager
Safety Analysis & Research Department
Executive Directorate

Postal address: Postfach 10 12 53 • D-50452 Cologne, Germany – Visiting address: Ottoplatz, 1 • D-50679 Cologne, Germany

APPENDIX A, ANNEX 4–
EMAIL WITH FOLLOW-UP QUESTIONS

Dear Sir,

Re: Follow-Up Questions Regarding Survey Conducted With Respect to EASA-sponsored Study Regarding Runway Friction, Runway Condition Reporting and Aircraft Braking Performance

Thank you for taking the time to fill out our questionnaire in relation to the above study. This was much-appreciated.

We seek some additional information, in regard to how your airline assesses the performance of its aircraft on wet and contaminated runways for both takeoff and landing. Would you please reply regarding the following? We apologize for not asking these questions in our initial mail-out.

1. What information is contained in the AFM? Does it contain more information than that which is required to be provided to regulatory bodies, such as EASA or FAA, for aircraft certification?
2. Are your aircraft performance assessments based on the contaminant type, e.g., wet, snow, slush, ice, other? Which contaminant types are included?
3. Are your performance assessments based on readings from a ground friction vehicle? If so, which one(s) is it based on?
4. Is this information supplied by the aircraft manufacturer? If not, how is this information determined?
5. Does your airline have an onboard computer that calculates the aircraft's landing or takeoff performance based on the runway surface condition?
6. Please add any further comments that you may have.

We recognize that it may not be possible to answer these questions in a simple, concise, general manner, as they may vary from case to case. Would it be simpler and more convenient for you to discuss these issues during a telephone conversation? If so, please let us know and we will be pleased to set up a call at your convenience.

Thank you again for your cooperation and assistance.

George Comfort
Manager Cold Regions Technology Centre
BMT Fleet Technology Limited
311 Legget Drive
Kanata, ON K2K 1Z8
Tel: 613-592-2830, Ext. 226
Fax: 613-592-4950
Email: gcomfort@fleetech.com

APPENDIX B –
LITERATURE REVIEW OF RUNWAY FRICTION STANDARDS

Contents:

- Appendix B.1: Survey of Civil Aviation Authorities (Comfort, Rado and Mazur, 2008)
- Appendix B.2: Literature Review of Runway Friction Standards
- Appendix B.3: Runway Friction Standards for the Former Yugoslavia
(taken from their AIP)

APPENDIX B, ANNEX 1–
SURVEY OF CIVIL AVIATION AUTHORITIES
(excerpt from Comfort, Rado and Mazur, 2009)

Reference:

Comfort, G., Rado, Z., and Mazur. A., 2009, Correlation of Continuous Friction Measuring Equipment and Development of Runway Friction Standards, BMT FTL report 6176 submitted to Transport Canada.

SURVEY OF CIVIL AVIATION AUTHORITIES

Survey Objectives and Scope

Several Civil Aviation Authorities (CAAs) were contacted to obtain information regarding the friction standards they employ for runway pavements. Table B.1 summarizes the contacts that were made. Information was sought regarding:

- (a) The type of criteria – for example, information was requested regarding whether or not the criteria include:
 - (i) both a maintenance planning and action level
 - (ii) criteria based on both the whole runway and the lowest section of the runway, and if so, the shortest runway section that is considered
- (b) The friction values that are used as the criteria.
- (c) The friction measuring devices that are specified, and used
- (d) The friction test conditions that are specified such as:
 - (i) the speed(s) to be tested
 - (ii) the water film depth
 - (iii) the test tire and pressure
- (e) The frequency of friction measurement that is required, such as the number of times per year.
- (f) The process by which a particular friction-measuring device could get accepted for collecting friction data for this purpose

Table B.1: Contacts Made

Organization	Contact
BAA (British Airports Authority) & the UK CAA (United Kingdom Civil Aviation Administration)	Contacted John Lim of BAA & the UK CAA website (www.caa.co.uk)
EASA (European Aviation Safety Agency)	Contacted EASA website (www.easa.eu.int)
FAA (Federal Aviation Administration)	Contacted David Evans de Maria & the FAA website (www.faa.gov)
ICAO (International Civil Aviation Administration)	Not applicable
NCAA (Norwegian Civil Aviation Administration)	Contacted Armann Norheim
STBA - French acronym for the French Civil Aviation Administration	Contacted website (www.stac.aviation-civile.gouv.fr)
Munich airport	Contacted T. Torsten Meyer, and Peter Mascha, Munich airport
Transport Canada	Contacted the TC website (www.tc.gc.ca)

Organization	Contact
Hong Kong Airport Authority	Contacted by email: Eric Poon & Wing Yeung Civil Aviation Department of Hong Kong, etlpoon@cad.gov.hk; tw.yeung@hkairport.com
Australian Airport Authority	Contacted website for Australian Airport Authority www.casa.gov.au .

Detailed Survey Results

International Civil Aviation Administration

The ICAO develops and promulgates standards and recommended practices for the safety, regularity and efficiency of international air navigation and to which contracting states are expected to adopt. ICAO's recommendations are contained in ICAO, Annex 14, Aerodromes, Volume 1, Aerodrome Design and Operations, Fourth Edition, July 2004. A review of Annex 14 showed the following.

- (a) Runway friction levels are advised for the following criteria (Figure B.1):
 - o Design Objective Level (DOL) for a new runway, or a re-surfaced one;
 - o Maintenance Planning Level (MPL) – maintenance actions should be planned when the runway friction falls below this level; and
 - o Maintenance Action Level (MAL) – maintenance actions should be carried out when the runway friction falls below this level.

The following test conditions apply to the values in Figure B.1:

- o water film depth: 1.0 mm;
 - o test speed: 65 and 95 km/hr – ICAO recommends that tests be done at both speeds.
- (b) Runway friction levels are recommended for several devices (Figure B.1). The ICAO document states that friction measurements should be made with a continuous friction measuring device provided with a smooth tread tire.
 - (c) Extent of runway – ICAO's recommendations apply to a "significant length". The ICAO recommendations do not include a definition of a "significant length". However, Section 10.4 of ICAO Annex 14 states "Corrective maintenance action shall be taken when the friction characteristics for either the entire runway or portion thereof are below a minimum friction level specified by the State. Note – A portion of runway in the order of 100 m long may be considered significant for maintenance or reporting action."

- (d) Friction measurement frequency - ICAO states that:
- o Friction of a runway surface should be taken when first constructed or after resurfacing to establish a base line for future comparisons; and
 - o Friction tests of existing runway surfaces should be undertaken periodically to identify areas with low friction when wet.
- (e) the ICAO documents provides guidance on establishing the design objective for new runway surfaces, maintenance planning and minimum friction levels depending upon the continuous friction measuring device being used.

Table A-1.

Test equipment	Test tire		Test speed (km/h)	Test water depth (mm)	Design objective for new surface	Maintenance planning level	Minimum friction level
	Type	Pressure (kPa)					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Mu-meter Trailer	A	70	65	1.0	0.72	0.52	0.42
	A	70	95	1.0	0.66	0.38	0.26
Skiddometer Trailer	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Surface Friction Tester Vehicle	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Runway Friction Tester Vehicle	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.54	0.41
TATRA Friction Tester Vehicle	B	210	65	1.0	0.76	0.57	0.48
	B	210	95	1.0	0.67	0.52	0.42
GRIPTESTER Trailer	C	140	65	1.0	0.74	0.53	0.43
	C	140	95	1.0	0.64	0.36	0.24

**Figure B.1: Runway Friction Levels Specified by ICAO
(ICAO, Annex 14, Aerodromes, Volume 1 Aerodrome Design and Operations,
4th Edition, July 2004)**

Federal Aviation Administration

The FAA's recommendations are contained in FAA Advisory Circular 150-5320-12C. Key items are summarized below:

- (a) Only approved CFMEs are to be used. The FAA Advisory Circular (AC) provides a list of approved devices (Figure B.2). This AC notes that some of these devices are no longer available, although they are still on the list of devices contained in its table of DOL, MPL, and MAL friction criteria (Figure B.3).

- (b) The FAA provides advisories regarding Design Objective Level (DOL), Maintenance Planning Level (MPL), and Maintenance Action Level (MAL) friction levels (Figure B.3). These vary with the device and the test speed. Furthermore, the FAA advises that:
- o A water film depth of 1.0 mm should be used for friction surveys;
 - o Tests should be done at both speeds (i.e., 40 mph and 60 mph). The FAA Advisory Circular notes that the lower test speed determines the overall macrotexture/contaminant/drainage condition whereas the high test speed provides an indication of the condition of the surfaces' microtexture. The case where a runway might pass at one speed but fail at the other speed is not addressed explicitly in the FAA Advisory Circular.

AIRPORT SURFACE FRICTION TESTER INDUSTRIES AB Metallgatan 7 271 39 Ystad, Sweden SWEDEN	AIRPORT SURFACE FRICTION TESTER +46 0 411 651 00 FAX +46 0 411 190 12 email: sales@asft.se
AIRPORT TECHNOLOGY USA	NO LONGER AVAILABLE
DOUGLAS EQUIPMENT LTD Douglas House, Village Road Arle, Cheltenham Gloucestershire GL51 0AB UK	MU METER +44 1242 531219 FAX +44 1242 571667 email: spd@douglas-equipment.com
DYNATEST CONSULTING, INC., (FORMERLY K.J. LAW ENGINEERS, INC.) 13952 US Highway 301 South Starke, FL 32091	RUNWAY FRICTION TESTER (6810, 6850 and 6875) +(904) 964-3777 FAX +(904) 964-3749
FINDLAY, IRVINE, LTD. ESTER 42-44 Bog Road, Penicuik Midlothian EH 26 9 BU SCOTLAND www.findlayirvine.com	GRIPTESTER FRICTION +44 1968 672111 FAX +44 1968 671237
INTERTECH ENGINEERING	NO LONGER AVAILABLE
NEUBERT AERO CORP. ESTER 4105 West De Leon Street Tampa, FL 33609	NAC DYNAMIC FRICTION +(727) 538-8744 FAX +(727) 538-8765 email: info@airportnac.com www.airportnac.com
NORSE METER P. O. Box 125 Bogstadveien 0323 0310 NORWAY	RUNAR RUNWAY ANALYSER AND RECORDER +47 23 20 1270 FAX +47 23 20 1271
PATRIA VAMMAS AEC SKIDDOMETER P.O. Box 18 Vammaksentie FIN-38201 Vammala 4694250 FINLAND	BV-11 +358 20 4694041 FAX +358 20 www.patria.fi
SCANDINAVIAN AIRPORT AND ROAD SYSTEMS AB (SFT) Box 31, Sjöviksvägen 4 23121 Trelleborg SWEDEN US/Canada Tradewind Scientific Ltd.	SARSYS FRICTION TESTER SARSYS TRAILER FRICTION TESTER (STFT) +46 410 46 110 FAX +46 410 46 111 www.tradewindscientific.com

Figure B.2: CFME Devices Approved by the FAA

	40 mph			60 mph		
	Minimum	Maintenance Planning	New Design/ Construction	Minimum	Maintenance Planning	New Design/ Construction
Mu Meter	.42	.52	.72	.26	.38	.66
Dynatest Consulting, Inc. Runway Friction Tester	.50	.60	.82	.41	.54	.72
Airport Equipment Co. Skiddometer	.50	.60	.82	.34	.47	.74
Airport Surface Friction Tester	.50	.60	.82	.34	.47	.74
Airport Technology USA Safegate Friction Tester	.50	.60	.82	.34	.47	.74
Findlay, Irvine, Ltd. Griptester Friction Meter	.43	.53	.74	.24	.36	.64
Tatra Friction Tester	.48	.57	.76	.42	.52	.67
Norsemeter RUNAR (operated at fixed 16% slip)	.45	.52	.69	.32	.42	.63

Figure B.3: Runway Friction Levels Advised by the FAA

- (c) The FAA provides advisories regarding the frequency of runway friction surveys (Figure B.4).
- (d) The FAA includes advisories regarding the length of runway section, as follows:
- (e) Friction deterioration below the MPL for 500 ft: no corrective action is required when the friction is above the MAL for 500 ft, and the adjacent 500 ft segments are at or above the MPL.
- (f) Friction deterioration below the MPL for 1000 ft or more: FAA advises the airport operator to investigate the causes for the observed deterioration in friction.
- (g) Friction deterioration below the MAL: corrective action should be taken immediately when the friction is below the MAL for 500 ft or more. When the adjacent 500 ft sections are above the MAL but below the MPL, the airport operator should undertake an extensive investigation of the reasons for the runway friction deterioration.
- (h) Lateral location for friction test to be based on the type of aircraft operating on the runway – 3 m for narrow body aircraft and 3 m and 6 m to the right of runway centerline for runways serving both narrow body and wide body aircraft.

NUMBER OF DAILY MINIMUM TURBOJET AIRCRAFT LANDINGS PER RUNWAY END	MINIMUM FRICTION SURVEY FREQUENCY
LESS THAN 15	1 YEAR
16 TO 30	6 MONTHS
31 TO 90	3 MONTHS
91 TO 150	1 MONTH
151 TO 210	2 WEEKS
GREATER THAN 210	1 WEEK

Figure B.4: Friction Survey Frequencies Advised by the FAA

British Airport Authority and the United Kingdom Civil Aviation Administration

The UK CAA's recommendations are contained in UK CAA, CAP 683 – The Assessment of Runway Surface Friction for Maintenance Purposes. Friction levels are recommended for the DOL, the MPL, and the Minimum Friction Level (MFL) based on readings obtained with either the Mu-Meter or the GripTester (Figure B.5). Other devices can be used if they provide comparable results with the currently accepted CFMEs.

The criteria used reflect the CAA's interpretation of ICAO Annex 14 in so far as these have been adopted by the UK.

CFME	DOL	MPL	MFL
Mu-Meter	0.72 or greater	0.57	0.50
GripTester	0.80 or greater	0.63	0.55

Figure B.5: Friction Levels Recommended by the UK CAA (UK CAP 683 – 2004)

The following additional information, which is not in UK CAA, CAP 683, 2004, was obtained from the British Airport Authority through personal contacts:

- (a) Friction measurement speed: 65 km/h.
- (b) The values in Figure 1.5 are an average of the three thirds data collected for the whole runway. The criteria apply to all paved runways exceeding 1200 metres.

- (c) The water film depth used for the GripTester and Mu-Meter are 0.25 mm and 0.50 mm, respectively.
- (d) The values listed by the UK CAA are based on input from Cranfield University.

Munich Airport and Germany

The friction standards employed by Munich Airport are summarized in Figure B.6. Subsequent communications confirmed that these are standardized throughout Germany. Their standards are based solely on friction data collected with the Saab Surface Friction Tester (SFT).

Calibration of the runway:		
Friction device :	Saab SFT	
Friction wheel :	ASTM E1551	
Wheel inflation pressure :	210kPa	
Depth of the waterpath :	1mm	
Width of the waterpath :	10cm	
Friction level for rwy 08:		
Measuring speed	65kmh	96kmh
Design level	0.82	0.78
Maintenance friction level	0.60	0.51
Minimum friction level	0.50	0.35

**Figure B.6: Friction Standards for Munich Airport
(T.T. Meyer and P. Mascha, personal communication)**

French Civil Aviation Authority

The French friction standards are summarized in Figure B.7. The friction values given in Figure B.7 are Maintenance Action Levels (MALs). They vary with the device and the test speed. A water film depth of 1 mm is specified for all cases. They apply to the whole runway or to an unspecified portion of the runway (DGAC, Journal officiel no. 159 – juillet 2006 - Annexe technique n°1 relative aux caractéristiques physiques des aérodromes civils utilisés par les aéronefs à voilure fixe).

Runway friction measurements are to be performed within a time frame of at least two years.

Dispositif de mesure	Pneu d'essai		Vitesse durant l'essai (km/h)	Epaisseur d'eau durant l'essai (mm)	Niveau minimal de frottement
	Type	Pression (kPa)			
Munètre MK6	A	70	65	1,0	0,30
	A	70	95	1,0	0,20
Skiddcmètre BV11	B	210	65	1,0	0,41
	B	210	95	1,0	0,28
SFT	B	210	65	1,0	0,40
	B	210	95	1,0	0,27
RFT	B	210	65	1,0	0,42
	B	210	95	1,0	0,28
SARSYS STFT	B	210	65	1,0	0,37
	B	210	95	1,0	0,24
IMAG	C	150	65	1,0	0,30
	C	150	95	1,0	0,20

(A) Pneu d'essai ASTM (American Society for Testing and Materials), à bande de roulement lisse conforme à la spécification E670
 (B) Pneu d'essai ASTM (American Society for Testing and Materials), à bande de roulement lisse conforme à la spécification E1551
 (C) Pneu d'essai AIPCR (Association Internationale des Congrès de la Route) à bande de roulement lisse

Figure 2.7: STBA Friction Standards (STBA, Journal 159 – 2006 Annex 1)

Norwegian Civil Aviation Administration

The Norwegian Aeronautical Information Publication (AIP) states that “Norway does not accept the method as described using continuous friction measuring device as satisfying in order to be able to publish necessary information concerning slippery conditions” - Section Gen 1.7- 9.4.4.

However, personal contacts with NCAA staff indicated that two separate criteria are accepted by the NCAA (A. Norheim, NCAA, personal communication):

- (a) The ICAO criteria – the SFT is used at Gardermoen airport.
- (b) Criteria based on texture measurements, as Avinor does not follow the ICAO recommendations. The Avinor method is described in the reference below.

Reference:

Avinor, __, Runway – Wet and Contaminated, Certification Limitations, available as “Note 110106 Wet Runway.pdf” at www.ippc.no.

Australian Civil Aviation Authority

The CAA survey found that the Australian Civil Aviation Authority has a Manual of Standards Part 139 for Aerodromes (Australian CAA, Manual of Standards Part 139, Chapter 10 Version 1.2 2004). This document includes runway friction characteristics. Key items from this document are as follows.

- (c) Effective January 2006, designated international aerodromes conducting international air transport operations are required to use an ICAO-accepted CFME device with self-wetting features to measure friction levels on runways.

- (d) Runways must be evaluated when first constructed or after resurfacing to determine the wet runway surface friction characteristics.
- (e) Although desirable, it is not mandatory to test friction characteristics at more than one speed.
- (f) The Australian Manual of Standards for Aerodromes provides a table showing friction values for various CFMEs, which is summarized as Figure B.8. The table identifies DOL, MPL, and MAL friction limits.
- (g) The water film depth used is 1 mm.

Test Equipment	Test Tyre Tyre Pressure (kPa)	Test Speed (km/h)	Test Water Depth (mm)	Design Objective for New Surface	Maintenance Planning Level	Minimum Friction Level
Mu-meter trailer	A 70	65	1.0	0.72	0.52	0.42
	A 70	95	1.0	0.66	0.38	0.26
Skiddometer trailer	B 210	65	1.0	0.82	0.60	0.50
	B 210	95	1.0	0.74	0.47	0.34
Surface friction tester vehicle	B 210	65	1.0	0.82	0.60	0.50
	B 210	95	1.0	0.74	0.47	0.34
Runway friction tester vehicle	B 210	65	1.0	0.82	0.60	0.50
	B 210	95	1.0	0.74	0.54	0.41
TATRA friction tester vehicle	B 210	65	1.0	0.76	0.57	0.48
	B 210	95	1.0	0.67	0.52	0.42
GRIPTESTER trailer	C 140	65	1.0	0.74	0.53	0.43
	C 140	95	1.0	0.64	0.36	0.24

Figure B.8: Friction Standards in the Australian Manual of Standards

Hong Kong Airport Authority

The following information was received from the Hong Kong Airport Authority, which performs runway friction testing:

- (a) Friction surveys are conducted every 10 days;
- (b) They only use the GripTester for runway friction surveys;
- (c) They follow the ICAO criteria for the GripTester for maintenance planning (i.e., 0.53) and for maintenance action (i.e., 0.43);
- (d) They only test at 65 km/hr; and
- (e) They conduct friction measurements using a 1 mm water film depth.

Transport Canada

Transport Canada's recommendations are contained in TP 312, and the following Aerodrome Safety Circulars (ASCs):

- (a) Runway Friction Testing Program: ASC 2004-024;
- (b) Guidelines Respecting the Measurement, Evaluation and Maintenance of Airfield Pavement Surface Friction - Appendix A to ASC 2004-024.

Key points regarding Transport Canada's recommendations are summarized below:

- (c) Airfield runways must provide adequate skid resistance to ensure the safe braking of aircraft. Furthermore, measurements of friction characteristics of the runway surface shall be made using a continuous friction-measuring device using self-wetting features.
- (d) The ASCs only specify a Maintenance Planning Level (MPL) and a Maintenance Action Level (MAL). See Figure B.9. A Design Objective Level (DOL) is not specified.
- (e) Different friction criteria are specified for the runway average compared to the lowest 100 meter section of the runway.
- (f) The SFT is the benchmark friction measuring device, in combination with the operational parameters listed in Figure B.10.
- (g) The GripTester is considered an approved CFME for use in Canada, in combination with the operational parameters listed in Figure B.11. The ASCs advise that the equivalent SFT reading can be determined from GripTester (GT) readings using the equation and approach shown in Figure B.12.

The GripTester maintenance planning level friction value of 0.48 is considered approximately equivalent to an SFT maintenance planning reading of 0.60, using the TC correlation equation and a water film depth of 0.5 mm.

The GripTester maintenance action level number of 0.37 is considered approximately equivalent to an SFT maintenance action reading of 0.50, using the TC correlation equation and a water film depth of 0.5 mm.

The ASCs advise that in cases where different values are obtained, the SFT readings will govern.

The ASCs also advise that an alternative water depth of 0.25 mm may be used with the GripTester. In that case, the results would be evaluated against the runway friction standards as given in Table 1 of ASC 2004-024 Appendix A (which is reproduced as Figure B.9 in this report).

Airfield Pavement Runway Friction Standards (derived from 9.4 of TP312 4th Edition)	
Airfield Pavement Runway Friction Standards Determining the Need for Corrective Action to Restore Surface Friction	
Corrective Action ⁽⁴⁾ To Restore Runway Surface Friction	Coefficient of Friction (COF) Numbers as Measured With a Surface Friction Tester ⁽²⁾
	When The "Runway Average COF" ⁽³⁾ Is Less Than
Shall Be Planned	0.60
Shall Be Taken	0.50
*****	When A "Runway 100 Metre Section Average COF" ⁽³⁾ Is Less Than
Shall Be Planned	0.50 (Treaded Tire) 0.40 (Smooth Tire) ⁽⁶⁾
Shall Be Taken	0.30

(Note: Airport Operators are cautioned to refer to the latest standards associated to CAR's Part III SubPart 2)

- The above friction values are taken from TP 312 4th Edition and are used to establish the need for corrective action to be planned and/or taken to restore runway surface friction that has deteriorated below the Coefficient of Friction (COF) levels shown.
- The friction levels specified in the above table apply to Coefficient of Friction (COF) measurements made with the benchmark Surface Friction Tester device as defined in Section 1.2.1 and in accordance with the conditions of test specified in Section 1.4.
- For the purposes of interpreting the above table: (i) the "Runway Average COF" value shall be taken to mean the average coefficient of friction measured over the entire length of the runway less a distance required for test vehicle acceleration and deceleration; and; (ii) the "Runway 100 Metre Section Average COF" shall be taken to mean any contiguous section of the runway that is 100 metres or greater in length.
- When COF values are below levels specified in the above table, the corrective action categories listed shall be taken to have the following meaning and the requirements respecting the provision of "slippery when wet" NOTAMs are to be complied with in accordance with the standard: (i) "Shall Be Planned" - the Airport Operator shall investigate the cause of the low friction values and develop a plan to restore friction levels on the affected runway or portions thereof; (ii) "Shall Be Taken" - surface restoration to restore friction shall be undertaken immediately.
- The purpose of the corrective maintenance shall be to restore the surface friction characteristics of the affected pavement areas so that subsequently measured COF values will meet or exceed the "Shall Be Planned" levels specified in the above table.
- Friction measurements made with a non-treaded tire (smooth) are lower than those made with a treaded tire. As a result the "Runway 100 m Section Average" COF standard established for the " shall be planned" action level has been correspondingly adjusted downwards from 0.50 to 0.40 to accommodate the change in standard test tire.

Figure B.9: Transport Canada's Friction Standards (Transport Canada, 2004)

1.4.1 The following conditions of test are applicable to measurements that are made with the Surface Friction Tester and will be assessed against the friction standards given in Table 1.

- a. The friction test tire must be manufactured to meet the requirements of ASTM E1551.
- b. The friction test tire is to be inflated to a pressure of 207 ± 3 kPa.
- c. The vertical load on the friction test tire is to be 1400 ± 20 N.
- d. The vehicle test speed must be held constant at 65 ± 5 km/h.
- e. The depth of water placed in front of the friction test tire by the self-wetting system must be 0.5 mm in thickness.
- f. The friction test tire is to be continuously braked during testing and have a constant slip ratio in the range of 10-20 percent.
- g. The friction measuring system and components are to be calibrated in accordance with the manufacturer's instructions so as to ensure a consistent relationship between measured forces and the coefficient of friction output.
- h. The friction tests are to be conducted only when both the pavement surface and the ambient air temperatures are above 0°C (zero degrees Celsius) and the pavement is dry or no more than "damp" prior to testing. Note: "Damp" means that the surface appears wet but that the moisture depth cannot be readily determined.
- i. The friction measurements are to be taken on tracks parallel to the runway longitudinal centerline, at right and left offsets of:
three (3) metres for Runways Serving only Narrow Body Aircraft and
three (3) and six (6) metres for Runways Serving Narrow and Wide Body Aircraft.

Figure B.10: Operational Parameters for the SFT (Transport Canada, 2004)

2.3.2 The conditions of test applicable to measurements made with the GripTester should be as follows.

- i. The friction test tire must be manufactured to meet the requirements of ASTM E1844.
- ii. The friction test tire is to be inflated to a pressure of 138 ± 3 kPa.
- iii. The vertical load on the friction test tire is to be the standard GripTester tire load of 205 N.
- iv. The test speed must be held constant at 65 ± 5 km/h.
- v. The depth of water placed in front of the friction test tire by the self-wetting system should be 0.50 mm in thickness. An alternative water depth of 0.25 mm may also be used (see Section 2.4.3 below).
- vi. The friction test tire is to be continuously braked during testing and should have a constant slip ratio in the range of 10-20 percent.
- vii. The friction measuring system and components are to be calibrated in accordance with the manufacturer's instructions so as to ensure a consistent relationship between the measured force input and the COF output.
- viii. The friction tests are to be conducted only when the pavement surface and the ambient air temperatures are above 0°C (zero degrees Celsius) and the pavement is dry or no more than "damp" prior to testing. Note: "Damp" means that the surface appears wet but that the moisture depth cannot be readily determined.
- ix. The friction measurements are to be taken on tracks parallel to the runway longitudinal centerline, at right and left offsets of:
three (3) metres for Runways Serving only Narrow Body Aircraft and
three (3) and six (6) metres for Runways Serving Narrow and Wide Body Aircraft..

Figure B.11: Operational Parameters for GripTester (Transport Canada, 2004)

2.4 Estimating Standard Friction Values from GripTester Measurements

2.4.1 The equivalent friction value that would be obtained using the Surface Friction Tester can be estimated from measured GripTester friction values by applying the following equation which requires that GripTester friction measurements be made and determined for pavement test sections 100 metres in length:

$$\text{SFT} = (0.92 * \text{GT}) + 0.16$$

where:

1. "SFT" represents an estimate of the average Coefficient of Friction that would be measured by the Surface Friction Tester over a section of pavement 100 metres in length, and
2. "GT" is the average Coefficient of Friction measured by the GripTester over a section of pavement 100 metres in length.

2.4.2 Caution should be exercised when using the above equation to estimate "equivalent" Surface Friction Tester measurements. The equation was derived on the basis of a series of parallel field tests conducted on a wide range of runway pavement surfaces using both the Surface Friction Tester and the GripTester under the standard conditions of test applicable to each device. The Standard Error of the Estimate associated with the conversion equation is ± 0.057 SFT friction units and the Correlation Coefficient of Determination R^2 is 0.81 which is indicative of the difficulty inherent in attempting to achieve correlations between measurements obtained with different friction testing devices.

2.4.3 An acceptable modification to the conditions of test applicable to measurements made with the GripTester involves reduction of the depth of water placed in front of the friction test tire by the self-wetting system from 0.50 mm to 0.25 mm. All other GripTester conditions of test remain unchanged. GripTester friction numbers obtained using a 0.25 mm water depth will typically be 0.03 to 0.04 COF units lower than those that would be obtained with the SFT under standard conditions of test. As a result, GripTester friction results obtained at a 0.25 mm water depth will be more conservative in relation to the established SFT benchmark values and any runway surface that meets friction standards under the GripTester 0.25 mm water depth test condition should also meet standards if tested with the reference SFT equipment.

Figure B.12: Calculating Equivalent SFT Values from GT Values
(ref: TC ASC 2004-024)

Overall Comparisons

The following observations are made:

- (a) Summary comparisons – The DOL, MPL, and MAL friction values given by the different agencies are summarized in Tables B.2, B.3, and B.4, respectively. Figures B.13 and B.14 compare the MPL and MAL friction standards for the GripTester and the SFT, respectively.

These comparisons show that:

- (i) GripTester – the MPLs and the MALs vary over a wide range, which is probably due in part to the fact that different water film depths apply to the various standards.

Transport Canada's criteria for the MPL and the MAL for a 0.5 mm film depth for the GT are considerably lower than those recommended by ICAO and FAA, recognizing that the ICAO and FAA standards have been

developed for a 1.0 mm film depth whereas Transport Canada's standard applies to a 0.5 mm film depth.

Transport Canada's criteria for the MPL and the MAL for a 0.25 mm film depth for the GripTester are in reasonable agreement with those of the UK for a 0.25 mm film depth.

- (ii) SFT – the MPLs and the MALs are consistent for most agencies. Transport Canada's criteria for the SFT are in close agreement with the other agencies, recognizing that TC conducts tests at 0.50 mm film depth, versus 1.0 mm for the other agencies.

The MAL recommended by the French CAA is considerably lower than all of the other agencies. The reasons for this variation are unclear, although it may be related to the fact that the French criteria apply to either the whole runway or to an unspecified portion of the runway. Thus, their criteria may include an allowance for local sections of the runway. It is not clear whether the French criteria should be compared to Transport Canada's standards for the whole runway, or for the lowest 100 m section.

- (iii) Most of the agencies follow either the ICAO or the FAA advisories, to varying extents. However, there are a number of exceptions and variations as summarized below.
- (iv) Transport Canada is the only agency to specify different friction criteria for a portion of the runway (i.e., the lowest 100 m section) compared to the average for the whole runway.
- (v) The ICAO and the FAA advisories allow for the greatest number of CFMEs. Most of the other advisories are limited to fewer CFMEs. Only the SFT and the GripTester are approved for use at Canadian airports.
- (vi) Transport Canada specifies a water film depth of 0.5 mm for runway friction testing compared to 1.0 mm for most other agencies.
- (vii) Transport Canada conducts friction-testing at only one speed, of 65 km/hr.

Table B.2: Comparison of Friction Standards: Design Objective Level

	Film	Mu-Meter	Skiddometer	SFT	RFT	Tatra	Griptester	Safegate	Norsemeter	IMAG	SARSYS
	Depth (mm)	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh
ICAO	1.0	0.72	0.82	0.82	0.82	0.76	0.74				
FAA	1.0	0.72	0.82	0.82	0.82	0.76	0.74	0.82	0.69		
France	1.0										
Germany	1.0			0.82							
Hong Kong	1.0						0.74				
Australia	1.0	0.72	0.82	0.82	0.82	0.76	0.74				
UK CAA	0.5	0.72									
Transport Cda	0.5										
UK CAA	0.25						0.80				

Design Objective Levels: Test Speed = 95 km/hr

	Film	Mu-Meter	Skiddometer	SFT	RFT	Tatra	Griptester	Safegate	Norsemeter	IMAG	SARSYS
	Depth (mm)	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh
ICAO	1.0	0.66	0.74	0.74	0.74	0.67	0.64				
FAA	1.0	0.66	0.74	0.74	0.72	0.67	0.64	0.74	0.63		
France	1.0										
Germany	1.0			0.78							
Hong Kong	1.0						0.64				
Australia	1.0	0.66	0.74	0.74	0.74	0.67	0.64				

Table B.3: Comparison of Friction Standards: Maintenance Planning Level

Maintenance Planning Levels: Test Speed = 65 km/hr

	Film	Mu-Meter	Skiddometer	SFT	RFT	Tatra	Griptester	Safegate	Norsemeter	IMAG	SARSYS
	Depth (mm)	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh
ICAO	1.0	0.52	0.60	0.60	0.60	0.57	0.53				
FAA	1.0	0.52	0.60	0.60	0.60	0.57	0.53	0.60	0.52		
France	1.0										
Germany	1.0			0.60							
Hong Kong	1.0						0.53				
Australia	1.0	0.52	0.60	0.60	0.60	0.57	0.53				
UK CAA	0.5	0.57									
Transport Cda	0.5			0.60			0.48				
UK CAA	0.25						0.63				
Transport Cda	0.25						0.60				

Maintenance Planning Levels: Test Speed = 95 km/hr

	Film	Mu-Meter	Skiddometer	SFT	RFT	Tatra	Griptester	Safegate	Norsemeter	IMAG	SARSYS
	Depth (mm)	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh
ICAO	1.0	0.38	0.47	0.47	0.54	0.52	0.36				
FAA	1.0	0.38	0.47	0.47	0.54	0.52	0.36	0.47	0.42		
France	1.0										
Germany	1.0			0.51							
Hong Kong	1.0						0.36				
Australia	1.0	0.38	0.47	0.47	0.54	0.52	0.36				

Notes:

1. Test Speed in Germany = 96 km/hr, not 95 km/hr
2. Transport Canada (TC) values for the Griptester were calculated using an equation in TC ASC 2004-024.
3. The Transport Canada values apply to the runway average.
4. Transport Canada specifies that when testing with the GripTester using the 0.25 mm water depth, the results are to be evaluated against the friction standards given in Table 1 of ASC 2004-024.

Table B.4: Comparison of Friction Standards: Maintenance Action Level

Maintenance Action Levels: Test Speed = 65 km/hr

	Film	Mu-Meter	Skiddometer	SFT	RFT	Tatra	Griptester	Safegate	Norsemeter	IMAG	SARSYS
	Depth (mm)	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh	65 kmh
ICAO	1.0	0.42	0.50	0.50	0.50	0.48	0.43				
FAA	1.0	0.42	0.50	0.50	0.50	0.48	0.43	0.50	0.45		
France	1.0	0.30	0.41	0.40	0.42					0.30	0.37
Germany	1.0			0.50							
Hong Kong	1.0						0.43				
Australia	1.0	0.42	0.50	0.50	0.50	0.48	0.43				
UK CAA	0.5	0.50									
Transport Cda	0.5			0.50			0.37				
UK CAA	0.25						0.55				
Transport Cda	0.25						0.50				

Maintenance Action Levels: Test Speed = 95 km/hr

	Film	Mu-Meter	Skiddometer	SFT	RFT	Tatra	Griptester	Safegate	Norsemeter	IMAG	SARSYS
	Depth (mm)	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh	95 kmh
ICAO	1.0	0.26	0.34	0.34	0.41	0.42	0.24				
FAA	1.0	0.26	0.34	0.34	0.41	0.42	0.24	0.34	0.32		
France	1.0	0.20	0.28	0.27	0.28					0.20	0.24
Germany	1.0			0.35							
Hong Kong	1.0						0.24				
Australia	1.0	0.26	0.34	0.34	0.41	0.42	0.24				

Notes:

1. Test Speed in Germany = 96 km/hr, not 95 km/hr
2. Transport Canada (TC) values for the Griptester were calculated using an equation in TC ASC 2004-024.
3. The Transport Canada values apply to the runway average.
4. Transport Canada specifies that when testing with the GripTester using the 0.25 mm water depth, the results are to be evaluated against the friction standards given in Table 1 of ASC 2004-024.

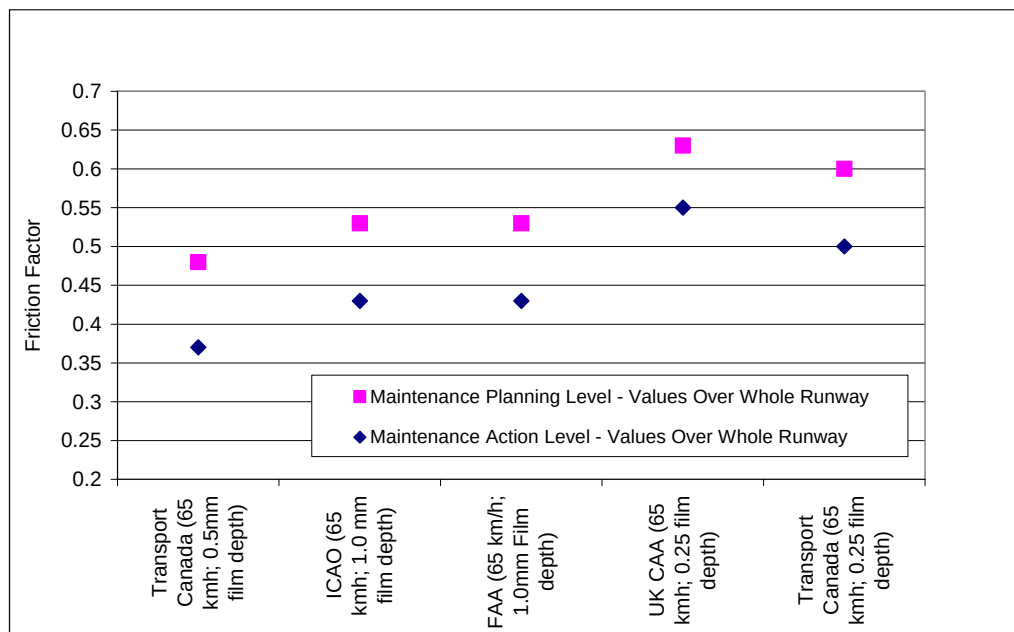


Figure B.13: Comparison of Friction Standards for the GripTester

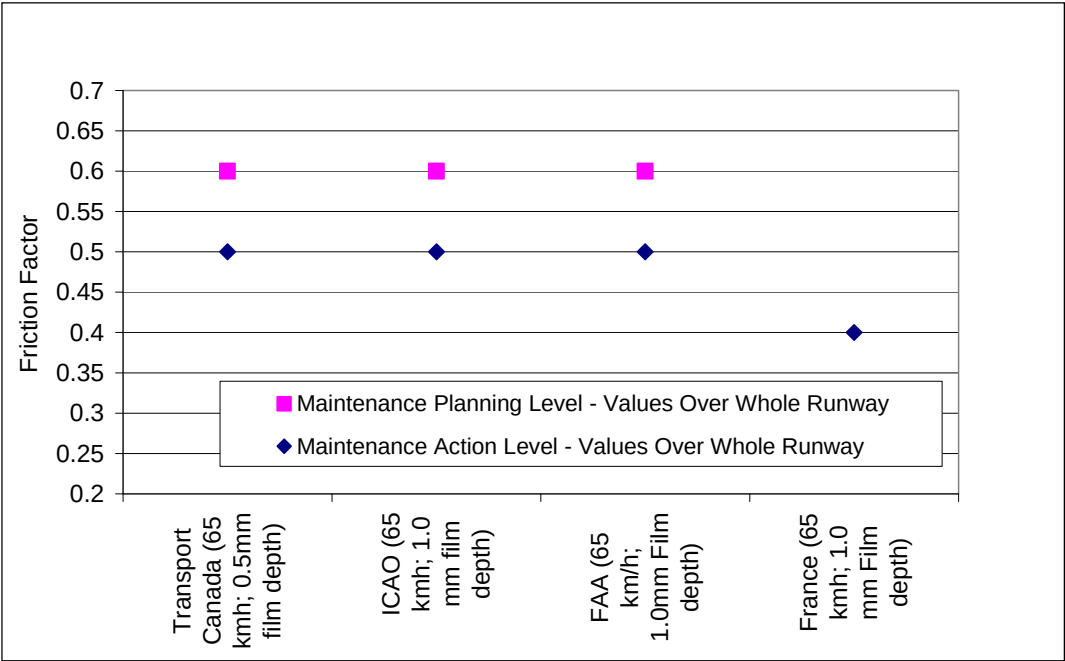


Figure B.14: Comparison of Friction Standards for the SFT

APPENDIX B, ANNEX 2 –
LITERATURE REVIEW OF RUNWAY FRICTION STANDARDS

The documents listed in the Table below were reviewed. Detailed descriptions of the most relevant ones are provided in subsequent subsections.

Literature Review of Runway Friction Standards

Report	Status
Comfort, G “Investigation of Friction Standards for Wet Runway Pavements”, Fleet Technology report 4793 submitted to Transport Canada, July 1998	INCLUDED
County Surveyor Society Guidance Note, “Skidding resistance”, Wiltshire, May 2005	Not applicable
TRL Report 510 : “A guide to levels of skidding resistance for roads”, Salt, GF, Szatkowski, WS, 1973	Not applicable
“Traffic Standards and Guidelines 1999 Survey RSS 10 Skid Resistance”, Land Transport Safety Authority, October 1999	Not applicable
Highway Research Board: “Recommendations for an international minimum skid resistance standard for pavements”, Highway Research Board Special Report 101, 1969	Not applicable
Safety Regulation Group: “The Assessment of Runway Surface Friction for Maintenance purposes “ CAP 683, Civil Aviation Authority, 2004	INCLUDED
ICAO International Standards and Recommended Practices: Annex 14, Aerodromes: Volume 1 – Aerodrome Design and Operations, Fourth Edition, ICAO, July 2004	INCLUDED
Aerodrome Standards and Recommended Practices (TP 312), 4 th Edition, Transport Canada, Civil Aviation, March 1993	INCLUDED
Aerodrome Safety Circular ASC 2004-024 Runway Friction Testing Program (Appendix A), Transport Canada, Civil Aviation, Aerodromes and Air Navigation, April 1994	INCLUDED
AK-68-35-000 Airport Pavement Evaluation – Surface Friction, Transport Canada, Airports and Construction, July 1984.	INCLUDED
Regeling stroefheid start- en landingsbanen (Skid resistance regulation for Dutch runways and taxiways), Staatscourant nr. 23, 1998	INCLUDED
Information and standards from other Civil Aviation Authorities	INCLUDED

B.1 Comfort, G. “Investigation of Friction Standards for Wet Runway Pavements”**ABSTRACT**

For many years, Transport Canada has used friction coefficients measured with the SAAB Friction Tester (SFT) as the criteria for determining whether or not runways have acceptable friction in summertime, and whether or not friction maintenance operations (such as pavement maintenance or rubber removal) are required.

However, airport operations are now being devolved to Canadian Airport Authorities (CAAs) from Transport Canada. As well, many other friction-measuring devices have now been developed which are less costly than the SFT. Hence, it is expected that in future, airports may use other devices for friction measurement surveys.

SUMMARY:***Recommended Water Film Depth Range***

For the GripTester and the SFT it is 0.5 mm to 1.0 mm

For other devices it needs to be evaluated

Required Survey Frequency

For smaller airports – minimum two years

Recommended Friction Device

SFT

See next pages for further information.

Table 2.8 General Format Comparison

Organizaton	Type of Criterion	Applicable Distance Scales For The Specified Minimum Friction Level	
		Local Criterion	Global Criterion
Transport Canada	Objective for New Design or Construction	not part of specification	
	Maintenance Planning Level	lowest 100 m section	average for the whole runway
	Maintenance Action Level	lowest 100 m section	average for the whole runway
ICAO	Objective for New Design or Construction	not part of specification	average for the whole runway, or "significant portion thereof".
	Maintenance Planning Level - the ICAO Manual describes this as "a maintenance level below which corrective maintenance action should be initiated".	not part of specification	average for the whole runway, or "significant portion thereof". A portion of the order of 100 m long may be considered to be "significant".
	Minimum Friction Level - this is "a minimum friction level for runway surfaces in use", and "below which information that a runway may be slippery when wet should be made available".	not part of specification	average for the whole runway, or "significant portion thereof". See above for information regarding "significance".
FAA	Objective for New Design or Construction	Each 500 ft long segment must meet the specified friction objective.	
	Maintenance Planning Level (μ_{maint}) - the required action depends on the distance over which the runway friction is low, and those of the adjacent sections. Minimum Friction Level (μ_{min}) - the required action depends on the distance over which the runway friction is low, and those of the adjacent	- Case 1 : the measured friction (μ_{meas}) < μ_{maint} for 500 ft but $\mu_{\text{meas}} > \mu_{\text{min}}$ and the adjacent 500 ft segments are at or above the maintenance planning level - Action : monitor situation closely by conducting periodic friction surveys - Case 2 : friction below the maintenance planning level for 1000 ft or more - Action : conduct extensive evaluation into the cause(s) and extent of the friction deterioration and take appropriate corrective action. - Case 3 : friction below μ_{min} for 500 ft or more and the adjacent 500 ft segments are below μ_{maint} - Action : take corrective action immediately after determining	

- Measurement Devices - Transport Canada's current guidelines are limited to two devices (i.e., the SFT and the Griptester) although other ones can be used provided that the measured friction coefficients are "correlatable with SFT values" [2].

The ICAO guidelines include several devices and they specify the procedures by which new devices may be approved. New devices can be accepted provided that they have been correlated with at least one of the devices listed in Table 2.6, and that they meet specified performance criteria.

The FAA Advisory Circular lists the currently approved Continuous Friction Measuring Equipment (CFME), and the qualification process used for these CFMEs (i.e., they were correlated against the Mu-Meter during tests conducted at NASA's Wallops Island Flight Facility). The process by which other CFMEs could be qualified is not described specifically, although one would expect that the same procedure would apply.

- Comparison Between The SFT And The Griptester - The relationship implied in Transport Canada's guidelines is given in equation 2.2. The relationship implied in the ICAO's and FAA's guidelines (for a ground vehicle speed of 65 km/h) is shown in equation 2.3.

$$\text{SFT Friction Coefficient} = \text{Griptester Friction Coefficient} + 13 \quad [2.2]$$

$$\text{SFT Friction Coefficient} = \text{Griptester Friction Coefficient} + 7 \quad [2.3]$$

It should be noted that equations 2.2 and 2.3 are not directly comparable because they are applicable to different water film depths. Equation 2.2 is based on a water film depth of 0.50 mm for the Griptester and 0.50 mm for the SFT (section 2.1). The relationship implicit in the FAA's and ICAO's guidelines is based on a water film depth of 1.0 mm for both devices.

The relationship in Transport Canada's guidelines was developed based on extensive comparative testing with the SFT and the Griptester at several Canadian airport runways. These test results are discussed in section 5. The relationship in the FAA's guidelines was developed from qualification and correlation tests conducted at NASA's Wallops Island Flight Facility in 1989. The source of the relationship given in the ICAO's Manual is given as "a research study conducted in a State".

- Water Film Depth - The ICAO and the FAA guidelines both specify a water film depth of 1.0 mm whereas Transport Canada's guidelines for the SFT are based on a water film depth of 0.5 mm. Transport Canada's most recent guidelines which were developed for the Griptester [10] apply to a water depth of 0.25 mm.

The FAA's guidelines are the only ones to specify the precision to which the water must be applied. They specify a tolerance of +/- 10 % for the flow rate, and a tolerance of +/- 3 mmh for both test speeds (i.e., 40 and 60 mmh). The combination of these tolerances

results in a possible range of film depths from 0.84 to 1.19 mm, and from 0.86 to 1.16 mm for test speeds of 40 and 60 mph, respectively, and a target depth of 1.0 mm.

- Ground Vehicle Speed - Transport Canada's guidelines specify a speed of 65 km/h.

The ICAO Manual provides friction criteria for two test speeds (of 65 and 95 km/h), and cautions that the friction factors in it can not be applied to other test speeds. Furthermore, the ICAO document advises that it is "desirable to test the friction characteristics of a paved runway at more than one speed". However, testing at two speeds is not mandatory. The potential case where a particular pavement may pass a criterion at one speed and fail at the other speed is not addressed in the ICAO Manual.

The FAA Advisory Circular indicates that friction testing can be carried out at either of the two specified speeds (i.e., 40 and 65 mph) although it recommends that tests be carried out at both speeds for a complete survey. As for the ICAO Manual, the potential case where a particular pavement may pass a criterion at one speed and fail at the other speed is not addressed in the FAA Advisory Circular.

- Required Frequency Of Friction Surveys - Transport Canada's guidelines [2] recommend that runways at the larger airports be tested annually at a minimum, whereas the smaller ones should be tested at least once every 2 years.

The ICAO Manual states that runway friction surveys should be conducted "periodically" and that the State should determine the required survey frequency. The ICAO Manual warns that the runway may become slippery after a long dry period and that this should be checked if this is suspected to be occurring.

The FAA Advisory Circular specifies the minimum required friction survey frequency based on the aircraft traffic volume.

- Requirement For Texture Measurements - Texture measurements are not part of Transport Canada's guidelines or of the ICAO. The FAA Advisory Circular does not impose any requirement for texture measurements although it states that texture measurements should be done when the measured friction values don't meet the specified criteria and the cause is not obvious.
- Test Tire - Transport Canada's criteria allow a range of test tires.

The ICAO does not specify the tire type directly ; rather it specifies acceptance criteria for test tires.

The FAA Advisory Circular specifies that the test tires shall meet ASTM standard E670, E1551, or E1844, as appropriate. Also, the FAA Advisory Circular specifies that

B.2 Safety Regulation Group: “The Assessment of Runway Surface Friction for Maintenance Purposes” CAP 683, Civil Aviation Authority, 2004

ABSTRACT

The purpose of this document is to outline the procedures for undertaking runway surface friction assessments and to define the criteria by which friction values should be assessed on runways under specified conditions.

This document also provides guidance to aerodrome operators on how they may assess the friction of runway surfaces in order to adjust maintenance schedules to ensure that the runway condition is adequate for aircraft to operate safely.

SUMMARY

- (1) **Purpose:** friction level acquisition for surface maintenance purposes
- (7) **Relevant devices:** Mu-meter, Grip tester
- (8) **Applicable for runways:** exceeding 1200m in length
- (9) **Data reporting:** every 10m, 100m rolling average, every third of the runway
- (10) **Recommended periodicity of measurements:**

Average number of movements in the runway per day	Interval between assessments
Less than 400	11 months
400 or more	5 months

- (1) **Device preparation:** full working order and calibrated, competent CFME operator
- (11) **Runway surface conditions:** free from precipitation
- (12) **Assessment procedure:**
 - o two check runs
 - o 1 standard run on each recommended lateral displacement line from the center line
- (13) **Friction level criteria:**

CFME	DOL	MPL	MFL
Mu-meter	0.72 or greater	0.57	0.50
GripTester	0.80 or greater	0.63	0.55

**B.3 ICAO International Standards and Recommended Practices: Annex 14,
Aerodromes: Volume 1 – Aerodrome Design and Operations, Fourth Edition,
ICAO, July 2004**

SUMMARY

- (1) Purpose:
- o verify the friction characteristics of new or resurfaces paved runways when wet;
 - o Assess periodically the slipperiness of paved runways when wet;
 - o Determine the effect on friction when drainage characteristics are poor; and
 - o Determine the friction of paved runways that become slippery under unusual conditions.
- (14) **Relevant devices:** Mu-meter, Grip tester trailer, Skidometer trailer, SFT, RFT, Tatra
- (15) **Applicable for runways:** N/A
- (16) **Data reporting:** N/A
- (17) **Recommended periodicity of measurements:** as soon as the runway suspected to become slippery
- (18) **Device preparation:** N/A
- (19) **Runway surface conditions:** N/A
- (20) **Assessment procedure:** N/A
- (21) **Friction level criteria:** Each State should establish their own criteria for the friction characteristics of new or resurfaced runway surfaces.

CFME	Tire type	Tire pressure	Test speed	Water depth	DOL	MPL	MFL
Mu-meter trailer	A	70	65	1.0	0.72	0.52	0.42
	A	70	95	1.0	0.66	0.38	0.26
Skidometer	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
SFT	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
RFT	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.54	0.41
TATRA	B	210	65	1.0	0.76	0.57	0.48
	B	210	95	1.0	0.67	0.52	0.42
GripTester	C	140	65	1.0	0.74	0.53	0.43
	C	140	95	1.0	0.64	0.36	0.24

**B.4 Aerodrome Standards and Recommended Practices (TP 312), 4th Edition,
Transport Canada, Civil Aviation, March 1993****SUMMARY**

- (1) **Purpose:** friction level acquisition for runway surface maintenance purpose
- (22) **Relevant devices:** continuous friction measuring device using self wetting features
- (23) **Applicable for runways:** runway serving turbo-jet airplanes
- (24) **Data reporting:** N/A
- (25) **Recommended periodicity of measurements:** periodically
- (26) **Device preparation:** N/A
- (27) **Runway surface conditions during measurement:** N/A
- (28) **Assessment procedure:** N/A
- (29) **Friction level criteria:**

ACTION	COF for the entire runway	COF for any 100m or longer section
Immediate action required	0.5 or less	0.3 or less
Action shall be programmed	0.6 or less	0.5 or less

**B.5 Aerodrome Safety Circular ASC 2004-024 Runway Friction Testing Program
(Appendix A), Transport Canada, Civil Aviation, Aerodromes and Air
Navigation, April 2004**

SUMMARY

- (1) **Purpose:**
Runway friction measurements made in accordance with this Appendix are intended for use in detecting deterioration of friction characteristics and determining the need for and timing of corrective action to restore friction to acceptable levels.
- (30) **Relevant devices:** Surface Friction Tester (SFT), other CFME has to be correlated SFT.
- (31) **Applicable for runways:** all hard-surfaced runways serving turbojet airplanes and runways serving heavy turboprop aeroplanes that have runway takeoff and landing distance requirements close to the limits of available runway length.
- (32) **Data reporting:**
- (33) **Recommended periodicity of measurements:** established by the Airport Operator
- (34) **Device preparation:**
- o The friction test tire must be manufactured to meet the requirements of ASTM E1551;
 - o The friction test tire is to be inflated to a pressure of 207 ± 3 kPa;
 - o The vertical load on the friction test tire is to be 1400 ± 20 N;
 - o The vehicle test speed must be held constant at 65 ± 5 km/h;
 - o The depth of water placed in front of the friction test tire by the self-wetting system must be 0.5 mm in thickness;
 - o The friction test tire is to be continuously braked during testing and have a constant slip ratio in the range of 10-20 percent; and
 - o The friction measuring system and components are to be calibrated in accordance with the manufacturer's instructions so as to ensure a consistent relationship between measured forces and the coefficient of friction output.
- (35) **Runway surface conditions during measurement:**
The friction tests are to be conducted only when both the pavement surface and the ambient air temperatures are above 0°C (zero degrees Celsius) and the pavement is dry or no more than "damp" prior to testing. Note: "Damp" means that the surface appears wet but that the moisture depth cannot be readily determined
- (36) **Assessment procedure:**
It is recommended that two (2) friction measurement runs be performed at each of the right and left three and six meter offsets, as applicable. Results of the four (4) measured runs should be averaged to determine "100 Meter Section Average COF" values along the length of the runway and the overall "Runway Average COF".

(37) **The friction measurement location:**

The friction measurements are to be taken on tracks parallel to the runway longitudinal centerline, at right and left offsets of:

- o three (3) meters for Runways Serving only Narrow Body Aircraft and
- o three(3) and six(6) meters for Runways Serving Narrow and Wide Body Aircraft

The friction measurement should begin at a distance of 200 meters from the runway threshold end and terminate approximately 200 meters from the opposite end of the runway

(38) **Friction level** criteria:

ACTION	COF for the entire runway	COF for any section 100m or greater in length
Immediate action required	0.5 or less	0.3 or less
Action shall be programmed	0.6 or less	0.5 or less (Treaded tire) 0.4 or less (Smooth tire)

B.6 AK-68-35-000 Airport Pavement Evaluation – Surface Friction, Transport Canada, Airports and Construction, July 1984.

- (1) **Purpose:** measuring and evaluating the surface friction characteristics for paved airport runways in their normal wet state.
- (39) **Relevant devices:** Surface Friction Tester (SFT).
- (40) **Applicable for runways:**
- (41) **Data reporting:** N/A
- (42) **Recommended periodicity of measurements**
- (43) **Device preparation:** The friction measuring system and components are to be calibrated in accordance with the manufacturer's instructions.
- (44) **Runway surface conditions during measurement:** The friction tests are to be conducted only when both the pavement surface and the ambient air temperatures are above 0°C (zero degrees Celsius) and the pavement is dry or no more than "damp" prior to testing.
- (45) **Assessment procedure:** Two (2) friction measurement runs to be performed at each of the right and left three meter offsets from the center line. Results of the four (4) measured runs should be averaged to determine "100 Meter Section Average COF" values along the length of the runway and the overall "Runway Average COF".
- (46) **The friction measurement location:** The friction measurements are to be taken on tracks parallel to the runway longitudinal centerline, at right and left offsets of 3m. The friction measurement should begin at a distance of 200 meters from the runway threshold end and terminate approximately 200 meters from the opposite end of the runway.
- (47) **Friction level criteria:** No action required when a measured runway surface coefficient of friction is above 0.6.

ACTION	COF for the entire runway	COF for any section 100m or greater in length
Immediate action required	0.5 or less	0.3 or less
Action shall be programmed	0.6 or less	0.5 or less

B.7 Regeling Stroefheid Start- en Landingsbanen (Skid Resistance Regulation for Dutch Runways and Taxiways), Staatscourant nr. 23, 1998

SUMMARY

Friction level criteria:

Friction – measuring device and tire	Tire load force (N)	Inflation pressure (kPa)	Slip ratio (%)	Test speed (km/h)	COF design objective for new surface	COF maintenance planning level	COF minimum level NOTAM
Skidometer BV11 ASTM E1551 smooth	1420	210	10-20	65	0.82	0.60	0.50
				95	0.74	0.47	0.34
Skidometer BV11 Aero tire, ribbed	1420	700	10-20	65	0.70	0.50	0.40
				95	0.60	0.40	0.32
DWW trailer PIARC smooth	2000	200	15	65	0.80	0.60	0.50
				95	0.60	0.40	0.32

Water depth:

1mm for all devices

APPENDIX B, ANNEX 3 –
RUNWAY FRICTION STANDARDS FOR THE FORMER YUGOSLAVIA (TAKEN
FROM THEIR AIP)

Test Equipment	Design objective for new RWY	Surface Maintenance Level	Water film depth (mm)	Test speed (km/h)
MU-meter method 1	0.7	0.5	1	65L
method 2	0.64	0.4	1	95L
	0.65	0.45	0.5	130L
Skidometer and Surface Friction Tester	0.7	0.5	1	65H
	0.6	0.4	1	95H
	0.6	0.35	1	130H
Skidometer	0.8	0.67	1	65L
Surface Friction Tester and	0.8	0.6	1	65L
Runway Friction Tester	0.7	0.5	1	95L

Notes:

1. The values in columns 2 and 3 are averaged values representative of the runway or significant points thereof.
2. L : with low pressure tyre
3. H : with high pressure tyre

APPENDIX C –
LITERATURE REVIEW OF PERFORMANCE SPECIFICATIONS, CORRELATION
METHODS, AND CORRELATION TRIALS

Contents:

Appendix C.1:	Literature Review of CFME Performance Specifications
Appendix C.2:	Literature Review of CFME Correlation Methods
Appendix C.3:	Literature Review of CFME Correlation Trials
Appendix C.4:	Reports from the Joint Winter Runway Friction Measurement Program

APPENDIX C, ANNEX 1–
LITERATURE REVIEW OF CFME PERFORMANCE SPECIFICATIONS

This portion of the study focused on collecting performance requirements from the available documentation where parameters with their quantified requirements were available or could be deduced, such as but not limited to repeatability, reproducibility, variation, uncertainty and other factors. The review also compiled a list with qualitative aspects of performance and the associated possible sensitivities.

The compiled literature was reviewed and analyzed in the following areas:

CFME

- Mechanical design
- Output
- Operating conditions
- Accuracy
- Repeatability
- Watering system
- Test speed
- Device documentation
- Instrumentation

Hosting Vehicle

- Speed
- Acceleration
- Equipment

Test Tire

- Type
- Vertical static load
- Tire pressure

The following documents were reviewed (Table C.1). Detailed descriptions of the most relevant ones are provided in subsequent subsections.

Table C.1: Literature Review of CFME Performance Specifications for Weet

Reports and standards	
Comfort, G., Rado, Z., and Mazur, A., 2009, Proposed Performance Specifications and Standard Correlation Method for Continuous Friction Measurement Equipment, BMT FTL report 6176 submitted to Transport Canada.	Included
Arnberg P. W., Sjogren L.; "Nordiska friktionsmätare". VII Meddelande 333. Statens Väg- och Trafikinstitut. Linköping. 1983.	Not available
Nordström O.; "Development and validation of BV14, a new twin track fixed slip friction tester for winter road maintenance monitoring in Sweden." Xth PIARC International Winter Road Congress. Luleå Sweden. 1998.	Not applicable – winter tests
Giles C. G., Sabey B. E., Cardew K. H. F., 1964, "Development and Performance of the Portable Skid-Resistance Tester." Road Research Technical Paper No. 66. Road Research Lab.. London.	Not applicable
Meyer, W E; Hegmon, R R; Gillespie, T D "LOCKED-WHEEL PAVEMENT SKID TESTER CORRELATION AND CALIBRATION TECHNIQUES", National Cooperative Highway Research Program Report 151, Transportation Research Board, Washington, D.C. 1974	Not applicable
Choubane B., Holzshuher C.R., and Gokhale S.; "Precision of Locked Wheel Testers for Measurement of Roadway Surface Friction Characteristics." Research Report FL/DOT/SMO/03-464. State Materials Office, Florida. (2003).	Not applicable
The performance specifications for Continuous Friction Measurement Equipment (CFME) part of the FAA Advisory Circular 150/5320-12C, titled "Measurement, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces."	INCLUDED
ICAO "Airport Services Manual, Part 2: Pavement Surface Conditions, Chapter 5– Runway Friction-Measuring Devices, 5.2 Criteria for new Friction-measuring devices"	INCLUDED
New ASTM E17 Standard: "Standard Test Method for Measuring the Skid Resistance of Pavements and other Trafficked Surfaces using a Continuous Reading, Fixed Slip Technique"	INCLUDED
ASTM E 274-97 (2002). "Standard Test Method for Skid Resistance of Paved Surfaces Using a Full-Scale Tire". American Society for Testing and Materials.	Not applicable
ASTM E 303-93 (2002). "Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester".	Not applicable
ASTM E 501-94 (2002). "Standard Specification for Standard Rib Tire for Pavement Skid-Resistance Tests".	Not applicable
ASTM E 524-88 (2002). "Standard Specification for Standard Smooth Tire for Pavement Skid Resistance Tests".	Not applicable
ASTM E 670-94 (2002). "Standard Test Method for Side Force Friction on Paved Surfaces Using the Mu-Meter".	INCLUDED
ASTM E 867-02 (2002). "Terminology Relating to Vehicle Pavement Systems"	Not applicable
ASTM E 965-96 (2002). "Standard Measuring Pavement Macrottexture Depth Using a Volumetric Technique". American Society for Testing and Materials.	Not applicable
ASTM E 1859-97 (2002). "Standard Test Method for Friction Coefficient Measurements Between Tire and Pavement Using a Variable Slip Technique".	INCLUDED
ASTM E 1911-98 (2002). "Standard Test Method for Measuring Paved Surface Frictional Properties Using the Dynamic Friction Tester". American Society for Testing and Materials.	Not applicable
ASTM E 1960-98 (2002). "Standard Practice for Calculating International Friction Index of a Pavement Surface".	Not applicable – winter tests
BS 7941-1 : 1999 : Methods for measuring the skid resistance of pavement surfaces - Part 1 : Side-way force coefficient routine investigation machine	Not available
BS 7941-2 : 2000 : Surface friction of pavements - Part 2 : Test method for measurement of surface skid resistance using the GripTester braked wheel fixed slip device	Not available
ASTM E1551 "Standard Specifications for a Special Purpose, Smooth-Tread Tire, Operating on Fixed Braking Slip Continuous Friction Measuring Equipment", ASTM International	INCLUDED
ASTM E1844 "Standard Specification for a Size 10x4-5 Smooth Tread Friction Test Tire".	INCLUDED
Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields", CROW Report D06-05	INCLUDED

C.1.1 Proposed Performance Specifications and Standard Correlation Method for Continuous Friction Measurement Equipment

Performance Specifications for CFMEs

Detailed performance specifications intended to represent minimum acceptable performance and functionality were developed for the parameters listed below, among other items.

- General Mechanical requirements
- Basic Equipment Requirements
- Operating Conditions
- Speed
- Test Tire
- Watering System
- Instrumentation
- Data Collection and Signal Conditioning
- Repeatability
- Braking Slip
- Reporting

Standard Test Method for Correlating CFMEs

A correlation test specification was developed, which describes the methodology for correlating a candidate CFME family to the reference SFT device family.

The specification provides the frame work and methodology for:

- (a) Surface selection and preparation.
- (b) Device preparation.
- (c) Development of a test matrix.
- (d) Test procedures and quality assurance.
- (e) Data collection.
- (f) Data analysis
- (g) Determination of device specific correlation equations.

C.1.2 The Performance Specifications for Continuous Friction Measurement Equipment (CFME) Part of the FAA Advisory Circular 150/5320-12C, titled "Measurement, Construction and Maintenance of Skid Resistant Airport Pavement Surfaces"

SUMMARY

Performance specification for CFMEs:

- (1) **Mechanical design:**
 - o provide fast, continuous accurate and reliable friction measurements for the entire length of the runway;
 - o sustain rough usage.
- (2) **Output:**
 - o provide average friction values for both 500 foot and one-third segments of the runway length;
 - o produce a permanent trace of friction measurements through the whole runway length.
- (3) **Operating conditions:** not defined.
- (4) **Repeatability:** for each 500 foot segment it should be $\pm 0.06 \text{ Mu}$.
- (5) **Watering system:**
 - o Self-wetting system distributing 1mm uniform water depth;
 - o Tolerance within $\pm 10 \%$.
- (6) **Test speed:**
 - o 40 and 60 mph (65 and 96 km/h).
 - o Tolerance: $\pm 3 \text{ mph}$ ($\pm 5 \text{ km/h}$).
- (7) **Device documentation:** complete operation and maintenance manual including guidelines for training airport personnel.
- (8) **Instrumentation:** have electronic instrumentation, including keyboard.

Vehicle:

- (1) **Speed:**
 - o 40 and 60 mph (65 and 96 km/h);
 - o Tolerance: $\pm 3 \text{ mph}$ ($\pm 5 \text{ km/h}$).
- (2) **Acceleration:** with fully loaded water accelerate to 40 and 60 mph (65 and 96 km/h) with in 500 and 1000 feet (150 m and 300 m) respectively.
- (3) **Equipments:**
 - o Electronic speed control;
 - o Transceiver(s);
 - o Water tank with sufficient capacity for a friction survey on 14,000 foot (4267m) runway on one direction;
 - o Heavy duty shock absorbers and suspension;
 - o Internally controlled spot lights on each side, at least two flood lights for trailer mounted friction devices; and
 - o Air conditioner.

Tire:

- (1) Blank tires according to ASTM E670, E 5551, E 1844;
- (48) Split rim;
- (49) Curved valve stems; and
- (50) Calibrated pressure dial gauge.

C.1.3 ICAO “Airport Services Manual, Part 2: Pavement Surface Conditions, Chapter 5– Runway Friction-Measuring Devices, 5.2 Criteria for new Friction-measuring devices”

This chapter of the manual describes the requirements for new CFME friction measuring devices.

- (1) **Mechanical design:**
 - o Mode of measurements: Continuous measurements in motion;
 - o The design of the equipment should exclude any possibility of sustained vertical vibration of the cushioned and uncushioned mass occurring in all travel speed ranges during the measuring operation, particularly in respect of measuring wheel; and
 - o The equipment should possess positive directional stability during all phases of operation, including high-speed turns which are sometimes necessary to clear a runway.
- (2) **Output:**
 - o The recorded range of the friction coefficient should be from 0 to at least 1.0;
 - o The equipment should be able to provide a permanent record of the continuous graphic trace of the friction values of the runway, as well as allowing the person conducting the survey to record any observations and the date and the time of the recording;
 - o For a fixed slip device, the recorded friction value should be proportional to the ratio of the longitudinal friction force to the vertical wheel loading;
 - o The equipment should be capable to automatically providing mu averages for at least the following conditions: (a) the first 100m of the runway; (b) each 150m increments; (c) each one third segment of the runway; and
 - o To minimize substantial variations in scale between the various friction devices, the manufacturer may provide as one option, a scale of 25 mm equals 100m.
- (3) **Operating conditions:**
 - o Any time and in all weather conditions.
- (4) **Accuracy:**
- (5) **Repeatability:** The equipment should be capable to consistently repeating friction averages throughout the friction range at the confidence level of 95.5 percent , ± 6 μ .
- (6) **Time Stability:**
 - o The equipment should be designed to with stand rough use and still maintain calibration, thereby ensuring reliable and consistent results.
- (7) **Watering system:**
 - o The friction measuring device should have the capability of using self-wetting features to enable measurements of the friction characteristics of the surface to be made at a controlled water depth of at least 1 mm.
- (8) **Test speed:**
 - o the speed range should be from 40 to at least 130 km/h.
- (9) **Braking slip:**
 - o Mode of braking: for a fixed slip device, the wheel should be continuously braked at the constant slip ratio within a range of 10 to 20 percent.
- (10) **Device documentation:**

- (11) **Instrumentation:**
- (12) **Signal conditioning:**

Vehicle:

- (1) Speed:
- (2) Acceleration:
- (3) Equipments:

Test tire:

Type/Pressure:

- o yaw-type – ASTM E670 with 70 kPa
- o Braking slip type – ASTM E1551 with 210 kPa
- o GripTester – ASTM E1844

C.1.4 New ASTM E17 Standard: “Standard Test Method for Measuring the Skid Resistance of Pavements and other Trafficked Surfaces using a Continuous Reading, Fixed Slip Technique”

SUMMARY:

This test method sets out the essential common principles for different friction measurements with different friction measuring devices.

CFME:

(1) **Mechanical design:**

- o “The measuring apparatus may be built into a vehicle, built onto a trailer that is towed by a vehicle or built into a device that is manually pushed”;
- o “The basic apparatus shall be equipped with a force transducer to provide a direct measurement of the braking force or torque transducer to measure the torque on the test wheel generated by this force or both”;
- o “The design of the test apparatus shall ensure that unless the average load force acting on the test wheel remains within 1% of the static wheel load over the reporting length, the apparatus shall be equipped with a force transducer to measure the load force”;
- o “The test apparatus shall include a mechanism for measuring test speed and distance traveled”;
- o “Unless the test apparatus is to be used solely for operational testing, it shall include a mechanism for measuring rate of water flow”; and
- o “The test apparatus shall be such that the chosen fixed braking slip can be maintained with in $\pm 3\%$ of full scale throughout the length of the test surface at the chosen test speed”.

(2) **Output:**

- o Speed;
- o Distance; and
- o Water flow (recommended only).

(3) **Operating conditions:**

- o “The exposed portions of the system shall tolerate 100% relative humidity (rain or spray) and all other adverse conditions, such as de-icing chemicals, dust, shock, and vibrations that may be encountered in the type of testing”;
- o At outside ambient air temperature between -40 and $+45^{\circ}\text{C}$ (-40 and 110°F)

(4) **Accuracy:**

- o “The overall static ambient air temperature measurement accuracy shall be $\pm 1.5\%$ of full scale”;
- o “If the load force is measured, the accuracy of the measurement shall conform to the requirements set out in the show that the assumed dynamic wheel load is within $\pm 2\%$ of the actual dynamic wheel load”;
- o “Distance shall be measured with a resolution of 0.1% and an accuracy of $\pm 0.5\%$ and shall continuously recorded”; and
- o “Speed shall be measured with a resolution of 2 km/h (1 mph) and an accuracy of $\pm 1\text{ km/h}$ ($\pm 0.5\text{ mph}$). It is recommended that these measurements be continuously recorded”.

- (5) **Repeatability:**
 - o Because the method is a general description of friction measurements, it is not included in the document.
- (6) **Watering system:**
 - o “Water shall be applied to the test surface just ahead of the test tire so as to provide the chosen nominal water film thickness across the full width of the test tire at any speed”;
 - o “The water application system shall be protected from the effects of side winds”;
 - o “Water used for testing shall be reasonably clean and have no chemicals such as wetting agents or detergents added and shall be above 30°C”;
 - o “The nominal water film thickness shall be in accordance with the manufacturer’s handbook and the test application”;
 - o Rate of water flow shall be continuously measured and it is recommended that it be continuously recorded; and
 - o Regulation of rate of water flow shall be within $\pm 10\%$.
- (7) **Test speed:**
 - o “one selected steady test speed, which could vary from application to application”;
 - o “With the test tire operating at the chosen fixed braking slip, the test apparatus shall be capable of maintaining the chosen test speed within $\pm 3\%$ for the duration of the survey”.
- (8) **Device documentation:** No specification included in the document.
- (9) **Instrumentation:**
 - o “If there is a force transducer that provides a direct measurement of the braking force, it shall do so with minimal inertial effect. It is recommended that this transducer provides output directly proportional to force with hysteresis less than 1% of the applied load up to the maximum expected loading”;
 - o “If there is a torque transducer that measures the torque on the test wheel generated by the braking force, this shall provide output directly proportional to torque with hysteresis less than 1% of the applied load and nonlinearity up to the maximum expected loading less than 1% of the applied load.”

Host Vehicle:

- (1) **Speed** - No specification included in the document;
- (2) **Acceleration** - No specification included in the document; and
- (3) **Equipment** - No specification included in the document.

Test tire:

- (4) **Type:**
 - o “The test tire shall conform to the applicable ASTM, ISO, or BSI specification or equivalent. Applicable ASTM standards include Specification E 510, E 524, E1551, and E1844.”
- (5) **Vertical static load** – No specification included in the document
- (6) **Tire pressure** - No specification included in the document

C.1.5 ASTM E 670-94 (2002). “Standard Test Method for Side Force Friction on Paved Surfaces Using the Mu-Meter”. American Society for Testing and Materials.

SUMMARY

Standard test method for side force friction on paved surface using the Mu-meter.

CFME:

- (1) **Mechanical design:**
 - o
- (2) **Output:**
 - o
- (3) **Operating conditions:**
 - o 40 to 100°F (4 to 38°C);
 - o Up to 100% relative humidity.
- (4) **Accuracy:** overall system accuracy is ± 3 % of full scale
- (5) **Repeatability:** SD = 2.0MuN
- (6) **Watering system:**
 - o At 40 mph (65 km/h) shall be 8 gal/min (1.20L l/min) with min. 1 in (25mm) width;
 - o Tolerance within ± 10 % /in, ± 10 % /mm.
- (7) **Test speed:** N/A
- (8) **Device documentation:**
- (9) **Instrumentation:**
 - o A force cell providing a directly proportional output to the force with hysteresis less than 2 % and with less than 2 % sensitivity to any expected cross-axis load;
 - o Force cell tensile force recorder from 0 to 500 lbf (0 to 2225N) correspond to 0 to 100 MuN;
 - o Remotely controlled event marker; and
 - o Vehicle speed- measuring transducer with the accuracy of $\pm 1.5\%$ of the indicated speed or $\pm$ mph whichever greater.

Host Vehicle:

- (1) **Speed:**
 - o at least 40 mph (65 km/h);
 - o tolerance 0.5 mph (0.8 km/h) or for higher speed ± 1 mph (1.5 km/h).
- (2) **Acceleration:** not defined
- (3) **Equipment:** adjustable hitches

Test tire:

- (1) Type: Mu-meter test tire.
- (2) vertical static load of 171 ± 2 lbf (761N $\pm$ 9N).
- (3) tire pressure 10 ± 0.5 psi (69 $\pm$ 3 kPa).

**C.1.6 ASTM E 1859-97 (2002). “Standard Test Method for Friction Coefficient Measurements Between Tire and Pavement Using a Variable Slip Technique”.
American Society for Testing and Materials**

SUMMARY

CFME:

- (1) **Mechanical design:**
 - o
- (2) **Output:**
 - o
- (3) **Operating conditions:**
 - o 0 to 100°F (-20 to 40°C);
 - o Up to 100% humidity.
- (4) **Accuracy:** overall system accuracy is ± 2 % of full scale.
- (5) **Repeatability:** not determined yet.
- (6) **Watering system:**
 - o Nominal 0.5 mm (0.02 in) thickness at any speed over the full width of test tire tread with an additional 25 mm (1 in).
- (7) **Test speed:**
 - o 40 mph (65km/h) ± 1.5 mph (3 km/h);
 - o 60 mph (95km/h) ± 2.5 mph (5 km/h); and
 - o 80 mph (130km/h) ± 2.5 mph (5 km/h).
- (8) **Device documentation:**
- (9) **Instrumentation:**
 - o A *transducer* providing a directly proportional output to the force with hysteresis less than 1% and with sensitivity less than 1 % of any expected cross-axis load or torque loading and with nonlinearity less than 1% of the applied load up to the maximum expected loading.

Host Vehicle:

- (1) **Speed:**
 - o 40 mph (65km/h) ± 1.5 mph (3 km/h);
 - o 60 mph (95km/h) ± 2.5 mph (5 km/h);
 - o 80 mph (130km/h) ± 2.5 mph (5 km/h).
- (2) **Acceleration:** not defined
- (3) **Equipment:** not defined

Test tire:

- (1) Type: ASTM E1551
- (2) normal load of 320 ± 6.4 lbf ($1423\text{N} \pm 28.5\text{N}$)
- (3) tire pressure 30 ± 0.5 psi (207 ± 3 kPa)

C.1.7 ASTM E1551 “Standard Specifications for a Special Purpose, Smooth-Tread Tire, Operating on Fixed Braking Slip Continuous Friction Measuring Equipment”, ASTM International**SUMMARY**

This standard covers the specification for special purpose, smooth friction measuring tires.

Relevant test tire specifications:

- (1) static test load of 200 ± 2 lbf ($890\text{N} \pm 9\text{N}$);
- (51) maximum load of 320 ± 3 lbf ($1423\text{N} \pm 14\text{N}$); and
- (52) tire pressure 30 ± 0.5 psi (207 ± 3 kPa).

C.1.8 ASTM E1844 “Standard Specification for a Size 10x4-5 Smooth Tread Friction Test Tire”, ASTM International**SUMMARY**

This standard covers the specification for special purpose, smooth friction measuring tires.

Relevant test tire specifications:

- (1) static test load of 46 lbs (21 kg)
- (53) tire pressure 20 ± 0.5 psi (138 ± 3 kPa)

C.1.9 “Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields”, CROW Report D06-05

SUMMARY

This report contains a performance specification for CFME to be used in airport for runway surface maintenance purposes.

CFME:

- (1) **Mechanical design:**
 - o May be self contained or towed;
 - o Shall provide fast, continuous, accurate and reliable measurements for the entire length of the runway;
 - o May be braking force type or side-force type CFME;
 - o Rough design; and
 - o Shall be capable of performing dry tests between 20 km/h and 40 km/h.
- (2) **Output:**
 - o Shall provide permanent record of friction values and provide averages for 10m, 100m and for any length of the runway or runway segments.
- (3) **Operating conditions:**
 - o Up to 100% humidity.
- (4) **Repeatability:** shall provide consistently repeating friction averages for the whole friction range and all types of pavements.
- (5) **Watering system:**
 - o Shall provide uniform water film of $1\text{mm} \pm 0.1\text{mm}$.
- (6) **Test speed:**
 - o 40 mph (65km/h) ± 2.5 mph (5 km/h);
 - o 60 mph (95km/h) ± 2.5 mph (5 km/h).
- (7) **Device documentation:** complete set of the latest operation manuals.
- (8) **Instrumentation:**
 - o A *transducer* with no inertial effects;
 - o The information collected during the friction survey should be visible for the driver;
 - o Event marker;
 - o Electronic instrument including data entry facility; and
 - o Preferably: ambient and tire temperature sensor.

Hosting Vehicle:

- (1) **Speed:**
 - o 40 mph (65km/h) ± 2.5 mph (5 km/h)
 - o 60 mph (95km/h) ± 2.5 mph (5 km/h)
- (2) **Acceleration:** able to accelerate to 40 mph (65km/h) within 300m and 60 mph (95km/h) within 500m.
- (3) **Equipment:** water tank with sufficient water for 4.5km runway friction survey in one direction.

Test tire:

Not defined

APPENDIX C, ANNEX 2 –
LITERATURE REVIEW OF CFME CORRELATION METHODS

Relevant standards with the potential to help the development of a practical and valuable standard for correlating friction measurement equipment were reviewed. The compiled literature was reviewed for different correlation techniques, methodology, data treatment and statistical procedures. The following documents were reviewed. Detailed descriptions of the most relevant ones are provided in subsequent subsections.

Table C.2: Literature Review of CFME Correlation Methods

Report	Status
Comfort, G., Rado, Z., and Mazur. A., 2009 Proposed Performance Specifications and Standard Correlation Method for Continuous Friction Measurement Equipment, BMT FTL report 6176 submitted to Transport Canada.	Included – review already presented in Appendix C.1
Van Es, G.W.H. “Correlation of self wetting friction measuring devices”, National Airspace Laboratory, April 2004	Included
Wambold J. C., Antle C. E., Henry J. J. & Rado Z.; “International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements.” 01.04.T. PIARC. 1995.	Included
Horne, W.B., Buhlmann, F. :“A Method for Rating the Skid Resistance and Micro/Macrottexture Characteristics of Wet Pavements“, Frictional Interaction of Tire and Pavement, ASTM SRP 793, 1983	Not available
Van Es, G.W.H, Giesberts: “A Literature Survey on Tire Surface Friction on Wet Pavements: Application of Surface Friction Testers”, CROW, Report 03-06, Ede, The Netherlands, 2003	Included
Merritt L.R.: “Concorde Landing Requirements Evaluation Tests”, FAA, FS-160-74-2, 1974	Not available
Van ES, G.H.W.: “Correlation of Self-wetting Friction Measuring devices: Evaluation of the ESDU method”, CROW, Report 03-10, Ede, The Netherlands, 2003	Separate review not done – same reference as #1
ICAO “Airport Services Manual, Part 2: Pavement Surface Conditions”, Appendix 3, NASA Certification Test Procedure for New Continuous Friction-Measuring Equipment Used at Airport Facilities”	Included
Aerodrome Safety Circular ASC 2004-024 Runway Friction Testing Program, Appendix A, Section 2.1 Alternative Device Requirements, Transport Canada, Civil Aviation, Aerodromes and Air Navigation, April 2004.	Included
“Correlation Trial of Self-Wetting Friction-Measuring Devices for Dutch Airfield Pavements”, CROW Report 04-05, Ede, The Netherlands, 2004	Separate review not done – same reference as #1
“Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields”, CROW Report D06-05.	Separate review not done – same reference as #1

C.2.1 Van Es, G.W.H. “Correlation of Self Wetting Friction Measuring Devices”

ABSTRACT

Airfield runway friction measurements are made to detect any deterioration of the skid resistance and to determine if there is a need for maintenance action. A large number of different friction-measuring devices are available for this purpose. Many attempts have been made in the past to correlate the output of different devices, however with limited success. There are many variables that affect the measured friction values. Some of these variables can be controlled and others not. These uncontrolled variables contribute to the random uncertainty in the output of a friction-measuring device.

The Engineering Science Data Unit (ESDU) company developed a statistical method for relating the braking performances of aircraft and friction-measuring devices in naturally wet surface conditions. This method takes the random uncertainty in the output of a friction-measuring device in to account. The ESDU method has been successfully applied to friction measurements made on naturally wet surface conditions. The ESDU method was not yet applied to correlate the output of friction-measuring devices that operate in a self-wetting mode. A Dutch working group on runway friction (under supervision of the CROW Technology Centre for Transport and Infrastructure) has examined the potential of the ESDU method to correlate the output of friction-measuring devices that are operated in a self-wetting mode on airfield runway type of surfaces. This paper presents some the results of this analysis.

SUMMARY

This method assumes the following functions between:

- μ coefficient of friction
- V ground speed
- p inflation pressure
- ρ surface contaminant density

$$\mu = \frac{\mu_{datum}}{1 + \beta \frac{0.5\rho V^2}{p}}$$

Where

μ_{datum} is coefficient of friction at zero ground speed on a dry surface, which is estimated from friction measurements made on a dry surface at low speed.

- β an empirical variable

Each of the β an empirical variable can be combined with the corresponding macro texture d of the tested wetted surface to define the κ runway interaction parameter:

$$\kappa = \sqrt{\beta d}$$

The runway interaction parameter should conform to a normal distribution given by

$$\kappa = \bar{\kappa} + z \sigma[\kappa]$$

where

$\bar{\kappa}$ the mean value

$\sigma[\kappa]$ the standard deviation

z the percentage point of the normal distribution

For each friction measuring device the $\bar{\kappa}$, $\sigma[\kappa]$ μ_{datum} can be obtained and used to correlate any two devices A and B with the following form:

$$\frac{(\kappa_A - \bar{\kappa}_A)}{\sigma[\kappa_A]} = r \frac{(\kappa_B - \bar{\kappa}_B)}{\sigma[\kappa_B]}$$

If the correlation exists and the r correlation coefficient is tested to be significant, then the values of κ of the two devices A and B are normally correlated. The significance of the correlation can be tested using the Spearman rank order correlation method.”

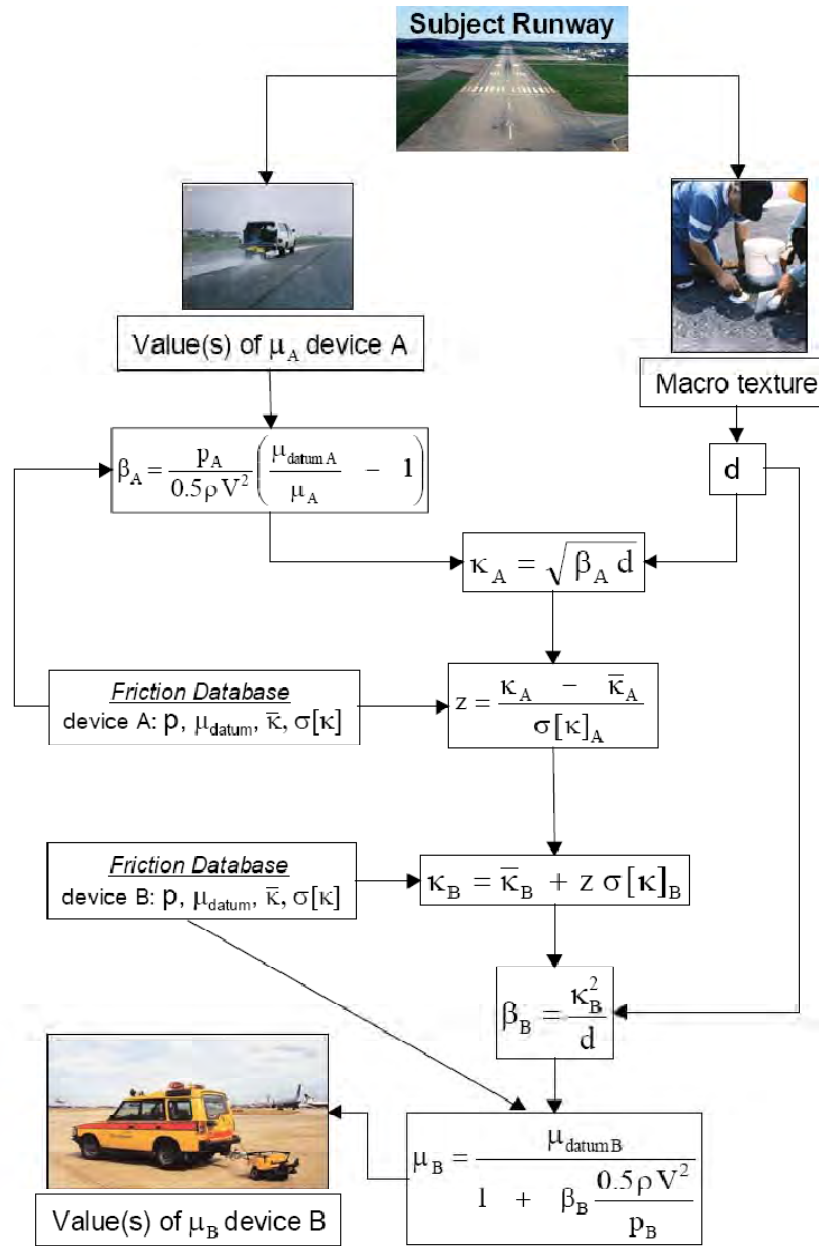


Figure C.1: Schematic of the ESDU Method

C.2.2 Wambold J. C., Antle C. E., Henry J. J. & Rado Z.; “International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements.” 01.04.T. PIARC. 1995

SUMMARY

point by point one variable linear regression for each speed

$$Y = A * X + B$$

one variable linear regression of the averaged measurements for all measurements for a given speed and a given site

$$Y = A * X + B$$

speed corrected one variable linear regression of the averaged measurements for all measurements for a given site.

Speed correction is based on the Penn State Model:

$$F(S) = F0 * \exp[-(S/S0)]$$

where, S is the sliding speed of the test tire

the corrected golden value correlation

$$S_p = a + b * T_x,$$

where T_x is a texture measure

$$FR60 = FRS \exp[(S-60)/S_p],$$

where FRS is the friction reading of a device at the slip speed S

$$F60 = A + B * FR60$$

where F60 is the gold value

C.2.3 Van Es, G.W.H, Giesberts: “A Literature Survey on Tire Surface Friction on Wet Pavements: Application of Surface Friction Testers”, CROW, Report 03-06, Ede, The Netherlands, 2003

SUMMARY

The relevant conclusions:

- (1) Wet surface friction cannot be correlated to a single surface texture parameter
- (54) The use of a single type of friction measuring device for all airports is currently the best practical way for surface friction measurement for maintenance purposes
- (55) A formal international standard for surface friction measuring device certification does not exist
- (56) The International Friction Index IFI and the similar European Friction Index has shortcomings, which will limit the success of these methods

C.2.4 ICAO “Airport Services Manual, Part 2: Pavement Surface Conditions”, Appendix 3, NASA Certification Test Procedure for New Continuous Friction-Measuring Equipment Used at Airport Facilities

SUMMARY

A point-by-point one variable linear regression for each individual test

$$Y = A * X + B$$

**C.2.5 Aerodrome Safety Circular ASC 2004-024 Runway Friction Testing Program,
Appendix A, Section 2.1 Alternative Device Requirements, Transport Canada,
Civil Aviation, Aerodromes and Air Navigation, April 2004**

SUMMARY

According to the Aerodrome Safety Circular, friction-testing devices other than the Surface Friction Tester (SFT) must be correlated to produce friction measurements comparable to those that would be obtained with the Surface Friction Tester. Such correlations should be established by performing parallel field tests using the benchmark Surface Friction Tester and the alternate friction device on a series of 100 metre long pavement sections selected to span the range of Coefficient of Friction (COF) values from approximately 0.30 to 1.00. A minimum of sixteen (16) pavement sections should be used for the correlation.

From the 100 metre COF data, a regression equation should be determined from which SFT friction values can be estimated using measurements made with the alternate friction testing device. A satisfactory correlation between the two devices will generally require that the Correlation Coefficient of Determination (R^2) be 0.80 or greater and that the Standard Error of the Estimate ($S_{y/x}$) not exceed 0.06 COF units.

The equivalent friction value that would be obtained using the Surface Friction Tester can be estimated from measured GripTester friction values by applying the following equation which requires that GripTester friction measurements be made and determined for pavement test sections 100 metres in length:

$$\text{SFT} = (0.92 * \text{GT}) + 0.16$$

where:

"SFT" represents an estimate of the average Coefficient of Friction that would be measured by the Surface Friction Tester over a section of pavement 100 metres in length, and;

"GT" is the average Coefficient of Friction measured by the GripTester over a section of pavement 100 metres in length.

APPENDIX C, ANNEX 3 –
LITERATURE REVIEW OF CFME CORRELATION TRIALS

Table C.3: Literature Review of Correlation Trials for CFMEs for Wet

Report Description	Comments
Lund B, "Friction test. Comparative testing with 3 different equipments carried out during the summer 1996." Report 82. Road Directorate, Danish Road Institute. 1997.	Was not available
Nordström O., "Correlation test between SARSYS Saab 9-5 Wagon Surface Friction Tester and VTI Safegate Saab 9000 SFT." Test Report Dnr 605/99-8. Swedish Road and Transport Research Institute. Linköping.	Was not available
Schmidt B.; "Friktionsmålinger. Sammenlignende målinger mellem ROAR och Stradograf." Rapport 90. Vejdirektoratet, Vejteknisk Institut. Denmark 1999. (Translation: "Friction measurements. Comparative measurements between the ROAR and the Stradograf." Report 90. Road Directorate, Danish Road Institute. 1999.	Not applicable – not one of the devices being evaluated
"Measuring systems for evaluation of Skid-Resistance and Texture, Part 1: Comparison of repeatability standard deviation", Road Directorate, Danish Road Institute. March 1998	Was not available
Wambold J. C., Antle C. E., Henry J. J. & Rado Z.; "Interantional PIARC experiment to compare and harmonize texture and skid resistance measurements." 01.04.T. PIARC. 1995.	INCLUDED
TP 14498E, "Friction coefficients for various winter surfaces", BMT Fleet Technology Limited, 2004	Review to Come – winter tests
TP 14318E, "Joint Winter Runway Friction Measurement Program (JWRFMP): International Runway Friction Index (IRFI) versus aircraft braking coefficient (Mu)", CDRM Inc., 2003	Review to Come – winter tests
TP 14083E, "Repeatability and reproducibility of Saab friction measurement devices in self-wet mode", Transportation Infrastructure Consulting and Services Ltp., 2003	INCLUDED
TP 14065E, "Comparison of the IRV and the ERD on winter contaminated surfaces", CDRM Inc., 2001	Not Reviwed – winter tests
Comparison of GripTester and Saab SFT Measurements, Interim report	INCLUDED
Runway Friction Monitoring with the SFT - 0.5mm versus 1.0mm Water Depths,	INCLUDED
Runway Friction Monitoring with the GripTester - 0.5mm versus 0.25mm Water Depths	INCLUDED
TP 14190E NASA Wallops Tire/Runway Friction Workshops: 1993-2002	INCLUDED
Meyer, W E; Hegmon, R R; Gillespie, T D "LOCKED-WHEEL PAVEMENT SKID TESTER CORRELATION AND CALIBRATION TECHNIQUES", National Cooperative Highway Research Program Report 151, Transportation Research Board, Washington, D.C. 1974	Not applicable – not one of devices being evaluated
Reliability and Performance of Friction Measuring Tires and Friction Equipment Correlation. - Final rept. Federal Aviation Administration, Washington, DC. Office of Airport Safety and Standards Mar 1990 Author: T. H. Morrow, DOT/FAA/AS-90-1	INCLUDED
Van ES, G.H.W.: "Correlation of self-wetting Friction Measuring devices: Evaluation of the ESDU method", CROW, Report 03-10, Ede, The Netherlands, 2003	INCLUDED
"Correlation Trial and Harmonization Modeling of Friction Measurements on Runways 2005", CROW Report 06-02, Ede The Netherlands, 206	INCLUDED
Friction Workshop held at LCPC Centre de Nantes, France (June 2004)	INCLUDED
"Correlation Trial of Self-Wetting Friction-Measuring Devices for Dutch Airfield Pavements", CROW Report 04-05, Ede, The Netherlands, 2004	INCLUDED
"Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields", CROW Report D06-05	INCLUDED
Results From A Calibration Workshop Held 25-29 May 1998, Avinor Report OKK 1998-3	INCLUDED
Harmonizing Avinor-Operated Griptesters 1999, Avinor Report OKK 1999-1	INCLUDED
Harmonizing Friction Measures of Avinor-Operated BV-11s in June 2000, Avinor Report OKK 2000-1	INCLUDED
OKK Friction Profiles of Avinor-Operated Friction-Measuring Devices 1998-2000, Avinor Report OKK 2000-2	INCLUDED
Comparison of Pavement Texture Measurement Systems, Avinor Report OKK 2003-1	INCLUDED
Results from the International Texture Workshop, Avinor Report OKK 2003-2	INCLUDED

C.3.1 Wambold J. C., Antle C. E., Henry J. J. & Rado Z.; “International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements”

ABSTRACT

“This document presents the International Experiment involving 41 friction and texture measuring devices that operated on 58 locations (including 10 airfield runways) in Spain and Belgium in September-October 1992.

The analysis of the results and conclusions bear on correlations between texture measuring devices and friction measuring devices; relationships between friction and texture according to different models; repeatability of each device; reproducibility between devices and a proposal of a universal standard for measuring and characterizing anti-skid performances of roads and airfield surfaces.

The report proposes a common scale (IFI). It provides a uniform means of reporting friction characteristics of pavements, adjusts the values provided by the traditional measurement to the common scale and allows for the retention of those traditional values to relate to historical data and includes information on both friction and texture.”

SUMMARY

- (1) The applied methodologies:
 - o Surfaces in combination of high and low micro-, macro-, mega-texture and polishing and wear were selected;
 - o Control tests were made before and after test periods;
 - o Local climate conditions during the test period were documented;
 - o Four repeated runs were planned, but if any of the two individual test' deviation was more than two SD from the mean, then additional runs were made;
 - o To prevent variation due to the variation of the water depth, each device ran through its own water after each measurement; and
 - o The test sections were divided into two sections A and B, and they were tested for homogeneity and if they were out of the range, they were considered as two different sections.
- (2) Test matrix development:
 - o 54 test sites in two different countries;
 - o Three test speeds: 30,60, 90 km/h;
 - o Four repeated runs; and
 - o Testing for a given site was usually done in two days, due to the large number of participating devices.
- (3) The conditions and surface selections:
 - o Surfaces in combination of high and low micro-, macro-, mega-texture and polishing and wear were selected;
 - o Surfaces homogenous in texture were selected;
 - o Trial tests were made by 4 different devices;
 - o Texture profiles and spectra for all sites were measured;
 - o In most cases the right wheel path of the right most lane was selected; and
 - o The test section was marked with two lines 50cm apart from each other.

- (4) The development and plan to ensure sufficient data collection:
 - o 54 test sites in two different countries;
 - o Surfaces in combination of high and low micro-, macro-, mega-texture and polishing and wear were selected; and
 - o Four repeated runs were planned, but if any of the two individual test's deviation was more than two SD from the mean, then additional runs were made.
- (5) The findings on data requirements and data quality:
 - o No information found.
- (6) The frame work of quality assurance:
 - o No information found.
- (7) The employed test and data collection control techniques:
 - o Four repeated runs were planned, but if any of the two individual test's deviation was more than two SD from the mean, then additional runs were made;
 - o To prevent variation due to the variation of the water depth, each device run through its own water after each measurement;
 - o Testing for a given site was usually done in two days, due to the large number of participating devices, but control tests were made before and after test periods;
 - o Statistical analysis was done on the data to see if the first and second run showed a significant difference, and the result indicated that 95% of the runs had no difference;
 - o Outliers with a +4 SD or higher were eliminated; and
 - o All of the sites were reviewed and some sites were dropped from the analysis.
- (8) The correlation techniques used:
 - o Speed corrected point by point correlation;
 - o Speed corrected average by average correlation; and
 - o The corrected golden value correlation.
- (9) The assessment of measurement and correlation uncertainty:
 - o No information found.

C.3.2 TP 14083E, “Repeatability and Reproducibility of Saab Friction Measurement Devices in Self-wet Mode”, Transportation Infrastructure Consulting and Services Ltp., 2003

ABSTRACT

“A series of tests to establish the repeatability and reproducibility statistics of the Saab friction tester were conducted in March 2002 at Prague Airport. The basic issue for the study was to analyze the behaviour of the different Saab friction measurement devices in self-wet mode on different surfaces with respect to repeatability, reproducibility, and stability.

The surface areas measured during the data collection were on the south end of Runway 04/22 of the PRAHA/Ruzene. The surface was divided into three test sections: (A) the section of bare asphalt; (PAINT) the paint section that was defined to fall onto the touchdown paint-marks; and (C) the third section of bare asphalt.

Nine Saab friction measurement devices from four different manufacturers (ASFT, Sarsys, Safegate, Saab), a BV-11, the IRV and the Tatra friction measurement devices participated in the test session. The procedures employed in this study were the standard data analysis procedures in the ASTM E691 and ISO 5725 standards. It was determined that the participating Saab friction measurement devices in self-wet mode produced a repeatability uncertainty of 0.07, a reproducibility standard deviation of 0.10, a repeatability coefficient of variation of 6.6%, and a reproducibility coefficient of variation of 11.4%.”

SUMMARY

- (1) The applied methodologies :
 - o Devices were running in waves, following one another at a safe distance;
 - o To prevent water accumulation, a blower with sweeper brush was operated between waves;
 - o All participating devices were calibrated on site according to their standard calibration procedure; and
 - o Before each recorded run , each device made a surface and tire preparation run.
- (2) Test matrix development:
 - o Test sites: 1 test site with 3 section;
 - o Repeated runs: 10;
 - o Test speed: varied by tests;
 - o Self watering: 1 mm;
 - o Test tire: varied with devices and tests; and
 - o Tire pressure: varied with devices and tests.
- (3) The conditions and surface selections:
 - o The surface selection was very limited.
- (4) The development and plan to ensure sufficient data collection:
 - o No information found.
- (5) The findings on data requirements and data quality:
 - o No information found.
- (6) The frame work of quality assurance:
 - o No information found.
- (7) The employed test and data collection control techniques:
 - o The Grubbs’ test was used to detect outliers.

- (8) The correlation techniques used:
 - o It was a repeatability study.
- (9) The assessment of measurement and correlation uncertainty:
 - o It was a repeatability study.

C.3.3 Comparison of GripTester and Saab SFT Measurements, Transport Canada Interim Report

ABSTRACT

The SAAB Surface Friction Tester (SFT) has been used for several years in Canada for measuring the friction levels on airport runways. Transport Canada, Airports, started a program in 1994 to evaluate the suitability of the GripTester as an alternative to the SFT equipment. The evaluation program included parallel SFT and GT testing on eight runways in 1994, and another 15 runways in 1995. The measurements are compared in this report, along with some other operating characteristics of the SFT and GripTester friction measuring equipment. This report is interim in nature as further evaluation work is required.

SUMMARY

- (1) The applied methodologies:
 - o Profiles were obtained in the aircraft wheel path, 3m left and right from the centreline;
 - o Parallel distance paired runs for every 100m sections; and
 - o Testing was done within the same time period.
- (2) Test matrix development:
 - o 11 airports, 23 runways;
 - o 4 repeated runs;
 - o Test speed: 65 km/h;
 - o Self watering: 0.5mm; and
 - o Tire pressure – SFT: 210 kPa, GT: 140kPa.
- (3) The conditions and surface selections:
 - o The test surface was located in the aircraft wheel path, 3m left and right from the centerline.
- (4) The development and plan to ensure sufficient data collection:
 - o The correlation was based on measurement from 11 airports, 23 runways.
- (5) The findings on data requirements and data quality:
 - o the SFT data was obtained for each 100m section from the hardcopy friction profile traces;
 - o the GT data was obtained for each 10m section electronically and then was calculated for each 100m section.
- (6) The frame work of quality assurance:
 - o Both SFT and GT tires were extensively tested before they could be used for friction data collection;
 - o The consistent and accurate water thickness of the GT was insured by using a LSN nozzle and brush.
- (7) The employed test and data collection control techniques:
 - o Report does not contain any information on this subject.
- (8) The correlation techniques used:
 - o Speed independent one variable linear correlation.
- (9) The assessment of measurement and correlation uncertainty:
 - o Report does not contain any information on this subject.

C.3.4 Runway Friction Monitoring with the SFT - 0.5mm versus 1.0mm Water Depths

ABSTRACT

Transport Canada normally uses a water depth of 0.5 mm when testing runway friction levels in Canada. During the 1994 annual runway friction testing program, additional friction testing runs were conducted on selected runways, using a water depth of 1.0 mm. This report compares the coefficient of friction levels measured using the two (2) water depths.

SUMMARY

- (1) The applied methodologies :
 - o Profiles were obtained in the aircraft wheel path, 3m left and right from the centerline;
 - o Parallel distance paired runs for every 100m section; and
 - o Testing was done within the same time period.
- (2) Test matrix development:
 - o Nine (9) airports, 18 runways;
 - o Four (4) repeated runs;
 - o Test speed: 65 km/h (but report does not contain any information on this subject);
 - o Self watering: 0.5mm and 1.0mm;
 - o Test tire: ASTM E1551, low pressure bald tire; and
 - o Tire pressure – SFT: 210 kPa.
- (3) The conditions and surface selections:
 - o The test surface was located in the aircraft wheel path, 3m left and right from the centerline.
- (4) The development and plan to ensure sufficient data collection:
 - o The correlation was based on measurements from nine (9) airports, 18 runways
- (5) The findings on data requirements and data quality:
 - o Report does not contain any information on this subject.
- (6) The frame work of quality assurance:
 - o SFT tires were extensively tested before they could be used for friction data collection.
- (7) The employed test and data collection control techniques:
 - o Report does not contain any information on this subject.
- (8) The correlation techniques used:
 - o Speed independent one variable linear correlation.
- (9) The assessment of measurement and correlation uncertainty:
 - o Report does not contain any information on this subject.

C.3.5 Runway Friction Monitoring with the GripTester - 0.5mm versus 0.25mm Water Depths

ABSTRACT

Transport Canada normally uses a water depth of 0.5 mm when testing runway friction levels in Canada. During the 1995 annual runway friction testing program, additional friction testing runs were conducted on selected runways, using a water depth of 0.25 mm. This report compares the friction levels measured using the two (2) water depths.

SUMMARY

- (1) The applied methodologies:
 - o Profiles were obtained in the aircraft wheel path, 3m left and right from the centerline;
 - o Parallel distance paired runs for every 100m section; and
 - o Testing was done within the same time period.
- (2) Test matrix development:
 - o 11 airports, 13 runways;
 - o Four (4) repeated runs;
 - o Test speed: 65 km/h;
 - o Self watering: 0.25mm and 0.5mm;
 - o Test tire: ASTM E1844; and
 - o Tire pressure – 140 kPa.
- (3) The conditions and surface selections:
 - o The test surface was located in the aircraft wheel path, 3m left and right from the centerline.
- (4) The development and plan to ensure sufficient data collection:
 - o The correlation was based on measurements from 11 airports, 13 runways.
- (5) The findings on data requirements and data quality:
 - o Report does not contain any information on this subject.
- (6) The frame work of quality assurance:
 - o GT tires were extensively tested before they could be used for friction data collection.
- (7) The employed test and data collection control techniques:
 - o Report does not contain any information on this subject.
- (8) The correlation techniques used:
 - o Speed independent one variable linear correlation.
- (9) The assessment of measurement and correlation uncertainty:
 - o Report does not contain any information on this subject.

C.3.6 Appendix 3 (Fourth Edition – 2002) NASA Certification Procedure for New Continuous Friction-Measuring Equipment Used at Airport Facilities – ICAO Airport Services Manual – Part 2: Pavement Surface Conditions

ABSTRACT

“Since the 19050s, many different friction-measuring devices have been developed to monitor runway friction performance under all types of wetness and contaminations. In recent years, several types of continuous friction-measuring equipment (CFME) have proven to be reliable, accurate and consistent in a variety of extensive test programs, which included a range of pavement conditions and test speeds. From a cost, dependability, or ease of operation standpoint, some of the more widely used CFME, which have been certified as acceptable by NASA from earlier test include the mu-meter trailer, the runway friction meter, the BV-11 skiddometer trailer, the surface friction tester (Saab), the Grip Tester trailer, the Tatra runway friction tester and the RUNAR runway analyzer and recorder.”

SUMMARY

- (1) The applied methodologies:
 - o To prevent variation due to the variation of the water depth, one set of runs was made by all devices to pre-wet the surface.
- (2) Test matrix development:
 - o Minimum of 4 different test surfaces;
 - o Repeated runs: 6;
 - o Test speed: min. two: 65, 95 km/h;
 - o Self watering: 1 mm;
 - o Test tire: varied by devices; and
 - o Tire pressure: varied by devices.
- (3) The conditions and surface selections:
 - o the individual test pavements should be inspected prior to conducting CFME test runs to ensure that the surface is dry, clean, free of dirt or loose material;
- (4) The development and plan to ensure sufficient data collection:
 - o Minimum of 4 different test surfaces;
 - o Repeated runs: 6.
- (5) The findings on data requirements and data quality:
 - o Report does not contain any information on this subject.
- (6) The framework of quality assurance:
 - o During the CFME testing , ambient weather conditions (e.g. temperature, wind, and humidity) should be recorded at reasonable intervals together with the time of day the test run was conducted;
 - o The individual test pavements should be inspected prior to conducting CFME test runs to ensure that the surface is dry, clean, free of dirt or loose material;
 - o All CFME test runs must be performed in the same direction;
 - o CFME has to be checked and calibrated before test runs; and
 - o Two or three test runs with each CFME on a given test surface is performed to achieve $\pm 0,03$ repeatability.
- (7) The employed test and data collection control techniques:
 - o Two or three test runs with each CFME on a given test surface is performed to achieve $\pm 0,03$ repeatability.
 - o Six repeated runs on minimum four (4) test pavement surfaces.

- (8) The correlation techniques used:
 - o Average by average correlation for each speed.
- (9) The assessment of measurement and correlation uncertainty:
 - o Report does not contain any information on this subject.

C.3.7 Reliability and Performance of Friction Measuring Tires and Friction Equipment Correlation. - Fnal Report. Federal Aviation Administration, Washington, DC. Office of Airport Safety and Standards Mar 1990 Author: T. H. Morrow, DOT/FAA/AS-90-1

SUMMARY

“The purpose of the tire performance study was twofold: (1) To establish the reliability, performance, and consistency of tires on all types of dry runway pavement surfaces, using continuous friction-measuring devices equipped with self-water system. (2) To select the best performing tires that will achieve consistent correlation between the various friction-measuring devices and to develop guidelines that would be dependable and useful to airport operators in maintaining runway pavement surfaces for safe aircraft operation during wet weather conditions.”

- (1) The applied methodologies:
 - o All tire were labeled with proper identification;
 - o All CFMEs were calibrated according to the manufacturer’s instruction; and
 - o Texture depth measurement were made on the pavements using the NASA grease-smear method.
- (2) Test matrix development:
 - o Number of test sites: 3;
 - o Number of test segments per test site: 5;
 - o Number of runs: 6; and
 - o Number of test speeds: 2.
- (3) The conditions and surface selections:
 - o Test segment’s length: 200 to 350 ft;
 - o Texture depth measurement were made on the pavements using the NASA grease-smear method.
- (4) The development and plan to ensure sufficient data collection:
 - o Total of 1643 runs and total of 2725 data points were collected.
- (5) The findings on data requirements and data quality:
 - o Limits of acceptability;
 - coefficient of correlation min 0.980
 - coefficient of determination min 0.9604
 - SE: $\pm 3.5 \mu$
- (6) The frame work of quality assurance:
 - o Report does not contain any information on this subject.
- (7) The employed test and data collection control techniques:
 - o Report does not contain any information on this subject.
- (8) The correlation techniques used:
 - o One-to-one correlation.
- (9) The assessment of measurement and correlation uncertainty:
 - o report does not contain any information on this subject.

C.3.8 Van ES, G.H.W.: “Correlation of Self-Wetting Friction Measuring Devices: Evaluation of the ESDU Method”**SUMMARY**

The correlation study did not include any friction measurement; it was based on the data collected during the PIARC experiment.

C.3.9 “Correlation Trial and Harmonization Modeling of Friction Measurements on Runways 2005” CROW Report 06-02

SUMMARY

- (1) The applied methodologies:
 - o They used dry, wet and MPD measurements to calculate the ESDU parameters;
 - o Between runs minimum of five minutes space allocated to water run off.
- (2) Test matrix development:

Measurements	Dry	Wet	Repeatability
test sites:	12 with two 100m segments	12 with two 100m segments	4 with two 100m segments
repeated runs:	2	3	6
test speed:	one speed between 20-40 km/h	40, 65, 95 km/h	65, 95 km/h
self watering:	none	1mm	1mm
test tire:	varied by device	varied by device	varied by device
tire pressure:	varied by device	varied by device	varied by device

- (3) The conditions and surface selections:
 - o Test site selection was based on pre-survey to make sure the friction and texture levels were different, MPD range:0.4mm – 1.3mm, Friction range:0.53 – 0.80;
 - o 12 test sections with two 100m segments on each was selected.
- (4) The development and plan to ensure sufficient data collection:
 - o Report does not contain any information on this subject.
- (5) The findings on data requirements and data quality:
 - o All the test runs were checked for the allowable test speed variation – result: all devices were able to keep the test speed within 5 km/h.
- (6) The frame work of quality assurance:
 - o Report does not contain any information on this subject.
- (7) The employed test and data collection control techniques:
 - o Report does not contain any information on this subject.
- (8) The correlation techniques used:
 - o ESDU statistical correlation method.
- (9) The assessment of measurement and correlation uncertainty:
 - o After harmonization by the ESDU method all the device complied with the 0.090 standard deviation requirement.

C.3.10 Friction Workshop Held at LCPC Centre de Nantes, France (June 2004)

We only have data available for this correlation test.

SUMMARY

- (1) The applied methodologies:
 - o MPD from 0.05 – 1.68 mm; and
 - o Friction levels from 0.15 to 0.93.
- (2) Test matrix development:
 - o Test surface: 6;
 - o Repeated runs: 3;
 - o Test speed: 40 km/h, 65 km/h, 95 km/h;
 - o Self watering: No information;
 - o Test tire: mainly ASTM E1551, except two devices;
 - o Tire pressure: mainly 207 kPa, except two devices; and
 - o Slip ratio: 15%.
- (3) The conditions and surface selections:
 - o No information.
- (4) The development and plan to ensure sufficient data collection:
 - o No information.
- (5) The findings on data requirements and data quality:
 - o No information.
- (6) The frame work of quality assurance:
 - o No information
- (7) The employed test and data collection control techniques:
 - o No information.
- (8) The correlation techniques used:
 - o Test section average by test section average correlation.
- (9) The assessment of measurement and correlation uncertainty:
 - o No information.

C.3.11 Correlation Trial of Self-Wetting Friction-Measuring Devices for Dutch Airfield Pavements, CROW Report 04-05

SUMMARY

- (1) The applied methodologies:
 - o Three levels of profile depth between 0.5mm and 2mm surfaces;
 - o 300 m test sections with 100m segments;
 - o Line up of the test tire was guided by yellow short lines before each 100 m section;
 - o Four minutes were allotted between two consecutive runs for the water to run off the surface;
 - o Zero test before data collection runs;
 - o Just before of each test run series, the MPD values was measured by a laser;
 - o The testing date was chosen to be a dry day ; and
 - o Before the test all equipment was checked and calibrated by the owners.
- (2) Test matrix development:
 - o Test surface: eight (8) test sections, three (3) test sites;
 - o Repeated runs: 3;
 - o Test speed: 40 km/h, 65 km/h, 95 km/h;
 - o Self watering: 1mm;
 - o Test tire: varied by devices; and
 - o Tire pressure: varied by devices.
- (3) The conditions and surface selections:
 - o Three levels of profile depth between 0.5mm and 2mm surfaces;
 - o 300 m test sections with 100m segments; and
 - o Line up of the test tire was guided by yellow short lines before each 100 m section.
- (4) The development and plan to ensure sufficient data collection:
 - o According to the report conclusion the data collection was not sufficient, because of the limited repeated runs and the limited profile depth variation.
- (5) The findings on data requirements and data quality:
 - o Each test speed was analyzed for variation, and it turned out that not all devices were able to keep the required speeds;
 - o Each test section was measured for profile depth before each test series, and it turned out that the MPD value variation was less than expected; and
 - o The friction values were analyzed in relation to the macro texture, but there was no unified relation found.
- (6) The frame work of quality assurance:
 - o Line up of the test tire was guided by yellow short lines before each 100 m section;
 - o Four minutes were allotted between two consecutive runs for the water to run off the surface; and
 - o Zero test before data collection runs to ensure homogeneous test result.

- (7) The employed test and data collection control techniques:
 - o Report does not contain any information on this subject.
- (8) The correlation techniques used:
 - o ESDU statistical correlation method.
- (9) The assessment of measurement and correlation uncertainty:
 - o The significance of correlation was tested by the Spearman rank order correlation method.

C.3.12 “Qualification Protocol for Candidate Self-Wetting Friction-Measuring Devices on Dutch Airfields”, CROW Report D06-05.

SUMMARY

This report contains a qualifying correlation test specification for CFME to be used in airport for runway surface maintenance purposes.

- (1) The applied methodologies:
 - o Three levels of profile depth between 0.5mm and 2mm surfaces;
 - o 300 mm test sections with 100m segments;
 - o Check runs before data collection runs;
 - o The testing has to be done on a dry day, the pavement temperature shall be between 5- 45°C; and
 - o Before the test all equipment was checked and calibrated by the owners.
- (2) Test matrix development:
 - o Test surface: min six (6) test section;
 - o Repeated runs: minimum three (3);
 - o Test speed: 65 km/h $\pm$ 5 km/h, 95 km/h $\pm$ 5 km/h;
 - o Self watering: 1mm;
 - o Test tire: varied by devices; and
 - o Tire pressure: varied by devices.
- (3) The conditions and surface selections:
 - o Straight section with homogeneous friction and texture;
 - o Leave 150 m or 300m speed up and slow down zone on each end of the site;
 - o Three levels of profile depth between 0.5mm and 1.5mm surfaces;
 - o Select one low and one high friction surface per profile level; and
 - o At least 200 mm test sections with at least two 100m segments.
- (4) The development and plan to ensure sufficient data collection:
 - o Average friction values and speed values shall be reported for each 100m segments.
- (5) The findings on data requirements and data quality: N/A
- (6) The frame work of quality assurance:
 - o Check run before data collection runs to ensure homogeneous test result.
- (7) The employed test and data collection control techniques:
 - o Not defined.
- (8) The correlation techniques used:
 - o ESDU statistical correlation method.
- (9) The assessment of measurement and correlation uncertainty. N/A

C.3.13 Results From A Calibration Workshop Held 25-29 May 1998, Avinor Report OKK 1998-3

ABSTRACT

54 runway friction-measuring devices were successfully calibrated to a common scale of friction units during an internal workshop of the Norwegian Civil Aviation Administration held at Ottar K. Kollerud Friction Calibration Test Track in May 1998.

The calibration was made valid for wetted pavement only and comprised 26 Griptester units and 18 BV-11 units operated at Norwegian airports.

The calibrating method reduced significantly of the variance of the reported friction values over 8 different asphalt surfaces of different recipes. Group statistics for each make and type of friction device, as well as, statistics for the individual machines were worked out.

A demonstration of on how calibration affects the interpretation of the current ICAO friction threshold values for different objectives was made.

SUMMARY

The analysis shows that the applied calibration method in itself brings about an improved statistical quality of the reported friction values. The variance about the average friction value as expressed in standard deviations typically goes down 20 – 30 % for the majority of the devices.

The device specific calibration constants have been successfully applied to each individual test surface to verify that all surface-device combinations exhibit the same positive result. From this one may conclude that the calibration constants are applicable to any similar type of asphalt surfaces to those at the Ottar K. Kollerud Friction Calibration Test Track.

The Norwegian Civil Aviation Administration has achieved a common internal scale of friction measurement units for the devices operated at Norwegian airports doing wet pavement measurements when the calibration constants are used to correct the reported friction values of each calibrated device.

SAMPLE RESULTS

Table 11 - Statistics of the Griptesters as a Group at 65 km/h Measuring Speed by Surface Number

Surface No.	Average Friction of Group Before Calibrating	Average Friction of Group After Calibrating to GRT110	Standard Deviation of Group Friction Before Calibrating	Standard Deviation of Group Friction After Calibrating	95% Confidence of Group Friction Before Calibrating	95% Confidence of Group Friction After Calibrating	Coefficient of Variation of Group Friction Before Calibrating	Coefficient of Variation of Group Friction After Calibrating
1	0.632	0.621	0.040	0.025	0.015	0.010	6.3	4.1
2	0.598	0.587	0.048	0.021	0.018	0.008	8.0	3.6
3	0.485	0.475	0.050	0.017	0.018	0.006	10.3	3.5
4	0.503	0.494	0.061	0.029	0.023	0.011	12.1	5.9
5	0.234	0.237	0.073	0.031	0.027	0.012	31.0	13.7
6	0.506	0.494	0.038	0.026	0.014	0.010	7.6	5.2
7	0.513	0.501	0.034	0.033	0.013	0.013	6.7	6.6
8	0.603	0.590	0.040	0.037	0.015	0.014	6.7	6.2

C.3.14 Harmonizing Avinor-Operated Griptesters 1999, Avinor Report OKK 1999-1

ABSTRACT

26 friction measuring devices of the GripTester type were gathered in the week of 7 – 11 June 1999 for comparative tests and calibration at the Ottar K. Kollerud Friction Calibration Test track at Oslo Airport Gardermoen with the following objectives,

1. Harmonise the friction devices to a common scale of wet friction measurement,
 - a) in the condition the devices were in at arrival to the track from the airports, and
 - b) in the condition the devices were in after they had been serviced at the test track according to the manufacturer's handbook and equipped with new measuring tyres.
2. Obtain a measure of variance of all measuring tyres used at the airports.

ORGANIZATION OF THE TEST PROGRAM

The test program was organised in 3 projects:

1. Comparison of reported friction values from GripTesters as received from the airports.
2. Comparison of reported friction values after the GripTesters had been serviced to conform with the requirements of the manufacturer's handbook and fitted with new measuring tyres.
3. Comparison of reported friction values from a single Grip Tester operated with all the airport used tyres following the runs for project 1.

SUMMARY

Satisfactory correlations with a reference GripTester device serial 110 were achieved as indicated by correlation coefficients $R^2 \geq 0.9$. The GripTester serial 110 was an ordinary operative GripTester. All the testers were equipped with measuring tyres according to the ASTM E-1844 standard.

All testers were run at target speeds 65 and 95 km/h. Harmonisation is worked out for each of these speeds using the general linear relationship:

$$\text{Harmonised friction value} = A + B * \text{reported friction value by device.}$$

Comparing measures of friction on the same tracks taken in 1998 with those of runs prior to service 1999 significant differences were observed.

Variances in measuring tyres were observed and have influence on the results, but tyre variance did not solely explain the total variance of results. The variance of reported friction values when all used measuring tyres were run on the same device was less than the variance of reported friction values when the devices operated with their original used tyres.

The manufacturer serviced the testers in a field workshop after initial comparative runs had been made with the testers as received from the airports. The variance of friction values were significantly reduced for the serviced testers relative to the as received condition of the testers.

A few testers could not be completely serviced to satisfactory standards within the constraints of a field workshop and time available.

SAMPLE RESULTS

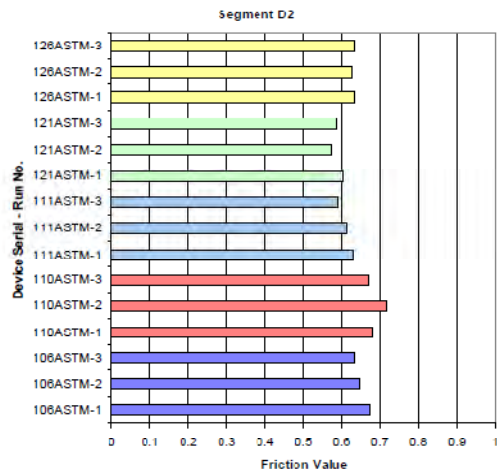


Figure 2 A sample collection of runs for a segment for the same devices in project 1. The segment was traversed 3 times. Each bar represent the average of 10 reported friction values of a run. The average of all runs by a device over a segment in a project constitute one observation.

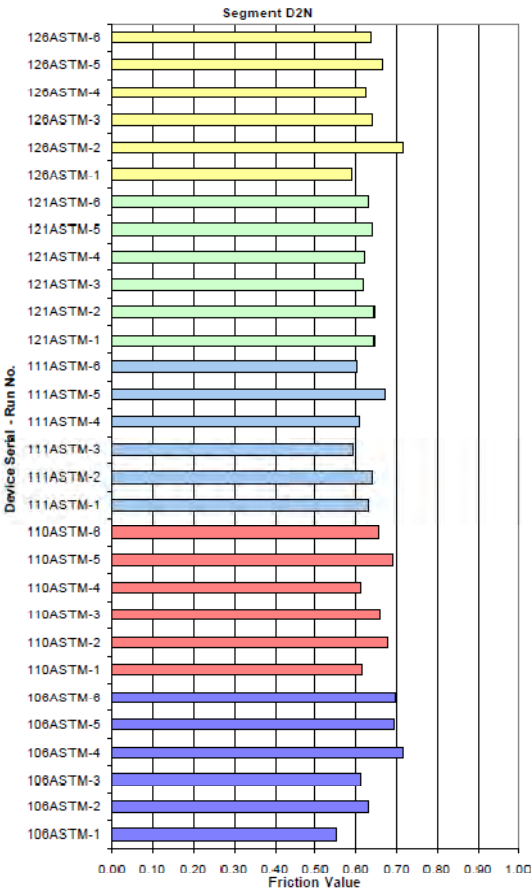


Figure 3 - A sample collection of runs for a segment for the same devices in project 2. The segment was traversed 6 times. Each bar represent the average of 10 reported friction values of a run. The average of all runs by a device over a segment in a project constitute one observation.

C.3.15 Harmonizing Friction Measures of Avinor-Operated BV-11s in June 2000, Avinor Report OKK 2000-1

ABSTRACT

15 friction measuring devices of the BV 11 type were gathered in the week of 26-30 June 2000 for comparative tests and calibration at the Ottar K. Kollerud Friction Calibration Test Track at Oslo Airport Gardermoen. The objective were to:

1. Determine how much the reported friction values of a fleet of the same generic type of devices differ.
2. Harmonise the friction devices to a common scale of wet friction measurement.

SUMMARY

The difference in reported friction value between the highest and lowest reporting devices was approximately 0.2 friction coefficient units. At 65 km/h measuring speed the average difference was 0.18 friction coefficient units. At 95 km/h the average difference was 0.21 friction coefficient units.

The spread among the devices expressed in standard deviation was 0.054 at 65 km/h and 0.058 at 95 km/h.

A criterion for satisfactory correlation was set at $R^2 \geq 0.90$. At 65 km/h 3 of 14 devices satisfied the correlation requirement. At 95 km/h 10 of 14 devices achieved this correlation target.

The fleet of devices were harmonised at each of the two measuring speeds using the general linear relationship:

$$\text{Harmonised friction value} = A + B * \text{reported friction value by device.}$$

A new device was chosen as a reference device that ran with every group of 3 devices. Also the average of all devices was chosen as a second reference in a second Harmonisation. Comparing the harmonizing result obtained for the same devices in 1998 with these obtained in 2000, a number of devices showed similar correlation constants A and B in both years, but many had also changed significantly.

When applying the harmonisation results to a commonly used threshold value like the ICAO Design Objective Level (DOL), it was found that the devices deviated 0.04 friction coefficient units from at both measuring speeds. The ICAO DOL values are 0.82 and 0.74 at 65 km/h and 95 km/h, respectively.

Prior to test runs the devices were calibrated statically according to the manufacturers recommendations. A representative of the manufacturer, Patria Vammass AEC AB, Finland, supervised the calibrations.

One device could not be satisfactorily calibrated and it did not participate in the runs.

SAMPLE RESULTS

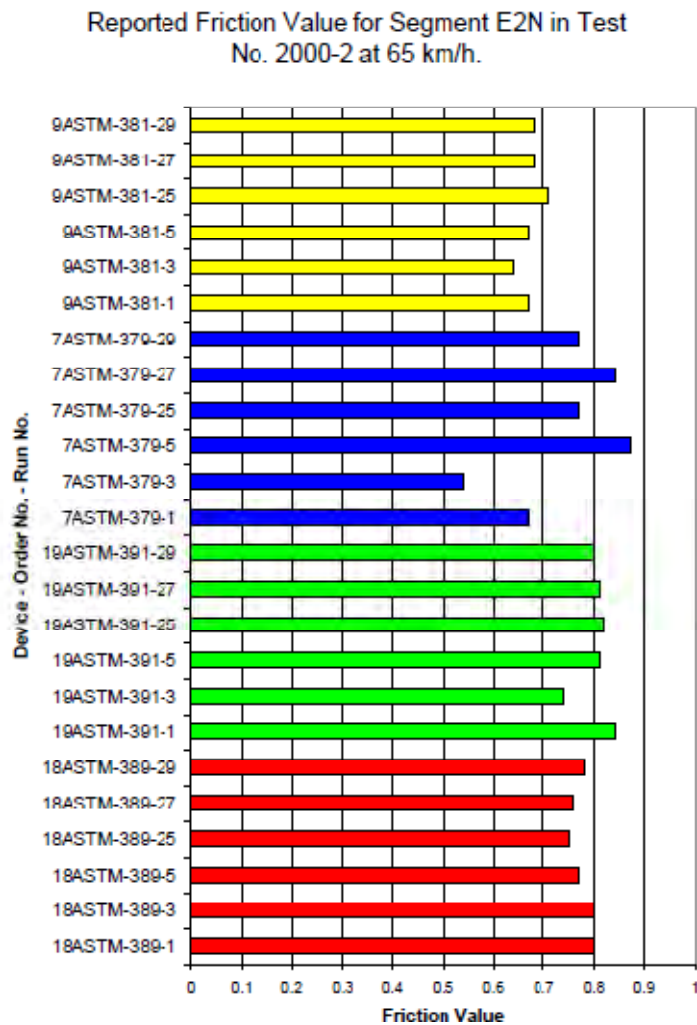


Figure 2 - A sample collection of runs for a segment by one group of devices. The segment was traversed 6 times. Each bar represent the average reported friction value of a run. The average of all runs by a device over a segment in a test constitute one observation for that device on the segment.

C.3.16 OKK Friction Profiles of Avinor-Operated Friction-Measuring Devices 1998-2000, Avinor Report OKK 2000-2

ABSTRACT

Friction profile charts from the OKK Database from comparative tests and calibration at the Ottar K. Kollerud Friction Calibration Test Track at Oslo Airport Gardermoen. Results from 1998, 1999 and 2000 are shown for two generic types of devices, the GripTesters and the BV11's.

The objective for the tests were to:

1. Determine how much the reported friction values of a fleet of the same generic type of devices differ.
2. Harmonise the friction devices to a common scale of wet friction measurement.

\

C.3.17 Comparison of Pavement Texture Measurement Systems, Avinor Report OKK 2003-1

ABSTRACT

The Norwegian Roads Administration had acquired a fleet of instrumented vans that were prepared to conduct a comprehensive survey of the national road network in the forthcoming summer months. Seven members of this fleet gathered at Oslo Airport, Gardermoen, on April 19th, 2002 for a systems calibration and comparison workshop. The workshop objectives were to:

1. Determine how much the reported pavement texture values of a device differ for repeated measurements over the same set of surfaces (repeatability).
2. Determine how much the reported pavement texture values of a fleet of the same generic type of devices differ over a range of texture values (reproducibility).
3. Determine the performance of a software routine of the laser signal processing software to remove the effects of surface grooves on the reported texture values.
4. Determine a relationship of the non-contact texture measurements with a contact measuring method (sand patch).
5. Determine a harmonization relationship among the non-contact texture measuring systems.
6. Investigate any relationship of the texture values with friction values obtained with a friction measuring device.

This report presents illustrated results from the workshop.

C.3.18 Results from the International Texture Workshop, Avinor Report OKK 2003-2**ABSTRACT**

An international texture workshop was held at the Kollerud test track during June 2-6, 2003.

The objectives of the International Texture Workshop 2003 were to conduct field tests to enable

- 1) Comparison of the performances of texture measurement systems generally.
- 2) Comparison of the performances of 2002 with the performances of 2003 of texture measurement systems that participated both years.
- 3) Secure the measurement data into the OKK computerized database for dissemination and future analysis.

This report presents illustrated results from the workshop.

INTRODUCTION

1 Introduction

1.1 The Ottar K.Kollerud Test Track

Avinor has for the past seven years worked continuously with problem issues related to runway surface characteristics.

In 1997 Avinor constructed the Ottar K. Kollerud Test Track located at the new Oslo Airport as a field laboratory site for runway surface tests. The test track, also known as the OKK test track in short, has ten different asphalt pavements. Eight of these pavements have been used to harmonize devices measuring surface characteristics.

Five connected surfaces are constructed with incremental less texture of the same pavement material. This is a unique feature the OKK test track.

1.2 Use of Texture Information

Avinor does not declare wet friction values for their runways. After studies of the JAR and FAR regulations [7], [9] and related background material [5], [6], [8], Avinor decided instead to measure texture and declare these values in the AIP.

The harmonized FAR Part 25 and JAR 25 use texture as a variable for predicting the maximum tyre-to-ground wet runway braking coefficient.

A practice is now established to measure the mean texture depth, when performing the annual runway inspection, and publish this value in the AIP AD 2.12.

As member of the Institute of Asphalt Technology (ATI), Avinor has access to their instrumented van that has the capabilities to perform measurements of transverse profiles, rut depth and texture in terms of mean profile depth.

A good correlation between mean texture depth and mean profile depth was found from measurements at the OKK test track since 2001.

1.3 The International Texture Workshop 2003

The objectives of the International Texture Workshop 2003 were to conduct field tests to enable:

- 4) Comparison of the performances of texture measurement systems generally.
- 5) Comparison of the performances of 2002 with the performances of 2003 of texture measurement systems that participated both years.
- 6) Secure the measurement data into the OKK computerized database for dissemination and future analysis.

Avinor invited operators of texture measurement devices internationally. The workshop participants came from six countries: Belgium, Denmark, Japan, Norway, Sweden and United States of America.

The participating devices were:

One instrumented van from Greenwood Engineering A/S, Denmark.

One instrumented van from Swedish Road and Transport Research Institute (VTI), Sweden.

One instrumented van from Scandiaconsult AB, Sweden.

Two Circular Track Texture Meters from Kinki Construction, Japan, and CDRM, USA, respectively.

Two Dynamic Friction Testers from Kinki Construction, Japan, and CDRM, USA, respectively.

One instrumented van and static texture measurement device from the Belgian Road Research Centre (BRRC), Belgium.

Eight instrumented vans from The Norwegian Road Administration (SV), Norway.

One instrumented van from the Institute of Asphalt Technology, Oslo, Norway.

Two TRL Pendulum Friction Testers from The Norwegian Road Administration (SV) and the Norwegian Technical University (NTNU/NGU), Norway, respectively.

Volumetric texture measurements were made with glass beads (sand patch) from MFT Mobility Friction Technology, Norway.

Images of the participating devices and operators are enclosed in Appendix H.

OBJECTIVES AND SUMMARY

2 Report Objectives

The objectives of this report were to:

1. Illustrate the performance of the participating devices leaving in depth analysis to future reports,
2. Determine relationships of the non-contact texture measurements with a volumetric contact measuring method [1], and
3. Encourage further analysis and reports by others.

3 Summary of Report

3.1 Relative Performance

The different types of texture measurement systems showed different performance characteristics. This was expected, since the systems have no common calibration or harmonization reference.

3.2 Relationship of Mean Profile Depth to Mean Texture Depth

It was found that the mean texture depth (MTD) values at the OKK test track can be predicted from mean profile depth (MPD) values of ALFRED devices with the simplified transform:

$$T_{XMTD} = 1.15 \cdot T_{XMPD}$$

where T_{XMTD} denotes an estimated volumetric measurement value and T_{XMPD} denotes a non-contact measurement value, both in units of mm.

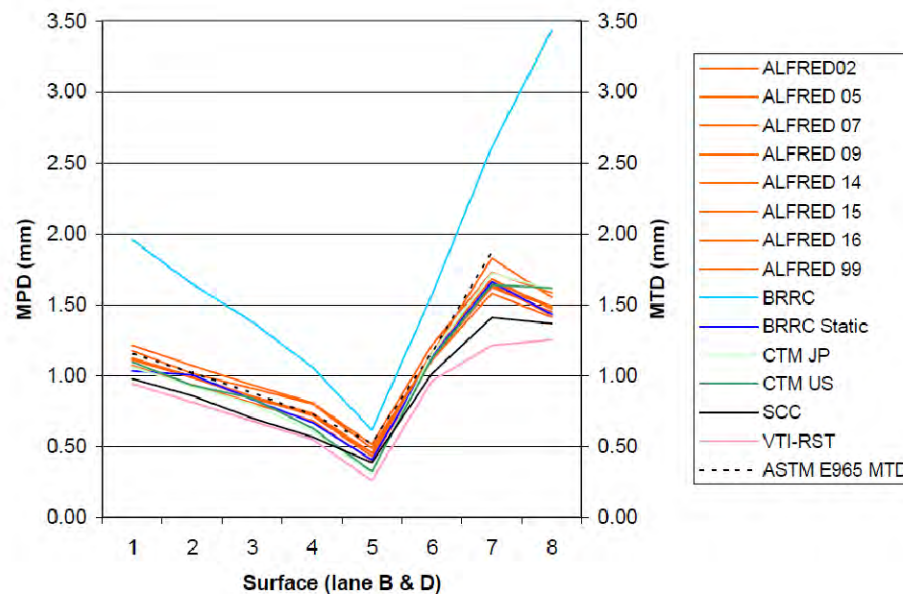


Figure 1 – A summary comparison chart of all MPD devices in 2003 showing average texture value of 30 samples per segment (5 samples in each repeat run totaling 6 runs) or 60 samples per surface, 30 from each lane. Volumetric method ASTM E965 also shown sample size 5 each lane, 10 samples per surface.

APPENDIX C, ANNEX 4–
REPORTS FROM THE JOINT WINTER RUNWAY FRICTION MEASUREMENT
PROGRAM

Table C.4: Reports from the Joint Winter Runway Friction Measurement Program

Report
Aircraft tire braking friction under winter conditions: Laboratory testing (TP 12584E)
Proceedings of the international meeting on aircraft performance on contaminated runways, IMAPCR '96 (TP 12943)
Characteristics of winter contaminants on runway surfaces in North Bay – January and February-March 1997 tests (TP 13060E)
Braking friction coefficient and contamination drag of a B727 on contaminated runways (TP 13258E)
Falcon 20 aircraft performance testing on contaminated runway surfaces during the winter of 1997/1998 (TP 13338E)
Analysis of the friction factors measured by the ground vehicles at the 1998 North Bay trials (TP 13366E)
Laboratory testing of tire friction under winter conditions (TP 13392E)
Measuring tires for harmonized friction measurements of runway surfaces and prediction of aircraft wheel braking (TP 14005E)
Overview of the joint winter runway friction measurement program (TP 13361E)
Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the winter of 1998-1999 (TP 13557E)
Proceedings of the 2nd International Meeting on Aircraft Performance on Contaminated Runways, IMAPCR '99 (TP 13579)
Joint Winter Runway Friction Measurement Program (JWRFMP): 1997-98 testing and data analysis (TP 13836E)
Winter contaminants on surfaces during friction tests at Munich Airport – February 2000 (TP 13658E)
Runway surface and environmental conditions during friction tests at K.I. Sawyer Airbase, Michigan, USA – February 1999 (TP 13672E)
Friction factor measurements on non-uniform surfaces: sampling frequencies required (TP 13784E)
Comparison of the IRV and the IMAG on winter contaminated surfaces (TP 13791E)
First Air B727 aircraft landing performance on contaminated arctic runway surfaces during the winters of 1998-1999 and 1999-2000 (TP 13800E)
Falcon 20 aircraft performance testing on contaminated runway surfaces during the winter of 1999/2000 (TP 13833E)
Friction fundamentals, concepts and methodology (TP 13837E)
Wet runway friction: literature and information review (TP 14002E)
Runway friction accountability risk assessment: Results of a survey of Canadian airline pilots (TP 13941E)
Evaluation of aircraft braking performance on winter contaminated runways and prediction of aircraft landing distance using the Canadian Runway Friction Index (TP 13943E)
Dash 8 aircraft braking performance on winter contaminated runways (TP 13957E)
Effect of vehicle parameters on the friction coefficients measured by decelerometers on winter surfaces (TP 13980E)
Dornier DU328 aircraft braking performance on winter contaminated runways (TP 13983E)
International Runway Friction Index (IRFI): Development technique and methodology (TP 14061E)
Joint winter runway friction measurement program (JWRFMP): 2000 Testing and data analysis (TP 14062E)
Evaluation of IRFI calibration procedures for new and existing devices (TP 14063E)
Repeatability of friction measurement devices in self-wetting mode (TP 14064E)
Comparison of the IRV and the ERD on winter contaminated surfaces (TP 14065E)
Joint Winter Runway Friction Measurement Program (JWRFMP): 2001 testing and data analysis (TP 14192E)
Environmental and runway surface conditions during friction tests at North Bay Airport: Jan-Feb 2002 (TP 14158E)

Report
NASA Wallops Tire/Runway Friction Workshops: 1993-2002 (TP 14190E)
Benefit-cost analysis of procedures for accounting for runway friction on landing (TP 14082E)
Repeatability and reproducibility of Saab friction measurement devices in self-wet mode (TP 14083E)
Decelerometer tests: CRFI quality assurance tests and the effect of the vehicle's ABS system (TP 14176E)
Joint Winter Runway Friction Measurement Program (JWRFMP): 2002 testing and data analysis (TP 14193E)
Joint Winter Runway Friction Measurement Program (JWRFMP): 2003 testing and data analysis (TP 14194E)
Joint Winter Runway Friction Measurement Program (JWRFMP): International Runway Friction Index (IRFI) versus aircraft braking coefficient (μ) (TP 14318E)
Development of a comprehensive method for modelling performance of aircraft tyres rolling or braking on dry and precipitation-contaminated runways (TP 14289E)
Meeting on Aircraft Performance on Contaminated Runways, IMAPCR 2004 (TP 13579)
Effect of surface conditions on the friction coefficients measured on winter surfaces (TP 14220E)
Effect of surface conditions on the friction coefficients measured on winter surfaces (TP 14220E)
Evaluation of wide-body aircraft braking performance with the determined runway friction index from tests conducted in Japan in 2003 (TP 14399E)
Friction coefficients for various winter surfaces (TP 14498E)
Evaluation of Falcon 20 turbojet and DHC-8 series 100 and 400 turbopropeller aircraft safety margins for landings on wet runway surfaces (TP 14627E)
Airport operations under cold weather conditions: Observations on operative runways in Norway (TP 14648E)
Study of warm, pre-wetted sanding method at airports in Norway (TP 14686E)

C.4.1 Aircraft Tire Braking Friction Under Winter Conditions: Laboratory Testing (TP 12584E)

Summary

A laboratory test program was conducted to evaluate tire friction for a wide range of winter conditions. As none of the available test facilities was capable of meeting the project's requirements, Transport Canada commissioned Fleet Technology Limited (FTL) to design and build a specialized test setup in FTL's refrigerated chamber. After the test rig was successfully built and verified, a total of 831 tests were carried out.

Results: Effect of Type II Fluids on Friction Factor

Relative to a wet asphalt surface at -2°C, the friction factor was approximately 0.15 (15%) less on asphalt contaminated with a Type II fluid, 0.25 (25%) less on a mixture of Type II and potassium acetate, and 0.38 (38%) less on a mixture of Type II and urea.

Relative to a wet concrete surface at -2°C, the friction factor was 0.13 (30%) less on concrete contaminated with Type II Ultra, and 0.20 (49%) less on Type II Octagon and a mixture of Type II fluid and potassium acetate.

Relative to wet ice at -2°C, the friction factor was 100% more on ice contaminated with a Type II fluid (0.10 compared to 0.05), and was 200% (0.11) higher on a mixture of urea and Type II fluid.

Results: Effect of Type II Fluid Deposition Rate on Friction Factor

On asphalt, the friction factor decreased approximately linearly with the log of the application rate. The friction factor decreased by up to 0.20 (22%) and 0.10 (14%) for Octagon and Ultra Type II fluids respectively when the application rate was increased by 100 fold on asphalt. On ice, the friction did not change significantly with application rate.

Results: Difference in Friction between a Wet and a Type II Fluid-Coated Surface

This difference was much higher for the low-pressure SFT tire than for the aircraft tire. The following trends were observed:

- Higher tire pressure resulted in a lower difference in friction.
- Higher microtexture resulted in a lower difference in friction.
- Lower temperatures resulted in a higher difference in friction.

Results: Aircraft Tire Braking Friction on Loose Snow and Slush

On slush, the friction factor was higher than on ice or frozen snow, but lower than on a wet asphalt surface, which was used as the substrate for these tests. On loose snow, the friction factor was similar to that for slush.

Results: Effect of Runway Ice Control Chemicals on Friction Factor

Solid de-icing chemicals altered the microtexture of the surface, and hence the friction, as they had usually not liquefied completely when the friction factor measurements were made.

Each of the liquid de-icers (i.e., potassium acetate, E36T, and UCAR) reduced the friction on asphalt and concrete relative to both wet and dry conditions, and they increased the friction on bare ice and frozen snow. The friction changes produced by each de-icer were similar.

Each of the solid de-icers (i.e., urea, sodium acetate, and sodium formate) decreased the friction on asphalt and concrete relative to both wet and dry conditions. On ice and frozen snow, each of the solid de-icers increased the friction in relation to a bare surface.

Results: Correlation between the SFT and Aircraft Tire Friction Factors

General comment – Many factors influence the correlation between the SFT tire and the aircraft tire friction coefficients, and a consistent relationship was not observed over the whole test matrix.

Conditions Producing Good Correlation – Both SFT tires provided reasonable correlation to the aircraft tire on dry surfaces with high microtexture, such as on dry asphalt, which had the highest microtexture of the surfaces tested, and on dry concrete.

The correlation between the aircraft tire and each SFT tire friction factor was improved when solid de-icers, rather than liquids, were applied. On loose snow and slush, both SFT tires measured lower friction factors than did the aircraft tire, and the high-pressure SFT tire tended to measure lower friction factors than did the low-pressure SFT tire.

Conditions Producing Poor Correlation – Neither SFT tire provided a good "index" for assessing aircraft braking friction on surfaces with low enough microtexture to significantly affect the friction when fluids (i.e., water or other fluids) were applied on the surface.

Effect of Other Factors

- o Temperature – Similar correlation for +15°C to +18°C, -2°C and -10°C.
- o Type II Fluid Type – Similar correlation for both Type II fluids.
- o Sanded Ice and Comparison of Different Sands

Although the aircraft tire and the high-pressure SFT tire results show reasonable correlation, somewhat different relative rankings were indicated by the two tires for the sands tested. The aircraft tire is recommended for use in comparing candidate sands.

- o High Pressure vs Low-Pressure SFT Tires - Neither one is clearly superior to the other.

Results: Sanded Ice and Sanded Frozen Snow Friction Factors

The friction factor increased with the application rate up to about 100 to 200 kg/1000 m². The friction factor did not increase greatly when sand was applied at higher rates. On frozen snow, the friction factor increased steadily with the application rate. The friction factor on slush was increased by adding sand to the slush.

Most of the local sands produced equal or higher friction on ice than did the Transport Canada sand (supplied by the Ottawa and Churchill airports) for the same application rates. Generally, the finer natural sands produced higher friction than did the coarser manufactured sands. This result is believed to be because the finer sands produced higher area coverage. The area coverage produced by the sand tested varied by a factor of about 10. However, other factors, such as (probably) the percentage of rough, angular particles, also influence sand friction on ice and frozen snow.

Further testing and analyses are required to fully identify all of the controlling factors.

Results: Freezing Rain and Residual Effect Tests

The ice formation process varied with the application rate of the chemicals. Well-bonded ice quickly formed on the test surface at low rates; at high rates, slush was formed. At intermediate rates, ice that could be removed by plowing was formed.

In freezing rain, the friction factor after 20 minutes increased with the application rate, and it tended to level off at the highest rate tested. The higher rates were more effective, however, in maintaining friction longer, and the friction factors measured at 40 minutes were considerably higher at the higher rates.

All of the chemicals showed some residual effect at the higher application rates, as the chemicals were able to maintain higher friction somewhat longer. There was no residual effect at the lower application rates.

All chemicals maintained higher friction and ice-free conditions longer than did bare concrete. Significantly more urea (by a factor of about 5) was required to produce the same friction in the freezing rain tests, and to achieve the same residual effect as sodium formate and sodium acetate. Potassium acetate and E36 T produced similar friction in freezing rain and similar residual effects at the same application rates.

Recommendations and Issues Requiring Further Investigation

The data collected in this project should be analyzed in more detail.

Correlation with ground vehicle and aircraft tire friction coefficients – more testing is recommended with another aircraft tire (of different tire pressure). Also, test data should be collected to compare the friction factors given by the Electronic Recording Decelerometer with an aircraft tire.

Sand Friction – Parametric tests are recommended to identify the factors controlling sand friction. Further numerical analyses should then be carried out.

Freezing Rain and Residual Effect Tests – Further testing is recommended to evaluate other conditions and to develop a more standard procedure.

C.4.2 Proceedings of the international meeting on aircraft performance on contaminated runways, IMAPCR '96 (TP 12943)

Preface

IMAPCR '96 took place in Montreal, Quebec, on October 22 and 23. The meeting was attended by 138 delegates from eight countries. They represented aircraft operators, pilots, ground friction measuring equipment manufacturers, regulators and related industries. The meeting's overall objective was to establish and develop a global standard to measure and report runway contaminants. The meeting was structured to include four information sessions and three workshops.

This record of the proceedings is not a chronological account. A review of the agenda and the meeting's objectives is followed by summaries of the information sessions and workshops, workshop recommendations and concluding remarks. Handouts for the information sessions are included, as well as the list of last year's delegates, in the annexes at the end of this report.

C.4.3 Characteristics of winter contaminants on runway surfaces in North Bay – January and February-March 1997 tests (TP 13060E)

Summary

To develop an understanding of and to quantify the factors that influence the aircraft landing or take-off distances on wet and winter contaminated runways, a five-year (1995 to 1999) collaborative agreement was made between the National Aeronautics and Space Administration (NASA) and Transport Canada (TC) to conduct field tests using different types of instrumented aircraft and ground friction measuring vehicles. The US Federal Aviation Administration (FAA) and the National Research Council Canada (NRC) also joined this project, called the joint winter runway friction measuring program.

The first series of tests were conducted at North Bay Airport, Ontario, during the winter of 1995/96. The primary goal was to determine and compare winter friction and drag conditions of runways, taxiways and other operating surfaces with aircraft and ground vehicles. After these tests, it was realized that the characteristics of the winter contaminants on the runway and taxiway surfaces should have been measured quantitatively. NRC was given the responsibility of collecting necessary data on surface contaminants in the field tests conducted in North Bay during the winter of 1996/97.

This report concerns observations made to characterize the winter surface contaminants at North Bay Airport during the two test phases: January 19 to 31, 1997 (Phase 1) and February 23 to March 7, 1997 (Phase 2). Nine ground test vehicles and two aircraft (NRC's Falcon 20 and the FAA's Boeing 727) were used in Phase 1. Ten ground vehicles and one aircraft (de Havilland Dash 8-200) were involved in Phase 2. Surface conditions included bare and dry, bare and wet, smooth ice, natural snow, groomed loose snow, age-hardened groomed snow, mechanically compacted hard snow, and man-made slush – at temperatures ranging from +2°C to -30°C.

Harvesting previously ploughed-away snow and grooming the material to create man-made snow covers, immediately before tests, produces covers that behave in a significantly different manner from natural snow covers. The short time does not allow the groomed materials to develop interparticle (between the snow particles or grains) bonds and bonds between the particles and the pavement surfaces. The density of groomed snow was found to be significantly higher than that of natural snow covers. Moreover, the density of groomed snow increased with further grooming operations. Grooming processes cannot be used to simulate in-service naturally accumulated snow covers. Effort should be made to conduct tests on natural snow covers.

Phase 1 led to the conclusion that a quick and simple technique should be used to measure the in situ mechanical properties of snow. The classical techniques for measuring snow properties could not be applied to sheets 20 mm to 50 mm thick. A macro-indentor system was devised for trial during Phase 2. This was a scaled-down version of the bore-hole indentor test system designed, fabricated and used extensively by the author for determining in situ strengths of ice. This macro-indentor seemed to provide a measure of the in situ confined compressive strengths of the snow covers. A properly designed system should be developed for future applications.

C.4.4 Braking friction coefficient and contamination drag of a B727 on contaminated runways (TP 13258E)

Abstract

This report summarizes the results of Federal Aviation Administration (FAA) B727 aircraft performance tests on winter contaminated runways at the Jack Garland Airport in North Bay, Ontario, Canada. The purposes of the tests were to measure the drag due to the runway surface contaminant and to determine the aircraft braking coefficient. The tests were conducted under a multi-year collaborative agreement among Transport Canada, the National Aeronautics and Space Administration (NASA), the FAA and the National Research Council Canada (NRC).

The results of the unbraked tests for contaminant drag showed that the aircraft drag on snow-covered surfaces was essentially constant over a wide range of ground speeds. These results agree with test results on other aircraft, such as the NRC Falcon 20 and DH Dash 8, but differ significantly from conventionally accepted methods of determining contaminant drag.

The results of the limited braking tests showed a predictable relationship between aircraft braking coefficient and the James Brake Index (JBI), agreeing with previous test results of the NRC Falcon 20, a smaller aircraft with similar landing gear configuration.

It is recommended that further tests be conducted with the B727 on additional contaminated surfaces to confirm these results, and that tests be conducted on aircraft with multiple wheel bogies to determine whether differences exist.

C.4.5 Falcon 20 aircraft performance testing on contaminated runway surfaces during the winter of 1997/1998 (TP 13338E)

Abstract

The performance of the NRC Falcon 20 research aircraft was tested on winter contaminated runway surfaces at the North Bay airport during the months of January through March 1998. This was the third year of a five-year collaborative test program among Transport Canada, NASA, NRC and the FAA.

The test data for aircraft braking performance during full anti-skid braking runs agreed, in general, with data from previous winters' testing. Based on the additional data, a revised model of aircraft braking performance was used to refine the table of recommended landing distances versus the Canadian Runway Friction Index published in the Transport Canada Aeronautical Information Publication.

Test data for contamination drag were obtained on natural snow covered surfaces rather than snow which had been manipulated and regroomed as in previous years tests, and these data were generally consistent with previous test results.

Several recommendations are made regarding both technical content and procedures for next year's test program

C.4.6 Analysis of the friction factors measured by the ground vehicles at the 1998 North Bay trials (TP 13366E)

Summary

This project covers the analysis of the data collected by the ground vehicles during the 1998 North Bay Joint Winter Runway Friction Measurement Program. The work focused on:

- Reducing and presenting the data; and
- Conducting basic analyses.

Certain trends became evident and the following conclusions can be drawn:

Effect of vertical load – Tests with the instrumented tire test vehicle (ITTV) indicated clearly that the vertical load is a major parameter controlling friction. Tests done with the ITTV on bare and dry pavement, on rough ice, and on loose snow over a packed snow base indicated that the friction factor was reduced with increasing vertical load.

The test data collected with the other ground vehicles generally support the above conclusion for the tests done on ice, compacted snow, and bare and dry pavement. No clear trend was observed for the tests done on wet ice, slush, and loose or fresh snow. This variation is believed to be related to the amount of contaminant drag.

Note that trends cannot be established for the other ground vehicle data with the same clarity as for the ITTV because the variation in vertical load among the other ground vehicles is relatively small and because the results contain more scatter.

Correlation among the devices – Lower friction factors were more often measured with the ITTV and electronic recording decelerometer (ERD) than with the other devices, although there were a few exceptions. This trend is believed to be related to differences in vertical load, as the ITTV and ERD conduct friction factor measurements at higher vertical loads than do the other ground vehicles.

The correlation was greatly affected by whether or not the bare and dry test data were included because this effectively divided the data set into two data clusters that were widely separated in magnitude. As a result, the degree of fit (for a linear regression) was much better when the bare and dry data were included in the analyses. Correlations using only the snow and ice-covered surfaces were much less consistent and reliable.

Correlations based on all test speeds were similar to those obtained using only data collected at 65 km/h.

Tire study: effect of tire tread – In some cases, higher friction was recorded using a ribbed tire rather than a smooth one. However, clear, consistent trends are not evident over the full range of conditions tested, since in other cases, similar friction was measured using ribbed and smooth tires. More investigation and testing are required before definitive conclusions can be made.

Tire study: effect of inflation pressure – The effect of inflation pressure depended on the nature of the surface and whether or not the tire was treaded. Similar results were obtained at vehicle ground speeds of 40 and 65 km/h.

Tire study: effect of ground vehicle device – The KJ Law runway friction tester (RFT) consistently recorded higher friction than the other devices. The reasons for this variation should be investigated further.

The effect of temperature on friction – Clear, consistent trends were not observed over the full range of tests. In some cases, the friction factors reduced with increasing surface temperature, while for others the friction did not change significantly as the surface temperature was increased.

This variation indicates that other processes and factors (other than temperature changes) were affecting the friction. Significant factors could include "polishing" of the surfaces during the tests, differences in temperature variations, and varying surface textures. More testing and investigation are required before definitive conclusions can be made.

Decelerometer study – Higher friction factors were measured with the Bowmonk and Tapley meters than with the ERDs. The effect of the operator was variable. In one case, different friction factors were measured between two different operators while in the other case, two operators produced similar results.

Effect of speed – Friction is not strongly related to the ground vehicle speed. The slip speed was also found to not have a strong effect, although in some cases the friction was observed to decrease with increasing slip speed. However, the results have considerable scatter, and in some cases, the friction did not appear to be related to the slip speed.

Recommendations

The test results indicate that the friction factor is most strongly related to vertical load and contact pressure. An understanding of this relationship is required for the development of more general correlations among the devices.

Consequently, it is recommended that this be investigated further. The processes causing this relationship should be investigated in relation to the heat build-up that occurs and the strength, temperature, and type of surface.

C.4.7 Laboratory testing of tire friction under winter conditions (TP 13392E)

Summary

This project was undertaken to obtain more data to define the friction coefficient of typical surfaces found on airport runways during winter.

Braking Friction Tests

Tests were undertaken to:

Compare the friction measured for various tire types on a wide range of winter surfaces; and

Investigate the effects of load and pressure on friction.

The effects of tire type and pressure depended on the surface (i.e., asphalt vs. ice) and the type of material (i.e., liquid vs. solid) applied on the ice and asphalt, as shown in the following table.

Trend Summary

Type of Material on Substrate	Substrate: Asphalt	Substrate: Ice
None (bare and dry)	Friction increases with tire pressure	Friction independent of tire type and pressure
Solid	Not tested	Similar trends for all tires tested
Liquid	Friction increases with tire pressure	Friction independent of tire type and pressure

The load and pressure tests were conducted on bare ice and frozen snow at -10°C, using the Type VII 26.6 x 6.6 aircraft tire. The friction decreased with the vertical load for both substrates. The friction was not related to the tire inflation pressure, as similar results were obtained for the three pressures tested. These results are similar to those from the load and pressure study conducted at the 1998 North Bay field trials.

Sand Friction Tests

Tests were conducted on ice and frozen snow at -5°C and -15°C. The friction increased with the application rate for all sands. Typically, sand applications at rates up to 400 g/m² increased the friction factor from about 0.1 (for bare ice or frozen snow) to a maximum value of 0.25 to 0.3.

Sands available locally at airports were compared to one that meets the Transport Canada specification (termed Ottawa TC sand). The differences in friction factor among the sands were small. But the relative amounts required for one sand to provide the same friction as another varied greatly, because large increases in application rate produce only small friction increases. Most of the local sands provided better performance than the Ottawa TC sand since less material was required to provide the same friction.

The parameters controlling sand friction were investigated by conducting tests in which the area coverage, the grain size, and the angularity were varied independently. The friction was most strongly related to the surface area covered by the sand. Thus, the results generally

show that the friction is expected to decrease slightly as the sand becomes coarser. The friction also increased with the sand's grain size and angularity. Sand applications at -5°C produced greater friction increases than at -15°C. Equations were developed that provide a reasonable data fit.

The equations were used to compare the friction expected across the size distributions specified by Transport Canada (TC) and the Federal Aviation Administration (FAA). The friction is expected to reduce slightly across the range from the fine edge of the FAA specification to the coarse edge of the TC specification at both -5°C and -15°C. This reflects the effect of area coverage, which decreases steadily over this range.

Freezing Rain Tests

Potassium acetate, UCAR, sodium acetate, urea, and sodium formate were tested in the laboratory. The test method appears to produce credible results and is highly repeatable.

The friction was affected greatly by the ice formation process. The ice formation processes were similar for all chemicals and varied with the application rate. At high and intermediate application rates, the surface initially remained wet, causing relatively high friction measurements. Eventually, slush was produced by the freezing rain, later hardening into ice on the test track. A steady drop in friction was recorded over the slush and ice formation process. For low application rates, the freezing rain quickly formed ice on the test track, resulting in low friction. Once ice had formed, the friction coefficient remained essentially constant with further exposure to freezing rain.

The protection time provided by the solid chemicals increased linearly with the application rate. The quantities required for sodium acetate and sodium formate to provide the same protection time as urea were about 70 percent and 40 percent of those for urea, respectively. The protection times provided by the liquid chemicals also increased with the application rate, although in contrast to the solid de-icers, the trend was non-linear. This variation may be due to the improved ability of the liquid de-icing chemicals to coat the surface in a uniform manner. The quantity of UCAR required to provide 30 minutes protection time was about 60 percent of that for potassium acetate.

Recommendations

Braking friction – The tests indicated that the vertical load and the contact pressure have a large effect on the friction factor on ice and frozen snow. Because this is an important issue for developing general correlations between aircraft and ground vehicle friction factors, parametric load and pressure tests should be conducted over a wider range of vertical loads, surfaces, temperatures, and tire types.

Sand friction – No further testing or analyses are recommended.

Performance of de-icing chemicals in freezing rain – The test method and results should be compared with field data. Also, simpler indexes (e.g., using the results from ice melting tests, or the freezing points of various solutions of the chemicals) should be investigated by comparing these trends with those obtained during the test program.

Finally, it is recommended that the effect of the impervious test surface used in this project be investigated in comparison to the porous surfaces found on runways.

C.4.8 Measuring tires for harmonized friction measurements of runway surfaces and prediction of aircraft wheel braking (TP 14005E)

Summary

This project compares the various tires used to measure runway friction, for both summer and winter conditions. This is a necessary step in achieving harmonization of different friction measurement devices. Measurements with the various tires will be compared to measurements with the NASA ITTV system using an aircraft tire. Subsequently, comparisons will be made with the NASA ITTV and actual aircraft braking. The project uses the test data and results from the ongoing Joint Winter Runway Friction Measurement Program. Ribbed treaded tires versus smooth treaded tires are discussed based on the literature and actual test results. The effects of natural rubber versus the ASTM compounds for temperature and slip speed were studied, and a review of a study by the FAA found that the repeatability of the natural rubber tire (DICO tire) was unsatisfactory for friction measurement on fixed and variable slip devices.

The general trends found from the field tests are as follows:

Bare and dry: the AERO tire produces a lower reading than other tires.

Wet: all devices produce similar values, lower friction than on dry pavement, and a speed effect that depends on the surface texture. The exception to this is that the ASFT gave a value higher than its dry value and gave about the same value as the dry measurements by force devices.

Rough ice produces higher values than smooth ice.

Coefficient of friction decreases with increased vertical load (tire contact pressure).

On bare and dry or bare and wet pavements the AERO tire (natural rubber) produces lower friction values than the ASTM tire; however, the ribs on the AERO tire make it insensitive to the macrotexture. Thus, the ASTM smooth treaded tire is far superior in evaluating the surface condition for surface maintenance.

Under snow and ice conditions the performance of the tires is very nearly the same so that either tire could be used. However, due to the fact that a tire at 207 kPa (30 psi) is very close to V_{crit} (the critical hydroplaning speed) in slush, the 690 kPa (100 psi) pressure appears to be preferable. The effects of braking rate and contact pressure have by far the most significant effect on friction values. Because of the effects of tire contact pressure, friction force values increase by decreasing the contact area or increasing the load on the tire. The 1998 test data indicates that the ASTM 1551 ribbed 100 psi tire, the AERO 100 psi tire, and the ASTM 1551 ribbed 30 psi tire all give higher frictional values than the ASTM smooth 100 psi or 30 psi tires when mounted on the KJ Law Runway Friction Tester on snow surfaces. These tests further support the effect of contact pressure on snow surfaces and the need for further study of the effect for each type tire used to measure winter friction.

Based on the results of this study the following actions are recommended:

- (1) The ASTM smooth treaded test tire should be used with 207 kPa (30 psi) pressure for summer or surface maintenance testing.
- (57) A high contact pressure tire should be used for winter measurements, especially for torque measuring devices on loose snow. On packed snow and ice surfaces any tire will give satisfactory correlation. However, if a single tire is to be used, a high contact pressure tire is recommended.
- (58) Tests should be conducted to determine the braking rate on aircraft tires using anti skid systems. Since variable slip testers have an advantage in that they can adjust their braking rate, tests should be made with different rates to determine an equivalent rate for fixed slip tests. Tire testing should be performed in the laboratory, where possible, to reduce the amount of field-testing required. Limited field tests were performed in 1998 with the IMAG and RUNAR, and the limited results further support the need for these tests in the coming year.
- (59) Since braking or wrap-up rate and loading or contact pressure will vary with tire type (stiffness and pressure), it is recommended that a new tester similar to the variable slip ITTV be constructed that can test all of the ground vehicle tire types as well as some aircraft tires.
- (60) Load tests should be performed on each of the tires used to measure winter friction to determine each tire's contact pressure effect on the friction forces on ice and snow.

C.4.9 Overview of the joint winter runway friction measurement program (TP 13361E)

Summary

For centuries researchers have tried to understand and quantify the effects of friction. With the advent of aviation, many new questions arose. In winter conditions particularly, an understanding of friction factors is needed for safe operations, and the aviation community has studied the problem from the outset. Wet and icy runways have been shown to be the foremost cause of landing accidents.

A fatal aircraft crash in Dryden, Ontario, in 1989, brought the subject into sharp focus. Among its many recommendations, the Dryden Commission of Inquiry that investigated the disaster stressed the need "to expedite the search for a technically accurate means of defining runway surface conditions and their effects on aircraft performance".

While most countries have guidelines, no universal measures or practices have been established. Canada used the James Brake Index (JBI) until 1998, when it was revised and renamed the Canadian Runway Friction Index (CRFI). One of the basic technical problems lies in relating aircraft braking performance to the friction measurements taken by ground vehicles.

In response to these concerns, Transport Canada (TC) and the US National Aeronautics and Space Administration (NASA) signed a Memorandum of Understanding in December 1995. The memorandum agreed on a five-year initiative to study winter runway friction measurements. With the added support of other North American and European organizations (the Norwegian Civil Aviation Administration, for example, also signed a joint agreement) a concerted international effort – the Joint Winter Runway Friction Measurement Program (JWRFMP) – began in January 1996.

Supporting Organizations

The National Research Council Canada (NRC) and the US Federal Aviation Administration (FAA) immediately backed the TC/NASA program. The Norwegian Civil Aviation Administration and France's Service technique des bases aériennes and Direction générale d'aviation civile also offered support. Over time other agencies, such as the International Civil Aviation Organization, the Joint Aviation Authority (the European counterpart of the FAA), and the Canadian Department of National Defence, as well as Canadian, US, UK, French, and Norwegian aviation operators and manufacturers, have become involved. Participants provide varied assistance: financial backing, data acquired in their own programs, technical expertise, equipment, materials, personnel, and facilities.

The American Society for Testing and Materials (ASTM) offered to work with industry and the aviation community to develop standards for a common reporting index for ground friction measuring devices, based on the program findings and input from program participants. An ASTM task group with international representation was established to develop concepts for this index, which became known as the International Runway Friction Index (IRFI).

The Transportation Development Centre, TC's research organization, coordinates the overall management of the program, with the guidance of the JWRFMP steering committee.

The Program

To achieve the program objectives, the TC/NASA team planned a five-phase approach: acquisition of data through ground vehicle tests; acquisition of data through tests with instrumented aircraft; data analysis, correlation, and interpretation; application of the knowledge gained to the development of an IRFI; and validation of the IRFI development. Meetings to disseminate information and to discuss the development of the IRFI are also part of the program plan.

Series of tests have been conducted each year (1996, 1997, 1998, 1999) since the program began. The 1999 series is not yet complete. Aircraft tests cover three critical manoeuvres – takeoff, landing, and rejected takeoff (accelerate-stop) – on a variety of surfaces. Measured parameters include the braking coefficient, the increment in drag, and aircraft speed. Ground vehicle friction measurements are taken before and after aircraft runs, to compare the readings from aircraft and ground vehicles. Aircraft-based measurements are used to establish a theoretical model relating the coefficient of friction to operating distances and to develop precise computational tables. Over 13 ground vehicles and five specially instrumented aircraft types – a Falcon 20, a Dash 8, a B 757, a B 737, and a B 727 – have taken part in the program.

The major test site is the Jack Garland Airport in North Bay, Ontario, where the first tests were held in January 1996. NASA's Wallops Flight Facility in Virginia, the Gwinn-Sawyer Air Base in Michigan, and the Ottar K. Kollerud test track at Oslo Airport in Norway are also used for tests.

The data acquired in each series of tests is analysed, interpreted, and used for correlation and validation purposes.

IRFI Development

The ASTM task group first developed and agreed upon a concept for calculating an IRFI and determined the requirements for such an index. As work progressed, the testing program was adapted to address problems and to validate requirements.

After a substantial amount of data had been collected and analysed, a prototype computing tool was developed, based on the principle of correlating maximum friction values of a measurement device with those of a reference device. In January 1998 work towards a reference device began. A virtual vehicle, representing a combination of several devices now in use, was proposed.

An IRFI proposal was then submitted to the ASTM for preliminary review. The reviewers voiced a number of concerns. The 1999 test program is designed to address the questions raised. The results will be incorporated into a revised proposal, and the procedures leading to acceptance will continue.

Achievements

JWRFMP achievements to date include:

Development of the first extensive set of runway friction data for temperatures at and below 0°C

Revision of the James Brake Index. The Canadian Runway Friction Index, the revised version developed under the program, provides pilots with more accurate guidelines for calculating landing distances on contaminated runways

Increased understanding of the many factors affecting friction coefficients, e.g., slush drag and impingement drag

International cooperation on the development of an approved IRFI, based on the most accurate and comprehensive data possible

Future Goals

The overall immediate goals are to develop and validate the IRFI and to achieve its official acceptance by the international aviation community. All other goals are aimed at adding to the accuracy and scope of the index and thus hastening the approval process.

Following official acceptance of the IRFI, it will be important to ensure that it is accepted and implemented by regulatory bodies, airport authorities, airline operators, and pilots.

C.4.10 Falcon 20 Aircraft Performance Testing on Contaminated Runway Surfaces During the winter of 1998-1999 (TP 13557E)

Abstract

The performance of the NRC Falcon 20 research aircraft was tested on winter contaminated runway surfaces at the North Bay airport from January to March 1999. This was the fourth year of a five-year collaborative test program among Transport Canada, NASA, NRC, and the FAA.

The aircraft braking performance during full anti-skid braking runs on snow-covered runway surfaces agreed, in general, with data from previous testing. Additional data was gathered on runway surfaces with very low friction indices, such as those covered with smooth ice and having a Canadian Runway Friction Index (CRFI) as low as 0.12. The aircraft landing data obtained over the entire four-year test period, including that from additional braking runs, was used to update the aircraft performance model for landings on contaminated runways.

Recommendations were made to update the CRFI table of recommended landing distances currently published in the Transport Canada Aeronautical Information Publication (AIP). Based on an analysis of reverse thrust data for other aircraft types, a recommendation was made to include an additional CRFI table, incorporating the effects of reverse thrust, in the AIP. No data was obtained for contamination drag, because very little natural snow fell in North Bay during the 1998-1999 winter.

C.4.11 Proceedings of the 2nd International Meeting on Aircraft Performance on Contaminated Runways, IMAPCR '99 (TP 13579)

Preface

IMAPCR '99 took place in Montreal, Quebec, on 2-4 November 1999. One hundred and forty delegates from nine countries attended the meeting. They included representatives from government, industry, national and international organizations, researchers interested in aircraft operations in severe winter conditions, aircraft certification and operating authorities, aircraft and equipment manufacturers, airport authorities, airlines, pilots' professional associations, and the military.

The meeting's overall objective was to review current and future initiatives for improving our understanding and application of measured runway friction values and related aircraft performance.

This record of proceedings reviews the agenda and the meeting's objectives and summarizes the presentations, the panel discussion, and the resulting action plan. Presentations and papers are also included.

C.4.12 Friction factor measurements on non-uniform surfaces: sampling frequencies required (TP 13784E)

Summary

Background and Objectives

The Ministry of Transportation of Ontario (MTO) is currently considering continuous friction measurements as one potential means for evaluating and monitoring the quality of winter maintenance operations. It is well known that surface conditions on roads in wintertime can vary over a wide range on a variety of distance scales reflecting the effect of factors such as: (a) local variations in road conditions and vegetation; and (b) variations in structure (e.g., bridges vs. pavement; intersections and corners vs. straight sections).

It is intuitively obvious that less frequent sampling is required to measure the average friction reliably on long, relatively uniform road sections than on short ones or on ones with more variability. Numerical analyses have been conducted for a wide range of potential road surfaces to investigate sampling requirements by comparing the friction factor that a device would be expected to measure with the actual friction factor.

Conclusions

Measuring the Average Friction Factor Along the Length of a Runway or Road – The sampling interval should be selected based on the following:

- (a) The ranges of cases analyzed should be reviewed and compared to field information, if available.
- (b) Maximum permissible errors should be specified so that the analyses could be focussed on that range.

The analyses suggested that sampling intervals should be no more than about 20 to 30 percent of the segment length to keep sampling errors less than 1 to 5 percent.

Friction Factor Variability – Randomness in the road surfaces will introduce variations in the measured friction factor. The magnitude of the variations is governed by the following:

- (a) The ranges of cases analyzed should be reviewed and compared to field information, if available.
- (b) Maximum permissible errors should be specified so that the analyses could be focussed on that range.

For sampling intervals that are in the range of about 20 to 30 percent of the segment length, the analyses suggested that randomness will introduce variations of about +/-1 and +/-2 percent at one and two standard deviations from the mean, respectively.

Recommendations:

Continued work would be useful in the following areas:

- (a) The ranges of cases analyzed should be reviewed and compared to field information, if available.
- (b) Maximum permissible errors should be specified so that the analyses could be focussed on that range.

C.4.13 Joint Winter Runway Friction Measurement Program (JWRFMP): 1997-98 testing and data analysis (TP 13836E)

Summary

Measuring the capability of a runway surface to provide aircraft tire braking action is fundamental to airport aviation safety, especially under winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying natures and qualities that contribute to reduced braking friction capabilities. Because the operational window for aircraft movement can change quite rapidly and frequently in the winter, a service is warranted for the measurement of surface friction.

In the past, users of friction information have generally perceived the quality of the friction measurement service as poor. Often, these users have indicated that the reported friction values do not represent the actual braking friction that is experienced with aircraft tire braking.

International research of friction measurement confirmed that friction measurement devices measure and report different friction values for the same surface. Differences occurred among units of the same generic device as well as across different device types. The perception of non-uniformity was compounded by surfaces exhibiting large variances in reported values. These variances further augmented the differences among device types.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the highest accuracy, but the procedure is limited to machine component calibrations. Research over the past four years has made significant advances toward solving these problems. Methods of measurement are being improved to increase measurement quality, remove uncertainties, and provide better correlation to aircraft tire braking. Prototype methods that incorporate ground friction measurement devices have shown very promising results.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program, led by the National Aeronautics and Space Administration and Transport Canada. Support is received from National Research Council Canada, the US Federal Aviation Administration, the Norwegian Civil Aviation Authority, and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States are also participating.

Objectives of the project include:

- Compiling a database containing all test data available from ground vehicles and aircraft that participated in the winter and summer runway friction programs.

- Using the data to determine a harmonized runway friction index: the International Runway Friction Index (IRFI).

IRFI Models

A statistical model and a physical model are the two approaches currently being developed. Both are valid for defined surface classification.

Statistical Model

Normally, regression techniques would be used to find relationships between the reported friction values of pairs of ground friction measurement devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. The device, or an algebraic transformation of reported friction values, such as the average friction of two or more devices, would be selected as a reference. All devices would then be compared to the reference device to establish transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step or an interim method, which can be applied by the aviation community in the near future. The following equation represents a linear regression of the data for each device to an IRFI reference:

$$\mu_{\text{IRFI}} = a + b \times \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts failed because the data were not acquired at the same time in the same tire track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of measurement devices run in a wave pattern so that they measure the same surface within 15 seconds of each other. However, even with this systematic approach there are considerable variations in the measured surface condition because of the lateral placement of the devices and the resulting effect of surface compaction. The database now includes more than 30,000 friction measurements.

Physical Model

Unlike the statistical model, this model first develops a physical relationship between the surface and the tire. A regression is then applied to the database to determine the constants that relate to the properties selected. Properties having little or no effect are disregarded and the properties with significant effects are retained in the model.

Bare ice and bare compacted snow were selected as generic surfaces for the investigation of the physical IRFI model. A bare condition means that there is no loose snow or fluid layer on the travelled surface. The proven exponential models, with speed and/or slip speed, have been successfully applied to pavement friction monitoring in the past and will facilitate a general unified technique across all surfaces.

The pavement friction models incorporate measurements of texture in their exponential constant term. More data, representing a greater speed and temperature range, are needed to fully develop the physical IRFI model. For details of the physical model, refer to Friction Fundamentals, Concepts and Methodology.[1]

(Virtual) IRFI Reference – 1998

Based on a review of virtual references in 1998, it was concluded that the best option was to use the average of the Transport Canada 1979 Surface Friction Tester (SFT79) and the

Instrument de Mesure Automatique de Glissance (IMAG). There are several reasons for this choice:

They were tested at both Gardermoen and North Bay.

In the analysis they produced equivalent or better correlations, R2 and CV.

Their average was about the same as the average friction of the measurement devices.

They can measure both force and torque, which is necessary for future work.

They will likely be at the three sites in the coming years.

Statistical IRFI

All of the 1998 data were combined and the statistical analysis was run to calculate the regression coefficients. The table below is a summary of these values. The values a and b were applied to the device to calculate the IRFI and thus harmonize the friction measurement. The average correlation (R^2) was 0.94.

Correlation Constants with all 1998 Data

Device	Sensitivity	Standard Error of Estimate
ASFT	0.012028	0.0193
BV-11	0.013426	0.0209
ERD	0.039085	0.0449
ERD in a Nissan	0.018095	0.0184
GT-STD	0.005061	0.0051
GT-SC	0.007147	0.0095
IMAG	0.018074	0.014
OSCAR	0.026533	0.026
RUNAR	0.038688	0.0287
SFT79	0.006615	0.0084

Sensitivity and the Standard Error of Estimate of the Statistical IRFI

Sensitivity is defined as the change in the predicted value, IRFI, for a given change in the measuring device, μ_{device} . The table below is for bare ice and compacted snow, and it gives the sensitivity to a 10 percent change in measurement and the standard error of estimate for each device. The average sensitivity is 0.018 and the average standard error of estimate is 0.02.

Statistical IRFI Sensitivity

Device	Sensitivity	Standard Error of Estimate
ASFT	0.012028	0.0193
BV-11	0.013426	0.0209
ERD	0.039085	0.0449
ERD in a Nissan	0.018095	0.0184
GT-STD	0.005061	0.0051
GT-SC	0.007147	0.0095
IMAG	0.018074	0.014
OSCAR	0.026533	0.026
RUNAR	0.038688	0.0287
SFT79	0.006615	0.0084

Conclusions and Recommendations

Currently, the recommended procedure for harmonizing ground vehicle data is the Statistical IRFI, which includes the International Friction Index (IFI) for bare dry and bare wet surfaces. This works adequately for the equipment that was used in the Joint Winter Runway Friction Measurement Program for the past three years on ice, compacted snow, and compacted snow with a few millimetres of loose snow. It achieves the objective of providing a uniform number representing the friction sensed by the ground vehicles and has the advantage of only needing to classify whether the surface is bare and dry, bare and wet, or covered with ice and/or snow. In practice, the friction level should be able to separate these three surface types, especially when combined with tire and surface temperature measurements. The model gives good correlations with reasonable standard errors for bare ice and bare compacted snow surfaces. Its advantage is that the exact class of snow or ice does not have to be specified, only whether the surface is contaminated. The correlations from the NASA Wallops data will be applied to the bare and wet surfaces. For wet pavement, the IFI, as specified in ASTM Standard E1960, has been adopted; only the texture information, or the friction speed gradient, is needed in the correlation equation.

Additional data are required to validate the physical model for the IRFI. The physical IRFI model is felt to have a greater potential for relating ground vehicle data to aircraft braking performance. During the remaining test seasons, emphasis will be placed on obtaining data over a broader range of temperature and slip speeds, which should improve the significance of both models. In addition, the effect of contact pressure should be added to the physical model. Unlike the statistical method, this model requires that the snow or ice surface be identified to know which constants to use. However, the model should be able to correct for a wider set of conditions. The two models may be merged into a universal model in the future.

C.4.14 Winter contaminants on surfaces during friction tests at Munich Airport – February 2000 (TP 13658E)

Summary

A five-year project was initiated in December 1995 to understand and to quantify the factors that influence aircraft braking friction and the contamination drag of various aircraft on winter contaminated runways, in order to estimate landing and take-off distances on wet and winter contaminated runways. A collaborative agreement was made between the National Aeronautics and Space Administration (NASA) and Transport Canada (TC) to conduct field tests using variously instrumented aircraft and ground friction measuring vehicles. The US Federal Aviation Administration (FAA), the National Research Council Canada (NRCC) and organizations from other countries, including the Norwegian Civil Aviation Administration, eventually joined this program, which is now called The Joint Winter Runway Friction Measurement Program (JWRFMP).

The JWRFMP was extended to include trials at Munich Airport in Germany during the week of February 21-27, 2000. Thirteen ground friction measuring devices from different countries were assembled and used at the Munich Airport. During the week, five commercial passenger aircraft also participated in the tests. They included one Airbus A320-DALAE from Aero Lloyd airline, one Airbus A321 from Sabena airline, one Boeing B737-300 from Deutsche British Airways, one Dornier D328-100 from Dornier aircraft manufacturer and one Airbus A319 from Swissair airline.

This report concerns information on environmental conditions during the tests and surface contaminants collected during the tests. Due to the environmental limitations, man-made winter contaminants from stored snow were used for testing. Harvesting previously removed snow and grooming that material to create man-made snow, which was spread on the runway immediately before the tests, resulted in covers that behaved in a significantly different manner than natural snow. The density of the groomed snow was significantly higher than that of natural snow covers. The particles of stored snow were orders of magnitude larger than the size of snow particles found in freshly fallen snow. Moreover, the particle size varied across the width of the test strips made for the tests. Consequently, most of the tests were carried out under conditions that may be far from real-life airport operational conditions.

The wide (20 m or more) and long (1000 m) uniform concrete asphalt surface of the test site at Munich Airport provided an ideal, textbook-type platform for conducting vehicular tests on a winter contaminated surface. Tests could be performed with a number of vehicles at the same time, running on different tracks parallel to each other. This avoided the condition of running the vehicles in sequential manner on previously travelled and disturbed surfaces. The highlight of the Munich program was a test series of 12 ground-friction measuring devices running parallel to each other at the same time on a 600-m long uniform, flawless pavement covered with a uniform layer of freshly fallen snow. No such tests had ever been performed in the past five years of JWRFMP runway friction tests. Munich Airport is a unique facility and should be used for future testing.

C.4.15 Runway surface and environmental conditions during friction tests at K.I. Sawyer Airbase, Michigan, USA – February 1999 (TP 13672E)

Summary

A five-year project was initiated in December 1995 to understand and to quantify the factors that influence aircraft braking friction and the contamination drag of various aircraft on winter contaminated runways, in order to estimate landing or take-off distances on wet and winter contaminated runways. A collaborative agreement was made between the National Aeronautics and Space Administration (NASA) and Transport Canada (TC) to conduct field tests using variously instrumented aircraft and ground friction measuring vehicles. The US Federal Aviation Administration (FAA), National Research Council Canada (NRC) and organizations from other countries (e.g., the Norwegian Civil Aviation Administration) eventually joined this program, which is now called the Joint Winter Runway Friction Measurement Program (JWRFMP).

Following field tests at North Bay Airport in North Bay, Ontario, Canada in January 1999, JWRFMP was extended to include trials at K.I. Sawyer Airbase in Gwinn, Michigan, USA, during the week of February 1-7, 1999. Five ground friction measuring devices from Canada, France, UK and USA were assembled and used at K.I. Sawyer Airbase. These included the Surface Friction Tester (SFT) and Electronic Recording Decelerometer (ERD) from Canada, the Instrument de Mesure Automatique de la Glissance (IMAG) from France, the Instrumented Tire Test Vehicle (ITTV) from the USA and the GripTester (GT) from the UK. During the week, one instrumented commercial passenger aircraft, a Boeing B757 belonging to NASA, also participated in the tests. This report concerns information on environmental conditions during the tests and surface contaminants collected during the tests. Natural contaminants included freshly fallen snow as well as old accumulated snow. The low volume of commercial air traffic and the long (3700 m) and wide (20 m or more) uniform asphalt concrete surface of the movement area (taxiway and runway) at K.I. Sawyer Airbase provided an ideal, textbook-type platform for conducting vehicular tests on a winter contaminated surface. Tests could be performed with a number of vehicles at the same time, running on different tracks parallel to each other. This avoided the condition of running the vehicles in sequential manner on previously travelled and disturbed surfaces. One series of tests involving three ground friction devices – IMAG, GT and SFT – and (incidentally) the aircraft, conducted on freshly fallen snow, proved the real possibility of conducting such parallel tests. No such tests had ever been performed in the past three years of runway friction tests. The tests showed that the degree of compaction (96%) produced by the IMAG test tires (at 40 km/h) was comparable to that (98%) developed by the tires of the slowly moving (app. 10 km/h) aircraft main gear. At the speed of 40 km/h, the SFT and the GT produced 74% and 44% compaction, respectively.

C.4.16 Comparison of the IRV and the IMAG on winter contaminated surfaces (TP 13791E)

Summary

The proposed American Society for Testing and Materials standard for the International Runway Friction Index (IRFI) specifies a reference tester that is similar to the Instrument de Mesure Automatique de Glissance (IMAG). The objective of this study was to compare the IMAG and the International Reference Vehicle (IRV), which was provided to the Joint Winter Runway Friction Measurement Program to serve as the standard reference, and to establish the relationship between the data obtained from the two devices. This relationship is intended to be used to convert measurements made by the IMAG prior to January 2000 to the IRFI, which would have been determined by the IRV had it been available.

To determine this relationship, the IRV and the IMAG participated in 807 paired tests in North Bay, Ontario, Canada, from January 17 to 27, 2000, and in 134 paired tests in Munich, Germany, from February 21 to 26, 2000. Tests were conducted for a wide variety of winter surface conditions, including ice, compacted snow, slush, and bare pavement. Test speeds ranged from 30 to 90 km/h. The surface conditions provided a range of friction measurements from 0.05 to 0.91.

Because of the similarity of the IMAG and the IRV, a simple linear regression of the data was considered to be adequate to develop a relationship to relate the results of one to the results of the other. Based on a very large data set it was found that a high degree of correlation existed between the IRV and the IMAG. It was found that the IRV produced values for friction that were five percent lower than the IMAG on winter contaminated surfaces. In practice it would therefore be sufficient to multiply the value produced by the IMAG by 0.95 to predict the value expected from a measurement by the IRV. This result is applicable to friction measurements based on both friction force and braking torque.

Given that this study was limited to data on winter contaminated surfaces, it is recommended that the IRV and the IMAG be compared on wet pavement conditions and an analysis of the relationship between the IRV and the IMAG for wet pavement friction be presented in a separate report.

C.4.17 First Air B727 aircraft landing performance on contaminated arctic runway surfaces during the winters of 1998-1999 and 1999-2000 (TP 13800E)

Abstract

The landing performance of a First Air B727 aircraft was recorded on contaminated runway surfaces at the Resolute Bay and Nanisivik airports during the winters of 1998-1999 and 1999-2000. Using data from the aircraft Flight Data Recorder and Global Positioning System, the actual aircraft landing distances during normal operations were determined in comparison with the CRFI (Canadian Runway Friction Index) table of recommended landing distances contained in the Transport Canada Aeronautical Information Publication. Out of a total of 26 B727 landings recorded, only one landing resulted in an actual landing distance in excess of the landing distance recommended by the CRFI table, indicating that the CRFI table was accurate in predicting the landing distance of the B727 to a confidence level of at least 95%. The safety factors included in the CRFI tables of recommended landing distance accounted for minor deviations in optimal short field landing techniques, such as a slightly extended flare, late application of reverse thrust or less than full anti-skid wheel braking. Good winter maintenance of the runway surfaces, which included a scarification process at Resolute Bay, was responsible for the relatively high runway friction index during both winter periods

C.4.18 Falcon 20 aircraft performance testing on contaminated runway surfaces during the winter of 1999/2000 (TP 13833E)

Abstract

The landing performance of the NRC Falcon 20 research aircraft was tested on winter contaminated runway surfaces at the North Bay airport during the month of January 2000. This was the final year of a five-year collaborative test program involving Transport Canada, NASA, NRC and the FAA. The aircraft braking performance during full anti-skid braking runs on snow covered runway surfaces agreed very well with data from previous testing. Additional data was gathered on runway surfaces with very low friction indices, such as those covered with smooth ice and having a Canadian Runway Friction Index (CRFI) as low as 0.09. The aircraft braking performance was also tested against a vehicle that measured the International Runway Friction Index (IRFI). The aircraft braking coefficient did correlate as well as with the IRFI as it did with the CRFI, the notable exception being on a smooth ice surface. The aircraft landing data obtained was used to verify landing data from the previous four years of testing. No further recommendations were made to update the CRFI table of recommended landing distances published in the Transport Canada Aeronautical Information Publication (AIP). No data points were obtained for contamination drag, due to very few instances of natural snow in North Bay during the available test period.

C.4.19 Friction fundamentals, concepts and methodology (TP 13837E)

Summary

Transport Canada commissioned MFT Mobility Friction Technology AS to author a report summarizing tire-surface friction knowledge as it applies to runway friction measurement. The report is in the form of a thesis and includes topics of tire-surface friction engineering with emphasis on comparison and harmonization of friction measurement devices. An overview of recent developments in tire-surface friction modelling and standard measures (Unit of friction measurement) of friction is presented, including the International Friction Index and the International Runway Friction Index. Suggestions for new friction measurement techniques are outlined.

Friction measurement devices are also called tribometers. The friction that arises from the partial sliding or skidding of a tire on a surface is called braking slip friction.

Theoretical analysis of the mechanics of interaction between a braked tribometer wheel and a contaminated surface shows that the measured braking slip friction values are adversely influenced by any presence of loose or fluid winter-contaminants. Fluid or loose particle displacement drag, tire-rolling resistance and planing (water-, slush-, and snowplaning) introduce errors in the reported friction value. The best measuring performance is achieved on bare, base surfaces (i.e., pavement, ice and compacted snow with no additional cover of loose particles or fluid). When a cover of loose particles or fluid is present on a base surface, the combined adverse effect on the reported friction value increases with increasing travel speed of the tribometer.

Tribometers of different types exhibit different dynamic friction characteristics. When using a normal load on the wheel axis to calculate the friction coefficient, the reported friction value of a horizontal force-measuring tribometer will include errors from tire-rolling resistance, any displacement drag and planing. The reported friction value of a torque-measuring device includes no errors from displacement drag or tire-rolling resistance. In situations of planing or compaction of snow, the normal force has a ground reaction force from the braking slip area and a reaction force from the area where the tire is detached from the useful braking surface and rests on the fluid or snow. Since the ground reaction force in the braking slip area is smaller than the force on the wheel axis in such cases, the reported friction value can be conservatively low for either a force-measuring or torque-measuring tribometer.

Tribometers processes measuring signals with much noise, a well-known characteristic of braking slip friction. Non-uniformity of the surface is believed to be a major source for the variability of reported friction values. On rigid pavement the tribometer tire will yield and be the sacrificed part of the tire-surface interaction. On less rigid compacted snow or ice, the surface material often yields and becomes the sacrificed part of the tire-surface interaction.

Because of the variability in reported friction values, descriptive statistics should accompany a friction measurement to describe the quality of the measurement. These statistics are the average friction value, the number of samples used for calculating the average and the standard deviation of the sample values. With these three statistics, the standard error, coefficient of variation and confidence can be calculated.

The descriptive statistics vary with number of samples, and tribometers report average friction values based on different sample sizes. To compare the qualities of measurements, the descriptive statistics must refer to the same sample size for the same measured length of surface. To accommodate this, a scheme of normalized friction measures is suggested as follows: an average friction value is processed for every 10-m measured distance; an average friction value is reported for each 100-m distance together with the associated descriptive statistics for a fixed sample size of 10.

In recent years comparative field tests of several types of tribometers have revealed that repeatability of single tribometers and reproducibility of several tribometers of the same type, as a rule of thumb, is in the 0.05 friction coefficient range expressed as a standard error statistic. A single reported friction measurement for a 100-m distance, therefore, has an uncertainty of ± 0.05 friction coefficient. This poses a problem relative to current qualitative gradations of runway friction, such as the estimated braking action tables for winter contaminated runways published in guidelines by several aviation organizations. Each grade, such as Good, Medium-to-Good, Medium, etc., is defined for a 0.05 friction coefficient range. With the uncertainty of tribometers demonstrated, they are not capable of reliably distinguishing grades less than 0.10 friction coefficient.

The poor repeatability and reproducibility also poses a quality problem for the harmonization of tribometers of different types. As an approximation, a harmonization translation of a reported friction value of one device type to another has an uncertainty of ± 0.05 friction coefficient in 19 of 20 cases.

The World Road Association (PIARC) proposed in 1995 an International Friction Index (IFI) for use in surveys of pavement friction. The IFI acknowledges the speed dependency of braking slip friction on wet pavements and includes measurements of macrotexture. The IFI is in essence a method of harmonizing friction and texture measurement devices. The reference of harmonization is a virtual average performance of the participating devices in an extensive field-test program conducted in 1992. The IFI is a universal, two-parametric index with a friction number related to a chosen measurement slip speed of harmonization and a speed number related to macrotexture measurements. Both the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO) have developed standards for the IFI.

The Joint Winter Runway Friction Measurement Program and the ASTM have developed an International Runway Friction Index (IRFI) to become a common harmonized measure of friction for tribometers. Unlike the IFI, the IRFI does not acknowledge speed dependency of friction or influence by macrotexture. The IRFI uses a physical reference device to determine harmonization constants. The initial ASTM standard for IRFI was issued in 2000.

The report suggests including friction models in harmonization methods for tribometers. Different sets of friction model parameters define different surface classifications. Harmonization constants shall be determined and applied for each surface classification in an attempt to reduce the uncertainty of harmonized friction values.

C.4.20 Wet runway friction: literature and information review (TP 14002E)

Summary

Introduction

Aircraft landings and take-offs regularly occur on damp and wet runways. The frictional forces developed between the aircraft tires and the runway have an important effect on the safety of these operations. Wet runway friction has been studied for many years with the result that a significant information base has been built up. However, it is fragmented. This work was aimed at reviewing the available information, and assessing the current state-of-knowledge and the most critical information gaps. In its simplest terms, the issue of wet runway friction, and its effect on aircraft operations, can be formulated by the following two basic questions, which were both considered in this project:

- (1) How much water is likely to build up on the runway?
- (61) What is the resulting friction level experienced by an aircraft operating on the runway?

In practice, of course, the problem is more complex as it is affected by many factors, as follows.

Water Buildup on the Runway

Of the two major questions posed above, the current state-of-knowledge is considered to be further advanced regarding the issue of water buildup on the runway. The current state-of-knowledge is summarized below.

Environmental mechanisms causing water buildup – Although moisture can be produced on the runway by a variety of mechanisms (e.g., rain, fog, dew, frost), only rain has been studied to any significant extent. Most likely, the other environmental conditions would only cause damp runway conditions as opposed to wet or flooded ones.

Amount of water built up during steady-state rainfall conditions – This has been studied extensively and several predictor equations have been developed. Although information gaps still exist, this subject area is relatively well understood.

Transient effects, such as winds, variations in rainfall rates during a rain storm, or time lags for water runoff – These are not well understood although the current state-of-knowledge is sufficient to allow preliminary assessments.

Pavement recovery from a wet or damp surface, to a dry condition – Some information is available from studies done on highways in the United States. No information was found relating to airport runways in Canada.

There are important information gaps for each of the above issues, with the result that:

The current state-of-knowledge is useful for general studies and evaluations;

It is inadequate to predict or evaluate water buildup on the runway in a real-time, operational mode; and

Regular monitoring of friction levels is required for real-time assessments in an operational mode.

Wet Runway Friction and Its Effect on Aircraft Operations

This topic encompasses two important issues as follows:

- (1) The friction level of a damp, wet, or flooded runway, and the factors controlling it, such as (i) measurement technique (e.g., slip ratio, speed, tire pressure and type); (ii) hydroplaning; (iii) water film depth; (iv) pavement texture, and the presence of contaminants; and (v) long-term and short term variations in friction level.
- (62) The relationships between the friction factors experienced by an aircraft; those recorded on aircraft tires tested under laboratory conditions (which did not include simulation of the aircraft's braking system); and those recorded by ground vehicles used to measure friction at airports.

A relatively large database of information is available which provides an understanding of the basic processes and trends. However, the state-of-knowledge is primarily empirical. The current state-of-knowledge is summarized below, in relation to the key issues.

Friction level variations with time – Friction levels vary on long-term time scales (of months to years) and also in the short term in response to pavement rejuvenation actions, the buildup of contaminants, and rains which wash the contaminants off. The short-term variations are larger than the long-term ones.

Factors controlling wet runway friction levels – The important factors include (i) speed; (ii) slip ratio; (iii) whether hydroplaning occurs; (iv) water film depth; (v) pavement texture; (vi) tire pressure; and (vi) the presence of contaminants.

Hydroplaning – Hydroplaning has been studied extensively, and the general conditions causing hydroplaning have been identified. However, only general quantitative criteria are available to define the onset of hydroplaning. Predictor equations have been developed by NASA which have been generally corroborated with field data for aircraft and large trucks. Recent observations have brought into question whether the NASA equations can be extended to friction-measuring ground vehicles.

Overall evaluation methods &18211; Only a small number of approaches are available for undertaking an overall evaluation, such as relating the friction level experienced by an aircraft to either ground vehicle measurements or to basic pavement data, such as texture. They all suffer from a number of serious drawbacks. No universal, widely accepted, proven method is available for doing evaluations of this type.

The most significant limitation in the current information base is considered to be the relationships among (a) the friction factors experienced by an aircraft; (b) the friction factors measured by ground vehicles; and (c) basic pavement parameters, such as texture, and water film depth. This gap makes it difficult to evaluate operations outside the range of current experience, and leaves detailed testing as the most reliable approach for evaluating them.

Recommendations

Efforts should be focussed on developing an overall understanding among (a) the friction factors experienced by an aircraft; (b) the friction factors measured by ground vehicles; and (c) basic pavement parameters such as water film depth and pavement texture.

Because the state-of-knowledge regarding wet runway friction is primarily empirical, it is our opinion that the most reasonable method for evaluating it for operational conditions is on a case-by-case basis, with site-specific, and case-specific, measurements and monitoring.

C.4.21 Runway friction accountability risk assessment: Results of a survey of Canadian airline pilots (TP 13941E)

Summary

Introduction

Transport Canada (TC), in association with the Federal Aviation Administration, the National Aeronautics and Space Administration and National Research Council Canada, implemented a five-year program for winter runway friction testing in 1995. The program expanded in 1996 to include other North American and European organizations, and has become a concerted international effort known as the Joint Winter Runway Friction Measurement Program. The program has led to the collection of a substantial database of aircraft and ground vehicle friction measurement data from various runways, and to the development of a greater understanding of the factors affecting runway friction, its measurement, and the relationship between runway friction and aircraft braking. For runways with shallow contaminant depth and therefore very little or no drag (wet or covered with compacted snow or ice contamination), the runway friction measurements were found to be consistent and the correlation between runway friction and aircraft braking high.

With this improved knowledge of runway friction, Transport Canada is looking at improving the use of runway friction information in practice to reduce the risks and possibly aircraft operating costs.

TC contracted Sypher:Muller International Inc. to conduct a study to better understand the use of the currently available guidance material related to runway condition and develop an economic rationale for the changes being considered. As part of the study, Sypher conducted a survey of commercial pilots in Canada to obtain their perspective on the issue. The purpose of the survey was:

- To understand how guidance material for operating on slippery runways is being used;

- To obtain feedback on the perceived risks of slippery runways, the need for additional measures to reduce the risks and the preferred form of those measures; and

- To obtain information for use in evaluating the reduction in risks as a result of specific measures.

Survey of Pilots

The survey of commercial pilots was supported by the Air Canada Pilots Association (ACPA), the Air Line Pilots Association (ALPA) and TC. The questionnaire was developed with input from TC, ACPA and ALPA.

The survey questionnaire was distributed to 1,000 randomly selected airline pilots from ACPA and to all (approximately 2,450) pilots in ALPA (Canada). A French version of the survey was also distributed to predominantly Francophone councils in ALPA. A total of 393 pilots completed the questionnaire, a response rate of 11.4%. The survey was distributed

in July and this was likely a factor in a lower response rate than was anticipated. The deadline for responses was extended to improve the response rate.

The survey covered a good cross section of pilots of commercial aircraft operating in Canada in terms of experience as a pilot and aircraft type flown. The survey provides a good picture of the use of runway friction information in Canada and of the types of improvements pilots would like to see. With the response rate being just over 11%, those that responded will likely be those with more interest in the topic.

Summary of Findings

The major findings on the availability and quality of runway friction information in Canada and its use by commercial pilots are summarized below.

Most commercial pilots (95%) in Canada are aware of guidance material for operating on slippery runways.

Most pilots (85%) have guidance material available to determine landing distances and crosswind limits when runways are slippery, although some of this material does not specifically use runway friction values such as the Canadian Runway Friction Index (CRFI) or the James Brake Index (JBI).

Many pilots lack guidance material for determining accelerate-stop distances and adjustments to V1/VR, and would like to have this material available to them.

Most pilots find the guidance material very useful and make use of it when runway and crosswind conditions warrant. However, many do not consult the charts each time and often rely on experience in similar conditions.

Pilots find that the current format of the guidance material makes it confusing and difficult to use. They would like the material to be presented in simple, easy-to-use lookup charts specific for each aircraft type in the company's fleet.

Most pilots monitor the runway friction values closely, but do not consider it the only source of information on runway slipperiness. Many consider pilot reports (PIREPS) to be as good a source of information, or better, and would like to see greater use made of PIREPS. However, the consistency in the levels of braking effectiveness reported in PIREPS could be improved and the aircraft type should be included in the report.

For landings on runways that are icy or covered with compacted snow, most pilots apply the 15% increase in landing distances, which is a requirement for many aircraft on wet runways, or a greater factor. However, 20% of pilots do not apply an adjustment. About 5% of pilots indicated the 15% adjustment is a requirement for their aircraft on wet runways, but that they don't apply it, or a greater factor, on icy/compacted snow runways where it is not a requirement.

Pilots adjust their procedures when landing on slippery runways to reduce the risks. Actions included: “firm” touchdown (don’t float), applying reverse thrust aggressively and quickly, using a higher autobrake setting and applying autobrake quickly, using high landing flap settings, and ensuring airspeed is not above VREF.

Pilots currently adjust their flight plans to account for slippery runways. Last winter about half the pilots either remained airborne until runway friction improved, or diverted to another airport because of low runway friction. Reductions in weight prior to take-off or while en route were far less common.

Pilots indicated that the quality of runway friction information provided by airports varies between airports. Generally the quality is better at large airports, but each airport differs depending on various factors.

Pilots indicated that improvements are needed to the runway friction information provided by the airports. Friction values need to be updated more frequently, particularly at small airports, and steps taken to ensure out-of-date values do not result in unnecessary risks. The timeliness with which information is distributed is a concern; improvements in the methods of distributing the information quickly and alerting pilots of low runway friction should be investigated, possibly through the use of the Automatic Terminal Information Service. Accuracy of CRFI is also a concern, although perceived inaccuracies could be the result of variability along and across the runway, changes in friction since the last measurement, or differences in braking under the same conditions between aircraft types.

Training for accounting for low runway friction needs improvement for many pilots. Over 20% of pilots of large jet aircraft have not received any formal training on the use of runway friction information, and only half have received training in the last 12 months. Of those that received training, 20% indicated that training on the use of runway friction values was covered “poorly”. Many indicated that the format of the material is too complicated to be covered in the short time allotted.

Despite the low number of accidents in recent years due to slippery runways, pilots report frequent occurrences of safety concerns such as significantly reduced braking (12 per 1000 landings), slipping sideways due to crosswinds (3 per 1000 landings) and being close to not stopping on the runway (0.4 per 1000 landings).

The majority of pilots feel that the current runway friction information could be better used.

Most pilots would like to see CRFI values used in determining landing distances/weights. Pilots are split on whether to include the procedures in aircraft operating manuals or as guidance material. Either way, the charts must be simple, easy-to-use and type-specific.

Although there is significant variation between pilots, the large majority feel the landing distances/weights determined using the CRFI values should be recommended values only, and that flexibility should be allowed for pilots to take into account other information. Generally, they feel that the CRFI values available to them at present are not accurate enough for their use in setting maximum allowed landing weights.

C.4.22 Evaluation of aircraft braking performance on winter contaminated runways and prediction of aircraft landing distance using the Canadian Runway Friction Index (TP 13943E)

Abstract

The braking performance of eight aircraft (six different aircraft types), all with similar anti-skid braking systems, was evaluated on winter contaminated runway surface conditions under the Joint Winter Runway Friction Measurement Program over a six-year period between 1996 and 2001. The aircraft included an NRC-operated Falcon 20, a NASA-operated B737 and B757, FAA- and First Air-operated B727's, deHavilland- and Nav Canada-operated Dash 8's, and a Fairchild Dornier-operated DU328 turboprop. A total of 275 full anti-skid braking runs were made on more than 70 contaminated surface conditions, most of which occurred naturally during winter conditions, and some of which were man-made. For all aircraft tested, the aircraft braking coefficients during full anti-skid braking remained essentially independent of aircraft groundspeed on contaminated surfaces.

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 International Runway Friction Index (IRFI). The correlation between aircraft braking coefficients and the Canadian Runway Friction Index (CRFI), provided by the ERD, was considered to be good enough to be used for the prediction of aircraft braking performance based on the measured CRFI. Tables of recommended landing distance, independent of specific aircraft type, were developed as a function of the CRFI and published in the Transport Canada Aeronautical Information Publication. It is recommended that the results of the tests on the ground friction measurement devices be analyzed expeditiously to provide an internationally acceptable IRFI, and that the CRFI tables then be converted into IRFI tables.

C.4.23 Dash 8 aircraft braking performance on winter contaminated runways (TP 13957E)

Abstract

The braking performance of a NavCanada-owned Dash 8 research aircraft was evaluated on winter contaminated runway surfaces at the North Bay airport during the months of January and March 2001. This was done as part of the Joint Winter Runway Friction Measurement Program (JWRFMP), a five-year collaborative test program involving Transport Canada, the US National Aeronautics & Space Administration, National Research Council Canada, and the US Federal Aviation Administration.

Aircraft braking performance was measured during full anti-skid braking runs on snow- and ice-covered runway surfaces. The aircraft-braking coefficient was compared to the Canadian Runway Friction Index and the International Runway Friction Index. Both indices were found to have a linear relationship with the aircraft-braking coefficient. The results agreed very well with those of other aircraft that had previously participated in JWRFMP testing.

C.4.24 Effect of vehicle parameters on the friction coefficients measured by decelerometers on winter surfaces (TP 13980E)

Summary

A field test program was undertaken to obtain data to investigate the factors affecting the friction coefficients recorded by decelerometers systems commonly used for friction measurement at airport runways. Data were obtained to evaluate the effect of vehicle type, vehicle parameters (Antilock Braking System (ABS) on or off, weight distribution), decelerometer type, and runway surface condition. A total of 76 tests were conducted over the January 15-18, 2002, period at North Bay Jack Garland Airport.

Results

Decelerometers: The Electronic Recording Decelerometer (ERD) Mk II and Mk III decelerometers recorded equivalent friction coefficients to all practical purposes. The Tapley decelerometer recorded friction coefficients that were consistently higher than the ERD Mk II or ERD Mk III decelerometers, by about 0.05 over the full range of surfaces tested. The Bowmonk decelerometer recorded friction coefficients that were about 0.025 higher on average over the full range of surfaces tested) than the ERD Mk II or ERD Mk III decelerometers. These variations are similar to those of previous comparative tests and may be due to the fact that the Tapley and the Bowmonk are “peak-measuring” devices whereas the ERDs are “averaging” devices. For the range of Canadian Runway Friction Indices (CRFIs) in the current Aeronautical Information Publication (AIP), the observed variations in friction coefficient with respect to decelerometer type represent a maximum variation in landing distance of about 600 ft. (182.9 m) and 250 ft. (76.2 m) for the Tapley and Bowmonk, respectively, in comparison to the two ERDs. (It should be noted that these values are for an unfactored landing distance of 3000 ft. and no reverse thrust.)

Vehicle Type Comparison: The friction values recorded were affected by the vehicle type. The effect of vehicle type varies with the friction level and the decelerometer type. The maximum variation in the recorded friction coefficient ranged from about 0.02 to 0.08, depending on the case being considered. For the range of CRFIs in the current AIP, the observed variations in friction coefficient with respect to vehicle type represent a maximum variation in landing distance of about 400 to 600 ft. (121.9 to 182.9 m) for an unfactored landing distance of 3000 ft. and no reverse thrust.

Vehicle ABS On or Off: The decelerometer readings changed depending on whether the vehicle was operated with ABS on or ABS disabled. The observed variation depended on surface condition. Generally, it was less when the surface friction was very low, being about 0.01 for low-friction surfaces and about 0.05 when the surface friction was in the 0.3 range. For the range of CRFIs in the current AIP, the observed variations in friction coefficient with respect to the vehicle’s ABS being on or off represent a maximum variation in landing distance of about 400 ft. (121.9 m) for an unfactored landing distance of 3000 ft. and no reverse thrust.

Vehicle Weight Distribution and/or Total Weight: The friction coefficient recorded with the half-ton pickup truck in a “50:50” weight balance (front:rear) was about 0.02 lower than for the “as is” weight distribution (which was about 60:40 front:rear). The observed variation in friction coefficient could be due to the difference in total weight for the “50:50” and the “as is” cases as the weight was increased for the “50:50” case. For the range of CRFIs in the current AIP, the observed variations in friction coefficient with respect to the vehicle’s weight distribution, or total weight, represent a maximum variation in landing distance of about 200 ft. (61 m) for an unfactored landing distance of 3000 ft. and no reverse thrust.

Recommendations

The following issues warrant further investigation:

- Effect of decelerometer type

- Decelerometer calibration techniques and procedures

- Effect of ABS systems being on or off

- Variation among the decelerometer systems (i.e., decelerometer, vehicle, and operator) in common use at airports now

- Effect of vehicle type and weight distribution/total weight

- Effect of loose contaminants

- Effect of combinations

C.4.25 Dornier DU328 aircraft braking performance on winter contaminated runways (TP 13983E)

Abstract

The landing performance of a Dornier DU328 turboprop aircraft was evaluated during the winters of 1999-2000 and 2000-2001, at Munich International Airport and at Erding Air Force Base in Germany. This was done as part of the Joint Winter Runway Friction Measurement Program, a collaborative test program involving Transport Canada, the US National Aeronautics & Space Administration, National Research Council Canada, and the US Federal Aviation Administration.

The aircraft performed 13 full anti-skid braking runs on four different test surfaces. In addition to the test aircraft, two ground vehicles measured the surface friction: the Electronic Recording Decelerometer (ERD) and the International Reference Vehicle (IRV). The aircraft braking coefficient was determined for each test run and compared against the two vehicles. Both test vehicles compared very well with the aircraft, obtaining a correlation of 94 percent for the ERD and 82 percent for the IRV. Aircraft brake pressures and wheel speeds were also examined to determine the effectiveness of the anti-skid system of the aircraft. The anti-skid system was found to work very well and was able to maintain an overall slip ratio of 7 percent.

C.4.26 International Runway Friction Index (IRFI): Development technique and methodology (TP 14061E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially during winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying nature and qualities that contribute to reduced wheel braking friction capabilities. A service is warranted for runway condition reporting because the operational window for aircraft movement can change quite rapidly and frequently in the wintertime. Such a service includes measurement of tire-surface friction.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the best accuracy, but the procedure has been limited to machine component calibrations. Research over the past four years has confirmed that different friction measuring devices report considerably different values, and this research has made significant advances to solve these problems. Methods of measurement are being improved to increase measurement quality, remove the uncertainties and provide better correlation to aircraft wheel braking.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program (JWRFMP), led by Transport Canada and the US National Aeronautics and Space Administration. Support was received from National Research Council Canada, the US Federal Aviation Administration, the Norwegian Civil Aviation Authority and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States also participated.

The JWRFMP objectives include:

Compiling a database containing all test data available from a few selected and representative ground vehicles and aircraft that participated in the winter and summer runway friction programs.

Using the data to determine a harmonized runway friction index: i.e., the International Runway Friction Index (IRFI).

The IRFI Method

This report describes the method developed and standardized by ASTM E 2100-00 Standard Practice for Calculating the International Runway Friction Index. Traditionally, regression techniques are used to find relationships between the reported friction values of pairs of devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. A device or an algebraic transformation of reported friction values, such as the average friction of two or more devices, may be selected as a reference. All devices would then be compared to the reference device to establish harmonization constants, also called transformation constants. A simple linear regression, as

shown in the equation below, is seen as a first step or an interim method, which can be applied by the aviation community in the near future. The equation below represents a linear regression of the data for each device to an IRFI reference.

$$\mu_{\text{IRFI}} = a + b \cdot \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts have failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of testers run in a wave pattern so that they measure the same surface within two minutes of each other.

In order to harmonize devices, they are calibrated with an IRFI reference to determine their a and b values and then these calibration values are used when making measurements to report μ_{IRFI} . An IRFI reference can be the International Reference Vehicle (IRV) or a master device that has been calibrated with the IRV. The JWRFMP uses an Instrument de Mesure Automatique de Glissance donated by Service Technique des Bases Aériennes (Paris) as its IRV.

Conclusions and Recommendations

The ASTM standard defines and prescribes how to calculate the IRFI for winter surfaces. The IRFI is a harmonized reporting index to provide information of tire-surface friction characteristics of the movement area to aircraft operators.

The IRFI is calibrated directly or indirectly to the IRFI reference device, thereby achieving harmonization of local friction devices of any airport to a common unit of measure, regardless of which local friction device was used.

The IRFI also can be used by airport maintenance staff to monitor the winter frictional characteristics for surface maintenance actions.

The method evaluates each 100 m (300 ft.) and averages them for each third of the runway. The IRFI method reduces the present variations of the 100 m surface lengths from as much as 0.2 down to typically 0.04. The sampling scheme of a full runway length (spot or continuous measurements) may yield additional variation.

Ongoing work has shown that the IRFI can be used to predict aircraft braking and will be reported in a separate document. Transport Canada has implemented a runway friction index called the Canadian Runway Friction Index (CRFI), which is based on only one ground friction measuring device. This index, based on an electronic recording decelerometer, correlates well to aircraft braking and is used in Canada to predict aircraft stopping distance.

C.4.27 Joint winter runway friction measurement program (JWRFMP): 2000 Testing and data analysis (TP 14062E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially under winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying natures and qualities that contribute to reduced braking friction capabilities. A service is warranted for the measurement of winter surface friction, because the operational window for aircraft movement can change quite rapidly and frequently in the winter.

In the past, users of friction information have generally perceived the quality of the friction measurement service as poor. Often, these users have indicated that the reported friction values do not represent the actual braking friction that is experienced with aircraft tire braking.

International research of friction measurement confirmed that friction measurement devices measure and report different friction values for the same surface. Differences occurred among units of the same generic device as well as across different device types. The perception of non-uniformity was compounded by surfaces exhibiting large variances in reported values. These variances further augmented the differences among device types.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the highest accuracy, but the procedure is limited to machine component calibrations. Research over the past four years has made significant advances toward solving these problems. Methods of measurement are being improved to increase measurement quality, remove uncertainties, and provide better correlation to aircraft tire braking. Prototype methods that incorporate ground friction measurement devices have shown very promising results.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program, led by the National Aeronautics and Space Administration and Transport Canada. Support is received from National Research Council Canada, the US Federal Aviation Administration, the Norwegian Civil Aviation Authority, and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States are also participating.

Objectives of the project include:

- Compiling a database containing all test data available from ground vehicles and aircraft that participated in the winter and summer runway friction programs.

- Using the data to determine a harmonized runway friction index: the International Runway Friction Index (IRFI).

The objective of this report is to update the 1997-98 JWRFP report (TP 13836E) with the data collected, analysis and findings through the year 2000.

Statistical IRFI Model

Normally, regression techniques would be used to find relationships between the reported friction values of pairs of ground friction measurement devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. The device, or an algebraic transformation of reported friction values, such as the average friction of two or more devices, would be selected as a reference. All devices would then be compared to the reference device to establish transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step or an interim method, which can be applied by the aviation community in the near future. The following equation represents a linear regression of the data for each device to an IRFI reference:

$$\mu_{IRFI} = a + b \times \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of measurement devices run in a wave pattern so that they measure the same surface within 15 seconds of each other. However, even with this systematic approach there are considerable variations in the measured surface condition because of the lateral placement of the devices and the resulting effect of surface compaction. The database now includes more than 30,000 friction measurements.

Stability of the Harmonization Method

The correlation constants were calculated for devices that participated in the 1997-98 test seasons and were reported in the 1997-98 JWRFP report. The constants were calculated by combining the two years of data. However, in the current year, 2000, it was established that not only does a calibration not apply across similar types of devices, but it changes from year to year for a particular device.

Conclusions and Recommendations

The ASTM standard E-2100 defines and prescribes how to calculate IRFI for winter surfaces. IRFI is a harmonized reporting index to provide information to aircraft operators on tire-surface friction characteristics of the movement area.

In addition to reporting surface conditions to aircraft, IRFI can be used by airport maintenance staff to monitor the winter frictional characteristics for surface maintenance actions.

The method evaluates each 100 m (300 ft.) and averages them for each third of the runway. The IRFI method reduces the present variations of the 100 m surface lengths from as much as 0.2 down to typically 0.04. The sampling scheme of a full runway length (spot or continuous measurements) may yield additional variation.

A reference device, which is required for calibration, must be a dedicated device for this purpose only, and the aviation community must agree on its provision, ownership and services. The device chosen for the exercises of the JWRFMP, to demonstrate that IRFI is possible, was an IMAG called the International Reference Vehicle (IRV). The IRV must be evaluated at some point for stability. If it is not stable with time, other references would need to be investigated. All harmonization constants will have to be reworked when a permanent IRFI reference has been designated. In the meantime at least harmonization was demonstrated to work and was accomplished with the devices participating in the JWRFMP.

There is proof that the participating devices in the JWRFMP are not representative of the other devices even when they are of the same generic type. This suggests that harmonization constants must be determined and applied to individual devices, rather than to generic groups of devices, as was done in the past. To accomplish this, a master device can be calibrated to the IRFI reference device in order to serve as a secondary reference, and the manufacturer or owner of this secondary reference can then calibrate other devices to this master.

Ongoing work has shown that IRFI can be used to predict aircraft braking and will be reported in a separate report. Transport Canada has reported that its version of the IRFI, called the Canadian Friction Index (CRFI), correlates well

C.4.28 Evaluation of IRFI calibration procedures for new and existing devices (TP 14063E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially during winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying nature and qualities that contribute to reduced wheel braking friction capabilities. A service is warranted for runway condition reporting because the operational window for aircraft movement can change quite rapidly and frequently in the wintertime. Such a service includes measurement of tire-surface friction.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the best accuracy, but the procedure has been limited to machine component calibrations. Research over the past four years has confirmed that different friction measuring devices report considerably different values, and this research has made significant advances to solve these problems. Methods of measurement are being improved to increase measurement quality, remove the uncertainties and provide better correlation to aircraft wheel braking.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program (JWRFMP), which is led by Transport Canada (TC) and the National Aeronautics and Space Administration (NASA). Support was received from National Research Council Canada, the US Federal Aviation Administration (FAA), the Norwegian Civil Aviation Authority and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States also participated.

The IRFI Method

This report describes the correlation method developed and standardized by ASTM E 2100-00 Standard Practice for Calculating the International Runway Friction Index. The linear regression technique is used to find relationships between the reported friction values of pairs of ground friction measurement devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. All devices are then compared to the reference device to establish transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step or an interim method, which can be applied by the aviation community in the near future.

$$\mu_{\text{IRFI}} = a + b \cdot \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. The friction measurement and corresponding data collection must be carried out more systematically.

A test series to verify the E 2100 method of the International Runway Friction Index (IRFI) to calibrate the International Reference Vehicle (IRV) to a master device and then to use the master device to calibrate local devices was conducted at the 2001 NASA Wallops Runway Friction Workshop using the devices and tires listed in the table below.

Devices and Tires Tested at 2001 NASA Wallops Runway Friction Workshop

Device Description	Tire Type
IRFI-Int'l Reference Vehicle (IRV)	PIARC Smooth Treaded Tire
NASA GripTester	ASTM E-1844
TC Surface Friction Tester (SFT)-Turbo	ASTM E-1551
USAF GripTester	ASTM E-1844
FAA Runway Friction Tester (RFT)	ASTM E-1551
FAA Trailer BV-11	ASTM E-1551
FAA Surface Friction Tester (SFT)	ASTM E-1551
VA DOT E275 trailer	ASTM E-524
PA DOT E275 trailer	ASTM E-524

Two sets of surfaces were utilized to perform these tests. Set 1 was used to calibrate the IRV with a master device and Set 2 was used to correlate the master device to the local devices. Five runs were made at 65 km/h (40 mph) on each set of surfaces.

Data and Analysis

Data Set 1 was used to pair each device with the IRV and determine the correlation constants a and b as well as R^2 . The analysis clearly shows that when the IRFI harmonization constants are applied to the data, all devices produce similar friction values. The exception was the USAF GripTester, which measured three of the four surfaces to be nearly the same. It is obvious that the data was incorrectly read or the device was faulty.

The harmonizing constants were determined for each device when harmonized to the IRV (from data Set 1) and then these constants were used on each device to make it the reference (called a master device in ASTM E 2100) to harmonize the rest of the devices with data Set 2.

The data show that four surfaces for calibration of a master device with the IRV and then four surfaces for calibration of other devices with the master is not sufficient. Also, the data show that harmonization of 100% slip with fixed slip does not work on wet pavements because of the different slip speeds. This is to be expected since the slip speed of the fixed slip devices is on the order of 10 km/h, whereas the 100% slip devices have a slip speed of 65 km/h. At these slip speeds the fixed slip devices are near the peak with little influence of macrotexture, whereas the locked wheel devices are greatly affected by the macrotexture.

Mean Errors

The average absolute error of the devices without harmonization was 0.165 for the two sets combined. When the correlation constants were applied (predicted IRFI values) the average

absolute error was reduced to 0.051 for data Set 1, to 0.081 with the correlation constants found from Set 1 applied to Set 2, and to 0.053 with the correlation constants from all the data applied to the data set. The average absolute error between each device and the IRV in data Set 2 was 0.132. Thus, the harmonization closed the range of reported friction values by device versus harmonized friction values 0.081 units or an average of 40 percent. When the complete data set was used, the average absolute error was reduced to 0.053 units or an average of 60 percent. When the NASA GripTester or the FAA Runway Friction Tester were used as master devices, the average absolute errors were 0.072 and 0.075.

Conclusions and Recommendations

ASTM Standard E 2100-00 defines and prescribes how to correlate IRFI devices for winter surfaces. The IRFI is calibrated directly or indirectly to the IRFI reference device, thereby achieving harmonization of local friction devices to a common unit of measure regardless of the local friction device used.

There is proof that the devices that have participated so far in the JWRFMP are not representative of the other devices of the same generic type that are operated at airports worldwide. This suggests that harmonization constants must be determined and applied to individual devices, rather than to generic groups of devices, as was done in the past.

For any common scale of friction measure to work satisfactorily for the industry, annual harmonization meetings must be arranged to determine the current harmonization constants.

To accomplish annual calibration, master devices can be calibrated to the IRFI reference vehicle and then used as secondary references to calibrate other devices. The results of this study show that master devices can be calibrated with the IRFI reference device and then used to calibrate other devices. However, there are several precautions that are needed:

- (1) At least six (eight recommended) surfaces with friction ranging from 0.1 to 0.7 are needed for the calibrations.
- (2) Only devices that calibrate with a 0.05 or less average mean error should be used as a master device.
- (3) Surfaces where device self-wetting was used did work, but the correlations made in this report must be checked with ones made in winter conditions.
- (4) On surfaces where device self-wetting is applied, only devices with similar slip ratios can be calibrated against each other.

If item 3 can be verified, then surfaces where self-wetting devices are used could be used for calibration surfaces and the calibration constants could be used under winter conditions.

C.4.29 Repeatability of friction measurement devices in self-wetting mode (TP 14064E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially during winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying natures and qualities that contribute significantly to reduced braking friction capabilities. Because the operational window for aircraft movement can change quite rapidly in the wintertime, a service is warranted for measurement of surface friction.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces (some coming from a fore transducer and some coming from a torque transducer), they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the best accuracy, but the procedure has been limited to machine component calibrations. Research over the past four years has made significant advances toward solving these problems. Methods of measurement and correlation of equipment are being improved to increase measurement quality and remove the uncertainties.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program (JWRFMP), led by Transport Canada and the US National Aeronautics and Space Administration (NASA). Support was received from National Research Council Canada, the US Federal Aviation Administration, the Norwegian Civil Aviation Authority and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States also participated.

The field tests and data for this study were provided by the participants of the 8th annual NASA Tire/Runway Friction Workshop, which took place at NASA Wallops Flight Facility in May 2001. The repeatability findings are therefore linked to the condition of the surfaces of the NASA Wallops Flight Facility at Chincoteague, Virginia, USA, at the time of testing.

As friction measurements have no fundamental calibration reference, the repeatability parameters are associated with the friction measurement device/surface pair. The repeatability findings of a device for one surface do not apply for another surface. Many surfaces must therefore be measured by a friction measurement device to obtain a better view of repeatability for the device. This study obtained practical values of repeatability for reported friction values on several runway and taxiway surface types for each participating friction measurement device.

It was generally found that the repeatability of the participating friction measurement devices in self-wet mode yielded an average repeatability expressed as a standard deviation of 0.027 friction units as a coefficient of variation of 5 percent.

Significant differences of repeatability statistics were found between different friction measurement devices for the same surfaces. To a large extent this is explained by the different units of friction measurement that the devices report to. One indication of this is the wide range of average friction values each device produced for a surface. As a rule of thumb, the range was found to be two thirds of the averaged friction value of the group of devices. If

the average friction value for a surface by the group of devices was 0.60, the difference between a device reporting the lowest average friction value and a device reporting the highest average friction value for a surface would be 0.40. For a normal distribution, this translates to a group variance of ± 33 percent.

Harmonization to a common unit of friction measurement, such as the International Friction Index, is suggested before calculating repeatability statistics for friction measurement devices on wet pavement. Repeatability values would then be more comparable between devices and the range of variability between different devices would become smaller.

If a device were chosen as a physical reference for friction measurement units, the statistics of repeatability as found for different surfaces for that device would apply as a measure of quality of the reference friction measure.

C.4.30 Comparison of the IRV and the ERD on winter contaminated surfaces (TP 14065E)

Summary

The American Society for Testing and Materials standard for the International Runway Friction Index (IRFI) specifies a reference tester for calibration of runway friction devices in order to harmonize measurements to the IRFI. The International Reference Vehicle (IRV) was dedicated to the Joint Winter Runway Friction Measurement Program (JWRFMP) in January 2000. In earlier years testing was performed with an Instrument de Mesure Automatique de Glissance (IMAG), which is of the same design as the IRV. In an earlier report (TP 13791E) the relationship between the IMAG used prior to 2000 and the IRV was established.

The objective of this report is to compare measurements made by Electronic Recording Decelerometers (ERDs) with the measurements made by the IRV. Starting in 1998 the JWRFMP conducted tests in a manner that all devices made measurements on the same surfaces within a very short time of each other. These paired data are used in this report to compare the ERD with the IRV. The data from 1998 and 1999 obtained by the IMAG are converted to the predicted IRV values using the relationship ($IRV = 0.95 \text{ IMAG}$) developed in the previous study (TP 13791E). The normal slip ratio for the IRV and the IMAG is 15% slip, although it can be operated at slip ratios up to 90%.

Most of the ERD data (10 data sets) used in the comparison were for a Chevrolet Blazer, but two data sets were for the ERD mounted on a Ford pickup truck and one data set was on a Nissan SUV. A total of 2069 data points were used in the comparison on ice, compacted snow and bare pavement. The IRV was operated at slip ratios of 30, 60 and 90% for 158 additional data points.

Linear regressions of the data showed poor correlation between the IRV/IMAG data and the ERD for many of the data sets analyzed. This is due to several factors that differentiate the ERD and the IRV/IMAG measurements:

- (1) The ERD measures several spots in the test section while the IRV and IMAG average the entire length of the segment.
- (5) The ERD operates at a much higher slip ratio (100%) than the normal slip ratio of the IRV and IMAG (15%).
- (6) The contact pressure between the tire and the surface is much higher for the ERD than for the IRV and IMAG.

When the best four correlations are combined and outliers removed, the agreement is fair for the resulting data set of 712 points:

$$IRV = 0.115 + 0.765 \text{ ERD Blazer}$$

$$R^2 = 0.849$$

C.4.31 Joint Winter Runway Friction Measurement Program (JWRFMP): 2001 testing and data analysis (TP 14192E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially under winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying natures and qualities that contribute to reduced braking friction capabilities. A service is warranted for the measurement of winter surface friction, because the operational window for aircraft movement can change quite rapidly and frequently in the winter.

In the past, users of friction information have generally perceived the quality of the friction measurement service as poor. Often, these users have indicated that the reported friction values do not represent the actual braking friction that is experienced with aircraft tire braking.

International research of friction measurement confirmed that friction measurement devices measure and report different friction values for the same surface. Differences occurred among units of the same generic device as well as across different device types. The perception of non-uniformity was compounded by surfaces exhibiting large variances in reported values. These variances further augmented the differences among device types.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the highest accuracy, but the procedure is limited to machine component calibrations. Research over the past six years has made significant advances toward solving these problems. Methods of measurement are being improved to increase measurement quality, remove uncertainties, and provide better correlation to aircraft tire braking. Prototype methods that incorporate ground friction measurement devices have shown promising results.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program, led by the National Aeronautics and Space Administration and Transport Canada. Support is received from National Research Council Canada, the US Federal Aviation Administration, the Norwegian Air Traffic and Airport Management (NATAM), and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States are also participating.

Objectives of the project include:

- Compiling a database containing all test data available from ground vehicles and aircraft that participated in the winter and summer runway friction programs.

- Using the data to determine a harmonized runway friction index: the International Runway Friction Index (IRFI).

- Relating aircraft stopping performance to ground vehicle IRFI.

The objective of this report is to update the 2000 JWRFP report (TP 14062E) with the data collected, analysis and findings through the year 2001.

Statistical IRFI Model

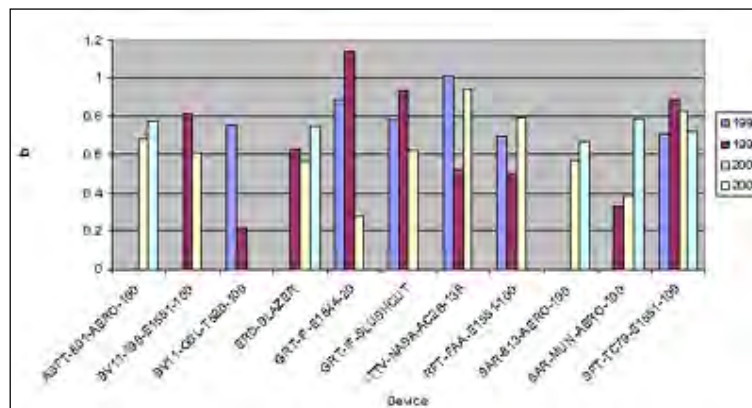
Normally, regression techniques would be used to find relationships between the reported friction values of pairs of ground friction measurement devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. The device, or an algebraic transformation of reported friction values, such as the average friction of two or more devices, would be selected as a reference. All devices would then be compared to the reference device to establish transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step, which can be applied by the aviation community. The following equation represents a linear regression of the data for each device to an IRFI reference:

$$\mu\text{IRFI} = a + b \times \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of measurement devices run in a wave pattern so that they measure the same surface within 15 seconds of each other. However, even with this systematic approach there are considerable variations in the measured surface condition because of the lateral placement of the devices and the resulting effect of surface compaction. The database now includes 32,627 friction measurements.

Stability of the Harmonization Method

The correlation constants were calculated for devices that participated in the 1998-1999 test seasons and were reported in the 1997-98 JWRFP report (TP 13836E) and the Fourth Year JWRFP report. The constants were calculated by combining the two years of data. However, in 2000, it was established that not only does a calibration not apply across similar types of devices, it changes from year to year for a particular device. The figure below shows the variations of the IRFI multiplier b for the past four years (1998 to 2001). IMAG (IRV) is not shown since it is the reference and thus is always $b = 1.0$.



Multiplier b vs. Years (1998-2001) by device

Reproducibility of SARSYS Devices

At the Erding test site four devices of the same brand and type were tested. This enabled a limited study of reproducibility, i.e. how different each device of the same type measured the same surface segments. This was the first opportunity for a reproducibility study in the JWRFMP.

With the surfaces available for testing at the Erding site, the SARSYS devices exhibited reproducibility as expressed in standard deviation in the order of 0.08 friction units for ribbed tires and 0.05 for blank tires. The reproducibility varied with changes in friction level for both ribbed and blank tires.

Conclusions and Recommendations

The ASTM standard E 2100 defines and prescribes how to calculate IRFI for winter surfaces. IRFI is a harmonized reporting index to provide information to aircraft operators on the tire-surface friction characteristics in the aircraft movement area.

In addition to reporting surface conditions to aircraft, IRFI can be used by airport maintenance staff to monitor the winter frictional characteristics for surface maintenance actions.

The method evaluates each 100 m (300 ft.) and averages them for each third of the runway. The IRFI method reduces the present variations of the 100 m surface lengths from as much as 0.2 down to typically 0.04. The sampling scheme of a full runway length (spot or continuous measurements) may yield additional variation.

A reference device, which is required for calibration, must be a dedicated device for this purpose only, and the aviation community must agree on its provision, ownership and services. The device chosen for the exercises of the JWRFMP, to demonstrate that IRFI is possible, was an IMAG and called the International Reference Vehicle (IRV). The IRV must be evaluated at some point for stability. If it is not stable with time, other references will need to be investigated. All harmonization constants would have to be reworked when a permanent IRFI reference has been designated. In the meantime at least harmonization was demonstrated to work and was accomplished with the devices participating in the JWRFMP.

There is proof that the participating devices in the JWRFMP are not representative of the other devices even when they are of the same generic type. This suggests that harmonization constants must be determined and applied to individual devices, rather than to generic groups of devices, as was done in the past. To accomplish this, a master device can be calibrated to the IRFI reference device in order to serve as a secondary reference and the manufacturer or owner of this secondary reference can then calibrate other devices to this master.

Ongoing work has shown that the IRFI can be used to predict aircraft braking performance. This will be discussed in a separate report.

C.4.32 Environmental and runway surface conditions during friction tests at North Bay Airport: Jan-Feb 2002 (TP 14158E)

Summary

A five-year project was initiated in December 1995 to understand and to quantify the factors that influence aircraft braking friction and the contamination drag of various aircraft on winter contaminated runways, in order to estimate landing or take-off distances on wet and winter contaminated runways. A collaborative agreement was made between the National Aeronautics and Space Administration (NASA) and Transport Canada (TC) to conduct field tests using various instrumented aircraft and ground friction measuring vehicles. The US Federal Aviation Administration (FAA), National Research Council Canada (NRC) and organizations from other countries (e.g., the Norwegian Civil Aviation Administration) eventually joined this program, which is now called the Joint Winter Runway Friction Measurement Program (JWRFMP).

The JWRFMP was extended to include trials at North Bay Airport in Ontario from January 27 to February 8, 2002. Seven ground friction measuring devices from different countries were assembled and used at North Bay Airport. During this period, one commercial passenger aircraft, a Cessna 414, also participated in the tests.

The primary objectives of the 2002 North Bay Airport friction tests were to:

- (1) Validate the International Runway Friction Index using the International Reference Vehicle (IRV)
- (7) Calibrate local devices a master device calibrated by the IRV
- (8) Conduct scarified ice tests between the IRV and the Electronic Recording Decelerometer (ERD)
- (9) Conduct tests with the ERD, the Surface Friction Tester (SFT) and the IRV on operational runways
- (10) Compare variable slip, tires and pressure to the ERD

This report contains information on environmental conditions during the tests and surface contaminants collected during the tests. Due to the environmental limitations, man-made winter contaminants (in the form of ice) and natural contaminants were used for testing. Natural contaminants included freshly fallen snow and old accumulated snow significantly thicker than the allowable snow accumulation on operational runways. Consequently, some of the tests were carried out under conditions that may exceed real-life airport operational conditions. However, the results obtained from the ground vehicles are useful for comparative studies.

Most of the objectives were met, except for the studies on scarified ice, which experienced unavoidable limitations due to a lack of uniformly thick ice cover. An effort was made to thicken the man-made ice strip, but it was found not to be practical.

Air temperature; relative humidity; wind speed and direction; sky conditions, including cloud cover; the presence of solid or liquid particles in the air and on the pavement surface; movement-area surface texture; pavement surface temperature; the vertical and spatial temperature gradient in the pavement; and solar radiation all play important roles in determining the surface conditions of a runway. Continuity in the measurement of all these parameters should be ensured. It is also recommended that continuous measurement of solar radiation at the test site be an integral part of future measurements.

C.4.33 NASA Wallops Tire/Runway Friction Workshops: 1993-2002 (TP 14190E)

Summary

In the fall of 1992, data was collected in Belgium and Spain for the PIARC International Experiment to compare and Harmonize Friction and Texture Measurements. The following May, some of the devices used in the tests in Belgium and Spain were assembled at the NASA Wallops facility. Measurements were also made at Wallops with other devices that were not used in Europe. Each May for the next consecutive nine years (1994-2002) data was collected with ground vehicles on the test surfaces at the NASA Wallops Flight Facility during the annual Tire/Runway Friction Workshops. These differed from the 1993 program in that one day was set aside for presentations by vendors and other interested parties. The actual test programs for these workshops were similar to the 1993 program. This extensive database has been compiled into spreadsheets summarizing the average values of repeat runs made on each site by each device and has been added to the JWRFMP database. In most cases the high-speed testers performed measurements at several speeds ranging from 32 to 96 km/h. The following information is given in the appendices:

Key:

AC	Asphalt Concrete
CC	Portland Cement Concrete
ST	Surface Treatment
P	Metal Panel
X	A

Below is a summary of the equipment was used over the years. In the report, the devices are listed for each year along with tables of their measurements.

Texture Devices used to take measurements included:

Key:

AC	Asphalt Concrete
CC	Portland Cement Concrete
ST	Surface Treatment
P	Metal Panel
X	A

Friction Devices used to take measurements included:

Key:

AC	Asphalt Concrete
CC	Portland Cement Concrete
ST	Surface Treatment
P	Metal Panel
X	A

Roughness measuring systems used to take measurements included:

Key:

AC	Asphalt Concrete
CC	Portland Cement Concrete
ST	Surface Treatment
P	Metal Panel
X	A

Site Descriptions:

Key:

AC	Asphalt Concrete
CC	Portland Cement Concrete
ST	Surface Treatment
P	Metal Panel
X	A

Key:

AC	Asphalt Concrete
CC	Portland Cement Concrete
ST	Surface Treatment
P	Metal Panel
X	A

Some of the systems that were used in the PIARC Experiment were also used at the NASA Wallops tests starting in 1993. Those systems were calibrated to the IFI using the European data. Unfortunately some of the devices were altered after the PIARC Experiment or used different measuring tires.

The most data for the calculation of the IFI for the Wallops Flight Facility sites through the six-year period from 1993 to 1998 was the combination of MTD (Volumetric Texture Depth using glass beads) and the BPN (British Pendulum Number). The history of the IFI of the Wallops surfaces, where data is available, is given in the report.

Profiling is a relatively new addition to the workshop. In 1999 the first real data was recorded and a comparison of the dipstick, ARP, RoadPro and a rod and level measurement was shown. The data was in good agreement. The data from 2000 was not recorded, the equipment was only demonstrated. In 2002 there were a number of devices and the data as submitted was put onto a CD; however, much of the data was in the devices' own codes and still needs to be converted into common files so that accuracy and repeatability can be calculated. It is recommended that rod and level data be taken in May 2003 and more profiling activity be attempted, including a fourth site similar to site three.

The Annual NASA Wallops Runway Friction Workshop is considered to be an excellent workshop and are well liked by the friction measuring industries, both aviation and highway. Attendance continues to be well representative of the industry and the workshop always

includes an audience from all over the world. One can see by the equipment that is brought to the workshop year after year the effort and importance that many organizations place on these workshops, and all at their own expense. NASA is to be commended for conducting these workshops, which have proven to contribute to the safety of the aviation and highway industry. It is hoped that these workshops continue for many years.

C.4.34 Benefit-cost analysis of procedures for accounting for runway friction on landing (TP 14082E)

Summary

Introduction

Transport Canada (TC), in association with the Federal Aviation Administration (FAA), the US National Aeronautics and Space Administration, and National Research Council Canada (NRC), implemented a five-year program for winter runway friction testing in 1995. The program expanded in 1996 to include other North American and European organizations, and has become a concerted international effort known as the Joint Winter Runway Friction Measurement Program. The program has led to the collection of a substantial database of aircraft and ground vehicle friction measurement data from various runways, and to the development of a greater understanding of the factors affecting runway friction, its measurement, and the relationship between runway friction and aircraft braking. For runways with compacted snow or ice contamination, or loose snow with shallow contaminant depth and therefore very little or no contaminant drag, the runway friction measurements were found to be consistent and correlate well with aircraft braking.

With this improved knowledge of runway friction, Transport Canada is looking at making better use of runway friction information in practice to reduce the risks and possibly operating costs. The objective of this study was to better understand the use of the currently available guidance material related to runway condition and to develop an economic rationale for changes requiring commercial air carriers operating passenger services using turbo-jet aircraft to account for slippery runways on landing.

Approach

Much of the benefit of accounting for runway friction will likely be due to a reduction in the risk of overrun accidents on landing. An analysis of the reduction in risks due to the use of runway friction information is therefore an important component of the benefit-cost analysis. The approach used to better understand the use of the currently available guidance material related to runway condition and to determine the benefits and costs of accounting for slippery runways was to:

- Review existing standards and guidance material;

- Review runway conditions and reporting of friction at airports;

- Conduct a survey of Canadian airline pilots on current practices, their use of guidance material and their views on accounting for runway friction;

- Examine past overrun accident/incident experience on landing, analyze the risks on landing and the reduction in risks due to use of runway friction information;

- Determine the incremental benefits and costs to airports of changes in the measurement and reporting of runway friction information;

Analyze the benefits and costs to air operators and passengers of accounting for runway friction in landing performance calculations; and

Determine overall benefits and costs, and the benefit-cost ratio.

Current Situation

The current TC and FAA regulations require the aircraft landing distance specified in the Aircraft Flight Manual (AFM) to be not more than 60% of the landing field length available. The regulations include a requirement for an additional 15% runway length when the destination runway is forecast to be wet at the time the aircraft is dispatched. Important implications of these regulations are as follows.

Reverse thrust cannot be used in determining the AFM landing distance and landing field length for most aircraft types, although reverse thrust is typically used in operational situations to reduce stopping distance. Aircraft with reverse thrust therefore have an additional safety feature not accounted for in the regulations that is especially effective on slippery runways when braking friction is low.

There is no requirement to adjust the landing distances to account for snow, ice or frost on the runway. The factor of 115% for wet runways does not have to be applied in these runway conditions.

The requirement to adjust for a wet runway applies only at the time of dispatch and take-off – once airborne, if the runway conditions change and become wet, there is no requirement for the pilot to re-calculate the factored landing distance with the additional 15% margin.

The survey of Canadian airline pilots indicated that most pilots are aware of guidance material for operating on contaminated runways, and that most apply some adjustment factor to the landing field length when runways are slippery. The TC Aeronautical Information Publication includes tables, referred to as the Canadian Runway Friction Index (CRFI) Tables, derived from the Falcon-20 tests at North Bay, which provide adjustments to the landing field length for given CRFI values. However, most pilots surveyed indicated that their aircraft manuals and company material referred to reporting braking action as “good”, “medium” or “poor” and do not specifically refer to runway friction.

Runway condition data over a one- to three-year period was obtained for Calgary, Toronto, Ottawa and Halifax airports and analyzed in conjunction with data from five airports collected between 1988 and 1990. The frequency of slippery runways varies greatly between airports. Typical frequencies of contaminant types resulting in slippery runways and average CRFI values for each contaminant type are as follows:

Contaminant Type	During Winter Months	Over Year	Avg. CRFI
Ice	6.6%	2.8%	0.32
Compact Snow	2.4%	1.0%	0.32
Frost	0.7%	0.3%	0.41
Loose snow 1/8"	3.5%	1.4%	0.40
Any of above	13.2%	5.5%	

Source: Runway Surface Condition reports from airports

Notes:

Values applicable for contaminant type greater than or equal to 20% of runway (but often <100%).
Runways typically treated to improve friction.

CRFI values vary significantly from these averages. Over a year, approximately 0.5% of the time CRFI values are 0.2 or less, 2.1% are between 0.21 and 0.3, 1.7% are between 0.31 and 0.4, 0.8% are between 0.41 and 0.5, and 94.9% are 0.51 or greater.

Benefit-Cost Analysis

The benefit-cost analysis compared the use of the CRFI Tables for accounting for slippery runways with use of the current regulations (no adjustment), the 115% wet runway adjustment, and adjustments based on the manufacturers' guidance material. For aircraft types where no manufacturer's guidance material was available, the adjustment was based on adjustments for similar aircraft.

The benefits of accounting for slippery runways were determined by estimating the reduction in accident costs. A model was developed to estimate the probability of overrun and the consequences when an overrun occurs. The landing distance was estimated from the AFM landing distance with adjustments for slippery runways based on analysis of Falcon-20 tests at North Bay by NRC and TC. The model allows for variation in air distance prior to touchdown, delay time, braking μ on slippery runway, and the setting and application of brakes. The risk model was shown to be consistent with past history of overruns in Canada.

The costs to air carriers and passengers considered included delays until CRFI improves, cancelled or diverted flights, weight reductions, updating manuals, and additional training. Additional cost to airports will be small as CRFI values are already collected at all airports with paved runways with jet service. There is only one with gravel runway that may be affected, but an exemption is being considered for collection of CRFI on gravel runways. Possible additional costs to airports include the provision of CRFI values earlier in morning and changes in procedures and training to improve the consistency of reporting.

Conclusions

The risk of a jet aircraft overrunning the end of the runway on landing when the runway is slippery is approximately 13 times greater than when the runway is dry. The risks of overruns on landing for aircraft without reverse thrust are approximately 4 to 7 times greater than for aircraft with reverse thrust.

The overrun accident/incident rate of jet aircraft landing on a slippery runway in Canada over the period 1989 to 2001 was approximately 17 per million landings on slippery runways

(excluding cases where aircraft went off the side of the runway). For commercial passenger jet aircraft the rate was 13 per million landings. Due to the small proportion of landings on slippery runways, the overrun accident/incident rate due to slippery runways over all landings was 1.3 per million, or 1.0 per million for commercial passenger jet aircraft. The consequences of these overruns also tend to be low, with no fatalities recorded in these types of accidents in the last 25 years in Canada.

The benefits of using the CRFI Tables to adjust landing field length (LFL) exceed the costs of doing so for all aircraft types when the LFL under current regulations equals the runway length available and the runway is very slippery (CRFI approximately 0.2).

For most jet aircraft landings in Canada, the runway length available far exceeds the LFL required and this provides an additional margin of safety above that provided by the regulations. The risk of an overrun when the runway is slippery is greatly reduced by this additional margin of safety. The additional runway length available will result in extremely few flights (less than 0.01%) being affected by LFL requirements that account for slippery runways using the CRFI Tables.

Considering only the benefits and costs to passenger and air carrier operations, the benefit-cost ratio for use of the CRFI Tables relative to the current regulations for all air carrier jet aircraft landings in Canada, allowing for the range in runway conditions and aircraft weights, is estimated to be approximately 4.7. Much of the benefit is attributed to a small number of landings of B747 aircraft on runways of 9,000 ft. or less.

Considering the benefits and costs to passengers and air carriers of operations, updating manuals and training, and the additional costs to the airport, the benefit-cost ratio for use of the CRFI Tables is estimated to be approximately 1.2.

Costs associated with extending the applicability of the 115% adjustment to LFL to cover slippery runways are low and the benefits for the few landings affected are very high giving a benefit-cost ratio of over 4. As a minimum, the 115% adjustment should be extended to slippery runways. Many pilots already use an adjustment of 115% or greater. Considering only the operational benefits and costs, the incremental benefits of moving from the 115% adjustment to the use of the CRFI Tables for slippery runways are slightly greater than the incremental costs (benefit-cost ratio of 1.1). However, if the costs of manual updates and training are considered, costs exceed the benefits.

Application of adjustments in LFL for slippery runways based on manufacturers' guidance material would result in very high costs if applied to all landings on slippery runways, irrespective of the actual CRFI value and Pilot Report (PIREP) braking reports. Under these conditions, the CRFI Table adjustment provides a very cost-effective alternative for accounting for slippery runways.

Recommendations

Based on the analysis of Canadian aircraft landing operations, it is recommended that:

The 115% adjustment to the calculation of the required LFL for a wet runway applicable at the time of dispatch be extended to include runway conditions where

the CRFI value is 0.5 or less, or where there is ice, compacted snow and/or shallow depth loose snow covering 20% or more of the runway.

Guidance material be provided for turbo-jet aircraft by the air operator, which will allow the pilot of the aircraft to determine the runway distance required to land the aircraft when the runway is slippery due to ice, compact snow and/or shallow depth loose snow contamination. The guidance material may base the determination of the landing distance on a combination of the CRFI value, PIREP braking reports and the type and extent of snow/ice contamination on the runway, taking into consideration the time of the last reports. Guidance or other material provided by the manufacturer of the aircraft and the CRFI Tables provide acceptable sources of information for developing the guidance material. The procedures for determining landing distance should be easy to use so as to allow pilots to make the calculations while en route, just prior to landings if necessary.

Consideration be given to allow an air carrier to exclude aircraft types from the above requirement where the adjusted LFL with a CRFI value of 0.18, allowing for the pressure-altitude of the airport, zero headwind and 0°C ambient temperature, is less than the runway length available at all airports where that carrier is approved to operate.

C.4.35 Repeatability and reproducibility of Saab friction measurement devices in self-wet mode (TP 14083E)

Summary

Under severe winter conditions several countries rigorously impose limits and weight penalties for aircraft takeoffs and landings. These limits depend on the weather conditions and the runway conditions, which are established by visual inspection and the measurement of runway friction coefficient using ground friction measurement equipment.

It is expected and indeed is proven that the aircraft braking friction coefficients of contaminated runways are different for aircraft than those reported by the ground equipment on which the penalties and limits are based. Measuring the capability of the runway surface to provide aircraft tire-braking action is fundamental to airport aviation safety, especially under winter conditions. Thus, a system directly capable of determining the aircraft braking friction coefficient would represent a direct and substantial benefit for the aviation industry.

The wide range of different ground friction measurement devices used today by different countries and the large number of differing procedures in measuring winter surface friction result in non-harmonized, high scatter frictional parameters on winter contaminated surfaces and, in fact, on all contaminated surfaces.

It has been established that the frictional values reported by different types of ground friction measurement equipment are substantially different. In fact, the same type and manufacture, and even the same model of equipment report highly scattered frictional data. Calibration and measurement procedures are different for different types of devices. The repeatability and reproducibility scatter of each type of ground friction measurement device is therefore amplified and the spread of friction measurement values among different equipment types is significant. It is necessary to develop a practical and simple solution to harmonize the different groups and families of ground friction measurement equipment for winter operation in order to ensure the meaningful and uniform reporting of winter runway surface friction across borders and regions.

The Joint Winter Runway Friction Measurement Program has conducted uncertainty analyses for many different friction measurement devices. This study focused on the exploration of the uncertainty factors of repeatability and reproducibility of the Saab friction measurement equipment family based on the fixed slip measurement principle.

The original scope of the data collection at the Prague airport test site was to quantify uncertainties in the measurement process of the Saab friction measurement equipment that would be difficult to quantify under conditions of actual measurements.

The procedures employed in this study were the standard data analysis procedures in the ASTM E691 and ISO 5725 standards that are intended for test agencies and scientific laboratories that report results of measurements from ongoing or well-documented processes [1].

For computational procedures, this study followed the ISO approach [2] to computing and combining components of uncertainty. To this basic structure was added a statistical framework for estimating individual components.

The original scope of the test was to conduct measurements on numerous different surfaces, mainly winter surfaces, but due to mild weather it was not possible. Accordingly, the measurements analyzed in this report were made on a limited selection of surfaces. Therefore, these results can only be used with careful consideration as a general evaluation for the participating measurement devices.

It was determined that the repeatability of the participating Saab friction measurement devices in this study produced an uncertainty of 0.07 average repeatability standard deviation friction units on a scale of 0 to 1.00, with a maximum uncertainty deviation of 0.08 and the minimum uncertainty 0.06. Thus, the uncertainty content of the Saab friction measurement units as a whole under self-wet conditions is an average of 7% of the maximum scale.

The family of the Saab measurement equipment produced relatively uniform and well distributed uncertainty characteristics with regard to the differences between the different measurement units. Thus, the repeatability uncertainty statistical parameters gave very similar characteristics for the participating measurement equipment.

The measurement devices reported a relatively wide range of average friction values for the different surfaces. The calculated average of the absolute differences between the maximum and minimum friction values reported by the different equipment for the surfaces A, PAINT, and C were 0.16, 0.12, and 0.12, respectively.

The devices and surfaces included in this study produced an average reproducibility standard deviation equal to 0.10. This is an average value of the reproducibility standard deviation of all devices for each measurement session. As one would expect, the repeatability of the devices was better than the reproducibility of the device family.

Relating the variability with the friction level by using the coefficient of variation provides compatibility of this study to other repeatability studies. The average repeatability coefficient of variation for all devices and surfaces combined was 6.6% and the corresponding average reproducibility coefficient of variation was 11.4%.

C.4.36 Decelerometer tests: CRFI quality assurance tests and the effect of the vehicle's ABS system (TP 14176E)

Summary

This was a two-part project to investigate the friction coefficients measured by decelerometers at Canadian airports, comprised of: (a) Canadian Runway Friction Index (CRFI) Quality Assurance Tests and (b) Antilock Braking System (ABS) Effect tests.

CRFI Quality Assurance Tests – These tests were done to compare the CRFIs obtained with decelerometer systems in use at different airports with the Transport Canada (TC) system. The test vehicles consisted of (a) the TC Blazer, and (b) an Electronic Recording Decelerometer (ERD) Mk II. D. Booth, of North Bay airport, operated the Blazer. The Transport Canada system has been used throughout the Joint Winter Runway Friction Measurement Program (JWRFMP), which commenced in 1996. Tests were conducted at five airports in northern Ontario during two periods in January and February 2003. CRFIs were obtained with the Transport Canada system and the sites' vehicles on the same surface. Tests were done on operational surfaces, rather than prepared surfaces, at the airports. The surfaces covered a range of friction levels. Tests were also done with the operators switched.

The findings were as follows:

The CRFI variations between the airport systems and the Transport Canada system varied with airport and Circuit. As expected, more small landing distance variations were observed than large ones. Seventy percent of the inferred landing distances for these cases varied by less than 500 ft. The maximum variation in inferred landing distance was 826 ft. (Note that all references made to inferred landing distances apply to an unfactored landing distance of 3000 ft., and to no reverse thrust.)

Generally, greater variation was observed between the Transport Canada and airport systems for sites that used the ERD Mk III as part of their system.

In all cases, similar results were obtained with Transport Canada and site operators. The average CRFI variation was 0.013, with a maximum variation of 0.04. This probably indicates that the operators had all been trained to employ similar measurement techniques. It was concluded that switching the operators did not affect the CRFI readings significantly, compared to the other differences seen between vehicle-decelerometer pairs.

Instrumentation problems were encountered with the ERDs used in the TC system that limited the strength of the conclusions that can be drawn.

Further investigation is recommended regarding: (a) the stability of the standard used as the basis of comparison for this project; (b) decelerometer calibration and certification; (c) decelerometer acceptance and regulation; and (d) the significance of the observed CRFI variations.

ABS Effect Tests – The tests were done to measure the degree to which CRFIs are affected by whether or not the vehicle's ABS is on or off. The tests were aimed at expanding the database obtained during a similar test program conducted in 2002. The 2003 testing evaluated this for: (a) a wider range of vehicles; (b) several decelerometer types; and (c) a wider range of surfaces.

The findings from the whole data set were as follows:

The effect of ABS on versus off depended on the specific vehicle, decelerometer, and surface under consideration. No universal relationships were apparent, although trends were evident for each vehicle. The effect of ABS on versus off ranged from: (i) increasing the respective friction coefficient to; (ii) decreasing the respective friction coefficient to; and (iii) no effect. Substantial CRFI variations were measured in some cases, depending upon whether or not the vehicle's ABS was on or off.

The observed friction coefficient variations were examined with respect to their effect on inferred landing distances to evaluate their significance. (Note that all references made to inferred landing distances apply to an unfactored landing distance of 3000 ft., and to no reverse thrust). The largest variations were observed for the ½-ton and the ¾-ton on February 24 during tests done with 6 mm (¼ in.) of loose snow on bare pavement. Data were only obtained with the ERD Mk III and the ERD Mk II on that day. The Tapley and Bowmonk were not tested on that day as they were not available.

Maximum Variation in Inferred Landing Distances for ABS On vs. Off

	ERD MK III	ERD Mk II	Tapley	Bowmonk Peak	Bowmonk Average
Blazer	-549	-533	-171	-106	-695
½-Ton	876	829	-152	-448	614
¾	924	853	41	220	no data
1-Ton	-202	-334	no data	no data	-116
RWD Car	-302	-310	-189	-256	no data
FWD Car	257	258	34	-427	no data

Notes:

1. The above differences in inferred LD are measured in ft.
2. Negative and positive variations indicate that the inferred LD based on the friction coefficient measured with the ABS off was shorter or longer, respectively.

The above maxima are larger than those observed during the 2002 tests, which was 449 ft. This variation may be due to differences in surface conditions as no tests were done in 2002 on loose snow on pavement. The 2002 tests were all done on bare ice and compacted snow.

The recommended actions depend upon whether or not the above variations in inferred landing distance are considered to be significant. Transport Canada should undertake this evaluation.

Effect of Decelerometer Type – Tests were done with the Electronic Recording Decelerometer (ERD Mk II and ERD Mk III), the Tapley, and the Bowmonk (which was set to record either the peak or the average friction coefficient). These decelerometers produced different values, which is similar to the results obtained during a test program in 2002. Instrumentation problems were encountered with the ERDs that make it difficult to make general statements; and to compare the MK II and Mk III. The ERD Mk III consistently read about 0.05 lower than did the Tapley over the full range of friction coefficients. This finding is similar to the result from the 2002 program. The relationship between the Bowmonk and the ERD Mk III depended upon whether peak or average Bowmonk values were compared.

The peak values read by the Bowmonk were both above and below the readings from the ERD Mk III. The maximum variation in friction coefficient between the Bowmonk peak and the ERD Mk III was about 0.1. The average values read by the Bowmonk were generally similar to those from the ERD Mk III, although only a few data points were obtained.

C.4.37 Joint Winter Runway Friction Measurement Program (JWRFMP): 2002 testing and data analysis (TP 14193E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially under winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying natures and qualities that contribute to reduced braking friction capabilities. A service is warranted for the measurement of winter surface friction, because the operational window for aircraft movement can change quite rapidly and frequently in the winter.

In the past, users of friction information have generally perceived the quality of the friction measurement service as poor. Often, these users have indicated that the reported friction values do not represent the actual braking friction that is experienced with aircraft tire braking.

International research of friction measurement confirmed that friction measurement devices measure and report different friction values for the same surface. Differences occurred among units of the same generic device as well as across different device types. The perception of non-uniformity was compounded by surfaces exhibiting large variances in reported values. These variances further augmented the differences among device types.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the highest accuracy, but the procedure is limited to machine component calibrations. Research over the past seven years has made significant advances toward solving these problems. Methods of measurement are being improved to increase measurement quality, remove uncertainties, and provide better correlation to aircraft tire braking. Prototype methods that incorporate ground friction measurement devices have shown promising results.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program, led by the National Aeronautics and Space Administration and Transport Canada. Support is received from National Research Council Canada, the US Federal Aviation Administration, Avinor (was the Norwegian Air Traffic and Airport Management), and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Australia, Austria, Canada, Czech Republic, England, France, Germany, Japan, Norway, Scotland, Sweden, Switzerland, and the United States are also participating.

Objectives of the project include:

Compiling a database containing all test data available from ground vehicles and aircraft that participated in the winter and summer runway friction programs.

Using the data to determine a harmonized runway friction index: the International Runway Friction Index (IRFI).

Relating aircraft stopping performance to ground vehicle IRFI.

The objective of this report is to update the 2001 JWRFMP report (TP 14192E) with the data collected, analysis and findings through the year 2002.

Statistical IRFI Model

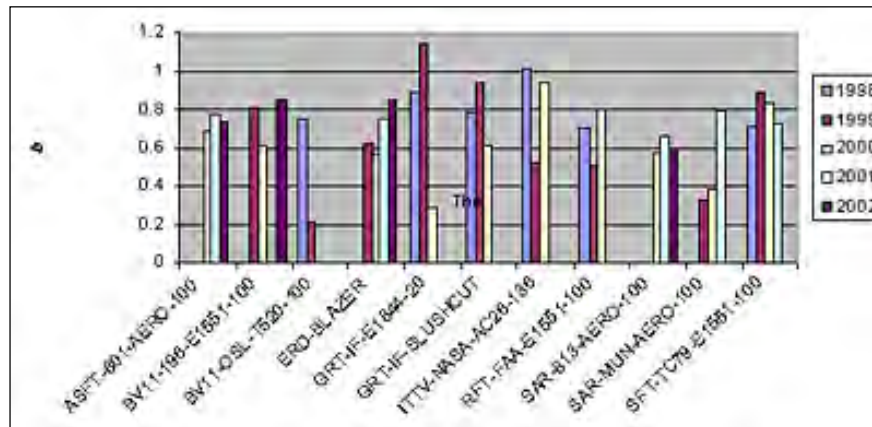
Normally, regression techniques would be used to find relationships between the reported friction values of pairs of ground friction measurement devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. The device, or an algebraic transformation of reported friction values, such as the average friction of two or more devices, would be selected as a reference. All devices would then be compared to the reference device to establish transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step, which can be applied by the aviation community. The following equation represents a linear regression of the data for each device to an IRFI reference:

$$\mu\text{IRFI} = a + b \times \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of measurement devices run in a wave pattern so that they measure the same surface within 15 seconds of each other. However, even with this systematic approach there are considerable variations in the measured surface condition because of the lateral placement of the devices and the resulting effect of surface compaction. The database now includes over 41,000 friction measurements.

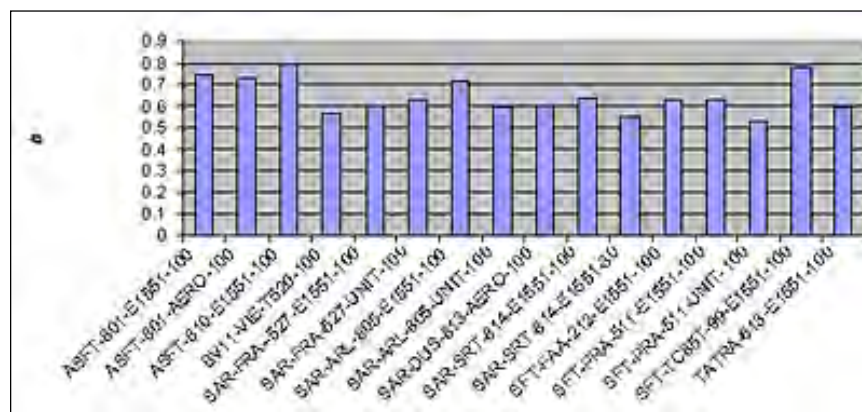
Stability of the Harmonization Method

The correlation constants were calculated for devices that participated in the 1998-1999 test seasons and were reported in the 1997-98 JWRFMP report (TP 13836E). The constants were calculated by combining the two years of data. However, in 2000, it was established that not only does a calibration not apply across similar types of devices, it changes from year to year for a particular device. The figure below shows the variations of the IRFI multiplier b for the past five years (1998 to 2002). IMAG (IRV) is not shown since it is the reference and thus is always $b = 1.0$.



Mutipier b vs. years (1998-2002) by Device

Reproducibility of SARSYS Devices At the 2001 Erding test site four devices of the same brand and type were tested. This enabled a limited study of reproducibility, i.e., how different each device of the same type measured the same surface segments. This was the first opportunity for a reproducibility study in the JWRFMP. In 2002, at Prague, several more SARSYSs, SFTs and ASFTs were tested. The reproducibility from these tests was reported by TICS, a Hungarian Company. The figure below shows the values of b for the different units at the Prague tests in 2002.



2002 Prague tests

With the surfaces available for testing at the Erding site, the SARSYS devices exhibited reproducibility as expressed in standard deviation in the order of 0.08 friction units for ribbed tires and 0.05 for blank tires. The reproducibility varied with changes in friction level for both ribbed and blank tires.

Conclusions and Recommendations

The ASTM standard E 2100 defines and prescribes how to calculate IRFI for winter surfaces. The IRFI is a harmonized reporting index to provide information to aircraft operators of tire-surface friction characteristics in the aircraft movement area.

In addition to reporting surface conditions to aircraft, IRFI can be used by airport maintenance staff to monitor the winter frictional characteristics for surface maintenance actions.

The method evaluates each 100 m (300 ft.) and averages them for each third of the runway. The IRFI method reduces the present variations of the 100 m surface lengths from as much as 0.2 down to typically 0.04. The sampling scheme of a full runway length (spot or continuous measurements) may yield additional variation.

A reference device, which is required for calibration, must be a dedicated device for this purpose only, and the aviation community must agree on its provision, ownership and services. The device chosen for the exercises of the JWRFMP, to demonstrate that IRFI is possible, was an IMAG device called the International Reference Vehicle (IRV). The IRV must be evaluated at some point for stability. All harmonization constants will have to be reworked when a permanent IRFI reference has been designated. In the meantime at least harmonization was demonstrated to work and was accomplished with the devices participating in the JWRFMP.

There is proof that the participating devices in the JWRFMP are not representative of the other devices even when they are of the same generic type. This suggests that harmonization constants must be determined and applied to individual devices, rather than to generic groups of devices, as was done in the past. To accomplish this, a master device can be calibrated to the IRFI reference device in order to serve as a secondary reference and the manufacturer or owner of this secondary reference can then calibrate other devices to this master.

Data was collected with the IRV during the NASA Wallops Runway Friction Workshops and also during the tests at the Jack Garland Airport at North Bay Ontario. Data thus far has shown that summer calibration can be applied to winter conditions. Further testing is recommended for the coming year.

Ongoing work has shown that IRFI can be used to predict aircraft braking performance. This will be discussed in a separate report.

C.4.38 Joint Winter Runway Friction Measurement Program (JWRFMP): 2003 testing and data analysis (TP 14194E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially under winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying natures and qualities that contribute to reduced braking friction capabilities. A service is warranted for the measurement of winter surface friction, because the operational window for aircraft movement can change quite rapidly and frequently in the winter.

In the past, users of friction information have generally perceived the quality of the friction measurement service as poor. Often, these users have indicated that the reported friction values do not represent the actual braking friction that is experienced with aircraft tire braking.

International research of friction measurement confirmed that friction measurement devices measure and report different friction values for the same surface. Differences occurred among units of the same generic device as well as across different device types. The perception of non-uniformity was compounded by surfaces exhibiting large variances in reported values. These variances further augmented the differences among device types.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the highest accuracy, but the procedure is limited to machine component calibrations. Research over the past eight years has made significant advances toward solving these problems. Methods of measurement are being improved to increase measurement quality, remove uncertainties, and provide better correlation to aircraft tire braking. Prototype methods that incorporate ground friction measurement devices have shown promising results.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program, led by the National Aeronautics and Space Administration and Transport Canada. Support is received from National Research Council Canada, the US Federal Aviation Administration, Avinor (was the Norwegian Air Traffic and Airport Management), and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Australia, Canada, Czech Republic, England, France, Germany, Japan, Norway, Scotland, Sweden, Switzerland, and the United States are also participating.

Objectives of the project include:

- Compiling a database containing all test data available from ground vehicles and aircraft that participated in the winter and summer runway friction programs.

- Using the data to determine a harmonized runway friction index: the International Runway Friction Index (IRFI).

- Relating aircraft stopping performance to ground vehicle IRFI.

The objective of this report is to update the 2002 JWRFMP report (TP 14193E) with the data collected, analysis and findings through the year 2003.

Statistical IRFI Model

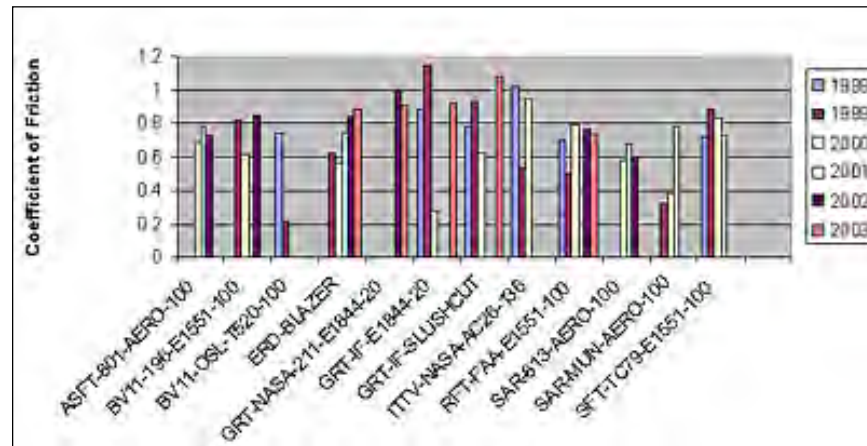
Normally, regression techniques would be used to find relationships between the reported friction values of pairs of ground friction measurement devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. The device, or an algebraic transformation of reported friction values, such as the average friction of two or more devices, would be selected as a reference. All devices would then be compared to the reference device to establish transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step, which can be applied by the aviation community. The following equation represents a linear regression of the data for each device to an IRFI reference:

$$\mu\text{IRFI} = a + b \times \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of measurement devices run in a wave pattern so that they measure the same surface within 15 seconds of each other. However, even with this systematic approach there are considerable variations in the measured surface condition because of the lateral placement of the devices and the resulting effect of surface compaction. The database now includes over 41,000 friction measurements.

Stability of the Harmonization Method

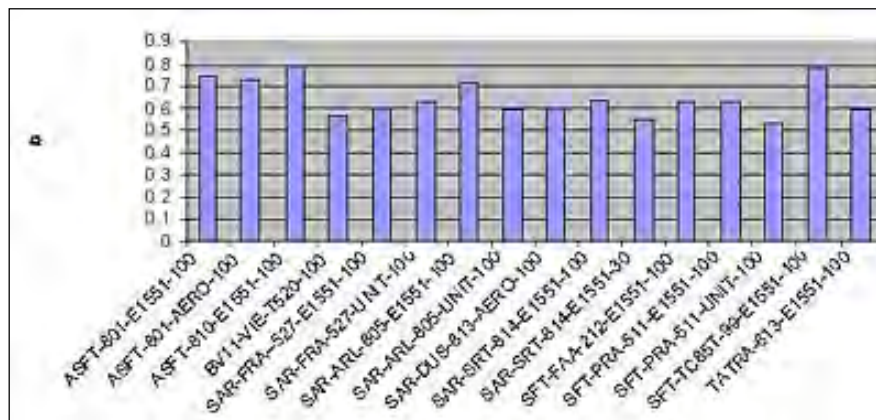
The correlation constants were calculated for devices that participated in the 1998-1999 test seasons and were reported in the 1997-98 JWRFMP report (TP 13836E). The constants were calculated by combining the two years of data. However, in 2000, it was established that not only does a calibration not apply across similar types of devices, it changes from year to year for a particular device. The figure below shows the variations of the IRFI multiplier b for the past six years (1998 to 2003). IMAG (IRV) is not shown since it is the reference and thus b would always be 1.0.



Multiplier b vs. Years (1998-2003) by Device

Reproducibility of SARSYS Devices

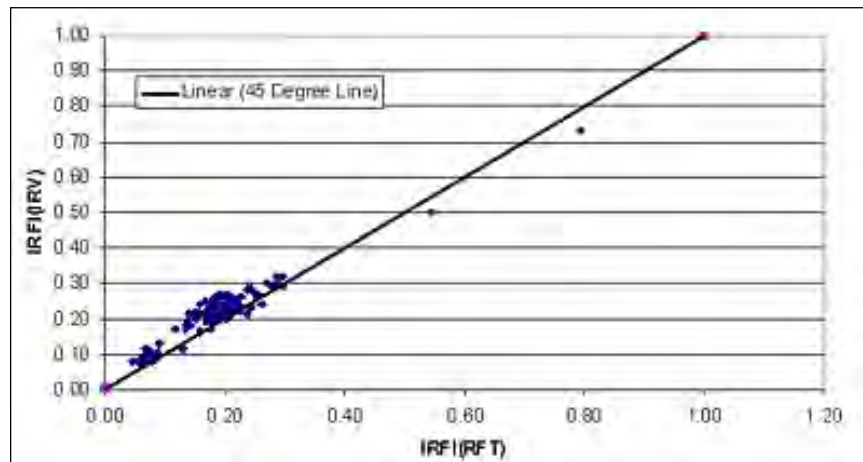
At the 2001 Erding test site, four devices of the same brand and type were tested. This enabled a limited study of reproducibility, i.e., how different each device of the same type measured the same surface segments. This was the first opportunity for a reproducibility study in the JWRFP. In 2002, at Prague, several more SARSYSs, SFTs and ASFTs were tested. The reproducibility from these tests was reported by TICS, a Hungarian Company. The figure below shows the values of b for the different units at the Prague tests in 2002.



2002 Prague tests

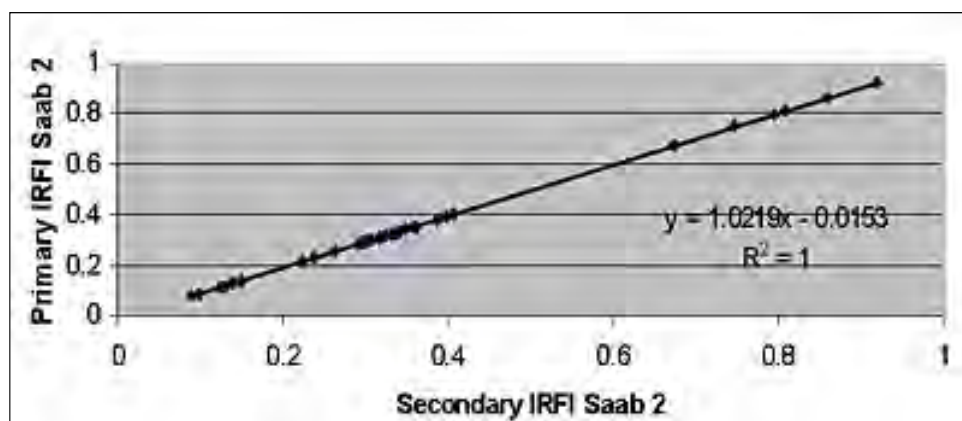
With the surfaces available for testing at the Erding site, the SARSYS devices exhibited reproducibility as expressed in standard deviation in the order of 0.08 friction units for ribbed tires and 0.05 for blank tires. The reproducibility varied with changes in friction level for both ribbed and blank tires.

During the past year, 2002-2003, two sets of tests are noteworthy. First, tests at NASA Wallops have shown that calibrations can be done under wet summer conditions and applied to winter conditions if done in the same year. The figure below shows a summer calibration from NASA Wallops with the winter data superimposed. The significance of this is that annual calibrations for IRFI can be performed in the summer or fall and then applied the coming winter.



IRFI (IRV) vs. IRFI (RFT) summer 2001 calibration and winter 2002 North Bay data

The second test of significance was the calibration of a master device and the use of the master to calibrate a local device. The test was performed in Japan at the New Chitose Airport in February 2003. Two SFTs were first calibrated to the IRV, and the second SFT was calibrated to the first SFT. The figure below shows the primary calibration of the second SFT to IRV versus the calibration of the second SFT (local device) to the first SFT (Master). The tests on the SFT showed that calibrations to a master device were virtually identical to the calibration to the IRV.



Primary IRFI Saab 2 vs. secondary IRFI Saab 2

ASTM Standard

The ASTM standard E 2100 defines and prescribes how to calculate IRFI for winter surfaces. The IRFI is a harmonized reporting index to provide information to aircraft operators of tire-surface friction characteristics of the aircraft movement area.

In addition to reporting surface conditions to aircraft, IRFI can be used by airport maintenance staff to monitor the winter frictional characteristics for surface maintenance actions.

The method evaluates each 100 m (300 ft.) and averages them for each third of the runway. The IRFI method reduces the present variations of the 100 m surface lengths from as much as 0.2 down to typically 0.04. The sampling scheme of a full runway length (spot or continuous measurements) may yield additional variation.

Conclusions and Recommendations

A reference device, which is required for calibration, must be a dedicated device for this purpose only, and the aviation community must agree on its provision, ownership and services. The device chosen for the exercises of the JWRFMP, to demonstrate that IRFI is possible, was an IMAG device called the International Reference Vehicle (IRV). The IRV must be evaluated at some point for stability. If it is not stable with time, other references would need to be investigated. All harmonization constants will have to be reworked when a permanent IRFI reference has been designated. In the meantime at least harmonization was demonstrated to work and was accomplished with the devices participating in the JWRFMP.

There is proof that the participating devices in the JWRFMP are not representative of the other devices even when they are of the same generic type. This suggests that harmonization constants must be determined and applied to individual devices, rather than to generic groups of devices, as was done in the past. To accomplish this, a master device can be calibrated to the IRFI reference device in order to serve as a secondary reference and the manufacturer or owner of this secondary reference can then calibrate other devices to this master. Further, calibrations can be done in the summer.

Data was collected with the IRV during the NASA Wallops Runway Friction Workshops and applied to the coming winter conditions. Further testing is recommended for the coming year.

Ongoing work has shown that IRFI can be used to predict aircraft braking performance. This will be discussed in a separate report.

C.4.39 Joint Winter Runway Friction Measurement Program (JWRFMP): International Runway Friction Index (IRFI) versus aircraft braking coefficient (μ) (TP 14318E)

Summary

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially under winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying natures and qualities that contribute to reduced braking friction capabilities. A service is warranted for the measurement of winter surface friction, because the operational window for aircraft movement can change quite rapidly and frequently in the winter.

In the past, users of friction information have generally perceived the quality of the friction measurement service as poor. Often, these users have indicated that the reported friction values do not represent the actual braking friction that is experienced with aircraft tire braking.

International research of friction measurement confirmed that ground friction measuring devices (GFMD) measure and report different friction values for the same surface. Differences occurred among units of the same generic device as well as across different device types. The perception of non-uniformity was compounded by surfaces exhibiting large variances in reported values. These variances further augmented the differences among device types.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the highest accuracy, but the procedure is limited to machine component calibrations. Research over the past four years has made significant advances toward solving these problems. Methods of measurement are being improved to increase measurement quality, remove uncertainties, and provide better correlation to aircraft tire braking. Prototype methods that incorporate GFMDs have shown promising results.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program, led by the National Aeronautics and Space Administration and Transport Canada. Support is received from National Research Council Canada, the US Federal Aviation Administration, Avinor (formerly the Norwegian Air Traffic and Airport Management), and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Australia, Austria, Canada, Czech Republic, England, France, Germany, Japan, Norway, Scotland, Sweden, Switzerland, and the United States are also participating.

Objectives of the project include:

Compiling a database containing all test data available from ground vehicles and aircraft that participated in the winter and summer runway friction programs.

Using the data to determine a harmonized runway friction index: the International Runway Friction Index (IRFI).

Determining the relationship between aircraft stopping performance and ground vehicle IRFI.

The objective of this report is to present the results of a comparison of aircraft braking performance and the IRFI of ground vehicle measurements.

Statistical IRFI Model

Normally, regression techniques would be used to find relationships between the reported friction values of pairs of ground friction measurement devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. The device, or an algebraic transformation of reported friction values, such as the average friction of two or more devices, would be selected as a reference. All devices would then be compared to the reference device to establish transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step, which can be applied by the aviation community. The following equation represents a linear regression of the data for each device to an IRFI reference:

$$\mu_{\text{IRFI}} = a + b \times \text{device friction measurement}$$

where a is the intercept and b is the gradient that were determined by the regression to the reference device. Past attempts failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of measurement devices run in a wave pattern so that they measure the same surface within 15 seconds of each other. However, even with this systematic approach there are considerable variations in the measured surface condition because of the lateral placement of the devices and the resulting effect of surface compaction. The database now includes over 41,000 friction measurements.

Stability of the Harmonization Method

The correlation constants were calculated for devices that participated in the 1998-1999 test seasons and were reported in the 1997-98 JWRFMP report (TP 13836E). The constants were calculated by combining the two years of data. However, in 2000, it was established that not only does a calibration not apply across similar types of devices, it changes from year to year for a particular device.

IRFI Correlations with Aircraft Braking Performance

The table below compares the zero intercepts and slope multiplier values of each GFMD before and after IRFI is applied. Clearly IRFI reduces the difference of each GFMD when compared to the 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), a 64% reduction in the error.

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

ASTM International Standard

The ASTM Standard E 2100-00 defines and prescribes how to calculate IRFI for winter surfaces. IRFI is a standard reporting index to provide information on tire-surface friction characteristics of the movement area to aircraft operators.

IRFI can be used by airport maintenance staff to monitor the winter frictional characteristics in support of surface maintenance actions.

The IRFI method typically reduces the present variations among different GFMDs from 0.2 down to 0.05 friction units.

Conclusions and Recommendations

A reference device, which is required for calibration, must be a dedicated device for this purpose only, and the aviation community must agree on its provision, ownership and services. The device chosen for the exercises to demonstrate that IRFI is possible was an IMAG device called the International Reference Vehicle (IRV). The IRV must be evaluated at some point for stability. If it is not stable with time, other references would need to be investigated. All harmonization constants will have to be reworked when a permanent IRFI reference has been designated. It is recommended that a reference device:

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.

IRFI does help reduce the differences between GFMDs when correlated to aircraft. The average difference is 0.14 without IRFI and 0.05 with IRFI (absolute error of 0.1), a 64% reduction in the difference. The project has shown that IRFI can be used to predict aircraft braking performance.

C.4.40 Development of a comprehensive method for modelling performance of aircraft tyres rolling or braking on dry and precipitation-contaminated runways (TP 14289E)

Summary

Introduction

Research has led to a substantial accumulation of data that leaves no doubt that contamination from precipitation is a major factor in loss of braking friction and hence in incidents and accidents. However, to date, no simple mathematical model has been developed that enables the quantification of these adverse frictional effects from a minimal set of parameters. This report shows how such a model has been developed and can be justified by reference to a wide range of experimental data. The model incorporates data from experiments as diverse as blocks of rubber sliding on glass to a large transport aircraft braking on a runway covered with up to six inches of snow.

The modelling is dependent on knowledge of eight independent variables:

- (1) Depth of macro-texture
- (11) Depth of contaminant
- (12) Density of contaminant
- (13) Speed
- (14) Tyre inflation pressure
- (15) Vertical loading
- (16) Nominal tyre width
- (17) Nominal tyre diameter

Of these only the first three are related to the runway and its condition. All the other quantities¹ are part of conventional ground performance calculations. Whilst it is not mentioned in the list, the mode of operation of the aircraft antiskid system is also needed; that is, the range of values of slip ratio over which it operates. This too is normally available or, in the case where the system is not torque-limited, can be inferred from tests on a dry runway.

When a flexible tyre is rolled and braked on a paved surface that is covered with either a fluid or a particulate substance, it is assumed that there are three sources for decelerating force:

- (1) Rolling resistance due to the absorption of energy in the tyre carcass;
- (18) Rolling resistance due to moving through or compressing the contaminant;
- (19) Braking resistance due to the frictional interaction between the tyre compound and the pavement.

Total force resisting motion – ignoring aerodynamic and impingement forces – is taken to be the simple sum of these three components with no cross coupling between the forces. This perception forms the basis of the approach adopted in constructing the various parts of the model described here. Furthermore, in order to preserve both simplicity and consistency, careful attention has been paid to ensuring that the more complex cases contain the less complex as defaults. For example, the case of slipping on a flooded runway defaults to static braking friction logically by setting speed and water depth to zero in the model.

In order to maximise the usefulness of the model, the statistical properties of the model are given. Thus, the uncertainty associated with any prediction made using the model can be readily calculated. Consequently, the effects of such uncertainties can be traced through to the performance of either aircraft or ground vehicles.

Rolling On Any Paved Surface

Coefficient of rolling friction on paved runways is shown to correlate with inflation pressure, vertical load and speed. The correlation, which is derived from both single wheel testing and measurements on an aircraft, is acceptable for use as an empirical model. No dependence on the degree of dryness of the surface has been identified.

The uncertainty associated with a value of coefficient of rolling friction calculated from the model is ± 0.0012 at the 95% level of probability. This uncertainty is applicable to the range of conditions likely to be encountered in both aircraft operations and research.

Rolling Through Fluid

Decelerating force on a tyre rolling through water is demonstrated to be dependent on seven readily available, independent variables. The combined effect of these seven variables is not simple. A drag coefficient is therefore defined as a function of the ratio of kinetic pressure and tyre inflation pressure in absolute measure together with tyre geometry and water depth. This drag coefficient is used, together with kinetic pressure and a simple reference area, to calculate drag force. Forces so obtained reflect measured data up to and beyond the observed, characteristic speed for maximum drag, which occurs within the operating range of many tyres.

The effect of slush is verified to be similar to that of water when specific gravity is introduced. However, there is an additional term in the model that accounts for squeezing air from slush and melting the suspended ice.

Random error in calculated drag forces is considered and a simple method is given for calculating the contribution that uncertainty in drag force makes to the statistics of performance estimation.

Rolling Through Snow

A viable mathematical model based on dimensional analysis has been developed to describe the decelerating force acting on an aircraft or a ground vehicle when rolling, unbraked, over a runway contaminated with snow that has been subject only to natural ageing processes. The model is simple in form and accounts for speed, tyre diameter, vertical loading and inflation pressure but depends on knowledge of snow depth and specific gravity. Relevant mechanical properties – shear strength and shear modulus – are predicted through specific gravity, two exponential equations and a probability distribution.

It is shown that the model is applicable across a wide range of tyre geometries, undercarriage designs and a sufficient range of snow specific gravity.

In modest depths of fresh snow, so that $\sigma < 0.2$ and $d < 2$, the model is capable of predicting decelerating force due to rolling to within 2% of aircraft weight at the 95% level of significance. If predictions that are more precise are needed, then specific information on the mechanical properties of the snow is required.

Coefficient of Friction for Static Braking on Dry Runway

Experimental evidence from a variety of sources is used to develop and justify a simple relationship that describes static coefficient of braking friction for aircraft tyres with an uncertainty that adequately reflects the uncertainties in the measuring process. Given vertical load on the tyre and mean bearing pressure, static coefficient of braking friction for aircraft tyres can be calculated with an uncertainty better than ± 0.01 at the 95% level of probability.

For tyres that are typical of those used for specialist ground vehicles, similar relationships are presented but are based on fewer experimental measurements. In these cases, static coefficient of braking friction may also be calculated with an uncertainty better than ± 0.01 at the 95% level of probability.

The simple correlation is ideally suited to be the starting point for development of a model that enables the prediction of coefficient of braking friction over the full operational range of aircraft and ground vehicles.

Coefficient of Friction for Full Skid on Dry Runway

Data from skidding and slipping experiments conducted at NASA Langley are used to substantiate a mathematical description of the effect of speed on coefficient of braking friction in a full skid on dry runways. The formulation is an extension of that used to calculate static coefficient of braking friction.

Although the experimental process led to uncertainties in measured friction coefficient that are larger than those generally expected, use of the correlation as a model results in uncertainties of estimate in the order of ± 0.012 at the 95% level of statistical significance.

Coefficient of Friction for Slipping On Dry Runway

The mathematical model for coefficient of braking friction in a fully developed skid on a dry runway is extended to include the effects of slip ratio by introducing one additional freedom. This model is shown to be consistent with experiment.

Although the scatter of the experimental data about the model is quite large, it is estimated that the uncertainty in an estimate of coefficient of braking friction from the model is in the order of $U[\mu_{\text{SLIP DRY}}] = \pm 0.01$ at the 95% level of significance.

In addition, the model can be used to calculate maximum values of coefficient of braking friction. The uncertainty of this calculation is $U[\mu_{\text{MAX DRY}}] = \pm 0.016$ at the 95% level of significance.

Pressure under Tyre Running on Wet Runway

The three-zone model of the area under the footprint of an aircraft tyre rolling or skidding on a wet runway is used as the basis for a scheme to represent the mean pressures over the footprint.

It is shown that, under static conditions, the tyre inflation pressure – in absolute measure – is a good approximation to the bearing pressure under load. It is argued that the pressure in the region of dry contact may then be equated to that pressure. The pressure in the most forward of the three zones is shown to be identical to the kinetic pressure. A formula that relates the

pressure in the region of viscous contact to kinetic pressure is developed: this formula closely represents a well-established set of measurements made by NASA.

Using the correlations, the uncertainty associated with the calculated mean pressure in any one zone is shown to be $\pm 5 \text{ lbf/in}^2$ at the 95% level of significance.

Coefficient of Friction for Full Skid on Wet Runway

The mathematical model used to describe coefficient of braking friction in full skid on a dry runway is extended to incorporate the effects of wet runways. Data from systematic testing on single wheels are used to show that the model is sufficiently robust to predict coefficients of friction for aviation-style tyres skidding under a wide range of conditions.

Surface finishes for which data have been compared range from smooth concrete through fine-textured asphalts to mixed-aggregate asphalts with good drainage. Although the smooth surfaces are not typical of modern runways, the balance between micro- and macro-texture for all the other surfaces is believed to represent constructions used in current aviation practice.

Investigations of the distribution of measured data about the model show that there is significant between-test and within-test variability for both of the test facilities from which data have been acquired. However, the size of the sample is so large and the data are so extensive in scope that the uncertainty in an estimate of $\mu_{\text{SKID WET}}$ from the model is ± 0.003 at the 95% level of significance over the full operational range of tyres and runways used in civil aviation.

Coefficient of Friction for Slipping on Wet Runway

The mathematical model for coefficient of braking friction in a fully developed skid on a wet runway is amended to include the effects of slip ratio by introducing one additional freedom. This extended model is shown to be consistent with experiment.

Although the scatter of the experimental data about the model is quite large, the comparison with experiment is based on a large sample: it is calculated that the uncertainty in an estimate of coefficient of braking friction from the model is in the order of $U[\mu_{\text{SLIP WET}}]_{0.95} = \pm 0.006$ at the 95% level of significance.

In addition, the model can be used to calculate maximum values of coefficient of braking friction in the wet. Sufficient measurements of this quantity were observed in the series of experiments used to substantiate the modelling; the uncertainty of such a calculation is in the order of $U[\mu_{\text{MAX WET}}]_{0.95} = \pm 0.01$ at the 95% level of significance.

Coefficient of Friction for Braking on Ice- and Snow-covered Runways

The mathematical model developed for braking on dry runways is shown to be capable, with minor modifications, of providing a means of estimating the braking performance of aircraft when operating on runways contaminated with winter precipitation. These modifications are solely to values of reference coefficient of friction.

It is shown that reference coefficient of friction is dependent on ground temperature. However, ground temperature has not been published for many of the experiments considered. As an alternative, three types of “ice” are identified and reference coefficient of friction is shown to be a normally distributed statistic with a mean value that is determined by type.

In addition, it is shown that the model can be used to calculate the James Braking Index and Runway Condition Reading. It is therefore arguable that the reference coefficient of friction can be used as a general Runway Friction Indicator.

C.4.41 Meeting on Aircraft Performance on Contaminated Runways, IMAPCR 2004 (TP 13579)

Preface

IMAPCR 2004 took place in Montreal, Quebec, on 3-5 November 2004. One hundred and fifty delegates from thirteen countries attended the meeting. They included representatives from government, industry, national and international organizations, researchers interested in aircraft operations in severe winter conditions, aircraft certification and operating authorities, aircraft and equipment manufacturers, airport authorities, airlines, pilots' professional associations, and the military.

The meeting's overall objective was to review current and future initiatives for improving our understanding and application of measured runway friction values and related aircraft performance.

This record of proceedings reviews the agenda and the meeting's objectives, and summarizes the presentations and the panel discussions. Presentations and papers are also included.

C.4.42 Effect of surface conditions on the friction coefficients measured on winter surfaces (TP 14220E)

Summary

Introduction

Testing has been under way at North Bay and elsewhere since 1996 as part of the Joint Winter Runway Friction Measurement Program (JWRFMP). The main research objectives are to:

Compare friction readings from various devices

Evaluate the relationship between ground vehicle and aircraft friction coefficients

The results of this testing have led to the generation of a large information database regarding friction coefficients on winter surfaces.

The general objective of this project was to investigate the effect of surface conditions on friction coefficients. The work comprised two general parts: analyses for individual surfaces and correlation analyses.

Analyses for Individual Surfaces

This work investigated the friction coefficients measured for various surface types such as ice, snow, packed snow, and dry and wet pavement. Three devices were analyzed:

- (1) Electronic Recording Decelerometer (ERD)
- (20) Transport Canada's Surface Friction Tester (TC SFT'79)
- (21) Instrument de Mesure Automatique de la Glissance (IMAG)

The following issues were examined:

Range and distribution of friction coefficient values by surface and friction-measuring device

Effect of surface temperature

Effect of snow depth for surfaces with loose snow

The results were compared to the Canadian Runway Friction Index (CRFI) guidelines given in the Aeronautical Information Publication (AIP). The results varied from device to device and from surface to surface, which makes it difficult to infer general conclusions. It was, however, commonly observed that the ranges of values observed in the JWRFMP were larger than those given in the AIP.

Correlation Analyses

This work evaluated the effects of surface conditions on correlations between measurements recorded by the above devices.

Again, the results varied from device to device and from surface to surface, which makes it difficult to infer general conclusions. However, it was noted that:

ERD readings on contaminated surfaces were generally higher and more scattered on contaminated surfaces than those for the TC SFT'79 and the IMAG. This probably reflects the fact that the ERD is a locked-wheel test.

TC SFT'79 and the IMAG showed good correlation for all surfaces.

Recommendations

This was an exploratory project to investigate general trends and relationships. The results obtained here should be followed up with more detailed quantitative analyses to investigate issues such as:

Variability among the results for different surfaces

Degree of confidence that one could have in friction coefficients inferred solely from surface descriptions, in comparison to data obtained with friction-measuring

C.4.43 Evaluation of wide-body aircraft braking performance with the determined runway friction index from tests conducted in Japan in 2003 (TP 14399E)

Summary

Past experience and research clearly demonstrate that a contaminated runway can degrade safety to the point that takeoff and landing can become hazardous. Within the framework of the Joint Winter Runway Friction Measurement Program (JWRFMP), an extensive data collection and analysis study was conducted in Japan during the winter of 2003. The objective of this test program was to achieve a better understanding of how winter runway contaminants can adversely affect aircraft stopping distance through the comparative analysis of real in-service wide-body passenger aircraft landing and ground friction measurement data. Based on the outcome of this study, it is anticipated that more accurate models of the effect of runway contaminants on landing and takeoff performance of aircraft can be developed.

The main objective of this test program was to determine the braking friction value of airplanes such as the B767, B777 or other wide-body aircraft during landing and compare it with the International Runway Friction Index (IRFI) according to the ASTM E2100 standard measured and reported by different ground friction measuring devices. The most important priority of the study was to use actual in-service passenger flights to obtain aircraft braking performance data. To achieve the main objective, the data recorded in the Quick Access Recorder (QAR) from the selected aircraft were collected and analyzed, and the aircraft braking friction was calculated.

According to the original test plan, after each selected wide-body airplane landing, the ERD (Electronic Recorder Decelerometer), IRV (International Reference Vehicle) and the airport's Ground Friction Measuring Device (GFMD) were to make a measurement run and report the IRFI according to ASTM E2100. The reported IRFI and the calculated aircraft braking friction were to be compared to evaluate the IRFI number.

To achieve the project's main objective, the study also included special aircraft measurements, called tare measurements, to obtain the effects of the spoilers, ailerons, flaps and aircraft body with regard to the aerodynamic drag and lift; the effect of the thrust-reverser; and the effects of the wheel drag (rolling resistance).

According to the original test plan, measurements were to be taken at two different locations: New Chitose Airport and Akita Airport. Unfortunately, because of a lack of winter weather conditions, there were no aircraft measurements taken at New Chitose Airport. Winter weather conditions did, however, occur at Akita Airport, where several aircraft landing QAR data sets were recorded together with measurements taken with Akita Airport's SAAB friction measuring device. Furthermore, several tare configuration landings were achieved by aircraft, and the QAR data were collected.

A total of 43 flights were identified as candidates to be included in the study, where the requested procedures were followed on winter surfaces. The flight data recorded in the QAR systems were saved and paired with additional airport data for future analysis. The data validation, checking of actual runway conditions, inspection of the ground friction measurement data, and other consistency assessments eliminated a number of landing data sets.

Of the 43 flights, 10 flights proved to be valid friction limited landings. For these landings, a correlation between the B767-300 and Akita Airport's SAAB friction measuring device was developed, and the obtained correlation coefficient ($R^2 = 0.88$) shows a strong dependence of the aircraft braking friction on the reported ground friction measurements.

Akita Airport's SAAB friction measuring device was not calibrated to report the IRFI. However, it is anticipated that the difference in the result would be only the difference of the correlation values, but that the quality of the correlation (R^2) would be similar or improved.

C.4.44 Friction coefficients for various winter surfaces (TP 14498E)**Abstract**

A large set of field data has been obtained over the past eight years, as part of the Joint Winter Runway Friction Measurement Program (JWRFMP), to define Canadian Runway Friction Indexes (CRFIs) on winter surfaces. The field data from the JWRFMP have been analyzed to update Table 4 of the Aeronautical Information Publication (AIP), which contains representative values for CRFIs on various surfaces.

The JWRFMP data were also used to investigate the effect of surface conditions on CRFIs for: (a) decelerometers; (b) the TC SFT'79, and (c) the combination of the IRV and the IMAG (both force and torque measurements).

C.4.45 Evaluation of Falcon 20 turbojet and DHC-8 series 100 and 400 turbopropeller aircraft safety margins for landings on wet runway surfaces (TP 14627E)

Abstract

Aircraft braking performance tests were conducted on wet runway surfaces with the NRC Falcon 20 research aircraft at the Montreal Mirabel, Ottawa and North Bay airports, and with the Nav Canada DHC-8-100 and Bombardier Aerospace DHC-8-400 aircraft at the Mirabel airport. Saab Surface Friction Tester (SFT) ground friction vehicles were used to measure the friction on the wet runway surfaces for comparison with the aircraft data. Runway texture varied considerably for the four different runways on which tests were conducted, with SFT friction values ranging from less than 0.40 to above 0.90. The Falcon 20 braking coefficients also varied considerably on the different wet runways, and at a given groundspeed, correlated well with the mean SFT measured friction. The DHC-8-100 and DHC-8-400 aircraft braking coefficients were measured only on runway 11/29 at Mirabel; thus, their variation over a wide range of runway textures was not determined from these tests, but is expected to be similar to that of the Falcon 20.

An analysis of Falcon 20 landing distances, using the braking coefficients obtained during the tests on wet surfaces, indicates 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. A similar analysis for the DHC-8-100 and DHC-8-400 aircraft indicates that the current operational dispatch factor of 1.43 for turbopropeller aircraft does not provide an adequate safety margin for landings on wet runways. These conclusions are identical to those made in separate statistical studies done by Transport Canada. Recognizing that a single wet runway factor cannot adequately cover aircraft performance differences as a function of runway texture, a table of wet runway factors for three different runway textures is proposed in this report.

C.4.46 Airport operations under cold weather conditions: Observations on operative runways in Norway (TP 14648E)

Summary

The contamination of runways with snow, ice and slush causes difficulties during airport operations. The presence of such contaminants reduces the attainable friction between aircraft tires and pavement and may drop below a level required for safe and efficient taxiing, take-off, and landing. Therefore, pilots and runway maintenance personnel need to be informed about the actual runway surface conditions. It is a known problem that the conditions reported by friction measurement devices do not always reflect the attainable friction experienced by aircraft. A cause of this discrepancy is the correlation and harmonization issue, addressed by the Joint Winter Runway Friction Measurement Program (JWRFMP). Besides the harmonization and correlation issues, there can be other issues responsible for the discrepancy.

The objective of this study was to highlight issues during cold weather operation of runways that negatively influence the operator's objectives of (1) maintaining runway surface conditions at an acceptable level, and (2) accurately reporting actual runway surface conditions.

Observations were made on two runways (Tromsø and Kirkenes Airports, Norway) that were operative during cold weather conditions. The observations consisted of inspections of runway surface conditions in general, and tracks left by aircraft and friction measurement devices in particular. The observations were supplemented with meteorological data as well as the confirmed departure and arrival times of the aircraft. All collected data were structured as separate case studies. In addition to the case studies, all runway status reports made at Tromsø Airport between 1 November 2004 and 31 March 2005 were analyzed. These give a general description of the surface condition reporting system in practice.

The case studies show situations where the runway surface conditions changed shortly (within 30 minutes) after conditions were reported. These situations occurred during snowfall and when sand was displaced by the engine thrust of operating aircraft. Typically, conditions are reported after the runway is cleaned and prepared, just before reopening for air traffic. The measurements were, therefore, taken on surfaces that were virtually free from snow, and/or surfaces that had been uniformly sanded. As aircraft operations proceeded, the runways became progressively contaminated and sand was displaced to the sides. Under these conditions, the update frequency of the surface condition reports was too low to inform pilots about the actual surface conditions.

During the winter of 2004-2005 the majority (70%) of the runway status reports at Tromsø Airport were updated within a 30 minute to 4 hour period. Only 3.4% of the reports were updated within 30 minutes. When runway surface conditions were reported as "poor" or "unreliable", the runway status reports were updated more frequently: 74% of the reports were updated within a 30 minute to 2 hour period. The percentage of reports that were updated within 30 minutes remained low (6.2%).

The landing of an aircraft on an undisturbed layer of freshly fallen snow showed differences in snow compaction, depending on speed and the use of reversed thrust. Most compaction occurred during taxiing. Compacted snow is persistent and requires repetitive efforts to

improve surface conditions. Hence, if taxiing on the runway surface can be reduced (for example by constructing taxiways along the whole runway length) the runway would be less exposed to snow compaction.

A new sanding method based on a mixture of hot water and sand is being implemented at some airports in Norway, including Kirkenes Airport. With this method, sand is adhered to the runway surface by freeze bonding. This prolongs the effectiveness of the sanding operation and avoids the displacement of sand by wind and engine thrust. An iced runway that was treated with this method maintained good frictional properties four days after the last application. However, besides these good results, an event was documented where the treated surface lost its good frictional properties. This occurred after the runway was cleaned with runway sweepers and ice was deposited on the surface. The large changes in frictional conditions were not detected by the friction measurement device.

C.4.47 Study of warm, pre-wetted sanding method at airports in Norway (TP 14686E)

Summary

A new sanding method has recently been adopted at several Norwegian airports. The method forms an additional tool for winter maintenance (snow and ice control) of compacted snow and ice contaminated runways, taxiways, and aprons. It is based on wetting the sand with hot water before it is applied onto the surface. The added water freezes and binds the sand to the surface. The spreading pattern differs from loose sand applications: the pre-wetted sand deposits in lumps of particles and water, rather than in individual particles.

As the method becomes more regularly used, information is needed regarding the method itself: how and why it works, its performance in practice, optimization, possible negative effects, and limitations. A field study was conducted in the winter of 2005-2006 to answer these questions.

The data collected during the field study included experiences from runway maintenance personnel, observations from an application on compacted snow, practical experiences regarding Foreign Object Damage (FOD), and an aircraft braking test on smooth ice treaded with the new method, in comparison with traditional loose sanding. The study also included a case study, where comments were investigated from pilots who indicated that the runway surface was slipperier than reported in the SNOWTAM reports.

This study was primarily intended to provide information to airport operators and public road administrations who use, or are considering using this sanding method. The scope of the case study is wider and considers the issue of correlation between friction measurement devices and aircraft performance. The use of friction measurement devices as part of the runway surface conditions reporting system is discussed.

Conclusions

The warm, pre-wetted sanding method performs well at airports that operate under prolonged winter conditions. Maintenance personnel that have used the method for at least two winter seasons expressed a very positive general attitude toward the method. The main benefits are: (1) the durability of the result, (2) the larger increase in friction level after a sanding operation, and (3) reduction of sand that is blown to the sides of the runway by the engine thrust of operating aircraft.

The latter benefit shows that the method not only improves the surface conditions in terms of friction level, but also in terms of robustness against air traffic. The robustness of a surface is an important operational quality factor.

There are, however, some concerns regarding the new sanding method, especially with respect to the use of friction measurement devices to describe and report the runway surface conditions. Twelve pilot comments were received at two airports during one winter season, expressing that the runway was slipperier than reported. These comments were investigated as nine independent cases.

In all cases, the measured friction coefficients were high, describing the surface conditions as “medium to good” or “good”. The difference in response between friction measurement and aircraft on the runway surface appears to be the primary cause of the discrepancy between reported and experienced braking action. In 66 percent of the cases, there were clear indications (reduction or loss of directional control at low speeds) that the friction measurement gave a too optimistic picture of the actual situation. In addition, there were clear indications (meteorological and visual) that the surfaces were not as good as suggested by the friction numbers in 66 percent of the cases. These surface conditions involved either ice close to 0°C that was wetted by melt water or precipitation, or conditions where ice deposition from the atmosphere onto the pavement was likely to occur.

When all the available information sources were considered, and not just the friction measurements, it could have been derived that the surface conditions were worse than “medium to good” or “good” in 66 percent of the cases. Hence, in principle, sufficient information was available to expect slippery conditions in these cases. These information sources could be used to form a more complete picture of the whole situation at the airport, but they must be interpreted in a real-time manner. High friction numbers can easily inhibit such critical evaluation because they give the impression that the surface is good.

Practical experience points out that the pavement surfaces have to be properly cleaned before application in order to reduce the risk of foreign object damage (FOD). When the warm, pre-wetted sand is applied on thick, weakly bonded snow surfaces, there is a chance that the lumps will break loose in one piece. Such pieces are large enough to be a FOD threat. In addition, it has to be considered that the freeze bonded sand loosens over time, because the ice that binds the sand to the surface sublimates. Excessive amounts of loose sand on the surface also form a FOD threat. Specifically, during prolonged stable weather conditions the surface may need to be swept in order to reduce the amount of loose sand.

Observations during aircraft braking tests on iced surfaces that were treated with warm, pre-wetted sand in comparison with traditional loose sand showed that the whole interaction between tire, sand, and contaminated pavement changes with the addition of the water. It changes the way in which friction is provided to the aircraft. On the warm, pre-wetted sand, the interaction comprises both loose and fixed sand interaction, rather than only loose sand interaction. Part of the sand remains bonded during the interaction and acts in a similar way as road asperities. These fixed sand particles provide friction by increasing adhesional resistance, rubber hysteresis, and possibly tire wear. But there are also particles that break loose during the interaction. These loose particles provide friction by ploughing into the ice surface. Here, the friction mechanism is primarily ice deformation, rather than rubber deformation (hysteresis and rubber wear).

Recommendations

It is recommended that the risk of FOD be given attention in the education of runway maintenance personnel who use the warm, pre-wetted sanding method.

For research on, and development of, winter maintenance practices (e.g., equipment, procedures, guidelines) it is recommended that the robustness of the surface conditions be considered as a quality factor, in addition to the widely used measured friction coefficient. In practice, surfaces are exposed to different processes that deteriorate the surface conditions. Different surface conditions with initially similar friction levels can have different levels of

robustness. Hence they lose their ability to provide friction in different magnitudes and in different time scales. A surface is only of operational value when it holds its properties over a certain period of time.

To further optimize the performance of warm, pre-wetted sanding on thick compacted snow layers, it is recommended that a study be conducted on controlling the water/sand penetration into the snow by reducing the water temperature. However, this is recommended for road applications only, due to the increased risk of lumps that break loose in one piece.

For the exploration of alternative approaches to the current surface conditions reporting system, it is recommended that criteria be systematically defined to suggest slippery conditions based on meteorological data and visual observations at the airport. These criteria should be based on maintenance experiences and combined with meteorological and tribological knowledge of, and insights into the mechanical behaviour of snow and ice.

It is also recommended that a study be conducted on ways in which runway maintenance personnel could track the dew point of the air just above the pavement, in relation to the actual pavement surface temperature. This information makes the identification of ice deposition conditions possible. Such a study should address the accuracy that can be achieved with modern measuring techniques under the restricted possibilities for measurements in movement areas.

APPENDIX D – RUNWAY CONDITION REPORTING FORMS AND FORMATS

Contents:

- Figure D.1: ICAO SNOWTAM Form (from ICAO Airport Services Manual)
- Figure D.2: Instructions for Completing the ICAO SNOWTAM (ICAO Annex 15, App.2)
- Figure D.3: Transport Canada Aircraft Movement Surface Condition Report (AMSCR) Form
- Figure D.4: Form Used by Geneva Airport
- Figure D.5: Form Used by Nuernberg Airport
- Figure D.6: SNOCLO (from German AIP)
- Figure D.7: Format from Japanese AIP
- Table D.1: Detailed Summaries of RCR for Winter Contaminants

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 (Time of completion of measurement in UTC))	B)	→
(RUNWAY DESIGNATORS)	C)	→
(CLEARED RUNWAY LENGTH, IF LESS THAN PUBLISHED LENGTH (m))	D)	→
(CLEARED RUNWAY WIDTH, IF LESS THAN PUBLISHED WIDTH (m; if offset left or right of centre line add "L" or "R"))	E)	→
(DEPOSITS OVER TOTAL RUNWAY LENGTH (Observed on each third of the runway, starting from threshold having the lower runway designation number)) NIL — CLEAR AND DRY 1 — DAMP 2 — WET or water patches 3 — RIME OR FROST COVERED (depth normally less than 1 mm) 4 — DRY SNOW 5 — WET SNOW 6 — SLUSH 7 — ICE 8 — COMPACTED OR ROLLED SNOW 9 — FROZEN RUTS OR RIDGES	F)	→
(MEAN DEPTH (mm) 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 (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)	H)	→
(CRITICAL SNOWBANKS (If present, insert height (cm)/distance from the edge of runway (m) followed by "L", "R" or "LR" if applicable))	J)	→
(RUNWAY LIGHTS (If obscured, insert "YES" followed by "L", "R" or both "LR" if applicable))	K)	→
(FURTHER CLEARANCE (If planned, insert length (m)/width (m) to be cleared or if to full dimensions, insert "TOTAL"))	L)	→
(FURTHER CLEARANCE EXPECTED TO BE COMPLETED BY ... (UTC))	M)	→
(TAXIWAY (If no appropriate taxiway is available, insert "NO"))	N)	→
(TAXIWAY SNOWBANKS (If more than 60 cm, insert "YES" followed by distance apart, m))	P)	→
(APRON (If unusable, insert "NO"))	R)	→
(NEXT PLANNED OBSERVATION/MEASUREMENT IS FOR) (month/day/hour in UTC)	S)	→
(PLAIN LANGUAGE REMARKS (Including contaminant coverage and other operationally significant information, e.g. sanding, de-icing))	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 (not for transmission)

Figure D.1: ICAO SNOWTAM Form (from ICAO Airport Services Manual)

INSTRUCTIONS FOR THE COMPLETION OF THE SNOWTAM FORMAT

1. General

- a) When reporting on two or three runways, repeat Items C to P inclusive.
- b) Items together with their indicator must be dropped completely, where no information is to be included.
- c) Metric units must be used and the unit of measurement not reported.
- d) The maximum validity of SNOWTAM is 24 hours. New SNOWTAM must be issued whenever there is a significant change in conditions. The following changes relating to runway conditions are considered as significant:
 - 1) a change in the coefficient of friction of about 0.05;
 - 2) changes in depth of deposit greater than the following: 20 mm for dry snow, 10 mm for wet snow, 3 mm for slush;
 - 3) a change in the available length or width of a runway of 10 per cent or more;
 - 4) any change in the type of deposit or extent of coverage which requires reclassification in Items F or T of the SNOWTAM;
 - 5) when critical snow banks exist on one or both sides of the runway, any change in the height or distance from centre line;
 - 6) any change in the conspicuity of runway lighting caused by obscuring of the lights;
 - 7) any other conditions known to be significant according to experience or local circumstances.

- e) The abbreviated heading "TTAAiiii CCCC MMYYGggg (BBB)" is included to facilitate the automatic processing of SNOWTAM messages in computer data banks. The explanation of these symbols is:

TT = data designator for SNOWTAM = SW;

AA = geographical designator for States, e.g. LF = FRANCE, EG = United Kingdom (see *Location Indicators* (Doc 7910), Part 2, Index to Nationality Letters for Location Indicators);

iiii = SNOWTAM serial number in a four-figure group;

CCCC = four-letter location indicator of the aerodrome to which the SNOWTAM refers (see *Location Indicators* (Doc 7910));

MMYYGGgg = date/time of observation/measurement, whereby:

MM = month, e.g. January = 01,

December = 12

YY = day of the month

GGgg = time in hours (GG) and minutes (gg) UTC;

(BBB) = optional group for:

Correction to SNOWTAM message previously disseminated with the same serial number = COR.

Note.— Brackets in (BBB) are used to indicate that this group is optional.

Example: Abbreviated heading of SNOWTAM No. 149 from Zurich, measurement/observation of 7 November at 0620 UTC:

SWLS0149 LSZH 11070620

2. *Item A* — Aerodrome location indicator (four-letter location indicator).
3. *Item B* — Eight-figure date/time group — giving time of observation as month, day, hour and minute in UTC; this item must always be completed.
4. *Item C* — Lower runway designator number.
5. *Item D* — Cleared runway length in metres, if less than published length (see Item T on reporting on part of runway not cleared).
6. *Item E* — Cleared runway width in metres, if less than published width; if offset left or right of centre line, add "L" or "R", as viewed from the threshold having the lower runway designation number.
7. *Item F* — Deposit over total runway length as explained in SNOWTAM Format. Suitable combinations of these

Figure D.2: Instructions for Completing the ICAO SNOWTAM (Annex 15, App. 2)

Chapter 6. NOTAM

Appendix A NOTAM, SNOWTAM and ASHTAM

6-A-15

numbers may be used to indicate varying conditions over runway segments. If more than one deposit is present on the same portion of the runway, they should be reported in sequence from the top to the bottom. Drifts, depths of deposit appreciably greater than the average values or other significant characteristics of the deposits may be reported under Item I in plain language.

Note.— Definitions for the various types of snow are given at the end of this Appendix.

8. *Item G* — Mean depth in millimetres deposit for each third of total runway length, or “XX” if not measurable or operationally not significant; the assessment to be made to an accuracy of 20 mm for dry snow, 10 mm for wet snow and 3 mm for slush

9. *Item H* — Friction measurements on each third of the run-way and friction measuring device. Measured or calculated coefficient (two digits) or, if not available, estimated surface friction (single digit) in the order from the threshold having the lower runway designation number. Insert a code 9 when surface conditions or available friction measuring device do not permit a reliable surface friction measurement to be made. Use the following abbreviations to indicate the type of friction measuring device used:

BRD	Brakemeter Dynamometer
GRT	Grip tester
MUM	Mu-meter
RFT	Runway friction tester
SFH	Surface friction tester (high-pressure tire)
SFL	Surface friction tester (low-pressure tire)
SKH	Skiddometer (high-pressure tire)
SKL	Skiddometer (low-pressure tire)
TAP	Tapley meter

If other equipment is used, specify in plain language.

10. *Item J* — Critical snowbanks. If present insert height in centimetres and distance from edge of runway in metres, followed by left (“L”) or right (“R”) side or both sides (“LR”), as viewed from the threshold having the lower runway designation number.
11. *Item K* — If runway lights are obscured, insert “YES” followed by “L”, “R” or both “LR”, as viewed from the threshold having the lower runway designation number.
12. *Item L* — When further clearance will be undertaken, enter length and width of runway or “TOTAL” if runway will be cleared to full dimensions.

13. *Item M* — Enter the anticipated time of completion in UTC.

14. *Item N* — The code for Item F may be used to describe taxiway conditions; enter “NO” if no taxiways serving the associated runway are available.

15. *Item P* — If applicable, enter “YES” followed by the lateral distance in metres.

16. *Item R* — The code for Item F may be used to describe apron conditions; enter “NO” if the apron is unusable.

17. *Item S* — Enter the anticipated time of next observation/measurement in UTC.

18. *Item T* — Describe in plain language any operationally significant information but always report on length of uncleared runway (Item D) and extent of runway contamination (Item F) for each third of the runway (if appropriate) in accordance with the following scale:

Runway contamination — 10% — if less than 10% of runway contaminated
Runway contamination — 25% — if 11-25% of runway contaminated
Runway contamination — 50% — if 26-50% of runway contaminated
Runway contamination — 100% — if 51-100% of runway contaminated.

EXAMPLE OF COMPLETED SNOWTAM FORMAT

GG EHAMZQZX EDDFZQZX EKCHZQZX
070645 LSZHNYX
SWLS0149 LSZH 11070620
(SNOWTAM 0149

A) LSZH B) 11070620 C) 02 D) ... P)
C) 09 D) P)
C) 12 D) ... P)
R) NO S)11070920 T) DEICING)

Definitions of the various types of snow

Slush. Water-saturated snow which with a heel-and-toe slap-down motion against the ground will be displaced with a splatter; specific gravity: 0.5 up to 0.8.

Note.— Combinations of ice, snow and/or standing water may, especially when rain, rain and snow, or snow is falling, produce substances with specific gravities in excess of 0.8. These substances, due to their high water/ice content, will have a transparent rather than a cloudy

Figure D.2 (cont'd): Instructions for Completing the ICAO SNOWTAM (Annex 15, App. 2)

appearance and, at the higher specific gravities, will be readily distinguishable from slush.

Snow (on the ground).

- appearance and, at the higher specific gravities, will be readily distinguishable from slush.
- Wet snow (on the ground).*
- a) *Dry snow.* Snow which can be blown if loose or, if compacted by hand, will fall apart again upon release; specific gravity: up to but not including 0.35.
- b) *Wet snow.* Snow which, if compacted by hand, will stick together and tend to or form a snowball; specific gravity: 0.35 up to but not including 0.5.
- c) *Compacted snow.* Snow which has been compressed into a solid mass that resists further compression and will hold together or break up into lumps if picked up; specific gravity: 0.5 and over.

END OF INSTRUCTIONS

Figure D.2 (cont'd): Instructions for Completing the ICAO SNOWTAM (Annex 15, App. 2)

[illegible]

Figure D.3: Transport Canada Aircraft Movement Surface Condition Report (AMSCR)

			Runway Report								
Report N°:			Runway 05								
Date :			Time of check :			UTC					
Available length :			Available width :								
1 st part	2 nd part	3 rd part				1 st part mm	2 nd part mm	3 rd part mm			
☐	☐	☐	Clear and dry			NIL	NIL	NIL			
☐	☐	☐	Rime / Frost								
☐	☐	☐	Dry snow								
☐	☐	☐	Compacted snow								
☐	☐	☐	Ice								
☐	☐	☐	Frozen ruts / Ridges								
☐			Friction Coefficient (SFT)								
☐	☐	☐	Deiced			NIL	NIL	NIL			
☐	☐	☐	Wet / Damp / Wet snow / Slush 3 mm or less								
☐			Friction Coefficient and Braking Action NOT REPORTED								
☐	☐	☐	Wet snow more than 3 mm								
☐	☐	☐	Slush more than 3 mm								
☐	when contamination	0 - 50 %	Friction Coefficient and Braking Action UNRELIABLE								
☐		51 - 100 %	Friction Coefficient Not Reported / Braking Action POOR								
☐ % of Runway contamination			☐ 0 - 10		☐ 11 - 25		☐ 25 - 50		☐ 51 - 100		
☐ Height of critical snow-banks on the Runway (cm)			Left :		cm		Right :		cm		
☐ Taxiways covered with:			up to		mm		Breaking action				
☐ Critical Snow-banks on Taxiways			> 60		cm		Available width		m		
☐ Closed Taxiways			A	B	C	D	E	F	G	Y	Z
☐ Closed Links and Taxi-lanes			INNER	OUTER	1	2	3	4	5		
☐ Apron covered with :			up to		mm		Breaking action				
☐			TAXI WITH CAUTION								
Tel. 8232 MOTNE			__		__		__		at: UTC		
Name + Signature of Runway Agent			/								
Name + Signature of AAU Agent			/								

Figure D.4: Form Used by Geneva Airport



Airport Nürnberg

Messfahrt Piste									
Surface Friction Tester				VVÜ:					
Datum									
Messbereich 5m RCL									
	Süd 60km/h		Nord 60km/h		Süd 96km/h		Nord 96km/h		
Pistenabschnitt A (Aiming Point 10)									
Pistenabschnitt B (Mittelstück Piste)									
Pistenabschnitt C (Aiming Point 28)									
Messwert Total									
Messbereich 12-15m RCL									
	Süd 60km/h		Nord 60km/h		Süd 96km/h		Nord 96km/h		
Pistenabschnitt A (Aiming Point 10)									
Pistenabschnitt B (Mittelstück Piste)									
Pistenabschnitt C (Aiming Point 28)									
Messwert Total									
Durchschnittlicher Gesamtwert Piste									
5m RCL				12-15m RCL					
	60km/h		96km/h			60km/h		96km/h	
Pistenabschnitt A						Pistenabschnitt A			
Pistenabschnitt B						Pistenabschnitt B			
Pistenabschnitt C						Pistenabschnitt C			
Total						Total			
Teststreifen									
Testausrüstung	Typ	Druck (kPa)	Testge- schwin- digkeit (km/h)	Test Wasser- tiefe (mm)	Aufbau Planziel für neue Ober- fläche	Planungs- schwelle Wartung	Mindest- reibungs- schwelle		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)		
Surface Friction	B	700	65	1,0	0,82	0,60	0,50		
Messgerätsfahrzeug	B	700	95	1,0	0,74	0,47	0,34		
Bemerkungen: Die Messfahrt wurde gem. Annex14 bei trockener Piste und unter Zugabe von 1mm Wasser durchgeführt.									

Figure D.5: Form Used by Nuernberg Airport

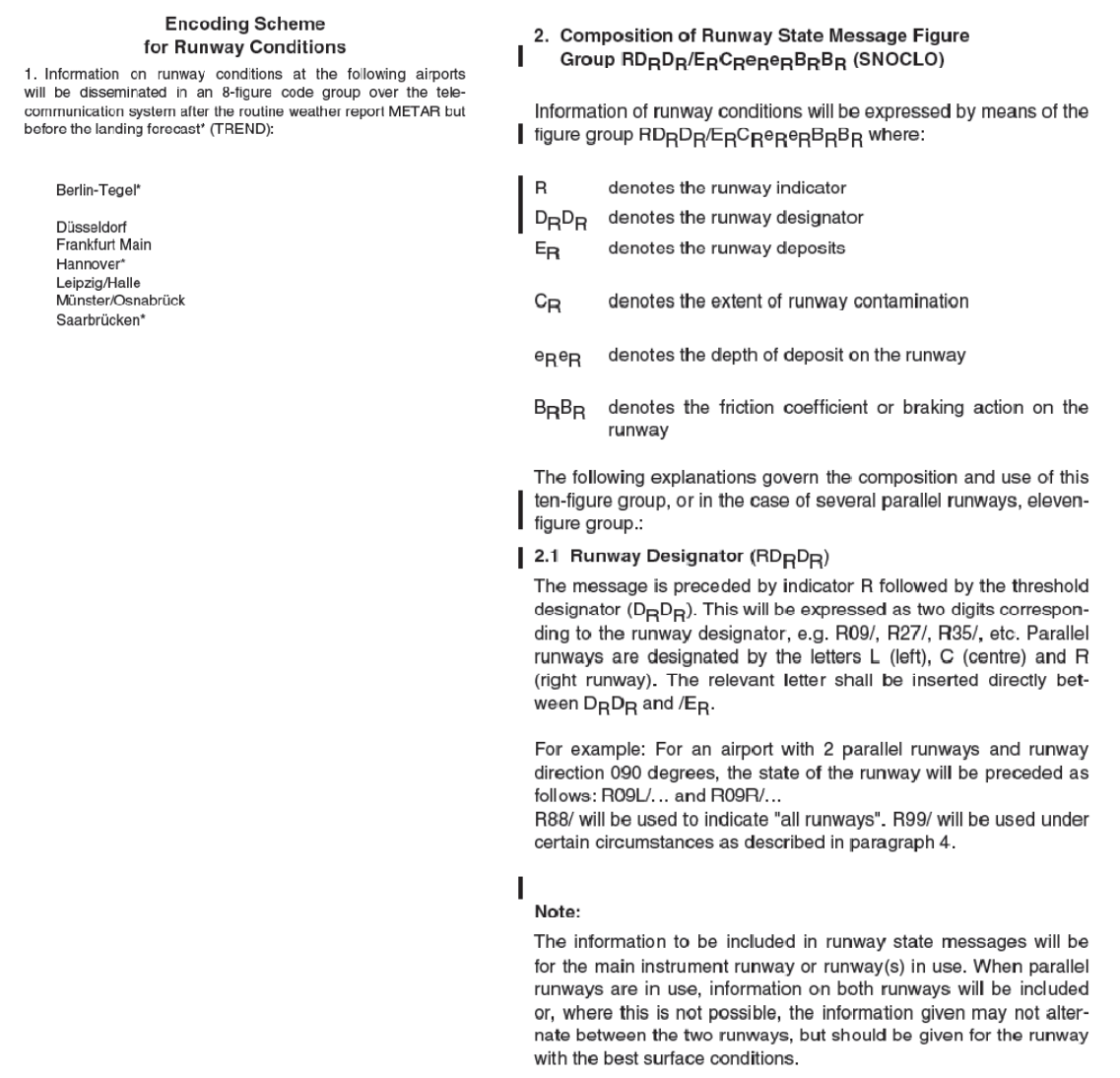


Figure D.6: SNOCLO (from German AIP)

2.2 Type of Deposits on the Runway (E_P)

The type of deposits on the RWY will be indicated by the digits 0 to 9 or a slash (/) in accordance with the following scale as follows:

- 0 – Dry and clear of deposits
- 1 – Damp
- 2 – Wet or water patches
- 3 – Rime or frost (depth normally less than 1 mm)
- 4 – Dry snow
- 5 – Wet snow
- 6 – Slush
- 7 – Ice
- 8 – Compact or rolled snow
- 9 – Frozen ruts
- / – Type of deposits not reported (e.g. due to runway clearance).

2.3 Extent of Contamination through Deposits on the RWY (C_P)

The extent of contamination through deposits on the runway is indicated in percentages in accordance with the following scale: It will be expressed as a single digit:

- 1 – up to 10% of runway contaminated (covered)
- 2 – more than 10% to 25% of runway contaminated (covered)
- 5 – more than 25% to 50% of runway contaminated (covered)
- 9 – more than 50% to 100% of runway contaminated (covered)
- / – not reported (e.g. due to runway clearance in progress)

2.4 Depth of Deposits on the Runway (a_{RP})

This will be denoted by two digits in accordance with the following scale:

- 00 – less than 1 mm
- 01 – 1 mm
- 02 – 2 mm
- etc.
- 10 – 10 mm
- etc.
- 15 – 15 mm
- etc.
- 20 – 20 mm
- etc. up to
- 90 – 90 mm

thereafter:

- 92 – 10 cm
- 93 – 15 cm
- 94 – 20 cm
- 95 – 25 cm
- 96 – 30 cm
- 97 – 35 cm
- 98 – 40 cm or more
- 99 – runway or runways non-operational due to snow, slush, ice or large drifts, depth, runway clearance.

// – depth of deposit operationally not significant or not measurable.

Note A:

This does not necessarily require depth to be measured to a millimetre unit. Larger intervals up to 90 can be expressed by using the above direct-reading scale.

Note B:

Where depth is measured at a number of points along a runway the average value should be transmitted or, if operationally significant, the highest value.

Note C:

Code Figure 91 is not used. Code Figures 92 to 98 permit the depth of deposit (in cm) to be derived by multiplying the last digit by 5 (e.g. 94 = 4 x 5 = 20).

Note D:

If deposits of the type reported by the code figures 3, 7, 8 and 9 of code ER are reported, the depth of deposits is normally not significant and two oblique strokes (//) will be reported. Similarly, the depth of standing water will only be reported if an accurate and representative measurement is guaranteed.

2.5 Friction Coefficient or Braking Action on the Runway (B_{RB})

This will be denoted by two digits corresponding to the friction coefficient or, if not available, the estimated braking action, in accordance with the following:

B _{RB} - Friction Coefficient or Braking Action on the Runway	
Key code	Meaning
00	Friction coefficient 0,00
01	Friction coefficient 0,01
02	Friction coefficient 0,02
...	...
50	Friction coefficient 0,50
...	...
89	Friction coefficient 0,89
90	Friction coefficient 0,90
91	Braking action poor
92	Braking action poor to medium
93	Braking action medium
94	Braking action medium to good
95	Braking action good
96 to 98	free
99	Values unreliable
//	Braking conditions not determined and/or runway not operational

Figure D.6 (cont'd): SNOCLO (from German AIP)

Erläuterungen zu den in der $B_R B_R$ -Tabelle angegebenen Reibungskoeffizienten: /
Explanations concerning friction coefficients shown in the $B_R B_R$ table:

Schlüsselzahl / code figure	Gemessener Reibungskoeffizient / measured friction coefficient	Entspricht einer geschätzten Bremswirkung / in accordance to an estimated braking action
25 und kleiner / 25 and below	$\leq 0,25$	schlecht / poor
26 bis / up to 29	0,26 bis / up to 0,29	schlecht bis mittelmäßig / poor to medium
30 bis / up to 35	0,30 bis / up to 0,35	medium
36 bis / up to 39	0,36 bis / up to 0,39	medium to good
40 und größer / and above	$\geq 0,40$	gut / good

Note A:

Where braking action is assessed at a number of points along a runway, the mean value should be transmitted or, if operationally significant, the lowest value.

Note B:

If measuring equipment does not allow measurement of friction with satisfactory reliability, which may be the case when a runway is contaminated by wet snow, slush or loose snow, the figures 99 will be reported.

Note C:

If the braking conditions cannot be reported (e.g. due to runway clearance in progress, runway not operational, runway conditions not watched during airport closure, etc.) two oblique strokes (/ /) will be entered.

2.6 Utilization of R/SNOCLO

The designation „R/SNOCLO“ (closed due to snow), indicated in a condition report, signifies that the airport is closed due to snow on the runway(s). This information shall also be distributed by VOLMET.

3. Explanations Regarding the Validity of Runway Conditions

A report from the aerodrome operator will be distributed in METAR as being valid as long as it is stipulated in ICAO Annex 15 regarding the issuance of SNOWTAM messages:

The maximum validity of a SNOWTAM is 24 hours. A new SNOWTAM must be issued if the runway condition changes significantly. The following changes concerning the runway are recognized as being significant:

- The friction coefficient changes by more than 0.05.
- The depth of deposits on the runway ($e_{R\bar{e}R}$) changes as follows: more than 20 mm in the case of dry snow, more than 10 mm in the case of wet snow, more than 3 mm in the case of slush.
- A change in the available length of the runway by 10% or more. This is also the case when changing the take-off and landing direction.
- A change of the runway deposits (E_R) or the extent of runway contaminations (C_R), which results in a change of the key figures.
- If critical snow masses exist on one or both sides of the runway and the depth of the deposits or the distance to the runway centre line varies. This is also the case when changing the take-off and landing direction.
- If changes occur concerning the ability of the runway lighting to be recognized.
- If any other significant changes are made known, which are regulated by local provisions.

Figure D.6 (cont'd): SNOCLO (from German AIP)

AIP Japan

AD1.2-1

A D 1. 2 救難及び消火並びに雪対策

AD1.2 Rescue, Fire Fighting, and Snow Plan

1. 救難及び消火

各空港の消火能力についてはA D 2 及びA D 3 を参照のこと。
と。 一時的変更については、ノータムにより通知される。

1. Rescue and Fire Fighting

Fire protection at each aerodrome are edited to
AD2 and AD3. Temporary
change of category is notified by NOTAM.

2. 空港における雪氷対策

国内配布用のノータムで通報される雪氷情報は次の記号を
使用する。

2. Information of Snow and Ice Condition in Aerodrome

The information concerning Snow and Ice condition
distributed by domestic
NOTAM will apply the following marks.

滑走路積雪等の状態 (A地区: 滑走路少数番号側 1/3 部分)

積雪量	積雪等の種類	測定器によるブレーキング・アクション	積雪又は凍結の割合
A1 積雪なし	B1 Dry snow	C1 Good $\mu = 0.40$ 以上	D1 20% 未満
A2 積雪平均 80mm 未満	B2 Wet *	C2 Medium to good $\mu = 0.36$ *	D2 40% *
A3 * 100mm *	B3 Slush	C3 Medium $\mu = 0.30$ *	D3 60% *
A4 * 150mm *	B4 Compacted snow	C4 Medium to poor $\mu = 0.26$ *	D4 80% *
A5 * 200mm *	B5 Ice	C5 Poor $\mu = 0.20$ *	D5 80% 以上
A6 * 200mm 以上	B6 ———	C6 Very poor $\mu = 0.20$ 未満	D6 100%

滑走路積雪等の状態 (B地区: 滑走路中央1/3部分)

積雪量	積雪等の種類	測定器によるブレーキング・アクション	積雪又は凍結の割合
E1 積雪なし	F1 Dry snow	G1 Good $\mu = 0.40$ 以上	H1 20% 未満
E2 積雪平均 80mm 未満	F2 Wet *	G2 Medium to good $\mu = 0.36$ *	H2 40% *
E3 * 100mm *	F3 Slush	G3 Medium $\mu = 0.30$ *	H3 60% *
E4 * 150mm *	F4 Compacted snow	G4 Medium to poor $\mu = 0.26$ *	H4 80% *
E5 * 200mm *	F5 Ice	G5 Poor $\mu = 0.20$ *	H5 80% 以上
E6 * 200mm 以上	F6 ———	G6 Very poor $\mu = 0.20$ 未満	H6 100%

滑走路積雪等の状態 (C地区: 滑走路多数番号側 1/3 部分)

積雪量	積雪等の種類	測定器によるブレーキング・アクション	積雪又は凍結の割合
I1 積雪なし	J1 Dry snow	K1 Good $\mu = 0.40$ 以上	L1 20% 未満
I2 積雪平均 80mm 未満	J2 Wet *	K2 Medium to good $\mu = 0.36$ *	L2 40% *
I3 * 100mm *	J3 Slush	K3 Medium $\mu = 0.30$ *	L3 60% *
I4 * 150mm *	J4 Compacted snow	K4 Medium to poor $\mu = 0.26$ *	L4 80% *
I5 * 200mm *	J5 Ice	K5 Poor $\mu = 0.20$ *	L5 80% 以上
I6 * 200mm 以上	J6 ———	K6 Very poor $\mu = 0.20$ 未満	L6 100%

滑走路面の状況

A地区	B地区	C地区
M1 吹きだまりがある	N1 吹きだまりがある	O1 吹きだまりがある
M2 表面は平らである	N2 表面は平らである	O2 表面は平らである
M3 凸凹又は高低がある	N3 凸凹又は高低がある	O3 凸凹又は高低がある
M4 雪が凝固した部分がある	N4 雪が凝固した部分がある	O4 雪が凝固した部分がある
M5 氷面に雪がおおっている部分がある	N5 氷面に雪がおおっている部分がある	O5 氷面に雪がおおっている部分がある
M6 氷面がとけて水になっている	N6 氷面がとけて水になっている	O6 氷面がとけて水になっている

Civil Aviation Bureau, Japan (EFF:1 JAN 1998)

6/11/97

Figure D.7: Format from Japanese AIP

AD 1.2-2

AIP Japan

2. Information of Snow and Ice condition on aerodrome

The information concerning Snow and Ice condition distributed by domestic NOTAM will apply the following marks.

RWY condition with snow fall (A area: The first one third of small numbered RWY)

Mean depth of snow		Class of snow		Braking action obtained by measuring equipment		Percentage of snow/ice coverage	
A1	Clear	B1	Dry snow	C1	Good $\mu = 0.40$ or more	D1	Portion covered with Snow/ice less than 20%
A2	Less than 80mm	B2	Wet	C2	Medium to good $\mu = 0.36$ or more	D2	40%
A3	100mm	B3	Slush	C3	Medium $\mu = 0.30$ or more	D3	60%
A4	150mm	B4	Compacted snow	C4	Medium to poor $\mu = 0.26$ or more	D4	80%
A5	200mm	B5	Ice	C5	Poor $\mu = 0.20$ or more	D5	80% or more
A6	200mm or more	B6	—	C6	Very poor $\mu = \text{less than } 0.20$	D6	100%

RWY condition with snow fall (B area: The middle one third of RWY)

Mean depth of snow		Class of snow		Braking action obtained by measuring equipment		Percentage of snow/ice coverage	
E1	Clear	F1	Dry snow	G1	Good $\mu = 0.40$ or more	H1	Portion covered with Snow/ice less than 20%
E2	Less than 80mm	F2	Wet	G2	Medium to good $\mu = 0.36$ or more	H2	40%
E3	100mm	F3	Slush	G3	Medium $\mu = 0.30$ or more	H3	60%
E4	150mm	F4	Compacted snow	G4	Medium to poor $\mu = 0.26$ or more	H4	80%
E5	200mm	F5	Ice	G5	Poor $\mu = 0.20$ or more	H5	80% or more
E6	200mm or more	F6	—	G6	Very poor $\mu = \text{less than } 0.20$	H6	100%

RWY condition with snow fall (C area: The first one third of large numbered RWY)

Mean depth of snow		Class of snow		Braking action obtained by measuring equipment		Percentage of snow/ice coverage	
J1	Clear	J1	Dry snow	K1	Good $\mu = 0.40$ or more	L1	Portion covered with Snow/ice less than 20%
J2	Less than 80mm	J2	Wet	K2	Medium to good $\mu = 0.36$ or more	L2	40%
J3	100mm	J3	Slush	K3	Medium $\mu = 0.30$ or more	L3	60%
J4	150mm	J4	Compacted snow	K4	Medium to poor $\mu = 0.26$ or more	L4	80%
J5	200mm	J5	Ice	K5	Poor $\mu = 0.20$ or more	L5	80% or more
J6	200mm or more	J6	—	K6	Very poor $\mu = \text{less than } 0.20$	L6	100%

Condition of RWY surface

A area		B area		C area	
M1	Snow drifted	N1	Snow drifted	O1	Snow drifted
M2	Surface even	N2	Surface even	O2	Surface even
M3	Surface rough	N3	Surface rough	O3	Surface rough
M4	Partially covered with frozen snow	N4	Partially covered with frozen snow	O4	Partially covered with frozen snow
M5	Frozen surface partially covered with snow	N5	Frozen surface partially covered with snow	O5	Frozen surface partially covered with snow
M6	Frozen surface covered with water	N6	Frozen surface covered with water	O6	Frozen surface covered with water

Civil Aviation Bureau, Japan (EFF: 1 JAN 1998)

6/11/97

AIP Japan

AD 1.2-3

滑走路のスノーバンクの状態

高 さ		間 隔	
P1	スノーバンクなし	Q1	最少 85 m 以上
P2	最高 0.5 m 未満	Q2	◇ 70 m ◇
P3	◇ 1.0 m ◇	Q3	◇ 55 m ◇
P4	◇ 2.0 m ◇	Q4	◇ 40 m ◇
P5	◇ 4.0 m ◇	Q5	◇ 30 m ◇
P6	◇ 4.0 m 以上	Q6	◇ 30 m 未満

測定計によるブレーキング・アクション

エ プ ロ ン		
R1	Good	$\mu = 0.40$ 以上
R2	Medium to good	◇ 0.36 ◇
R3	Medium	◇ 0.30 ◇
R4	Medium to poor	◇ 0.26 ◇
R5	Poor	◇ 0.20 ◇
R6	Very poor	◇ 0.20 未満

除雪の状況

誘導路 / エプロン		オーバーラン / ショルダー		滑走路灯		誘導路灯	
S1	誘導路は終了している	T1	オーバーランは終了している	U1	埋れた灯器なし	V1	埋れた灯器なし
S2	◇ に未了部分がある	T2	◇ に未了部分がある	U2	◇ 50 % 未満	V2	◇ 50 % 未満
S3	エプロンは終了している	T3	ショルダーは終了している	U3	◇ 50 % 以上	V3	◇ 50 % 以上
S4	◇ に未了部分がある	T4	◇ に未了部分がある	U4	全部埋れている	V4	全部埋れている

総合的な予想 (3 時間後)

W1	全体的に良くなる可能性が大きい
W2	大きな変化はないと思われる
W3	気温の上昇により融解が予想される
W4	気温の低下により凍結が予想される
W5	若干悪くなるが使用に差支えないと思われる
W6	全体的に悪くなる可能性が大きい
W7	不明である

備考

- 積雪量 (滑走路の平均積雪量が 80mm 未満の場合) :
A 地区… mm, B 地区… mm, C 地区… mm
- 各誘導路のブレーキング・アクション :
- その他

注 1. 積雪の種類は、次の区分により分類している

- (1) Dry snow: 乾燥した雪及び水分を余り含まない普通の雪 ((2) ~ (4) 以外の雪)
- (2) Wet snow: 水分をかなり含んでおり、手袋をした手で握ると水がにじんだりしみ出る状態の雪
- (3) Slush: 水分を十分に含んでおり、かかと又はつま先で踏みつけたりけったりするとスプラッシュがあがる状態の雪
- (4) Compacted snow: 除雪機材等で押しかためられた状態の雪

Note 1. Classification of snow.

- (1) Dry snow: Normal snow which is dry or not so watery. (Excluding those in (2) to (4) below.)
- (2) Wet snow: Snow which is rather watery and oozes out water if compacted by gloved hand.
- (3) Slush: Water saturated snow which with a heel and toe slap down motion against the ground will be displaced with a splash.
- (4) Compacted Snow: Snow which has been compressed and hardened by snow removal equipment or such others.

Civil Aviation Bureau, Japan (EFF: 1 JAN 1998)

6/11/97

Figure D.7 (cont'd): Format from Japanese AIP

AD 1.2-4

AIP Japan

Condition of snow bank along RWY

Height		Clearance	
P1	No snow bank	Q1	Snow banks located apart 85m or more
P2	Height of snow bank less than 0.5m	Q2	70m
P3	1.0m	Q3	55m
P4	2.0m	Q4	40m
P5	4.0m	Q5	30m
P6	4.0m or more	Q6	less than 30m

Braking action obtained by measuring equipment

Apron		
R1	Good	$\mu = 0.40$ or more
R2	Medium to good	0.36
R3	Medium	0.30
R4	Medium to poor	0.26
R5	Poor	0.20
R6	Very poor	less than 0.20

Progress of snow removal

TWY/Apron		Overrun/Shoulder		RWY lights		TWY lights	
S1	TWY: Finished	T1	Overrun: Finished	U1	All clear of snow	V1	All clear of snow
S2	: partially unfinished	T2	: partially unfinished	U2	Less than 50% covered with snow	V2	Less than 50% covered with snow
S3	Apron: Finished	T3	Shoulder: Finished	U3	50% or more covered with snow	V3	50% or more covered with snow
S4	: partially unfinished	T4	: partially unfinished	U4	All covered with snow	V4	All covered with snow

General forecast (3 hours later)

W1	Generally improved condition expected
W2	Change not expected
W3	Melting expected due to rising temperature
W4	Freezing expected due to falling temperature
W5	Condition slightly deteriorating, but operation will not be affected
W6	Generally deteriorating condition expected
W7	Unable to forecast

RMKS

- 1) Depth of snow (for less than 80mm mean snow depth on runway):
A area... mm, B area... mm, C area... mm,
- 2) Each taxiway braking action:
- 3) Others

Figure D.7 (cont'd): Format from Japanese AIP

AIP Japan

AD1.2-5

注2. 滑走路のA, B, C地区の平均積雪深が80ミリメートル未満の場合には、当該地区の平均積雪深をミリメートル単位で、備考欄に表示する。

Note2. Less than 80mm mean snow depth on area A, B and C of runway will be given by millimeter in the remarks column.

注3. 誘導路のブレーキング・アクションは、各誘導路について、滑走路の表示に適用する区分(1~6)を準用し該当数字を表示する。

Note3. Taxiway Braking Action will be given for each taxiway applying the Runway Braking Action grading(1-6).

注4. 滑走路の各地区毎の μ の平均値は、滑走路少数番号側の地区から順に小数点以下2数字を表示する。
ただし、ブレーキングアクションがGOODの場合、“95”と表記する

Note4. Measured coefficient for each third of runway will be given by two digits.

In case of the braking action is GOOD, the figures 95 will be used.

e.g. 36/30/95-The measured coefficient on the first one third is 0.36, the second one third is 0.30 and the braking action on the last one third is GOOD.

注5. 測定計によるブレーキング・アクションは、備考欄に測定機器の表示がない限りタプレメーターにより測定したものである。タプレメーター以外の機器により測定した場合は、次の用語により使用機器名を表示する。

Note5. Information on braking action shown as obtained by measuring equipment will be those obtained by Tapley Meter unless other type of equipment utilized is indicated in the Remarks column.

SAAB FRICTION TESTER
SAAB TYPE CONTINUOUS
MEASURING DEVICE

Measuring equipment to be used other than Tapley Meter will be SAAB TYPE CONTINUOUS MEASURING DEVICE.

注6. 積雪の種類がSlushの場合、測定計によるブレーキング・アクションは測定しない。

Note6. Braking Action will not be obtained by measuring equipment for slush.

注7. 積雪量が70ミリメートル以上である場合は、SAAB FRICTION TESTERを使用してのブレーキング・アクションは測定しない。

Note7. Braking Action will not be obtained by Saab Type Continuous Measuring Device for more than 70mm mean snow depth.

Figure D.7 (cont'd): Format from Japanese AIP

Table D.1: Detailed Summaries of RCR for Winter Contaminants

Country	What is Reported
Belgium	If SNOWTAM must give information on the braking action, the three equal sections of a RWY will be referred to as A, B and C. Section A will always be the first third measured from that end of the RWY with the lowest RWY designation number. However, in LDG instructions, the three sections will be referred to as the "first", "second" or "third" part of a RWY seen from the THR. The friction coefficient is the AVG value calculated for each third of the RWY at EBAW, EBBR, EBCI, EBLG, ELLX and EBOS. Information on braking action will be given according to the following table: (ICAO) <i>Note: "Unreliable" will be reported when more than 10% of a RWY surface is covered by wet ice, wet snow and/or slush. Measuring results and estimates are considered absolutely unrealistic in such situations. In reports "Unreliable" will be followed by either the friction number given by the instrument used or the estimated braking action.</i> The routine messages transmitted to ACFT landing in EBAW, EBBR, EBCI, EBLG, ELLX and EBOS will include the braking action. The friction coefficient will be given on request.
Canada	Transport Canada uses the AMSCR reporting format Conditions are reported for the whole runway, and not by thirds
Denmark	The Aerodrome Operational Service will use the SNOWTAM Format for the reporting which will be delivered to the Aerodrome Reporting Office/Air Traffic Service unit for further dissemination. The extent of ice, snow and/or slush on runway is reported on the basis of an estimate of the covered area and given in percent of the total area of the runway, in accordance with the following: (i) 10% 10% or less is covered; (ii) 25% 11-25% of the runway is covered; (iii) 50% 26-50% of the runway is covered; (iv) 100% more than 50% of the runway is covered. Information on braking action will be given in terms of friction numbers (friction coefficients indicated with two digits, 0 and comma being omitted) when based on measurements. In addition the kind of measuring device used will be reported (cf. item 2.3.2.2) When braking action is estimated the figures from the following table will be used: (ICAO)
Finland	For the purpose of reporting the deposit on the runway and the surface friction in SNOWTAM, each runway is divided into three sections of equal length referred to as A, B and C. Section A will always be the first one-third as viewed from the threshold having the lower runway designator number. In landing instructions, however, these sections will be referred to as the "first", "second" or "third" parts of a runway seen from the direction of landing. The extent of deposit (water, rime, frost, dry or wet snow, slush or ice) relative to the total area of runway (%). If the runway has not been cleared along its entire published width, the extent of deposit is calculated relative to the cleared runway area. Measured friction coefficient values (two digits) for each onethird of the runway will be entered in item H of the SNOWTAM format together with an indication of the type of measuring equipment used by three letter abbreviations given in the SNOWTAM format. Where measured friction coefficient values are not available, the (estimated) braking action (single digit) for the three sections of the runway will be entered in item H of the SNOWTAM format using the code figures 5 to 1 as appropriate.
Yugo-slavia	Information on braking action will be given in terms of the measured friction coefficient or estimated surface friction. When giving a measured coefficient two digits are indicated (0 and the comma being omitted). In addition, the kind of measuring device used will be reported in abbreviated form. When giving an estimated surface friction, single digits will be used. In MOTNE transmissions a special code will be used.

Country	What is Reported
France	TRANSMITTING A RUNWAYS CONDITIONS REPORT IN WINTER PERIOD <i>This information is broadcast after METAR messages, as a coded group which content and presentation are depicted in AD 1.2-14 for aerodromes having in charge the issuing of METAR messages via MOTNE network, in compliance with instructions planned in the “Plan de navigation aérienne”. Region Europe 8e partie. These instructions may be applied by all aerodromes having also in charge the broadcasting of SNOWTAM ; these aerodromes are under lined within the aerodrome list shown in AD 1.2-13.</i>
Iceland	The Aerodrome Operational Service will use the SNOWTAM form for the reporting which will be sent to the tower and the Area Control Center in Reykjavik for further dissemination according to AIP Iceland Information supplementing this snow-plan will be issued in an AIP supplement. Information on braking action will be given in terms of friction numbers (friction coefficient indicated with two digits, 0 and decimal symbol being omitted) when based on measurements. In addition, the kind of measuring device used will be reported. When braking action is estimated, plain language will be used.
Netherlands	A SNOWTAM will be issued immediately when circumstances so require like snow, ice, slush, etc. on runways, taxiways and aprons at the following airports: (i) AMSTERDAM/Schiphol; (ii) ENSCHEDE/Twenthe; (iii) GRONINGEN/Eelde; (iv) MAASTRICHT/Maastricht Aach; (v) ROTTERDAM/Rotterdam. A new SNOWTAM will be issued when conditions have changed significantly. Special care will be given to the issue of early morning SNOWTAMs. For AMSTERDAM/Schiphol airport a SNOWTAM will be issued at 0400 UTC if conditions so require. Notification of the closure or reopening of an aerodrome or runway, as a result of snow and ice conditions, will be promulgated by NOTAM.
Norway	The ICAO SNOWTAM format is used for reporting the winter conditions on the movement area. The format is described in ICAO Annex 15, Appendix 2.
Poland	Information on snow conditions at the aerodromes are published by means of a special series of NOTAM (SNOWTAM) in conformity with the ICAO SNOWTAM FORMAT contained in ICAO Annex 15. This information may be obtained in flight from the appropriate ATC unit from the AIS from ATS Reporting Offices. For the purpose of reporting braking action in SNOWTAM, each runway in use is divided into three sections of equal length referred to as A, B and C. Section A is always the first third measured from that end of the runway with the lowest runway designation number. In ATIS broadcasts and landing instructions from the aerodrome control tower (TWR), these sections will be referred to as the “first”, “second” or “third” part of runway seen in the direction of landing. Information on braking action are reported according to the following scale: (ICAO) In landing instructions from TWR estimated braking action for each section of runway is given in plain language.
Sweden	Reporting of movement area conditions is made to ATS using the SNOWTAM format. The reports are transmitted by the local AFTN station. For reporting depth and type of deposit and braking action every runway is divided into three sections of equal length A, B and C. >>Section A>> is the first part of the runway with the lowest designation number. In landing instructions braking action is given in plain language and if required for each runway section. These sections are reported as >>First>>, >>second>> and >>third>> seen in the direction of landing or take off). Braking action is reported in accordance with the table above (ICAO). Under item T also: -Slippery spots longer than 50m where the breaking action is below average by 0.1 (sec R and L resp.). -large differences ≥ 0.10 in breaking action between the left and right side of a section when the lowest value is below 0.3 simultaneously.

Country	What is Reported
UK	Information on the current state of progress of snow clearance and on the conditions of the movement areas is available from a designated authority at the aerodrome concerned. Information on pavement conditions is also be available by RTF from the aerodrome concerned. Information on current surface conditions at United Kingdom and other European aerodromes generally is also available from the following sources: (i) Flight Briefing Units at aerodromes; (ii) SNOWTAM; (iii) Locations served by the OPMET system. Runway surface conditions are reported in the runway state group as an eight digit code at the end of the METAR every half hour for as long as conditions warrent. The runway state group contains information on the runway designator; type; extent and depth of deposit and where appropriate, braking action. RTF reports to pilots provide an assessment in plain language of the available runway length, including a description of the prevailing conditions i.e., ice, snow or slush, and where appropriate braking action, together with the time of the measurement.
Japan	See Figure D.7 for the format used