Cir 329
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Runway Surface Condition Assessment, Measurement and Reporting

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FOREWORD

This Circular provides an overarching conceptual understanding of the surface friction characteristics contributing to controlling the aircraft via the critical tyre to ground contact area. The intent is to provide a broad and fundamental understanding to support proposed changes by the ICAO Friction Task Force to the Standards and Recommended Practices (SARPs) in Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations* and Annex 15 — *Aeronautical Information Services*.

These changes address:

a) surface friction characteristics of pavements and runway surface contaminants;
b) how surface characteristics relates to aircraft performance;
c) assessment of runway surface conditions;
d) reporting an dissemination of runway surface conditions; and
e) training of personnel

BACKGROUND

In the early 1950s, aerodrome requirements for jet aircraft were discussed including the need for ensuring that runways have reasonable surface friction characteristics for braking efficiency.

The Standing Committee on performance was set up in 1951 to develop a set of specifications for transport aircraft performance suitable for inclusion in the technical Annex 6 — *Operation of Aircraft* and Annex 8 — *Airworthiness of Aircraft* to the Convention on International Civil Aviation. The Committee was able to work out a complete performance code and defined a reference dry and wet surface.

In 1954 the Air Routes and Ground Aids (AGA) Committee exchanged technical views on the consideration of specific problems, including concerns with icy runway operations, following the introduction of turbo-jet operations. These discussions were summarized and published in 1955 in the ICAO *Circular 43 – Ice and Snow on Runways*.

1n 1957 the Airworthiness Committee compared two existing codes (UK and US) and decided to adopt their common specifications. The Committee published in 1961, for the take-off situation, an ICAO *Circular 60 – Operational measures for dealing with the problem of taking-off from slush- or water-covered runways*. An updated version (1968) was later copied into guidance material for the European Joint Aviation Authorities JAR 25 now CS 25.

Commencing 1965, the Air Navigation Commission established the following study groups to assist the Secretariat on issues related to friction:

1965 – 1974 Study Group on Snow, Slush, Ice and Water on Aerodromes.
1974 – 1978 Study Group on Braking Action
1979 – 1994 Study Group on Runway Surface Conditions

For the period from 1972 to 1974, ICAO administered a joint evaluation programme of equipment used to measure runway braking action undertaken by Canada, France, Sweden, Union of Soviet Socialist Republics, United Kingdom and United States. From the conclusions of the reduced test data it was noted that some degree of correlation exists among the devices tested and that correlation varies widely between equipment pairs and with changes in surface texture, and that a great lack of precision was evident among the measuring devices. Friction measuring device correlation charts was developed for wet surfaces and for compacted snow or ice surfaces.

The landing situation represented a challenge for the Airworthiness Committee and three landing methods were developed and published in the *Airworthiness Technical Manual* (Doc 9051). In the early stages of development of landing specifications, it had been hoped that a close enough correlation would be established between friction measuring devices and aircraft stopping distance to allow runway friction to be treated as an operational variable. In 1976, the Airworthiness Committee proposed a three-tier system comprising dry, normal and substandard runways. It was recognized that the operational distinction between normal and substandard wet runways posed problems which was not yet solved.

In 1981, arising from a comment on the recommendations of the AGA Divisional Meeting (AGA/81), the Air Navigation Commission agreed that the ICAO Secretariat should re-examine the criteria for the development of equipment for determining the friction characteristics for wet runways. The focus was on design and maintenance objectives which introduced initially, a maintenance level, and later, a minimum friction level, and a link to the operational aspect was sought through an aeroplane stopping distance ratio of two and the term “slippery when wet”.

To date, States, through numerous projects, have sought to resolve the problem of harmonizing the various friction measuring devices and to link them to aircraft performance, the latter task being still an unsolved goal. The contributing factors for this being the difficulty of developing a system comprising a universally agreed time stable reference for friction measuring devices and issues associated with the repeatability and reproducibility of the fleet of friction measuring devices in use.

In 2001, the *Airworthiness Manual* (Doc 9760) was published with the objective of providing guidance on the implementation of the airworthiness and maintenance provisions of Annex 6 and Annex 8. Doc 9760 replaced, amongst other documents, Doc 9051, the latter which contained technical detailed information referred to in Doc 9137, *Airport Services Manual*, Part 2 — *Pavement Surface Conditions*. This is now supplemented by the performance-based guidance in this *Circular*.

With respect to dissemination of the runway surface conditions, the ICAO SNOWTAM format was developed and introduced in 1967 arising from a detailed proposal from IATA in 1963. The SNOWTAM format has not gained global acceptance and has been implemented differently among States resulting in inconsistent information provided to aircraft operators and pilots. Runway condition reports should be timely, accurate and consistent with the operators needs for operations in compliance with Annex 6 and annex 8

In view of the historical developments, it was considered timely for ICAO to develop international specifications on, inter alia, the functions, principles and basic technical and operational characteristics of the friction measuring devices. In 2006 the Aerodromes Operations and Services Working Group, under the aegis of the Aerodromes Panel, considered establishing a separate subgroup on friction issues. The subgroup was named the ICAO Friction Task Force with the following deliverables:

1. To propose appropriate amendments to the relevant Standards and Recommended Practices (SARPs) in ICAO Annexes, primarily Annex 14, Volume I, supported by updated guidance materials;
2. To develop an ICAO Circular for assessing, measuring and reporting of runway surface condition including state-of-the-art treatment of friction issues; and
3. To propose an action plan for further improvement.

The ICAO Friction Task Force formally commenced its work in the summer of 2008.

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ACRONYMS AND ABBREVIATIONS

AC	*Advisory Circular (U.S. FAA)*
AFM	*Aircraft Flight Manual*
ADREP	*Accident/incident data reporting*
AIC	*Aeronautical Information Circular*
AIM	*Aeronautical Information Management*
AIP	*Aeronautical Information Publication*
AIS	*Aeronautical Information Services*
AIS-AIMSG	*Aeronautical Information Services and Aeronautical Information Management Study Group*
AIXM	*Aeronautical Information Exchange Model*
AMSCR	*Aircraft Movement Surface Condition Report*
ARC	*The United States Federal Aviation Authority Aviation Rulemaking Committee*
ASTM	*American Society for Testing and Materials*
ATC	*Air Traffic Control*
ATIS	*Automatic Terminal Information Service*
ATM	*Air Traffic Management*
ATS	*Air Traffic services*
CEN EN	*Comité Europeen de Normalisation (European Standards)*
CFME	*Continuous Friction Measuring Equipment*
CFR	*Code of Federal Regulations (US FAA)*
CRFI	*Canadian Runway Friction Index*
CRM	*Cockpit Resource Management*
CS	*Certification Specifications (EASA)*
EASA	*European Aviation Safety Agency*
ERD	*Electronic Recording Decelerometer*
ESDU	*Engineering Sciences Data Unit*
EUROCONTROL	*The European organisation for the safety of air navigation*
FAA	*Federal Aviation Administration*
FAR	*Federal Aviation Regulations*
FTF	*ICAO Friction Task Force*
HMA	*Hot-Mix Asphalt*
ICAO	*International Civil Aviation Organization*
IRFI	*International Runway Friction Index*
IATA	*International Air Transport Association*
JAA	*Joint Aviation Authorities*
JAR	*Joint Aviation Requirements*

JWRFMP	*Joint Winter Runway Friction Measurement Program*
METAR	*Aviation routine weather report (in aeronautical meteorological code)*
MFL	*Minimum Friction Level*
MPD	*Mean Profile Depth*
MTD	*Mean Texture Depth*
Mu	*Coefficient of friction*
NASA	*National Aeronautics and Space Administration (U.S.)*
NOTAM	*Notice to Airman*
PIREP	*Pilot report*
PCC	*Portland Cement Concrete*
PFC	*Porous Friction Course*
PSV	*Polished Stone Value*
SARPS	*Standards and Recommended Practices (ICAO)*
SMS	*Safety Management System*
TALPA	*Takeoff And Landing Performance Assessment*
TC	*Transport Canada*
μ	*Mu (coefficient of friction)*
V_1	*The maximum speed in the takeoff at which the pilot must take the first action (e.g., apply brakes, reduce thrust, deploy speed brakes) to stop the airplane within the accelerate-stop distance.* V_1 *also means the minimum speed in the takeoff, following a failure of the critical engine at* V_{EF}, *at which the pilot can continue the takeoff and achieve the required height above the takeoff surface within the takeoff distance.*

Chapter 1

DEFINITIONS

1.1 The definitions given below are to ensure that the readers understand the intended meaning of the terms used in the context of this Circular.

Braking action. A term used by pilots to characterize the deceleration associated with the wheel braking effort and directional controllability of the aircraft.

Coefficient of friction. A dimensionless ratio of the friction force between two bodies to the normal force pressing these two bodies together.

Contaminant. A deposit (such as snow, slush, ice, standing water, mud, dust, sand, oil, and rubber) on an aerodrome pavement the effect of which is detrimental to the friction characteristics of the pavement surface.

Critical tire/ground contact area. An area (approximately 4 square meters for the largest aircraft currently in service) which is subject to forces that drive the rolling and braking characteristics of the aircraft, as well as for directional control.

ESDU scale. A grouping of hard runway surfaces based on macro-texture depth.

Estimated Surface Friction. A term used by ground staff for SNOWTAM reporting purposes to characterize the slipperiness of the runway surface due to presence of contaminants and prevailing weather conditions.

Flexible pavement. A pavement consisting of a series of layers of increasing strength from the subgrade to the surface layer. The structure maintains intimate contact with and distributes loads to the subgrade and depends on aggregate interlock, particle friction, and cohesion for stability.

Friction. A resistive force along the line of relative motion between two surfaces in contact.

Friction characteristics. The physical, functional and operational features or attributes of friction arising from a dynamic system.

Hazard. A condition or an object with the potential to cause injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function.

Rigid pavement. A pavement structure that distributes loads to the subgrade having as its surface course a Portand cement concrete slab of relatively high bending resistance.

Retardation. The deceleration of a vehicle braking, measured in m/sec^2.

Significant change. Change in magnitude of hazard, which leads to change in safe operation of aircraft.

Skid resistant. A runway surface that is designed, constructed, and maintained to have good water drainage that minimizes the risk of hydroplaning when the runway is wet, and provides aircraft braking performance shown to be better than that used in the airworthiness standards for a wet smooth runway.

Surface friction characteristics. The physical, functional and operational features or attributes of friction that relates to the surface properties of the pavement that can be distinguished from each other.

(Note: The friction coefficient is not a property of the pavement surface but a system response from the measuring system. Friction coefficient can be used to evaluate surface properties of the pavement provided that the properties belonging to the measuring system are controlled and kept stable.)

DEFINTIONS FROM ANNEX 6

1.2 The definitions below for the operational use of flight crew were introduced via Amendment 33A to Annex 6 — *Operation of Aircraft*, Part I — *International Commercial Air Transport — Aeroplanes* in 2009.

1.3 Apart from the definitions for grooved or porous friction course runway, the origin of the definitions can be traced to an unpublished issue of a draft FAA Advisory Circular, *Performance information for operation with water, slush, snow, or ice on the runway,* AC No: 91-6B dated JUN 18 1986.

1.4 With minor changes, the definitions from the FAA Advisory Circular appears in the EASA Certification Specifications CS 25, Book 2, under the heading *AMC 25-13 Reduced And Derated TakeOff Thrust (Power) Procedures*. The definition for wet was simplified and minor editorial changes made to the contaminated definition.

1.5 Two accompanying notes had been added to the definitions in Amendment 33A. The concept of these notes can be traced back to discussions within in the FAA Airplane Performance Harmonization Sub-Working Group which completed their task in 2002.

1.6 These definitions are aimed at the operation of aircraft and not the operation of aerodromes. However, for reporting purposes of prevailing runway surface conditions there is a need to harmonize these definitions with those used for the operation of an aerodrome. At the publication date of this Circular, this is not the case.

1.7 Within the aviation industry, it is recognized that for safety reasons, harmonization is required. A concept of two sets of harmonized definitions has been discussed with one set targeting the operation of an aerodrome whilst the other, at the operation of the aircraft. These sets of definitions would need to be harmonized in such a way that safety is not impaired when reporting prevailing runway surface conditions.

Grooved or porous friction course runway. A paved runway that has been prepared with lateral grooving or a porous friction course (PFC) surface to improve braking characteristics when wet.

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 being used is covered by:

- water, or slush more than 3 mm (0.125 in) deep;

- loose snow more than 20 mm (0.75 in) deep; or

- 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.

1.2.1 *Note 1.— In certain situations, 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 take-off while at low speed. In this situation, the runway should be considered to be contaminated*.

1.2.2 *Note 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 takeoff performance. For example, if the first 25 per cent of the runway was damp, but the remaining runway length was dry, the runway would be wet using the definitions above. However, since a w et runway does not affect acceleration, and the braking portion of a rejected takeoff would take place on a dry surface, it would be appropriate to use dry runway takeoff performance.*

Chapter 2

INTRODUCTION

"There is no subject in science, perhaps, on which there is a greater diversity of opinion than in the laws which govern friction; and the previous experiments, though sufficient, in many cases, for practical purposes, yet by no means tend to bring the inquiry into any more settled state."

Nicholas Wood, Treatise upon railroads, 1836[*]

2.1 Aviation does not have such a long history as railroads, yet the diversity of opinions related to the laws that govern friction is great. The purpose of this Circular is to provide latest guidance on the subject of friction issues as far as is possible, given the present state of knowledge.

2.2 It is common knowledge that pavements tend to become slippery to both pedestrians and vehicles when they are wet or flooded or are covered with slush, snow or ice; however, no one yet has a complete understanding of the physical effects causing this slipperiness which in turn can cause accidents. The same applies to aircraft operation on the movement areas. For this reason, many papers on friction issues have been produced within the aviation community since the late 1940's.

2.3 The information within this Circular should be used by national authorities when implementing their safety activities and as necessary referenced for use by aerodrome operators, aerodrome air navigation service providers, aircraft operators and individuals within the organisations.

THE ROLE OF ICAO

2.4 ICAO promotes the safe and orderly development of international civil aviation throughout the world. It sets standards and regulations necessary for, inter alia, aviation safety. In this regard, ICAO has been instrumental in generating discussion on friction issues, establishing study groups and encouraging research programs as early as the mid-50's. Some of these activities include, but not limited to:

a) ICAO Circular *Ice and snow on runways,* 1955;

b) ICAO Circular *Operational measures for dealing with the problem of taking off from slush- or water-covered runways,* 1961 and 1968;

c) ICAO study group on snow, slush, ice and water on aerodromes, 1966 – 1974;

(*Programme, 1972 – 1974, for correlating equipment used in measuring runway braking action*)

d) ICAO study group on braking action, 1973 – 1978;

e) ICAO study group on runway surface conditions, 1979 – 1994; and

f) ICAO friction task force, 2008 – 2009 and beyond.

2.5 These activities have led to, and supplemented, numerous initiatives worldwide, with Europe and North America as major contributors. The overall goal, *inter alia*, is to:

[*] THE ENGINEER'S AND MECHANICS ENCYCLOPEDIA, COMPREHENDING PRACTICAL ILLUSTRATION OF THE MACHINERY AND PROCESSES EMPLOYED IN EVERY DESCRIPTION OF MANUFACTURE OF THE BRITISH EMPIRE, BY LUKE HERBERT, LONDON 1836.

a) develop a system for reporting friction issues of the movement area as part of a standardized reporting format. This format must meet the needs of the pilot for safe operation of the aircraft; and

b) develop a system for maintenance of the movement area. This system must meet the needs for airport operator to maintain the pavement in a state for safe operation of the aircraft.

CURRENT SITUATION

2.6 Worldwide, there have been various initiatives (*see Appendix A*) carried out among and within States resulting in different means of measuring and reporting of:

a) policies;

b) methods; and

c) parameters.

2.7 These differences may lead to confusion and the various parts of the industry may not speak the same "language" even though they believe they do. The most important key players are the person on the ground, identifying and reporting hazardous conditions on the movement area and the pilot using that information for safe operation of the aircraft. The role of the aeronautical information services (AIS) and air traffic management (ATM) is to disseminate the information in a timely manner in accordance with standardized formats and procedures established for international use.

2.8 There is currently such a preponderance of information, at times incorrect and conflicting, that often leaves the States and operators confused. The goal should be to aim towards global non-conflicting solutions for assessing, measuring, reporting, and using runway surface friction characteristics to determine the effect on airplane performance.

TERMINOLOGY

2.9 The friction issues discussed in the context of this Circular are those related to the safe operation of an aircraft as well as those that are relevant to the aerodrome operator. More specifically, these issues relate to aircraft/runway interaction that depend upon the critical tire/ground contact area.

2.10 At this critical tire/ground contact area, two distinct aspects of friction issues meet:

a) design, construction and maintenance of the pavement surface and its inherent friction characteristics, and

b) aircraft operation on the pavement surface and the contaminants present.

2.11 Both these aspects have, through time, developed their own terminologies that relate to friction and it is essential to distinguish the following aspects:

a) *skid resistance* – relates to the design, construction and maintenance of pavement;

b) *braking action* – represents the pilots characterization of the deceleration associated with the wheel braking effort and directional controllability of the aircraft. The term is used in pilot reports (PIREPs); and

c) *estimated surface friction* – represents the ground staff assessment, for SNOWTAM reporting purposes, to characterize the slipperiness of the runway surface due to presence of contaminants and prevailing weather conditions. The term is used in SNOWTAMs.

2.12 The term ”*skid resistance*” has been in more formal use since the establishment of a new technical committee on skid resistance (Committee E-17) in October 1959 by the American Society for Testing and Materials (ASTM). *Skid resistance*, as defined by the ASTM:

> *skid resistance* (friction number)—the ability of the travelled surface to prevent the loss of tire traction.

2.13 The term "*braking action*" has been in continuous use within the aviation industry although it has been used in different context and will, as such, continue to be used in the general sense. *Braking action*, in the context of reporting purposes, is used to define the stopping capability of an aircraft using wheel brakes and is related to *pilot braking action reports*. The term *braking action* has also been used to describe the *estimated surface friction* on the ground measured by a friction measurement device and reported as aircraft stopping capability. The ICAO SNOWTAM format use the term *estimated surface friction* and should be understood as the total assessment of the slipperiness of the surface as judged by the ground staff based upon all information available.

2.14 The following was documented in the *Report of the Aerodromes, Air Routes and Ground Aids Divisional Meeting (1981)* (Doc 9342):

> *It was pointed out that the term "runway braking action" had been used in several places in Annex 14. This term had not been defined. On the other hand, the term "coefficient of friction" was well known. It was therefore suggested that the use of the term "braking action" should be avoided. The meeting was advised that the term "braking action" had been selected for use in Annex 14 because some of the measuring devices used did not measure directly the coefficient of friction. This was particularly so in the case of devices for measurements on surfaces covered with ice and snow, so in these cases the more general term "braking action" was adopted. Otherwise, it was agreed that wherever feasible the term "braking action" should be replaced by "friction characteristics".*

2.15 Previously, the principal aim has been to measure surface friction in a manner that is relevant to the friction experienced by an aircraft tire. Currently, there is no consensus within the aviation industry that this is even possible. To avoid misunderstanding and confusion, measured surface friction should be referred to as measured friction coefficient, which is used in the current SNOWTAM format.

Chapter 3

THE DYNAMIC SYSTEM

3.1 The basic friction characteristics of the critical tire/ground contact area, the latter being a part of a dynamic system, influences the available friction that can be utilised by an aircraft. The basic friction characteristics are properties belonging to the individual components of the system, such as:

a) pavement surface (runway) ;

b) tire (aircraft);

c) contaminants (between the tire and the pavement); and

d) atmosphere (temperature, radiation; as affecting the state of the contaminant).

3.2 Figure 3.1 illustrates the friction characteristics and how they interrelate in the dynamic system of an aircraft in motion.

3.3 The three main components of the system are:

a) surface friction characteristics (static material properties);

b) dynamic system (aircraft and pavement in relative motion); and,

c) system response (aircraft performance).

The aircraft response depends largely on the available tire-pavement friction and the aircraft anti-skid system.

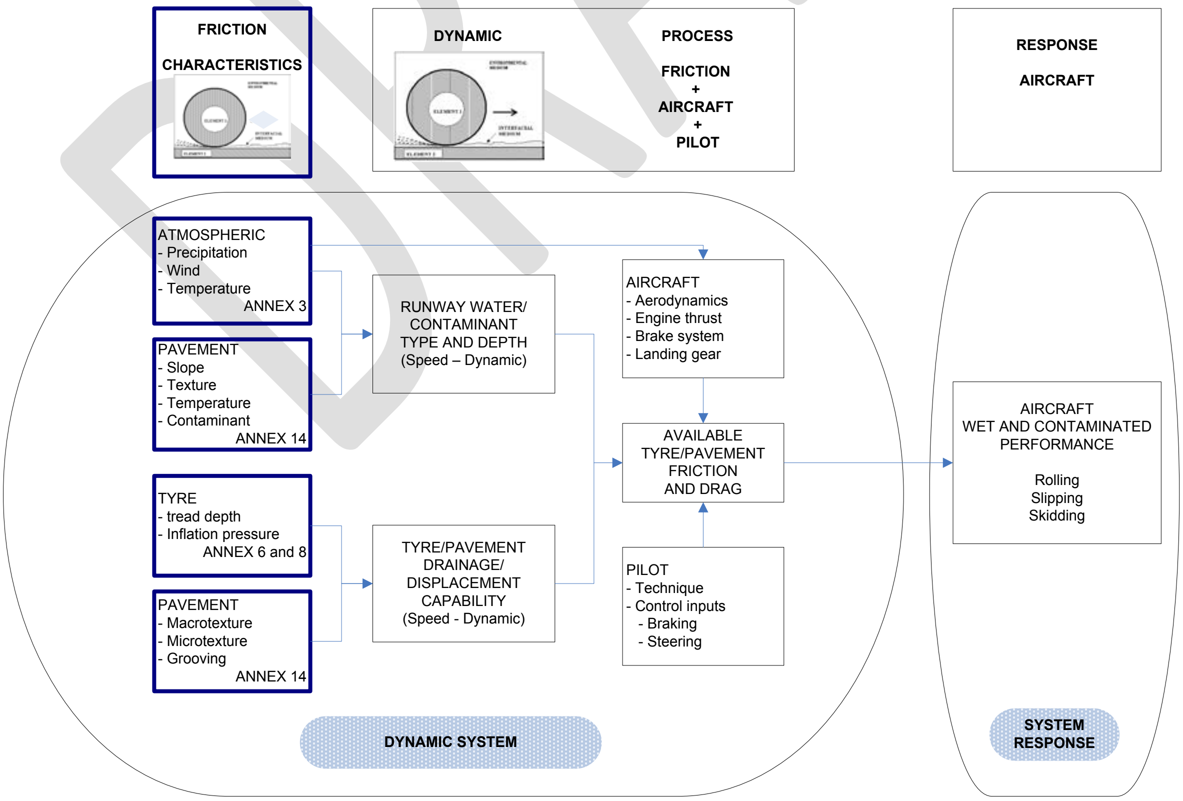


Figure 3.1 - Basic friction characteristics, the dynamic system and the system response.

Chapter 4

PAVEMENT

Functional requirements

4.1 A runway pavement, considered as a whole, is required too fulfil the three basic functions as follows:

a) to provide adequate bearing strength;

b) to provide good riding qualities; and

c) to provide good surface friction characteristics.

4.2 Other requirements include:

a) longevity; and

b) ease of maintenance.

4.3 The first criterion addresses the structure of the pavement, the second the geometric shape of the top of the pavement and the third the texture of the actual surface and drainage when it is wet; texture and slope being the most important friction characteristics of a runway pavement. The fourth and fifth criteria address, in addition to the economic dimension, the availability of the pavement for aircraft operations.

Dry runway

4.4 When in a dry and clean state, individual runways generally provide operationally insignificant differences in friction levels, regardless of the type of pavement and the configuration of the surface. Moreover, the friction level available is relatively unaffected by the speed of the aircraft. Hence, the operation on dry runway surfaces is satisfactorily consistent and no particular engineering criteria for surface friction are needed for this case.

Wet runway

4.5 The problem of friction on runway surfaces affected by water can be expressed primarily as a generalized drainage problem consisting of three distinct criteria:

a) Surface drainage (surface shape, slopes)

b) Tire/ground interface drainage (macrotexture)

c) Penetration drainage (microtexture)

4.6 These three criteria can be significantly influenced by engineering measures, and it is important to note that all of them must be satisfied to achieve adequate friction in all possible conditions of wetness.

Contaminated runway

4.7 The problem of friction on runway surfaces affected by contaminants can be expressed primarily as a generalized maintenance problem consisting of improved interfacial drainage or removal of the contaminants. The most dominant being:

a) maintenance of improved interfacial drainage capability for pavements contaminated by water (more than 3 mm depth);
b) removal of rubber deposits;
c) removal of snow, slush ice or frost; and
d) removal of other deposits such as sand, dust, mud, oil, etc.

4.8 These issues can be significantly influenced by the level of maintenance provided by the airport operator.

DESIGN

Texture

Surface texture

4.9 The most important aspect of the pavement surface relative to its friction characteristics is the surface texture. The effect of surface material on the tire-to-ground coefficient of friction arises principally from differences in surface texture. Surfaces are normally designed with sufficient macrotexture to obtain a suitable water drainage rate in the tire/road interface. The texture is obtained by suitable proportioning of the aggregate/mortar mix or by surface finishing techniques. Pavement surface texture is expressed in terms of macrotexture and microtexture. However, these are defined differently depending on the context and measuring technique the terms are used in. Furthermore, they are understood differently in various parts of the aviation industry. Doc 9137, *Airport Services Manual*, Part 2 — *Pavement Surface Conditions* contains further guidance on this subject.

4.10 Texture is defined internationally through ISO standards[3,4]. These standards refer to texture measured by volume or by profile and is expressed as Mean Texture Depth (MTD) or Mean Profile Depth (MPD). These standards define microtexture to be below 0.5 MPD and macrotexture to be above 0.5 MPD. There is no universally agreed relationship between MTD and MPD.

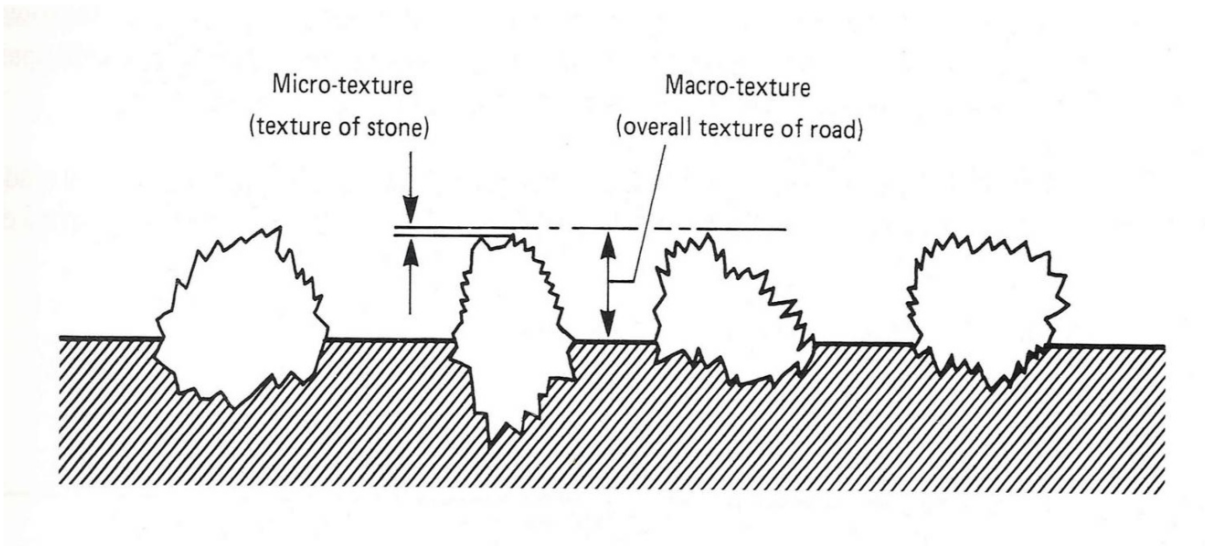


Figure 4.1 – Micro- and macro-texture

Microtexture

4.11 Microtexture is the texture of the individual stones and is hardly detectable by the eye. Microtexture is considered a primary component in skid resistance at slow speeds. On a wet surface at higher speeds a water film may prevent direct contact between the surface asperities and the tire due to lack of drainage from the tire-to-ground contact area.

4.12 Microtexture is a built-in quality of the pavement surface. By specifying crushed material that will withstand polishing, microtexture and drainage of thin water films are ensured for a longer period of time. Resistance against polishing is expressed through the polished stone values, which are in principle a value obtained from friction measurement in accordance with international standards (ASTM D 3319, CEN EN 1097-8).

4.13 A major problem with microtexture is that it can change within short time periods without being easily detected. A typical example of this is the accumulation of rubber deposits in the touchdown area which will largely mask microtexture without necessarily reducing macrotexture.

Macrotexture

4.14 Macrotexture is the texture between the individual stones. This scale of texture may be judged approximately by the eye. Macrotexture is primarily created by the size of aggregate used or by treatment of the surface. Grooving adds to the macrotexture, although how much it adds depend on width, depth and spacing. Macrotexture is the major factor influencing the tire/ground interface drainage capacity at high speeds.

Engineering Sciences Data Unit (ESDU)

4.21 ESDU describes the microtexture as the texture of the individual stones of which the runway is constructed and depends on the shape of the stones and how they wear. This type of texture is the texture which makes the surface feel more or less harsh but which is usually too small to be observed by the eye. It is produced by the surface properties (sharpness and hardness) of the individual chippings or particles of the surface which come in direct contact with the tires.

4.22 For measurement of macrotexture, simple methods such as the so called volumetric "sand patch" and "NASA grease patch" methods were developed. These were used for the early research which today's airworthiness requirements are based upon and as such referred to through underlying documentation. Within airworthiness, reference and use have been made of the ESDU documentation (ESDU 71026 and ESDU 95015). These documents refer to texture measurements from runways made in the seventies using sand or grease patch measuring technique. From these measurements ESDU developed a scale classifying the macrotexture A through E. (*See Chapter 6 – Aircraft Operations.)*

Drainage

4.23 Surface drainage is a basic requirement of utmost importance. It serves to minimize water depth on the surface. The objective is to drain water off the runway in the shortest path possible and particularly out of the area of the wheel path. Quite obviously, the longer the path that surface water has to take to exit the runway, the greater problem will be.

4.24 To promote the most rapid drainage of water, the runway surface should, if practicable, be cambered except where a single crossfall from high to low in the direction of the wind most frequently associated with rain would ensure rapid drainage.

4.25 The average surface texture depth of a new surface should be designed to provide adequate drainage in expected rainfall conditions. Macro and micro texture should be taken into consideration in order to provide good surface friction characteristics. This requires some form of special surface treatment.

4.26 Drainage capability can, in addition, be enhanced by special surface treatments, such as grooving and porous friction course which drains water initially through voids of a specially treated wearing course.

4.27 It should be clearly understood that special surface treatment is not a substitute for good runway construction and maintenance. Special a treatment is certainly one of the items that should be considered when deciding on the most effective method for improving the wet friction characteristics of an existing surface, but other items (drainage, surface material, slope) should also be considered.

4.28 When there is reason to believe that the drainage characteristics of a runway, or portions thereof, are poor due to slopes or depressions, then the runway surface friction characteristics should be assessed under natural or simulated conditions that are representative of local rainfall rates. Corrective maintenance action to improve drainage should be taken if found necessary.

Drainage characteristics of the movement and adjacent areas

4.29 Rapid drainage of surface water is a primary safety consideration in the design, construction and maintenance of pavements and adjacent areas. It serves to minimize water depth on the surface, in particular in the area of the wheel path. The objective is to drain water off the runway in the shortest path possible and particularly out of the area of the wheel path. There are two distinct drainage processes taking place:

a) natural drainage of the surface water from the top of the pavement surface.
b) dynamic drainage of the surface water trapped under a moving tire until it reaches outside the tire-to-ground contact area.

4.30 Both processes can be controlled through

a) design;
b) construction; and
c) maintenance.

of the pavements in order to prevent accumulation of water on the pavement surface.

Design and maintenance of pavement for drainage

4.31 Natural drainage is achieved through design of slopes on the various parts of the movement area allowing the surface water to flow away from the pavement to the recipient as surface water or through a sub surface drainage system. The resulting combined longitudinal and transverse slope is the path for the natural drainage runoff. This path can be shortened by adding transverse grooves.

4.32 Dynamic drainage is achieved through providing texture in the pavement surface. The rolling tire builds up water pressure and squeezes the water out the escape channels provided by the texture. The dynamic drainage of the tire-to-ground contact area is improved by adding transverse grooves.

4.33 The drainage characteristics of a surface are built into the pavement. These surface characteristics are:

a) slopes; and
b) texture, including microtexture and macrotexture.

Slopes

4.34 Adequate surface drainage is provided primarily by an appropriate sloped surface in both the longitudinal and transverse directions, and surface evenness. The maximum slope allowed for the various runway classes and various parts of the movement area is given in *ICAO Annex 14.* Further guidance is given in Airport Design Manual, Part 1.

Microtexture (drainage)

4.35 The objective is to achieve high water discharge rates from under the tyre with a minimum of dynamic pressure build-up, and this can only be achieved by providing a surface with an open macrotexture.

4.36 Interface drainage is actually a dynamic process highly correlated to the square of speed. Therefore, macrotexture is particularly important for the provision of adequate friction in the high-speed range. From the operational aspect, this is most significant because it is in this speed range where lack of adequate friction is most critical with respect to stopping distance and directional control capability.

4.37 In this context it is worthwhile to make a comparison between the textures applied in road construction and runways. The smoother textures provided by road surfaces can achieve adequate drainage of the footprint of an automobile tire because of the patterned tire treads, which significantly contribute to interface drainage. Aircraft tyres, however, cannot be produced with similar patterned treads and have only a number of circumferential grooves which contribute substantially less to interface drainage. Their effectiveness diminishes relatively quickly with tire wear.

4.38 ICAO Annex 14 recommends a macrotexture of no less than 1 mm MTD. Coincidentally, this happens to be consistent with the texture depth of the surface on the ESDU scale that is used in determining the certified performance data for a wet grooved or porous friction course surface.

Macrotexture (drainage)

4.39 The interface drainage between the individual aggregate and the tire is dependent upon the fine texture on the surface of the aggregate. At lower speeds water can escape as the pavement and tire come in contact. Aggregates susceptible to polishing can lessen this microtexture.

4.40 It is of utmost importance to choose crushed aggregates, which can provide a harsh micro texture that will withstand polishing.

Rainfall

4.41 Rainfall brings moisture to the runway, which will have an effect on aircraft performance. Flight test data shows that even small amounts of water may have a significant effect on aircraft performance, e.g. damp runways effectively reduce aircraft braking action below that of a clean and dry runway.

4.42 Rainfall on a smooth runway surface affects aircraft performance more than rainfall on a runway surface with good macrotexture. Rainfall on runway surfaces with good drainage has a lesser effect on aircraft performance. Grooved runways and runways with porous friction course surfaces fall into this category. However, there comes a time when the drainage capabilities of any runway exposed to heavy or torrential rain can be overwhelmed by water, especially if maintenance has been neglected.

4.43 At sufficiently high rainfall rates water will rise above the texture depth. Standing water will occur, leading to equally hazardous situations as might occur on smooth runways. Improved performance at such rainfall rates should not be used anymore. For example, a grooved or PFC runway subject to torrential rainfall might perform worse than a regular smooth wet runway.

Current Research

4.44 There is ongoing research trying to link rainfall rate, texture and drainage capacity. This is an important relationship where the aim is to establish critical rainfall rates as a function of texture and drainage characteristics. Threshold values could then be established where, for instance, a wet skid resistant surface would no longer qualify for performance credit, or for where there would be a risk of aquaplaning. Runways could then be classified based on different drainage characteristics.

4.45 Various studies have been performed over the past decades to relate rain intensity and runway characteristics to water depth on the runway. Water depth on the runway determines what aircraft performance data should be used by the flight crew, e.g. regular wet performance or standing water performance. It seems that water depth modelling is currently the only available method that can be used in a timely manner to inform flight crews of the amount of water present on a runway. Runway design parameters, notably texture depth, are a main indicator for water depth as a function of rain intensity. Rain intensity itself could be derived from weather radar data or forward scatter meters. Weather radar information could provide a timely warning, whereas forward scatter meters could potentially provide actual rain intensity information for each runway third. These are all subjects that needs further study.

Current reporting practices

4.46 Disregarding winter operations, a runway is currently reported as dry, damp, wet, or contaminated as a result of standing water. Additionally a NOTAM “slippery when wet” may be issued whenever a significant portion of a runway drops below the Minimum Friction Level (MFL) as indicated in Table A-1 of Annex 14 or as determined by the state.

4.47 Classifying a runway as damp or wet is not at all a straightforward matter, as various subjective criteria depending upon the aerodrome or the State’s standards or policies may be used. Different practices are used ranging from whether or not the runway wetness causes it to appear shiny, the use of the “effectively dry” provision in current EU-OPS, only reporting a runway as wet during heavy rainfall or reporting a runway as wet whenever rain is falling.

4.48 Reporting flooded runway conditions is difficult as methods for accurately, reliably and timely determining the water depth on a runway are not available. Flooded runway conditions have contributed to several accidents worldwide. Obviously the frequency of occurrence of flooded runway conditions will be higher for the regions more prone to torrential rainfall and equally for the lower macrotexture runways.

4.49 There are currently no international agreed terms for reporting the intensity level of rainfall.

CONSTRUCTION

Selection of aggregates and surface treatment

4.50 **Crushed aggregates.** Crushed aggregates exhibit a good micro texture, which is essential in obtaining good friction characteristics.

4.51 **Portland Cement Concrete (PCC).** The friction characteristics of PCC are obtained by transversal texturing of the surface of the concrete under construction in plastic physical state to give the following finishes:

a) Brush or Broom;

b) Burlap drag finish; and

c) Saw-cut grooving.

4.52 For existing pavements (or new brand hardened pavements) the saw-cut technique is typically used.

4.53 The two first techniques provide rough surface texture, whereas the saw groove technique provides a good surface drainage capacity.

4.54 **Hot Mix Asphalt.** Bituminous concrete must have a good waterproofing with high structural performance. The specification of mixture depends on different factors, such as local guidelines, type and function of surfaces, type and traffic intensity, raw materials and climate.

4.55 With a selection of good shape crushed aggregates and a well graded asphalt mix design rating combined with standard mechanical characteristics (e.g., adhesion of binder to aggregates, stiffness, resistance to permanent deformation, resistance to fatigue/crack initiation, resistance to abrasion), the expected macrotexture will normally reach 0.7-0.8 mm with an 11 - 14 mm size aggregate.

4.56 Grooving and Porous Friction Course. Two methods which have had significant influence on improved friction characteristics for runway pavements are grooving and the open graded, thin hot-mix asphalt (HMA) surface called Porous Friction Course (PFC).

4.57 Additional guidance on grooving of pavements and the use of a PFC is contained in the *Aerodrome Design Manual,* Part 3 , Pavements (Doc 9157).

Grooving

4.58 The primary purpose of grooving a runway surface is to enhance surface drainage and tire/ground interfacial drainage. Natural drainage can be slowed down by surface texture, but can be improved by grooving, which provides a shorter drainage path with more rapid drainage. Grooving adds to texture in the tire/ground interface and provides escape channels for dynamic drainage

4.59 The first grooved runways appeared on military aerodromes in the UK (mid 1950s). The US followed up by establishing a grooved NASA research track (1964 and 1966) The first civil aerodromes with grooved runways were Manchester in the UK (1961) and John F. Kennedy in the US (1967). Ten years later (1977) approximately 160 runways had been grooved worldwide. The research conducted in these early years is the foundation for the documentation within the *Aerodrome Design Manual,* Part 3, Pavements. Reports from this research are available from NASA Technicalø Report Server.

4.60 Runway grooving has been recognized as an effective surface treatment that reduces the danger of hydroplaning for an aircraft landing on a wet runway. The grooves provide escape paths for water in the tire/ground contact area during the passage of the tire over the runway. Grooving can be used on PCC and HMA surfaces designed for runways.

4.61 In addition, the isolated puddles that are likely to be formed on nongrooved surfaces because of uneven surface profile are generally reduced in size or eliminated when the surface is grooved. This advantage is particularly significant in the regions where large ambient-temperature variations may cause low magnitude undulations in the runway surface.

4.62 **Construction methods.** Grooves are saw-cut by diamond tipped rotary blades. The end product quality of the grooves produced can vary from operator to operator. The equipment is specialised, although it can be built 'in-house' by the operator. This equipment should only be operated by skilled operators.

4.63 **Tolerances.** In order for a surface to be considered for wet grooved runway aircraft performance, the saw-cut grooves must meet tolerances set by the State for alignment, depth, width and center-to-center spacing.

4.64 **Cleanup.** Cleanup of waste material must be continuous during a grooving operation. All debries, waste and by-products generated by the operation must be removed from the movement area and disposed of in an approved manner in compliance with local and State regulations.

4.65 **Maintenance.** A system must be established for securing the functional purpose of maintaining clean grooves (rubber removal) and preventing or repairing collapsed grooves.

4.66 The macrotexture of the runway surface can be effectively increased by grooving, and this is applicable to asphalt and concrete surfacings. The macrotexture of ungrooved continuously graded asphalt is typically in the range 0.5 to 0.8mm, and slightly higher for stone mastic asphalt. In service, grooves wear down with trafficking and this has the effect of reducing macrotexture over time. Various States use differing groove geometry, and Table 4-1 shows examples of these and the effect of grooving on macrotexture for new and worn grooves. Porous asphalt and special friction treatment surfacings normally have higher macrotexture and are not grooved.

State	Condition	Groove geometry			Macrotexture (mm)	
		Width (mm)	Depth (mm)	Spacing, centre-centre (mm)	Asphalt	
					ungrooved	grooved
Australia, USA	New	6	6	38	0.65	1.49
	Half worn	6	3	38		1.02
Norway	New	6	6	125	0.7-1.6	0.95-1.81
UK	New	4	4	25	0.65	1.19

Table 4-1 Groove geometry

The effect of grooving on macrotexture can be calculated for any groove geometry and surfacing macrotexture using equation 1, which is applicable to rectangular/square grooves.

$$M_g = \frac{WD + M_u (S-W)}{S}$$

where: M_g grooved macrotexture
W groove width
D groove depth
M_u ungrooved macrotexture
S groove spacing

Example: (from a UK airport)

grooves 3 mm deep and wide with a spacing of 25 mm and a ungrooved macrotexture of 0.64 mm will give an grooved macrotexture of

$$(3x3 + 0.64x(25 – 3))/25 = 0.92 \text{ mm}$$

4.67 In service, the grooves wear down with trafficking and partly fill with rubber in the touchdown areas. Although this wear and clogging affect only part of the runway, and the average texture is still mainly determined by the unworn and unclogged grooves on the rest of runway, it is usual to aim for a macrotexture of rather more than 1.0 mm during construction.

4.68 The pitch and size of groove varies by airport/authority, as shown in the table on a State level and through an example on airport level, and the resultant net effect on the texture of the grooved asphalt is demonstrated. This indicates that grooving adds more than a small amount to the runway texture on airports that use the larger grooves.

4.69 Grooving, however, has its limits. It will not cope totally with standing water due to ruts and ponding in the runway (common in worn-out runways). Nor will it cope with deep standing water due to heavy precipitation and it won't cope with standing water due to the grooves and texture being filled with accumulation of rubber. However, grooving does make a difference to the grip on a wet runway, as the water gets deeper on the runway.

4.70 Following on from the above, it has been shown (*Bernadetto and o thers*) that better macrotexture depth on a runway surface means the loss of skid resistance, during incidents of heavy precipitation, is reduced. See Fig 4.3 below. This is important because it underlines the ICAO requirement for both friction levels and texture depth.

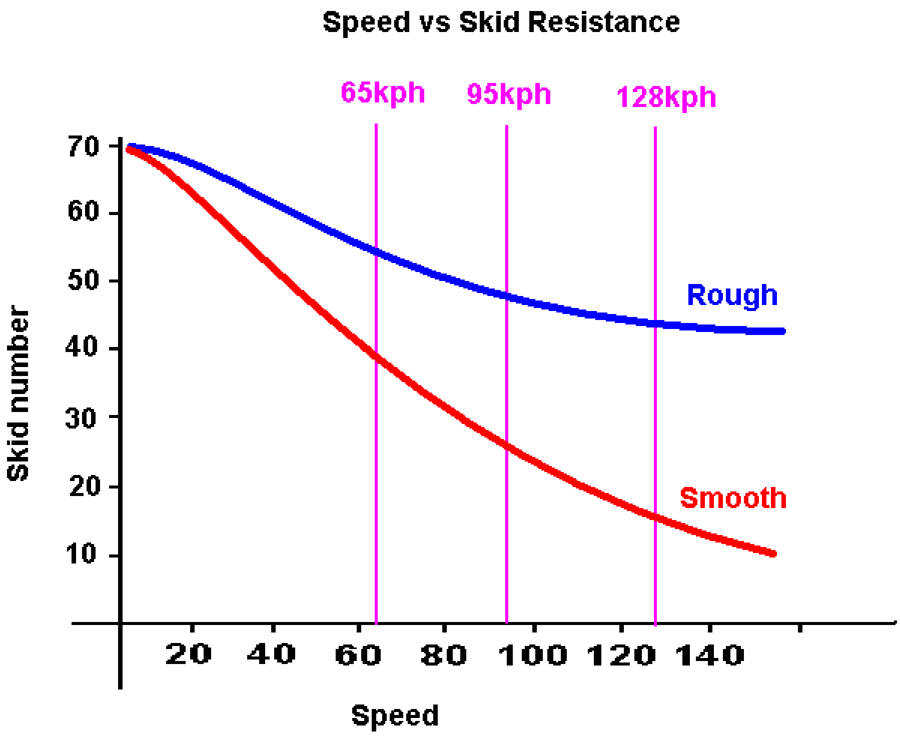


Figure 4.3 Effect of grooves on macrotexture.

As speed increases, grip reduces as shown above. Grooving offsets this effect by adding macrotexture, as indicated by the gap between the rough and smooth traces. *(courtesy of UK CAP 683)*

Porous Friction Course

4.71 As an alternative to grooving, a Porous Friction Course (PFC) was developed in the UK in 1959. The first "friction course" on a runway was laid in 1962. It was deliberately designed not only to improve the skid resistance but to reduce hydroplaning incidence by providing a highly porous material to ensure a quick getaway of water from the pavement surface directly to the underlaying impervious asphalt. This asphalt mixture is designed to present structural open voids (20 to 25 per cent) permitting natural or dynamic drainage at the tire/surface interface.

4.72 Two main skid resistant related difficulties that can appear when using PFC are:

a. Rubber deposits must be monitored and be removed before filling up the structural void spaces. The functional effectiveness of PFC becomes nil if the removal is performed too late;

b. Contamination may also fill void spaces and reduce this drainage efficiency.

MAINTENANCE

4.73 An appropriate maintenance program should ensure adequate side drainage, rubber removal and cleaning of runway (non-winter) contaminants.

Removal of rubber

4.74 The overarching purpose of rubber removal is to restore the inherent friction characteristics and unmask covered painted runway markings. Every aircraft landing creates rubber deposits. Over time rubber deposits accumulate, primarily in the touchdown and braking area of a runway. As a result the texture is progressively reduced, and the painted area is covered.

4.75 There are four methods to remove runway rubber:

a) waterblasting;
b) chemical removal;
c) shotblasting; and
d) mechanical means.

4.76 No single method for removal is superior to all others or for a given pavement type. Methods can be combined. The chemical method can be used to pretreat or soften the rubber deposit before waterblasting. Additional guidance on removal of rubber and other surface contaminants can be found in Doc 9137, *Airport Services Manual*, Part 2 — *Pavement Surface Conditions* and Part 9 — *Airport Maintenance Practices*.

4.77 **Damage to surface and installations.** One concern with rubber removal is not to damage the underlying surface. Experienced operators who are familiar with their equipment are able to remove the required amount of rubber without causing unintended damage to the surface. A less experienced or less diligent operator using the same equipment can inflict a great deal of damage to the surface, grooves, joint sealant materials, and ancillary items such as painted areas and runway lighting merely by lingering too long in one area or failing to maintain a proper forward speed.

4.78 Most damage appears to be associated with waterblasting so only experienced operators should be used. Least damage appears to be associated with chemical removal.

4.79 **Retexturing.** Removal of rubber with shotblasting can have the advantage of retexturing a polished pavement surface.

4.80 The Transportation Research Board report (see List of References) synthesizes the current information available in runway rubber removal, including the effects each removal method has on runway grooving, pavement surface, and to appurtenances normally found on an aerodrome runway. Some regard this field as more of an art than a science. Thus, this report seeks to find those factors that can be controlled by the engineer when developing a runway rubber removal program. The synthesis identifies different approaches, models, and commonly used practices, recognizing the differences in each of the different rubber removal methods.

SKID RESISTANCE

Loss of skid resistance

4.81 The factors that cause loss of skid resistance can be grouped into two categories:

a) Mechanical wear and polishing action from rolling, braking of aircraft tires or from tools used for maintenance.

b) Accumulation of contaminants.

4.82 These two categories directly relate to the two physical friction characteristics of runway pavements that generate friction when in contact and relative motion with the aircraft tire:

a) Microtexture

b) Macrotexture

Microtexture (skid resistance)

4.83 Microtexture can be lost when exposed to mechanical wear of the aggregate. The susceptibility for mechanical wear of the aggregates in the pavement is a built in quality usually referred to as a Polished Stone Value (PSV). PSV is a measure of an aggregate's resistance to polishing under simulated traffic and determines an aggregate's suitability where skid resistance requirements vary.

4.84 The PSV test involves subjecting a sample of similarly sized aggregate particles to a standard amount of polishing and then measuring the skid resistance of the polished specimen. Once polished, the specimens are soaked and then skid tested with a British Pendulum. Thus, the PSV value is in fact a friction measurement in accordance with international standards (ASTM D 3319, ASTM E 303, CEN EN 1097-8).

4.85 Microtexture is reduced by wear and polishing.

Macrotexture (skid resistance)

4.86 As macrotexture affects the high speed tire braking characteristics, it is of most interest when looking at runway characteristics for friction when wet. Simply put, a rough macrotexture surface will be capable of a greater tire to ground friction when wet than a smoother macrotexture surface.

Surfaces are normally designed with a sufficient macrotexture to obtain suitable water drainage in the tire/pavement interface.

4.87 Through the harmonised FAR 25 (1998) and CS 25 (2000) certification specifications, there are two airplane braking performance levels defined – one for wet smooth pavement surfaces and one for wet grooved or PFC pavement surfaces.. A basic assumption including these performance levels are that the aircraft tire has a remaining tread depth of 2 mm.

4.88 It is preferable to develop programmes aimed at improving surface texture and drainage of runways such that the safety is improved.

4.89 Macrotexture is reduced and lost as the voids between the aggregate are filled with contaminants. This can be a transient condition, such as with snow and ice, or a persistent condition, such as with the accumulation of rubber deposits

Surface dressing

4.90 Improvement of skid-resistance for pavement surfaces can be obtained by surface dressing using high quality crushed aggregates and modified polymer binder for better adhesion of granularities on the surface and for minimizing loose aggregates. The size of aggregates is limited to 5 mm.

4.91 Nevertheless, this kind of product exhibits high texture depth and may potentially damage aircraft tires through wear.

4.92 The application of these techniques must be considered on pavements which present good structural and surface condition.

4.88 Comprehensive guidance on methods for improving the runway surface texture is available in Doc 9157, *Aerodrome Design Manual*, Part 3 — *Pavements*, Chapter 5.

Chapter 5

COEFFICIENT OF FRICTION AND FRICTION MEASURING DEVICES

COEFFICIENT OF FRICTION

5.1 It is erroneous to believe that the coefficient of friction is a property belonging to the pavement surface and is therefore part of its inherent friction characteristics. This is not to be the case. As described in Chapter 3, it is a system response generated by the dynamic system consisting of the:

a) pavement surface;

b) tire;

c) contaminant; and

d) atmosphere.

5.2 It has been a long sought goal to correlate the system response from a measuring device to the system response from the aircraft when measured on the same surface. There have been a substantial amount of research activities carried out that has brought new insight in the complex processes taking place. Nevertheless, to date, there has not been a universally accepted relationship between the measured coefficient of friction and the system response from the aircraft although one State uses the coefficient of friction measured by a decelerometer and relates it to aircraft landing distances. *(refer Appendix A)*

FRICTION MEASURING DEVICES

Performance and use of friction measuring devices

5.3 Friction measuring devices have two distinct and different uses at an aerodrome:

a) For maintenance of runway pavement, as a tool for measuring friction related to the:

   i. maintenance planning level; and

   ii. minimum friction level

b) For operational use as a tool to aid in assessing estimated surface friction when compacted snow and ice are present on the runway.

State established criteria for friction characteristics

5.4 States should establish criteria for the friction characteristics related to the different levels mentioned above, and as part of this, determine the performance criteria for the approval of friction measuring devices to be used in that State. Annex 14, Volume I, Attachment A, Table A-1 indicates some levels of friction associated with some friction measuring devices. However, it must be noted that this table refers to specific tests and specific friction measuring devices and cannot, and must not, be taken as global friction values valid for other friction measuring devices of the same make and type.

State established performance criteria for friction measuring devices

5.5 States are required to ensure that the acceptable friction measuring devices fulfill the performance criteria set by the State, taking into consideration factors such as repeatability and reproducibility for individual friction measuring devices. In order for Annex 14, Volume I, Attachment A, Table A-1 to be utilized properly, States should have in place proper calibration and correlation methods. Repeatability and reproducibility of continuous friction measurement equipment should meet performance criteria based upon measurement on a 100 m test surface lengths. This length corresponds to the length considered significant for maintenance and reporting action by ICAO.

5.6 Currently, repeatability in the order of ± 0.03 and reproducibility in the order of ± 0.07 coefficient of friction units are claimed to be achievable. However, there has not yet been an international consensus on how to express repeatability and reproducibility in the context of friction measurements to be used for maintenance and reporting purposes at aerodromes although various design and measuring principles are available.

5.7 A major challenge for manufacturers producing friction measuring devices is an urgent replacement for the NASA Wallops Flight Facility, situated on the eastern shore of Virgina, U.S.A., which is no longer available as a place for the certification testing of friction measuring devices. State-endorsed facilities will be required in the future in order to take on the role played by the NASA Wallops facility.

5.8 There is, at present, no globally accepted procedures for developing methods and logistics for using the friction measuring devices. States have chosen to develop methods and logistics based on local conditions and historical fleets of friction measuring devices within the State. Some States have developed procedures for controlling the uncertainties involved and have approved specific friction measuring devices and how to use them relative to the design and maintenance criteria set by the State. Some of these States have made detailed information related to their use of friction measuring devices available through the internet such as:

a) US through FAA Advisory Circulars; and

b) UK through CAP683 The Assessment of Runway Surface Friction Characteristics

c) Canada (through its website http://www.tc.gc.ca/civilaviation/publications/tp14371/air/1-0.htm#1-6

http://tcinfo/civilaviation/nationalops/AudInspMon/Program/SafetyCirculars/2000002.htm

(links to be updated)

Chapter 6

AIRCRAFT OPERATIONS

FUNCTIONAL FRICTION CHARACTERISTICS

How rolling, slipping, and skidding affect the aircraft

6.1 **Aircraft/runway interaction.** Mechanical interactions between aircraft and runways are complex and depend on the critical tire/ground contact area. This small area (approximately 4 square meters for the largest aircraft currently in service) is subject to forces that drive the rolling and braking characteristics of the aircraft, as well as directional control.

6.2 **Lateral (cornering) forces.** These forces allow directional control on the ground at speeds where flight controls have reduced effectiveness. If contaminants on the runway or taxiway surface significantly reduce the friction characteristics, special precautions should be taken (e.g., reduced maximum allowable crosswind for takeoff and landing, reduced taxi speeds) as provided in operational manuals.

6.3 **Longitudinal forces.** These forces, considered along the aircraft speed axis (affecting acceleration and deceleration), can be split between rolling and braking friction forces. When the runway surface is covered by a loose contaminant (e.g., slush, snow, or standing water), the aircraft is subjected to additional drag forces from the contaminant.

Rolling friction forces

6.4 Rolling friction forces (un-braked wheel) on a dry runway are due to the tire deformation (dominant) and wheel/axle friction (minor). Their order of magnitude represents only around 1-2 per cent of the aircraft apparent weight.

Braking forces – general effects

6.5 Braking forces are generated by the friction between the tire and the runway surface when brake torque is applied to the wheel. Friction exists when there is a relative speed between the wheel speed and the tire speed at the contact with the runway surface. The slip ratio is defined as the ratio between the braked and un-braked (zero slip) wheel rotation speeds in revolutions per minute (rpm).

6.6 The maximum possible friction force depends mainly on the runway surface condition, the wheel load, the speed and the tire pressure. The maximum friction force occurs at the optimum slip ratio beyond which the friction decreases. The maximum braking force depends on the friction available as well as the braking system characteristics, i.e., anti-skid capability and/or torque capability.

6.7 The coefficient of friction μ is the ratio between the friction force and the vertical load. On a good dry surface, the maximum friction coefficient μ_{max} can exceed 0.6, which means that the braking force can represent more than 60 per cent of the load on the braked wheel. On a dry runway, speed has little influence on μ_{max}. ,When the runway condition is degraded by contaminants such as water, rubber, slush, snow, or ice, μ_{max} can be reduced drastically, affecting the capability of the aircraft to decelerate after landing or during a rejected take off.

6.8 General effects of runway surface conditions on the braking friction coefficient can be briefly summarized as follows:

6.8.1 **Wet condition (less than 3 mm water).** μ_{max} in wet conditions is much more affected by speed (decreasing when speed increases) than it is in dry conditions. At a ground speed of 100 kts, μ_{max} on a wet runway with standard texture will be typically between 0.2 and 0.3, this is roughly half of what you would expect to obtain at a low speed such as 20 kts.

6.8.2 On a wet runway, μ_{max} is also dependent on runway texture. A higher micro texture (roughness) will improve the friction. A high macro texture, porous friction course (PFC) or surface grooving will add drainage benefits; however it should be noted that the aircraft stopping performance will not be the same as on a dry runway. Conversely, runways polished by aircraft operations or contaminated by rubber deposits or where texture is affected by rubber deposits after repeated operations can become very slippery. Therefore, maintenance must be performed periodically.

6.8.3 **Loose contaminants (standing water, slush, wet or dry snow above 3 mm).** These contaminants degrade μ_{max} to levels which could be expected to be less than half of those experienced on a wet runway. Micro texture has little effect in these conditions. Snow results in a fairly constant μ_{max} with velocity, while slush and standing water exhibit a significant effect of velocity on μ_{max}.

6.8.4 Because they have a fluidic behaviour, water and slush create dynamic aquaplaning at high speeds, a phenomenon where the fluid's dynamic pressure exceeds the tire pressure and forces the fluid between the tire and ground, effectively preventing physical contact between them. In these conditions, the braking capability drops drastically, approaching/reaching nil.

6.8.5 The phenomenon is complex, but the driving parameter of the aquaplaning speed is tire pressure. High macro texture (e.g., a PFC or grooved surface) has a positive effect by facilitating dynamic drainage of the tire-runway contact area. On typical airliners, dynamic aquaplaning can be expected to occur in these conditions above 110 to 130 kts ground speed. Once started, the dynamic aquaplaning effect may remain a factor down to speeds significantly lower than that necessary to trigger it.

6.8.6 **Solid contaminants (compacted snow, ice and rubber).** These contaminants affect the deceleration capability of aircraft by reducing μ_{max}. These contaminants do not affect acceleration.

6.8.7 Compacted snow may show friction characteristics that are quite good, perhaps comparable to a wet runway. However, when the surface temperature approaches or exceeds 0º C, compact snow will become more slippery, potentially reaching a very low μ_{max}.

6.8.8 The stopping capability on ice can vary depending on the temperature and roughness of the surface. In general wet ice has a very low friction (μ_{max} dropping to as low as 0.05) and will typically prevent aircraft operations until the friction level is improved. However, ice that is not melting may still allow operations, albeit with a performance penalty.

6.8.9 Runway surface contaminants resulting from the operation of aircraft, but which are not usually considered as contaminants for airplane performance purposes, are rubber deposits or de-icing fluid residues. These items are usually localized and limited to portions of the runway. Runway maintenance should monitor these contaminants, and remove them as needed. Affected portions will be notified in NOTAMS when the friction drops below the minimum required friction level.

Contaminant drag forces

6.9 When the runway is covered by a loose contaminant (e.g., standing water, slush, non compacted snow), there are additional drag forces resulting from the displacement or compression of the contaminant by the wheel. The driving factors of these displacement drag forces are: aircraft speed and weight, tire size and deflection characteristics, and contaminant depth and density. Their magnitude can significantly impair the acceleration capability of the aircraft during take-off. For example, 13mm of slush would generate a retardation force representing about 3 per cent of the aircraft weight at 100 knots (kts) for a typical mid-size passenger aircraft.

6.10 A second effect of these displaceable contaminants (slush, wet snow, and standing water) is the impingement drag, whereby the plume of sprayed contaminant creates a retardation force when impacting the aircraft structure. The combination of the displacement retardation force and impingement retardation force can be as high as 8 to 12 per cent of the aircraft weight for a typical small/mid size passenger aircraft. This force can be large enough that in the event of an engine failure the aircraft may not be able to continue accelerating.

Aircraft runway performance implications

6.11 It is obvious from the information provided above that as soon as the runway condition deviates from the ideal dry and clean state, the acceleration and deceleration capabilities of the aircraft may be affected negatively with a direct impact on the required takeoff, accelerate-stop and landing distances. Reduced friction also impairs directional control of the aircraft and therefore the acceptable cross wind during take off and landing will be reduced.

6.12 **Qualitative assessment.** Qualitatively, the impacts on the aircraft's maximum braking capability can be summarized as follows:

6.12.1 **Wet and solid contaminant conditions:**

- acceleration (and hence take off distance) not affected; and
- braking capability reduced, longer accelerate-stop and landing distances

6.12.2 **Loose contaminants:**

- acceleration capability reduced by displacement and impingement drag (slush, wet snow, and standing water) or the force required to compress the contaminant (dry snow); and
- deceleration capability reduced by lower friction, aquaplaning at high speeds, partially compensated by displacement and impingement drag

6.12.3 As a result,

- take off distance is longer (worse when contaminant is deeper);
- accelerate-stop distance is longer (less so when contaminant is deeper because of higher displacement and impingement drag); and
- landing distance is longer (less so when contaminant is deeper because of higher displacement and impingement drag)

6.13 **Quantitative assessment.** Quantitatively, the following data provide the order of magnitude of the effects of runway conditions on the actual performance of a typical medium size aircraft, the reference being dry conditions. (Accelerate-stop distance effects assume take off rejection at the same V_1 speed, and the braked ground phase is calculated with maximum pedal braking.) It should be mentioned that impact on regulatory performance might be different as the regulatory calculation rules are dependent upon runway conditions.

6.13.1 **Wet conditions (no reversers):**

- the acceleration and continued takeoff is not affected;
- the accelerate-stop distance is increased by approximately 20-30 per cent. A grooved or PFC runway will reduce this penalty to approximately 10-15 per cent. (Note: Use of reverse thrust (one-engine-inoperative) will reduce this effect by 20-50 per cent depending on the reversers effectiveness and runway condition.)
- the braked landing ground phase is increased by 40 to 60 per cent on a smooth runway, and 20 per cent on a grooved or PFC runway. (Note: Use of all engine reverse thrust will reduce this effect by ~50 per cent depending on the reversers effectiveness and the runway condition

6.13.2 **13 mm water or slush covered conditions:**

- the take off distance is increased by 10 - 20 per cent with all engines operating due to displacement and impingement drag. (Note: The effect on the one-engine-inoperative takeoff distance will be significantly larger.);
- the accelerate-stop distance will increase by 50 up to 100 per cent, reduced to a 30-70 per cent increase with use of thrust reversers (one-engine-inoperative); and
- the braked landing ground phase is increased by 60 – 100 per cent depending on actual depth of water or slush on the runway. This can be reduced significantly by the use of reverse thrust.

6.13.3 **Compact snow:**

- the acceleration and continued takeoff is not affected;
- the accelerate-stop distance is increased by 30-60 per cent, reduced to 20-30 per cent with the use of thrust reversers (one-engine-inoperative); and
- the braked landing ground phase may increase by 60 to 100 per cent. Even with use of reverse thrust, this may be as much as 1.4 to 1.8 times the dry runway distance.

6.13.4 **Non-melting ice conditions:**

- the effect of non-melting ice conditions can vary considerably depending on the smoothness of the surface, whether it has been treated with sand or melting agents etc.

- the acceleration and continued takeoff is not affected;
- the accelerate-stop distance may vary from almost as good as compact snow to a level approaching wet ice conditions
- the braked landing ground phase may increase by distances from the values noted for compact snow to distances approaching the wet ice conditions noted below.

6.13.5 **Wet ice conditions:**

- the acceleration and continued takeoff is not affected;
- the accelerate-stop distance is more than doubled, even with use of thrust reversers; and
- the braked landing ground phase may increase by a factor of 4 to 5. Even with use of reverse thrust this may be as much as 3 to 4 times the dry runway distance.

6.13.6 Wet ice conditions correspond to a braking action reported as “Nil.” and Operations should not be conducted due to the performance impacts shown above and the potential for loss of directional control of the aircraft.

6.14 As a summary, the following graphs provide a visual indication of the severity of runway condition impact on take-off, accelerate-stop and landing ground phase for a typical medium size aircraft with thrust reversers of average efficiency. The typical effect of a wet skid resistant surface (e. g., porous friction course or grooved) is also provided.

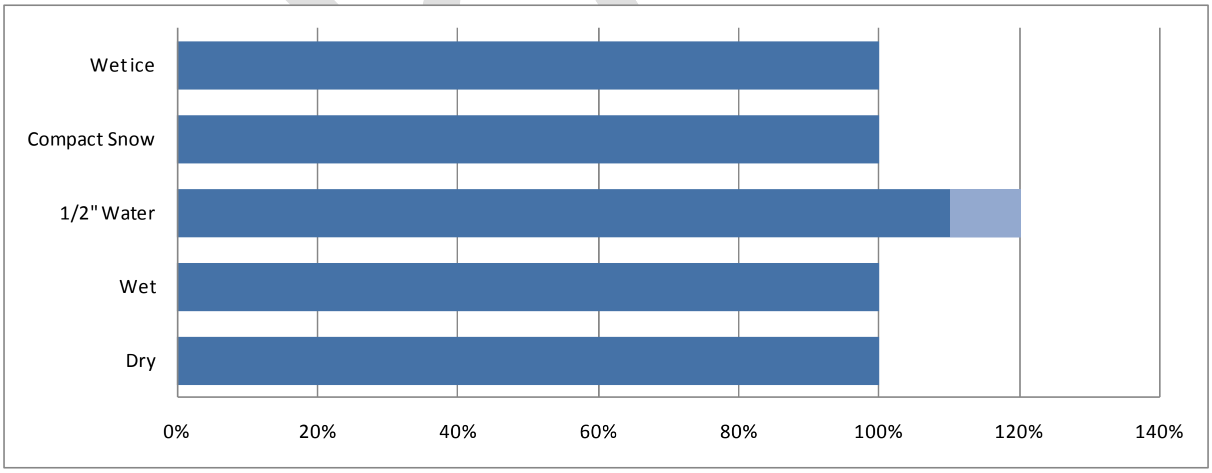


Figure 6.1 – Runway condition impact on actual take off distance (all engines operative)

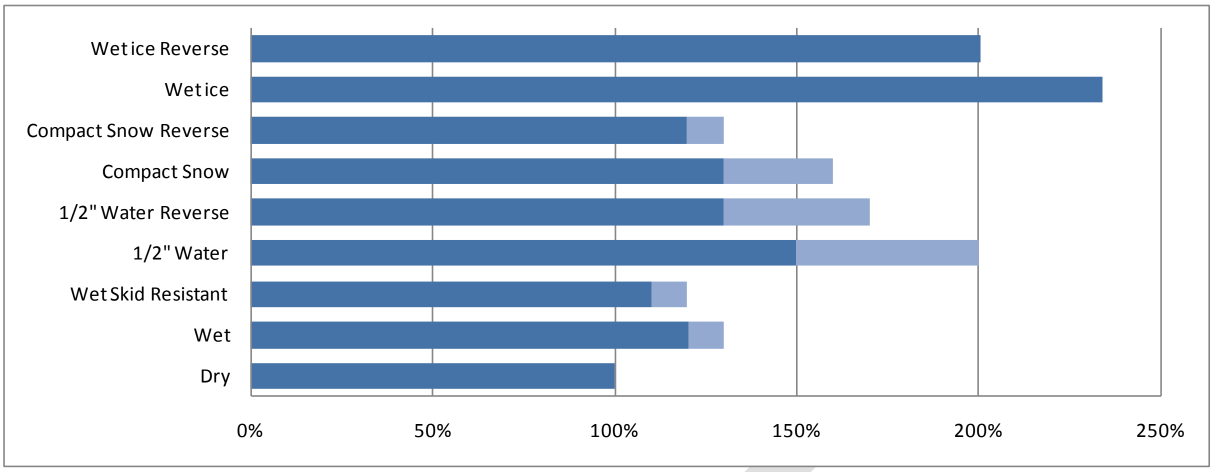


Figure 6.2 – Runway condition impact on Accelerate-stop distance

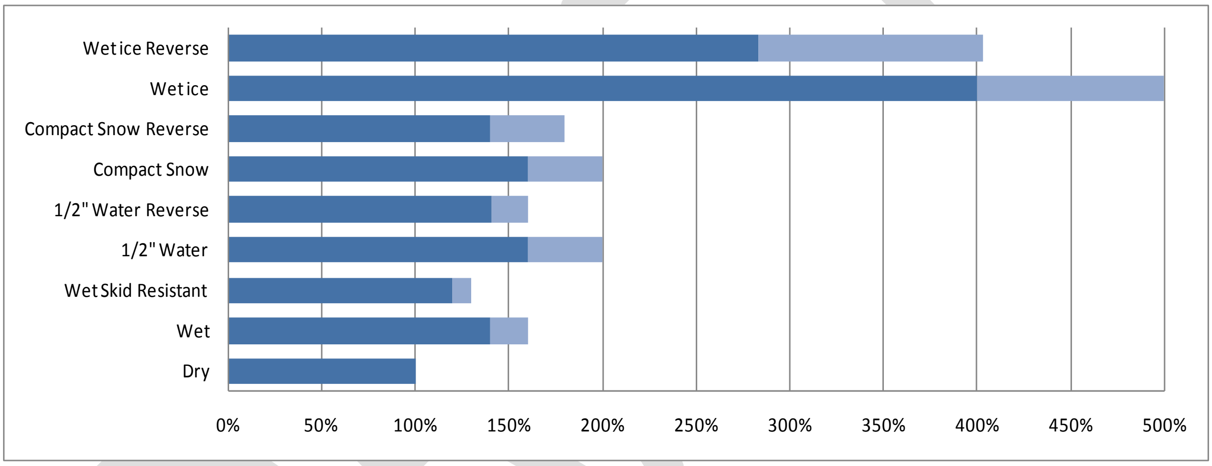


Figure 6.3 – Runway condition impact on landing ground phase

AIRCRAFT COMPONENTS – A REVIEW OF THE AIRCRAFT SYSTEM

6.15 A review of the aircraft system including aircraft tire, inflation pressure and wear, brake systems.

General

6.16 Aircraft braking system technology has evolved continuously in the past decades, in order to maximize its overall efficiency such as deceleration capability, weight, durability, maintainability and reliability and cost per landing

A short review of its main components is provided below.

6.17 **Tires.** The main evolution has been in the structure of the tire evolving from bias to radial plies with a reduction in weight and an improvement in the durability. Both bias and radial tires types exist today. In terms of friction, the durability/friction compromise of rubber compounds has reached maturity, with all tire types showing similar levels of μ_{max} on various types of surface.

6.17.1 Circumferential grooves contribute to drainage in the contact area, which reduces aquaplaning occurrences. This positive effect diminishes with tire wear. Maximum friction values provided for certification of accelerate-stop distances on wet runways are consistent with 2 mm minimum tread depth on all wheels.

6.18 **Wheels.** Wheel technology has long since come to maturity, with forged aluminium alloys ensuring the best weight and durability compromise. The wheels include fuse plugs that will ensure a safe tire deflation following a high-energy stop before there is any possibility of a potentially hazardous tire burst.

6.19 **Brakes.** Disc brakes are the norm. Disc materials have evolved from metal (steel or even copper in some specific cases) to carbon. Both types coexist, but the light weight, durability, and decreasing relative cost of carbon versus steel tend to make it the dominant technology for larger civil airliners.

6.19.1 While the maximum brake energy absorption capability is directly driven by the material and mass of the discs, the maximum torque depends on the disk number and diameter, as well as the applied pressure on the discs. Brake temperature and speed also affect this maximum torque.

6.19.2 Pressure is applied by hydraulic pistons through a pressure plate. Electrically actuated pistons are an emerging technology which will soon reach airline service.

6.20 **Anti-skid system.** Brakes are designed for a maximum torque that is achieved when the maximum available pressure is applied by pistons. When the vertical load on the wheel is high on a good friction surface (e.g., high aircraft weight on a dry runway), the maximum available tire/ground friction force will normally exceed that which can be obtained at maximum torque. In this case, the braking force will be torque limited (below the tire/runway friction limit), with the maximum value achieved when maximum pedal braking is applied.

6.21 When the load on the wheel and/or μ_{max} decreases, the maximum friction force between the tire and the ground may decrease to levels where the resulting torque will be below the maximum torque capability of the brake. In this case, if full pressure is allowed through the pistons to the wheel brake the wheel will lock and the tires could fail.

6.22 To avoid this phenomenon, anti-skid systems have been developed which monitor the wheel slip ratio and govern piston pressure to achieve the best braking efficiency. These systems have evolved from primitive on/off designs to fully modulating systems taking advantage of the latest digital control technologies. The efficiency of the anti-skid system is the ratio between the average braking force achieved and the theoretical maximum braking force obtained at the optimum slip ratio (providing μ_{max}).

6.23 This efficiency ranges between 0.3 for on/off systems to around 0.9 for modern digital anti-skid systems. For certification, anti-skid system operation must be demonstrated by flight-testing on a smooth wet runway, and its efficiency must be determined. In addition, modern anti-skid systems provide elaborate functions such as auto brake, maintaining a pre-set deceleration level (friction permitting), allowing a reduction in brake wear, and improvement in passenger comfort.

6.24 At very low speeds (below 10 kts), due to sensor accuracy limits, anti-skid behaviour may become erratic and affect directional control. The latest systems however include a means to avoid this anomaly.

6.25 By design, anti-skid systems are effective only if wheel spin exists, which may not be the case when dynamic aquaplaning occurs.

Braking system test and certification

6.26 Due to its critical influence on aircraft safety and regulatory performance, braking systems are subject to a thorough test and certification process before entry into service. They must comply with stringent regulations which will drive the architecture (e.g., redundancies, back-up modes in case of failure) as well as the design of components.

6.27 Brake endurance is proven by bench tests (dynamometer). The maximum energy capacity is tested both on the bench and through an actual aircraft rejected take off test in, or close to, the maximum wear condition. The maximum torque is identified by aircraft flight tests as well as the anti skid efficiency after fine-tuning on both dry and wet runways. These tests are also used to identify the aircraft performance model.

6.28 It has to be noted that no specific tests are required on contaminated runways with regards to braking system behaviour nor aircraft performance. The corresponding data may be calculated based on the certified model in dry and wet conditions, supplemented by accepted methods for the effects of contamination on performance that are based on previous test results obtained from a variety of aircraft types.

TEXTURE AND AIRCRAFT PERFORMANCE ON WET RUNWAYS

Aircraft wet runway certification standards

6.29 Since the early 90's, JAA certified aircraft takeoff performance for rejected takeoff has required wet runway accountability as part of the aircraft's performance certification. The FAA added a similar requirement in 1998. This wet runway standard uses a wet runway μ_{max} relationship from ESDU 71026 methods which have been codified in FAA/JAA airworthiness standards, endorsed subsequently by EASA in CS 25.

6.30 The FAA/JAA airworthiness standards allow 2 levels of aircraft performance to be provided in the airplane flight manual for wet runway takeoffs: wet smooth runway performance and wet grooved or porous friction course(sometimes referred to as wet skid-resistant) runway performance. The wet smooth runway performance data must be provided, while the wet grooved/PFC data may be provided at the aircraft manufacturer's option.

6.31 The certification requirements for aircraft rejected takeoff stopping performance on a wet runway uses the wet runway μ_{max} relationship from ESDU report 71026 “Frictional and Retarding Forces on Aircraft Types – Part II.” This ESDU report contains curves of wet runway braking coefficients versus speed for smooth and treaded tires at different inflation pressures. The data are presented for runways of various surface roughness including grooved and porous friction course (PFC) surfaces. The ESDU data accounts for variations in water depth from damp to flooded, runway surface texture within the defined texture levels, tire characteristics and experimental methods. In defining the standard curves of wet runway braking coefficient versus speed that are prescribed by the equations codified in 14 CFR and EASA CS 25.109, the effects of tire pressure, tire tread depth, runway surface texture and depth of the water on the runway were considered.

- Tire pressure – the regulations provide separate curves for different tire pressures.
- Tire tread depth – the standard curves are based on a tire tread depth of 2 mm. This tread depth is consistent with tire removal and retread practices reported by aircraft and tire manufacturers and tire retreaders.
- Depth of water on the runway – The curves used in the regulations represent a well-soaked runway with no significant areas of standing water.

6.32 Runway surface texture is taken into account in the definition of two different performance levels. One performance level is defined for a wet-smooth runway performance. The other is for a wet, grooved or PFC runway performance level.

6.33 ESDU 71026 groups runways into five classifications. These classifications are labelled “A” through “E” with “A” being the smoothest and “C” the most heavily textured non-grooved, non-PFC surface.

6.34 Runway classification based on texture from ESDU 71026:

Classification	Texture depths (mm)
A	0.10 – 0.14
B	0.15 – 0.24
C	0.25 – 0.50
D	0.51 – 1.00
E	1.01 – 2.54

Wet-smooth runway performance

6.35 The wet-smooth runway performance is a level that has been deemed appropriate for use on the “normal” wet runway. That is a runway which has not been specifically modified or improved to provide improved drainage and therefore better friction.

6.36 Classification A represents a very smooth texture (an average texture depth of 0.10 mm) and is not often found at aerodromes served by transport category airplanes. Most ungrooved runways at aerodromes served by transport category airplanes fall into the classification C. The curves in FAR and CS 25.109 used for wet smooth rejected takeoff runway performance represent a level midway between classification B and C.

Wet, grooved or PFC runway performance

6.37 FAA/JAA/EASA part 25 standards allow for a second wet runway rejected takeoff performance level that reflects the improvement in braking friction available from grooved and PFC runways.

6.38 These surface treatments will result in a significant improvement in the wet runway stopping performance, but will not be equivalent to dry runway performance. The μ_{max} level in the FAA/JAA/EASA standards for grooved and PFC runways is a level midway between classification D and E as defined in ESDU 71026. As an alternative, the regulations also permit using a wet, grooved or PFC braking coefficient that is 70 per cent of the braking coefficient used to determine the dry runway accelerate-stop distances.

6.39 One additional constraint for taking performance credit for the grooved/PFC surface is that the runway must be built and maintained to a specific standard as described in FAA AC 150/5320-12C or its equivalent.

Wet skid resistant pavement – Improved stopping capability

6.40 The standards adopted by the FAA in the Improved Standards for Determining Rejected Takeoff and Landing Performance (Ref. 1) allow operators to take credit for the improved stopping capability during a rejected takeoff on wet runways that are grooved or treated with a PFC overlay, but only if such data are

a) provided in the Aircraft Flight Manual	Aircraft manufacturer
b) and the operator has determined that the runway is	Aircraft operator
i. designed	Aerodrome operator
ii. constructed; and	Aerodrome operator
iii. maintained	Aerodrome operator
c) in a manner acceptable to the administrator.	State

6.41 The standard enhances safety by taking into account the hazardous wet runway rejected takeoff condition and it creates an economic incentive to develop more stringent design, construction, and maintenance programs for runways to be considered available for wet grooved or PFC runway aircraft performance. While the improved wet friction of these surfaces also benefits to landing safety, the basic FAA/JAA/EASA certification and operational rules do not provide landing performance credit for them. Nevertheless, some States such as the FAA/JAA/EASA have developed alternative means of compliance which may provide such credit on a case by case basis. At present it has been recognized by the aviation industry that further development and regulation of the concept is needed.

6.42 FAA has produced an Advisory Circular which provides relevant guidelines and procedures related to construction and maintenance of skid resistant aerodrome pavement surfaces. (Ref 4)

6.43 States should make sure that the safety level represented by ICAO design guidance is met, and develop standards and guidance material requirements for further improving drainage and friction characteristics.

RELATIONSHIP BETWEEN AIRCRAFT PERFORMANCE STANDARDS AND AERODROME MINIMUM FRICTION STANDARDS FOR WET RUNWAYS

6.44 In the aviation world it is often assumed that the minimum friction criteria in Table A-1 of ICAO Annex 14 and FAA AC 150/5320-12C provide a minimum friction level which would allow the aircraft to achieve the performance published in the AFM for a smooth wet runway. It has also further been assumed in many quarters that if the runway cannot meet the minimum friction level that is called out for in Table A-1 and the aerodrome declares the runway slippery when wet, then the aircraft's performance would be degraded.

6.45 However, the truth of the matter is that there has not been a relationship established between the wheel braking and friction assumptions used in the aircraft performance and the minimum friction standards stated in ICAO Annex 14/FAA AC 150/5320-12C. The certification requirements for aircraft performance do not provide a performance level to specifically address the case when an aerodrome reports a runway as slippery when wet because it failed a friction survey as defined by the ICAO/FAA advisory levels.

6.46 The FAA Aviation Rulemaking Committee (ARC) working on Takeoff and Landing Performance Assessment (TALPA) recommends reducing the effective braking action for a wet runway from "good" to "medium" when the runway is designated as slippery when wet.

Chapter 7 and 8

(to be developed)

Chapter 9

SAFETY, HUMAN FACTORS AND HAZARDS

SAFETY

9.1 **Evolution of safety.** In retrospect, the historical progress of aviation safety can be divided into three distinct areas.

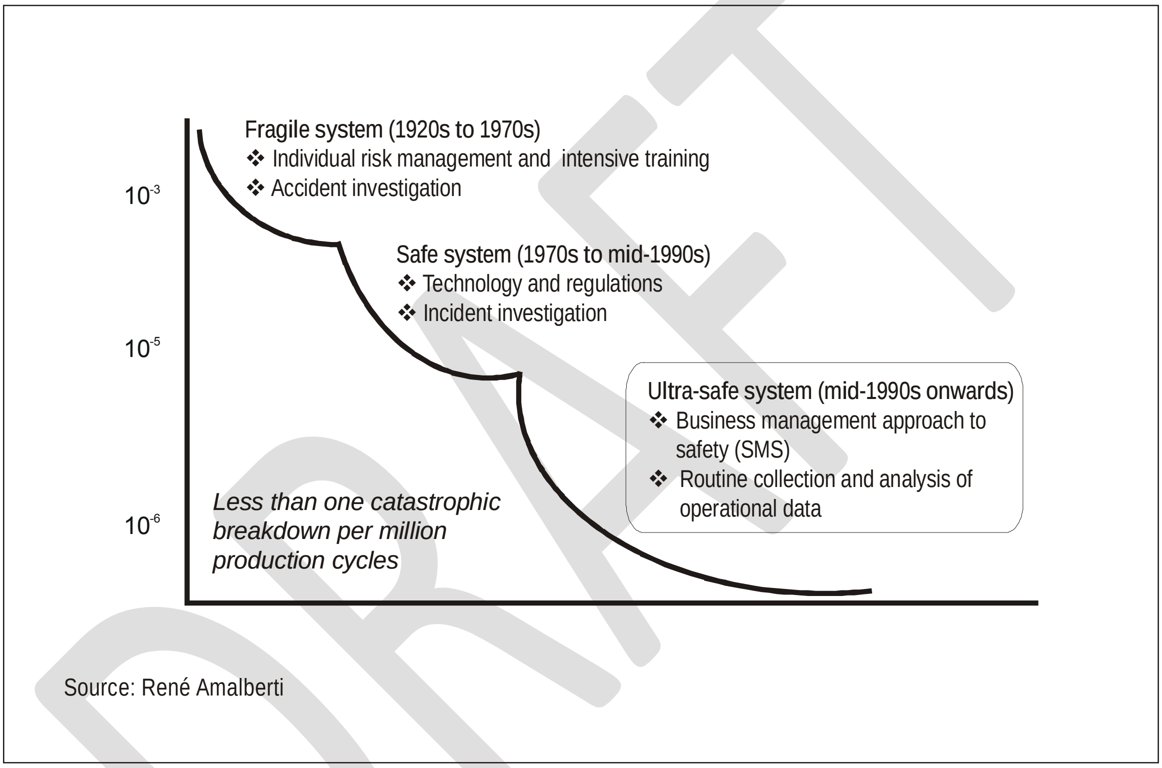


Figure 9.1 - The first ultra-safe industrial system (source ICAO *Safety Management Manual (SMM)* (Doc 9859))

9.1.1 Modern technologies make the daily collection and analysis of routine operational data, including friction data, possible. This information exchanged through the NOTAM system highlights the emerging issues related to friction.

9.2 **Digital up-to-date data.** Future Air Traffic Management (ATM) relies on advanced data exchange and data sharing services that communicate aeronautical information. As a prerequisite, all information has to be supplied in digital format rendering it suitable for automatic processing without human intervention. A "digital NOTAM or SNOWTAM" can be defined as a structured data set that contains the information currently distributed by text NOTAM messages.

9.2.1 The focus is on correct, complete and up-to-date data. The current NOTAM and SNOWTAM messages will continue to be issued, but, the messages will be based on the conversion of the digital aeronautical data, which will become the reference.

9.2.2 In short, it can be said that frictional issues were developed in the fragile system and updated partly into the safe system and now need to be brought into the ultra-safe system with digital up-to-date data as shown in Figure 3.

9.3 **Human interface.** Even with automatic processing three distinct human interfaces can be identified.

a) The persons who produce the information or control/calibrate the instrument providing the information for automatic processing. This is the ground staff.

b) The persons who by radio phraseology transfer the information to end user. This is the ATM staff.

c) The persons who make use of the information. This is the flight crew.

9.3.1 To assist with introducing commonality on friction issues across States, it is recommended that States introduce regulations requiring operators to provide training to the ground and ATM staff and flight crew in accordance with Appendix B – Training for ground, ATM staff and flight crew.

9.4 **Gate-to-gate concept.** The gate-to-gate concept involves considering and managing a flight as a continuous event. It involves coordination of ATM processes with those of the airport and aircraft operators to provide a safe and seamless management approach. With the new gate-to-gate concept espoused in the ICAO Global Air Navigation Plan, all the aerodrome movement-area related activities will be in the middle of the loop. Up-to-date friction related data will be dealt with from a human factors perspective highlighting when and how to use it. *Appendix C – Friction issues versus segment of flights*, lists the friction issues relevant to each segment of flight.

9.5 **Safety margins.** On the whole, to be on the safe side, the methodology used for aircraft performance assessments should be conservative. Some parameters that have an influence on aircraft performance are known beforehand with sufficient accuracy; other parameters have greater uncertainty or may change rapidly. For parameters that cannot be determined accurately, additional conservatism may need to be applied.

9.5.1 A double (and unnecessary) application of safety factors may lead to great economic penalties and unintended consequences such as an ill advised diversion and the absence of a (necessary) safety factor may lead to unsafe situations. Therefore, it is essential to know the uncertainty of relevant parameters and whether or not a parameter used by the flight crew already includes a safety margin.

HUMAN FACTORS

Introduction

9.6 Human Factors (HF) affect the gathering of runway friction data, and also the way such information is given to those who need it. The key participants in this process are 1) the data gatherers 2) the data transmitters and 3) the users of the information. (See Figure 4) It is essential that both parties (transmitter & receiver) within the communication loop have a clear, unambiguous and common understanding of the terminology. Situations such as routine maintenance or runway contamination scenarios alter the demands for co-operation between the various participants.

Maintenance - (Functional)			
Aerodrome (1)		**ATC (2)**	**Flight crew (3)**
Operatives	**Management**		
Gathers info➔	Interprets info & Takes action		

Operational - (Contaminated)		
Aerodrome (1)	**ATC (2)**	**Flight crew (3)**
Gathers info➔	Transmits info➔	Interprets info & ←Makes decision

Figure.9.2 – Key participants.

Problem Statement

9.7 The main HF issue is that each action is part of a chain of events that requires co-operation between parties and for those actions to be executed in a particular order, each one dependent upon a successful outcome from the previous. Although the "how to do it" part can be planned, written down as instructions and agreed in advance by all participants, it relies on team work, negotiation, communication and co-operation to achieve an end result. Work accomplished so far by the FTF has shown that, worldwide, this has not always been achieved.

Participants

9.8 Who are the main participants in these operations? From within the aerodrome authority, a small team of trained operatives is responsible for using specialist equipment (such as CFME) to gather runway friction data. From the airline operator, flight crew are responsible for the safe management of the flight. Between these two sits the Air Traffic Controller (ATC) who, in this case, primarily passes information about the runway to the aircraft and then acts upon responses that are generated from the cockpit as a result. Connected to this information flow are the airlines' dispatch, operations centre or handling agent, who use information gathered from flight crew, ATC and the aerodrome authority to plan or amend flight schedules accordingly.

Communication and Teamwork

9.9 For over twenty years much emphasis in flight deck human factors has been placed on team training and Crew Resource Management (CRM) with the aim of training pilots to utilise all the resources available to them (including the human resources) to operate safely. Many tasks involve an element of teamwork, and in such cases communication among team members is crucial. One of the questions often posed during the introductory phase of team training is “who is the team?” In answering this question, most people, initially at least, mention their colleagues in the immediate vicinity actually involved in the day-to-day task. Few will look outside their immediate area of expertise and consider other players in the system with whom they come into contact. Failure to consider the extent of the “team” at best leads to poor communication and, at worst, can lead to mistrust, misunderstandings or even personality conflicts. In any event, the safety of the system is likely to suffer.

9.10 Beginning a series of friction runs on an active runway clearly requires close liaison between the duty runway controller in the vehicle control room and the operative driving the friction vehicle. These individuals have different goals, however; the driver wants adequate time to carry out all the runs without interruption; the ATC officer wants minimum disruption to traffic flow. In the case of regular data gathering runs for maintenance purposes, this work can generally be accommodated at night after the aerodrome closes or during times of the day when traffic levels are low.

9.11 In adverse weather conditions, when contamination may be present, a shift in goals occurs. The ATC officer wants the operatives out to the runway as soon as possible and wants them to remain available so that regular updates can be obtained on demand. However, the driver may now have other higher priorities and may not be able to wait at the end of the runway in case another friction run is called for. The possibility that the friction equipment driver has other pressures should be borne in mind though good management and supervision should alleviate these. He may also believe that the task of gathering data, which he may consider to be unreliable is a waste of time but, because of traditional hierarchies, he doesn't feel empowered to refuse the request from ATC.

9.12 With planning and co-operation, routine friction testing should not inconvenience pilots; indeed they might well be unaware of the operation. But, when the runway is contaminated flight crew are keenly aware that information from the runway passed via ATC is of vital importance. As a diversion is never a 'desirable' event, this may contribute to the fact that crews focus on that portion of information that supports their desire to land at the destination, so any transmission that indicates good conditions will be seized upon. It is possible that some aircraft can have limited air holding time before being committed to divert whilst remaining within fuel reserve limits.

Challenges

9.13 For all participants, there are a number of factors that can obstruct good information gathering and exchanging. Instead of focussing on the individuals and tasks, paying attention to the situation or conditions in which individuals operate can give a view of problems and hence reveal solutions. It is difficult to change people, changing the situation in which they work is the answer.

9.13.1 a) Communication

9.13.1.1 One of the prime issues within human factors is communication. ATC depends on it, CRM is all about it and engineers spend a good deal of their time working with equipment to facilitate it.

9.13.1.2 There are many factors that contribute to communication breakdown; they include such things as expectation - hearing what we want or expect to hear rather than what was actually said; and assumption. Human corruption of data through emphasis or opinion can have an impact on meaning and can cause misunderstanding or misinterpretation.

9.13.1.3 Communication, however, is about more than just the human voice. While verbal communication may be fraught with problems, written communication can also be a minefield. Handover of work at breaks or shift changes often involves written as well as verbal communication and has been shown to be a source of problems in many industries, not just aviation. Incomplete log entries, rushed and inadequate verbal exchanges or the lack of a systematic means of conveying the status of a task all contribute to handover problems.

9.13.2 b) Standards and Procedures

9.13.2.1 Some of the major sources of written communication are the procedures and instructions, which are based on regulatory standards designed to assist in the correct performance of the task. Not infrequently however, procedures can be poorly written, incomplete, incompatible with other procedures related to complementary tasks, non-existent or just plain wrong. Correct procedure writing is an art and it is all too easy to find examples which contravene many of the basic tenets of good human factors management with, for example, too much cross referencing or a poor layout. The manner in which procedures are presented and accessed is also important. If procedures are difficult to access they will not be used. In an ideal world it should be as easy to do the right thing as the wrong one. Inadequate attention to the production of good procedures is a guaranteed means of ensuring that they will not be followed. It may be that frontline staff know better than the procedure writer what conditions the procedures are to be used in. If so, they should be consulted in advance.

9.13.3 c) Training, Education & Skills maintenance

9.13.3.1 After initial training, comes the challenge of maintaining competency in the task. This is not normally a problem with everyday, well-practised tasks but the increasing reliability of systems and the increase in replaceable components can make it difficult for the individual to maintain skills, once learned. Infrequent faults may be experienced only by chance. This is why training and practice in handling CFME is vitally important, as it is a rarely used non-standard operation. Allied to this should be clear reference material that explains data or assessment methods and the use to which they can be put. Tools that make this process speedy, efficient and accurate may have to be developed. The event may be unanticipated, not previously experienced and possibly dangerous, perhaps involving the use of unfamiliar equipment. Rather than just training, more education should be considered, such as the question of how to convey knowledge to everyone involved, how to decide which aspects are most important and when specialist judgment must be used. This education should provide individuals with an understanding of their own role, and also an appreciation of how their personal roles interact with the roles of others.

9.13.4 d) On-the-Job Training

9.13.4.1 Another area, which involves a good deal of communication, is that of on-the-job training. Learning from the expert may be effective but relies on clear and accurate communication. It also depends on teaching skills. Often the assumption is made that the best worker may be the most capable of passing on his skills, but this is not always the case. The real “natural” may find it extremely difficult to understand why the novice is having problems.

9.13.5 e) Conclusion

9.13.5.1 The study of Human Factors is a task, which demands a methodical approach. Whenever error intrudes into human activity, disrupting objectives or even causing incidents or accidents, its cause must be identified. Such cause will often be a sequence of misunderstandings or inappropriate actions. Each of these might well be harmless in isolation, but together lead to failure. The human traits which lead to these mistakes require patient study if they are to be overcome.

HAZARDS

9.14 **Risk management vs. friction issues.** The application of safety management in the conduct of aircraft operations relative to the critical tire/ground contact area is a complex one.

9.14.1 No activity can be absolutely free of risk, but activities can be controlled to ensure that risk is reduced to an acceptable level. If the risk remains unacceptably high, activities will have to be delayed or modified and a new risk assessment carried out. Often, a balance must be stuck between the requirements of the task and the need to make the performance of the task safe. The balance may sometimes be difficult to achieve but should always be biased towards safety.

The modern approach to risk management recommends a process as follows:

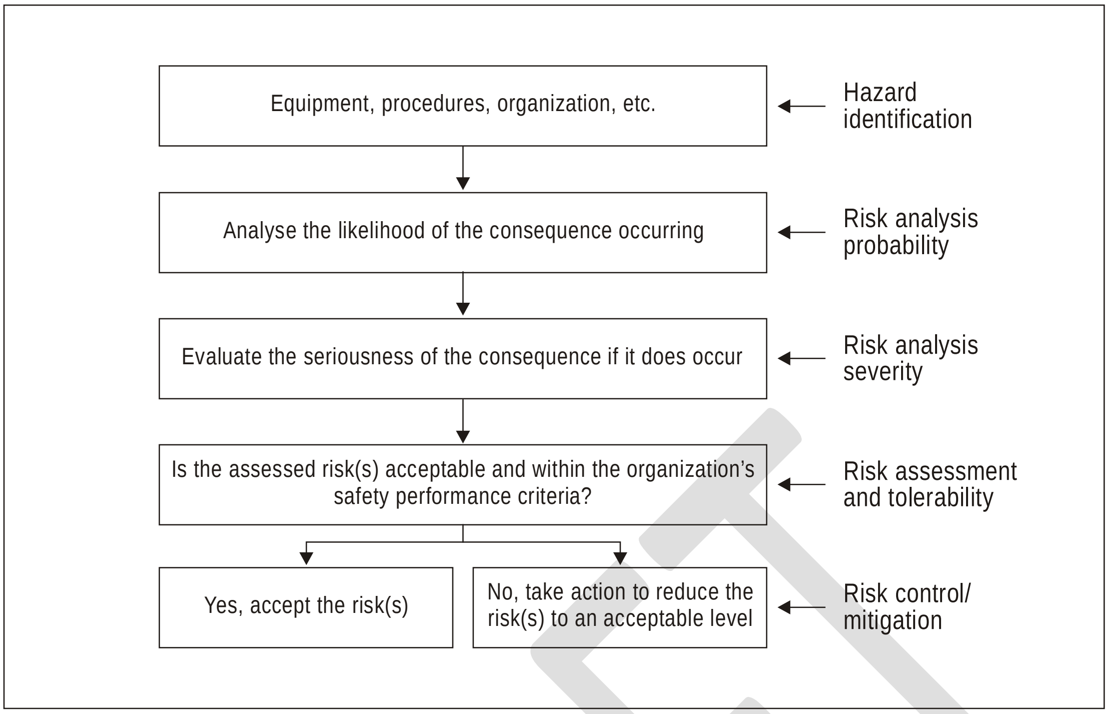


Figure 9.3 – The process of safety risk management (source ICAO *Safety Management Manual (SMM)* (Doc 9859))

9.14.2 This process appears rather simple in concept and, indeed, the process may actually be easily introduced for those process-based industries that benefit from sufficient knowledge, time and planning capacity and that have firm control over their operations. However, organisations with responsive roles, such as ground staff and flight crew with respect to friction issues face a more complex process due to the variable nature of meteorological conditions than the schematic model suggests. The exposure to the hazards might be too low to gain experience. This stresses the importance of training.

9.14.3 Effective risk assessment first requires sound data to enable the **identification of hazards**. *Appendix D* through *G* list some known hazards commonly associated with physical, functional and operational friction characteristics:

a) *Appendix D* – Hazards related to friction issues and pavement
b) *Appendix E* – Hazards related to friction issues and aircraft
c) *Appendix F* – Hazards related to friction issues and reporting format
d) *Appendix G* – Hazards related to friction issues and atmosphere

9.14.4 Persons involved should be trained to identify hazardous conditions and to follow established procedures and standards associated with the identified hazard. The processes involved in the critical tire/ground contact area necessitate sound assessment and judgement to be made by those who identify the conditions at the movement area and those who operate on the movement area in the prevailing conditions. The question to be asked while executing their assessment and judgement should be; should you be doing this? This way they will challenge their own assessment and judgement.

Chapter 10

FUTURE ACTIVITIES FOR FURTHER IMPROVEMENT

10.1 The Friction Task Force has identified the following future activities for further improvement:

a) global reporting format;

b) revision of ICAO guidance material;

c) common taxonomy across ICAO documents, including ADREP;

d) criteria for wet skid resistant pavement; and

e) study into rainfall rate, drainage, texture and aircraft performance

f) update criteria for and approval of new friction measuring devices

The above mentioned activities will need to be part of an action plan.

GLOBAL REPORTING FORMAT

10.2 There is an urgent need to report runway state conditions in a standardized manner that will enable flight crews to use this information to determine, as accurately as possible, aircraft performance for takeoff and landing. Runway state reporting must therefore use terminology and values that can be used in conjunction with the aircraft performance charts supplied by the manufacturers. This commonality of terminology and values must be designed to be used by the manufacturers who develop the performance tables, the aerodromes personnel who evaluate and report the runway conditions, the air traffic controllers and aeronautical information specialists who transmit the data, and the pilots and the flight operations officers/flight dispatchers who apply the data For example, ideally, a global harmonized solution needs to be created that can, to a reasonable extent, enable the friction coefficient values of a given runway to be related to the manufacturer's landing/takeoff performance tables for a given aircraft.

10.3 As has been identified in Chapter 6, there has not been a relationship established between the wheel braking and friction assumptions used in the aircraft performance and the minimum friction standards stated in ICAO Annex 14. This relationship needs to be established in order that meaningful and consistent performance characteristics for each take off and landing can be determined.

10.4 There is a need for standardized terms so that:

a) information is presented in a manner allowing flight crew to easily make a correlation with the aircraft performance information ; and

b) to a reasonable extent, enable the friction coefficient values of a given runway to be related to the manufacturer's landing/takeoff performance tables for a given aircraft.

10.5 There is a urgent need for a common understanding of definitions and processes related to reporting of runway state conditions. In this respect, it is propose to consider the possibility of merging into one new format, the results arising from the following initiatives:

a) ICAO SNOWTAM

b) ICAO NOTAM

c) Canadian CRFI

d) FAA – TALPA ARC initiative

10.6 The suggested name given is ICAO CONTAM to be defined as a special series NOTAM notifying the presence or removal of hazardous conditions due to contaminants on the movement area by means of a specific format.

10.7 Harmonize terms and definitions used for promulgating information on runway surface condition through the new AIXM protocol. Produce overarching standardization of terms concerning the:

a) gathering of information by ground staff as per Annex 14;

b) reporting format as per Annex 15; and

c) use of information to meet operational requirements of the flight operator as identified in Annex 6.

REVISION OF ICAO GUIDANCE MATERIAL

10.8 Driven by the global change, a task to be established to review and update appropriate guidance across ICAO documentation containing friction related issues with special focus on:

a) ICAO Doc 9137, *Airport Services Manual,* Part 2, Pavement Surface Conditions;

b) ICAO Doc 9137, *Airport Services Manual*, Part 8, Airport Operational Services, in particular Chapters 2, 3, 6 and 7;

c) ICAO Doc 9137, *Airport Services Manual*, Part 9, Airport Maintenance Practices, in particular Chapter 4;

d) ICAO Doc 9157, *Aerodrome Design Manual,* Part 3, Pavements, in particular Chapter 5; and

e) ICAO Doc 8168, *Aircraft Operations,* Volume 1, Flight Procedures

COMMON TAXONOMY

10.9 Using the same taxonomy for reporting surface and contaminant related information and the reporting and dissemination of the same information in accident and incident investigation and associated databases.

CRITERIA FOR WET SKID RESISTANT PAVEMENT

10.10 Develop criteria for qualifying the operational use of a wet skid resistant pavement involving:

a) construction – performance criteria

b) maintenance – Safety Management System in place

c) Approval – State Authority approval

d) Documentation in Aircraft Flight Manual

STUDY INTO RAINFALL RATE, DRAINAGE, TEXTURE AND AIRCRAFT PERFORMANCE

10.11 Develop criteria for a quantitative relationship between rainfall rate, surface characteristics and aircraft performance. The provisions of adequate wet runway friction is closely related to the drainage characteristics of the runway surface. The drainage demand in turn is determined by local precipitation rates. Drainage demand, therefore, is a local variable which will essentially determine the engineering effort and associated investment/cost required to achieve the objective. In general, the higher the drainage demand, the more stringent the interpretation and application of the relevant engineering criteria will become. Criteria should cover the range of expected rainfall rates at aerodromes, heavy tropical rainfall included as applicable.

UPDATE CRITERIA FOR AND APPROVAL OF NEW FRICTION MEASURING DEVICES

10.12 Doc 9137 ASM Part 2, Chapter 5, section 5.2 *Criteria for new friction-measuring devices* needs to be updated. The criteria should be performance based and with the aim towards the use of friction measuring devices for maintenance purposes at aerodromes.

10.13 Appendix 3 of the same document concerning *NASA Certification Test Procedure for New Continuous Friction-Measuring Equipment Used at Airport Facilities* needs to be updated. The role that NASA had as a facility for the approval and correlation of friction measuring devices, at its Wallops Flight Facility, Virgina, is no longer available. The test procedure should be updated and reflect the new situation with respect to test facilities.

Appendix A

PROGRAMMES ON FRICTION MEASUREMENT AND RUNWAY CONDITION ASSESSMENT AND REPORTING

1.1 CANADIAN RUNWAY FRICTION INDEX (CRFI)

The Canadian Runway Friction Index (CRFI) and associated Recommended Landing Distance Tables are commonly used in Canada as a pilot aid in determining whether a landing can be safely accomplished on a winter contaminated runway. The following describes the measurement of CRFI, the research that went into establishing a direct correlation with aircraft braking performance, and the basis for establishing the Recommended Landing Distance Tables.

1.2 Measurement

Findings from the JWRFMP have led to improved aeronautical guidance material in Canada, where winter is a major preoccupation. A decelerometer is used to determine with some accuracy the effect that a contaminant has on reducing the surface friction of a runway and to provide meaningful information to pilots. The readings taken by this instrument are averaged and reported as a Canadian Runway Friction Index (CRFI).

An electronic recording decelerometer (ERD) is used for runway friction measurement during winter operations at virtually all Canadian airports. It's a spot measurement device that uses a piezo-electric accelerometer to measure deceleration. The device is rigidly mounted in the cab of an airport vehicle, and readings are taken by accelerating the vehicle to 50 km/h and then applying the brakes to the point of wheel lockup. A number of measurements are taken at various intervals on each side of the runway centreline, and averaged to provide a single friction value for the entire runway surface. The output is termed the CRFI.

The advantages of the ERD over other friction measurement devices are its simplicity and the fact that the CRFI correlated well with aircraft braking coefficients measured during the JWRFMP. The main disadvantages of the ERD compared to continuous friction measuring devices are a longer runway occupancy time and the effect of operator technique on measurement, particularly on surfaces where contamination is not uniform.

Decelerometers are used only during winter operations and only on surfaces contaminated by ice or frost, wet ice (ice covered with a thin film of water), sand, aggregate material, compacted snow, loose snow up to 2.5 cm (1 inch) deep, and ice covered by slush. They are also used when anti-icing or de-icing chemicals have been applied to the runway.

Decelerometer readings may be inaccurate under certain conditions, so CRFI is not provided to pilots for wet surfaces with no other contaminant, for slush with no other contaminant, or when loose snow on the runway is deeper than 2.5 cm (1 inch).

The CRFI value describes braking action quantitatively. This number, along with a runway surface condition report, provides an overall description of the runway in the Aircraft Movement Surface Condition Reports (AMSCR) provided to air traffic services, which in turn provide it to pilots through ATIS or NOTAMs.

1.3 Reporting

A typical aircraft movement surface condition report (AMSCR) includes a CRFI number along with a surface description and other relevant information.

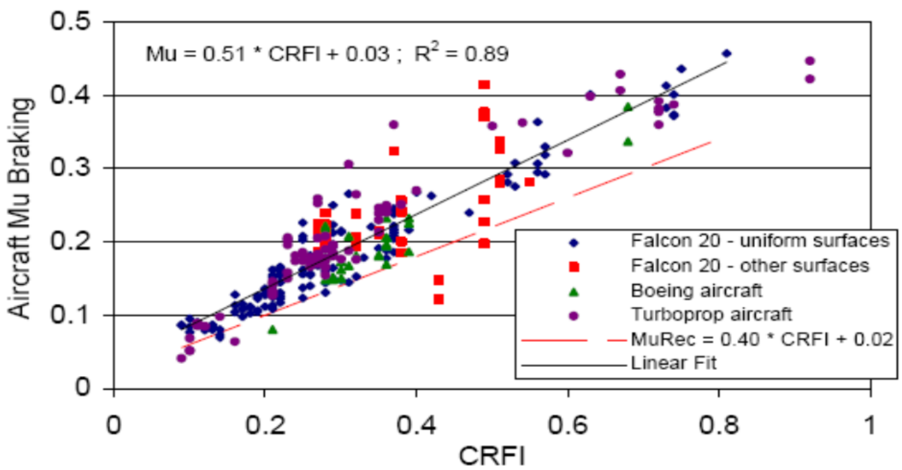
Typically during preflight planning, a NOTAM is available. Once airborne, the crew gets information through the ATIS – and with rapidly changing conditions, verbal updates are usually available through the tower.

1.4 Predicting Landing Distance

The prediction of landing distance as a function of the CRFI is based on an acceptable correlation of aircraft braking coefficient (Mu braking) and CRFI. Aircraft deceleration is modeled as a function of aircraft parameters and measured runway friction (CRFI), and models of aircraft braking distance and recommended landing distance are created for contaminated runways. The expression for recommended landing distance is given in terms of aircraft flight manual (AFM) landing distance and CRFI.

The attached figure plots the mean aircraft Mu braking against the CRFI for 275 aircraft test runs on contaminated surfaces, including surfaces which were non-uniformly contaminated.

To account for data scatter resulting from uncertainties in the measurement of both Mu braking and CRFI, as well as operation on non-uniform surfaces, a line is shown representing the minimum *recommended* Mu, given by the equation: $Mu_{rec} = 0.40 \times CRFI + 0.02$.



Mu Braking vs. CRFI – all Aircraft Tested

The term *recommended* indicates that the values include a safety factor. The Mu_{rec} line is drawn below at least 95 percent of the data points in the above figure, giving a 95 percent probability that the braking distances computed from the deceleration models will be achievable.

The CRFI tables of recommended landing distances were developed for a turbojet aircraft type using no reverse thrust , or using either turbojet reverse thrust or turbo-propeller discing thrust..

1.5 Application of the CRFI Tables

Although the CRFI tables of recommended landing distance have been derived from performance data from Falcon 20 and Dash 8 aircraft, they are considered to be applicable to jet transport aircraft and turboprop aircraft in general for a number of reasons. First, the correlation between aircraft braking coefficient and CRFI was found to be similar for the different aircraft types tested. The relationships used for the deceleration models are essentially dependent on the aircraft wheel braking system (and reverse/discing thrust if used), and are not significantly affected by other aircraft characteristics. An aircraft with a more advanced anti-skid braking system could perform better than the CRFI table predictions, while an aircraft without an anti-skid system would exceed the CRFI table predictions. Second, the equations used to model the components of the recommended landing distances were based on a series of Falcon 20 performance landings, but are typical of most aircraft types, being essentially time/distance relationships dependent on approach groundspeed, flare technique and time to deploy lift dump devices. The inclusion of safety factors allows for minor deviations in landing techniques, such as a *slightly* extended flare or late application of reverse thrust, which will result in landing distances longer than optimal, but still within the CRFI table of recommended distances. Third, major differences between aircraft types are accounted for by entering the CRFI table with the specific aircraft AFM landing distance, and *factoring* that distance based on the value of the CRFI. The CRFI table data are consistent with current regulations requiring the factoring of AFM landing distance for operations on wet or dry runways

CRFI Table Example: If a surface condition report was provided by the airport which included a CRFI reading of 0.4, an aircraft having an unfactored landing distance of 3000 ft. on a bare and dry surface based on the aircraft flight manual would need 5910 ft. of runway length without the use of thrust reversers using the CRFI Table without thrust reversers. If the pilot chooses to use thrust reversers, the recommended landing distance would be 5340 ft. using the CRFI Table with thrust reversers. If the friction reading had been 0.27 these distances would have been 6860 ft. and 5950 ft. respectively. (see tables in TC AIM)

1.6 Conclusion

Braking coefficients were obtained for several instrumented aircraft during full braking tests on winter-contaminated runways during the JWRFMP. These data were compared to the runway friction measured by the Transport Canada ERD to provide a model for the prediction of aircraft landing distance on winter contaminated runways based on the CRFI. Tables of recommended landing distance, independent of specific aircraft type, have been developed as a function of the CRFI and published by Transport Canada as advisory material.

2. TAKEOFF AND LANDING PERFORMANCE ASSESSMENT – AVIATION RULEMAKING COMMITTEE (TALPA/ARC)

2.1 Following the overrun of a Boeing 737 at Midway in December of 2005 the FAA found a number of deficiencies in the regulations and guidance affecting certification and operation of aircraft and aerodromes for aircraft takeoff and landing operations on runways contaminated by snow, slush, ice, or standing water. As such they chartered an Aviation Rulemaking Committee (ARC) to address Takeoff and Landing Performance Assessment (TALPA) requirements and guidance for the turbine-engined aircraft~~s~~ certified under 14 CFR parts 23 or 25 and operated under parts 91 subpart K, 121, 125 or 135. In formulating their recommendations it became clear to the ARC that the ability to communicate actual runway conditions to the pilots in real time and in terms that directly relate to expected aircraft performance was critical to the success of the project.

2.2 While researching current NOTAM processes, numerous significant shortcomings were discovered that hampered this communication effort. Without accurate real time information, pilots cannot adequately assess takeoff or landing performance.

2.3 The cornerstone of the TALPA ARC recommendations is a concept using a **Paved Runway Condition Assessment Table** (referred to as "the matrix") as the basis for performing runway condition assessments by aerodrome operators and for interpreting the reported runway conditions by pilots in a standardized format. The matrix:

- Aligns runway surface conditions reported by aerodrome operators to contaminated landing performance data supplied by the airplane manufacturer;
- Ties together runway contaminant descriptions and braking action, and can be used to translate between these two methods of reporting runway surface condition;
- Provides a shorthand method of relaying runway surface condition information to flightcrews through the use of runway condition codes to replace the reporting of μ readings;
- Provides for a standardized method of reporting runway surface conditions for all aerodromes;
- Provides more detailed information for the flightcrew to make operational decisions; and
- Standardizes pilot braking action report terminology

2.4 In order to succeed, this concept will require extensive retraining of aerodrome operations personnel, dispatchers and pilots to assure that the application of the matrix is consistent across aerodromes and that interpretation of the results and reporting of braking performance via PIREPs is consistent with the terms of the matrix.

3. INTERNATIONAL RUNWAY FRICTION INDEX (IRFI)

3.1 The ASTM standard E2100 *International Runway Friction Index* defines and prescribes how to calculate the IRFI for winter surfaces. The IRFI is a harmonized reporting index intended to provide aircraft operators with information on the tire–surface friction characteristics of a runway. In addition, aerodrome maintenance staff can use it to monitor runway friction characteristics, as a guide to the surface maintenance required.

3.2 The prescribed method evaluates each 100 m and averages them for each third of the runway. It 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.

3.3 A reference device, which is required for calibration, must be dedicated to this purpose, and the aviation community or each state must agree on its provision, ownership, and services. A standard to calculate the IRFI has been developed by the ASTM that accommodates all major measurement techniques and equipment currently used around the world.

3.4 In order to implement a concept such as the IRFI an infrastructure, logistics and associated harmonisation methods to control the friction measuring devices themselves need to be established to such a degree by States so that they can be utilized within the constraint of a Safety Management System.

4. EASA RUNWAY FRICTION CHARACTERISTICS MEASUREMENT AND AIRCRAFT BRAKING (RUFAB)

4.1 In 2008 the EASA launched the research project “RuFAB - Runway Friction Characteristics Measurement and Aircraft Braking”. Its aim was to help identify possibilities of harmonising runway friction characteristic measurement technologies and provide a basis for improving and harmonising the implementation of current ICAO Standards and Recommended Practices (SARPS) within the EASA Member States. This could provide the opportunity for a global standardised application, and contribute to the progress of the ICAO action plan. Finally it would prepare prerequisites to the future EASA rules for aerodrome safety.

4.2 The first phase of the project was to review pertinent literature as well as existing and previous research results in the field of runway surface friction characteristics evaluation and aircraft braking performance.

4.3 The scope of the following two phases of the study was to obtain an overview of the state of implementation of the provisions for contaminated runways (as contained in ICAO Annex 14 Volume 1 SARPs, advisory documents and international specifications) and of the state of harmonisation between these and national requirements and practices. The study distinguished in its comprehensive overview on the implementation of the ICAO SARPs between functional friction characteristics measurements and operational runway friction characteristics measurements.

4.4 The research project has reached the state of completion. The results and recommendations are ready for discussion with ICAO working groups, experts and the stakeholder communities but may also be reviewed in the light of the work carried out by the FAA Takeoff and landing performance assessment – Aviation Rulemaking Committee (TALPA/ARC).

4.5 The report from the project are available at:

http://www.easa.eu.int/ws_prod/g/g_sir_research_projects_airports.php#2008op28

Appendix B

TRAINING FOR GROUND, ATM STAFF AND FLIGHT CREW

Friction issue	Training			Remark
	Ground staff	**ATM staff**	**Flight crew**.(OPS to provide input by end of August)	
AIP	Publishing frictional characteristics		Use of published characteristics What to look for.	
AICs	New frictional info		New frictional info. What to look for.	
Reporting format	Assessment	Dissemination	Use of information	
Terminology	Hazards Contaminants	Hazards Contaminants	Hazards Contaminants	
Phraseology	Frictional terms	Frictional terms	Frictional terms	
Processes	Data collection and reporting	Dissemination	Use of information	

Appendix C

FRICTION ISSUES VERSUS SEGMENT OF FLIGHTS

Objectives, requirements and information	Essential	Comments	Cruise	Collection	Approach Landing	Surface arrival	Ramp	Planning Dispatch	Ramp	Surface departure	Departure Take off	Dispersion
ATM objective **Global Air Traffic Management concept (Doc 9854 AN/458)**			In which aircraft are at altitude and moving towards their destination, but are not yet subject to actions related to the arrival phase.	The state in which aircraft are sequenced and spaced to bring them into the terminal area for arrival.	The phase in which aircraft are assigned to runways and onto the surface.	Where aircraft are moved off runways and to the ramp.	Where aircraft are manoeuvred into the parking location.	Integration into the ATM environ-ment to achieve a close match between the user-preferred trajectory and the system-delivered trajectory	Move the flights in and out of the parking locations	Move the aircraft from the ramp to the departure queue.	Where the departure queue and the runway are managed to launch aircraft from the queue into the airspace.	Get aircraft up and out of the terminal into the en-route structure.
Cleared Length Reported when less than published length	**Y**	Relevant for Aircraft Performance.		●	●			●			●	
Cleared Width Reported when less than published width	**Y**	Crosswind and Engine Failure scenarios.		●	● Crosswind			●			● Crosswind Engine failure	
Deposits	**Y**	In thirds for RSM & harmonized		●	●			●			●	
Mean Depth	**Y**	In Thirds for RSM Presented as a range of possible depths depending upon the accuracy		●	●			●			●	
Extent of Contamination	**Y**	In thirds for RSM		●	●			●			●	
Braking Action (Friction Coefficient)	**Y**	In thirds for RSM		●	●			●			●	
Runway Temperature Currently not available.	**N/Y**	Could be relevant in anticipation of possible reduced braking action as a result of precipitation and cold runway surface temperatures		● Possible reduced braking action				● Possible reduced braking action				
Rainfall Rate Currently not harmonized. Broad indications such as –RA/RA/+RA could be linked to range of rainfall rates which in turn could be linked to texture overfilling.Part of METAR/ATIS	**N/Y**	Could be indication of potential hazardous runway conditions depending upon rainfall rate and runway design.		●	● Significant increase			●			● Significant increase	
Further Clearance Expected	**N**		●					●				
Taxiway	**N**	Anticipated taxi routing				●		●		●		
Apron	**N/Y**						●	●	●			

Appendix D

HAZARDS RELATED TO FRICTION ISSUES AND PAVEMENT

Hazard	Friction characteristics			Significant change
	Physical	Functional	Operational	
Texture	Microtexture	Slippery	Slippery	Retexture
	Macrotexture	Wet smooth		BC
	Macrotexture	Wet skid resistant		DE
No slope	Standing water	Poor drainage at tire/ground interface.	longer stopping distance.	New design
		Hydroplaning	Loss of directional control	
Natural rounded aggregate	Susceptible for polishing	Slippery	Slippery when wet	Retexture Repave
Rubber deposit on crushed aggregate	Cover texture	Reduced texture	No performance credit on Wet skid resistant pavement	Remove rubber deposit
		Slippery	Slippery	
Rubber deposit on natural, smooth aggregate	Cover texture	Reduced texture	Longer stopping distance. Slippery	
		Slippery		
Grooves	Closing due to deformation	Poor drainage at tire/ground interface	Longer stopping distance	Open grooves
			No performance credit on Wet skid resistant pavement	
	Filled with contaminant	Poor drainage at tire/ground interface	Longer stopping distance	Remove contaminant
			No performance credit on Wet skid resistant pavement	

Appendix E

HAZARDS RELATED TO FRICTION ISSUES AND AIRCRAFT

Hazard	Friction characteristics			Significant change
	Physical	Functional	Operational	
Tire wear	Tire tread depth	Drainage at tire/ground interface.	Basic assumption for wet skid resistance	Basic assumption based on tire tread depth of 2 mm.
Change in inflation pressure	Inflation pressure	Drainage capability at tire/ground interface.	Basic assumption for wet skid resistance	Curves (e.g. equations) in harmonized certification specifications for 50, 100, 200 and 300 psi.

Appendix F

HAZARDS RELATED TO FRICTION ISSUES AND REPORTING FORMAT

Hazard	Friction characteristics			Significant change
	Physical	Functional	Operational	
Clear and dry	Dry		Certification limited	
Damp			Wet performance data	
Wet smooth	Wet	Reduced braking action	Wet performance data	Less than 3 mm
Wet skid resistant	Wet	Reduced braking action	Wet skid resistant performance data	Less than 3 mm
Standing water	Wet	Hydroplaning susceptible		Above 3 mm
Rime or frost covered	Thin layer depth normally less than 1 mm			
Loose snow				20 mm[1]
Dry snow				
	Coverage	Reduced braking action.	Longer stopping distance	10, 25, 50, 100 per cent
	Depth	Drag force	Longer takeoff distance	20[2], 40, 60… mm
Wet snow				
	Coverage	Reduced braking action.	Longer stopping distance	10, 25, 50, 100 per cent
	Depth	Drag force	Longer takeoff distance	10, 20, 30… mm
Slush				
	Coverage	Reduced braking action.	Longer stopping distance	10, 25, 50, 100 per cent
	Depth	Drag force	Longer takeoff distance	3, 6, 9, 12 mm
Wet ice				
Compacted snow or ice				
Ice				
	Coverage	Reduced braking	Longer stopping	10, 25, 50, 100 per

[1] Recommended changed
[2] Recommended changed

		action.	distance	cent
Compacted or rolled snow	Coverage	Reduced braking action.	Longer stopping distance	10, 25, 50, 100 per cent
Frozen ruts or ridges	Coverage	Reduced braking action.	Longer stopping distance	10, 25, 50, 100 per cent
Sand	Present	Reduced braking action.	Longer stopping distance	
Mud	Present	Reduced braking action.	Longer stopping distance	
Oil/fuel spillage	Present	Reduced braking action.	Longer stopping distance	

Appendix G

HAZARDS RELATED TO FRICTION ISSUES AND ATMOSPHERE

Hazard	Friction characteristics			Significant change
	Physical	Functional	Operational	
Precipitation	Contaminant	Influence anti skid system	Reduced braking action	
Wind	Crosswind	Move aircraft	Loss of directional control	
Temperature	Freezing precipitation	Influence anti skid system	Reduced braking action	
Radiation	Freezing moisture on ground	Influence anti skid system	Reduced braking action	

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6.

Internet Link to CRFI section of Transport Canada Aaeronautical Information Manual:
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