



EAC

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FOREWORD

PURPOSE

1. This circular aims to provide an overarching conceptual understanding of the surface friction characteristics that contribute to controlling an aircraft via the critical tire-to ground contact area. The intent is to provide broad and fundamental concepts to support proposed amendments, by ECAA, to the Standards and Recommended Practices (SARPs) in ECAR 139
2. The proposed amendments address the following issues:
 - a) Surface friction characteristics of pavements and runway surface contaminants;
 - b) How surface characteristics relate to aircraft performance;
 - c) Assessment of runway surface conditions;
 - d) Reporting and dissemination of runway surface conditions; and
 - e) The need for appropriate training of personnel involved in c) and d).

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GLOSSARY**ABBREVIATIONS/ACRONYMS**

AC	Advisory circular (FAA)
ADREP	Accident/incident data reporting
ADS-C	Aeronautical dependent surveillance — contract
AFM	Aircraft flight manual
AIC	Aeronautical information circular
AIDC	ATS interfacility data communication
AIM	Aeronautical information management
AIP	Aeronautical information publication
AIS	Aeronautical information services
AIS-AIMSG	Aeronautical Information Services and Aeronautical Information Management Study Group AIXM
AMSCR	Aircraft movements surface condition report
ARC	Aviation Rulemaking Committee (FAA)
ASTM	American Society for Testing and Materials
ATC	Air traffic control
ATIS	Automatic terminal information service
ATM	Air traffic management
ATS	Air traffic services
ATSMHS	ATS message handling services applications
CAA	Civil aviation authority
CAP	Civil Aviation Publication (United Kingdom)
CEN	Comité Européen de Normalisation (European Committee for Standardization)
CFME	Continuous friction measuring equipment
CFR	Code of Federal Regulations (FAA)
CPDLC	Controller-pilot data link communications
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 (United States)
FAR	Federal Aviation Regulations (United States)
FTF	ICAO Friction Task Force
HMA	Hot-mix asphalt
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization

IRFI	International runway friction index
JAA	Joint Aviation Authorities (Europe)
JAR	Joint Aviation Requirements (Europe)
JWRFMP	Joint Winter Run way Friction Measurement Programme
METAR	Aerodrome routine meteorological report
MFL	Minimum friction level
MPD	Mean profile depth
MTD	Mean texture depth
Mu	Coefficient of friction
NASA	National Aeronautics and Space Administration (United States)
NOTAM	Notice to airmen
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
SPECI	Aerodrome special meteorological report
TALPA	Take-off and landing performance assessment
TC	Transport Canada
μ	Mu (coefficient of friction)
VEF	The calibrated air speed at which the critical engine is assumed to fail.
V1	The maximum speed in the take-off at which the pilot must take the first action (e.g. apply brakes, reduce thrust, deploy speed brakes) to stop the aeroplane within the accelerate-stop distance. V1 also means the minimum speed in the take-off, following a failure of the critical engine at VEF, at which the pilot can continue the take-off and achieve the required height above the take-off surface within the take-off distance.
WMO	World Meteorological Organisation

EXPLANATION OF TERMS

The terms contained herein are used in the context of this circular. Formally recognized ICAO definitions are noted with an asterisk (*).

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 metres 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 the 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 dynamics system.

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

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

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

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

Runwaysurfacecondition.*Thestateofthesurfaceoftherunway,eitherdry,wetorcontaminated:

- a) Contaminatedrunway.Arunwayiscontaminatedwhenmorethan25percentoftherunwaysurfacearea (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 wetice.
- b) Dry runway. A dry runway is one which is clear of contaminants and visible moisture within the requiredlength and the width beingused.
- c) Wet runway. A runway that is neither dry norcontaminated.

Note1.

—Incertain situations, itmaybeappropriatetoconsidertherunwaycontaminatedevenwhenitdoesnot meet the above definition. For example, if less than 25 per cent of the runway surface area is covered with water, slush, snoworice, butitislocatedwhererotationorlift-offwilloccur, orduringthehighspeedpartofthetake-offroll, theeffectwillbefarmoresignificantthanifitwereencounteredearlyintake-offwhileatlow speed.Inthissituation,therunways should be considered to becontaminated.

Note2.—

Similarly,arunwaythatisdryintheareawherebrakingwouldoccurduringahighspeedrejectedtake-off, but damp or wet (without measurable water depth) in the area where acceleration would occur, may be considered tobedryforcomputingtake-offperformance.Forexample,ifthefirst25percentoftherunwaywasdamp,butthe remainingrunwaylengthwasdry,therunwaywouldbewetusingthedefinitionsabove.However,sincea runway does not affect acceleration, and the braking portion of a rejected take-off would take place on a dry surface, it wouldbeappropriate to use dry runway take-offperformance.

Significantchange.Achangeinthemagnitudeofahazard,whichleadstoachangeinthesafeoperationofth aircraft.

Skidresistant.Arunwaysurface that is designed, constructed and maintained to have good water drainage, which minimizestheriskofhydroplaningwhenthe runway is wet and provides aircraft braking performanceshow notobetterthanthatusedintheairworthinessstandardsforawet,smoothrunway.

Surface friction characteristics. The physical, functional and operational features or attributes of friction that relateto thesurfacepropertiesofthepavementandcanbedistinguishedfromeachother.

Note.— The friction coefficient is not a property of the pavement surface but a system response from themeasuring system. Friction coefficient can be used to evaluate the surface properties of the pavement provided that thepropertiesbelonging to the measuring system are controlled and keptstable.

DEFINITIONS IN ANNEX 6, PART I

1. The definitions in Annex 6, Part I, for the operational use of flight crew were introduced via Amendment 33-A in 2009.
2. Apart from the definition of “grooved or porous friction course runway”, the origin of these 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 91-6B dated June 18, 1986.
3. With minor changes, the definitions from the FAA Advisory Circular appear in the EASA Certification Specifications for Large Aeroplanes CS-25, Book 2, under the heading “AMC 25-13, Reduced and Derated Takeoff Thrust (Power) Procedures”. The definition of “wet” was simplified and minor editorial changes were made to the definition of “contaminated runway”.
4. Two accompanying notes were added to the definition of “contaminated runway” in Amendment 33-A. The concept of these notes can be traced back to discussions in the FAA Airplane Performance Harmonization Sub-Working Group which completed its task in 2002.
5. These definitions are aimed at the operation of the aircraft and not the operation of the aerodrome. However, for the purposes of reporting 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 was not the case.
6. The aviation industry recognizes that, for safety reasons, harmonization is required. The concept of two sets of harmonized definitions has been discussed, with one set targeting the operation of the aerodrome and the other, 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.

Chapter 1 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

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

1.2 It is common knowledge that pavement tends to become slippery for both pedestrians and vehicles alike when they are wet, 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 operations on the movement areas. For this reason, many papers on friction issues have been produced within the aviation community since the late 1940s.

1.3 The information in this circular should be used by national authorities when implementing their safety activities and referenced as necessary by aerodrome operators, aerodrome air navigation service providers, aircraft operators and individuals within those organizations.

CURRENT SITUATION

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

- a) policies;
- b) methods; and
- c) parameters.

1.5 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 key players are the persons on the ground, identifying and reporting hazardous conditions on the movement area, and the pilots using that information for safe operation of the aircraft. The role of 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.

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

TERMINOLOGY

1.7 The friction issues discussed in 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 depends on the critical tire/ground contact area.

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

- a) the design, construction and maintenance of the pavement surface and its inherent friction characteristics; and
- b) aircraft operations on the pavement surface and the contaminants present.

1.9 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 pilot's 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's assessment, for SNOWTAM reporting purposes, of the slipperiness of the runway surface due to the presence of contaminants and prevailing weather conditions.

1.10 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). It is defined by the ASTM as:

Skid resistance (friction number). The ability of the travelled surface to prevent the loss of tire traction.

1.11 The term "braking action" has been in continuous use in the aviation industry although it has been used in different contexts 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 an aircraft stopping capability. The ICAO SNOWTAM format uses 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.

1.12 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 ECAR 139.

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 ECAR 139 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, and it was agreed that wherever feasible the term “braking action” should be replaced by friction characteristics.

1.13 Previously, the principal aim had been to measure surface friction in a manner that was 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 frictions should be referred to as measured friction coefficient, which is used in the current SNOWTAM format.

Chapter 2

THE DYNAMICS SYSTEM

2.1 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 utilized by an aircraft. The basic friction characteristics are properties belonging to the individual components of the system, such as:

- a) pavement surface (runway);
- b) tires (aircraft);
- c) contaminants (between the tire and the pavement); and
- d) atmosphere (temperature, radiation affecting the state of the contaminant).

2.2 Figure 2-1 illustrates the friction characteristics and how they interrelate in the dynamic system of an aircraft in motion.

2.3 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.

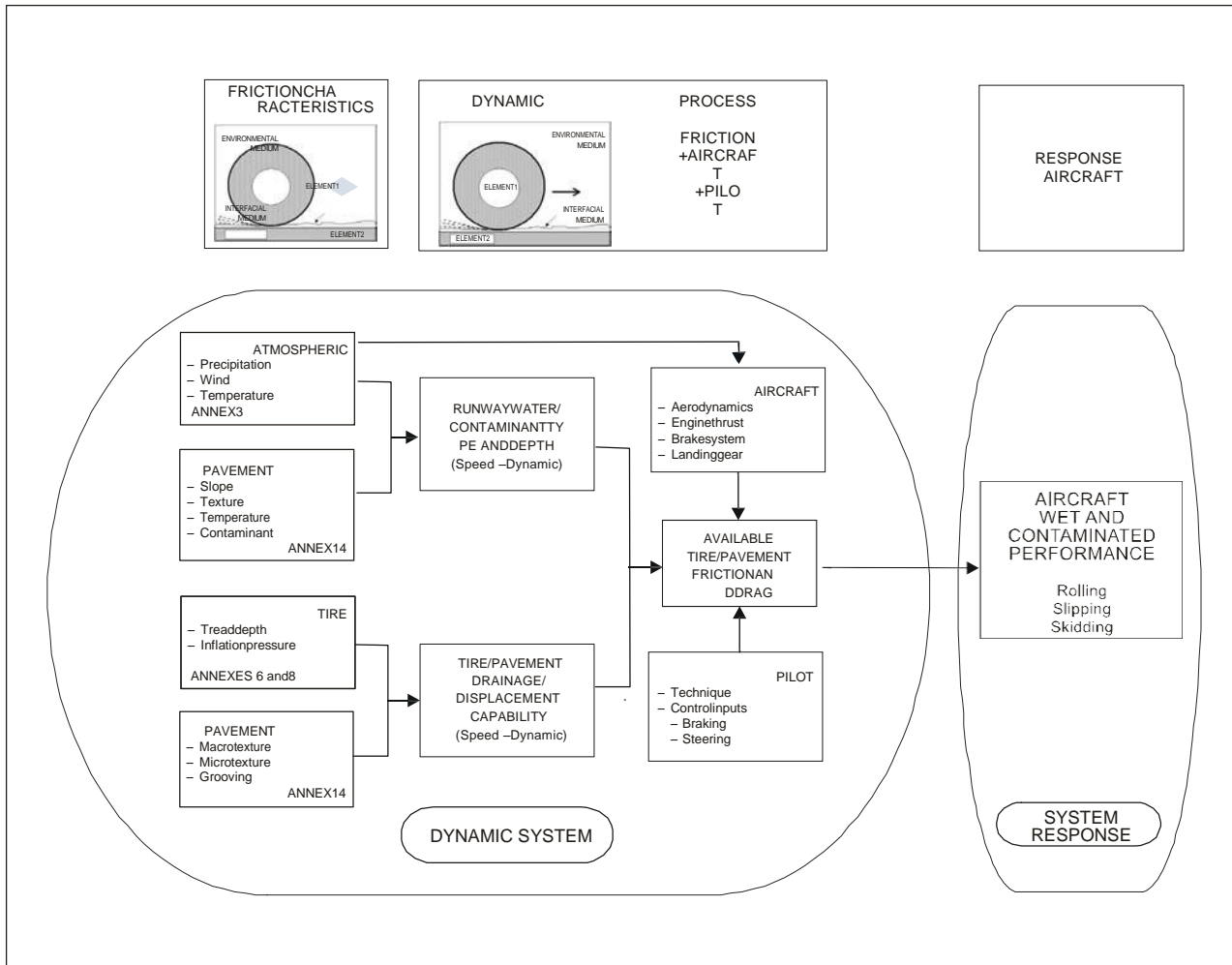


Figure 2-1. Basic friction characteristics, the dynamic system and the system response

PAVEMENT

FUNCTIONAL REQUIREMENTS

3.1 A runway pavement, considered as a whole, is required to fulfil three basic functions as follows:

- a) provide adequate bearing strength;
- b) provide good riding qualities; and
- c) provide good surface friction characteristics.

3.2 Other requirements include:

- a) longevity; and
- b) ease of maintenance.

3.3 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 runway pavement. The fourth and fifth criteria address, in addition to the economic dimension, the availability of the pavement for aircraft operations.

DRY RUNWAY

3.4 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

3.5 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); and

- c) penetration drainage(microtexture).

3.6 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

3.7 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 of these are:

- a) maintenance of improved interfacial drainage capability for pavements contaminated by water (more than 3 mm in 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 and oil.

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

DESIGN Texture

Surface texture

3.9 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 (see Figure 3-1). 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. EAC 139.19 contains further guidance on this subject.

3.10 Texture is defined internationally through ISO standards.¹ These standards refer to texture measured by volume or by profile and 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.

Chapter 3

Microtexture

3.11 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.

1. The International Organization for Standardization, Characterization of pavement texture by use of surface profiles:—Part 2: Terminology and basic requirements related to pavement texture profile analysis, ISO 13473-2, 2002.

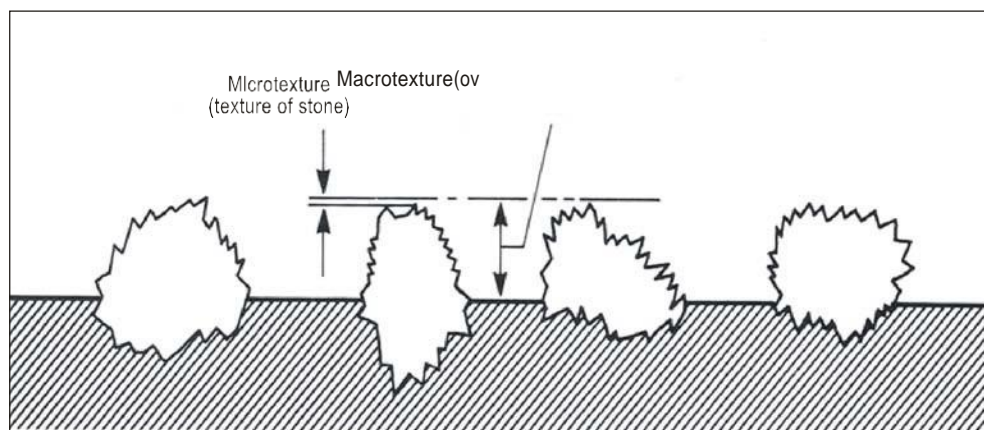


Figure 3-1. Microtexture and macrottexture

3.12 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 value, which is in principle a value obtained from friction measurement in accordance with international standards (ASTM D 3319, CEN EN1097-8).

3.13 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 macrottexture.

Macrotexture

3.14 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 depends 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)

3.15 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.

3.16 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 are referred to through underlying documentation. For airworthiness, ESDU documentation is referenced and used. ESDU 71026 and ESDU 95015 refer to texture measurements from runways made in the seventies using the sand or grease patch measuring technique. From these measurements ESDU developed a scale classifying the macrotexture A through E (see Chapter 5 of this circular).

Drainage

3.17 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 the drainage problem will be.

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

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

3.20 Drainage capability can, in addition, be enhanced by special surface treatments, such as grooving and

orous friction course which drains water initially through voids of a specially treated wearing course.

3.21 It should be clearly understood that special surface treatment is not a substitute for good runway construction and maintenance. Special 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.

3.22 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

3.23 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 the 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:

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

3.24 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

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

3.2 Dynamic drainage is achieved by 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.

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

- a) slope; and
- b) texture, including microtexture and macrotexture.

Slope

3.4 Adequate surface drainage is provided primarily by an appropriately 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 ECAR 139. Further guidance is given in EAC 139.9.

Macrotexture (drainage)

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

3.6 Interfacial 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 a lack of adequate friction is most critical with respect to stopping distance and directional control capability.

3.7 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 interfacial drainage. Aircraft tires, however, cannot be produced with similar patterned treads and have only a number of circumferential grooves which contribute substantially less to interfacial drainage. Their effectiveness diminishes relatively quickly with tire wear.

3.8 ECAR 139 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.

Microtexture (drainage)

3.9 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.

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

Rainfall

3.11 Rainfall brings moisture to the runway, which will have an effect on aircraft performance. Flight test data show 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.

3.12 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 less severe 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.

3.13 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

3.14 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 where there would be a risk of aquaplaning. Runways could then be classified based on different drainage characteristics.

3.15 Various studies have been performed over the past decades to relate rain intensity and runway characteristic 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 crew of the amount of water present on a runway. Runway design parameters, notably texture depth, are a main indicator of water depth as a function of rain intensity. Rain intensity itself can be derived from weather radar data or forward-scatter meters. Weather radar information can provide a timely warning, whereas forward-

scatter meters can potentially provide actual rain intensity information for each runway third. These are all subjects that need further study.

Current reporting practices

3.16 Disregarding winter operations, a runway is currently reported as dry, damp, wet or contaminated as are a surface 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 3-1 of EAC 139.19

3.17 Classifying a runway as damp or wet is not at all a straightforward matter because 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, reporting a runway as wet only during heavy rainfall or reporting a runway as wet whenever rain is falling.

3.18 Reporting flooded runway conditions is difficult because methods for accurate, reliable and timely determination of 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.

3.19 There are currently no internationally agreed terms for reporting the intensity level of rainfall.

CONSTRUCTION

Selection of aggregates and surface treatment

3.20 **Crushed aggregates.** Crushed aggregates exhibit a good microtexture, which is essential in obtaining good friction characteristics.

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

- a) brush or broom;
- b) burlap drag finish; and
- c) saw-cut grooving.

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

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

3.24 Hot-

mix asphalt. Bituminous concrete must have 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 intensity of traffic, raw materials and climate.

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

3.26 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).

3.27 Additional guidance on grooving of pavements and the use of a PFC is contained in EAC 139.11 Doc 9157, Part 3.

Grooving

3.28 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 texture to the tire/ground interface and provides escape channels for dynamic drainage.

3.29 The first grooved runways appeared on military aerodromes in the United Kingdom (mid-1950s). The United States followed up by establishing a grooved NASA research track (1964 and 1966). The first civil aerodromes with grooved runways were Manchester in the United Kingdom (1961) and John F. Kennedy in the United States (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 in EAC 139. Reports from this research are available from the NASA Technical Report Server (NTRS).

3.30 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.

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

3.32 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 specialized, although it can be built “in-house” by the operator. This equipment should be operated only by skilled operators.

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

3.34 Clean-up. Clean-up of waste material must be continuous during a grooving operation. All debris, 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.

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

3.36 The macrotexture of the runway surface can be effectively increased by grooving, and this is applicable to asphalt and concrete surfacing. The macrotexture of ungrooved, continuously graded asphalt is typically in the range of 0.5 to 0.8 mm and slightly higher for stone mastic asphalt. In service, grooves wear down with traffic, and this has the effect of reducing macrotexture over time. Various States use differing groove geometry, and Table 3-1 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.

Table 3-1. Groove geometry

		Groove geometry			Macrotexture (mm)	
		Width (mm)	Depth (mm)	Centre-to-centre spacing (mm)	Asphalt	
					Ungroove	Grooved
Australia	New	6	6	38	0.65	1.49
Norway	New	6	6	125	0.7–1.6	0.95–1.81
United Kingdom	New	4	4	25	0.65	1.19
United States	Half worn	6	3	38		1.02

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

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

where: M_g = grooved macrotexture;
 W =
 D = grooved depth;
 M_u = ungrooved macrotexture;
 S =

Example from a United Kingdom airport

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

$$(3 \times 3 + 0.64 \times (25 - 3)) / 25 = 0.92 \text{ mm.}$$

3.62 In service, the grooves wear down with traffic 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 the runway, it is usual to aim for a macrotexture of rather more than 1.0 mm during construction.

3.63 The pitch and size of groove vary by airport/authority (as shown for the State level in Table 3-1 and for the airport level in the example above), 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 large grooves.

3.64 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), deep standing water due to heavy precipitation and 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.

3.65 Following on from the above, it has been shown (Benedetto² et al.) that better macrotexture depth on a runway surface means the loss of skid resistance during incidents of heavy precipitation is reduced (see Figure 3-2).

This is important because it underlines the ECAA requirement for both friction levels and texture depth. As shown in Figure 32, as speed increases, grip reduces. Grooving offsets this effect by adding macrotexture, as indicated by the gap between the rough and smooth traces.

Porous friction course

3.66 As an alternative to grooving, a porous friction course (PFC) was developed in the United Kingdom 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 the incidence of hydroplaning by providing a highly porous material to ensure a quick getaway of water from the pavement surface directly to the underlying impervious asphalt. This asphalt mixture is designed to present structural open voids (20 to 25 percent) permitting natural and dynamic drainage at the tire/surface interface.

3.67 Two main difficulties that relate to skid resistance that can appear when using PFC are:

2. A. Benedetto. "A decision support system for the safety of airport runways: the case of heavy rain storms" in: *Transportation Research Part A: Policy and Practice*, 2002, Vol. 36, Issue 8, pp.665–682.

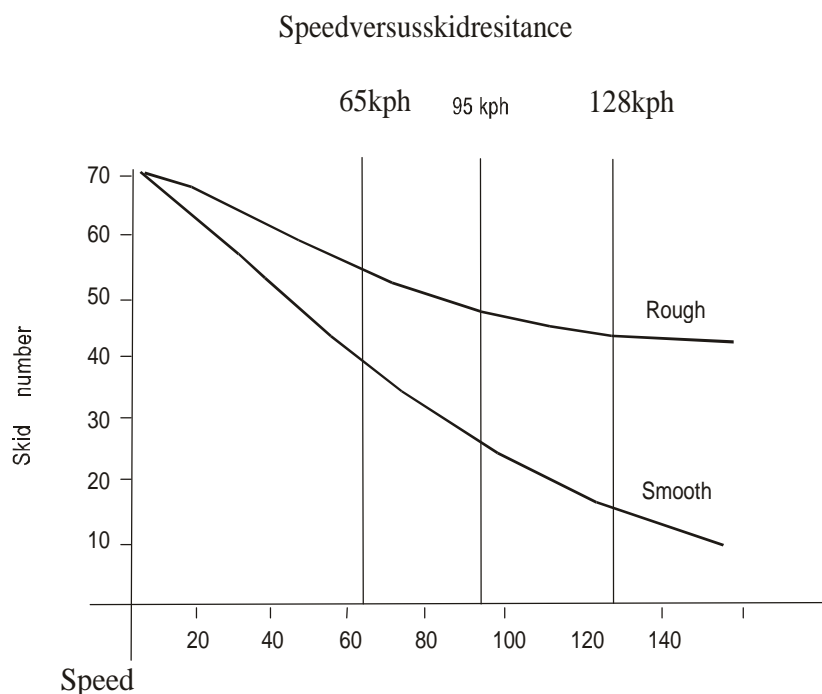


Figure3-2. The effect of grooves on macrotexture (courtesy of UK CAP683)

- a) Rubber deposits must be monitored and must 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

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

Removal of rubber

3.69 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.

3.70 There are four methods of removing runway rubber:

- a) water blasting;
- b) chemical removal;
- c) shot blasting; and
- d) mechanical means.

3.71 No single method of removal is superior to any other or for a given pavement type. Methods can be combined. The chemical method can be used to pre-treat or soften the rubber deposit before water blasting. Additional guidance on removal of rubber and other surface contaminants can be found in EAC 139.19.

3.72 **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.

3.73 Most damage appears to be associated with water blasting so only experienced operators should be used. Least damage appears to be associated with chemical removal.

3.74 **Retexturing.** Removal of rubber with shot blasting can have the advantage of retexturing a polished pavement surface.

3.75 The United States Transportation Research Board report³ synthesizes the current information

available in runway rubber removal, including the effects each removal method has on runway grooving, pavement surface and appurtenances normally found on an aerodrome runway. Some regard this field as more of an art than a science. Thus, the report seeks to find those factors that can be controlled by the engineer when developing a runway rubber removal programme. 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

3.76 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; and
- b) accumulation of contaminants.

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

- a) microtexture; and
- b) macrotexture.

3.78 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 EN1097-8).

3.79 Microtexture is reduced by wear and polishing.

Macrotexture (skid resistance)

3.80 Because 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.

3.81 Through the harmonized FAR 25 (1998) and CS-25 (2000) certification specifications, there are two aeroplane braking performance levels defined—

one for wet, smooth pavement surfaces and one for wet, grooved or PFC pavement surfaces. A basic assumption about these performance levels is that the aircraft tire has a remaining tread depth of 2mm.

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

3.83 Macrot texture is reduced and lost as the voids between the aggregate become 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

3.84 Skid resistance for pavement surfaces can be improved 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. Nevertheless, this kind of product exhibits high texture depth and may potentially damage aircraft tires through wear. The application of these techniques must be considered on pavements which present good structural and surface condition.

3.85 Comprehensive guidance on methods for improving the runway surface texture is available in EAC 139.11, Chapter 5.

Chapter 4

Coefficient Of Friction and friction Measuring devices

COEFFICIENT OF FRICTION

4.1 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. As described in Chapter 2, it is a system response generated by the dynamic system consisting of the:

- a) pavement surface;
- b) tire;
- c) contaminant; and
- d) atmosphere.

4.2 It has been a long sought goal to correlate the system response from a measuring device with the system response from the aircraft when measured on the same surface. A substantial number of research activities have been carried out that have brought new insight into the complex processes taking place. Nevertheless, to date, there is no 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 (see Appendix A).

FRICTION MEASURING DEVICES

Performance and use of friction measuring devices

4.3 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:
 - 1) maintenance planning level; and
 - 2) 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

4.4 States should establish criteria for the friction characteristics related to the different levels mentioned in 4.3 and, as part of this, determine the performance criteria for the approval of friction measuring devices to be used in their State. EAC 139.19 Table 3-1, indicates the level of friction associated with some friction measuring devices. However, it must be noted that Table 3-1 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

4.5 States are required to ensure that the acceptable friction measuring devices fulfil the performance criteria set by the State, taking into consideration factors such as repeatability and reproducibility for individual friction measuring devices. In order for Table 3-1 of EAC 139 to be utilized properly, States should have in place proper calibration and correlation methods. Repeatability and reproducibility of continuous friction measuring equipment should meet performance criteria based upon measurement on a 100-m test surface length. This length corresponds to the length considered significant for maintenance and reporting action by ICAO.

4.6 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.

4.7 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 Virginia, United States, which is no longer available 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 Flight Facility.

4.8 There is, at present, no globally accepted procedures for developing methods and logistics for using 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) Canada <http://www.tc.gc.ca/eng/civilaviation/publications/tp14371-air-1-0-462.htm>
<http://www.tc.gc.ca/eng/innovation/tdc-projects-air-f-5620-332.htm>

b) UnitedKingdom

<http://www.caa.co.uk/application.aspx?catid=33&pagetype=65&appid=11&mode=detail&id=165>

c) UnitedStates

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/2B97B2812BE290E986256C690074F20C?OpenDocument

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/B2A4EA852BABD7B7862569F1006DC943?OpenDocument

http://www.airweb.faa.gov/Regulatory_and_Guidance_Library/rgAdvisoryCircular.nsf/0/F9FEF87275AF78E986256A7900707EE1?OpenDocument

Chapter 5 AIRCRAFT OPERATIONS

FUNCTIONAL FRICTION CHARACTERISTICS

How rolling, slipping and skidding affect the aircraft

5.1 **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 metres 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.

5.2 **Lateral (cornering) forces.** These forces allow directional control on the ground at speeds where flight control has reduced effectiveness. If contaminants on the runway or taxiway surfaces significantly reduce the friction characteristics, special precautions should be taken (e.g. reduced maximum allowable crosswind for take-off and landing, reduced taxi speeds) as provided in operations manuals.

5.3 **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

5.4 Rolling friction forces (unbraked 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 to 2 percent of the aircraft apparent weight.

Braking forces — general effects

5.5 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 unbraked (zero slip) wheel rotation speeds in revolutions per minute (rpm).

The maximum possible friction force depends mainly on the runway surface condition, the wheel

5.1 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.

5.2 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.

5.3 The general effects of runway surface conditions on the braking friction coefficient are briefly summarized in paragraphs 5.9 to 5.17 below.

5.4 **Wet condition (less than 3 mm of 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 kt, μ_{max} on a wet runway with standard texture will be typically between 0.2 and 0.3; this is roughly half of what one would expect to obtain at a low speed such as 20 kt.

5.5 On a wet runway, μ_{max} is also dependent on runway texture. A higher microtexture (roughness) will improve the friction. A high macrotexture, 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.

5.6 **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. Microtexture 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} .

5.7 Because they have a fluid 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 or reaching nil.

5.8 The phenomenon is complex, but the driving parameter of the aquaplaning speed is tire pressure. High macrotexture (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 ground speeds of 110 to 130 kt. Once started, the dynamic aquaplaning effect may remain a factor down to speeds significantly lower than those necessary to trigger it.

5.9 **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.

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

5.11 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} as low as 0.05) and will typically prevent aircraft operations until the friction level has improved. However, ice that is not melting may still allow operations, albeit with a performance penalty.

Runway-surface contaminants resulting from the operation of aircraft, but which are not usually considered as contaminants for aeroplane 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 via NOTAM when the friction drops below the minimum required friction level.

Contaminant drag forces

5.1 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, 13 mm of slush would generate a retardation force representing about 3 percent of the aircraft weight at 100 kt for a typical mid-size passenger aircraft.

5.2 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

5.1 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 take-off, accelerate-stop and landing distances. Reduced friction also impairs directional control of the aircraft, and therefore the acceptable crosswind during take-off and landing will be reduced.

Qualitative assessment

5.2 Qualitatively, the impacts on the aircraft's maximum braking capability can be summarized as follows:

- a) Wet and solid contaminants:
 - 1) acceleration and hence take-off distance not affected; and
 - 2) reduced braking capability, longer accelerate-stop and landing distances.
- b) Loose contaminants:
 - 1) 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
 - 2) deceleration capability reduced by lower friction, aquaplaning at high speeds, partially compensated by displacement and impingement drag.

5.3 As a result:

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

Quantitative assessment

5.4 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 V₁ speed, and the braked ground phase is calculated with maximum pedal braking.) It should be mentioned that the impact on regulatory performance may be different because the regulatory calculation rules are dependent upon runway conditions.

- a) Wet conditions (no reversers):
 - 1) acceleration and continued take-off are not affected;
 - 2) the accelerate-stop distance is increased by approximately 20 to 30 per cent. A grooved or PFC runway will reduce this penalty to approximately 10 to 15 percent;

Note. — Use of reverse thrust (one-engine inoperative) will reduce this effect by 20 to 50 percent depending on the effectiveness of the reversers and runway conditions.

-
- 3) 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 approximately 50 per cent depending on the effectiveness of the reversers and runway conditions.

b) 13 mm of water or slush-covered conditions:

- 1) the take-off distance is increased by 10 to 20 per cent with all-engines operating due to displacement and impingement drag;

Note.— The effect on the one-engine inoperative take-off distance will be significantly larger.

- 2) the accelerate-stop distance will increase by 50 to 100 per cent, reduced to a 30 to 70 per cent increase with the use of thrust reversers (one-engine inoperative); and
- 3) the braked landing ground phase is increased by 60 to 100 per cent depending on the actual depth of the water or slush on the runway. This can be reduced significantly by the use of reverse thrust.

c) Compact snow:

- 1) acceleration and continued take-off are not affected;
- 2) the accelerate-stop distance is increased by 30 to 60 per cent, reduced to 20 to 30 per cent with the use of thrust reversers (one-engine inoperative); and
- 3) the braked landing ground phase may increase by 60 to 100 per cent. Even with the use of reverse thrust, this may be as much as 1.4 to 1.8 times the dry runway distance.
- 4) 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.

d) Wet ice conditions:

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

5.5 Wet ice conditions correspond to a braking action reported as “nil”, and operations should not be conducted due to the performance impacts discussed above and the potential for loss of directional control of the aircraft.

5.6 As a summary, Figures 5-1 to 5-3 provide a visual indication of the impact of the severity of runway conditions on take-off distance, accelerate-stop distance and the 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. PFC or grooved) is also provided.

General

5.7 Aircraft braking system technology has evolved steadily over the past decades in order to maximize it over all efficiency such as deceleration capability, weight, durability, maintainability, reliability and cost per landing. A short review of its main components is provided below.

Tires

5.8 The main evolution has been in the structure of the tire evolving from bias to radial plies with reduced weight and improved durability. Both bias- and radial-type tires exist today. In terms of friction, the durability/friction compromise of rubber compound has reached maturity, with all tire types showing similar levels of μ_{max} on various types of surfaces.

5.9 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 a 2-mm minimum tread depth on all wheels.

Wheels

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

Figure5-1. Impactoftherunwayconditiononactualtake-offdistance(all-enginesoperative)

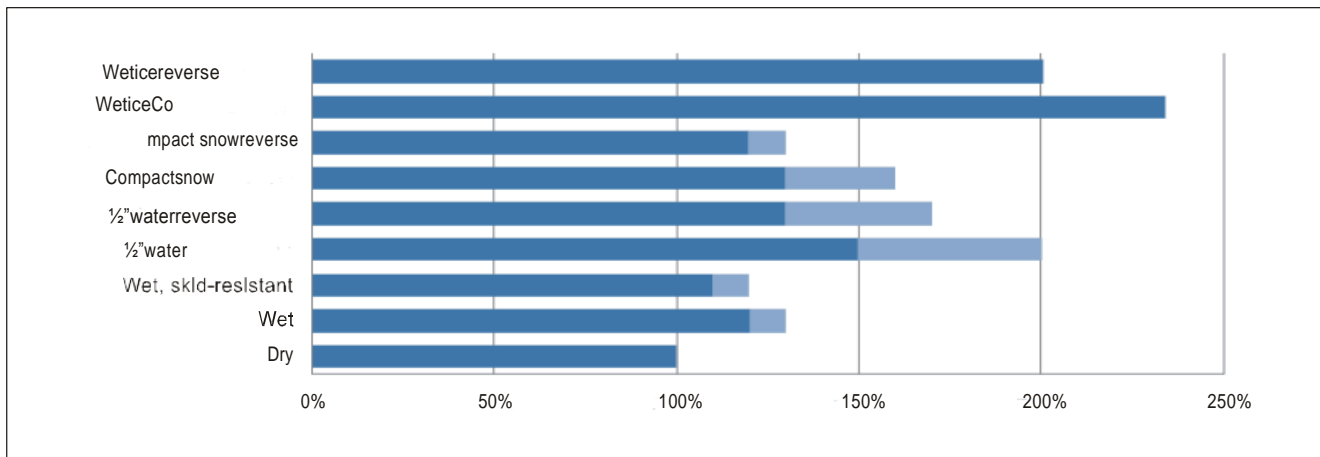


Figure5-2. Impact of the runway condition on accelerate-stopdistance

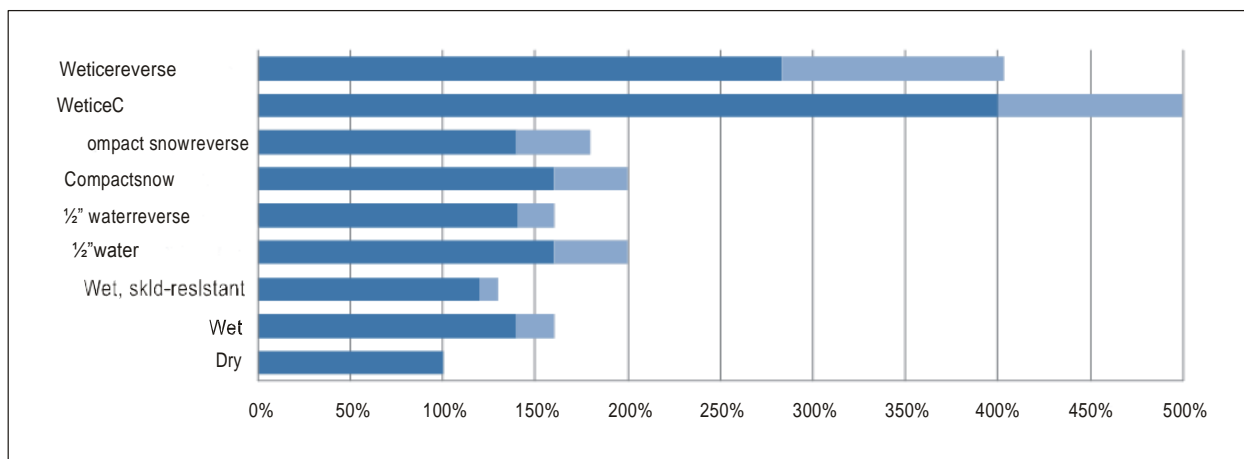


Figure5-3. Impact of the runway condition on the landing groundphase

Brakes

5.1 Discbrakesarethenorm.Discmaterialshaveevolvedfrommetal(steelorencopperinsomespecificcases) to carbon. Both types coexist, but the light weight, durability and decreasing relative cost of carbon versussteeltend to make it the dominant technology for larger civilairliners.

5.2 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.

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

Anti-skid system

5.4 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.

5.5 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 piston to the wheel brake, the wheel will lock and the tires could fail.

5.6 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}).

5.7 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 autobraking, maintaining a preset deceleration level (friction permitting), allowing a reduction in brake wear and improvement in passenger comfort.

5.8 At very low speeds (below 10 kt), 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. 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

5.1 Due to their 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.

5.2 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.

5.3 It should be noted that no specific tests are required on contaminated runways with regard to braking system behaviour or 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

Wet runway certification standards

5.4 Since the early 1990s, JAA-certified aircraft take-off performance for rejected take-off 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.

5.5 The FAA/JAA airworthiness standards allow two levels of aircraft performance to be provided in the aeroplane flight manual for wet runway take-offs: wet, smooth runway performance and wet, grooved or PFC (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.

5.6 The certification requirements for aircraft rejected take-off stopping performance on a wet runway use the wet runway μ_{max} relationship from ESDU report 71026, which contains curves of wet runway braking coefficients versus speed for smooth and treaded tires at different inflation pressures. The data are represented for runways of various surface roughness including grooved and PFC surfaces. The ESDU data account 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 as follows:

a) **Tire pressure.** The regulations provide separate curves for different tire pressures.

5.1 **Tire tread depth.** The standard curves are based on a tire tread depth of 2mm. This tread depth is consistent

a) with tire removal and retread practices reported by aircraft and tire manufacturers and tire retreaders.

b) **Depth of water on the runway.** The curves used in the regulations represent a well-soaked runway with no significant areas of standing water.

5.2 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.

5.3 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 as follows:

Classification	Texture depth (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

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

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

Wet, grooved or PFC runway performance

5.6 FAA/JAA/EASA standards allow for a second wet runway rejected take-off performance level that reflects the improvement in braking friction available from grooved and PFC runways.

5.7 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.

5.8 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

The “Improved Standards for Determining Rejected Takeoff and Landing Performance”¹ adopted by the

5.9 FAA allow operators to take credit for the improved stopping capability during a rejected take-off on wet runways that are grooved or treated with a PFC overlay, but only if:

- a) such data are provided in the aircraft flight manual [aircraft manufacturer];
- b) the operator [aircraft operator] has determined that the runway is:
 - 1) designed [aerodrome operator];
 - 2) Federal Aviation Administration, Department of Transportation, Office of Aviation Policy and Plans, Improved Standards for Determining Rejected Takeoff and Landing Performance, Federal Register, RIN: 2120-AB17, 63, FR 8298, February 18, 1998.
 - 3) constructed [aerodrome operator]; and
 - 4) maintained [aerodrome operator];
- c) in a manner acceptable to the administrator [State].

5.1 The standard enhances safety by taking into account the hazardous condition of a rejected take-off on a wet runway, and it creates an economic incentive to develop more stringent design, construction and maintenance programmes for runways to be considered acceptable for wet, grooved or PFC runway aircraft performance. While the improved wet friction characteristics of these surfaces also benefit landing safety, the basic FAA/JAA/EASA certification and operational rules do not provide landing performance credit for them. Nevertheless, some State authorities, 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 is recognized by the aviation industry that further development and regulation of the concept are needed.

5.2 The FAA has produced an advisory circular² which provides relevant guidelines and procedures related to construction and maintenance of skid-resistant aerodrome pavement surfaces.

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

5.3 In the aviation world it is often assumed that the minimum friction criteria in EAC 139.19 Table 3-1, and FAAAC 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 for in Table 3-1 and the aerodrome declares the runway slippery when wet, then the aircraft's performance would be degraded.

5.4 However, the truth of the matter is that a relationship has not been established between the wheel braking and friction assumptions used in the aircraft performance standards and the minimum friction standards stated in ECAAECAR 139 and FAAAC 150/5320-12C. The certification requirements for aircraft performance do not provide a performance level that specifically address the case when an aerodrome reports a runway as slippery when wet because it failed a friction survey as defined by the ECAA and FAA advisory levels.

5.5 The FAA Aviation Rulemaking Committee (ARC) working on take-off 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.

1. Federal Aviation Administration, Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces, FAAAC 150/5320-12C, 1997.

Chapter 6

REPORTING OF RUNWAY SURFACE CONDITIONS

ICAO REPORTING FORMATS

6.1 The need to report and promulgate runway surface conditions is specified in ECAR 139 which stipulates that information on the condition of the movement area and the operational status of related facilities

shall be provided to the appropriate aeronautical information services units, and similar information of operational significance to the air traffic services units, to enable those units to provide the necessary information to arriving and departing aircraft. The information shall be kept up to date and changes in conditions reported without delay.

6.2 Additionally, Annex 3, Appendix 3, 4.8.1.5, requires that information on, *inter alia*, the state of the runway be provided as supplementary information in the aerodrome routine meteorological report (METAR) and aerodrome special meteorological report (SPECI). This provision is subject to regional air navigation agreement and is not implemented in all ICAO regions but does require that information on runway surface conditions should be passed to the aerodrome meteorological office as needed.

6.3 Information on the runway surface condition includes the runway surface friction characteristics which are assessed according to the aerodrome maintenance programme, the presence of water, snow, slush, ice or other contaminants on the runway, as well as the estimated surface friction in operational conditions.

6.4 ICAO specifies that the reporting and promulgation of information on runway surface condition is made through the following media:

- a) aeronautical information publications (AIPs);
- b) aeronautical information circulars (AICs);
- c) notice to airmen (NOTAM);
- d) SNOWTAM;
- e) aerodrome routine and special meteorological reports (METAR/SPECI);
- f) automatic terminal information services (ATIS); and
- g) air traffic control (ATC) communications.

The reporting formats for a) to d) are described in Annex 15. The reporting formats for e) are described in Annex 3 and, for f) and g), in Doc 4444.

The increasing use of ground/air-ground data link and computerized systems, both on

board the aircraft and on the ground, is being progressively supplemented with digitized information such as CPDLC and digital SNOWTAM.

6.1 Currently, Annex 15 requires, *inter alia*, a description to be provided in the AIP of the type of friction measuring device used. In addition, the runway surface friction characteristics are required to be described in the AIP, AICs and NOTAMs. For winter operations, a brief description of the snow plan is also required to be promulgated in the AIP.

Aeronautical information publication (AIP)

6.2 Friction issues in the AIP are related to:

- a) runway physical characteristics; and
- b) the snow plan.

6.3 Annex 15, Appendix 1, Part 3—Aerodromes (AD), AD 2.12, requires a detailed description of runway physical characteristics. The physical characteristics of a wet, skid-resistant surface can be included in the remarks.

6.4 In AD 1.2.2, a brief description should be given of general snow plan considerations for aerodromes and heliports available for public use at which snow conditions are normally liable to occur. Related friction issues include:

- a) measuring methods and measurement taken;
- b) system and means of reporting;
- c) cases of runway closure; and
- d) distribution of information about snow, slush or ice conditions.

Aeronautical information circular (AIC)

6.5 An AIC should be originated whenever it is necessary to promulgate aeronautical information that does not qualify for inclusion in an AIP or a NOTAM. Related friction issues include the advance seasonal information on the snow plan.

Notice to airmen (NOTAM)

6.6 A NOTAM should be originated and issued promptly whenever information to be distributed is of a temporary nature and of short duration or when operationally significant permanent changes or temporary changes of long duration are made at short notice.

- 6.7 This applies to the friction issues related to the:
- physical characteristics published in the AIP; and
 - presence or removal of, or significant changes in, hazardous conditions due to snow, slush, ice or water on the movement area.

SNOWTAM

6.8 The need to establish the SNOWTAM format originated from IATA as a consequence of bad experiences in southern Europe during the winter of 1962 to 1963. IATA considered that “the time has come to recognise the fact that with the operation of high speed turbine-powered aircraft such information is often of equal importance to information concerning other weather phenomena which at present determines the operational usability of an aerodrome”.

6.9 At an informal ICAO meeting in Paris in 1963, the SNOWTAM format was recommended. The meeting agreed that the most important objective, as espoused by IATA and IFALPA and recognized by States, was to reach the ideal conditions where precipitants were removed from all aerodrome manoeuvring areas as soon as they appeared, thus ensuring that flight operations remained unhampered.

6.10 SNOWTAM is a special series NOTAM notifying the presence or removal of hazardous conditions due to snow, ice, slush or standing water associated with snow, slush and ice on the movement area by means of a specific format. Annex 15, Appendix 2, provides instructions for the completion of the SNOWTAM format, including descriptions of the terms used.

METAR/SPECI

6.11 Subject to regional air navigation agreement, it is permissible to include information on the state of the runway as a part of the supplementary information of the METAR/SPECI meteorological report, which is issued hourly or half-hourly in the case of METAR, or as needed in the case of SPECI. The detailed specifications of the required information can be found in Annex 3, Appendix 3, with detailed coding information provided in the World Meteorological Organisation’s *Manual on Codes* (WMO-No.306).

DATA GATHERING AND INFORMATION PROCESSING

6.12 Several automated systems are becoming available which provide a remote indication of runway surface conditions, while others are still under development. At present, these systems are not in widespread use, and systems that provide an accurate indication of braking action seem a long way off. This unavailability strongly affects the related communication process.

6.13 Consequently, aerodrome operators need to gather relevant data, process the related information using manual systems and make information available to users using conventional ways that require a considerable amount of time in addition to the need to obtain access to runways, which is often difficult, particularly at busy aerodromes.

6.14 Presently, the primary means of communication are ATIS and ATC, in addition to SNOWTAM.

Automatic terminal information service (ATIS)

6.15 ATIS presents a very important means of transmitting information, relieving operational personnel from the routine duty of transmitting runway conditions and other relevant information to the flight crew.

6.16 One inherent weakness in the ATIS system is the currency of the information. This is due to the fact that flight crews generally listen to ATIS on arrival, some twenty minutes before landing, and in rapidly changing weather, the runway conditions may vary dramatically in such a timespan.

Air traffic control (ATC)

6.17 The organization responsible for gathering data and processing information of operational significance relating to runway conditions usually transmits such information to ATC, and ATC, in turn, provides this information to the flight crew if different from the ATIS. At present, this procedure appears to be the only one that is able to provide timely information to the flight crew, especially in rapidly changing conditions.

6.18 In addition to being timely, information disseminated through ATC may contain additional information associated with weather observed and forecasted by MET personnel, even before it is available on ATIS, as well as information gathered by other flight crew, such as braking action reports. This arrangement provides pilots with the best possible information available within the current system for sound decision making.

6.19 Finally, where visibility conditions and aerodrome configuration permit, ATC can provide the flight crew, at very short notice, with their own immediate observations, such as a rapid change in rainfall intensity or the presence of snow, notwithstanding that this may be considered as unofficial information.

Communication network

6.20 Air-ground communication between the flight deck and ATIS has generally been conducted through radiotelephony speech but large areas remain beyond the high frequency (HF) or very high frequency (VHF) coverage.

The burden of voice communication and the saturation of present ATC capabilities have created a strong demand for automated ATIS transmission of which digital data link has become a key element. Therefore, in the near future, service providers and users will need to adapt their ground communication systems to international data link requirements.

6.21 Amendments 82 and 83 to Annex 10, Volume III, Part I, which became applicable on 22 November 2007 and 22 November 2008, respectively, contain provisions in Chapter 3, 3.5.2 and 3.5.3, concerning:

- a) ADS-C and CPDLC;
- b) FIS (including ATIS and METAR);
- c) ATIS interfacility data communication (AIDC); and
- d) ATIS message handling services applications (ATSMHS).

6.22 Both the attachment to Annex 10, Volume III, Part I, and Doc 9694 give guidance on air traffic service data link applications. Further, Doc 9776, Doc 9805, Doc 9816 and the upcoming Manual on Aeronautical Satellite Services provide guidance material for the implementation of telecommunications systems.

DIGITAL NOTAM

6.23 A transition strategy is being developed to ensure the availability of real-time accredited and quality assured aeronautical information to any ATM user in a globally interoperable and fully digital environment. It is recognized that to satisfy new requirements arising from the Global ATM Operational Concept, aeronautical information services (AIS) must transition to the broader concept of aeronautical information management (AIM).

6.24 One of the most innovative data products that will be based on the standard aeronautical data exchange model is a digital NOTAM that will provide dynamic aeronautical information to all stakeholders with an accurate and up-to-date common representation of the aeronautical environment in which flights are operated. The digital NOTAM is defined as a dataset that contains the information included in a NOTAM in a structured format which can be fully interpreted by an automated computer system for accurate and reliable update of the aeronautical environment both for automated information equipment and humans.

6.25 Some radical improvements that will be delivered by the digital NOTAM project include:

- a) graphical visualization instead of simple text;
- b) improved NOTAM data quality because digital data enable automatic validation; and
- c) improved information-filtering capabilities.

6.26 Together with other States and international organizations, EUROCONTROL and the FAA are working with the ICAO AIS/AIM Study Group to define the future exchange of NOTAM information in an XML format. This format, the aeronautical information exchange model (AIXM), is a specification designed to enable the encoding and distribution, in digital format, of the aeronautical information that must be provided by the national AIS in accordance with ICAO provisions. The FAA is currently deploying a system to be used for digital NOTAM submission in the federal United States NOTAM system that uses AIXM5 as the data encoding format. Similarly, EUROCONTROL plans to have an initial digital NOTAM operational capability early in 2012 through the European AIS Database (EAD). AIXM5 is being considered for inclusion in ICAO guidance material.

6.27 The digital NOTAM concept of operations assumes that the current NOTAM format will continue to be used for at least 15 years, in parallel with the new XML format which is easier for computers to decode. The same applies to SNOWTAM messages.

FUTURE DEVELOPMENTS

6.28 There are inherent weaknesses in both the ATIS and ATC systems as means of transmitting safety-critical information.

6.29 With the introduction of new technologies which will make widespread automated equipment available for data gathering and information processing, relevant information will be transmitted instantaneously to all parties concerned such as the flight crew, ATC and the aerodrome operator. Such a system should also be capable of ATIS integration, eliminating weak points of communication through ATC.

6.30 The ATC community is aware of its critical role in disseminating information on runway conditions, such as information on contaminants, runway friction and braking action. Notwithstanding, ATC is also aware that relying on operational personnel for such a task invites opportunities for human-related active failures to occur.

Automated systems

6.31 Norway has developed an automated system where SNOWTAM information gathered and assessed is processed from the inspection vehicle. The ground staff is specially trained and authorized to use personal identification to log on to the system. The assessed data are entered on a touch screen where there is a built-in logic that prohibits entering wrong or conflicting data according to applicable rules and regulations.

6.32 Upon activating the SEND button, the SNOWTAM data are then sent to an AIS network for screening and processing. The operator is given feedback as the data are processed and can verify if the transmission has been successful. Using the AIS network, the ATC and other end users will be able to receive the SNOWTAM, which is also available on the Internet. The whole process occurs within a time frame of typically less than 15 seconds.

Chapter 7**SAFETY, HUMAN FACTORS AND HAZARDS****SAFETY****Evolution of safety**

7.1 In retrospect, the historical progress of aviation safety can be divided into three distinct areas:

- a) the fragile system (1920s to 1970s);
- b) the safe system (1970s to mid-1990s); and
- c) the ultra-safe system (mid-1990s onwards).

7.2 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.

Digital, up-to-date data

7.3 Future air traffic management (ATM) will rely on advanced data exchange and data-sharing services that will 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 SNOTAM” can be defined as a structured data set that contains the information currently distributed by text NOTAM messages.

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

7.5 In short, it can be said that provisions developed during the fragile system and revised in the safe system now need to be updated in the ultra-safe system using digital, up-to-date data as shown in Figure 7-1.

Humaninterface

- 7.6 Even with automatic processing three distinct human interfaces can be identified:
- the ground staff** who produce the information or control/calibrate the instrument providing the information for automatic processing;
 - the ATM staff** who, by radio phraseology, transfer the information to the end user; and
 - the flight crew** who make use of the information.

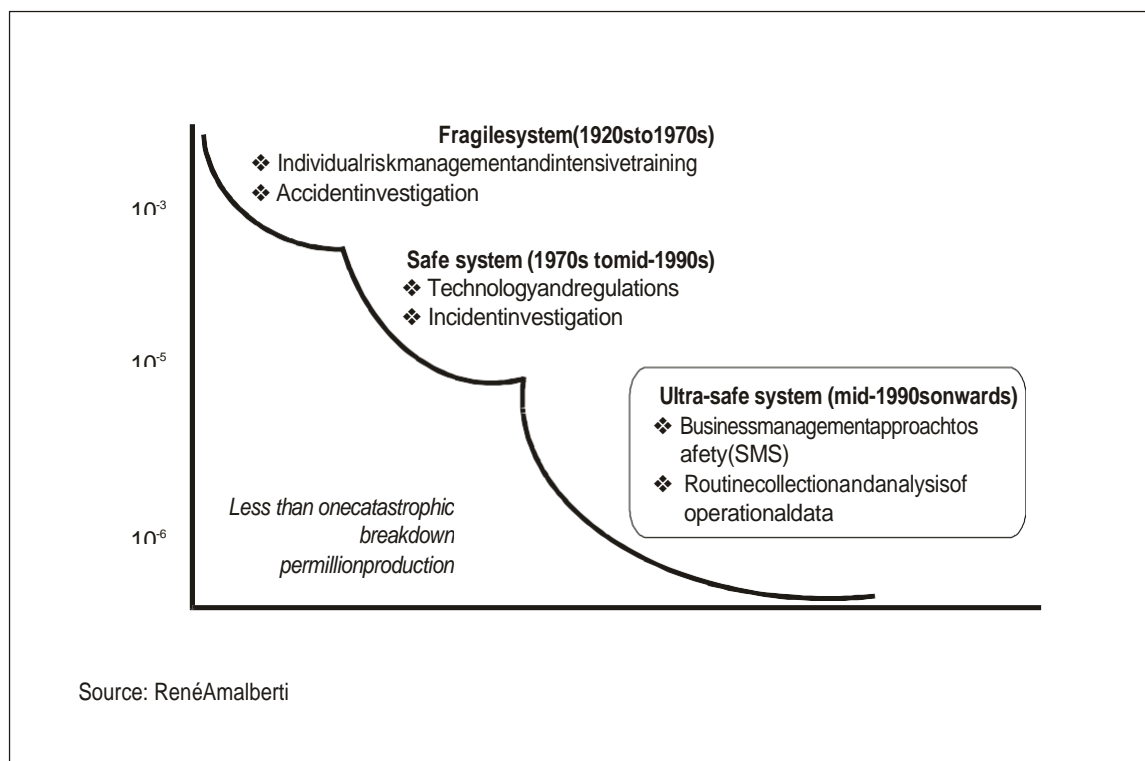


Figure 7-1. Historical evolution of aviation safety

7.7 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.

Gate-to-gate concept

7.8 The gate-to-gate concept involves considering and managing a flight as a continuous event. It involves coordinating 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 activities related to the aerodrome movement are now 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 them. Appendix C lists the friction issues relevant to each segment of flight.

Safety margins

7.9 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.

7.10 A double (and unnecessary) application of safety factors may lead to greater 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

7.11 Human Factors affect the gathering of runway friction data and also the ways such information is given to those who need it. The key participants in this process are the data gatherers, data transmitters and the users of the information (see Figure 72). It is essential that both parties (transmitter and 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 cooperation between the various participants.

Problem statement

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

Participants

7.13 Who are the main participants in these operations? From 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, the flight crew is 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 is the airline's dispatch, operations centre or handling agent that uses the information gathered from the flight crew, ATC and the aerodrome authority to plan or amend flight schedules accordingly.

Communication and teamwork

7.14 For over twenty years much of the emphasis concerning flight deck Human Factors has been placed on team training and crew resource management (CRM) with the aim of training pilots to utilize all the resources available to them (including 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 tasks. Few will look outside of 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.

Maintenance (Functional)			
Aerodrome (1)		ATC (2)	Flight crew (3)
Operatives	Management		
Gathers information	information and takes action		
Operational (Contaminated)			
Aerodrome (1)		ATC (2)	Flight crew (3)
Gathers information	Transmits information	Interprets information and makes a decision	

Figure 7-2. Key participants in the gathering and provision of runway friction data

7.15 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, and 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.

7.16 In adverse weather conditions, when contamination may be present, a shifting goal occurs. The ATC officer wants the operative 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 although good management and supervision should alleviate these. The driver may also believe that the data are unreliable and thus the task of gathering the data is a waste of time. However, because of traditional hierarchies, the driver may not feel empowered to refuse the request from ATC.

7.17 With planning and cooperation, routine friction testings should not inconvenience pilots; indeed they may well be unaware of the operation. But when the runway is contaminated, the flight crew is keenly aware that information from the runway passed via ATC is of vital importance. A diversion is never a “desirable” event, and this may contribute to the fact that flight 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 may have limited air holding time, within fuel reserve limits, before being committed to divert.

Challenges

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

Communication

7.19 One of the prime Human Factors issues 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.

7.20 There are many factors that contribute to communication breakdowns such as expectation, hearing what one wants or expects 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.

7.21 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 lack of a systematic means of conveying the status of a task all contribute to handover problems.

Standards and procedures

7.22 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.

Training, education and skills maintenance

7.23 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 because 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, focus should also be placed on education, such as how to ensure everyone involved has the requisite knowledge, how to decide which aspects are most important and when specialist judgement 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.

On-the-job training

7.24 Another area that involves a good deal of communication is on-the-job training. Learning from the expert may be effective but relies on clear and accurate communication and good teaching skills. Often the assumption is made that the best workers are the most capable of passing on their skills, but this is not always the case. The real "natural" may find it extremely difficult to understand why the novice is having problems.

Conclusion

7.25 The study of Human Factors is a task which demands a methodical approach. Whenever an 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

Risk management versus friction issues

7.26 The application of safety management in the conduct of aircraft operations relative to the critical tire/ground contact area is a complex one.

7.27 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 struck 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 the process shown in Figure 7-3.

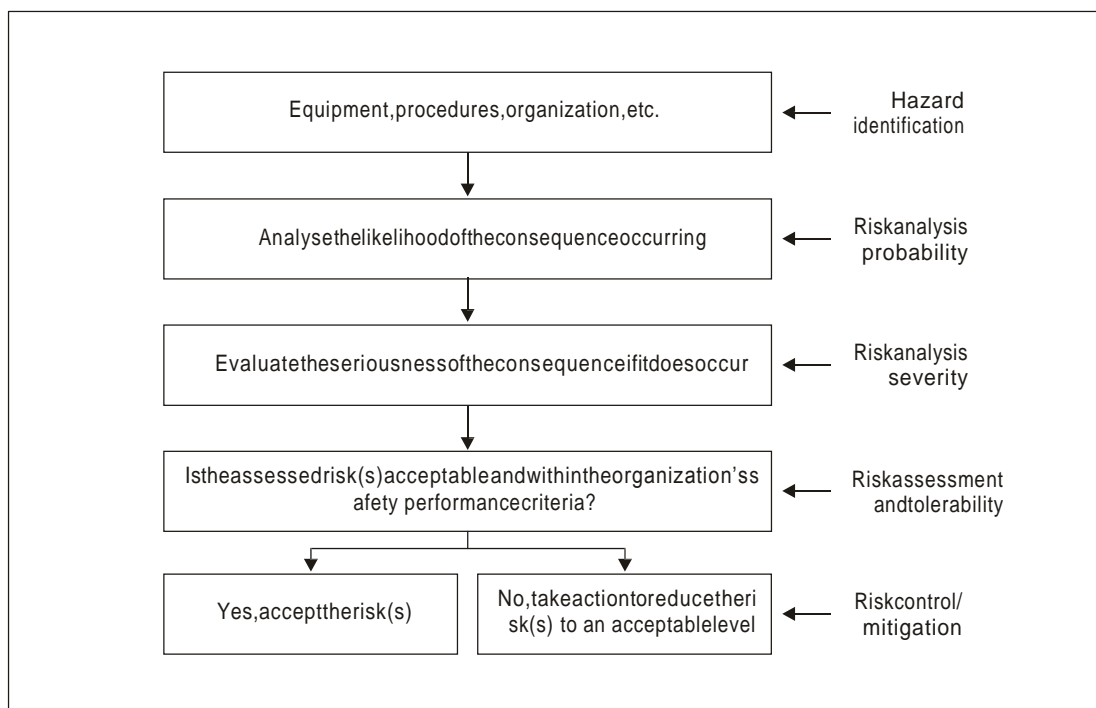


Figure 7-3. The process of safety risk management (source: Doc9859)

7.28 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, persons with responsive roles with respect to friction issues, such as ground staff and flight crew, face a more complex process due to the variable nature of meteorological conditions than the schematic model suggests. Exposure to the hazards might be too short to gain experience. This stresses the importance of training.

7.29 Effective risk assessment first requires sound data to enable the identification of hazards. Appendices 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; and
 - d) Appendix G — hazards related to friction issues and the atmosphere.
- 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 necessitates sound assessment and judgement to be made by those who identify the conditions at the movement area and

7.30 those who operate on the movement area in the prevailing conditions. The question they should ask while executing their assessment and judgement should be: “Should you be doing this?” This way they will challenge their own assessment and judgement.

Appendix A

PROGRAMMES ON FRICTION MEASUREMENT AND ASSESSMENT AND REPORTING OF RUNWAY SURFACE CONDITIONS

CANADIAN RUNWAY FRICTION INDEX (CRFI)

1. 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.

Measurement

2. Findings from the Joint Winter Runway Friction Measurement Programme (JWRFMP) have resulted in 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).

3. An electronic recording decelerometer (ERD) is used for runway friction measurement during winter operations at virtually all Canadian airports. It is 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 lock-up. 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.

4. The advantages of the ERD over other friction measuring devices are its simplicity and the fact that the CRFI correlates 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.

5. 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 in) 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

1. snow on the runway is deeper than 2.5 cm (1 in).

2. 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 movements surface condition reports (AMSCR) provided to air traffic services, which in turn provide it to pilots through ATIS or NOTAM.

Reporting

3. A typical AMSCR includes a CRFI number along with a surface description and other relevant information. Typically during pre-flight 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.

Predicting landing distance

4. The prediction of landing distance as a function of the CRFI is based on an acceptable correlation of the aircraft braking coefficient (μ braking) and CRFI. Aircraft deceleration is modelled 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.

5. Figure A-1 plots the mean aircraft μ braking against the CRFI for 275 aircraft test runs on contaminated surfaces, including surfaces which were non-uniformly contaminated.

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

7. The term “recommended” indicates that the values include a safety factor. The μ_{rec} line is drawn below at least 95 percent of the data points in Figure A-1, giving a 95 percent probability that the braking distances computed from the deceleration models will be achievable.

8. 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 turbopropeller discing thrust.

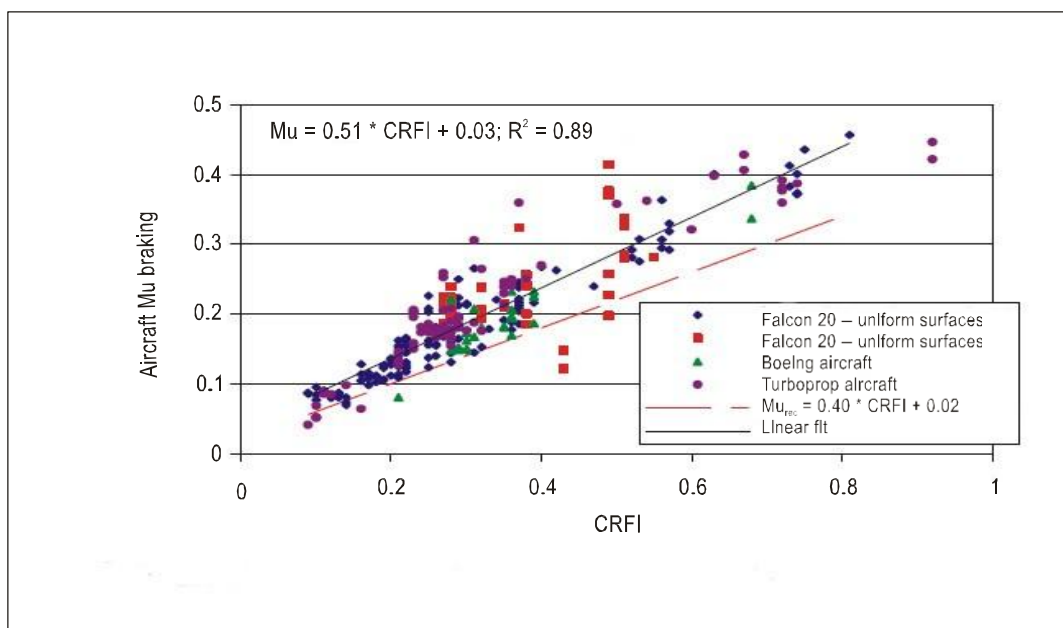


Figure A-1. Mean aircraft μ braking plotted against the CRFI for 275 aircraft test runs on contaminated surfaces

Application of the CRFI tables

9. Although the CRFI tables of recommended landing distances were derived from performance data from Falcon 20 and Dash 8 aircraft, they are considered to be applicable to jet transport aircraft and turboprop aircraft for a number of reasons. First, the correlation between the 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 ground speed, 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 specific aircraft AFM landing distance into the CRFI table 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.

Example using the CRFI table: If a surface condition report is provided by the airport which includes 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 with 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 is 0.27, these distances would be 6860 ft and 5950 ft, respectively (see the CRFI tables at www.tc.gc.ca/eng/civilaviation/publications/tp14371-air-1-0-462.htm).

Conclusion

10. Braking coefficients were obtained for several instrumented aircraft during full braking tests on winter-contaminated runways during the JWRFP. 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 distances, independent of specific aircraft type, were developed as a function of the CRFI and published by Transport Canada as advisory material.

TAKE-OFF AND LANDING PERFORMANCE ASSESSMENT— AVIATION RULEMAKING COMMITTEE(TALPA/ARC)

11. 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 the certification and operation of aircraft and aerodromes for aircraft take-off and landing operations on runways contaminated by snow, slush, ice or standing water. As such they chartered an Aviation Rulemaking Committee (ARC) to address take-off and landing performance assessment (TALPA) requirements and guidance for the turbine-engine aircraft certified under 14 CFR Parts 23 or 25 and operated under Part 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 pilots in real time and in terms that directly relate to expected aircraft performance was critical to the success of the project.

12. While researching current NOTAM processes, numerous significant shortcomings were discovered that hampered this communication effort. Without accurate real-time information, pilots cannot adequately assess take-off for landing performance.

13. 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:

- a) aligns runway surface conditions reported by aerodrome operators with contaminated landing performance data supplied by the aeroplane manufacturer;
- b) ties together runway contaminant descriptions and braking action and can be used to translate between these two methods of reporting runway surface conditions;
- c) provides a shorthand method of relaying runway surface condition information to flight crew through the use of runway condition codes to replace the reporting of μ readings;
- d) provides for a standardized method of reporting runway surface conditions for all aerodromes;
- e) provides more detailed information for the flight crew to make operational decisions; and
- f) standardizes the terminology used in pilot braking action reports.

14. In order to succeed, this concept will require extensive retraining of aerodrome operations personnel, dispatchers and pilots to ensure 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.

INTERNATIONAL RUNWAY FRICTION INDEX(IRFI)

15. The ASTM standard IRFI 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.

16. 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.

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

18. In order to implement a concept such as the IRFI, an infrastructure, logistics and associated harmonization methods to control the friction measuring devices themselves need to be established by States so such a device that they can be utilized within the constraint of a safety management system.

EASA RUNWAY FRICTION CHARACTERISTICS MEASUREMENT AND AIRCRAFT BRAKING (RuFAB)

19. In 2008 EASA launched the research project RuFAB to help identify possibilities for harmonizing runway friction characteristic measurement technologies and provide a basis for improving and harmonizing the implementation of current ECAA ICAO Standards and Recommended Practices (SARPs) within EASA member States. This could provide the opportunity for a global standardized application and contribute to the progress of the ICAO action plan. Finally it would prepare prerequisites for future EASA rules for aerodrome safety.

1. The first phase of the project was to review pertinent literature as well as existing and previous research results in the evaluation of runway surface friction characteristics and aircraft braking performance.
2. 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 (contained in ECAR 139 advisory documents and international specifications) and of the state of harmonization between these and national requirements and practices. In its comprehensive overview of the implementation of ECAA SARPs, the study distinguished between measurement of functional friction characteristics and measurement of operational runway friction characteristics.
3. The research project has been completed, and the results and recommendations are ready for discussion with ICAO working groups, experts and the stakeholder communities but may also be viewed in the light of the work carried out by the FAA TALPA/ARC. The report of the project is available at:

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

Appendix B

TRAINING FOR GROUND STAFF, ATM STAFF AND FLIGHTCREW

Frictionissue	Training			Remarks
	Groundstaff	ATMstaff	Flightcrew	
AIP	Publishingfrictional characteristics		Use ofpublished characteristics	
AICs	Newfrictional information		Newfrictional information	
Reportingformat	Assessment	Dissemination	Use ofinformation	
Terminology	Hazards	Hazards	Hazards	
	Contaminants	Contaminants	Contaminants	
Phraseology	Frictionalterms	Frictionalterms	Frictionalterms	
Processes	Data collectionandre	Dissemination	Use ofinformation	

FRICITION ISSUES VERSUS SEGMENT OFFLIGHTS

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)			Aircraft are at altitude and moving towards their destination but vectoring action related to the arrival phase	Aircraft are sequenced and brought to the terminal area for arrival	Aircraft are assigned runway and the surface	Aircraft are moved off runway and to the ramp	Aircraft are manoeuvred into the parking location	Integration into the ATM environment to achieve close match between the user's preferred trajectory and the system delivered trajectory	Flights are moved and the parking location	Aircraft are removed from the ramp to the departure queue	The departure queues are managed to launch aircraft from the queue in the airspace	Get aircraft unbound from the terminal into the en-route structure
Cleared length Reported when less than published length	Y	Relevant aircraft performance	●	●				●			●	
Cleared width Reported when less than published width	Y	Crosswind or engine failure scenario	●	●	Cross			●			●	Crosswind engine failure
Deposits	Y	In thirds for runways	●	●				●			●	
Mean depth	Y	In thirds for (RSM). Presence	●	●				●			●	
Extent of contamination	Y	In thirds	●	●				●			●	
Braking action (friction coefficient)	Y	In thirds	●	●				●			●	

Appendix C

Objectives, Requirements And information	Essential	Comments	Cruise	Collection	Approach landing	Surface arrival	Ramp	Planning/dispatch	Ramp	Surface departure	Departure take-off	Dispersion
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	N/Y	Could be an indication of potential hazardous runway conditions depending upon rainfall rate and runway design		•	• Significant increase			•			• Significant increase	
Overfilling. Part of METAR/ATIS.												
Further clearances 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		Different from BC
	Macrotexture	Wet, skid resistant		Different from DE
Noslope	Standing water	Poor drainage/tire/ground interface Hydroplaning	Longer stopping distance Loss of directional control	New design
Natural rounded aggregate	Susceptible to polishing	Slippery	Slippery when wet	Retexture Repave
Rubber deposit on crushed aggregate	Covert texture	Reduced texture	No performance credit on wet, skid-resistant pavement	Remove rubber deposit
		Slippery	Slippery	
Rubber deposit on natural, smooth aggregate	Covert texture	Reduced texture	Longer stopping distance	
		Slippery	Slippery	
Grooves	Closing due to deformation	Poor drainage/tire/ground interface	Longer No performance credit on wet, skid-resistant pavement	Open grooves
	Filled with contaminant	Poor drainage/tire/ground interface	Longer 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 ability/ ground interface	Basic assumption for wet skid resistance	Basic assumption based on tire tread depth of 2mm
Change in inflation pressure	Inflation pressure	Drainage capability/ ground interface	Basic assumption for wet skid resistance	Curves (e.g. equations) in harmonized certification specifications for 50, 100, 200 and 300 pounds per square inch (psi)

Appendix F**HAZARDS RELATED TO FRICTION ISSUES AND REPORTINGFORMAT**

	Friction characteristics			
	Physical	Functional	Operational	
Clear and dry	Dry		Certification limits	
Damp			Wet	
Wet, smooth	Wet	Reduced	Wet	Less than 3mm
Wet, skid resistant	Wet	Reduced braking action	Wet, skid-resistant performance data	Less than 3mm
Standing water	Wet	Hydroplaning susceptible		Above 3mm
Rime or frost covered	Thin layer; depth normally less than 1mm			
Loose snow				20mm*
Dry snow	Coverage Depth	Reduced braking action	Longer stopping distance	10, 25, 50, 100 percent
Wet snow	Coverage Depth	Reduced braking action	Longer stopping distance	10, 25, 50, 100 percent
Slush	Coverage Depth	Reduced braking action	Longer stopping distance	10, 25, 50, 100 percent
Wet ice Compacted snow or ice	Coverage	Reduced braking action	Longer stopping distance	10, 25, 50, 100 percent
Compacted or rolled snow	Coverage	Reduced braking action	Longer stopping distance	10, 25, 50, 100 percent
Frozen ruts or ridges	Coverage	Reduced braking action	Longer stopping distance	10, 25, 50, 100 percent
Sand	Present	Reduced	Longer	
Mud	Present	Reduced	Longer	
Oil/fuel spillage	Present	Reduced	Longer	
*Recommended change.				

AppendixG

HAZARDS RELATED TO FRICTION ISSUES AND THE ATMOSPHERE

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