



ICAO

Circular 355

Assessment, Measurement and Reporting of Runway Surface Conditions



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INTERNATIONAL CIVIL AVIATION ORGANIZATION



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FOREWORD

1. PURPOSE

1.1 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 and guidance to support maintenance of surface friction characteristics and the global reporting system and format for assessing and reporting runway surface conditions applicable as of 5 November 2020.

1.2 The global reporting format for assessing and reporting runway surface conditions is outlined in amendments to the following documents:

- Annex 3 — *Meteorological Service for International Air Navigation*
- Annex 6 — *Operation of Aircraft, Part I — International Commercial Air Transport — Aeroplanes and Part II — International General Aviation — Aeroplanes*
- Annex 8 — *Airworthiness of Aircraft*
- Annex 14 — *Aerodromes, Volume I — Aerodrome Design and Operations*
- Annex 15 — *Aeronautical Information Services*
- *Procedures for Air Navigation Services (PANS) — Aerodromes (PANS-Aerodromes, Doc 9981)*
- *Procedures for Air Navigation Services (PANS) — Aeronautical Information Management (PANS-AIM, Doc 10066)*
- *Procedures for Air Navigation Services (PANS) — Air Traffic Management (PANS-ATM, Doc 4444)*
- *Aeroplane Performance Manual (Doc 10064)*
- *Airport Services Manual, Part 2 — Pavement Surface Conditions, Part 8 — Airport Operational Services and Part 9 — Airport Maintenance Practices (Doc 9137)*

1.3 This circular addresses 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).

(iii)

2. BACKGROUND

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

2.2 The Standing Committee on Performance was set up in 1951 to develop specifications for transport aircraft performance suitable for inclusion in two Annexes to the Convention on International Civil Aviation: Annexes 6 and 8. The Committee was able to work out a complete performance code and defined a reference dry and wet surface.

2.3 In 1954, the Air Routes and Ground Aids (AGA) Committee exchanged technical views on specific problems, including concerns about icy runway operations, following the introduction of turbojet operations. These discussions were summarized and published in 1955 in Circular 43 — *Ice and Snow on Runways*.

2.4 In 1957, the Airworthiness Committee compared two existing codes (United Kingdom and United States) and decided to adopt their common specifications. In 1961, ICAO published Circular 60 — *Operational Measures for Dealing with the Problem of Taking Off from Slush- or Water-covered Runways* to address the take-off situation. An updated version (1968) was used as the basis for guidance material for the European Joint Aviation Authorities JAR 25, now CS-25.

2.5 Commencing in 1965, the Air Navigation Commission established various study groups to assist the Secretariat on issues related to friction.

2.6 From 1972 to 1974, ICAO administered a programme, undertaken by Canada, France, Sweden, Union of Soviet Socialist Republics, United Kingdom and United States, to evaluate equipment used to measure runway braking action. From the conclusions of the reduced test data it was noted that some degree of correlation existed among the devices tested and that correlation varied widely between equipment pairs and with changes in surface texture, and that a great lack of precision was evident among the measuring devices. Friction measuring device correlation charts were developed for wet surfaces and for compacted snow or ice surfaces. The landing situation represented a challenge for the Airworthiness Committee, and three landing methods were developed and published in the *Airworthiness Technical Manual* (Doc 9051). In the early stages of development of the landing specifications, it had been hoped that a close enough correlation would be established between friction measuring devices and aircraft stopping distance to allow runway friction to be treated as an operational variable. In 1976, the Airworthiness Committee proposed a three-tier system comprising dry, normal and substandard runways. It was recognized that the operational distinction between normal and substandard wet runways posed problems which were not yet solved.

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

2.8 In 2001, the *Airworthiness Manual* (Doc 9760) was published with the objective of providing guidance on the implementation of the airworthiness and maintenance provisions of Annexes 6 and 8. Doc 9760 replaced, among other documents, Doc 9051, which contained detailed technical information referred to in Doc 9137, *Airport Services Manual*, Part 2, which was supplemented by the performance-based guidance in Circular 329 — *Assessment, Measurement and Reporting of Runway Surface Conditions*.

2.9 With respect to dissemination of information on runway surface conditions, the ICAO SNOWTAM format was developed and introduced in 1967 arising from a detailed proposal from the International Air Transport Association (IATA) in 1963. The SNOWTAM format has not gained global acceptance and has been implemented differently among

States, resulting in inconsistent information being provided to aircraft operators and pilots. Runway condition reports should be timely, accurate and consistent with the need to conduct aircraft operations that are in compliance with Annexes 6 and 8.

2.10 Numerous projects have been aimed at resolving the problem of harmonizing the various friction measuring devices and linking them to aircraft performance. The latter goal still has not been achieved largely due to the difficulty of developing a system comprising a universally agreed reference for friction measuring devices and issues associated with the repeatability and reproducibility of the fleet of friction measuring devices in use.

2.11 In view of these historical developments, it was considered timely for ICAO to develop international specifications on, *inter alia*, the functions, principles and basic technical and operational characteristics of friction measuring devices. In 2006 the Aerodromes Operations and Services Working Group, under the aegis of the Aerodromes Panel, established the ICAO Friction Task Force (FTF) with the following deliverables:

- a) propose appropriate amendments to the relevant Standards and Recommended Practices (SARPs) in ICAO Annexes, primarily Annex 14, Volume I, supported by updated guidance material;
- b) develop an ICAO circular on assessing, measuring and reporting runway surface conditions including state-of-the-art treatment of friction issues; and
- c) propose an action plan for tasks that require future work.

The ICAO FTF formally commenced its work in 2008.

2.12 Having delivered on its first tasks, the FTF was asked to:

- a) address the problem statement – runway surface conditions have contributed to many safety events and *investigations have revealed shortfalls in the accuracy and timeliness of assessment and reporting methods currently provided for in ICAO provisions and guidance material*;
- b) develop provisions on the reporting of runway surface conditions in Annex 14, Volume I, and other related Annexes and Procedures for Air Navigation Services (PANS);
- c) develop guidance on operational requirements for aeroplane performance; and
- d) develop guidance for the assessment of runway surface conditions, including friction level and where contamination exists.

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GLOSSARY

ABBREVIATIONS AND ACRONYMS

AC	Advisory circular (FAA)
AFM	Aircraft flight manual
AIC	Aeronautical information circular
AIM	Aeronautical information management
AIP	Aeronautical information publication
AIREP	Air-report
AIS	Aeronautical information services
ARC	Aviation Rulemaking Committee (FAA)
ASTM	American Society for Testing and Materials
ATC	Air traffic control (in general)
ATIS	Automatic terminal information service
ATM	Air traffic management
ATS	Air traffic service
CFR	Code of Federal Regulations (FAA)
CRM	Crew resource management
CS	Certification specifications (EASA)
EASA	European Aviation Safety Agency
ESDU	Engineering Sciences Data Unit
FAA	Federal Aviation Administration (United States)
FAR	Federal Aviation Regulations (United States)
FTF	Friction Task Force
HF	High frequency
HMA	Hot-mix asphalt
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
JAA	Joint Aviation Authorities (Europe)
JAR	Joint Aviation Requirements (Europe)
LDA	Landing distance available
MET	Meteorological services
MPD	Mean profile depth
MTD	Mean texture depth
NASA	National Aeronautics and Space Administration (United States)
NOTAM	Notice to airmen
NTRS	NASA Technical Report Server
OAT	Outside air temperature
PANS	Procedures for Air Navigation Services
PCC	Portland cement concrete
PFC	Porous friction course
PSV	Polished stone value
RCAM	Runway condition assessment matrix
RCR	Runway condition report
RESA	Runway end safety area
RST	Runway Safety Team
RWYCC	Runway condition code

SARPS	Standards and Recommended Practices
SLA	Service level agreement
SMS	Safety management system
SOP	Standard operating procedure
TWY	Taxiway
μ	Mu (coefficient of friction)
$\mu_{\max}$	Maximum friction coefficient as experienced by an aircraft
VHF	Very high frequency
WMO	World Meteorological Organization

EXPLANATION OF TERMS

The terms contained herein are used in the context of this circular. Except where indicated, they have no official status within ICAO. Where a formally recognized ICAO definition is included for convenience, the definition is noted with an asterisk (*).

Aeronautical information circular (AIC).* A notice containing information that does not qualify for the origination of a NOTAM or for inclusion in the AIP, but which relates to flight safety, air navigation, technical, administrative or legislative matters.

Aeronautical information management (AIM).* The dynamic, integrated management of aeronautical information through the provision and exchange of quality-assured digital aeronautical data in collaboration with all parties.

Aeronautical information service (AIS).* A service established within the defined area of coverage responsible for the provision of aeronautical data and aeronautical information necessary for the safety, regularity and efficiency of air navigation.

Air-report.* A report from an aircraft in flight prepared in conformity with requirements for position, and operational and/or meteorological reporting.

Air traffic service.* A generic term meaning variously, flight information service, alerting service, air traffic advisory service, air traffic control service (area control service, approach control service or aerodrome control service).

Automatic terminal information service (ATIS).* The automatic provision of current, routine information to arriving and departing aircraft throughout 24 hours or a specified portion thereof:

Data link-automatic terminal information service (D-ATIS). The provision of ATIS via data link.

Voice-automatic terminal information service (Voice-ATIS). The provision of ATIS by means of continuous and repetitive voice broadcasts.

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-to-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 directional control.

ESDU scale. A grouping of hard runway surfaces based on macrotexture depth.

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

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

Grooved or porous friction course runway. A paved runway that has been constructed and maintained with lateral grooving or a porous friction course (PFC) surface to improve braking characteristics when wet in compliance with the *Aerodrome Design Manual* (Doc 9157) or equivalent.

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

Industry codes of practice.* Guidance material developed by an industry body, for a particular sector of the aviation industry to comply with the requirements of the International Civil Aviation Organization's Standards and Recommended Practices, other aviation safety requirements and the best practices deemed appropriate.

Note.— Some States accept and reference industry codes of practice in the development of regulations to meet the requirements of Annex 19, and make available, for the industry codes of practice, their sources and how they may be obtained.

Landing distance available (LDA).* The length of runway which is declared available and suitable for the ground run of an aeroplane landing.

NOTAM.* A notice distributed by means of telecommunication containing information concerning the establishment, condition or change in any aeronautical facility, service, procedure or hazard, the timely knowledge of which is essential to personnel concerned with flight operations.

Operational personnel.* Personnel involved in aviation activities who are in a position to report safety information.

Note.— Such personnel include, but are not limited to: flight crews; air traffic controllers; aeronautical station operators; maintenance technicians; personnel of aircraft design and manufacturing organizations; cabin crews; flight dispatchers; apron personnel and ground handling personnel.

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

Runway.* A defined rectangular area on a land aerodrome prepared for the landing and take-off of aircraft.

Runway condition assessment matrix (RCAM).^{*1} A matrix allowing the assessment of the runway condition code, using associated procedures, from a set of observed runway surface condition(s) and pilot report of braking action.

Runway condition code (RWYCC).^{*1} A number describing the runway surface condition to be used in the runway condition report.

Note.— The purpose of the runway condition code is to permit an operational aeroplane performance calculation by the flight crew. Procedures for the determination of the runway condition code are described in the PANS-Aerodromes (Doc 9981).

Runway condition report (RCR).^{*1} A comprehensive standardized report relating to runway surface conditions and its effect on the aeroplane landing and take-off performance.

Runway Safety Team. A team comprising representatives from the [aerodrome operator], air traffic service provider, airlines or aircraft operators, pilot and air traffic controllers associations and any other group with a direct involvement in runway operations [at a specific aerodrome,] that advise the appropriate management on potential runway [safety] issues and recommend mitigation strategies.

Note.— This definition is based on ICAO Doc 9870, Manual on the Prevention of Runway Safety Incursions, but takes into consideration evolving concepts resulting from recent work of the ICAO Runway Safety Programme. It therefore slightly improves the original definition without contradicting but rather clarifying it for the purposes of this document (Runway Safety Team Handbook). It may or may not be eventually harmonized in other publications, based on feedback on its use. For easy identification, the differences are between square brackets.

Runway surface condition(s).^{*1} A description of the condition(s) of the runway surface used in the runway condition report which establishes the basis for the determination of the runway condition code for aeroplane performance purposes.

Note 1.— The runway surface conditions used in the runway condition report establish the performance requirements between the aerodrome operator, aeroplane manufacturer and aeroplane operator.

Note 2.— Aircraft de-icing chemicals and other contaminants are also reported but are not included in the list of runway surface condition descriptors because their effect on runway surface friction characteristics and the runway condition code cannot be evaluated in a standardized manner.

Note 3.— Procedures on determining runway surface conditions are available in the PANS-Aerodromes (Doc 9981).

- a) **Dry runway.** A runway is considered dry if its surface is free of visible moisture and not contaminated within the area intended to be used.
- b) **Wet runway.** The runway surface is covered by any visible dampness or water up to and including 3 mm deep within the intended area of use.
- c) **Slippery wet runway.** A wet runway where the surface friction characteristics of a significant portion of the runway have been determined to be degraded.
- d) **Contaminated runway.** A runway is contaminated when a significant portion of the runway surface area (whether in isolated areas or not) within the length and width being used is covered by one or more of the substances listed in the runway surface condition descriptors.

¹ Applicable 5 November 2020.

Note.— Procedures on determination of contaminant coverage on runway is available in the PANS-Aerodromes (Doc 9981).

e) *Runway surface condition descriptors.* One of the following elements on the surface of the runway:

Note.— The descriptions for e) i) to e) viii) are used solely in the context of the runway condition report and are not intended to supersede or replace any existing WMO definitions.

- i) *Compacted snow.* Snow that has been compacted into a solid mass such that aeroplane tires, at operating pressures and loadings, will run on the surface without significant further compaction or rutting of the surface.
- ii) *Dry snow.* Snow from which a snowball cannot readily be made.
- iii) *Frost.* Frost consists of ice crystals formed from airborne moisture on a surface whose temperature is below freezing. Frost differs from ice in that the frost crystals grow independently and therefore have a more granular texture.

Note 1.— Below freezing refers to air temperature equal to or less than the freezing point of water (0 degree Celsius).

Note 2.— Under certain conditions frost can cause the surface to become very slippery and it is then reported appropriately as reduced braking action.

- iv) *Ice.* Water that has frozen or compacted snow that has transitioned into ice, in cold and dry conditions.
- v) *Slush.* Snow that is so water-saturated that water will drain from it when a handful is picked up or will splatter if stepped on forcefully.
- vi) *Standing water.* Water of depth greater than 3 mm.

Note.— Running water of depth greater than 3 mm is reported as standing water by convention.

- vii) *Wet ice.* Ice with water on top of it or ice that is melting.

Note.— Freezing precipitation can lead to runway conditions associated with wet ice from an aeroplane performance point of view. Wet ice can cause the surface to become very slippery. It is then reported appropriately as reduced braking action in line with procedures in the PANS-Aerodromes (Doc 9981).

- viii) *Wet snow.* Snow that contains enough water content to be able to make a well-compacted, solid snowball, but water will not squeeze out.

Safety.* The state in which risks associated with aviation activities, related to, or in direct support of the operation of aircraft, are reduced and controlled to an acceptable level.

Safety management system (SMS).* A systematic approach to managing safety, including the necessary organizational structures, accountability, responsibilities, policies and procedures.

Significant change. A change in the magnitude of a hazard, which leads to a change in the safe operation of the aircraft.

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

SNOWTAM. A special series NOTAM given in a standard format providing a surface condition report notifying the presence or cessation of hazardous conditions due to snow, ice, slush, frost, standing water or water associated with snow, slush, ice or frost on the movement area.

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

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

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 the calibrated airspeed at which the critical engine is assumed to fail (V_{EF}), at which the pilot can continue the take-off and achieve the required height above the take-off surface within the take-off distance.

LIST OF PUBLICATIONS

(Referred to in this Circular)

ICAO PUBLICATIONS

Annexes to the Convention on International Civil Aviation

Annex 3 — Meteorological Service for International Air Navigation

Annex 6 — Operation of Aircraft

Part I — International Commercial Air Transport — Aeroplanes

Part II — International General Aviation — Aeroplanes

Annex 8 — Airworthiness of Aircraft

Annex 14 — Aerodromes

Volume I — Aerodrome Design and Operations

Annex 15 — Aeronautical Information Services

Annex 19 — Safety Management

Procedures for Air Navigation Services (PANS)

ATM — Air Traffic Management (Doc 4444)

Aerodromes (Doc 9981)

AIM — Aeronautical Information Management (Doc 10066)

Manuals

Location Indicators (Doc 7910)

Airport Services Manual (Doc 9137)

Part 2 — Pavement Surface Conditions

Part 9 — Airport Maintenance Practices

Aerodrome Design Manual (Doc 9157)

Part 1 — Runways

Part 3 — Pavements (in preparation)

Airworthiness Manual (Doc 9760)

Safety Management Manual (SMM) (Doc 9859)

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Manual on the Prevention of Runway Incursions (Doc 9870)

Aeroplane Performance Manual (Doc 10064) (in preparation)

Circulars

Ice and Snow on Runways (Cir 43)*

Operational Measures for Dealing with the Problem of Taking Off from Slush- or Water-covered Runways (Cir 60)*

Handbooks

Runway Safety Team Handbook, second edition (unedited version) – June 2015

OTHER PUBLICATIONS

American Society for Testing and Materials (ASTM)

Standard Practice for the Accelerated Polishing of Aggregates Using the British Wheel (ASTM D 3319)

Standard Test Method for Measuring Surface Frictional Properties Using the British Pendulum Tester (ASTM E 303-93)

European Committee for Standardization (CEN)

Tests for Mechanical and Physical Properties of Aggregates — Part 8: Determination of the Polished Stone Value (CEN EN 1097-8)

Engineering Sciences Data Unit (ESDU)

Frictional and Retarding Forces on Aircraft Tyres. Part II: Estimation of Braking Force (ESDU 71026)

Definitions for Runway Contaminants and the Classification and Distribution of Hard Runway Surfaces (ESDU 15002)

* Permanently out of print.

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, perhaps, sufficient in many cases for practical purposes, yet by no means tend to bring the inquiry into any more settled state.

Nicholas Wood, 1838¹

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

1.2 It is common knowledge that pavements tend 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 has a complete understanding yet 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, air navigation service providers, aircraft operators and individuals within those organizations.

THE ROLE OF ICAO

1.4 ICAO promotes the safe and orderly development of international civil aviation throughout the world. It sets standards and regulations necessary for, *inter alia*, aviation safety. In this regard, since the mid-1950s, ICAO has been instrumental in generating discussion on friction issues, establishing study groups and task forces, and encouraging research programmes.

1.5 All these activities have culminated in a global reporting system and format adopted by the ICAO Council at its 207th Session in 2016 to become applicable as of 5 November 2020. This circular is part of the guidance provided for this global reporting system and format.

1 Nicholas Wood, *A Practical Treatise on Rail-roads, and Interior Communication in General: Containing Numerous Experiments on the Powers of the Improved Locomotive Engines and Tables of the Comparative Cost of Conveyance on Canals, Railways, and Turnpike Roads*. London: Printed for Longman, Orme, Brown, Green, and Longmans, 1838.

THE GLOBAL REPORTING SYSTEM AND FORMAT FOR ASSESSING AND REPORTING RUNWAY SURFACE CONDITIONS

- 1.6 The importance of removing contamination from a runway surface as rapidly and completely as possible to minimize accumulation prior to any reporting and operation cannot be overemphasized.
- 1.7 The global reporting system for assessing and reporting runway surface conditions involves all stakeholders involved in collecting data, converting the data into structured operational information and bringing the structured information to the end users, and the end users using the structured information.
- 1.8 The importance of Annex definitions of terms used in Standards and Recommended Practices (SARPs) must be stressed. These definitions do not have an independent status but are an essential part of each SARP in which a defined term is used, since a change in the meaning of the term would affect the specification.
- 1.9 A fundamental change in the new reporting system is the introduction of runway condition code (RWYCC). The assessment process of assigning a RWYCC is a *deterministic process*, starting with the identification of the various contaminants, that determines what initial RWYCC must be reported. Based on all other information available, this initial RWYCC can be downgraded or upgraded using procedures detailed in the *Procedures for Air Navigation Services — Aerodromes* (PANS-Aerodromes, Doc 9981).
- 1.10 The revised scale GOOD, GOOD TO MEDIUM, MEDIUM, MEDIUM TO POOR, POOR and LESS THAN POOR is used by the flight crew to characterize perceived braking action and lateral control of the aeroplane during landing roll. RWYCCs 0 through 5 are mapped to this terminology in the runway condition assessment matrix (RCAM) and describe a consistent runway surface condition in relation to its effect on aircraft braking performance and lateral control.
- 1.11 Another fundamental change is that WET runway conditions are included in the runway condition report (RCR) on a regular basis.
- 1.12 The global reporting system and format has been designed to cover all of the world's climatic zones. To achieve this, the global reporting system and format has a flexibility mechanism which States may use if a State never experiences ice, snow or frost.
- 1.13 There are two scenarios. A State may:
- a) not be exposed to snow or ice and therefore have no need to use the full global reporting format other than for water; or
 - b) be fully prepared to use the global reporting format (fully equipped, fully trained).
- 1.14 Use of the global reporting format requires the application of equipment, processes and procedures for the removal of contaminants and treatments, and most crucially, requires the involvement of competent personnel in maintenance activities as well as assessment and reporting activities. Personnel need to be competent to perform their duties, and training must be adjusted to the environment in which they operate.
- 1.15 With respect to the regulatory impact, this two-level solution will mean that each aerodrome operator can choose a set of provisions commensurate with its needs. As a result, limited or no extra costs will be incurred.
- 1.16 States build this flexibility into their State regulations, where appropriate, to ensure the smooth implementation of the global reporting format and hence transparency and global standardization.

TERMINOLOGY

1.17 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-to-ground contact area.

1.18 At this critical tire-to-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.

1.19 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 air-reports (AIREPs); and
- c) *RWYCC* is a number generated by the trained and competent aerodrome personnel's assessment of the runway surface conditions. The RWYCC permits an operational aeroplane landing performance calculation by the flight crew.

1.20 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.

1.21 The term "braking action" has been in continuous use in the aviation industry but 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 is used to define the stopping capability of an aircraft using wheel brakes and is related to pilot report of runway braking action. For a period of time, the term "braking action" was (but is no longer) also used to describe the estimated surface friction on the ground measured by a friction measurement device and reported as aircraft stopping capability. The ICAO SNOWTAM format uses the term "runway condition code" (RWYCC) and should be understood as the total assessment of the slipperiness of the surface as judged by the trained and competent aerodrome personnel based on given procedures and all information available. RWYCC and runway braking action are mapped against each other in the RCAM.

1.22 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 friction referred to as measured friction coefficient is no longer reported to the flight crew. When friction measurements are used as part of the overall runway surface assessment for compacted snow- or ice-covered surfaces, the friction measuring device shall meet the standard set or agreed by the State.

1.23 Some States have an established programme of runway friction measurements using State-approved friction measuring devices. The global reporting format allows this information to be included for situational awareness. The format and operational use of this information is set and communicated by the State.

Chapter 2

THE DYNAMIC SYSTEM

2.1 The basic friction characteristics of the critical tire-to-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.

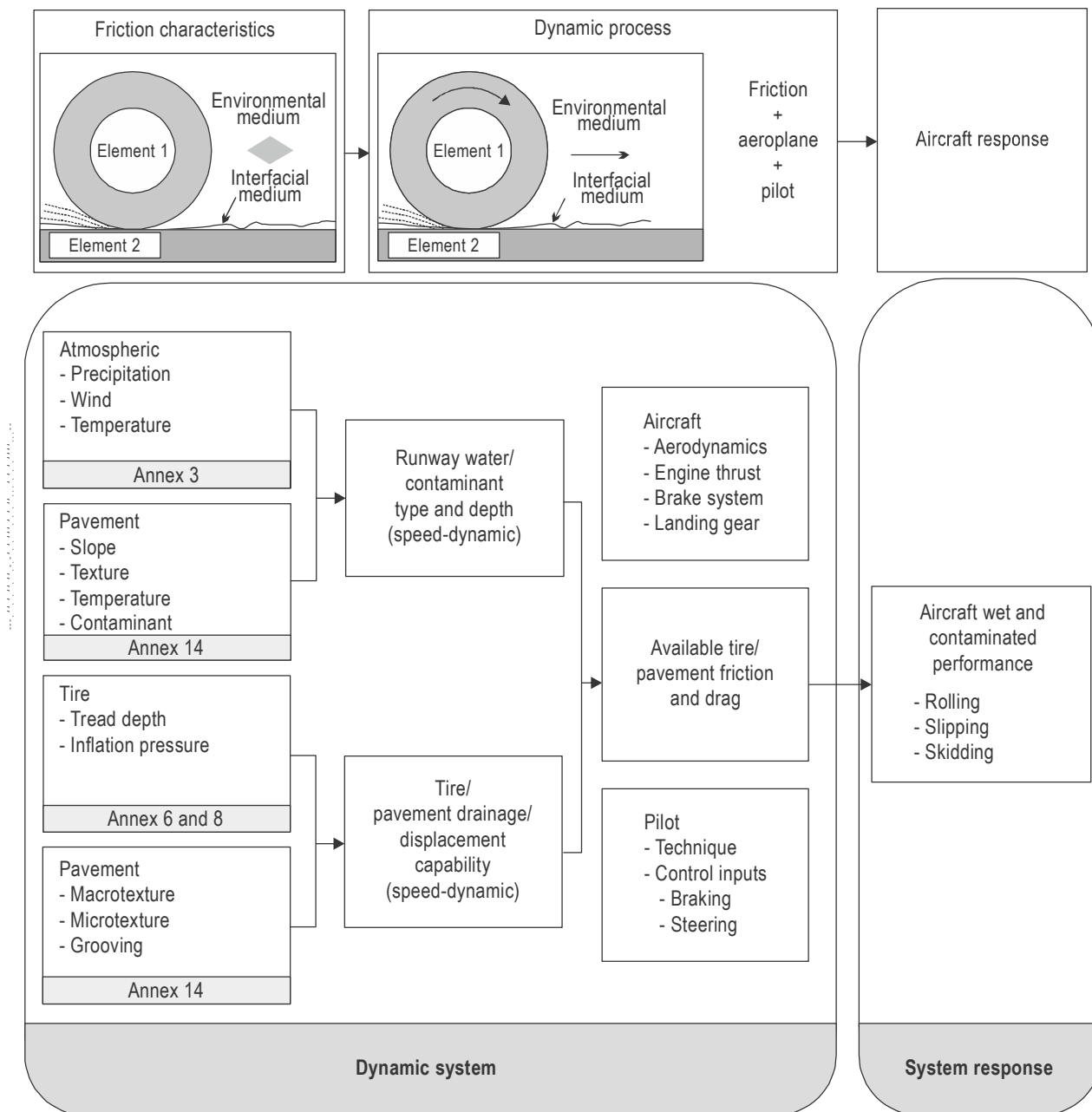


Figure 2-1. Basic friction characteristics, the dynamic system and system response

Chapter 3

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 configuration of the surface. Moreover, the friction level available is relatively unaffected by the speed of the aircraft. Hence, 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.

3.9 The level of maintenance provided is the capability to remove contaminants as rapidly and completely as possible to avoid accumulation. The level of maintenance required is a function of exposure to those contaminants, the maintenance equipment available and the competence of the personnel operating the maintenance equipment.

3.10 Aerodrome operators may be exposed to three main scenarios:

- a) wet runway condition scenarios only;
- b) snow and ice conditions occur only at irregular intervals and runway closure can be tolerated to a certain extent as a result of having limited or no removal capability; or
- c) snow and ice conditions during which the aerodrome operator must operate as normally as possible.

DESIGN

Texture

Surface texture

3.11 The most important aspect of the pavement surface relative to its friction characteristics is the surface texture. The effect of different 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-runway 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 at hand. Furthermore, they are understood differently in various parts of the aviation industry. The *Aerodrome Design Manual*, Part 3 — *Pavements* (Doc 9157), contains further guidance on this subject.

3.12 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.

Microtexture

3.13 Microtexture is the texture of the individual stones and is hardly detectable by the eye. Microtexture is considered a primary component in wet 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.

3.14 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 (PSV), which is in principle a value obtained from friction measurement in accordance with international standards (ASTM D 3319, CEN EN 1097-8).

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

Macrotexture

3.16 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.

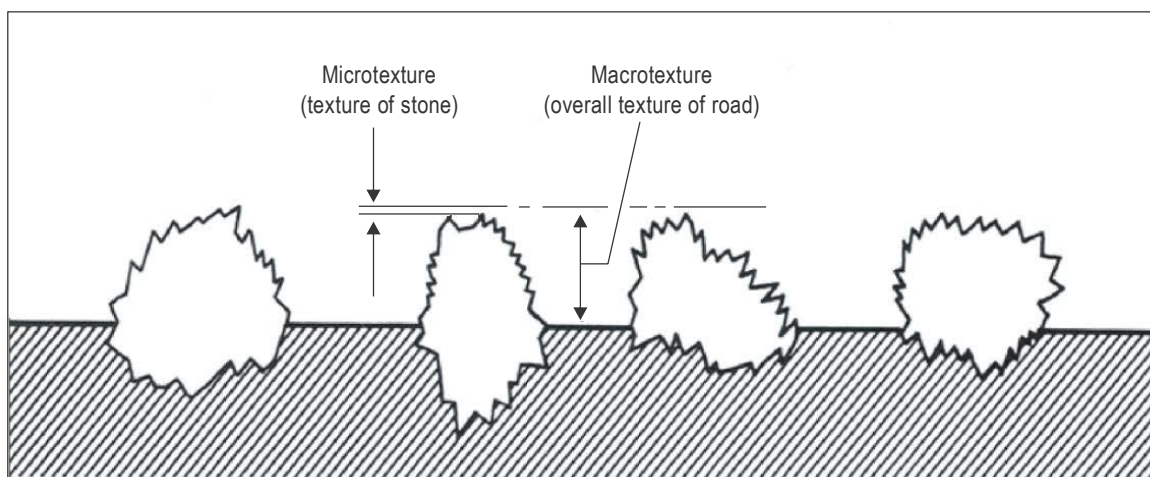


Figure 3-1. Microtexture and macrotexture

¹ The International Organization for Standardization (ISO), *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.

Engineering Sciences Data Unit (ESDU)

3.17 The Engineering Sciences Data Unit (ESDU) describes the microtexture as the texture of the individual stones of which the runway is constructed and as dependent 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.

3.18 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 that 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 15002 refers to texture measurements from runways made in the 1970s 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

3.19 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.

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

3.21 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 may require some form of special measures.

3.22 Drainage capability can, in addition, be enhanced by special measures such as grooving and porous friction course (PFC), which drains water initially through voids of a specially treated wearing course.

3.23 It should be clearly understood that special measures are 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) are the baseline for appropriate wet runway surface friction characteristics.

3.24 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

3.25 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.

3.26 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

3.27 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 as surface water or through a subsurface drainage system. The resulting combined longitudinal and transverse slope is the path for the natural drainage run-off. This path can be shortened by adding transverse grooves.

3.28 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.

3.29 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

3.30 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 Annex 14 — *Aerodromes*, Volume I — *Aerodrome Design and Operations*. Further guidance is given in Doc 9157, Part 1 — *Runways* and Part 3.

Macrotexture (drainage)

3.31 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.

3.32 Interface drainage is actually a dynamic process highly correlated with the square of speed. Therefore, macrotexture is particularly important for the provision of adequate friction in the high-speed range. From the operational

aspect, this is most significant because it is in this speed range where lack of adequate friction is most critical with respect to stopping distance and directional control capability.

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

3.34 Annex 14, Volume I, 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 PFC surface.

Microtexture (drainage)

3.35 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 into contact. Aggregates susceptible to polishing can lessen this microtexture.

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

Rainfall

3.37 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.

3.38 Rainfall on a smooth runway surface affects aircraft performance more than rainfall on a runway surface with good macrotexture. Rainfall on runway surfaces with good drainage has a lesser effect on aircraft performance. Grooved runways and runways with PFC 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.

3.39 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

3.40 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.

3.41 Various studies have been performed over the past decades to relate rain intensity and runway characteristics to water depth on the runway. Water depth on the runway determines what aircraft performance data should be used by the flight crew, e.g. regular wet performance or standing water performance. It seems that water-depth modelling is currently the only available method that can be used in a timely manner to inform flight crews of the

amount of water present on a runway. Runway design parameters, notably texture depth, are a main indicator 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.

Reporting practices

3.42 Disregarding winter operations, a runway surface condition is reported using the terms DRY, WET or STANDING WATER and is associated with a RWYCC. Additionally, a notice to airmen (NOTAM) will be issued whenever a significant portion of a runway drops below the minimum friction level set or agreed by the State.

3.43 Reporting STANDING WATER conditions is difficult because methods for accurate, reliable and timely determination of the water depth on a runway are not available. STANDING WATER conditions have contributed to several accidents worldwide. Obviously the frequency of occurrence of STANDING WATER conditions will be higher for regions more prone to torrential rainfall and equally for poor drainage runways.

3.44 There is no internationally agreed table that links World Meteorological Organization (WMO) terms for reporting the intensity level of rainfall to aeroplane performance. To establish such a relationship, the drainage capability of the runway pavement needs to be taken into consideration.

CONSTRUCTION

Selection of aggregates and surface improvement methods

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

3.46 *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.

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

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

3.49 *Hot-mix asphalt (HMA).* 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.

3.50 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 binder to aggregates, stiffness, resistance to

permanent deformation, resistance to fatigue/crack initiation, resistance to abrasion), the expected macrotexture will normally reach 0.7 to 0.8 mm with an 11 to 14 mm size aggregate.

3.51 *Grooving and PFC.* Two methods which have had significant influence on improved friction characteristics for runway pavements are grooving and the open-graded, thin, HMA surface called PFC.

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

Grooving

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

3.54 The first grooved runways appeared on military aerodromes in the United Kingdom (mid-1950s). The United States followed by establishing a grooved National Aeronautics and Space Administration (NASA) research track (1964 and 1966). The first civil aerodromes with grooved runways were Manchester Airport in the United Kingdom (1961) and John F. Kennedy International Airport in the United States (1967). Ten years later, in 1977, approximately 160 runways had been grooved worldwide. The research conducted in these early years is the foundation for the documentation in Doc 9157, Part 3. Reports from this research are available from the NASA Technical Report Server (NTRS).

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

3.56 In addition, the isolated puddles that are likely to be formed on non-grooved surfaces because of uneven surface profile 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.

3.57 *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.

3.58 *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.

3.59 *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.

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

3.61 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; 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 surfacing normally have higher macrotexture and are not grooved.

Table 3-1. Groove geometry

State	Condition	Groove geometry			Macrotexture (mm)	
		Width (mm)	Depth (mm)	Centre-to-centre spacing (mm)	Asphalt	
					Ungrooved	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

3.62 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:

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

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

Example from a 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:

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

3.63 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 runway, it is usual to aim for a macrotexture of more than 1.0 mm during construction.

3.64 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 at airports that use the larger grooves.

3.65 Grooving has its limits. It will not totally cope 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.