STATE OF KUWAIT

AVIATION SAFETY DEPARTMENT

Guidance material

Pavement Surface Conditions

PSC

Issue-1,Rev 0

April 2017

الإدارة العامة للطيران المدني
Directorate General of Civil Aviation

<u>List of Amendments</u>

S/No.	Issue No.	Rev. No.	Amended by	Signature	Date
1)	1	0	Engr. Shaheen M Al-Ghanim Aviation Safety Director		April 2017

LIST OF EFFECTIVE PAGES

Number	Effective Date	Entered Date	Entered by

Forward

The Aviation Safety Department guidance material is published to keep pace with the guidelines prescribed by ICAO documents and publications. The objective of this guidance material is to assist Kuwait International Airport's staff towards safety and fulfil the obligations to comply with the published KCASRs.

STATE OF KUWAIT Directorate General of Civil Aviation		Aviation Safety Department AEERODROME CERTIFICATION & SECURITY DIVISION

Ref.: MEMO / ACS / 27/ 2017	**INTERNAL MEMO**	**20/04/2017**			
Recipient	**Aviation Safety Director**				
CC.	DIR ☒	SUPDT-I ☒	OPS ☐	AW ☐	LIC ☐	ACS ☐
	SUPDT-R ☐		TDF ☐	S&R ☐	Other☐:	
Attachment	Application☐ Document☐ Other ☐:				
Subject	**Aerodrome Guidelines Materials**				

Dear Sir,
With reference to the above mentioned subject, please find enclosed herewith the below mentioned Guidance Materials which is self-explanatory.

1)Aerodrome Certification Procedures (Issue-1,Rev 0,April 2017
2)Airport Emergency Planning (Issue-1,Rev 0,April 2017)
3)Apron Management Services (Issue-1,Rev 0,April 2017)
4)Calculation of declared distances (Issue-1,Rev-0,April 2017)
5)Pavement Surface Condition(Issue-1,Rev-0,April 2017)
6)Prevention of Runway Incursion(Issue-1,Rev-0,April 2017)
7)Rescue Fire Fighting (Issue-1,Rev-0,April 2017)
8)Safety Management System(Issue-1,Rev-0,April 2017)
9)Surface of Movement Guidance & Control System (Issue-1,Rev 0,April 2017)
10)Visual Aids (Issue-1,Rev-0,April 2017)
11)Wildlife Reduction & Control (Issue-1,Rev-0,April 2017)

This is for your approval and necessary action.

Thanking you.

Approved

Engr. Shaheen M. Al-Ghanim
Aviation Safety Director

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Chapter 1

General

Note.— The terms contaminant *and* debris *are used in this manual with the following meanings. A contaminant is considered to be a deposit (such as snow, slush, ice, standing water, mud, dust, sand, oil, and rubber) on an airport pavement, the effect of which is detrimental to the friction characteristics of the pavement surface. Debris is fragments of loose material (such as sand, stone, paper, wood, metal and fragments of pavements) that are detri- mental to aeroplane structures or engines or that might impair the operation of aeroplane systems if they strike the structure or are ingested into engines. Damage caused by debris is also known as FOD (foreign object damage).*

1.1 INTRODUCTION

1.1.1 There is general concern over the adequacy of the available friction between the aeroplane tires and the runway surface under certain operating conditions, such as when there is snow, slush, ice or water on the runway and, particularly, when aeroplane take-off or landing speeds are high. This concern is more acute for jet transport aero- planes since the stopping performance of these aeroplanes is, to a greater degree, dependent on the available friction between the aeroplane tires and the runway surface, their landing and take-off speeds are high, and in some cases the runway length required for landing or take-off tends to be critical in relation to the runway length available. In addition, aeroplane directional control may become impaired in the presence of cross-wind under such operating conditions.

1.1.2 A measure of the seriousness of the situation is indicated by the action of national airworthiness authorities in recommending that the landing distance requirement on a wet runway be greater than that on the same runway when it is dry. Further problems associated with the take-off of jet aeroplanes from slush- or water-covered runways include performance deterioration due to the contaminant drag effect, as well as the airframe damage and engine ingestion problem. Information on ways of dealing with the problem of taking off from slush- or water-covered run- ways.

1.1.3 Further, it is essential that adequate infor- mation on the runway surface friction characteristics/aero- plane braking performance be available to the pilot and operations personnel in order to allow them to adjust operating technique and apply performance corrections. If the runway is contaminated with snow or ice, the condition of the runway should be assessed, the friction coefficient measured and the results provided to the pilot. If the runway is contaminated with water and the runway becomes slippery when wet, the pilot should be made aware of the potentially hazardous conditions.

1.1.4 Before giving detailed consideration to the need for, and methods of, assessing runway surface friction, or to the drag effect due to the presence of meteorological con- taminants such as snow, slush, ice or water, it cannot be overemphasized that the goal of the aerodrome operator should be the removal of all contaminants as rapidly and com- pletely as possible and elimination of any other conditions on the runway surface that would adversely affect aero- plane performance.

1.2 IMPORTANCE OF RUNWAY SURFACE FRICTION CHARACTERISTICS/AEROPLANE BRAKING PERFORMANCE

1.2.1 Evidence from aeroplane overrun and run-off incidents and accidents indicates that in many cases inad- equate runway friction characteristics/aeroplane braking performance was the primary cause or at least a contribu- tory factor. Aside from this safety-related aspect, the regularity and efficiency of aeroplane operations can become significantly impaired as a result of poor friction characteristics. It is essential that the surface of a paved runway be so constructed as to provide good friction characteristics when the runway is wet. To this end, it is desirable that the average surface texture depth of a new surface be not less than 1.0 mm. This normally requires some form of special surface treatment.

1.2.2 Adequate runway friction characteristics are needed for three distinct purposes:

a) deceleration of the aeroplane after landing or a rejected take-off;

b) maintaining directional control during the ground roll on take-off or landing, in particular in the presence of cross-wind, asymmetric engine power or technical malfunctions; and

c) wheel spin-up at touchdown.

1.2.3 With respect to either aeroplane braking or directional control capability, it is to be noted that an aero-plane, even though operating on the ground, is still subject to considerable aerodynamic or other forces which can affect aeroplane braking performance or create moments about the yaw axis. Such moments can also be induced by asymmetric engine power (e.g. engine failure on take-off), asymmetric wheel brake application or by cross-wind. The result may critically affect directional stability. In each case, runway surface friction plays a vital role in counter- acting these forces or moments. In the case of directional control, all aeroplanes are subject to specific limits regarding acceptable cross-wind components. These limits decrease as the runway surface friction decreases.

1.2.4 Reduced runway surface friction has a different significance for the landing case compared with the rejected take-off case because of different operating criteria.

1.2.5 On landing, runway surface friction is particu-larly significant at touchdown for the spin-up of the wheels to full rotational speed. This is a most important provision for optimum operation of the electronically and mechan-ically controlled anti-skid braking systems (installed in most current aeroplanes) and for obtaining the best possible steering capability. Moreover, the armed autospoilers which destroy residual lift and increase aerodynamic drag, as well as the armed autobrake systems, are only triggered when proper wheel spin-up has been obtained. It is not unusual in actual operations for spin-up to be delayed as a result of inadequate runway surface friction caused generally by excessive rubber deposits. In extreme cases, individual wheels may fail to spin up at all, thereby cre- ating a potentially dangerous situation and possibly leading to tire failure.

1.2.6 Generally, aeroplane certification performance and operating requirements are based upon the friction characteristics provided by a clean, dry runway surface, that is, when maximum aeroplane braking is achievable for that surface. A further increment to the landing distance is usually required for the wet runway case.

1.2.7 To compensate for the reduced stopping capa-bility under adverse runway conditions (such as wet or slippery conditions), performance corrections are applied in the form of either increases in the runway length required or a reduction in allowable take-off mass or landing mass. To compensate for reduced directional control, the allow- able cross-wind component is reduced.

1.2.8 To alleviate potential problems caused by inadequate runway surface friction, there exist basically two possible approaches:

a) provision of reliable aeroplane performance data for take-off and landing related to available runway surface friction/aeroplane braking performance; and

b) provision of adequate runway surface friction at all times and under all environmental conditions.

1.2.9 The first concept, which would only improve safety but not efficiency and regularity, has proved difficult mainly because of:

a) the problem of determining runway friction character-istics in operationally meaningful terms; and

b) the problem of correlation between friction-measuring devices used on the ground and aeroplane braking per-formance. This applies in particular to the wet runway case.

1.2.10 The second is an ideal approach and addresses specifically the wet runway. It consists essentially of speci-fying the minimum levels of friction characteristics for pavement design and maintenance. There is evidence that runways which have been constructed according to appro-priate standards and which are adequately maintained pro-vide optimum operational conditions and meet this objective. Accordingly, efforts should be concentrated on developing and implementing appropriate standards for runway design and maintenance.

1.3 NEED FOR ASSESSMENT OF RUNWAY SURFACE CONDITIONS

1.3.1 Runway surface friction/speed characteristics need to be determined under the following circumstances:

a) the dry runway case, where only infrequent measurements may be needed in order to assess surface texture, wear and restoration requirements;

b) the wet runway case, where only periodical measurements of the runway surface friction characteristics are required to determine that they are above a maintenance planning level and/or minimum acceptable level. In this context, it is to be noted that serious reduction of friction coefficient in terms of viscous aquaplaning can result from contamination of the runway, when wet, by rubber deposits;

c) the presence of a significant depth of water on the runway, in which case the need for determination of the aquaplaning tendency must be recognized;

d) the slippery runway under unusual conditions, where additional measurements should be made when such conditions occur;

e) the snow-, slush-, or ice-covered runway on which there is a requirement for current and adequate assessment of the friction conditions of the runway surface; and

f) the presence and extent along the runway of a significant depth of slush or wet snow (and even dry snow), in which case the need to allow for contaminant drag must be recognized.

Note.— Assessment of surface conditions may be needed if snowbanks near the runway or taxiway are of such a height as to be a hazard to the aeroplanes the airport is intended to serve. Runways should also be evaluated when first constructed or after resurfacing to determine the wet runway surface friction characteristics.

1.3.2 The above situations may require the following approaches on the part of the aerodrome operator:

a) for dry and wet runway conditions, corrective maintenance action should be considered whenever the runway surface friction characteristics are below a maintenance planning level. If the runway surface friction characteristics are below a minimum acceptable friction level, corrective maintenance action must be taken, and in addition, information on the potential slipperiness of the runway when wet should be made available (see Appendix 5 for an example of a runway friction assessment programme);

b) for snow- and ice-covered runways, the approach may vary depending upon the airport traffic, frequency of impaired friction conditions and the availability of cleaning and measuring equipment. For instance:

1) at a very busy airport or at an airport that frequently experiences the conditions of impaired friction — adequate runway cleaning equipment and friction-measuring devices to check the results;

2) at a fairly busy airport that infrequently experiences the conditions of impaired friction but where operations must continue despite inadequate runway cleaning equipment — measurement of runway friction, assessment of slush contaminant drag potential, and position and height of significant snowbanks; and

3) at an airport where operations can be suspended under unfavourable runway conditions but where a warning of the onset of such conditions is required — measurement of runway friction, assessment of slush contaminant drag potential, and position and height of significant snowbanks.

1.4 CONTAMINANT DRAG

1.4.1 There is a requirement to report the presence of snow, slush, ice, or water on a runway, as well as to make an assessment of the depth and location of snow, slush or water. Reports of assessment of contaminant depth on a runway will be interpreted differently by the operator for the take-off as compared with the landing. For take-off, operators will have to take into account the contaminant drag effect and, if applicable, aquaplaning on take-off and accelerate-stop distance requirements based on information which has been made available to them. With regard to landing, the principal hazard results from loss of friction due to aquaplaning or compacted snow or ice, while the drag effects of the contaminant would assist aeroplane deceleration.

1.4.2 However, apart from any adverse effects from contaminant drag which may occur on take-off or loss of braking efficiency on landing, slush and water thrown up by aeroplane wheels can cause engine flame-out and can also inflict significant damage on airframes and engines. This is further reason to remove precipitants from the runway rather than, for instance, devoting special efforts towards improving the accuracy of measurement and reporting the runway friction characteristics on a contami- nated runway.

1.5 EXPLANATION OF TERMS

1.5.1 It is not possible to discuss methods of measuring friction and assessing contaminant depth without first considering some of the basic phenomena which occur both under and around a rolling tire. For the sake of simplicity, these can, however, be given in a qualitative manner.

Percentage slip

1.5.2 Brakes in the older aeroplane models were not equipped with an anti-skid system; i.e. the harder the pilot applied the brakes, the more braking torque developed. In applying the brake pressure, the wheel slowed down and, provided there was sufficient braking torque, could be locked. Assuming an aeroplane speed of 185 km/h (100 kt) and the speed of the tire at its point of contact with the ground 148 km/h (80 kt), the tire would slip over the ground at a speed of 37 km/h (20 kt). This is termed 20 per cent slip. Similarly, at 100 per cent slip, the wheel is locked. The importance of this term lies in the fact that as the percentage slip varies, so does the amount of friction force produced by the wheel, as shown in diagrammatic form in Figure 1-1 for a wet runway. Therefore the maxi- mum friction force occurs between 10 to 20 per cent slip, a fact which modern braking systems make use of to increase braking efficiency. This is achieved by permitting the wheels to slip within these percentages.

1.5.3 The importance of this curve from the viewpoint of runway friction coefficient measurement is that the value at the peak of the curve (termed μ maximum) can, when plotted against speed, represent a characteristic of the runway surface, its contamination, or the friction-measuring device carrying out the measurement and is, therefore, a standard reproducible value. This type of device can thus be used to measure the runway friction coefficient. On snow- or ice-covered runways, the measured value can be given in a meaningful form to a pilot. On wet runways, the measured value can be used as an assessment of the friction characteristics of the runway when wet.

Locked wheel

1.5.4 The term "locked wheel" is exactly as implied and the friction coefficient μ skid produced in this condition is that at 100 per cent slip in Figure 1-1. It will be noted that this value is less than the μ max attained at the optimum slip. Tests have shown that for an aeroplane tire, μ skid varies between 40 and 90 per cent of μ max, subject to runway conditions. Even so, vehicles using a locked wheel mode have also been used to measure the runway friction coefficient. In this case, the measured value would be indicative for the wheel spin-up potential at touchdown.

Side friction coefficient

1.5.5 When a rolling wheel is yawed, such as when a vehicle changes direction, the force on the wheel can be resolved in two directions — one in the plane of the wheel and the other along its axle. The side friction coefficient is the ratio of the force along the axle divided by the vertical load. If this ratio is plotted against the angle of yaw on different surfaces, a relationship similar to Figure 1-2 is established.

1.5.6 When the wheel is yawed at an angle greater than 20 degrees, the side friction coefficient cannot be used to give a number representing the runway friction coefficient. Allowing for certain other considerations, the wheel can in effect be made to work at μ max. Depending on tire pressure, stiffness (construction) and speed, the relationship between side force and yaw angle will vary.

"Normal" wet friction and aquaplaning

1.5.7 When considering a wet or water-covered runway, there are certain separate but related aspects of the braking problem. Firstly, "normal" wet friction is the condition where, due to the presence of water on a runway, the available friction coefficient is reduced below that available on the runway when it is dry. This is because water cannot be completely squeezed out from between the tire and the runway, and as a result, there is only partial contact with the runway by the tire. There is consequently a marked reduction in the force opposing relative motion of tire and runway because the remainder of the contacts are between tire and water. To obtain a high coefficient of friction on a wet or water-covered runway, it is, therefore, necessary for the intervening water film to be displaced or broken through during the time each element of the tire is in contact with the runway. As the speed rises, the time of contact is reduced and there is less time for the process to be completed; thus, friction coefficients on wet surfaces tend to fall as the speed is raised, i.e. the conditions, in effect, become more slippery. Secondly, one of the factors of most concern in these conditions is the aquaplaning phenomenon whereby the tires of the aeroplane are to a large extent separated from the runway surface by a thin fluid film. Under these conditions, the friction coefficient becomes almost negligible, and wheel braking and wheel steering are virtually ineffective. A description of the three principal types of aquaplaning known to occur is given below. Further guidance on water depth and its influence on aquaplaning is contained in 2.1.

1.5.8 The typical reduction of friction when a surface is wet and the reduction of friction as aeroplane speed

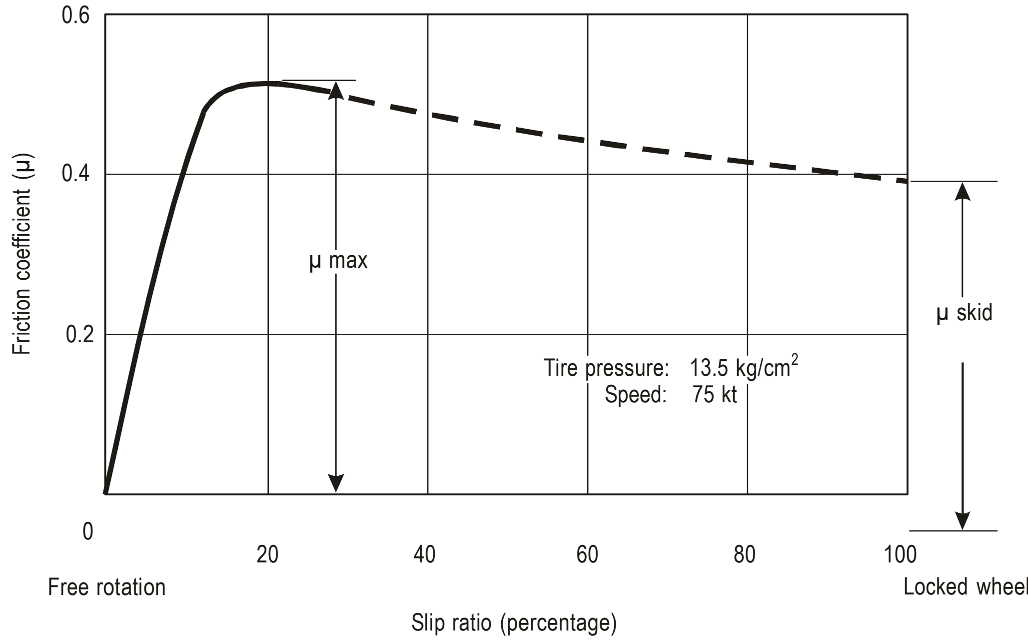

Figure 1-1. Relation between percentage slip and friction coefficient on a wet runway

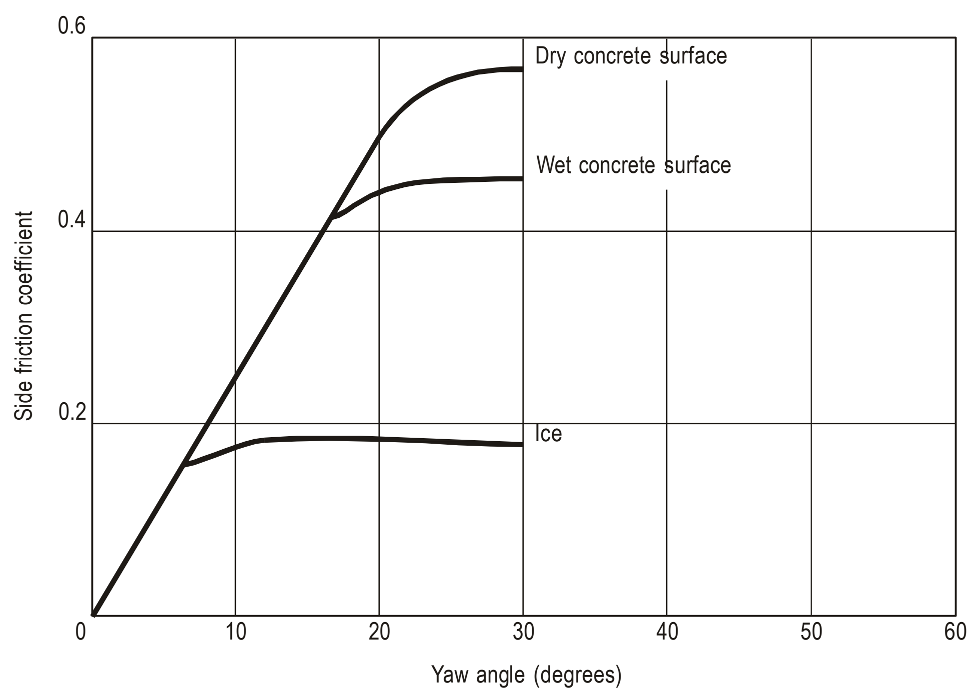

Figure 1-2. Typical variation of side friction coefficient with yaw angle

increases are explained by the combined effect of viscous/dynamic water pressures to which the tire/surface is subjected. This pressure causes partial loss of “dry” contact, the extent of which tends to increase with speed. There are conditions where the loss is practically total and the friction drops to negligible values. This is identified as either viscous, dynamic or reverted rubber aquaplaning. The manner in which these phenomena affect different areas of the tire/surface interface and how they change in size with speed is illustrated in Figure 1-3, which is based on the three zone concept suggested by Gough. In Zone 1 where there is dynamic pressure and in Zone 2 where there is viscous pressure, friction is virtually zero, whereas one can assume dry friction in Zone 3. Zone 3 will gradually decrease in size as speed increases and the friction coefficient μ will be reduced in proportion to the reduction in the size of Zone 3. It can be assumed that the proportion between the zones will be the same if two wheels are running at the same fraction of their aquaplaning speed.

1.5.9 In the case of viscous aquaplaning, loss of traction can occur at relatively low speeds due to the effect of viscosity in preventing water from escaping from under the tire footprint. However, a very smooth runway surface is required; such a surface can be encountered in areas that have become heavily coated with rubber deposited by tires during wheel spin-up at touchdown or that have been subjected to polishing by traffic. Viscous aquaplaning is associated with damp/wet runways or on wet ice-covered runways and, once begun, can persist down to very low speeds. Viscous aquaplaning can occur during the braking portion of either a rejected take-off or a landing ground roll.

1.5.10 Dynamic aquaplaning will occur beyond a critical speed which is a function of tire pressure. The condition is a result of an inertial effect of the water in which the downward pressure (inflation pressure) of the tire is insufficient to displace the water away from the footprint in the short time of contact. Dynamic aquaplaning can occur on a runway with inadequate macrotexture at speeds beyond the critical aquaplaning speed provided the fluid is deep enough. It is associated with a coverage of fluid of measurable depth on the runway and occurs at a critical velocity which is a direct function of the tire pressure. The higher the tire pressure, the higher the velocity at which (dynamic) aquaplaning will occur. However, the trade-off will be that with increasing tire pressure, the achievable wet friction will generally decrease in the speed range up to aquaplaning. Dynamic aquaplaning is experienced during the higher speeds of landing and take-off ground roll. As little as 0.5 mm of standing water has been found to be sufficient to support dynamic aquaplaning. This relatively small depth can occur in heavy rain showers or can result from water pools due to surface irregularities.

1.5.11 There is still much to be learned regarding rubber reversion, but present thinking indicates that super-heated steam is generated between the tire footprint and the runway surface at a temperature of approximately 200°C, which results in the melting of the affected area of the tire tread. One theory is that the melted rubber acts as a seal preventing escape of high-pressure steam. Following incidents when rubber reversion is known to have occurred, white marks have been observed on the runway surface characteristic of the “steam cleaning” action. Reverted rubber aquaplaning can develop in any situation and at any speed where a tire is non-rotating (braked or unbraked) for a prolonged period of time. Accordingly, avoidance of wheel lock-up appears to be the important preventative measure in this case. Additional material on the viscous/dy- namic aquaplaning theory is contained in Appendix 1.

Coefficient of friction

1.5.12 The coefficient of friction is defined as the ratio of the tangential force needed to maintain uniform relative motion between two contacting surfaces (aeroplane tires to the pavement surface) to the perpendicular force holding them in contact (distributed aeroplane weight to the aeroplane tire area). The coefficient of friction is often denoted by the Greek letter μ. It is a simple means used to quantify the relative slipperiness of pavement surfaces.

Braking system efficiency

1.5.13 Modern anti-skid braking systems are designed to operate as near to the peak friction value (μ max) as possible. Aeroplane brake system efficiency, however, usually provides only a percentage of this peak value. The efficiency tends to increase with speed; tests on an older type of system on a wet surface gave values of 70 per cent at 56 km/h (30 kt), rising to nearly 80 per cent at 222 km/h (120 kt). Even higher values have been claimed for the more modern systems. For anti-skid systems in use on many transport aeroplanes, the effective braking coef- ficient, μ eff, has been empirically established as:

$\mu\ eff = 0.2\ \mu\ max + 0.7\ \mu\ max^2$ for μ max less than 0.7 and $\mu\ eff = 0.7\ \mu\ max$ for $\mu\ max = 0.7$ or greater

Rolling resistance

1.5.14 Rolling resistance is the drag caused by the elastic deformation of the tire and a supporting surface. For a conventional, bias-ply, aeroplane tire, it is approximately 0.02 times the vertical load on the tire. For the tire to rotate, the coefficient of rolling friction must be less than the friction coefficient between the tire and the runway.

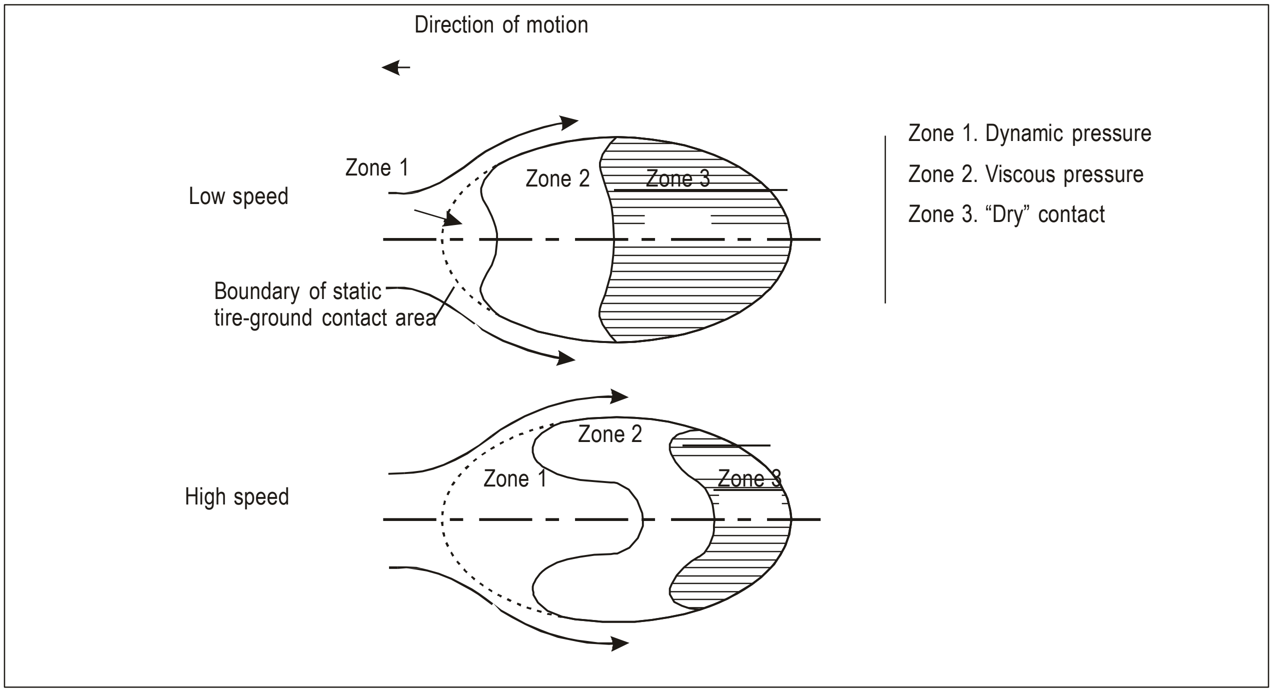

Figure 1-3. Areas of tire/surface interface

Friction/speed curves

1.5.15 Water is one of the best lubricants for rubber, and displacement of water and penetration of thin water films in the tire contact area take time. There are a number of runway surface parameters that affect the drainage capability in the tire contact area. If a runway has a good macrotexture allowing the water to escape beneath the tire, then the friction value will be less affected by speed. Conversely, a low macrotexture surface will produce a larger drop in friction with increase in speed. Another parameter is the sharpness of the texture (microtexture), which determines basically the friction level of a surface, as illustrated in Figure 1-4.

1.5.16 As speed increases, the friction coefficients of the two open-textured surfaces A and D drop slightly, whereas the friction coefficients for surfaces B and C drop more appreciably. This suggests that the slope of the friction/speed curve is primarily affected by the macrotexture provided. The magnitude of the friction coefficient is predominantly affected by the roughness of the asperities, A and B having a sharp microtexture, C and D being smooth. From the friction point of view, therefore, runway surfaces should always provide the combination of sharp and open textures. A friction/speed curve is, therefore, indicative of the effect of speed on the wet surface friction coefficient, particularly if it includes higher velocities, i.e. approximately 130 km/h (70 kt) and over.

Surface texture

1.5.17 The surface texture between the tire and the runway depends on a number of factors, such as speed, surface texture, type of runway contamination, depth of contamination, tire rubber compound, tire structure, tire tread pattern, tread surface temperature, tire wear, tire pressure, braking system efficiency, brake torque, wheel slip ratio and season of the year. Some of these factors have effects on each other, and their individual effect on the magnitude of the friction coefficient varies in significance. The parameter, however, that determines most signifi- cantly the magnitude of achievable wet friction and the friction/speed relationship is runway surface micro/macro- texture. Additional information on the influence of surface micro/macrotexture characteristics on tire friction performance is given in Appendix 2.

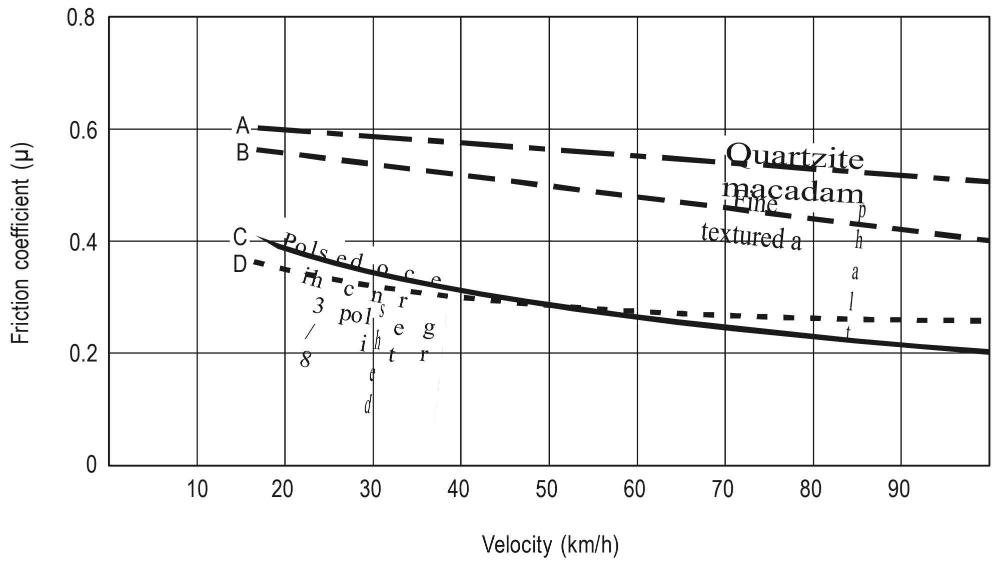

Figure 1-4. Relationship between braking friction coefficient achieved with anti-skid braking on different textured surfaces at certain operating conditions

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Chapter 2

Assessment of Basic Factors Affecting Friction

2.1 WATER DEPTH AND ITS INFLUENCE ON DYNAMIC AQUAPLANING

2.1.1 The critical speed at which aquaplaning occurs (see 1.5.7 to 1.5.11) depends on how it is defined, as illustrated in Figure 2-1. If aquaplaning speed is defined as the point at which the fluid drag versus speed curve reaches its maximum, this will not agree with the speed at which the wheel ceases to revolve. The pilot has little interest in the former, but he does wish to know when there is insufficient grip between the tire and ground to cause the wheel to spin up, that is, to overcome rolling resistance, since he cannot apply effective braking from that point. It is probable that there is still some contact with the ground at this speed but not sufficient to cause the wheel to revolve. When no part of the tire is in contact with the ground, this speed probably approximates more closely the point at which the fluid drag stops increasing (i.e. at the peak of the solid line in Figure 2-1).

2.1.2 Dynamic aquaplaning will start at a velocity in kilometres per hour (or in knots) that is approximately equal to 624 times (356 times) the square root of the tire pressure in kPa. The process is not entirely understood. It was encountered unexpectedly during friction trials with an instrumented aeroplane when a friction coefficient value of $\mu = 0.05$ was measured with the brakes on. The record of wheel speed showed there was insufficient rolling drag to spin up the wheel each time the automatic brake slowed it down.

2.1.3 Another important point is that, once having aquaplaned, the ground speed must be reduced well below the aquaplaning speed before the wheel will spin up again. This phenomenon is shown clearly in tests with a 23 cm wheel conducted by the University of Bristol as shown in Figure 2-2.

2.1.4 It will be noticed that, at a pressure of 206.8 kPa and a load of 90 kg, the tire aquaplanes at approximately 23 m/s but does not regain ground speed until the velocity is reduced to 9 m/s. A change in the load on the tire also changes its aquaplaning speed if this is assumed to be the velocity at which the wheel spins down. The practical aspect demonstrated by this experiment is that an aeroplane tire will not regain contact with the ground sufficiently to give any effective braking until a speed well below that required to initiate aquaplaning is reached.

2.1.5 It is clear that dynamic and viscous aquaplaning will only occur if there is a sufficient depth of water on the runway to preclude it from being cleared from the tire contact area sufficiently quickly to permit some dry contact. This then becomes a matter of drainage and is mainly a question of runway micro/macrotexture, while the tire tread pattern will contribute comparatively little to tire footprint drainage. A suitably grooved tire will provide additional drainage channels that will, however, decrease in effectiveness as the grooves wear to their permitted limits. It is now generally accepted that the risk of aquaplaning can be greatly minimized by the provision of an adequate micro/macrotexture of the runway surface. This aspect is dealt with in the *Aerodrome Design Manual* (Doc 9157), Part 3 — *Pavements*.

2.1.6 In order to determine how the water depth required to sustain aquaplaning varies with surface texture, the United Kingdom College of Aeronautics conducted tests for their aquaplaning characteristics on brushed (not wire-combed) concrete and on scored concrete surfaces. By building ponds on each surface in the intended wheel track and with a measuring device set into the runway, it has been possible to determine the height of an aquaplaning tire above the runway. Figure 2-3 was produced by plotting the depth of water above the marker against the height of the tire above the runway.

2.1.7 It is seen that, once having aquaplaned (which might occur in a puddle), the tire will not regain contact with the runway in more than 0.6 mm of water if the surface is brushed concrete and the tire pressure 827 kPa. The higher the tire pressure, the greater the depth of water required to sustain aquaplaning. Also, the coarser the surface macrotexture, the greater the water depth required.

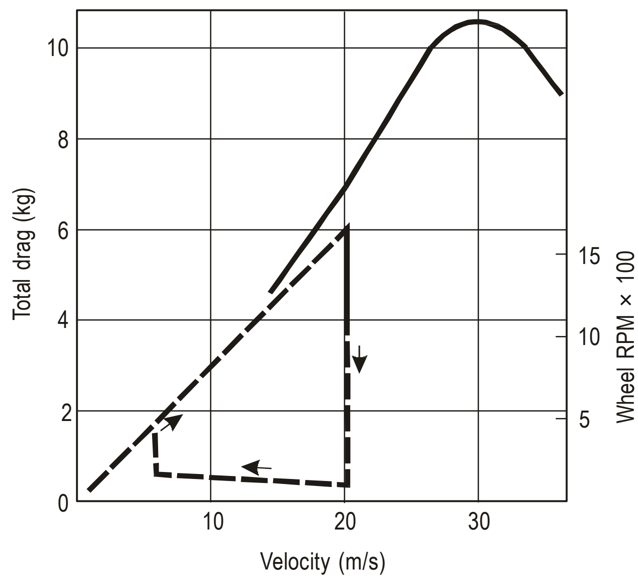


Figure 2-1. Variation of total drag of a small tire with wheel RPM and speed

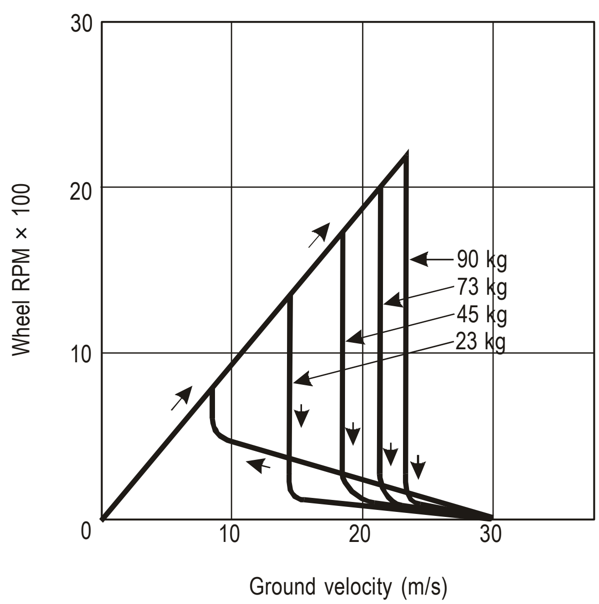


Figure 2-2. Variation of wheel rotation with ground speed and load

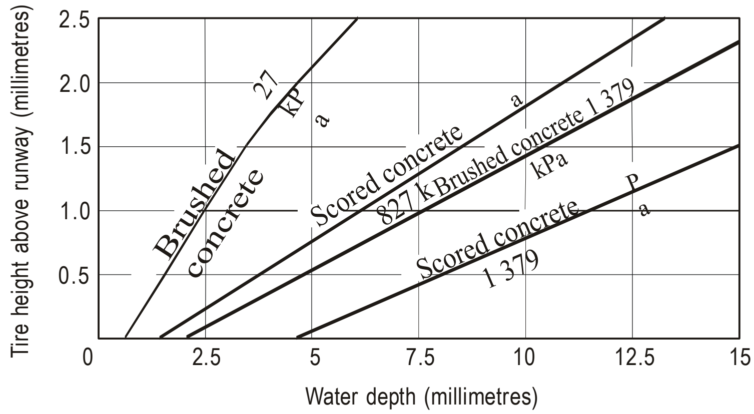


Figure 2-3. Height of a tire above a runway in different water depths, surface textures and tire pressures at above aquaplaning speed

These trials also revealed that aquaplaning can start in milliseconds once the critical water depth is encountered. The provision of good surface drainage and suitable texture are the essential requirements to minimize the risk of aquaplaning and to enhance generally the wet friction characteristics.

2.1.8 Since the initial water depth varies with surface texture, it is vital to translate the information into practical terms. Some method or device must be used to define texture, which, in itself, presents a difficult problem because the size, shape and angularity of the aggregate are all significant. Information on the various methods and measuring techniques in use is contained in 2.3.

2.1.9 It is apparent that few States, if any, are at present providing information on runway water depth, although in some States using preferential runway systems, the practice is to change the landing runway under wet conditions to a longer one and/or one having less cross- wind.

2.1.10 There has been some speculation on whether measuring water depth could perhaps replace measuring runway friction. To this end, a study was undertaken to ascertain the list of requirements to be met by water depth measuring devices. The study showed that the devices should, *inter alia*, be accurate, easy to use, quick to operate and capable of measuring the depth of a layer of water to a value of up to 10 mm. Further, the runway occupancy time must be minimal and the readings should not be affected by the concentration of salt on the surface of the water layer. None of the devices known to be used by States appear to meet these requirements, although at least one of them is considered to fulfil the requirements for research work purposes. Although possible, it would not be practical to develop a device that could meet all of the above require- ments; it is preferable to develop programmes aimed at improving the surface texture and drainage of runways rather than measuring the water depth. The devices could only be of some significance in rare cases of extremely heavy rain. Even assuming that a device meeting the specified requirements is developed, another big difficulty appears to be the number and location of devices needed for a runway. In light of the above, it has been concluded that standardization of water depth measuring devices with the object of measuring runway friction is not practical.

2.1.11 *Other considerations.* The depth of fluid is, of course, only one consideration. The density and viscosity existing within any given depth are most important. For any given measurable depth, consideration of fluid density, fluid viscosity, runway texture, tire tread design/wear and runway contamination is required before any operational application can be assessed.

2.2 SURFACE CONTAMINANTS

2.2.1 The presence of fluid state contaminants (wet snow, slush or standing water) on runways can have an extreme effect upon the operation of aeroplanes. Variations in the nature of the contaminant and the critical effect of its depth have created difficulties in satisfactorily evaluating the resulting precipitant drag effect. Operational measures for dealing with the problem of take-off from slush- or water-covered runways are contained in the *Airworthiness Manual* (Doc 9760).

2.2.2 During operation on runways with measurable depths of fluids, in addition to the presence of critically low levels of friction and the adverse effects of aquaplaning, there exists the retardation effect referred to as "precipitant drag". More specifically, precipitant drag can be broken down to include:

a) fluid displacement drag;

b) wheel spin-down characteristics; and

c) wheel spray patterns and fluid spray (impingement) drag. Based on actual aeroplane testing and ground-run tests, the levels of precipitant drag attained are a direct function of the following variables and their applied combination, namely, square of ground speed, vertical load, tire pressure, fluid density, fluid depth and wheel location.

2.2.3 When an unbraked tire rolls on a fluid-covered runway, the moving tire contacts and displaces the stationary runway fluid. The resulting change in momen-tum of the fluid creates hydrodynamic pressures that react on the tire and the runway surfaces. The horizontal component of the resulting hydrodynamic pressure force is termed "fluid displacement drag" or a retarding force to forward movement. The vertical component of this reaction is termed "fluid displacement lift" or the reacting force introducing potential dynamic aquaplaning and wheel spin-down tendencies. Additional fluid forces reacting to forward movements are "fluid spray drag" and "fluid spray lift" created on the aeroplane when some of the displaced runway fluid in the form of spray subsequently impinges on other parts of the aeroplane, such as the tires, landing gear, high lift/drag devices and rear-mounted engines.

2.2.4 Fluid displacement drag is primarily critical for the acceleration characteristics of the aeroplane on take-off. The effects of fluid displacement drag are also experienced during deceleration; however, the advantages of the retardation during deceleration are largely offset by the general reduction of the friction coefficient and the possible occurrence of aquaplaning.

2.2.5 The problem of precipitant drag due to surface contaminants is related to take-off. Bearing in mind that precipitant drag increases with the square of speed, a critical speed can be reached at which the precipitant drag is equal to the thrust. If the aeroplane is then below lift-off velocity, it will never leave the ground. In addition to speed, the precipitant drag will vary with the depth of the contamination and with its density. Since both, particularly the former, can vary throughout the runway length, the complexity of the problem can well be appreciated. Furthermore, the fact that precipitant drag on an aeroplane consists of two primary components, i.e., the displacement of the contamination by the wheels and the material thrown up by the wheels hitting the aeroplane, means that the total precipitant drag will vary with different types of aero- planes.

2.2.6 One method to measure the depth of the fluid is to take a large number of readings with a ruler or other device and calculate the average. This would be satisfactory if the depth were relatively uniform, but in practice, that is rarely the case.

2.2.7 The pilot will know the maximum depth of a specific fluid contaminant in which he is allowed to take off and will need reports on the state of the runway in terms of each third of the runway, of which the second or last third will have the most significance.

2.3 SURFACE TEXTURE

2.3.1 Surface texture is considered to be the main clue to differences in the braking friction coefficient of a wet runway. Runway surfaces contain both macrotextures and microtextures. Macrotexture is the coarse texture evidenced by the aggregate or by artificially applied texture such as grooving. Macrotexture can be measured by a number of methods and is primarily responsible for bulk water drainage from the surface. Microtexture, on the other hand, is the texture of individual pieces of aggregate that can be felt but cannot be directly measured. Microtexture is important in penetrating very thin water films. Thus, macro- texture is primarily used to increase bulk water drainage, thereby reducing the tendency for aeroplane tires to experi- ence dynamic aquaplaning, while microtexture is most important in reducing the onset of viscous aquaplaning that is associated with very thin water films. Since macrotextures and microtextures both have significant effects on wet friction coefficients, it can be reasoned that only general trends can be established using measurements of macro- texture only. Available data do show a general trend in favour of large macrotextures to increase wet friction coefficients.

2.3.2 KCASR 14 , recommends that the average surface macrotexture depth of a new surface be not less than 1 mm to provide good friction characteristics when the runway is wet. Although a depth of less than 1 mm may still provide good drainage, when constructing a new surface, a depth greater than the minimum value must be chosen as normal pavement use will result in surface deterioration. If some surface texture depth additional to the minimum is not provided when constructing a pavement surface, then maintenance action will soon be required.

2.3.3 It is logical, therefore, to apply a technique that will qualify the gradient of the friction/speed curve of a surface by measurement of surface macrotexture. To obtain an average macrotexture depth, representative samples should be taken over the entire surface. The number of samples required will depend upon variations in the surface macrotexture. To this end, it is desirable, before surface texture measurements are made, to conduct a visual inspection of the surface to determine significant changes in pavement surfaces.

2.3.4 It is generally recognized that the most suitable techniques available for measuring the surface macrotexture depth are the grease and sand patch methods. A description of these two methods, as well as others that can be used for measuring average texture depth, is given below.

Sand and grease patch methods

2.3.5 A known volume of grease or of sand particles of known size is spread over the surface until all the cavities are filled. If the known volume is then divided by the area covered, the mean depth of the cavities can be found. Measurements of this type can be expected to indicate only the effect of speed on the friction/speed curve; this has been confirmed by practical experiment (see 1.5.15).

2.3.6 Examples of measurements by the grease and sand patch methods are given below.

Example 1 — GREASE PATCH METHOD

A. Apparatus required

1. A metal cylinder open at both ends with an internal volume of about 16 000 mm^3. The actual volume is not critical, provided it is accurately known. Suitable dimensions might be: internal diameter pipe, 25.4 mm; length, 32.3 mm.

2. Putty knife.

4. A rubber-faced aluminium or wooden squeegee, some 30-40 mm in width.

5. Masking tape.

3. A tight-fitting plunger and rod to expel the grease from the cylinder.

B. Test procedure

1. The test cylinder is first packed with any general purpose grease using the putty knife in such a way as to avoid entrapped air. The ends are squared off using the putty knife. Two parallel lines of masking tape are applied to the runway surface about 10 cm apart, and a third line of masking tape is placed at right angles to and at one end of the two parallel lines of tape. The grease is expelled from the cylinder by means of the plunger on to the test area and worked into the voids in the surface to the level of the peaks and in a rectangular shape between the parallel masking tapes. Care is to be taken that no grease is left on the masking tapes or squeegee.

2. Measure the volume of the test cylinder and the dimensions of the grease patch. The average surface depth of the voids in mm is calculated using the equation:

$$\text{Surface texture index} = \frac{\text{Volume of grease (mm}^3\text{)}}{\text{Area covered (mm}^2\text{)}}$$

After completion of the grease patch tests, the grease must be removed from the runway surface.

Example 2 — SAND PATCH METHOD

A. Apparatus required

1. A metal cylinder of 86 mm internal depth and 19 mm internal diameter.

2. A flat wooden disc, 64 mm in diameter, with a hard rubber disc, 1.5 mm thick, stuck to one face, the reverse face being provided with a handle.

3. Dry natural sand, with a rounded particle shape, which will pass through a 300-micron sieve and be retained on a 150-micron sieve.

B. Test procedure

1. Dry the surface to be measured and sweep clean with a soft brush. Fill the cylinder with sand, tapping the base three times on the surface to ensure compaction, and strike off the sand level with the top of the cylinder.

Pour the sand into a heap on the surface to be tested. Spread the sand over the surface, working the disc with its face kept flat, in a circular motion so that the sand is spread into a circular patch with the surface depressions filled with sand to the level of the peaks.

2. Measure the diameter of the patch to the nearest 5 mm. The texture depth is 31 000/D^2 where D is the diameter of the patch in mm.

2.3.7 The following methods are also used for measuring surface macrotexture:

a) *direct measurement on the pavement.* The real length of a line running over this surface is measured;

b) *stereophotographic method.* By means of a specially constructed stereo camera, a part of this area is photographed. From the resulting contour lines, a profile is drafted, the length of which is measured;

c) *the bar method.* A 0.30 m long row of little thin bars (needles) kept vertical by two holders is placed on the pavement. When the tightening of the clips is diminished, the points of all bars will touch the upper side of the pavement and show a profile line of the surface, the length of which can be measured;

d) *the "replica" print.* A print of the surface is made using hardening material (plasticine). After it has been sawn, the length of the replica profile is measured;

e) *the carbon print.* By means of carbon paper, a copy of the surface of a piece of the pavement is printed on scribbling paper. The length of a profile constructed therefrom is measured;

f) *the water-flow measurement.* Determination is made of a quantity of water flowing during a certain time from the bottom of a flat cylinder placed on the pavement (loss of height).

2.3.8 By means of such measurements, an approximate indication of the surface roughness may be obtained. From volume measurement, the area of the smoothed sand or grease gives such an indication. The quotient of the volume of the smoothed material and its area is called the mean depth of the texture. The quotient of the length of a line measured along the profile of a diagonal section through the pavement and the length of a basis line is called profile metalling. Inquiries are being made to ascertain whether there is a correlation between the profile ratio and the reduction of roughness, but conclusions regarding this correlation have not yet been made. It is already known that for rough surfaces this ratio is more than 1.05.

2.3.9 It is also important that the mineral aggregate used for pavement purposes be laboratory-tested for resistance to polishing before being used for the construction of runways. In addition, it should be examined in relation to stiffness against crumbling and splintering of the surface by the action of traffic. The subject of runway surface texture is given detailed consideration in the *Aerodrome Design Manual* (Doc 9157), Part 3 — *Pavements.*

Measurement of surface microtexture

2.3.10 There is no direct measure available as yet to define the required fine-scale roughness of the individual aggregates in engineering terms. However, the importance of providing good microtexture should be emphasized as inadequate microtexture will result in a reduction of the friction characteristics of the runway surface. Degradation of microtexture caused by the effect of traffic and weathering may occur within a comparatively short period as compared with that required for degradation of surface macrotexture.

2.4 UNEVENNESS

Although runway constructors go to considerable lengths to produce an even runway with a suitable transverse slope, subsequent consolidation of the runway structure may cause the profile to change and give rise to areas of "ponding". These areas are clearly visible after rain when the drained part of the runway has dried leaving the ponds behind. Remedial action is required when it is found that the ponds are greater than a mean critical aquaplaning onset depth (approximately 3 mm) since aquaplaning, once started, can be sustained on a wet runway by a much smaller depth of water. Further, ponds will, in temperatures below freezing level, form ice patches which can cause considerable difficulties to aeroplane operations. Also, ex- cessive standing water from "ponding" can be ingested by aeroplane engines resulting in flame-out. Remedial action will normally require resurfacing to effectively alleviate the problem caused by ponding.

Chapter 3

Determining and Expressing Friction Characteristics of Wet Paved Surfaces

3.1 GENERAL

3.1.1 There is an operational need for information on paved runways that may become slippery when wet. To this end, there is a need to measure periodically the friction characteristics of a paved runway surface to ensure that they do not fall below an agreed level. An indication of the friction characteristics of a wet paved runway can be obtained by friction-measuring devices; however, further experience is required to correlate the results obtained by such devices with aeroplane braking performance due to the many variables involved, such as runway temperature, tire inflation pressure, test speed, tire-operating mode (locked wheel, braked slip), anti-skid system efficiency, and measuring speed and water depth.

3.1.2 The measurement of the friction coefficient has been found to provide the best basis for determining surface friction conditions. The value of the surface friction coefficient should be the maximum value that occurs when a wheel is braked at a specified percentage of slip but is still rolling. Various methods may be used to measure the friction coefficient. Operational considerations will gener- ally determine the most suitable method to be used at a particular airport. As there is an operational need for uniformity in the method of assessing the runway friction characteristics, the measurement should preferably be made with devices that provide continuous measuring of the maximum friction (between 10 and 20 per cent slip) along the entire runway.

3.1.3 Present technology cannot provide a direct and immediate correlation of runway surface friction measurements, taken with a friction-measuring device, with aeroplane braking performance on wet runways. It has been found, however, that the wet runway friction characteristics of a surface remain relatively constant and deteriorate slowly over long periods of time, depending on frequency of use. This finding is important because it eliminates the need to continually measure the friction characteristics of a wet runway. Test results have shown that comparisons between measurements made by friction devices and the effective braking friction developed by aeroplanes under similar contaminated runway surface conditions do not correlate directly but can be related indirectly. By conducting many tests at several speeds on pavements that had various types of microtextural/macrotextural surfaces, it was also found that friction-measuring devices did provide the aerodrome operator with the capability to distinguish between runway surfaces that have good or poor surface friction characteristics. It is, therefore, concluded that instead of reporting, on an operational basis, the friction characteristics of a wet runway, the runway friction can be periodically measured to ensure that its friction characteristics are of an acceptable standard.

3.1.4 The periodic measurement serves two purposes. First, it identifies the sub-standard runways, the location of which should be made known to pilots. Second, it provides qualitative information to aerodrome operators on the condition of the runway surface, thus permitting the development of more objective maintenance programmes and justifying development of budgets.

3.1.5 Ideally, the distinction between good and poor runway surface friction characteristics when wet should be related to airworthiness criteria for the certification of aeroplanes. International agreement for certification of aeroplanes on wet runways, however, does not exist at this time. Nevertheless, a number of States have operational experience with particular friction-measuring devices that enable them to initiate programmes for identifying runways which have poor surface friction when wet. This experience can be used to advantage by other States to establish their own programmes. Though such programmes may be theoretically imprecise in their relationship to aeroplane performance, they are considered adequate to distinguish between good and poor runway surface friction characteristics.

3.1.6 The criteria used by DGCA for evaluating runway surfaces should be published in the Jordan aeronautical information publication (AIP). When a runway surface that does not meet the criteria is found, a NOTAM should be issued until such time as corrective action has been taken.

3.1.7 Furthermore, it is desirable to measure the friction/speed characteristics of a new or resurfaced runway in order to verify whether or not the design objective has been achieved. The measurements should be made with a friction-measuring device using self-wetting features at two or more different speeds. An average value at each test speed for the entire runway should be obtained when the runway is wet but clean. To this end, friction-measuring devices providing continuous measurements of runway friction characteristics are preferable to those providing only spot measurements, as the latter may give misleading information. This information is considered of operational value as it gives an overall indication of the available surface friction of the relatively long central portion of the runway that is not affected by rubber build-up.

3.2 MEASUREMENT

3.2.1 The reasons for the requirement to measure the friction characteristics of a wet paved runway are:

a) to verify the friction characteristics of new or resurfaced paved runways;

b) to assess the slipperiness of paved runways;

c) to determine the effect on friction when drainage characteristics are poor; and

d) to determine the friction of paved runways that become slippery under unusual conditions.

3.2.2 Runways should be evaluated when first constructed or after resurfacing to determine the wet runway surface friction characteristics. Although it is recognized that friction reduces with use, this value will represent the friction of the relatively long central portion of the runway that is uncontaminated by rubber deposits from aeroplane operations and is therefore of operational value. Evaluation tests should be made on clean surfaces. If it is not possible to clean a surface before testing, then for purposes of preparing an initial report, a test could be made on a portion of a clean surface in the central part of the runway.

3.2.3 The friction value should be obtained by averaging the results of measurements made with the test device. If the friction characteristics differ significantly along major portions of a runway, the friction value should be obtained for each portion of the runway. A portion of runway approximately 100 m long may be considered sufficient for the determination of the friction value.

3.2.4 Friction tests of existing surface conditions should be taken periodically in order to identify runways with low friction when wet. DGCA should define what minimum friction level it considers acceptable before a runway is classified as slippery when wet and should publish this value in the Jordan AIP. When the friction of a runway or a portion thereof is found to be below this reported value, then such information should be promul- gated by a NOTAM. DGCA should also establish a maintenance planning level, below which appropriate corrective maintenance should be considered to improve the friction. However, when the friction characteristics for either the entire runway or a portion thereof are below the minimum friction level, corrective maintenance action must be taken without delay. Friction measurements should be taken at intervals that will ensure identification of runways in need of maintenance or special surface treatment before the condition becomes serious. The time interval between measurements will depend on factors such as aeroplane type and frequency of usage, climatic conditions, pavement type, and pavement service and maintenance requirements.

3.2.5 For uniformity and to permit comparison with other runways, friction tests of existing, new or resurfaced runways should be made with a continuous friction-measuring device having a smooth tread tire. The device should have the capability of using self-wetting features to enable measurements of the friction characteristics of the surface to be made at a water depth of at least 1 mm.

3.2.6 When it is suspected that the friction characteristics of a runway may be reduced because of poor drainage due to inadequate slopes or depressions, then an additional test should be made under natural conditions representative of local rain. This test differs from the previous one in that water depths in the poorly drained areas are normally greater in a local rain condition. The friction tests are thus more apt to identify those problem areas which will most likely experience low friction values that could induce aquaplaning than the previous friction test that used the self-wetting feature. If circumstances do not permit friction tests to be conducted during natural conditions representative of rain, then this condition may be simulated.

3.2.7 Even when friction has been found to be above the level set by DGCA

to define a slippery runway, it may be known that under unusual conditions, the runway may have become slippery when wet. These conditions are known to occur at certain locations when the initial rainfall on a runway, following a prolonged dry spell, results in a very slippery condition that is unrepresentative of the overall wet friction characteristics of the runway. This situation is a temporary one which remedies itself as further rainfall washes the runway's surface. It is believed to be caused by the emulsification of dirt and other deposits which are precipitated onto the runway and which may originate from adjacent industrial complexes. A similar phenomenon has, however, been observed on runways located in desert or sandy areas, and also in humid tropical climates where microscopic fungoid growths are believed to be responsible. When such conditions are known to exist, then friction measurements should be made as soon as it is suspected that the runway may have become slippery and should be continued until the situation has corrected itself.

3.2.8 When the results of any of the measurements identified above indicate that only a particular portion of a runway surface is slippery, then it is important to promul- gate this information and take corrective action.

3.2.9 When conducting friction tests on wet runways, it is important to note that unlike compacted snow and ice conditions in which there is very limited variation of the friction coefficient with speed, a wet runway produces a drop in friction with an increase in speed. However, as the speed increases, the rate at which the friction is reduced becomes less. Among the factors affecting the friction coefficient between the tire and the runway surface, texture is particularly important. If the runway has good macro- texture allowing the water to escape either through the tire tread pattern or beneath the tire, then the friction value will be less affected by speed. Conversely, a low macro-texture surface will produce a significantly larger drop in friction with increase in speed. Accordingly, when testing runways to determine their friction and whether or not maintenance action is necessary to improve it, different speeds sufficient to reveal these friction/speed variations should be used.

3.2.10 An accurate measurement of the friction charac- teristics of a wet runway can only be obtained if the relevant factors are measured as accurately as is practicable. Such items as the calibration of the friction-measuring device, its reliability, tire type, design, condition, inflation pressure, slip ratio and the amount of water on the surface have a significant effect on the final friction value for the particular surface. It follows that the most stringent control of the measuring techniques must be exercised.

3.2.11 DGCA of Kuwait specify three friction levels as follows:

a) a *design level* which establishes the minimum friction level for a newly constructed or resurfaced runway surface;
b) a *maintenance friction level* below which corrective maintenance action should be considered; and
c) a *minimum friction level* below which the information that a runway may be slippery when wet should be made available and corrective action initiated.

Table 3-1, which is based on experience with different friction-measuring devices, shows the criteria in use for specifying the friction characteristics of new or resurfaced runway surfaces, for establishing main- tenance planning levels and for setting minimum friction levels.

3.2.12 It is also considered highly desirable to test the friction characteristics of a paved runway at more than one speed in order to obtain adequate information about the friction characteristics of a runway when wet. In this respect, it is to be noted that when a runway is wet, the effect of unsatisfactory macrotexture and/or microtexture may not be found if the tests are made at only one speed. A standard test method for determining skid resistance on paved surfaces using a continuous fixed braking slip technique can be found at Appendix 4.

3.2.13 Because the value of the friction coefficient is so dependent on surface texture, it may vary with the source of the construction material and the method of construction. Also, some areas of a runway are used more frequently than others or have rubber deposits, both of which will change the basic friction coefficient value. Thus, it can be concluded that the whole runway length needs to be measured. To cover the required width, measurements should be carried out along two tracks; namely, along a line approximately 3 m on each side of the runway centre line or that distance from the centre line at which most operations take place. For runways that have a mix of wide- body and narrow-body aeroplane operations, measurements should be conducted at 5 m on both sides of the runway centre line.

3.2.14 To minimize variations in the friction measure- ments caused by the techniques used in applying a textural finish to the surface, runs should be made in both directions and a mean value taken. Significant variations between the readings obtained in both directions should be investigated. Additionally, if measurement of the friction is made along a track 5 m from the runway edge, it will provide a datum of the unworn and uncontaminated surface for comparison with the centre track(s) subjected to traffic.

3.2.15 Continuous friction-measuring devices such as those described in Chapter 5 can be used for measuring the friction values for wet runways. Other friction-measuring devices can be used provided they meet the criteria in 5.2

Table 3-1. Runway surface condition levels

Test equipment	Test tire: Type	Test tire: Pressure (kPa)	Test speed (km/h)	Test water depth (mm)	Design objective for new surface	Maintenance planning level	Minimum friction level
(1)	(2)		(3)	(4)	(5)	(6)	(7)
Mu-meter Trailer	A	70	65	1.0	0.72	0.52	0.42
	A	70	95	1.0	0.66	0.38	0.26
Skiddometer Trailer	B	210	65	1.0	0.82	0.60	0.50
	B	210	95	1.0	0.74	0.47	0.34
Surface Friction	B	210	65	1.0	0.82	0.60	0.50
Tester Vehicle	B	210	95	1.0	0.74	0.47	0.34
Runway Friction	B	210	65	1.0	0.82	0.60	0.50
Tester Vehicle	B	210	95	1.0	0.74	0.54	0.41
TATRA Friction	B	210	65	1.0	0.76	0.57	0.48
Tester Vehicle	B	210	95	1.0	0.67	0.52	0.42
RUNAR	B	210	65	1.0	0.69	0.52	0.45
Trailer	B	210	95	1.0	0.63	0.42	0.32
GRIPTESTER	C	140	65	1.0	0.74	0.53	0.43
Trailer	C	140	95	1.0	0.64	0.36	0.24

and have been correlated with at least one of the types mentioned in Chapter 5. A method of estimating the friction value when no friction-measuring devices are available at the airport is described in Appendix 6.

3.3 REPORTING

There is a requirement to report the presence of water within the central half of the width of a runway and to make an assessment of water depth, where possible. To be able to report with some accuracy on the conditions of the runway, the following terms and associated descriptions should be used:

Damp — the surface shows a change of colour due to moisture.

Wet — the surface is soaked but there is no standing water.

Water patches — significant patches of standing water are visible.

Flooded — extensive standing water is visible.

3.4 INTERPRETATION OF LOW FRICTION CHARACTERISTICS

3.4.1 The information that, due to poor friction characteristics, a runway or portion thereof may be slippery when wet must be made available since there may be a significant deterioration both in aeroplane braking performance and in directional control.

3.4.2 It is advisable to ensure that the landing distance required for slippery runway pavement conditions, as specified in the Aeroplane Flight Manual, does not exceed the landing distance available. When the possibility of a rejected take-off is being considered, periodic investigations should be undertaken to ensure that the surface friction characteristics are adequate for braking on that portion of the runway which would be used for an emergency stop. A safe stop from V_1 (decision speed) may not be possible, and depending on the distance available and other limiting conditions, the aeroplane take-off mass may have to be reduced or take-off may need to be delayed awaiting improved conditions.

Chapter 4

Measurement of Compacted Snow- or Ice-Covered Paved Surface Friction Characteristics

4.1 GENERAL

4.1.1 There is an operational need for reliable and uniform information concerning the friction characteristics of snow- and/or ice-covered paved runways. Accurate and reliable indications of surface friction characteristics can be obtained by friction-measuring devices. Nevertheless, further experience is required to ensure the validity of the correlation of results obtained by such devices with aeroplane performance due to the many variables involved, such as aeroplane mass, speed, braking mechanism, tire and undercarriage characteristics.

4.1.2 The measurement of the surface friction coefficient provides the best basis for determining surface friction conditions. The value of surface friction should be the maximum value that occurs when a wheel is slipping but still rolling. Various friction-measuring devices may be used. As there is an operational need for uniformity in the method of assessing and reporting runway friction, the measurement should preferably be made with devices that provide continuous measuring of the maximum friction along the entire runway. Chapter 5 provides a description of several different ground friction-measuring devices that meet these requirements. The possibility of standardization is discussed, together with correlation between ground vehicles and between ground vehicles and aeroplane tire braking performance.

4.2 THE AIRPORT PROBLEM IN CHANGING CONDITIONS

4.2.1 The day-to-day requirement for measuring the runway friction coefficient under winter conditions must be determined by the aerodrome operator having the responsibility of deciding whether or not the existing runway surface conditions are safe for aeroplane operations. If this authority is the Air Traffic Service Unit and it is advised by the meteorological service to expect ice or snow, it will probably need hourly reports as a minimum and, certainly, whenever there is reason to believe there has been a significant change in the runway surface condition. If the airport is open on a 24-hour basis, it will need to continually update runway surface condition information throughout this adverse weather period. If it is closed during the night, then it would need to have friction measurements conducted to check on the runway surface condition before opening the airport for aeroplane operations.

4.2.2 There are special circumstances under which particular attention is required, such as when runway temperatures are fluctuating around the freezing point or under changing weather conditions, such as when a warm moist air flow affects a very cold runway. Under such circumstances, it has also been found that friction values can differ significantly depending upon the runway surface material used. Friction measurements should, therefore, be taken on the actual runway in use and not on an adjacent runway or taxiway which may be constructed of a different material.

4.2.3 The reliability of conducting tests using friction-measuring devices in conditions other than compacted snow and/or ice may be compromised due to non-uniform conditions. This will apply in particular when there is a thin layer of slush, water film over ice, or uncompacted dry or wet snow on a runway. In such cases, the wheels of the friction-measuring device or of an aeroplane may penetrate the runway contaminant layer differently which would result in a significant difference in the friction performance indication. The results of friction tests obtained with different friction-measuring devices in such cases may be at great variance because of differences in test methods and, for a particular method, because of different characteristics of the vehicle and different individual techniques in performing the test. Care is also essential in providing runway friction information to pilots under conditions when a water film is observed on top of ice.

4.2.4 The effectiveness of providing runway friction information will depend upon the degree of correlation that

can be achieved with the actual stopping performance of the aeroplane. This information is undoubtedly required to assist the aerodrome operator in making operational judgements, but in the case of ice-covered runways, the measuring and reporting of friction coefficients should only be regarded as an interim procedure while clearing and other remedial measures to restore the runway to full serviceability are being completed. Although the coef- ficient of friction for a wet surface decreases with an increase in speed, tests on ice or compacted snow do not indicate an appreciable difference in friction coefficient values between the comparatively low friction-measuring device speeds and aeroplane speeds. However, the measured friction coefficient value on a runway covered with ice patches at regular, short intervals may differ from that experienced by the pilot due to the reaction time of the aeroplane antiskid system.

4.2.5 In considering the relative merits of measuring the friction coefficient on a compacted snow- and/or ice-covered runway, compared with effective measures to maintain a surface free of any contaminants at all times, it should be noted that immediate removal of snow and ice should receive the highest priority. Nevertheless, there are circumstances that justify a requirement for friction measurement and, therefore, the development of acceptable methods. For example, incidents have occurred involving loss of braking action or of directional control on runways that were apparently clean and dry. Such deterioration in the friction coefficient, while not visually apparent, could have been revealed by measurement. Incidents of this kind can occur at an airport having few or no traffic movements at night, when flight operations are resumed in the early morning and frost is observed, or when, under freezing conditions, the runway surface temperature falls below the dew point (e.g. through radiation). It should be noted that while the airport temperature reported may still be above the freezing point, the runway surface temperature may fall below the freezing point and the surface can have extremely low friction within a very short time due to sudden ice formation.

4.2.6 When a runway is icy, the friction value is liable to change. Under these circumstances, frequent measurements of runway friction coefficient are essential and call for cooperation and development of suitable procedures between the appropriate air traffic service units, the aerodrome operator, and the crew operating the friction-measuring device.

4.2.7 At an airport that regularly experiences heavy snowstorms, it is sometimes necessary to discontinue snow removal operations for a short period in order to permit flight operations to continue. Under these circumstances, it is unlikely that the runway will be completely clean, and measurements will be required as vital information to aeroplanes. Moreover, despite measures to keep the runway clear, slippery patches may remain. Measurements are, therefore, necessary to detect those areas requiring further treatment and to provide information to pilots on the friction characteristics along the runway.

4.2.8 The use of a friction-measuring device giving continuous measurement information is preferred. For day-to-day operations when dealing with a compacted snow- and/or ice-covered runway, it is essential that the vehicle used be capable of providing the required information quickly and in an operationally meaningful form.

4.2.9 The practicality of measuring the depth of dry snow, wet snow or slush on a runway has been questioned since it is a time-consuming process that could be more usefully employed in clearing the contaminants from the pavement, particularly since the removal of slush is a relatively fast and simple operation. Moreover, procedures for measuring the depth of contaminants are generally based on the assumption that there is a uniform layer on the runway and this is seldom found in practice. Notwithstanding the above, whenever dry snow, wet snow or slush is present on a runway, an assessment of the mean depth over each third segment of the runway should be made.

4.3 REQUIRED ACCURACY OF INFORMATION REGARDING FRICTION CHARACTERISTICS

4.3.1 For a modern turbo-jet transport aeroplane, the difference in stopping distance on a dry runway, as compared with an ice-covered runway, can amount in extreme cases of poor stopping performance to an extra distance in the order of 900 m. There is as yet no general agreement that accurate prediction of the variation in stopping distances due to low μ conditions is possible. Further research is required to correlate the measured friction coefficient of the friction-measuring devices to the stopping performance of aeroplanes.

4.3.2 An acceptable correlation between aeroplane stopping performance and friction-measuring devices is obtained on compacted snow- and/or ice-covered runways (see also 5.3). Aeroplane crews, as a result of practical operational experience, have already been able to achieve a practical correlation to a workable degree for certain friction-measuring devices. For this reason, aeroplane crews have a long-standing requirement for airport auth- orities to provide runway friction measurement information using one of the friction-measuring devices recognized for this purpose. There is evidence that the more slippery the runway, the more operational reliance can be placed upon the friction measurements currently provided; this tends to endorse the operational requirement. Accordingly, the most useful practical step that can be taken at this stage is to standardize the results of the field measurements taken in wintry conditions and allow the aeroplane crews, through their experience, to apply this information to their particular aeroplanes and operations at the airport.

4.4 MEASUREMENT

4.4.1 The friction coefficient should be measured if a runway is covered wholly or partly by snow or ice and should be repeated as conditions change. Friction measurements and/or braking action assessments on airport surfaces other than runways should be made when an unsatisfactory friction condition can be expected on such surfaces.

4.4.2 A continuous friction-measuring device (e.g. Mu-meter, Runway Friction Tester, Skiddometer, Surface Friction Tester or Grip Tester) can be used for measuring the friction values for compacted snow- and/or ice-covered runways. A decelerometer (e.g. Brakemeter-Dynometer or Tapley Meter) may be used only on surfaces covered by compacted snow and/or ice, with the possible additional covering of very thin layers of dry snow. Other friction-measuring devices can be used provided they have been correlated with at least one of the types mentioned above. A decelerometer should not be used in loose snow or slush or on ice covered with a water film because it can give misleading friction values. Other friction-measuring devices can also give misleading friction values under certain combinations of contaminants and when there are variations in air-to-pavement temperatures. Methods of estimating braking action when no friction-measuring devices are available at the airport are described in Appendix 2.

4.5 REPORTING

4.5.1 There is a requirement to report the presence of snow, slush or ice on a runway or a taxiway. To be able to report meteorological contaminants with some degree of reliability and consistency, a uniform method for describing them must be established. Therefore, the following definitions for slush and snow on the ground have been incorporated in KCASR 14.

Slush. Water-saturated snow which with a heel-and-toe slap-down motion against the ground will be displaced with a splatter; specific gravity: 0.5 up to 0.8.

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

Snow (on the ground)

a) *Dry snow.* Snow which can be blown if loose or, if compacted by hand, will fall apart again upon release; specific gravity: up to but not including 0.35.

b) *Wet snow.* Snow which, if compacted by hand, will stick together and tend to or form a snowball; specific gravity: 0.35 up to but not including 0.5.

c) *Compacted snow.* Snow which has been compressed into a solid mass that resists further compression and will hold together or break up into lumps if picked up; specific gravity: 0.5 and over.

4.5.2 There is also a requirement to report the friction characteristics of a compacted snow- and/or ice-covered runway. The friction conditions of a runway should be expressed as “braking action information” in terms of the measured/calculated friction coefficient μ or estimated braking action.

4.5.3 Specific numerical μ values are necessarily related to the design and construction of the friction-measuring device, as well as to the surface condition being measured and, to a lesser extent, the measuring speed employed.

4.5.4 Table 4-1 with associated descriptive terms was developed from friction data collected only in compacted snow and ice and should not therefore be taken to be absolute μ values applicable for all contaminant conditions. If the surface is affected by snow and/or ice and the braking action is reported as “good”, pilots should expect to find conditions not as good as those for a dry, clean runway pavement surface (where the available friction may well be greater than that needed in any case). The value “good” is a comparative value and implies that aeroplanes should not experience directional control or braking difficulties when landing.

4.5.5 It has been found necessary to provide surface friction information for each third of a runway. The one-third segments are called A, B and C. For the purpose of reporting information to aeronautical service units,

Table 4-1. Friction coefficient for compacted snow- and/or ice-covered runways

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

segment A is always the segment associated with the lower runway designation number. When giving information to a pilot before landing, the segments are referred to as the first, second or third part of the runway. The first part always means the first third of the runway where the aeroplane will land.

4.5.6 Friction measurements are made along two tracks parallel to the runway, i.e. a track on each side of the runway centre line, approximately 3 m from the centre line or that distance from the centre line at which most aeroplane operations take place. The object of the tests is to determine the mean friction (μ) value for segments A, B and C. In cases where a continuous friction-measuring device is used, the mean μ values are obtained from the friction values recorded for each segment. If a spot friction-measuring device is used, the distance between each test point should be not more than approximately 10 per cent of the usable length of the runway. If it is decided that a single test line on one side of the runway centre line gives adequate coverage of the runway, then it follows that each segment of the runway should have three tests conducted on it. The test results and calculated mean friction values can be entered in a form similar to that shown in Figure 5-1. Where applicable, figures for stopway friction value should also be made available on request.

4.5.7 When reporting the presence of dry snow, wet snow or slush on a runway, an assessment of the mean depth over each one-third segment of a runway should be made to an accuracy of approximately 2 cm for dry snow, 1 cm for wet snow and 0.3 cm for slush.

Chapter 5

Runway Friction-Measuring Devices

5.1 POSSIBILITY FOR STANDARDIZATION

Currently there are several types of friction-measuring equipment in operation at airports in various States. They incorporate diverse principles and differ in their basic technical and operational characteristics. The results of several research programmes for correlating the various friction-measuring equipment have shown that the correlation between the friction values obtained from the devices has been satisfactorily achieved on artificially wetted surfaces (5.3 refers). However, consistent and reliable correlation between these devices and aeroplane stopping performance has not been achieved on wet surfaces. On compacted snow- and/or ice-covered surfaces, the correlation between the various friction-measuring devices, although not perfect, is substantially better than that acquired on wet surfaces. Measurements obtained by fric- tion-measuring devices on artificially wetted surfaces can be used only as advisory information for maintenance purposes and should not be relied upon to predict aeroplane stopping performance.

5.2 CRITERIA FOR NEW FRICTION-MEASURING DEVICES

The Eighth Air Navigation Conference (1974) recommended that ICAO develop criteria for the basic technical and operational characteristics of equipment used to measure runway friction. In response to this recommendation, some relevant criteria were developed and transmitted to States. It was thought that the material would assist those States which might be planning to develop new friction-measuring devices. States, however, were informed of the uncertainty of obtaining, on wet runway surfaces, a more acceptable correlation between friction-measuring devices and aeroplane braking performance using any new measuring equipment developed in accordance with the proposed criteria. These criteria, which were reviewed and updated in 1991, are summarized below. The criteria are aimed at standardization of design parameters for new friction-measuring devices; they are intended to provide flexibility and allowance for future devices without precluding technical advancements in this field. In addition, the NASA Certification Test Procedure for friction-measuring devices can be found at Appendix 3.

Basic technical specifications for friction-measuring devices

1. *Mode of measurement.* Continuous measurement in motion should be taken along the part of the pavement to be tested.

2. *Ability to maintain calibration.* The equipment should be designed to withstand rough use and still maintain calibration, thereby ensuring reliable and consistent results.

3. *Mode of braking.* During friction measurement operations using:

   a) a fixed slip device, the friction-measuring wheel should be continuously braked at a constant slip ratio within a range of 10 to 20 per cent; and

   b) a side force device, the included angle (single wheel) should be within a range of 5° to 10°.

4. *Excessive vibrations.* The design of the equipment should exclude any possibility of sustained vertical vibrations of the cushioned and uncushioned mass occurring in all travel speed ranges during the measuring operations, particularly in respect of the measuring wheel.

5. *Stability.* The equipment should possess positive directional stability during all phases of operation, including high-speed turns which are sometimes necessary to clear a runway.

6. *Friction coefficient range.* The recording range of the friction coefficient should be from 0 to at least 1.0.

7. *Presentation of the results of measurements.* The equipment should be able to provide a permanent record of the continuous graphic trace of the friction values for the runway, as well as allowing the person conducting the survey to record any observations and the date and time of the recording (see Figure 5-1).

8. *Acceptable error.* The equipment should be capable of consistently repeating friction averages throughout the friction range at a confidence level of 95.5 per cent, ±6 µ (or two standard deviations).

9. *Measured and recorded parameter.*

   a) For a fixed slip device, the recorded friction value should be proportional to the ratio of the longitudinal friction force to the vertical wheel loading.

   b) For a side force device, the recorded friction value should be proportional to the ratio of the side force to wheel loading.

10. *Speed range.* When conducting friction measurements, the speed range for friction-measuring devices should be from 40 to at least 130 km/h.

11. *Averaged* µ *increments*. The equipment should be capable of automatically providing µ averages for at least the following conditions:

    a) the first 100 m of the runway;

    b) each 150 m increment; and

    c) each one-third segment of the runway.

12. *Horizontal scale.* To minimize substantial variations in scale between the various friction devices, the manufacturer may provide, as one option, a scale of 25 mm equals 100 m. This may simplify data comparisons when two or more friction-measuring devices are used at an airport.

13. *Standard tire specifications.* For testing on rain-wet or artificially wetted surfaces, the tread should be smooth with a pressure of 70 kPa for yaw-type friction-measuring devices; the tire must meet the specification contained in American Society for Testing Materials (ASTM) E670, Annex A2. With the exception of the Grip Tester, braking slip friction-measuring devices must use smooth tread tires made to ASTM E1551 specification and inflated to 210 kPa. The Grip Tester uses a tire made to ASTM E1844 specification. For loose, wet or dry snow or compacted snow- and/or ice-covered surfaces, a tread pattern tire meeting ASTM E1551 specification, with a pressure of 700 kPa, should be used for all fixed braking slip devices, except the Grip Tester, which should use either the manufac- turer's D-series (Slushcutter) or S-series (Disctyre).

14. *Allowable tire variations.* To minimize variations in the physical dimensions of the friction-measuring tire and the physical properties of tread compounds, the tire manufacturer should follow the requirements listed in the appropriate ASTM tire specification. The tire is a very critical component of the friction-measuring device; it is important to ensure that it will always be dependable and provide consistent and reliable results. The procedures for evaluating the performance and reliability of friction-measuring equipment and tires are given in 5.3.

15. *All-weather operation.* The design of the friction-measuring device should be such as to ensure its normal operation at any time and in all weather conditions.

16. *Equipment maintenance.* The technical maintenance of the friction-measuring device should be such as to ensure the safe execution of the work during both measurement operations and transportation.

17. *Artificial wetting.* Friction-measuring devices should have the capability of using self-wetting features to enable measurements of the friction characteristics of the surface to be made at a controlled water depth of at least 1 mm.

Note.— A certification test procedure, developed by NASA, for continuous friction-measuring equipment used at airports is shown in Appendix 3.

5.3 CORRELATION BETWEEN FRICTION-MEASURING DEVICES

5.3.1 The possibility of obtaining a useful degree of correlation between friction-measuring devices has been the subject of many trials in several States for many years. In 1989, the United States undertook a programme to develop standards that would ensure tire performance and reliability on artificially wetted runway surfaces. Subsequently, correlation trials were conducted using several continuous friction-measuring devices (see Figure 5-2).

Type of equipment	Time	Location	Programme No.
Date of test	Wind	Direction	
Weather	Condition prior to test		
Runway			
Surface description			

Surface texture tests	Grease (mm)	Water (seconds)
Position 1 Position 2 Position 3		

Tire wear test	Rubber loss (grams)
Left Right	
Total	

Tests conducted by	Towing vehicle (if applicable)
Method of wetting	Depth of water (mm)
Length covered by trace	Test speeds
Starting at	Ending at
Distance of run from centre line	
Friction results	

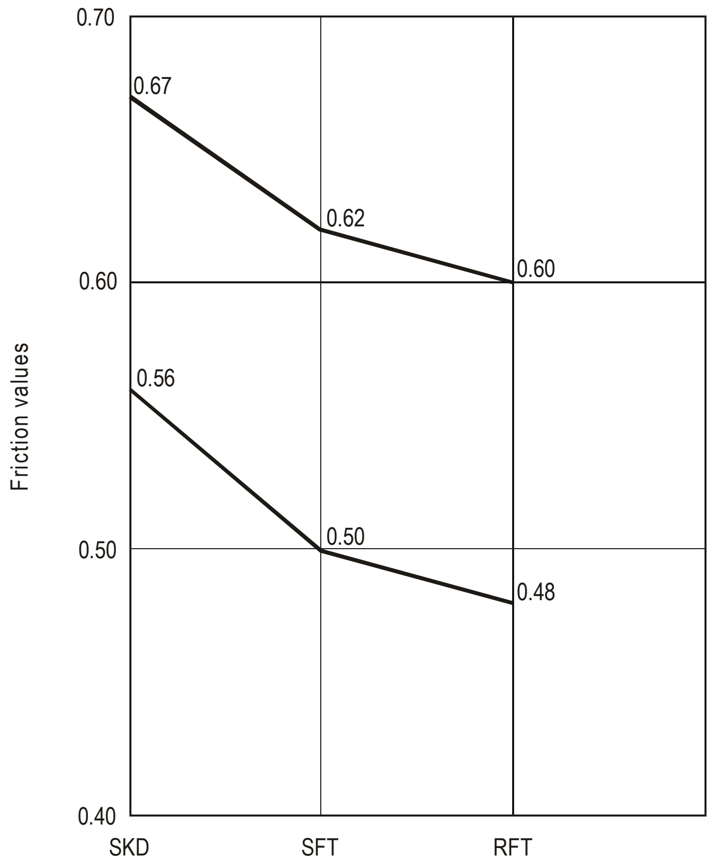
Speed km/h	32	65	95	130	145	160
1st third Middle third 3rd third						

Recorder chart reference number and means of identification of individual run and speed:

Speed km/h	32	65	95	130	145	160
Section of runway 45 m from centre line giving lowest coefficient of friction (excluding paint markings)						

Note.— The original recorder chart or a print of it must be attached to this form.

Figure 5-1. Test report form



Notes:
1. Test speed 65 km/h; water depth 1 mm.
2. Mu-meter value of 0.50 used as base in the correlation. The range quoted is ± two standard deviations.

Figure 5-2. Correlation chart for friction-measuring devices on artificially wetted dry surfaces

5.3.2 Originally, four friction-measuring devices were included in the trials. Three fixed slip devices (the Runway Friction Tester, Surface Friction Tester and Skiddometer) and one side force friction tester (the Mu-meter) were evaluated. Since that time, three additional fixed slip devices (the Grip Tester, the Tatra Friction Tester and the RUNAR Runway Analyzer and Recorder) have also undergone the same trials. The correlation among the seven devices used in the programme is set out in Table 3-1.

5.3.3 A programme for establishing tire performance and friction equipment correlation on compacted snow- and/or ice-covered surfaces was conducted at Brunswick Naval Air Station, Maine, in the winter months of 1985-1986 during the Joint FAA/NASA Runway Friction Programme. In addition to an instrumented NASA B-737 and FAA B-727 aeroplanes, the following types of ground test devices were included in the programme: Mu-meter, Runway Friction Tester, BV-11 Skiddometer, Tapley Meter, Bowmonk Brakemeter and Surface Friction Tester. Insufficient ground vehicle friction data were collected for slush and loose snow conditions to determine a reasonable correlation. Figure 5-3 shows the correlation between ground friction-measuring devices for compacted snow- and/or ice-covered surfaces only. The ambient temperature range for these winter runway conditions varied from –15° to 0°C. Additional friction measurements at lower tempera- tures are desirable to confirm the current data correlation.

5.3.4 The data suggest that for compacted snow- and/or ice-covered runway conditions, the temperature of the runway surface and the air, as well as the type of surface contaminant accumulation, affect the friction readings. At temperatures below freezing, runway friction depends on the shear strength of compacted snow and ice which tends to increase as temperatures decrease. Consequently, the lower the snow or ice temperature, the higher the runway friction level. When temperatures are near the melting point for compacted snow and ice, a thin water film is produced which can greatly reduce runway friction levels through lubrication or viscous hydroplaning effects. Although friction measurements were collected using ground vehicle devices operating at a speed between 32 and 95 km/h, the data indicate an approximately constant friction value over this speed range (speed effect is negligible).

5.3.5 Although some continuous friction-measuring devices use different tires or operate at a fixed braking slip or in yawed rolling test mode, tests have shown that their readings are reliable and correlate with each other when using self-water systems that apply a controlled water discharge in front of the friction-measuring tire(s), either at a constant speed or over a speed range. However, when these same devices are used on runway surfaces that are wet due to rainfall, correlation can be less reliable. This is attributed to differential changes in water depths caused by variations in the pavement surface. For this reason, it is very important to control water depth when classifying pavements for maintenance purposes. For compacted snow- and/or ice-covered surfaces, fewer interacting variables affect the friction values because the braking action on these surfaces is not speed-dependent.

5.3.6 The correlation between the various friction-measuring devices when pavement surfaces are covered with compacted snow and/or ice is presented in Figure 5-3. The following practices for tests should be employed:

A. *Continuous friction-measuring devices* (e.g. Mu-meter, Grip Tester, Surface Friction Tester, Runway Friction Tester or Skiddometer)

   Test speeds: 65 km/h, except under icy conditions when a lower speed may be used.

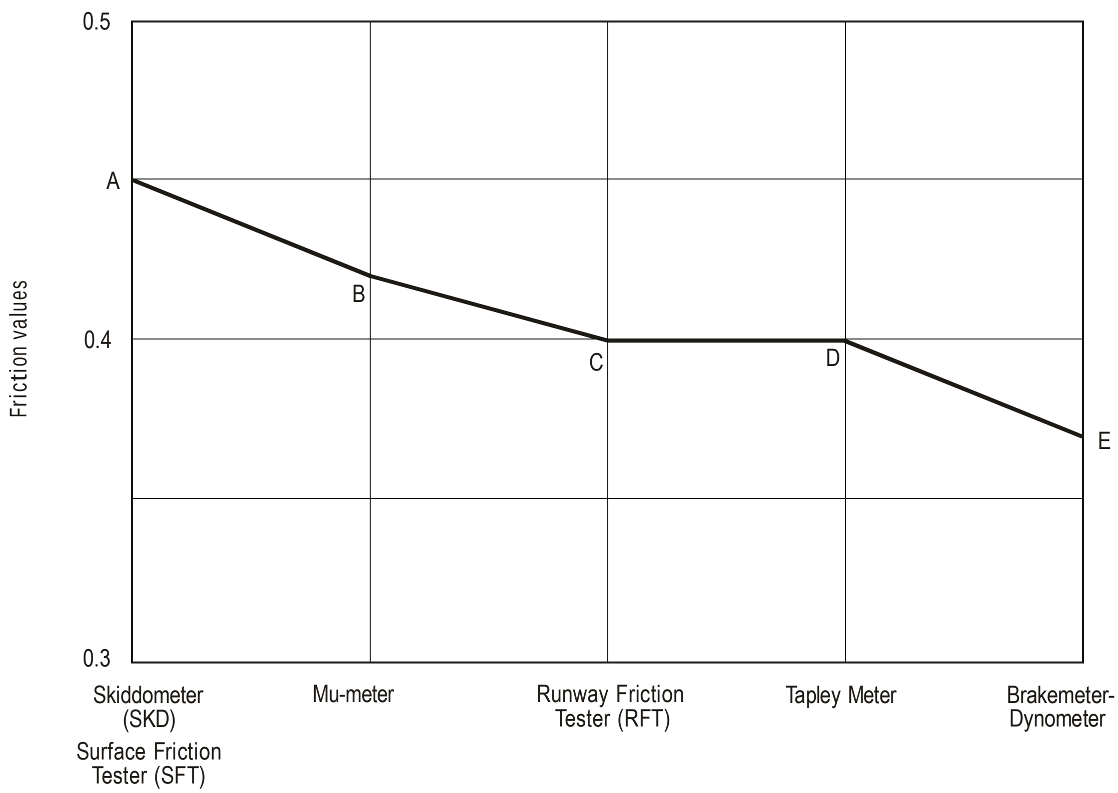


Figure 5-3. Correlation chart for friction-measuring devices on compacted snow- and/or ice-covered surfaces

B. *Decelerometer* (e.g. Tapley Meter, Brakemeter-Dynometer)

1. Vehicle specifications

   a) The vehicle should have a mass in the order of 1 to 2 tonnes.

   b) It should be equipped with winter tires without studs, with the tire pressure set at manufacturer's recommendation. Tire wear should not exceed 75 per cent.

   c) It must have 4 brakes properly adjusted to ensure a balanced action.

   d) The vehicle should have minimum pitching tendency and maintain satisfactory directional stability under braking.

2. The decelerometer should be installed in the vehicle according to the manufacturer's instructions. It should also be located and placed in the vehicle so it cannot be disturbed or displaced by either airport personnel or vehicle movement. The decelerometer should be maintained and calibrated according to the manufacturer's recommendations.

3. Speed at brake application should be approximately 40 km/h.

4. Friction survey techniques

   a) Brakes should be applied sufficiently hard to lock all four wheels of the vehicle and then should be released immediately. The time during which the wheels are locked should not exceed one second.

   b) The decelerometer used should record or retain the maximum retardation braking force occurring during the test.

   c) Random very high or very low readings may be ignored when calculating the average values.

5.3.7 Since decelerometers require the test vehicle to be accelerated to given test speeds, which takes a finite distance, the intervals at which the test readings can be taken are necessarily greater than those taken by the continuous friction-measuring devices. These devices, therefore, can be considered only as spot reading friction-measuring devices.

5.3.8 The following example shows how the chart in Figure 5-3 is applied:

A reading of 0.45 (point A) with a BV-11 Skiddometer or Surface Friction Tester is equivalent to a reading of:

0.42 with a Mu-meter (point B)

0.40 with a Runway Friction Tester (point C)

0.40 with a Tapley Meter (point D)

0.37 with a Brakemeter-Dynometer (point E)

5.4 CORRELATION WITH AEROPLANE STOPPING PERFORMANCE

5.4.1 In order to be operationally meaningful, it is necessary to first determine the correlation between the friction data produced by the friction-measuring devices and the effective braking friction performance of different aeroplane types. Once this relationship is defined for the ground operational speed range of a given aeroplane, the aeroplane flight crew should be able to determine aeroplane stopping performance for a particular runway landing operation by considering the other factors including touchdown speed, wind, pressure/altitude and aeroplane mass, all of which significantly influence the stopping performance. At present, there is general agreement that success in this respect is greater for the compacted snow-and/or ice-covered surface conditions since fewer parameters affecting tire frictional behaviour are involved compared to the more complex and variable wet runway case.

5.4.2 In 1984, the United States undertook a five-year programme to study the relationship between aeroplane tire braking performance and ground vehicle friction measurements. Several types of surface conditions were evaluated: dry, truck-wet, rain-wet and snow-, slush- and ice-covered. The ground friction-measuring devices used in this study were the diagonal-braked vehicle, Runway Friction Tester, Mu-meter, BV-11 Skiddometer, Surface Friction Tester and two decelerometers (Tapley and Brakemeter-Dynometer). The results of this investigation showed that the ground vehicle friction measurements did not directly correlate with the aeroplane tire effective braking friction on wet surfaces. However, agreement was achieved using the combined viscous/dynamic aquaplaning theory (see Appendix 1).

5.5 GENERAL DISCUSSION ON FRICTION-MEASURING DEVICES

5.5.1 There are several friction-measuring devices in use today throughout the world. Two decelerometers, the Tapley Meter and Brakemeter-Dynometer, provide a spot check on compacted snow- and/or ice-covered runway surface friction conditions. The seven devices described in this chapter (5.6 to 5.12) provide a permanent and continuous trace of friction values produced on a strip chart for the entire runway length surveyed.

5.5.2 Although the operational modes of the continuous friction-measuring devices are different, certain components operate in a similar manner. When conducting a friction survey for the maintenance programme, they all use the same smooth tread friction-measuring tire, size 4.00 - 8 (16 × 4.0, 6 ply, RL2) made to ASTM E1551 specification, with the exception of the Grip Tester which uses a smooth tread tire, size 10 × 4.5-5 made to ASTM E1844 specification. The friction-measuring tires mounted on the Mu-meter are made to ASTM E670, Annex A2, specification and operate at an inflation pressure of 70 kPa, whereas the Grip Tester tire uses 140 kPa inflation pressure. The five remaining devices use an inflation pressure of 210 kPa in the test tires. They all use the same friction scale, which ranges from 0.00 to 1.00, and they all provide friction averages for each 150 m of the runway length surveyed. It is required to provide information on the friction average for each one-third segment of the runway length (4.5.5 refers). With the exception of the Mu-meter and Grip Tester, the other five continuous friction-measuring devices provide, as an option, a high-pressure friction-measuring tire with an inflation pressure of 700 kPa, size 4.00 - 8 (16 × 4.0, 6 ply, RL2) that has either a patterned tread or circumferential grooves. This tire is used for operational purposes when pavement surfaces are covered with ice and/or compacted snow only. Another option available to the Mu-meter, Runway Friction Tester and Surface Friction Tester is a keyboard that allows the equipment operator the flexibility to record commands, messages and notes on observations taken during the time of the friction survey. All of these continuous friction-measuring devices are equipped with a self-watering system that provides a specified water depth in front of the friction-measuring tire(s). Friction surveys can be conducted at speeds up to 130 km/h.

5.5.3 The success of friction measurements depends heavily on the personnel responsible for operating the device. Adequate professional training in the operation and maintenance of the device and procedures for conducting friction measurements is essential to ensure reliable friction data. Periodic instruction is also necessary to review, update and certify that the operator maintains a high proficiency level. If this is not done, then personnel fail to maintain their experience level over time and lose touch with the new developments in calibration, maintenance and operating techniques. All friction-measuring devices should periodically have their calibration checked to ensure that it is maintained within the tolerances given by the manufac- turer. Friction-measuring devices furnished with self- watering systems should be calibrated periodically to ensure that the water flow rate is maintained within the manufacturer's tolerances, and that the amount of water produced for the required water depth is always consistent and applied evenly in front of the friction-measuring tire(s) throughout the speed range of the vehicle.

5.6 MU-METER

5.6.1 The Mu-meter is a 245 kg trailer designed to measure side force friction generated between the friction-measuring tires passing over the runway pavement surface at an included angle of 15 degrees. The friction-measuring tires on the Mu-meter are made to ASTM E670, Annex A2, specification. The trailer is constructed with a triangular frame on which are mounted two friction-measuring wheels and a rear wheel. The rear wheel provides stability to the trailer during its operation. Figure 5-4 shows the over-all configuration of the trailer. A vertical load of 78 kg is generated by ballast via a shock absorber on each of the friction-measuring wheels. The friction-measuring wheels operate at an apparent slip ratio of 13.5 per cent. The Mu-meter also has a rear wheel which has a patterned tread tire, size 4.00 - 8 (16 × 4.0, 6 ply, RL2). The tire operates with an inflation pressure of 70 kPa. The Mu-meter, being a trailer device, requires a tow vehicle; if the self-water system is required, a water tank must be mounted on the tow vehicle to supply water to the nozzles.

5.6.2 The distance sensor is a sealed photo-electric shaft encoder mounted on the rear wheel of the trailer. The distance sensor reads digital pulses in increments of a thousand-per-wheel revolution, transmitting them to the signal conditioner for calculation each time the trailer travels one metre. The load cell is an electronic transducer mounted between the fixed and movable members of the triangular frame. The load cell reads minute tension changes from the friction-measuring wheels. The signal conditioner is mounted on the frame and amplifies analog μ data received from the load cell and digital data from the distance sensor. The signals from the rear wheel distance sensor provide both distance measurement and, combined with increments of real time, speed measurement. The computer located in the tow vehicle is called a processor and it uses two microprocessors to display, calculate, store and process μ data received from the load cell and distance sensor (see Figure 5-5). Also shown in the figure is the keyboard which has command and function keys for selecting menus. The processor provides a continuous chart of friction values for the entire length surveyed. Five chart scales are available to the operator: 25 mm equals approximately 20 m, 40 m, 85 m, 170 m and 340 m. The expanded scales can be used to conduct a micro-investigation of areas where potential problems are suspected.

5.7 RUNWAY FRICTION TESTER

5.7.1 The Runway Friction Tester is a van which has a tire, made to ASTM E1551 specification, mounted on a fifth wheel connected to the rear axle by a gear chain drive. Figure 5-6 shows the configuration of the van. The van is equipped with front-wheel drive and a powerful engine. The friction-measuring wheel is designed to operate at a fixed slip ratio of 13 per cent. The test mode utilizes a two-axis force transducer which measures both the drag force and the vertical load on the friction-measuring wheel. This method eliminates the need to filter the vehicle's deflections and the effects of tire wear, thus giving instantaneous measurement of dynamic friction. A vertical load of 136 kg is generated on the friction wheel by weights mounted on a double shock absorber spring assembly. The Runway Friction Tester is supplied with a self-water system and tank.

5.7.2 Vehicle speed and distance travelled are computed in a digital computer from pulses supplied by an optical encoder. The drag force and vertical load forces on the test wheel are sensed by a strain-gauged, two-axis force transducer and amplified for input into the digital com- puter. The digital computer samples these values approxi- mately five times for each metre of travel and computes the dynamic friction coefficient. The friction coefficient, along with vehicle velocity (and, optionally, water flow rate), is stored in the memory of the digital computer. Figure 5-7 shows the vacuum fluorescent display unit which presents all programme menus and keyboard entries. All the menu selections and functions are entered into the digital computer from the keyboard.

5.7.3 When conducting a friction survey, the data are processed and sent to a printer which provides a continuous strip chart recording of μ and velocity. Average μ values are printed alongside the chart. Transmission continues throughout the survey at appropriate intervals until the entire length has been surveyed. Three chart scales are available to the operator: 25 mm equals approximately 30 m, 90 m and 300 m.

5.8 SKIDDOMETER

5.8.1 The BV-11 Skiddometer is a trailer equipped with a friction-measuring wheel with a tire, made to ASTM E1551 specification, designed to operate at a fixed slip ratio between 15 and 17 per cent, depending on test tire configuration. Figure 5-8 shows the overall configuration of the 360 kg trailer. It consists of a four-sided welded frame supported by two independently sprung wheels. The three wheels are connected together by roller chains and sprocket wheels, with a gear ratio to force the centre friction-measuring wheel to rotate with a motion relative to the surface at the desired slip ratio. A vertical load of 105 kg is applied on the friction-measuring wheel by a weight via a spring and shock absorber. Since the Skiddometer is a trailer, it requires a tow vehicle. If a self-water system is required, a water tank must be mounted on the tow vehicle, along with a water supply line to the nozzle which is mounted ahead of the test wheel on the BV-11 Skiddometer.

5.8.2 The torque applied to the friction-measuring wheel is measured by a special torque transducer. The speed of the trailer is measured by a tachometer generator, driven by one of the roller chains. A cable between the trailer and the towing vehicle converts the analog signals to a strip chart recorder located inside the tow vehicle. Figure 5-9 shows the Skiddometer MI-90 computer. The data taken on a friction survey are processed by a digital computer and recorded on a strip chart as a continuous trace of friction values for the entire length surveyed. Four scales are available to the operator for measuring distance on the strip chart: 25 mm equals approximately 112 m, 225 m, 450 m and 900 m.

5.9 SURFACE FRICTION TESTER

5.9.1 The Surface Friction Tester is an automobile which uses a fifth wheel with a tire, made to ASTM E1551 specification, located in the trunk to measure the coefficient of friction. Figure 5-10 shows the configuration of the Surface Friction Tester. The automobile is equipped with front-wheel drive; an optional turbo-charged engine is also available. The friction-measuring wheel is designed to operate at a fixed slip ratio of between 10 and 12 per cent, depending on the type of friction-measuring tire used in the survey. It is connected to the rear axle of the free rolling rear wheels by a chain transmission that is hydraulically retractable. A vertical load of 140 kg is generated by a weight via a spring and shock absorber on the friction- measuring wheel. The Surface Friction Tester is supplied with a self-water system and tank mounted in the rear seat area of the vehicle.

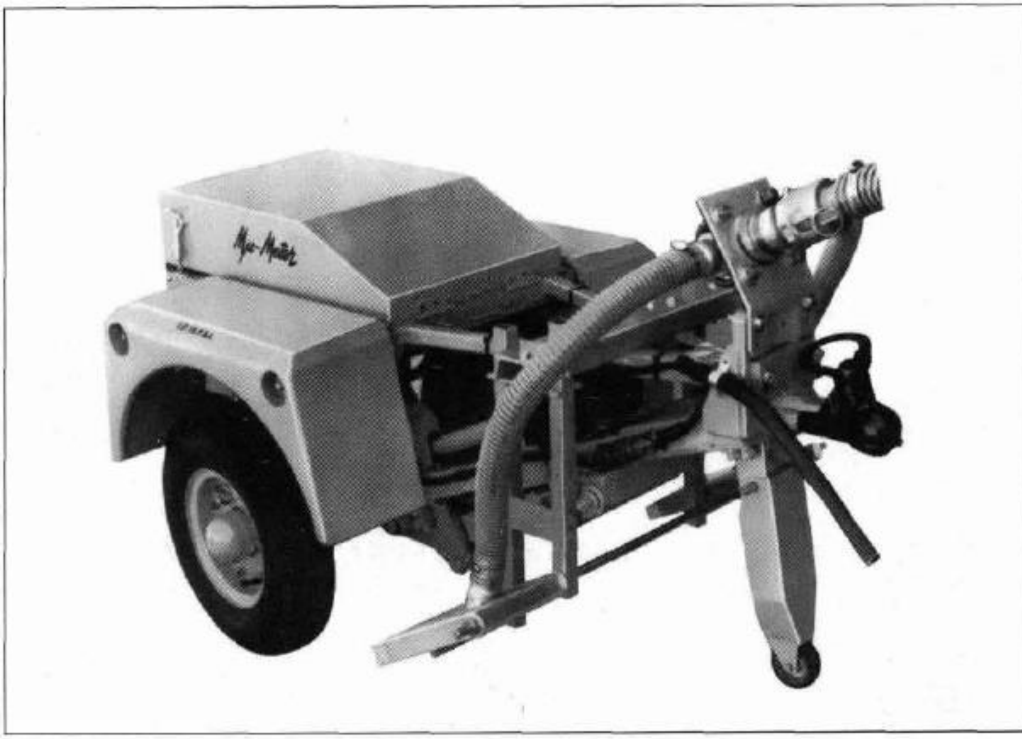


Figure 5-4. Mu-meter trailer

Figure 5-5. Processor unit and keyboard for Mu-meter trailer

Figure 5-6. Runway Friction Tester (T6810) van

Figure 5-7. The vacuum fluorescent display unit and keyboard for the Runway Friction Tester

Figure 5-8. Skiddometer BV-11 trailer

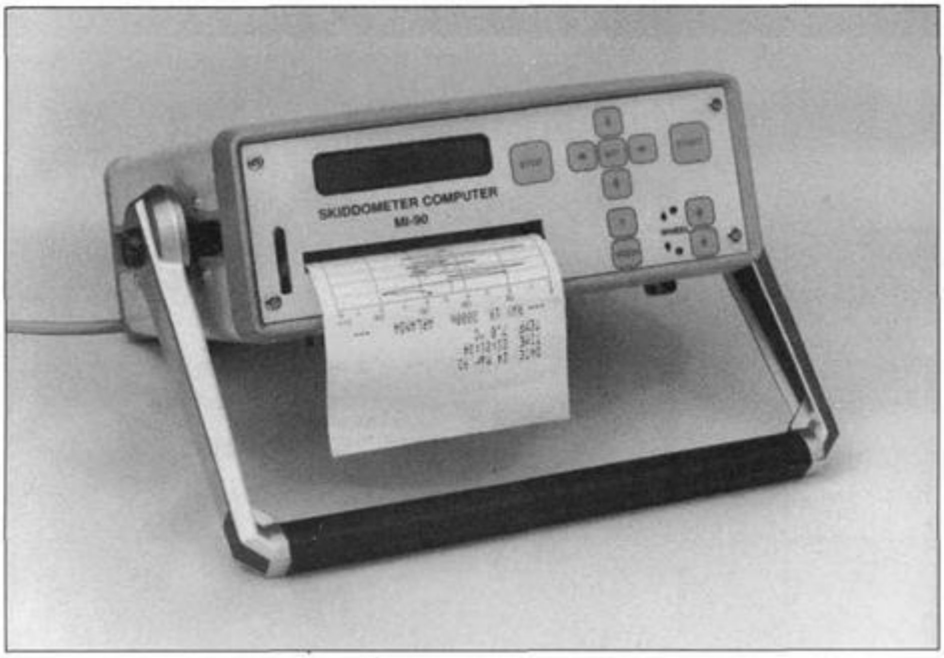


Figure 5-9. MI-90 computer for Skiddometer BV-11 trailer

Figure 5-10. Surface Friction Tester automobile

5.9.2 The torque acting on the friction-measuring wheel and the distance travelled are fed into a digital computer where the information is converted into coefficient form. The electric current flowing through the strain gauges within the torque sensor located on the frictionmeasuring wheel is affected by any minute changes in the tension of the chain transmission. Therefore, any variations in the frictional forces are monitored by the digital computer which measures these variations of the electric current and converts the analog signals into coefficient of friction data. The μ values are continuously stored in the digital computer; upon completion of the survey, they are recorded on a strip chart as a continuous trace of μ values for the entire length surveyed. Speeds during the test, as well as data to identify the test, are also recorded on the strip chart. The scale for measuring distance on the strip chart is *25* mm equals 100 m. A keyboard is available to the operator as an option.

5.10 GRIP TESTER

5.10.1 The Grip Tester is a lightweight, three-wheel trailer which measures friction using the braked wheel,

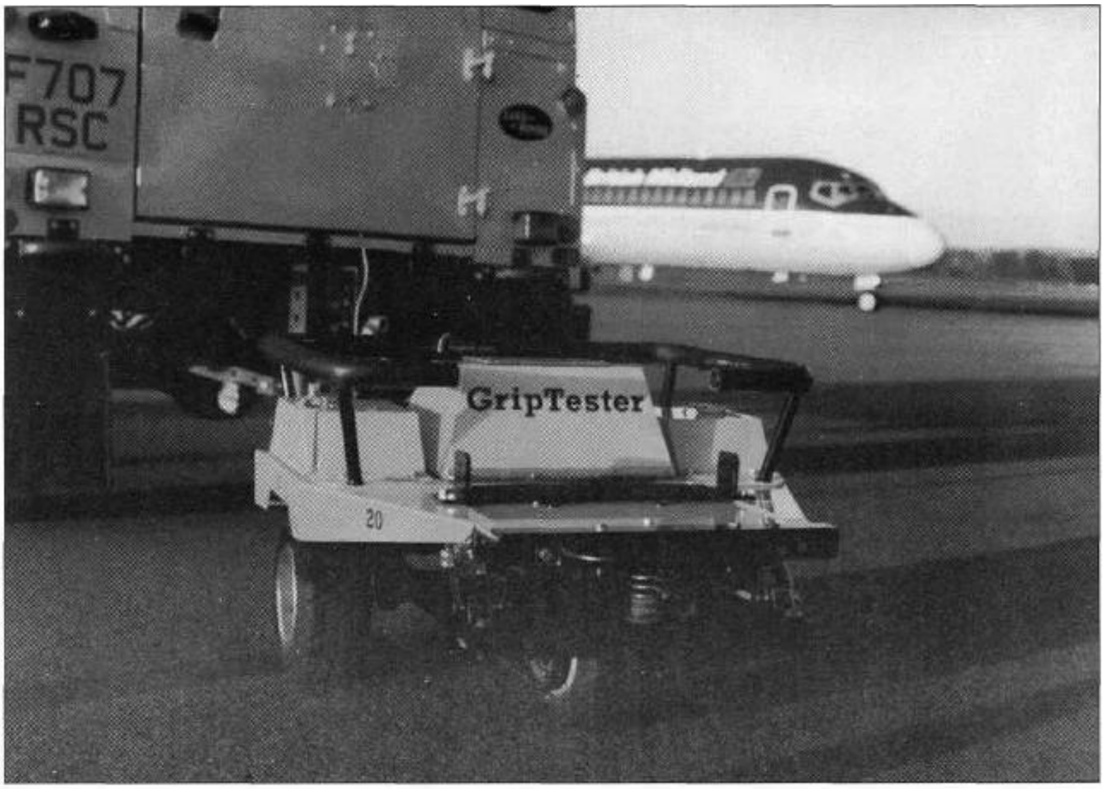


Figure 5-11. Grip Tester

fixed slip principle. It has a single measuring wheel fitted with a smooth tread tire made to ASTM El844 pecification. The wheel is mounted on an instrumented xle which measures both drag force and vertical load. From these measurements, the dynamic friction reading is alculated and transmitted to a data collection computer normally carried in the cab of the towing vehicle. The computer calculates and stores the survey speed .for each 10 m of friction reading.

5.10.2 The average friction reading for each third of the runway is displayed by the computer on a chematic runway "map". When the survey has been completed, averages over the width and length of the runway are displayed. The results may be printed immediately or stored in a database.

5.10.3 For maintenance testing, storing the data in a database facilitates comparison between different surveys and the early detection of any trend towards poorer friction. For operational testing, the computer is able to generate a complete SNOWTAM or NOTAM. The Grip Tester is illustrated in Figure 5-11.

5.11 TATRA FRICTION TESTER

5.11.1 The Tatra Friction Tester, shown in Figure 5-12, is an automobile which has a hydraulically operated fifth wheel using an ASTM El551 specification test tire, located in the rear seat area, to measure the coefficient of friction. The automobile is powered by an air-cooled, V-8 engine which is located above the rear-driven axle and produces 220 HP or, optionally, 300 **HP.** The vehicle is equipped with two internal water tanks and a water dispersal system. Vertical loading of the measuring wheel is adjustable from 25 kg to 145 kg.

5.11.2 The system can be programmed to perform in continuous friction-measuring equipment (CFME) mode or variable slip-measuring mode, either automatically or manually. In the CFME mode, the test tire can be slipped at between 0 and 60 per cent of the forward speed. Aircraft wheel braking is simulated by using the variable slipmeasuring mode which has an adjustable increase of the slip per time (distance) and the value (steepness) from 0 per cent to the maximum required, up to 99 per cent. The coefficient of friction of the surface to be tested is evaluated using the forward speed of the device, the distance measured, the surface characteristics and wheel slip. These data are measured and collected by the engine speed sensor, hydro generator speed induction sensor and a sensor on the left front wheel which measures the vehicle's forward speed and distance.

5.11.3 Monitoring equipment comprises a computer, three microprocessors, a display screen and a printer, as well as automatic calibration and diagnostic systems.

Figure 5-12. Tatra Friction Tester

5.12 RUNWAY ANALYZER AND RECORDER (RUNAR)

5.12.1 The standard RUNAR is a trailer equipped with the RUNAR basic friction-measuring unit. It is a hydraulically braked machine using an ASTM El551 specification test tire. The basic unit measures 90 cm H **x** 45 cm W x 80 cm L and weighs approximately 100 kg. The trailermounted configuration has a total weight of 400 kg. A version for side mounting on a maintenance truck has a total weight of approximately 150 kg. The standard trailermounted configuration is shown in Figure 5-13. The measuring sensors are mounted on the hydraulic brake providing continuous data which are collected, processed, stored and displayed to the operator by the data-processing computer. The instrumentation in the vehicle consists of a touch-screen operation panel and a 10-cm graphic roll or A4 colour graphic printer. The RUNAR can be operated at speeds up to 130 **km/h.** Measuring can take place above 20 **km/h.**

5.12.2 The RUNAR device can perform in the continuous friction-measuring equipment mode (CFME) and the variable slip-measuring mode. In the CFME mode the constant slip ratio of the measuring wheel may be set to any percentage between 5% and 100%. In the variable slipmeasuring mode, the test is conducted by applying wheel braking from free rolling to fully locked on the runway surface and measuring the braking friction force which the runway surface exerts against the braking wheel.

5.12.3 The RUNAR computer can be configured to provide average measurements for any length of pavement measured. It can also output averages for each third or for the whole length of the runway. The computer acquires and stores the following information:

a) brake friction force;

b) rotational speed of the measuring wheel, and host vehicle speed; and

c) ambient air temperature at approximately 20 cm above the runway surface.

All measured data are stored in a file for each measuring mission. As **a** backup, data are also saved on a computer diskette.

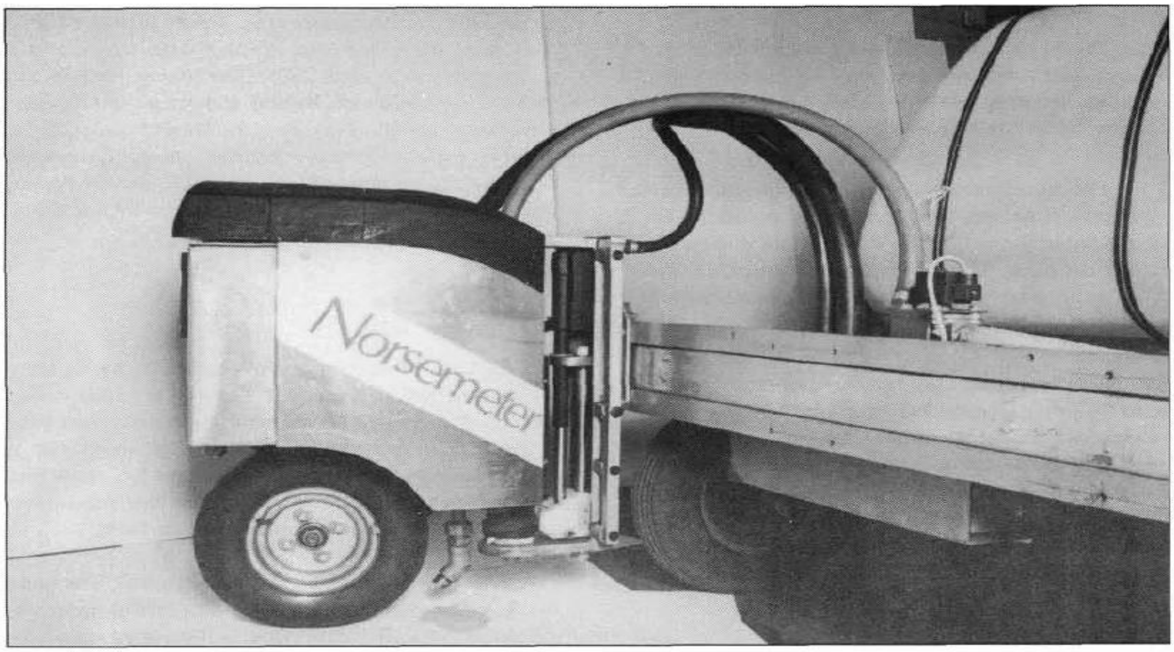


Figure 5-13. RUNAR Runway Analyzer and Recorder

5.13 DECELEROMETERS

General

5.13.1 Decelerometers provide the most reliable information when pavement surfaces are covered with compacted snow and/or ice. Decelerometers should not be used on wet pavement surfaces, and tests should not be conducted when pavement surfaces are covered with loose or dry snow exceeding 51 mm depth or with slush exceeding 13 mm depth.

5.13.2 Since decelerometers have to be mounted inside a vehicle, certain requirements for the vehicle have to be met to ensure that reliable and consistent measurements are obtained. Acceptable vehicles are large sedans, station wagons, intermediate or full-size automobiles, utility and passenger-cargo trucks, vehicles that have front-wheel or four-wheel drive, and vehicles that have an anti-locking braking system (ABS) on the rear axle.

5.13.3 Tires on the vehicle can significantly influence friction measurements. Therefore, they should all have tread patterns that do not exceed 50 per cent wear, and tire pressure should always be maintained at all times according to the manufacturer's specifications.

5.13.4 The vehicle brakes should always be properly adjusted to ensure a balanced action. The vehicle should have minimum pitching tendency and satisfactory direc- tional stability when the brakes are applied.

5.13.5 The decelerometer should be installed in the vehicle according to the manufacturer's instructions. It should be placed in the vehicle so that it is not displaced by any vehicle movement. The decelerometer should be maintained and calibrated according to the manufacturer's recommendations.

5.13.6 It is necessary to take a certain number of readings to obtain a reasonable appraisal of the runway surface condition. The total runway length is divided into three equal portions — the touchdown, mid-point and roll-out zones. A minimum of three tests at the speed of 35 km/h should be conducted in each zone. An averaged μ number should be determined for each zone. The averaged μ numbers are always recorded in the same direction the aeroplane lands.

a) Brakes should be applied sufficiently hard to lock all four wheels and then should be released immediately. The time during which the wheels are locked should not exceed one second.

5.13.7 The following procedures should be used in conducting friction surveys.

b) The decelerometer used should record or retain the maximum retardation braking force occurring during the test.

c) Random figures that are very high or very low may be ignored when calculating the average values.

5.13.8 Since decelerometers require the test vehicle to be accelerated to given test speeds, which takes a finite distance, the intervals at which the test readings can be taken are necessarily greater than those taken by the continuous friction-measuring devices. These devices, therefore, can be considered only as spot-reading friction-measuring devices.

Brakemeter-Dynometer

5.13.9 The Brakemeter-Dynometer consists of a finely balanced pendulum free to respond to any changes in speed and angle, working through a quadrant gear train to rotate a needle around a dial (see Figure 5-14). The dial is calibrated in percentage of "g", the accepted standard for measuring acceleration and deceleration. To stop all vibration, the instrument is filled with a fluid not sensitive to changes in temperature. The meter, which requires a vehicle for transport, should always be used with a floor-mounting stand. This device should only be used on runway surfaces covered with ice and/or compacted snow. It is not recommended for operation on wet runway pavement surfaces. The procedures for conducting friction tests are given in 5.13.7.

Tapley Meter

5.13.10 Two versions of the Tapley Meter are available on the market: the original Tapley (a standard mechanical decelerometer) and the Tapley Electronic Airfield Friction Meter. Both require a vehicle for transport and are recommended for use only on compacted snow and/or ice-covered runway surfaces. They are not recommended for operation on wet runway pavement surfaces.

5.13.11 *Mechanical decelerometer.* The mechanical version is a small pendulum-based decelerometer, consisting of a dynamically calibrated, oil-damped pendulum in a sealed housing (see Figure 5-15). The pendulum is magnetically linked to a lightweight gear mechanism to

Figure 5-14. Brakemeter-Dynometer

Figure 5-15. Tapley Standard Mechanical Meter

which is attached a circumferential scale which shows values in percentage of "g". A lightweight ratchet retains the maximum scale deflection reached upon completion of a test. The mechanism is enclosed in an aluminium case and the scale is covered with a glass face. The whole assembly is mounted in a cast base plate by means of a fork assembly. Each meter is statically tested and dynamically calibrated before being issued a calibration certificate. When the meter is used in a friction survey, it is placed on the floor of the vehicle. The data have to be visually read and recorded by the operator, and the averages for each one-third segment of the runway mentally calculated and recorded. The procedures for conducting friction tests are given in 5.13.7.

5.13.12 *Electronic decelerometer.* The Electronic Airfield Friction Meter provides a recording of the data taken during a friction survey, including averages for each one-third segment of the runway. Figure 5-16 shows the configuration of the meter. The meter is a pendulum-activated, semi-automatic, recording decelerometer, which operates on the same principles as the original Tapley Mechanical Decelerometer. When preparing for a friction survey, the operator places the meter on the floor of the test vehicle. The actuating pad is fitted to the brake pedal, and the command module is attached to the vehicle's window by a suction pad in front of the driver's side or in any location that is readily visible to the operator. The power leads are connected either to the vehicle's battery or to a separate battery. The electronic meter is tested at the factory against the standard Tapley Meter. These devices should be used only on runway surfaces covered with ice and/or compacted snow. The procedures for conducting friction tests are given in 5.13.7.

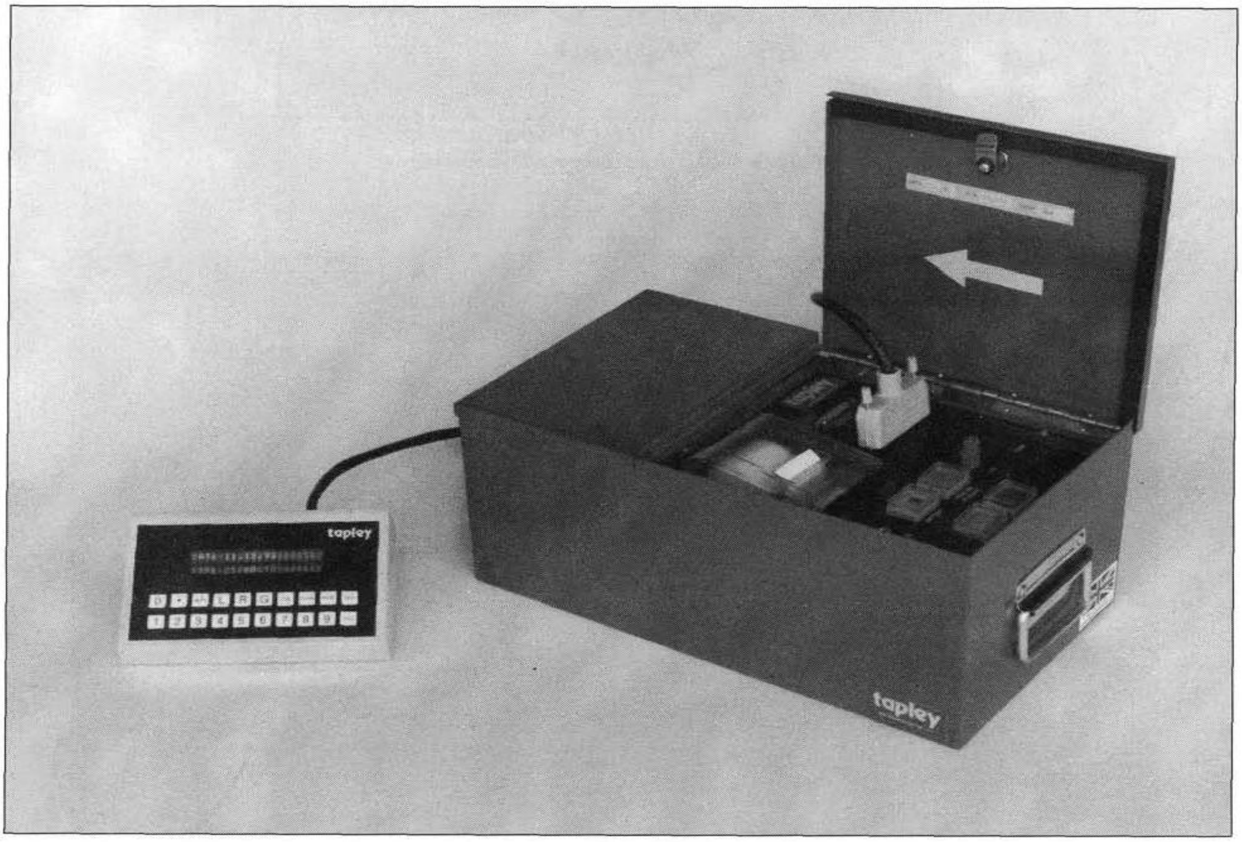


Figure 5-16. Tapley Electronic Airfield Friction Meter

Chapter 6

Collection and Dissemination of Pavement Surface State Information

6.1 GENERAL

6.1.1 The provisions in KCASR 14, , require that the appropriate authority assess the conditions of pavements whenever it has not been possible to clear the contaminants fully, and make this information available to the appropriate units at the airport.

a NOTAM notifying the presence or removal of or significant changes in hazardous conditions due to snow, slush, ice or water on the movement area must be issued. This information may be promulgated by means of a SNOWTAM .

6.1.2 The requirements for an effective system of collecting and disseminating pavement surface state information may be set out as described in this chapter. (It is assumed that it is not always possible to achieve and maintain a clean, dry pavement surface.)

6.1.3 Before take-off or landing, the pilot needs information on all aspects of an airport, its aids and operational facilities. In many cases, an adverse combination of available take-off or landing distance, tail or cross-wind components, visibility and poor friction characteristics will make a take-off or landing impossible.

6.1.4 In order to enable aeroplane operators and pilots to readily appraise and use the information received, it is necessary to have the information and its presentation standardized. Reports must be in the form of a positive statement and must be as complete as possible. This, in turn, generates a great deal of information. A standardized code is, therefore, necessary in order to streamline the communications processes, particularly when severe meteorological conditions prevail over a large area, and to allow rapid updating.

6.1.5 Data collection must be swift, comprehensive and accurate, and accuracy necessarily calls for special aids or instruments for the measurement of the different parameters so as to avoid subjective judgements.

6.1.6 Transmission of the information must be quick, regular and timely; i.e., it must reach the pilot in time to be of use and yet be up to date. This aspect is especially important as much of the information is necessarily very transitory.

6.1.8 It is essential that arrangements be made for the timely provision of required information to the aeronautical information service by each of services associated with aeroplane operations. Before introducing changes to the air navigation system, due account shall be taken by the services responsible for such changes of the time needed by the aeronautical information service for the preparation, production and issue of relevant material for promulgation. Timely and close coordination between the services concerned, including the aeronautical information service, is therefore required to ensure timely provision of the information to the aeronautical information service.

6.2 WET SURFACE STATE INFORMATION

6.2.1 The runway should be periodically tested to ensure that its friction characteristics are above an accept- able level. In addition, runways with friction characteristics below the minimum acceptable level should be identified and pilots informed accordingly. To this end, the criteria used by DGCA for evaluating the runway surface friction

characteristics should be published in the Jordan aeronautical information publication. This should include the type of friction-measuring device used and the minimum acceptable level selected by the State.

6.2.2 A NOTAM should be issued whenever the runway surface friction characteristics do not meet the minimum acceptable level selected by the State. The NOTAM should be issued until such time as corrective action has been taken by the State. Arrangements may be made by the DGCA for direct exchange of SNOWTAMs between aerodromes.

6.2.3 In addition to the periodic runway friction testing outlined in 6.2.1, when a runway is known to become slippery under unusual conditions, then additional measurements should be made when such conditions occur. It is intended that information on the runway surface friction characteristics be made available to the appropriate units when these additional measurements show that the runway or a portion thereof has become slippery.

Chapter 8

Removal of Rubber

8.1 GENERAL

8.1.1 Rubber deposited in the touchdown zone by tires of landing aeroplanes obliterates runway markings and, when wet, creates an extremely slick area on the runway surface. The removal of rubber is carried out by means of:

a) chemical solvents;

b) high-pressure water blasting;

c) chemical solvents and high-pressure water blasting; and

d) hot compressed air.

8.1.2 In assessing the effectiveness of any system for rubber removal, the objective must be clearly understood, i.e. to restore a good coefficient of friction in wet conditions so as to provide safe operational conditions for all aeroplanes. A change in surface colour, for example, from black to grey on Portland cement concrete can be very misleading, because even a small amount of residual rubber in the pores of the pavement can produce low friction values, while giving an overall clean appearance. It is therefore essential to quantify the friction coefficient by means of a reliable friction-measuring device.

8.1.3 In most cases, high-pressure water blasting is reasonably effective on lightly contaminated areas, but its effectiveness decreases as the depth of contamination increases. Depending upon the type and volume of traffic, cleaning may be required twice a year. A modern practice is to dissolve rubber deposits with chemical solvents followed by thorough flushing with high-pressure water blasting.

8.1.4 In order to determine the amount of rubber needed to be removed from the pavement to provide an acceptable surface condition, it is recommended that a test area be used to predetermine the water pressure and rate of travel required to produce this acceptable surface. Observed productivity of high-pressure water blasting during normal working conditions indicates a rate of 278 m^2 per hour per unit while cleaning. Refilling of a typical water tank accounts for approximately two hours in each eight-hour shift. Therefore, one touchdown zone 900 m × 24 m would require approximately 100 hours per unit.

8.1.5 The hot compressed air technique uses high-temperature gases to burn away the rubber deposits left by aeroplane tires and can be used on both Portland cement concrete and asphaltic concrete runways. It has been claimed that as no mechanical action takes place at the runway surface, there is little danger of the surfacing material becoming loose and causing foreign object ingestion. However, caution should be exercised and the condition of the pavement should be closely monitored when using this technique on asphaltic concrete runways.

8.2 CHEMICAL REMOVAL

8.2.1 Chemical solvents have been successfully used for removal of rubber deposits on both Portland cement concrete and asphaltic concrete runways. Chemicals having a base of cresylic acid (a derivative of creosote) and a blend of benzene, with a synthetic detergent for a wetting agent, are used for removal of rubber on concrete runways. For removal of rubber on asphalt runways, alkaline chemicals are applied.

8.2.2 The volatile and toxic nature of the cleaning compound dictates that EXTREME CARE be taken during and after application. If the chemical is allowed to remain on the surface for too long, the paint and possibly the pavement surface could be damaged. When washing the cleaning compound off the pavement surface, it must be so diluted that it will not harm the surrounding vegetation, drainage system or wildlife, or pollute nearby streams.

8.2.3 Since the application process consists of spraying the solvent solution on the contaminated area, waiting a period of up to one hour, then washing and sweeping, it is likely that one touchdown zone 900 m x 24 m could be treated in one eight-hour shift. A modem practice for the removal of rubber from pavement surfaces is to dissolve rubber deposits with chemical solvents followed by thorough flushing with high-pressure water blasting.

8.3 MECHANICAL REMOVAL

8.3.1 *High-pressure water cleaner.* The equipment ranges from a single, manually operated nozzle (or gun) supplied by pump and water tender, to a sophisticated, selfpropelled semi-trailer incorporating a pump, 22 700 L capacity water tank and oscillating high-pressure

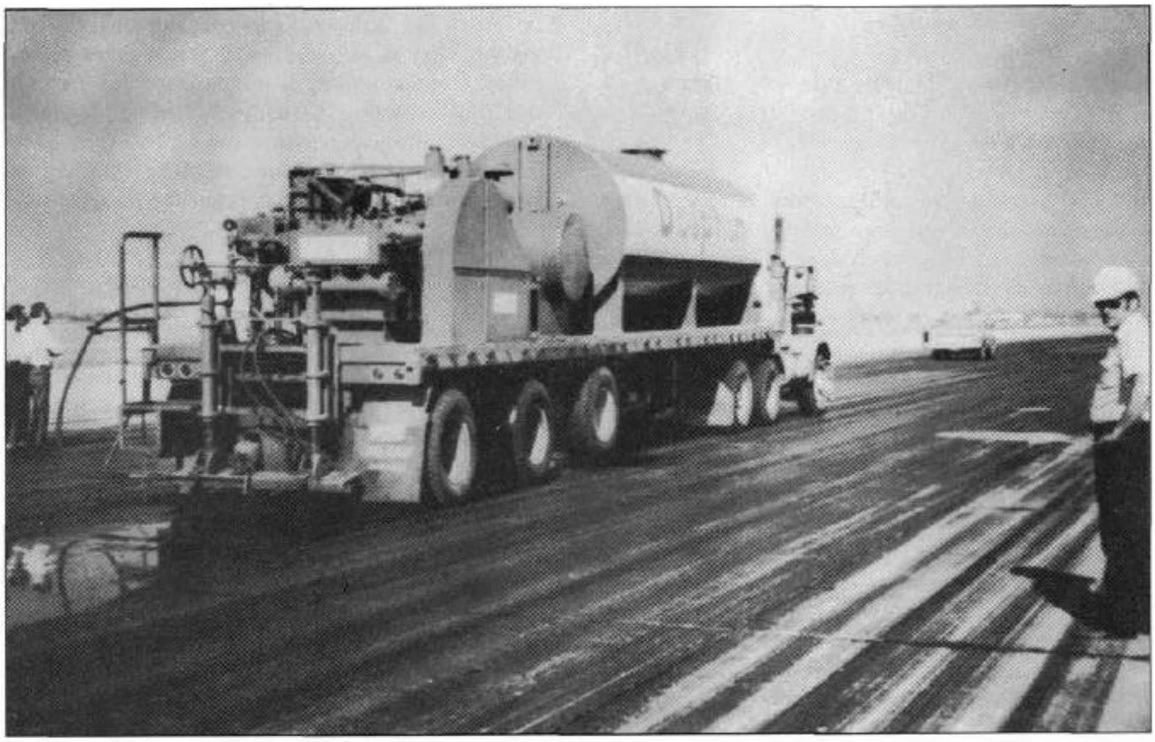


Figure 8-1. Oscillating high-pressure water vehicle

water spray bar (Figure 8-1). Pressures between 350 kg/cm2 and 700 kg/cm2 are common.

8.3.2 ***Hot,*** *compressed air cleaner.* The machine operates on an airlgas mixture fed into a combustion chamber where burning takes place. The resulting exhaust is emitted at about 400 mls from orifices at a temperature of approximately 1 200°C directly onto the surface. These gases soften and shear off the rubber particles. When a hot compressed air cleaner is used on concrete surfaces, a small amount of carbon deposit is produced; this can be brushed from the surface of the concrete using a normal tractor- or truck-mounted brush machine which most airports already have. In the case of asphaltic concrete surfaces, a slightly rejuvenated surface is produced which is claimed to be a desirable effect.

Chapter 9

Clearance of Oil and/or Grease

9.1 GENERAL

9.1.1 Free deposits of these materials may be blotted up with rags, sawdust, sand, etc., and the residue then scrubbed with detergent using a rotary power broom. It will likely be necessary to remove the deteriorated portions of the oil-impregnated asphalt areas in order to successfully repair or seal the surface.

9.1.2 Oil-soaked and stained areas on concrete surfaces are washed to remove imbedded material using a detergent compound of sodium metasilicate and resin soap applied with water and scrubbed with a power broom. The loosened contaminants are flushed away with water. For asphaltic concrete pavements, an absorbent or blotting material, such as sawdust or sand, combined with a powdered alkaline degreaser, is used.

Chapter 10

Clearance of Debris

10.1 GENERAL

10.1.1 The specifications of KCASR 14 , call for the surface of aprons, taxiways and runways to be kept clear of any loose stones or other objects that might cause damage to aeroplanes or engines or impair the operation of aeroplane systems. Turbine engines are extremely suscep- tible to damage as a result of foreign object ingestion. Other components of aeroplanes are vulnerable, and some oper- ators experience aeroplane skin damage and incidents of nicked propellers as a result of loose stones or other debris becoming dislodged by slipstream, jet blast or tire action.

10.1.2 Although damage to aeroplanes is usually associated with engine ingestion, substantial damage to tires is also a significant aspect of the overall problem. Cuts or bursts resulting from contact with sharp objects, untreated joints, or deteriorating pavement edges are responsible for reduced tire life and account for a large proportion of aeroplane tires being scrapped prematurely. Of particular concern are tire failures during the take-off run and the resulting risk of consequential failure of neighbouring tires from overloading, thereby causing an aborted take-off.

10.1.3 Debris constitutes a potential hazard to the safety of operations and has in the past been directly responsible for aeroplanes abandoning take-offs or execut- ing emergency landings. Apart from the safety aspect, the unscheduled replacement of damaged parts may involve significant economic penalties.

10.1.4 The introduction of new aeroplane types with their engines installed closer to the ground has aggravated the problem. The cleanliness of the entire airport surface should, therefore, be a matter of ongoing concern, requiring attention by aerodrome operators.

10.1.5 Based on operational experience, the following are some of the aspects that should not be overlooked in the development of a suitable programme intended to achieve and maintain the required standard of cleanliness in the areas concerned.

10.1.6 Experience with turbine engine aeroplanes indicates that one of the most effective measures to mini- mize the problem of debris on the movement area is frequent inspection and sweeping, including the use of sweeping equipment with magnetic attachments. Where aeroplanes operate over an extensive route network, it is sometimes difficult to pinpoint the precise location where damage has occurred, but airports at which regular inspection and sweeping are known to be the practice are less likely to encounter this problem.

10.1.7 Regular inspection by an airport official, together with a nominated representative of the operators, is already a recognized procedure at many airports and can form the basis for regular airport inspection reports testifying to the effectiveness of the cleaning programme. Arrangements for such joint inspections (which should permit access to all operational areas, including runways and taxiways, as well as the immediate apron area) and the development of a proper reporting form can be carried out in consultation with a representative of the operators. In one State, this procedure has been used to establish a sweeping priority/frequency programme, which includes analysis of the debris to determine its origin. Thus, areas where debris is most likely to occur can be isolated and cleaning operations in those areas increased. Where the source of debris can be established, remedial measures can also be taken with those responsible. In connection with this programme, a plan of the paved area is divided into conveniently sized squares, 20 m × 20 m, to assist in pinpointing the location of any debris found.

10.1.8 A potential source of debris, particularly on aprons, obviously stems from the activities of the operators themselves in the handling and servicing of their aero- planes. Airline personnel receive training and recurrent reminders on the need for apron cleanliness, but aerodrome operators can also assist by ensuring that covered receptacles for litter and other debris are provided in sufficient number and are used. Such receptacles should also be provided on all vehicles routinely used on the movement area, regardless of ownership.

10.1.9 Other apron users, such as aeroplane caterers, fuel suppliers, forwarding agents and handling agents, do not come under the direct supervision of the operators. Aerodrome operators should check that those engaged in the provision of such services have also taken steps to instruct their staff properly regarding the prevention of litter and the disposal of waste material. Widespread use of polythene bags and sheets by the catering services and aeroplane maintenance personnel, and as temporary protection for freight or components against weather, considerably increases the chance of engine ingestion of this type of material. Engine failures have occurred as a direct consequence. Sand used to clean fuel and oil spillage from aprons is a further potential cause of turbine engine and propeller damage and should be immediately and efficiently removed after use.

10.1.10 Cargo areas, by the very nature of the operations they support, are particularly susceptible to contamination from strapping, nails, paper and wood, which may become detached from crates or other containers in the course of freight handling. Other equipment which has been found in cargo areas includes loose buckles from cargo tiedown nets, loose turnbuckles and large sheets of polythene film. To the extent that forwarding agents operate in these areas, the aerodrome operator should require that they assume their share of the responsibility for keeping it in good condition. Where night activities are frequently involved, good illumination is necessary so that the areas can be kept clean.

10.1.11 On taxiways, bypass areas and holding bays, and on runways themselves, the presence of stones and other debris as a result of erosion of the adjacent areas can constitute a problem, and guidance on preventive measures, including the sealing of runway and taxiway shoulders, is already contained in Part 2 of the *Aerodrome Design Manual* (Doc 9157). The need for adequate sealing has been highlighted by the introduction of large jet aeroplanes with greater engine overhang. Until runway and taxiway shoulders are adequately sealed, care is needed to ensure that vegetation and grass cuttings do not present an ingestion problem to overhanging engines. Moreover, the areas immediately adjacent to the paved and sealed surfaces should also receive regular inspection and attention to ensure that debris which could subsequently find its way onto the more critical areas is not present.

10.1.12 Deterioration of the bearing surface itself, leaving loose sand, fragments of concrete and bitumen, is another possibility, and concrete joints, if not properly filled, are excellent traps for debris. Such joints should be filled to permit effective sweeping. There is also an indication that kerosene spillage on bitumen taxiways and runways, caused by the venting of fuel tanks of aeroplanes in motion, can result in deterioration of the surface and engine ingestion problems. These areas should be frequently inspected and prompt repair work carried out, whenever necessary, so as to prevent further break-up of the pavement.

10.1.13 Sand and grit remaining on the runway, after serving to improve runway braking action under icy conditions, form debris which should be removed as soon as possible after their requirement ceases. Similarly, slush containing sand, grit and lumps of ice should be removed from the pavement as soon as possible.

10.1.14 Where construction is in progress on an airport, the authorities should, if possible, prohibit use of the movement area by contractors' vehicles or at least minimize it by restricting them to marked lanes, particu- larly when they are engaged in transporting the type of loads from which spillage frequently occurs, such as building waste, gravel and fill. Earth and stones adhering to the wheels of such vehicles can also become dislodged and subsequently create a hazard to aeroplanes using the same areas. Where building construction is in close proximity to the movement area, it is important that some form of screening be provided to prevent sand and small stones from being blown onto the movement area by high winds or jet blast. Following the completion of construction, the contractor must remove **all** debris from the surrounding areas.

10.2 EQUIPMENT FOR THE REMOVAL OF DEBRIS

10.2.1 Different methods for providing clean airport pavement have been developed by aerodrome operators throughout the world. Removal of debris is generally accomplished by utilization of mechanical units, such as power brooms and vacuums or compressed air sweepers, which are operated on the pavements to be cleaned.

10.2.2 *Magnetic beam trailer.* This unit is a two-wheeled trailer designed for towing on runways to magnetically pick up loose metallic objects from the surface. Permanent magnets are mounted across a bar to which brush segments are attached. The bar is lowered to a sweeping position and the magnet attracts the metallic objects, gathering them from the pavement surface. However, it would appear that powered sweeping brooms are more effective for removing these objects from the surface.

10.2.3 Mechanical sweepers should have characteristics such that the maximum possible amount of debris is removed in each pass of the unit at the required operating speed: for fine sand, thinly spread on the surface of a pavement, pick-up of the order of 98 per cent in one pass has been achieved at speeds in excess of 16 km/h; for small, ferrous, metallic debris, magnetic trailers can achieve up to 100 per cent pick-up in one pass at the required operating speed. If mechanical debris removal units are to be operated on active sections of the movement area, it is most desirable that they have a high operating

speed capability so that they present minimal interference to aeroplane operations. Some modern, truck-mounted sweeping units are capable of sweeping at speeds up to 40 km/h. It is generally a characteristic of mechanical units, however, that their pick-up efficiency decreases significantly with increases in operating speed.

10.3 SWEEPER TESTS

10.3.1 Sweepers should be tested regularly by a performance test. A description of the practice being used by one State for performance testing is given below.

a) Select a flat, smooth, bituminous, concrete area and mark out a section 6 m × 2 m on the surface.

b) Assemble a 0.45 kg mixture comprising equal portions of each of the materials (dry) specified as medium/fine gravel, coarse sand and medium/fine sand.

   1) *Medium/fine gravel.* The gradation of this material is such that 100 per cent shall pass a 9.5 mm screen size and not more than 2 per cent pass a 2.4 mm screen size.

   2) *Coarse sand.* The gradation of this material is such that 100 per cent shall pass a 2.4 mm screen size and no particles pass a 0.6 mm screen size.

   3) *Medium/fine sand.* The gradation of this material is such that 100 per cent shall pass a 0.6 mm screen size and no particles pass a 0.3 mm screen size.

c) Obtain eight stones, spherical in shape, 50 mm diameter, and one of each of the following: 6 cm nail, 12 mm diameter ball-bearing, a piece of aluminium (50 mm square × 1.2 mm thick), and 12 mm nut.

d) Spread the mixture of medium/fine gravel, coarse sand and medium/fine sand evenly over the test area. Along one diagonal of the test area, place the eight stones at equal spacings, and along the other diagonal, place the nail, ball-bearing, aluminium square and nut at equal spacings.

e) The sweeper shall be operating normally and, on passing over the prepared test area at 16 km/h, shall pick up and retain 98 per cent of the sand and gravel and 100 per cent of the stones and miscellaneous objects.

10.3.2 In the event of a sweeper failing to comply with a performance test, action should be taken to restore the sweeper to the acceptable operational standard of performance. The frequency of sweeper tests will depend largely on the utilization of the unit. It is common practice to undertake such tests on a regular weekly basis.

Appendix 1

Method for Determining the Minimum Friction Level

1. Historically, the term "minimum friction level" (MFL) is related to ensuring the safe operation of aeroplanes when the runway is wet. The method described herein attempts a rational approach to the problem of defining MFL by equating the wet runway "MFL" to aeroplane wet landing performance as defined by the Federal Aviation Administration (FAA) wet landing field length.

2. The dry landing field length for an aeroplane is determined during certification braking tests conducted on a dry runway surface as shown in Figure A1-1. For wet runway operation, the dry landing field length is increased by 15 per cent. Thus, it can be seen that all three segments of the certification aeroplane dry landing distance — air distance, transition distance and braking distance — are multiplied by the two factors 1.667 × 1.15 = 1.92 to obtain the aeroplane wet landing field length. In effect, the Federal Air Regulations (FAR) allow for the wet runway braking friction coefficient developed by the aeroplane to be decreased to approximately half of the dry runway braking friction coefficient or a wet/dry braked stopping distance ratio of 1.92.

3. Figure A1-2 shows the variation of wet/dry braked stopping distance ratio with average wet runway braking friction coefficient for typical 2-engine narrow body and 3-engine wide body jet transports. The curves in Figure A1-2 show that use of half the dry runway MU-EFF results in a wet/dry braked stopping distance ratio (SDR) of 1.68 for the 2-engine and 1.77 for the 3-engine jet transport. It should be noted that these SDRs are less than 1.92 due to the effects of aeroplane aerodynamic drag and tire-rolling resistance, as well as to wheel braking, on each aeroplane's stopping performance. The minimum wet runway friction values currently assigned to runway

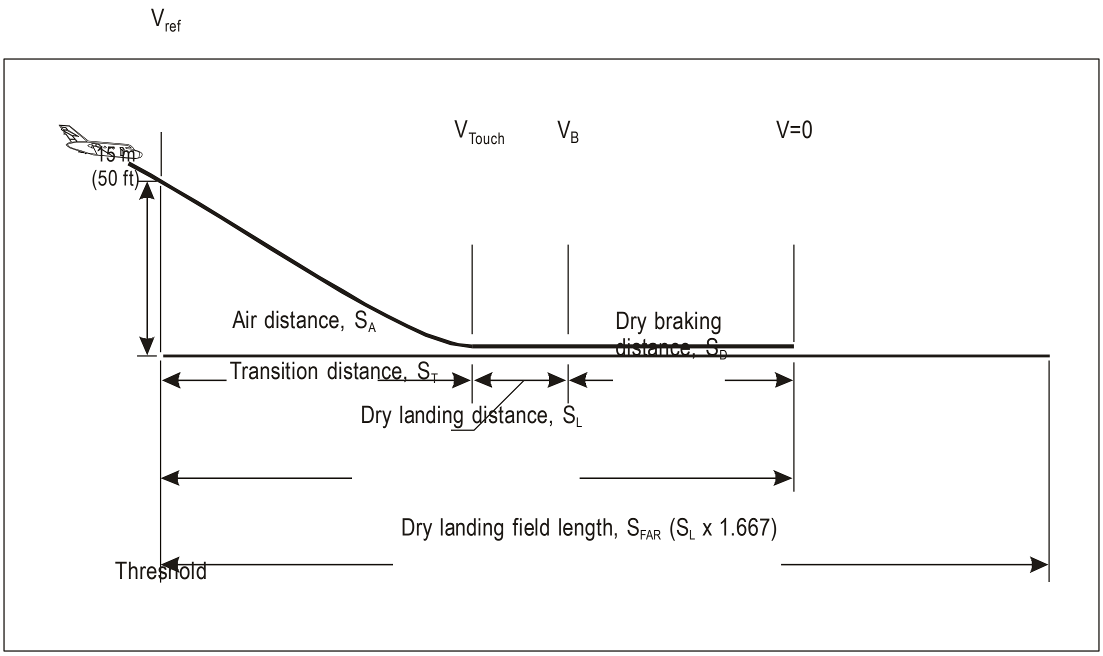
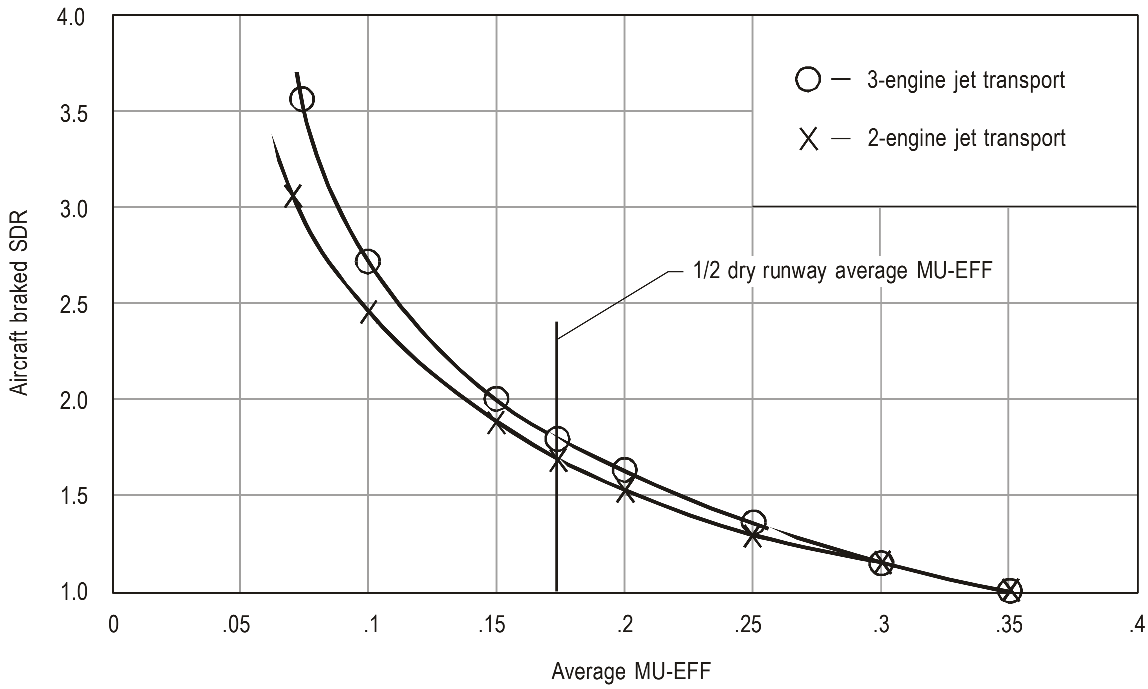


Figure A1-1. Aircraft landing terminology



Antvik Aircraft SDR/Average MU-EFF correlation equation:

$$SDR = A/MU\text{-}EFF + B/MU\text{-}EFF^{2} + C/MU\text{-}EFF^{3} + D/MU\text{-}EFF^{4} + E/MU\text{-}EFF^{5}$$

A = +0.447126	A = +0.411922
B = –4.29469E-2	B = –2.6458E-2
C = +4.05005E-3	C = +2.05336E-3
D = –2.34017E-4	D = –1.01815E-4
E = +5.61025E-5	E = +2.22342E-5

Figure A1-2. Aircraft wet/dry braked stopping distance ratio versus average MU-EFF (reverse engine thrust not used during landing)

friction-measuring equipment were arbitrarily chosen based mainly on experience and some runway friction tests. When these friction numbers were chosen, no method existed to determine whether these numbers would result in higher or lower aeroplane wet/dry braked SDR than that obtained by using half the average aeroplane dry runway braking MU-EFF.

4. This proposed method makes use of the NASA Combined Viscous/Dynamic Hydroplaning Theory to transform runway friction tester MFL numbers into equivalent aeroplane braking MU-EFF numbers so that an average wet runway braking MU-EFF can be calculated. This calculated MU-EFF, based on the runway friction tester MFL, is then entered into Figure A1-2 to determine whether the friction

tester MFL is conservative or unconservative in terms of aeroplane stopping performance.

Calculation procedure

5. The NASA Combined Viscous/Dynamic Hydroplaning Theory (refer to references 1 and 3 at the end of this appendix) suggests that the friction/speed curves generated on wet pavements by tires having different sizes, tread rubber compounds, and inflation pressures can be normalized by using non-dimensional ratios for both friction (MU/MU-ULT) and speed (V/VC). Using this approach, the following equations have been derived to estimate the aeroplane effective braking coefficient (MU-EFF)

developed on wet, flooded, or slush-covered runways from a runway friction tester test.

6. Wet runway correlation equations

Predicted aeroplane tire $(MU\text{-}MAX)_A$:

$$(MU\text{-}MAX)_A = (MU_T)(MU\text{-}ULT)_A/(MU\text{-}ULT)_T \quad (1)$$

Predicted aeroplane braking $(MU\text{-}EFF)_A$:

$$(MU\text{-}EFF)_A = 0.2(MU\text{-}MAX)_A + 0.7143(MU\text{-}MAX)_A^2 \quad (2)$$

Predicted aeroplane speed $(V)_A$:

$$(V)_A = (V)_T(VC)_A/(VC)_T \quad (3)$$

Characteristic hydroplaning speed (VC):

Aeroplane: $(VC)_A = 6.35\sqrt{P}$, km/h;

P = tire pressure in kPa (4)

Tester: $(VC)_T$ must be determined from experimental test on flooded pavement (Table A1-1)

Characteristic friction coefficient (MU-ULT):

Aeroplane: $(MU\text{-}ULT)_A = 0.93 - 0.0001596(P_A)$ (5)

Tester:

$(MU\text{-}ULT)_T$ must be determined from experimental low-speed test (1.6–3.2 km/h) on dry pavement (Table A1-1)

$(MU)_T$ obtained from friction tester wet runway data

$(V)_T$ friction tester test speed to obtain $(MU)_T$

P_A aeroplane tire inflation pressure, kPa

Subscripts: A = aeroplane; T = runway friction tester

7. *Sample calculation.* The minimum friction level (MFL) for a runway friction tester is 0.5 at 65 km/h and 0.41 at 95 km/h (refer to reference 4 at the end of this appendix). The following step-by-step procedure transforms these friction and speed values into equivalent MU-EFF and speed values for the 2-engine jet transport aeroplane shown in Figure A1-2. These MU-EFF values will be averaged over a 0–278 km/h (0–150 knot) aeroplane braking speed range to obtain a value for this aeroplane which can be used in Figure A1-2 to obtain its braked SDR, which then can be compared with the SDR obtained from using half the dry runway aeroplane MU-EFF. Thus, it becomes possible to determine whether or not the friction tester

Step 1. Use equation (1) and Table A1-1 to calculate the $(MU\text{-}MAX)_A$ values for this aeroplane at the two friction tester test speeds of 65 km/h and 95 km/h.

For 65 km/h: $(MU\text{-}MAX)_A = 0.5(0.76)/1.0 = 0.38$
For 95 km/h: $(MU\text{-}MAX)_A = 0.41(0.76)/1.0 = 0.312$

Note.— The $(MU\text{-}MAX)_A$ values shown above indicate the maximum wet runway friction coefficients available for the unbraked aeroplane tire for this minimum wet runway friction level.

Step 2. Use equation (2) to calculate MU-EFF for this aeroplane at the two friction tester test speeds.

For 65 km/h:

$(MU\text{-}EFF)_A = 0.2(.38) + 0.7143(.38)^2 = 0.179$

For 95 km/h:
$(MU\text{-}EFF)_A = 0.2(0.312) + 0.7143(0.312)^2 = 0.132$

Step 3. Use equation (3) and Table A1-1 to calculate the equivalent aeroplane speeds for the friction tester test speeds of 65 km/h and 95 km/h.

For 65 km/h: $(V)_A = 65(207.5)/91.2 = 147.9$ km/h
For 95 km/h: $(V)_A = 95(207.5)/91.2 = 216.15$ km/h

Step 4. Use the linear regression equation $(MU\text{-}EFF)_A = m(V)_A + b$ and the $(MU\text{-}EFF)_A$ and $(V)_A$ values obtained from Steps 2 and 3 to develop and solve the simultaneous equations.

$0.179 = 147.9\, m + b$
$0.132 = 216.15\, m + b$

$m = (0.179 - 0.132)/(147.9 - 216.15)$
$m = -0.00068$

$b = 0.179 - 147.9(-0.00068)$
$b = 0.280$

$$(MU\text{-}EFF)_A = 0.280 - 0.00068(V)_A \quad (6)$$

The average MU-EFF developed during a braked landing from a brake application speed of V_B occurs at the speed $V_B/\sqrt{2}$ or 196 km/h (106 knots) for V_B = 278 km/h

MFL values at 65 km/h and 95 km/h test speeds are conservative or unconservative in terms of the 2-engine jet transport wet runway.

(150 knots). Use (6) to obtain the estimated average MU-EFF for $(V)_A$ = 196 km/h (106 knots).

$(\text{MU-EFF})_A = 0.280 - 0.00068(196) = 0.1468$

Average wet MU-EFF = 0.1468

Step 5. Go to Figure A1-2 and find the predicted wet/dry stopping distance ratio on the 2-engine jet transport curve for average wet MU-EFF = 0.1468 or use the Antvik correlation equation in Figure A1-2.

$$SDR = 0.447126/0.1468 – 4.29469E\text{-}2/0.1468^2 + 4.05005E\text{-}3/0.1468^3 – 2.34017E\text{-}4/0.1468^4 + 5.61025E\text{-}5/0.1468^5$$

SDR = 1.91

This SDR value (1.91) compares with the aeroplane wet/dry SDR = 1.68 (from Figure A1-2) and indicates that the friction tester values for the wet runway MFL are reasonable for the Law runway friction tester.

Concluding remarks. Similar calculations were made for brake application speeds of 278 km/h (150 knots), 259 km/h (140 knots), 241 km/h (130 knots) and 222 km/h (120 knots) for both the 2-engine and 3-engine jet transport, using the MFL method. The results are shown in Table A1-2. These calculations suggest that the 278 km/h (150 knots) brake application speed is more representative of an aborted take-off at or near V_1 speed, while the lower brake application speeds are more representative of typical aeroplane landing conditions. It can be seen from Table A1-2 that the lower brake application speeds show closer agreement between the estimated (MFL method) and the actual aeroplane wet/dry braked SDR than is the case for the 278 km/h (150 knot) brake application speed.

REFERENCES

1. Horne, Walter B. "Status of Runway Slipperiness Research", Transportation Research Record 624. Second International Skid Conference. Columbus, Ohio, 1977, pp. 95–121.

2. Horne, W. B. "Correlation Between Aircraft/Ground Vehicle Runway Friction Measurements". Prepared for Air Line Pilots Association, International.

3. Horne, W. B. and F. Buhlmann. "A Method for Rating the Skid Resistance and Micro/Macrotexture Characteristics of Wet Pavements". Frictional Interaction of Tire and Pavement, ASTM STP 793, 1983, pp. 181–218.

4. Anon. "Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces". FAA Advisory Circular 150/5320-12B.

Table A1-1. Friction tester/aeroplane braked tire conditions

Friction-measuring device/aeroplane	Test tire pressure (kPa)	Characteristic friction coefficient (MU-ULT)	Characteristic hydroplaning speed VC (km/h)
Runway friction tester	207	1.0	91.2
Surface friction tester	207	1.1	91.2
Skiddometer	207	1.15	91.2
Mu-meter	69	1.1	80.5
2-engine jet transport	1 069	0.76	207.5
3-engine jet transport	1 207	0.738	220.5

Table A1-2. Effect of brake application speed on actual and estimated aeroplane wet/dry braked stopping distance ratio using the MFL Method

Brake application speed (km/h (kt))	*RFT estimated aeroplane MU-EFF	*RFT estimated aeroplane wet/dry SDR	**Calculated aeroplane wet/dry SDR	Aeroplane type
278 (150)	0.1467	1.91	1.63	2-engine jet transport
259 (140)	0.1552	1.84	1.73	
241 (130)	0.1637	1.77	1.76	
222 (120)	0.1722	1.71	1.78	
(150)	0.1469	2.04	1.76	3-engine jet transport
(140)	0.1547	1.96	1.80	
(130)	0.1624	1.89	1.83	
(120)	0.1702	1.82	1.86	

* *From MFL Method*
** *Using wet average MU-EFF = ½ dry average MU-EFF*

Appendix 2

Procedures for Conducting Visual Inspection Runway Maintenance Surveys at Airports that Serve Turbo-jet Aeroplane Operations When Friction Equipment Is Not Available

FRICTION SURVEY PROCEDURES

1. When friction equipment is not available at the airport, the operator should conduct periodic visual maintenance inspection surveys to ensure that the pavement surface is acceptable for aeroplane operations. The operator should furnish appropriate communications equipment and frequencies on all vehicles used in conducting visual inspection surveys. This is to ensure that airport operations personnel, at both controlled and uncontrolled facilities, can monitor appropriate ground control and/or airport advisory frequencies. The following procedures should be followed when conducting visual inspection maintenance surveys.

2. *Frequency of runway visual inspection surveys.* Runway visual inspection surveys should be conducted periodically at all airports that serve turbo-jet aeroplane operations to ensure that wet runway pavement surfaces do not deteriorate below recommended minimum levels. Table A2-1, which can be used as a guide in scheduling runway visual inspection surveys, gives the suggested frequency for conducting friction surveys, based on the number of daily turbo-jet aeroplane operations for each runway end.

3. *Annual inspection surveys of pavement surface condition.* During the conduct of runway visual inspection surveys, a record of the pavement surface condition should be made and should note the extent and amount of rubber accumulation on the surface, the type and condition of pavement texture, evidence of drainage problems, surface treatment condition, and any evidence of pavement structural deficiencies. Table A2-2 shows a means for visually estimating rubber deposits accumulated in the touchdown zone. The inspector should stroke the pavement surface by hand at several locations in the touchdown zone as an aid in estimating the percentage of rubber deposits covering the pavement texture. The Mu values given in Table A2-2 represent values obtained from continuous friction-measuring devices that operate in the fixed braking slip mode. Table A2-3 shows a method for coding the condition of grooves in pavements, and Table A2-4 shows a method for coding the pavement surface type. These codes are pro- vided as a short-cut method for preparing notes concerning the pavement surface condition.

4. *Frequency of pavement textural measurement.* Pavement texture depth measurements should be conducted a minimum of three times a year when turbo-jet aeroplanes exceed 31 daily arrivals per runway end. A minimum of three measurements should be taken in each of the touchdown, mid-point and roll-out zones of the runway. An average texture depth should be recorded for each zone. These measurements should become part of the routine airport inspection of the runway surface condition, whether or not friction measurements are taken. The measurements can be used to evaluate the textural deterioration of the pavement surface caused by contaminant accumulation and/or wear/polishing effects of aeroplane braking action. For grooved pavements, texture depth measurements should be taken in non-grooved areas, such as near transverse joints or light fixtures.

5. *Measurement of pavement surface texture.* The following procedure is effective for measuring the macro-textural depth of pavements, but it will not measure the microtextural properties of the pavement surface. The texture depth along the length of the runway should average at least 0.625 mm for good skid-resistant properties. To obtain an average texture depth, represen- tative samples should be taken over the entire runway surface. The number of samples required will depend on variations in the surface texture. Descriptions of equipment, method of measurement and computations involved are as follows:

Equipment. On the left in Figure A2-1 is shown the tube which is used to measure the volume of grease which i

15 cm^3. On the right is shown the tight-fitting plunger which is used to expel the grease from the tube, and in the centre is shown the rubber squeegee which is used to work the grease into the voids in the runway surface. The sheet rubber on the squeegee is cemented to a piece of aluminium for ease in use. Any general purpose grease can be used. As a convenience in the selection of the length of the measuring tube, Figure A2-2 gives the relation between the inside diameter of the tube and tube length for an internal tube volume of 15 cm^3. The plunger can be made of cork or other resilient material to achieve a tight fit in the measuring tube.

Measurement. The tube for measuring the known volume of grease is packed full with a simple tool, such as a putty knife, with care to avoid entrapped air, and the ends are squared off as shown in Figure A2-3. A general view of the texture measurement procedure is shown in Figure A2-4. The lines of masking tape are placed on the pavement surface about 10 cm apart. The grease is then expelled from the measuring tube with the plunger and deposited between the lines of masking tape. It is then worked into the voids of the runway pavement surface with the rubber squeegee, with care that no grease is left on the masking tape or the squeegee. The distance along the lines of masking tape is then measured and the area that is covered by the grease is computed.

Computation. After the area is computed, the following equations are used to calculate the average texture depth of the pavement surface.

$$\text{Texture depth (cm)} = \frac{\text{Volume of grease (cm}^3)}{\text{Area covered by grease (cm}^2)}$$

$$\text{Average texture depth} = \frac{\text{Sum of individual tests}}{\text{Total number of tests}}$$

Table A2-1. Frequency of runway visual inspection surveys

Daily turbo-jet aeroplane arrivals for runway end	Annual aeroplane weight for runway end (million kg)	Minimum friction survey frequency
Less than 15	Less than 447	Once per year
16 to 30	448 to 838	Once every 6 months
31 to 90	839 to 2 404	Once every 3 months
91 to 150	2 405 to 3 969	Once every month
151 to 210	3 970 to 5 535	Once every 2 weeks
Greater than 210	Greater than 5 535	Once every week

Note.— After calculating the first two columns according to the procedures given in Appendix 6, the airport operator must select the column which has the higher value and then select the appropriate value in the last column.

Table A2-2. Inspection method for visual estimation of rubber deposits accumulated on runway

Classification of rubber deposit accumulation	Estimated percentage of rubber covering pavement texture in touchdown zone of runway	Description of rubber covering pavement texture in touchdown zone of runway as observed by evaluator	Estimated range of Mu values averaged 150 m segments in touchdown zone	Suggested level of action to be taken by Aerodrome operator
Very light	Less than 5%	Intermittent individual tire tracks; 95% of surface texture exposed.	0.65 or greater	None
Light	6-20%	Individual tire tracks begin to overlap; 80-94% of surface texture exposed.	0.55 to 0.64	None
Light to medium	21-40%	Central 6 m traffic area covered; 60-79% of surface texture exposed.	0.50 to 0.54	Monitor deterioration closely
Medium	41-60%	Central 12 m traffic area covered; 40-59% of surface texture exposed.	0.40 to 0.49	Schedule rubber removal within 120 days
Medium to dense	61-80%	Central 15 foot traffic area covered; 30-69% of rubber vulcanized and bonded to pavement surface; 20-39% of surface texture exposed.	0.30 to 0.39	Schedule rubber removal within 90 days
Dense	81-95%	70-95% of rubber vulcanized and bonded to pavement surface; will be difficult to remove; rubber has glossy or sheen look; 5-19% of surface texture exposed.	0.20 to 0.29	Schedule rubber removal within 60 days
Very dense	96-100%	Rubber completely vulcanized and bonded to surface; will be very difficult to remove; rubber has striations and glossy or sheen look; 0-4% of surface texture exposed.	Less than 0.19	Schedule rubber removal within 30 days or as soon as possible

Note.— With respect to rubber accumulation, there are other factors to be considered by the airport operator: the type and age of the pavement, annual climatic conditions, time of year, number of wide-body aeroplanes that operate on the runways, and length of runways. Accordingly, the recommended level of action may vary according to conditions encountered at the airport. The Mu ranges shown in the above table are from continuous friction-measuring devices that operate in the fixed braking slip mode. The Mu ranges are approximate and are to be used by the airport operator only when these devices are not available. When the devices are available, the airport operator should conduct friction surveys on the runways to establish the actual rubber classification level.

Table A2-3. Alphanumeric coding for groove condition

Pavement surface treatment	Alpha code	Numerical coding with description
Groove type	H	0 — none l — sawed grooves 2 — plastic grooves
Groove condition	G	0 — uniform depth across pavement 1 — 10% of grooves not effective 2 — 20% of grooves not effective 3 — 30% of grooves not effective 4 — 40% of grooves not effective 5 — 50% of grooves not effective* 6 — 60% of grooves not effective 7 — 70% of grooves not effective 8 — 80% of grooves not effective 9 — 90% of grooves not effective

* *When this level is exceeded, the airport operator should take corrective action to improve groove efficiency.*

Table A2-4. Alphanumeric coding for pavement surface type

Pavement surface type	Alpha code	Numerical coding with description
Asphalt concrete pavement	A	0 — slurry seal coat 1 — new, asphalt-covered aggregate, black color 2 — microtexture, 75% fine aggregate, color of aggregate 3 — mixed texture, 50-50 fine, coarse aggregate, color of aggregate 4 — macrotexture, 75-100% coarse aggregate 5 — worn surface, coarse aggregate protrudes and/or abraded out 6 — open-graded surface course, porous friction course 7 — chip seal 8 — rubberized chip seal 9 — other
Portland cement concrete pavement	C	0 — belt finished 1 — microtextured, predominately fine aggregate 2 — macrotextured, predominately coarse aggregate 3 — worn surface, coarse aggregate protrudes and/or abraded out 4 — burlap dragged 5 — broomed or brushed 6 — wire comb 7 — wire tined 8 — float grooved 9 — other

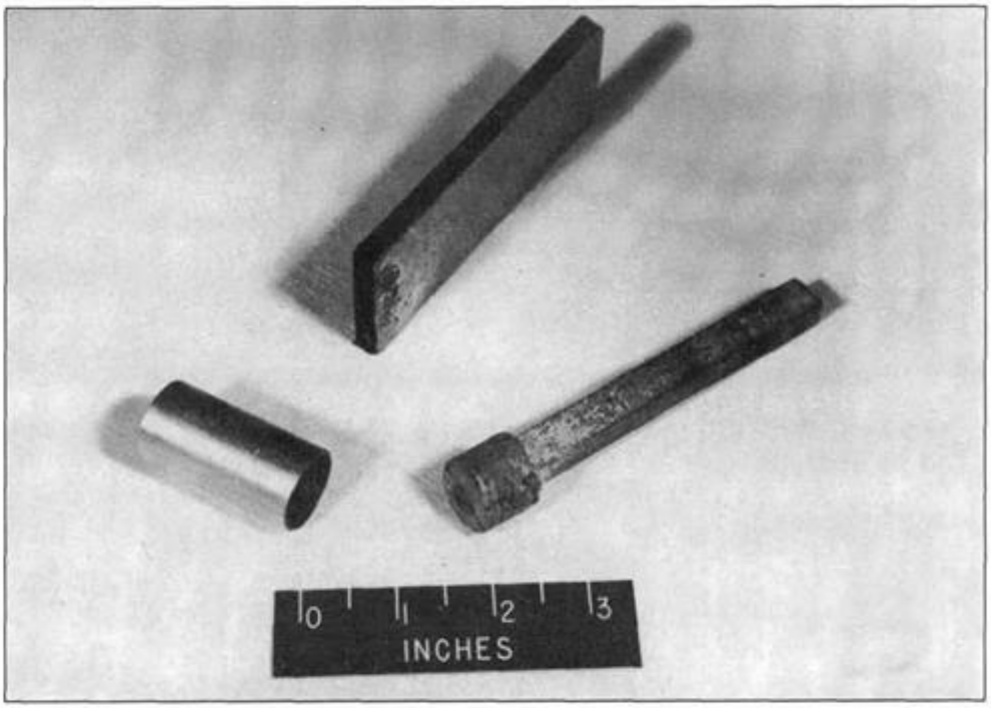


Figure A2-1. Grease-volume measuring tube, plunger and rubber squeegee

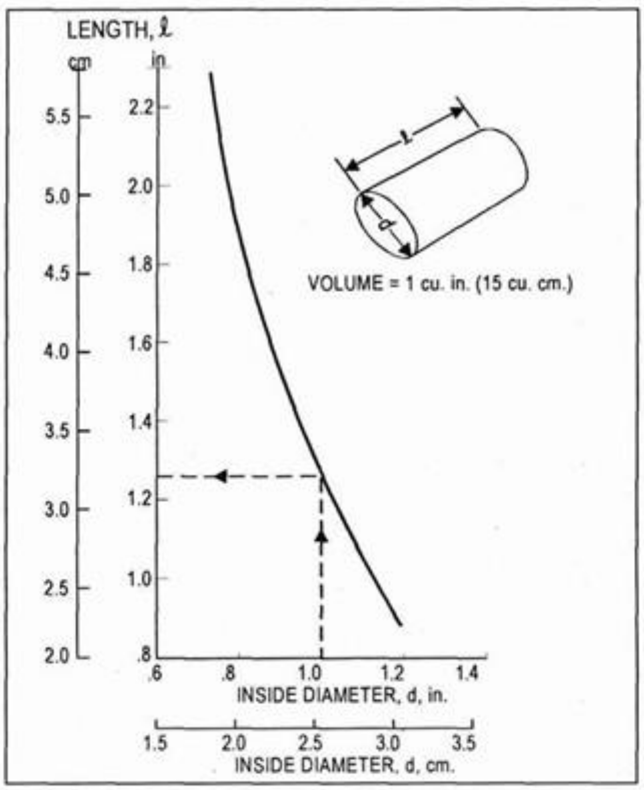


Figure A2-2. Measuring tube dimensions to measure one inch

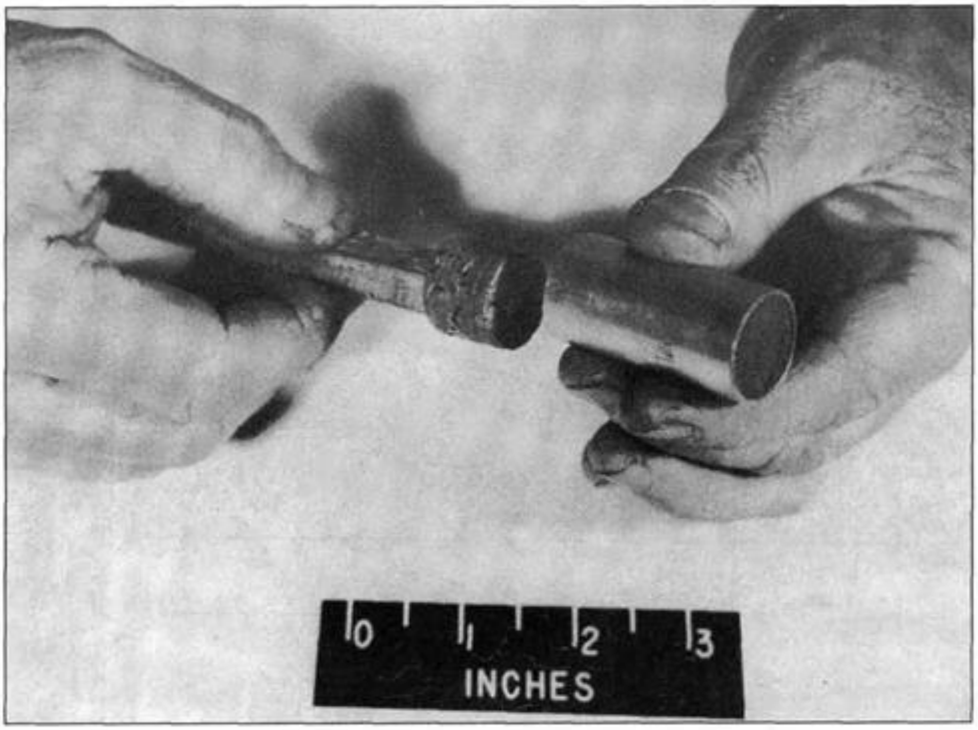


Figure A2-3. Measuring tube filled with grease

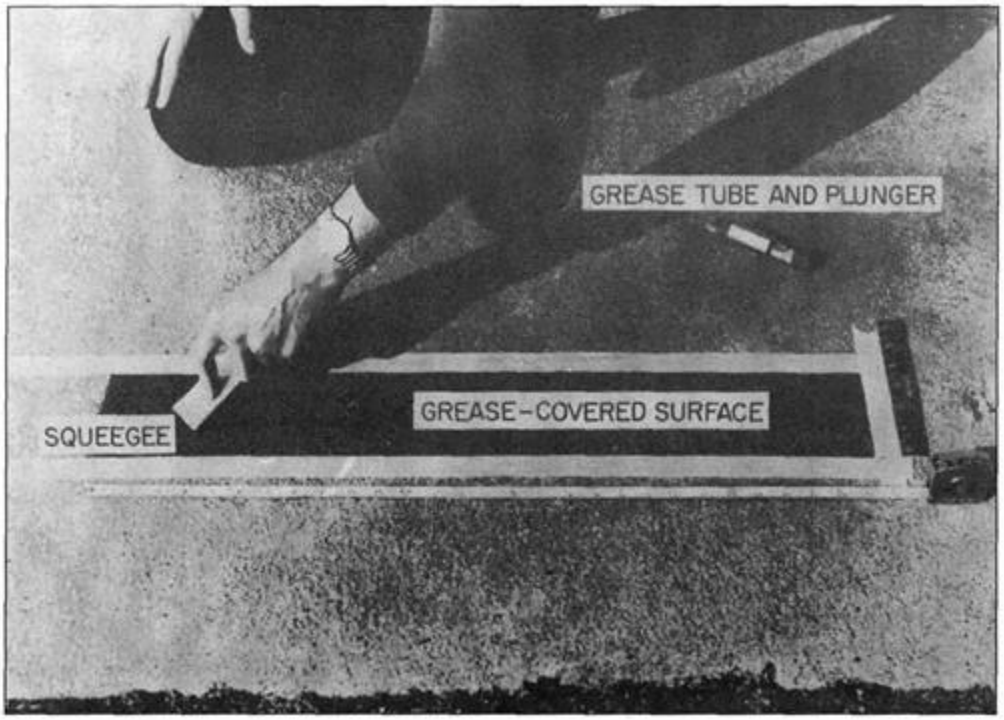


Figure A2-4. Illustration of apparatus used in grease application technique *for measuring runway surface texture depth*

Appendix 3

NASA Certification Test Procedure for New Continuous Friction-Measuring Equipment Used at Airport Facilities

INTRODUCTION

Since the 1950s, many different friction-measuring devices have been developed to monitor runway friction performance under all types of wetness and contamination conditions. In recent years, several types of continuous friction-measuring equipment (CFME) have proven to be reliable, accurate, and consistent in a variety of extensive test programmes, which included a range of pavement conditions and test speeds. From a cost, dependability, or ease of operation standpoint, some of the more widely used CFME, which have been certified as acceptable by NASA from earlier tests, include the mu-meter trailer, the runway friction tester, the BV-11 skiddometer trailer, the surface friction tester (Saab), the Grip Tester trailer, the Tatra runway friction tester, and the RUNAR runway analyzer and recorder.

PRIMARY OBJECTIVES

1. Establish that the manufacturer's instrument calibration procedures for friction measurement and water distribution systems for the CFME are satisfactory.
2. Collect CFME friction measurements on at least four (4) different pavement surfaces which will provide a wide range of friction levels.
3. Obtain CFME friction measurements at a minimum of two (2) test speeds, e.g. 65 and 95 km/h.
4. For each test speed/surface combination, conduct sufficient repeat runs with CFME and, if available, other previously certified CFME to determine repeat- ability and consistency of friction measurements.

TEST PROCEDURE

General

CFME certification testing has been carried out at NASA Wallops Flight Facility on the eastern shore of Virginia, U.S.A., which has a wide variety of pavement surface types installed for testing. Consequently, a large range of wet friction levels is available for evaluation, with sufficient space for conducting tests at high speed. A minimum of four (4) different wet friction level surfaces is considered sufficient for CFME certification testing with friction ranges at 65 km/h from 0 to 0.20, 0.25 to 0.45, 0.50 to 0.70, and 0.75 and above. During all CFME testing, ambient weather conditions (e.g., temperature, wind, and humidity) should be recorded at reasonable intervals, together with the time of day the test runs are conducted. The individual test pavements should be inspected prior to conducting CFME test runs to ensure that the surface is dry, clean, and free of dirt and/or loose material. For any given test surface, all CFME runs must be performed in the same direction. Close monitoring of all CFME test runs by experienced test personnel will help minimize the number of repeat runs and will ensure good data collection.

Steps

1. Check CFME test hardware, tire(s), and data acquisition system for proper configuration and working condition.
2. Perform CFME instrument calibration to manufacturer's specifications and store (record) values.
3. Perform a suitable check of the water distribution system so that the desired and consistent water quantity is provided in front of the test tire(s) at each planned test speed. Most States currently require a

water flow rate that will achieve average water depth on the surface of 1 mm.

4. Repeat steps 1–3 if a second, previously certified CFME will be tested with the new unit to establish friction data correlation.

5. Establish the testing order at the onset if two or more CFME are involved in certification testing and maintain this order throughout the evaluation.

6. Perform 2 or 3 test runs with each CFME on a given test surface to stabilize the wet friction measurements and to achieve an acceptable repeatability of ±0.03 during subsequent runs. If this level of consistency is not achieved in two series of test runs at similar speed, inspect the measuring and data acquisition systems for any irregularities; correct as necessary and recalibrate before continuing the certification tests.

7. At each selected test speed, conduct a minimum of six (6) test runs with each CFME on each of the test pavement surfaces (minimum of 4).

8. On each selected test pavement surface, conduct CFME test runs at a minimum of two test speeds: 65 and 95 km/h. Test runs at other speeds are desirable to better define the wet friction/speed gradient curve for each surface.

9. Analyse, when appropriate, the CFME recorded wet friction data time histories to verify accuracy, repeatability and consistency of average friction values for each test surface and speed increment evaluated.

10. For comparison to wet friction certification data, perform two (2) dry pavement CFME test runs on each surface at speeds similar to those used in certification tests.

11. Perform CFME instrument calibration to manufacturer's specifications at the conclusion of the testing and store (record) values. These values should be in close agreement (±0.03) to those obtained prior to test- ing. If not, find the cause and determine the necessity of repeating some or all of the previous tests.

12. Prepare friction/speed gradient graphs for each individual test surface using similar graph axis scales. If a second CFME is involved in certification tests with the new unit, use two different data symbols in order to differentiate between the friction/speed gradient data from both units on the same graph.

13. Compute linear regression equations and correlation coefficients (r squared) for each data set. These equations and correlation coefficient values should be indicated on each graph.

14. Prepare a test run data table of major test parameters including date, run number, time of day, surface, speed, direction used for test run, water depth, and average friction value.

15. Provide copies of all test run data time histories, general notes, weather conditions, and other test observations in a data package which is to be submitted to the agency requiring certification tests.

16. Copy Steps 2, 11, 12, 13, 14, and 15 on paper and/or floppy disk and submit to the appropriate agency.

Note.— Taking photos and making videos of the certification testing is recommended but not required. If such coverage is obtained, copies should be provided to the agency requiring certification tests.

Appendix 4

Standard Test Method for Skid Resistance on Paved Surfaces Using a Continuous Fixed Braking Slip Technique

1. SCOPE

1.1 This standard test method measures the skid resistance on paved surfaces (clean or contaminated) using a fixed braking slip technique. It is primarily intended to measure at or near the maximum skid resistance value but can be used for other braking slip rates. It utilizes a measurement obtained by forcing a test tire to roll at a fixed braking slip over a wetted pavement surface at a constant speed while the test tire is under a dynamically suspended fixed load. The method provides a record of the braking friction along the whole length of the test surface and enables averages to be obtained for any specified test length.

1.2 The values stated in SI units are to be regarded as the standard. The values in parentheses are in inch-pound units and are not exact equivalents; therefore, each system must be used independent of the other, without combining values in any way.

1.3 This test method may involve hazardous materials, operations, and equipment. It does not purport to address all of the safety problems associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use. Safety precautionary information is contained in Section 6.

2. REFERENCED DOCUMENTS

2.1 ASTM Standards

- E178 Recommended Practice for Dealing with Outlying Observations
- E274 Skid Resistance of Paved Surfaces Using a Full-Scale Tire
- E670 Standard Test Method for Side Force Friction on Paved Surfaces Using the Mu-Meter.
  A2. Specification for an Alternative Mu-Meter Tire.
- E867 Standard Definitions of Terms of Travelled Surface Characteristics
- E1551 Standard Specification for Special Purpose, Smooth Tread, Standard Tire
- E1844 Standard Specification for Grip Tester, Smooth Tread, Friction Test Tire
- F377 Calibration of Braking Force for Testing Pneumatic Tires
- F457 Method for Speed and Distance Calibration of a Fifth Wheel Equipped with Either Analog or Digital Instrumentation

2.2 Related documents

- FAA Advisory Circular 150/5320-12B Measurement, Construction, and Maintenance of Skid-Resistant Airport Pavement Surfaces
- K.J. Law Slip Friction Tester Instruction and Servicing Manual
- SAAB Friction Tester Instruction and Servicing Manual
- BV-11 Skiddometer Instruction and Servicing Manual
- Grip Tester Trailer Instruction and Servicing Manual
- BS 598 Draft Standard on Measuring Surface Friction
- Findlay, Irvine Ltd. Production Test Schedule, PTS 292-8, for Testing and Documenting Grip Tester Test Tyres
- Tatra Friction Tester Instruction and Servicing Manual
- RUNAR Runway Analyzer and Recorder Instruction and Servicing Manual
- ICAO Annex 14 to the Convention on International Civil Aviation — *Aerodromes*, Volume I — *Aerodrome Design and Operations*
- KCASR 14

3. SUMMARY OF METHOD

3.1 The test equipment consists of an automotive vehicle with a test wheel incorporated into it or forming part of a suitable trailer towed by a vehicle. The vehicle contains a transducer, instrumentation, a water supply and proper dispensing system, and actuation controls for the braking of the test wheel. The test wheel is equipped with a standard pavement test tire (see 5.4 for tire reference).

3.2 The device being tested is brought to the desired test speed. Water is delivered ahead of the test tire, and the braking system is actuated to force the test tire to roll at the designed braking slip. The relative braking slip velocity is equal to the difference between the peripheral velocity of the tire, relative to the wheel axle, and the horizontal velocity of the wheel axle relative to earth. The ratio of this relative braking slip velocity to the horizontal velocity of the wheel axle, usually expressed as a per cent, is defined as the slip ratio. The ratio of relative braking slip velocity to the horizontal velocity of the wheel axle is equal to the ratio of relative braking slip RPM to an identical unbraked wheel RPM.

3.3 The approximate maximum braking force developed between the tire and pavement is determined from the resulting braking force or torque reported as the braking slip number (BSN), which is determined from the force generated by rolling the tire at a fixed braking slip at a stated speed, divided by the measured or calculated wheel load, and multiplied by 100.

4. SIGNIFICANCE AND USE

4.1 The knowledge of the steady state braking friction serves as an additional tool in characterizing pavement surfaces. Research shows that for most pavement surfaces, the maximum or peak braking and cornering (side force) friction values developed between vehicle tires and pavement surfaces are similar in magnitude. Thus, maximum braking friction is useful in studying vehicle stopping and directional performance under different pavement conditions.

4.2 The values measured with the equipment do not necessarily agree or correlate directly with those obtained by other paved surface friction-measuring methods.

5. APPARATUS

5.1 *Vehicle.* The vehicle with the test tire operating at the desired fixed braking slip shall be capable of maintaining test speeds of 65 to 100 km/h (40 to 60 mph) within ±1.5 km/h (±1.0 mph) during a test on a dry pavement surface. The vehicle shall be capable of attaining a speed of 65 km/h (40 mph) in 152 m (500 ft) and a speed of 100 km/h (60 mph) in 300 m (1 000 ft) with the test wheel retracted or in a free roll mode (FAA Advisory Circular 150/5320-12B refers).

5.2 *Braking system.* The test wheel speed shall be controlled in such a manner that the designed test tire fixed braking slip can be maintained throughout the length of the test pavement surface at the design test speed. The standard BSN test is conducted at a fixed tire braking slip of 14% with an acceptable tolerance range of ±3% braking slip. Free rolling braking slip is 0%; locked wheel braking slip is 100%.

Note.— For a given set of tire/pavement parameters, the peak braking slip may exceed these tolerances. On low friction surfaces, i.e. contaminated with ice and/or snow, the peak friction may occur above the selected value of the fixed slip tester. In these cases, the measured friction can lead to erroneous conclusions because the tester will produce low values when not near the peak.

5.3 *Wheel load.* The apparatus shall be of such design as to provide a static load as specified in the vehicle manuals listed in 2.2.

5.4 *Tire.* The test tire shall be the standard tire for pavement tests as specified in Specification E1551 or other fixed slip tester specifications (see manufacturers' handbooks listed in 2.2). The tire pressure in the test wheel shall be 207 ±3 kPa (30 ±0.5 psi) measured at ambient temperature (cold) or 140 ±3 kPa (20 ±0.5 psi) for a Grip Tester trailer.

Instrumentation

5.5 *General requirements for measuring system.* The instrumentation system shall conform to the following overall requirements at ambient temperatures between 4°C and 40°C (40°F and 100°F):

Overall static system accuracy ±2% of the full scale
Time stability calibration 1 year minimum

The exposed portions of the system shall tolerate 100% relative humidity (rain or spray) and other adverse conditions, such as dust, shock, and vibrations, that may be encountered in pavement test operations.

5.6 *Force-measuring transducer.* The tire force-measuring transducer shall be of such design as to measure the tire-road interface force with minimal inertial effects. Transducers are recommended to provide an output directly proportional to force, with hysteresis less than 1% of the applied load, up to the maximum expected loading. The sensitivity to any expected cross-axis loading or torque loading shall be less than 1% of the applied load. The force transducer shall be mounted in such a manner as to experience less than 1 degree angular rotation with respect to its measuring plane at the maximum expected loading.

5.7 *Torque-measuring transducer.* Torque transducers shall provide output directly proportional to torque, with hysteresis less than 1% of the applied load, and nonlinearity up to the maximum expected, with loading less than 1% of the applied load. The sensitivity to any cross-axis loading shall be less than 1% of the applied load. Note that the torque transducers do not provide any measure of the dynamic vertical load, and hence, the vertical load must be assumed to equal the static value. Torque transducer measurements include rolling tire/wheel inertial effects which should be compensated for at all test speeds.

5.8 *Additional transducers*. Force transducers for measuring quantities such as vertical load shall meet the requirements stated in 5.6.

5.9 *Vehicle speed-measuring transducers*. Transducers such as “fifth wheel” or free-rolling wheels coupled to tachometers shall provide speed resolution and accuracy of 1.5% of the indicated speed or ±0.8 km/h (±0.5 mph), whichever is greater. Output may be viewable by the driver but must be simultaneously recorded on the data file. Fifth wheel systems shall conform to ASTM test method F457.

Signal conditioning and recorder system

5.10 Transducers that measure parameters sensitive to inertial loading shall be designed or located in such manner as to minimize this effect. If the foregoing is not practical, data should be corrected for vertical loading if this effect exceeds 2% of actual data during expected operation. All signal conditioning and recording equipment shall provide linear output and shall allow data-reading resolution to meet the requirements of 5.5. All systems, except the smoothing filter described in 5.11, shall provide a minimum bandwidth of at least 0 to 20 Hz (flat within ±1%).

5.11 It is required that an electronic filter, typically between 4.8 Hz/–3db/4 pole Bessel-type and a 10 Hz/–3db/8 pole Butterworth filter, be installed in the signal conditioning circuit preceding the electronic divider and integration calculation of BSN. Alternatively, if the recorder system is a programmable computer, some or all of the filtering may be carried out by software.

5.12 Ideally, the instrument calibration shall allow the whole measuring system including strain gage transducers to be calibrated (BS 598 Draft Standard on Measuring Surface Friction refers). If this is not possible, then all strain gage transducers shall be equipped with resistance shunt calibration resistors or equivalent that can be connected before or after test sequences. The calibration signal shall be at least 50% of the normal vertical load and shall be recorded.

5.13 Tire friction force or torque and any additional desired inputs, such as vertical load and wheel speed, shall be recorded in phase (±5 degrees over a bandwidth of 0 to 20 Hz). All signals shall be referenced to a common time base.

5.14 The signal-to-noise ratio shall be at least 20 to 1 on all recording channels and the noise must be reduced to 2% or less of the signal.

Pavement wetting system

5.15 The water being applied to the pavement ahead of the test tire shall be such as to provide a calculated surface water depth of 1 mm (0.04 in.). This may be achieved either by means of a simple nozzle or by means of a nozzle contained within a brush. In both cases, the water shall be applied in such a way that the width of the water layer underneath the test tire is at least as great as the test tire-pavement contact width. The volume of water per millimetre (inch) of wetted width shall be directly proportional to the test speed. At a test speed of 65 km/h (40 mph), the recommended quantity of water applied is 1.2 L/min per millimetre of wetted width ±10%/mm (8 US gals/min ±10%/in.).

5.16 The watering system will include a water tank of adequate capacity to furnish sufficient water to test a runway of 4 200 m (14 000 ft) using a 1 mm (0.04 in.) thick water layer.

5.17 Water used for testing shall be reasonably clean and have no chemicals, such as wetting agents or detergents, added.

6. SAFETY PRECAUTIONS

The test vehicle, as well as attachments to it, shall comply with all applicable state laws. All necessary precautions shall be taken beyond those imposed by laws and regulations to ensure maximum safety of operating personnel and other traffic. No test shall be made when there is a danger that dispersed water may freeze on the pavement.

7. CALIBRATION

7.1 *Speed.* Calibrate the test vehicle speed indicator at the test speed by determining the time for traversing, at constant speed, a reasonably level and straight, accurately measured pavement of a length appropriate for the method of timing. Load the test vehicle to its normal operating weight for this calibration. Make a minimum of three runs at each test speed to complete the calibration. Other methods of equivalent accuracy may be used. Calibration of a fifth wheel shall be performed in accordance with ASTM test method F457.

7.2 *Braking (fixed slip) force.* Place the test wheel of the assembled unit, with its own instrumentation, on a suitable calibration platform, which has been calibrated in accordance with ASTM test method F377, and load vertically to the test load. Measure the test load within ±0.5% accuracy whenever the transducer is calibrated. Level the transducers longitudinally and laterally such that the tractive force sensitive axis is horizontal. This can be accomplished by minimizing the tractive force output for large variations in vertical load. The system (vehicle or trailer) should be approximately level during this procedure. The calibration platform shall utilize minimum friction bearings, have an accuracy of ±0.5% of the applied load, and have a maximum hysteresis of ±0.25% of the applied loading up to the maximum expected loading. Take care to ensure that the applied load and the transducer-sensitive axis are in the same vertical line. Perform the tractive force calibration incrementally until the test tire starts to slip on the calibration platform, but at least up to 50% of the static vertical load. For other fixed slip testers, refer to related manufacturers' handbooks listed in 2.2.

8. GENERAL

8.1 *Tire preparation.* Condition the new test wheel tire by running it at fixed slip at the normal tire inflation pressure on dry pavement until such time as a smooth, flat rubber surface is obtained. Dynamically balance the wheel and tire assembly to ensure that there is no vibration at the anticipated test speed. Inspect the tire for damage and other irregularities that may affect the test results and reject the tire if damaged or worn to the extent that it is unlikely to complete any of the tests. When tread wear reaches the bottom of the wear holes, the tire should be replaced. For specific fixed slip tester tire preparation procedures, see manufacturers' handbooks listed in 2.2.

8.2 *Test preparation.* Check the tire for flat spots, irregularities, or other damage before running a test. Set the test tire inflation pressure to the required value (see 5.4) at ambient temperature just before the warm-up. Prior to each series of tests, warm up the test tire by running the test vehicle in the fixed slip test mode for at least 600 m (2 000 ft) in the self-wetting mode.

8.3 *Test speeds.* Run the standard braking slip number (BSN) test at 65 ±0.8 km/h (40 ±0.5 mph) and maintain similar accuracy for tests below 65 km/h (40 mph). For tests at speeds above 65 km/h (40 mph), maintain speed accuracy to ±1.5 km/h (±1.0 mph). Note the speed and per cent braking slip when quoting the BSN. This may be accomplished by adding the speed at which the test was run as a subscript to the BSN and the per cent braking slip as a superscript.

8.4 *Braking slip number speed gradient determination.* The change of braking slip number with speed is to be reported as the BSN per km/h (BSN per mph) and should be obtained as the slope of the BSN versus speed curve, which is plotted from at least three speeds in increments of approximately 32 km/h (20 mph). The standard speed gradient shall be defined as the slope of the BSN speed curve at 65 km/h (40 mph) and shall be so indicated.

9. PROCEDURE

9.1 Bring the apparatus to the desired test speed. Deliver water to the test tire. Ensure the test wheel is in the fixed slip mode at least 1 second before the test is initiated and continue until the test is completed. Indicate the beginning and end of the test by means of the event marker. If the test wheel can be disengaged, this should be done and the water shut off approximately 1 second after completion of the test.

9.2 Record electrical calibration signals prior to and after each test series, or as needed, to ensure valid data.

9.3 Evaluate the recorded trace of BSN in accordance with either the FAA or ICAO criteria.

10. FAULTY TESTS

Tests that are faulty or give braking slip numbers differing by more than 5 BSN from the average of all tests of the same test section shall be treated in accordance with ASTM Recommended Practice E178.

11. REPORT

11.1 *Field report.* The field report for each test section shall contain data on the following items:

- location and identification of test section
- date and time of day
- weather conditions
- section tested
- speed of test vehicle and surface water depth (for each test)
- per cent braking slip
- braking slip number (BSN)

11.2 *Summary report.* The summary report shall include, for each test section, data on the following items insofar as they are pertinent to the variables or combi- nations of variables under investigation:

- location and identification of the test section
- grade and alignment
- pavement type and condition
- age of pavement
- average daily traffic
- date and time of day
- weather conditions
- wheel path tested
- ambient and surface temperature
- average, high, and low braking slip number for the test section, and speed and per cent braking slip at which the tests were made. (If values not used in computing the average are reported, this fact should be stated.)
- the date of the last calibration

12. PRECISION AND BIAS

12.1 *Precision.* Data are not yet available for making a statement on the precision of this test method.

12.2 *Bias*. There are no standards or references with which the results of this test can be compared. The function of this test is to be able to make comparisons between pavement surfaces tested with the same tire. It is believed that the results of the test method are adequate for making such comparisons without an external reference for assessing accuracy. It must be noted that surface friction is affected by many variables such as environmental con- ditions, usage, age, surface contamination, natural precipi- tation type and artificial wetting type; measured values are only valid until one of these conditions significantly changes.

Appendix 5

An Example of a Runway Friction Assessment Programme

TABLE A5-1 (CHART A)

1. Determine the number of annual aeroplane landings for each type of turbo-jet aeroplane operating at an airport. Enter this data under column [B].

2. Determine the annual gross aeroplane landing mass. Enter this data under column [C].

3. Determine the total annual aeroplane landings [D].

4. Determine the total annual gross aeroplane landing mass [E].

TABLE A5-2 (CHART B)

5. Go to Chart B and follow instructions given. Determine the [H] and [K] values for each runway end for all runways that have turbo-jet aeroplane operations.

TABLE A5-3 (CHART C)

6. Take the [H] and [K] values as determined from Chart B and compare to the [H] and [K] values given on Chart C. This determines the minimum friction [M] and minimum rubber removal frequencies [N] for each runway end for all runways that serve turbo-jet aeroplane operations.

TABLE A5-4 (CHART D)

7. Enter values for [G], [H], [K], [M] and [N] on Chart D.

8. Each airport is responsible for conducting the above computations once a year. Airlines change airport location, type of aeroplane and number of daily operations at an airport, year to year. Computations conducted once a year will enable the airport management to keep up to date with the aeroplane activity at the airport. This is especially true when wide-body aeroplane operations increase over time, which will result in much faster rubber accumulation and pavement wear.

9. Forms for computations are provided for the airport operator in Tables A5-1 through A5-4.

Table A5-1. Estimate of annual commercial turbo-jet aeroplane landing mass at an airport — Chart A

Airport:

Identifier:

Site #:

	Aeroplane type	Maximum aeroplane landing mass (kg) [A]	Annual number aeroplane landings at airport [B]	Annual gross aeroplane landing mass (m kg) [A] × [B] = [C]
+	A300-B2	127 462		
+	A300-B4	132 996		
+	A300-600	138 000		
+	A310-200	122 000		
+	A310-300	123 000		
+	A320-100	63 000		
	A320-200	64 500		
	B707-120B	86 184		
	B707-[320/420]	93 895		
	B707-[720/720B]	79 380		
	B707-320B	97 524		
	B707-320C	112 039		
	B727-[100/100C]	64 638		
	B727-200	73 030		
	B737-100	44 906		
	B737-200	46 721		
	B737-[200C/200QC]	48 535		
	B737-300	52 527		
	B737-400	56 246		
+	B737-500	49 896		
+	B747-[100/B/SF/SR]	255 830		
+	B747-[200/B/C/F/P]	285 768		
+	B747-[300/400]	285 768		
	B747-[200B/300]	290 304		

	Aeroplane type	Maximum aeroplane landing mass (kg) [A]	Annual number aeroplane landings at airport [B]	Annual gross aeroplane landing mass (m kg) [A] × [B] = [C]
+	B747-300SR	242 676		
+	B747-SP	210 924		
	B757-200PF	95 256		
	B767-200	123 379		
	B767-200ER	129 276		
	B767-300	136 080		
	B767-300ER	145 152		
	BAC111-[200/400]	31 298		
	BAC111-500	39 010		
	BAC CONCORDE	111 132		
	BAe146-100	32 568		
	BAe146-200	34 927		
	BAe146-300	40 824		
	DC8-[20/30/40]	93 895		
	DC8-55	98 431		
	DC8-[55F/61/62/71/72]	108 864		
	DC8-72AF	113 400		
	DC8-[63F/73CF/73AF]	124 740		
	DC8-[61F/71CF/63/73]	117 029		
	DC9-[10/15/15F]	37 059		
	DC9-21	43 228		
	DC9-[32/33F]	44 906		
	DC9-41	46 267		
	DC9-51	49 896		
	DC9-81	58 061		
	DC9-82	58 968		
	DC9-83	63 277		
	DC9-[87/88]	58 968		
+	DC10-[10/10CF/15]	164 884		

	Aeroplane type	Maximum aeroplane landing mass (kg) [A]	Annual number aeroplane landings at airport [B]	Annual gross aeroplane landing mass (m kg) [A] × [B] = [C]
+	DC10-40	182 801		
+	DC10-[30CF/KC-10A]	197 770		
+	DC10-[30/40CF]	186 430		
	F28-[1000/2000]	26 762		
	F28-[3000/5000]	29 030		
	F28-[4000/6000]	30 164		
+	L1011-1	162 389		
+	L1011-[100/200/500EW]	166 925		
	CONVAIR 880	70 308		
	CONVAIR 990	91 627		
	SE210	47 583		
+	MD11	195 048		
+	MD11 COMBI	207 749		
+	MD11F	213 872		
	IL62	114 308		
	VC10-1100	97 978		
	VC10-1150	107 503		

+ = Wide-body aeroplane

Total annual non-wide-body aeroplane landings ______ ______%
Total annual wide-body aeroplane landings ______ ______%

Total annual aeroplane landings ______

[D] = [B]

Total annual non-wide-body aeroplane landing mass ______ ______%
Total annual wide-body aeroplane landing mass ______ ______%

Total annual aeroplane landing mass ______

[E] = [C]

Table A5-2. Form for computation procedure — Chart B

Daily aeroplane landings for all runways:

Annual aeroplane landings all runways		365 days per annum		Daily aeroplane landings all runways
___________	÷		=	___________
[D]				[F]

Average annual aeroplane mass for annual aeroplane landings for all runways:

Annual aeroplane landing mass		Annual aeroplane landings		Average annual aeroplane mass for annual aeroplane landings for all runways
___________	÷	___________	=	___________
[E]		[D]		[J]

RUNWAY ___________

Daily aeroplane landings:

Daily aeroplane landings all runways		Per cent aeroplane landings on Runway ( )		Daily aeroplane landings for Runway ( )
___________	×	___________	=	___________
[F]		[G]		[H]

Annual aeroplane landings for Runway ______:

Per cent aeroplane landings on Runway ( )		Annual aeroplane landings all runways		Annual aeroplane landings for Runway ( )
___________	×	___________	=	___________
[G]		[D]		[I]

Annual aeroplane mass for Runway ______:

Annual aeroplane landings on Runway ( )		Average annual aeroplane mass per aeroplane landings for all runways		Annual aeroplane mass for Runway ( )
___________	×		=	

[I] [J] [K]

Table A5-3. Friction maintenance programme schedule based on level of turbo-jet aeroplane operations for each runway end — Chart C

Daily turbo-jet aeroplane landings for runway end [H]	Annual aeroplane mass for runway end (million kg) [K]	Minimum friction survey frequency [M]	Minimum rubber removal frequency [N]
less than 15	less than 447	once per year	once every 2 years
16 to 30	448 to 838	once every 6 months	once every year
31 to 90	839 to 2 404	once every 3 months	once every 6 months
91 to 150	2 405 to 3 969	once every month	once every 4 months
151 to 210	3 970 to 5 535	once every 2 weeks	once every 3 months
greater than 210	greater than 5 535	once every week	once every 2 months

Notes:

1. Airports that exceed 31 daily turbo-jet aeroplane landings are more critical with respect to friction deterioration caused by rubber accumulation due to increased aeroplane activity.
2. In addition to daily turbo-jet aeroplane landings for runway ends, other factors should be considered by the airport operator when determining rubber removal, such as the type and age of pavement, annual climate conditions, time of year, number of wide-body aeroplanes that operate on the runways, and length of runways.
3. Reference columns [H] and [K]: After calculating [H] and [K], the airport operator should select the column which has the higher value and then select the appropriate values in columns [M] and [N].

Table A5-4. Summary form — Chart D

Airport: ____

Runway designation	Per cent annual aeroplane landings per runway [G]	Estimated daily aeroplane landings per runway [H]	Annual distribution of aeroplane landing mass per runway ($\times 10^6$ kg) [K]	Type of runway pavement	Type of surface treatment	Total runway length (m)	Estimated friction survey frequency [M]	Estimated rubber removal frequency [N]

Appendix 6

Methods of Measuring or Assessing Braking Action When No Friction Test Devices Are Available

MEASURING OF BRAKING ACTION BY BRAKING A TRUCK OR CAR TO A FULL STOP

1. One way of measuring the friction coefficient of a runway, when no special test equipment is available at the airport, is to measure the distance and/or time required to bring a truck or car to a stop from a given speed with the brakes fully locked.

2. The distance and time required to stop will give two separately derived values of the friction coefficient, μ distance and μ time, according to the following:

$$\mu \text{ distance} = \frac{V^2}{2gS}$$

$$\mu \text{ time} = \frac{V}{tg}$$

where V = speed at brake application, m/s

S = stopping distance, in m

t = stopping time, in s

g = acceleration of gravity, in m/s^2.

3. Normally, the friction coefficient based on time is a little too low because there is a tendency to start the stop watch an instant before the brakes become effective. On the other hand, the friction coefficient based on stopping distance is normally a little too high because the truck is being braked to some extent before the wheels begin to skid.

4. The μ value obtained is the skidding value but it is the μ max value that must be reported. In order to get an approximate value of μ max, the results with this method have to be multiplied by 1.3 for μ skid above 0.3, and 1.2 for lower μ skid values. Particularly, when the friction is low, the quote between μ skid and μ max varies with the specific conditions but the factors quoted above are considered to give acceptable results. The speed at brake application and the braking tests by this method may be the same as in the method described in 4.4.2 for measuring of braking action by braking a truck or car with a decelerometer installed. An example of a form to be used for recording and processing test results is given in Figure A6-1.

METEOROLOGICAL OBSERVATIONS (RELATED TO RUNWAYS COVERED BY SNOW OR ICE)

5. Meteorological observations in connection with a knowledge of the runway condition will, in many cases, permit a fair estimate to be made of braking action. The following data are based on Norwegian and Swedish experience.

6. On snow- or ice-covered runways not treated (with, for example, sand), the coefficient of friction varies from as low as 0.05 to 0.30. It is very difficult to state exactly how and why the runway conditions vary. If, however, the braking action is fairly good, it will so remain if the temperature decreases, but if the temperature rises to the freezing point or above, the braking action will decrease rapidly. The braking action is very much dependent upon the temperature especially near the freezing point. Sometimes very low friction coefficient values occur when humid air is drifting in over an icy runway even though the temperature may be well below the freezing point.

7. Some of the various conditions that can influence the braking action are given below:

a) coefficient of friction between 0.10 and 0.25:

   1) slush or rain on snow- or ice-covered runway;

Airport				Runway				Sector	
Date			Time			Temperature			
	About 10 m east* centre line of runway				About 10 m west** centre line of runway				
Distance from end of runway	Stop time (s)	μ_T	Stop distance (m)	μ_D	Stop time (s)	μ_T	Stop distance (m)	μ_D	Remarks

Time: $T = \dfrac{\mu_T \text{ East} + \mu_T \text{ West}}{\text{No. of observations}}$

Distance: $D = \dfrac{\mu_D \text{ East} + \mu_D \text{ West}}{\text{No. of observations}}$

Average: $\dfrac{\mu_T + \mu_D}{2}$

* For a runway 09/27 North
** For a runway 09/27 South

Figure A6-1. Example of schema that can be used when recording a friction test made with skidding wheels of a truck to a full stop from 40 km/h

2) change from frost to temperature above freezing point;

3) change from mild to frost (not always);

4) the type of ice which is formed after long periods of cold;

5) a thin layer of ice formed:

   i) by frozen ground having been exposed to humidity or rain at 0°C or above;

   ii) when, due to radiation (e.g. when the sky clears), the runway surface temperature drops below freezing point and below the dew point. (This ice formation can take place very suddenly and occur while the reported air temperature may still be a few degrees above the freezing point.)

b) coefficient of friction between 0.25 and 0.35:

   1) snow conditions at temperature just below freezing point;

   2) snow-covered runways at temperatures below freezing point, exposed to sun.

c) coefficient of friction between 0.35 and 0.45:

   snow-covered runways which have not been exposed to temperatures higher than about –2°C to –4°C.

Note.— The classification is meant only as a guide and it has been included solely to give an indication of the order of the braking action one may expect under various conditions. Whenever possible, it is advisable to assess the braking action by measuring the friction coefficient.

Appendix 7

Plough Types and Accessories

1. The costs of fuel and specialized equipment for snow removal and ice control may represent a substantial financial investment for many airports, and any concepts that can offer a reduction in these costs should be investigated. Some developments in airport snowploughs that may represent possible cost savings in fuel and equipment are reviewed in this appendix.

2. Polymer and composite mould-boards and mould-board coatings appear to reduce snow/slush/mould-board skin friction. Skin friction reduction may reduce the power required to propel the plough vehicle, thus reducing the plough's fuel consumption. Substantial plough fuel savings have been claimed by some manufacturers. Plough mould-boards that physically cast a large volume of snow high and away from the vehicle instead of simply wind-rowing or displacing snow could reduce equipment inventories. At some locations, depending on light snowfall, light winds, the type of snow, and runway location, lighting, and shoulder configuration, a high casting plough may not require a snowblower to move a substantial portion of the cleared snow over the pavement edge lights. Elimination of a snowblower can represent substantial fuel and equipment savings, but any selection of a casting plough for such a double-duty task should be carefully investigated, recognizing that the required performance may be highly dependent on the snow conditions at the site. Some snowplough blade sizes are as follows:

a) *Small snowplough.* The plough may be any physical design but should have a mould-board length ranging from approximately 1.8 m up to intermediate size. Included in this group are underbody truck scrapers having mould-board lengths ranging from 3 m to intermediate size.

b) *Intermediate snowplough.* The plough may be any physical design but should have a mould-board length ranging from approximately 3 m to 4.5 m. Included in this group are underbody truck scrapers having mould-board lengths ranging from 3 m to 4.5 m.

c) *Large snowplough.* The plough may be any physical design but should have a mould-board length of at least 4.5 m. Included in this group are apron dozer ploughs and large special-purpose ploughs.

d) Carrier vehicles for the various types and sizes of ploughs may be classified as follows:

   1) *Standard truck-type plough carriers.* These are standard production trucks meeting the requirements for airport snowplough carriers.

   2) *Large special-purpose plough carriers.* These are custom-constructed vehicles manufactured especially for high volume, large swath, airport snowploughing requirements.

   3) *Wheel loaders (front-end loaders).* These are standard production equipment used for low-speed, specialized snow removal operations such as apron snow removal, snow loading, stockpiling and snow removal around runway lights and other restricted areas.

   4) *Industrial tractors (large 4 × 4 types only).* These are standard production, hydrostatic drive types. This equipment is used for specialized snow removal operations similar to those performed by wheel loaders but requiring more speed and without any snow loading requirement.

3. *Plough types.* The following conventional plough types comprise a family of airport snowploughs. The snowplough unit may be of any physical design conforming to the equipment guidelines specified herein and should have a snow/slush removal ability within the swath width with minimal skipping or spillover at the manufacturer's recommended ploughing speed. The plough's performance should match its intended use; i.e. when used in conjunction with a large snowblower, a large reversible plough should perform satisfactorily at all snowblower team velocities, snow densities and depths.

a) *Tapered blade, one-way, left or right hand.* Designed for high-volume, high-speed runway and associated snowploughing operations, this snowplough is a conventional, one-way (single direction discharge only) type with a tapered mould-board, operated by hy- draulic power with conventional in-cab, driver- operated controls. The blade, depending on plough size, can vary from approximately 0.60 m to 0.76 m high at the intake end, and from 1.27 m to 2.03 m high at the discharge end. The blade should be equipped with replaceable cutting edges, either metal or non-metal, as specified. The unit should include a safety trip device and a manual or power-adjustable blade tilt for general purpose work, such as aprons and runways. When equipped with tungsten carbide cutting edges, it should not be used on surfaces equipped with in-pavement lighting. In these areas, rubber or polyurethane cutting edges are recommended. Ploughs of this design do not have the versatility of revers- ible types and are not recommended for general airport use.

b) *Conventional power-reversible.* The large size classification of this snowplough is intended for high-volume, high-speed runway snowploughing requiring the capability to discharge snow to the right or left at preselected cutting angles from the bulldozing position. The snowplough should have a detachable blade assembly; it should be equipped with replaceable cutting edges and be operated by hydraulic power with conventional controls located in the operator's cab. The mould-board design should be such that the tungsten carbide-tipped cutting edges and rubber/polyurethane cutting edges can be interchanged. The power-operated reversing mechanism should enable the blade to be positioned in a minimum of four positions either side of the bulldozing position, giving a maximum blade angle of approximately 35 to 40 degrees. The unit should be equipped with an automatic blade locking and unlocking feature, an oscillating or floating drive frame and, when specified, blade trip devices. The plough should be equipped with bolt-on replaceable shoes or castors when a non-metal cutting edge is specified. Adjustable blade tilt can be specified when this plough is to be used for general-purpose ploughing. The mould-board can vary from approximately 1.8 m to 6 m in length at the cutting edge, and from approximately 0.88 m to 1.20 m in height. When the plough is to be used on pavement areas equipped with in-pavement lighting, a rubber or polyurethane cutting edge is recommended in lieu of tungsten carbide. Deeply flared inlet/exit ends may be specified to increase snow-casting capabilities.

c) *Flip-reversing steel edge.* This plough is designed for high-speed, high-volume snow removal operations requiring the ability to discharge snow to the right or left at a fixed cutting angle. The unit is not recommended for use on areas equipped with in-pavement lighting and is not available equipped with interchangeable rubber or polyurethane blades. The snowplough has a full-length, deeply tapered mould-board and, by rotating the blade assembly on a horizontal axis through 180 degrees, is capable of ploughing and discharging snow to the right- or left-hand side as desired. Hydraulic power operation with in-cab conventional controls should be provided for raising, lowering, and rotating the blade assembly. The blade should have the same fixed-blade angle when the blade is rolled either right or left and should include replaceable tungsten carbide-tipped cutting edges. A provision should be made to lock and store the blade in a vertical position, and a suitable blade/vehicle mounting hitch should be provided. The mould-board may vary from approximately 3 m to 4 m in length at the cutting edge and depending on size, between approximately 1.50 m to 1.80 m high at the discharge end of that mould-board. Flip-reversing mould-boards are not equipped with automatic trip blades.

d) *Levelling wing, left or right hand.* This levelling wing is intended for heavy-duty snow removal operations and should provide adjustable blade operation at varying heights for window and snowbank levelling/trimming operations. The unit should also be capable of high-speed snowploughing when used in conjunction with a suitable front-mounted plough. The unit is not intended for use on areas equipped with in-pavement lighting. Hydraulic power operation with in-cab conventional hydraulic controls should be provided to raise, lower, and position the blade for operation and storage with adequate cab clearance against the truck side. The detachable blade should be approximately 0.62 m high at the front and approximately 0.88 m high at the rear and should be equipped with replaceable tungsten carbide-tipped cutting edges, safety trip device, shock-absorbing side brace, and manual blade tilt adjustment. Wings should be supported on either side by levelling wing tower posts and crane devices.

e) *Extension plough blade.* The extension plough blade operates on the right or left side of the vehicle in combination with the front-mounted snowplough blade to increase the width of cut. When this blade is to be used on pavement areas equipped with in-pavement lighting, a rubber or polyurethane cutting edge should be specified in lieu of standard tungsten carbide-tipped type. The unit should be operated by hydraulic power with conventional controls located in the cab for operation by the driver. The detachable blade should be approximately 0.76 m high at the front and approximately 1.52 m high at the rear end and be equipped with replaceable cutting edges, shock-absorbing side braces, and a manual blade tilt adjustment. The effective cutting width should be approximately 1.8 m; when not in use, the blade will be capable of folding against the side of the vehicle (while maintaining blade-to-cab clearance) by the vehicle's hydraulic power. Individual controls (located in the cab) for the inner and outer end of the blade can be specified when needed in lieu of a single control. A safety trip device should provide cushioned tripping action at all ploughing speeds and trip action should be readily adjustable. The front of the extension blade should be attached to a short post mounted on the push frame. Provision should be made for hydraulically raising the front of the blade a minimum of 30 cm. The rear mounting should consist of a short post attached to the side of the vehicle frame, which is adequately braced and reinforced for the attachment of the extension blade tilt adjustment. All braces should incorporate a shock absorbing safety device. The design and installation of the rear mounting should comply with the design installation require- ments of the vehicle's manufacturer. The installation should include safety chains for travelling and a provision to limit the blade to a safe, folded position.

f) *Wide-swath, large push plough, reversible, with folding wings.* This plough is designed for wide-swath (either high-speed or low-speed) operations. The unit functions should be hydraulically powered with conventional controls. All controls should be located in the cab for operation by the driver. The front-mounted main blade centre section can range from approximately 3 m to 6 m in length, depending on design, with two hydraulically actuated, folding wing sections, one left and one right; each wing can range from 1 m to 3 m in length. Maximum blade width with wings extended is approximately 9 m. Depending on design, centre section and/or wings should be heavy-duty, castor-equipped. Reversing mechanism and wing sections should be designed to minimize plough damage when striking pavement projections at high system speed. The cutting edge should be polyurethane, rubber (for areas with in-pavement lighting), or tungsten carbide-equipped. Large ploughs of this type could require a special purpose dedicated vehicle of relatively high horsepower and gross vehicle weight. When the plough blade is installed and set to maximum angle and wings are folded, the plough should pass through at least one door of the airport maintenance facility.

g) *Underbody scraper.* This plough is designed for maximum manoeuvrability in restricted areas without in-pavement lighting and for breaking and ploughing packed ice and snow. The unit should be either hydraulically or pneumatically operated with conven- tional in-cab controls. Depending on plough size, it should have a blade length range to approximately 3.6 m, with a 30 cm to 50 cm mould-board radius and a detachable cutting edge made of tungsten carbide steel. The mould-board should be heavy-duty steel with a minimum blade thickness of 1.2 cm. The plough should be power-reversible permitting change of blade angle to the left or right from the bulldozing position. The system should be equipped with an adjustable ground pressure device. A shock-absorbing suspension trip system to prevent damage from suddenly applied loads should be provided, and a system to fold or raise the blade for transport with a minimum of 15 cm road clearance should also be incorporated. The underbody blade hanger device should be constructed to provide the maximum load-bearing distribution surface for the mould-board. Blade turntable circles should be the welded type with at least four position indexing locks, manual or automatic.

h) *Apron snow blade.* The apron blade should be designed to be mounted on an aeroplane tug, wheel loader, industrial tractor, or other similar vehicles that may differ from a standard type plough vehicle. The plough is designed for wide-swath, low-speed operations in confined apron areas. This unit should be suitable for pushing snow and slush away from terminal building, gate, and apron areas and is not intended for use in areas with in-pavement lighting. The unit should have a mould-board length to 6 m, have a deeply recessed curvature, be approximately 1.42 m high, and may have optional full side plates. The replaceable tungsten carbide steel cutting edge should be fixed in the bulldoze position. The blade hitch should be of the vertical slide or similar quick disconnect configuration, and the plough should be equipped with a minimum of either two shoes or two castors. Parking legs may be provided as desired; plough shoes may provide this function on some models.

i) *Snow buckets (general purpose).* The bucket should be used by and fit on a standard wheel loader or similar type vehicle without modification, on a quick disconnect hitch. Snow buckets are designed for snow-loading operations, removing wind-rows, and stockpiling snow for storage or transport. They should be constructed of steel in accordance with the standard techniques of plough construction. The bucket capacity should be from 1 m^3 to 4 m^3. The bucket should be capable of a minimum 20 degree forward tilt, transverse tilt and level scoop operation. Bucket tilt may be provided by the articulating mechanism of the vehicle itself.

j) *Snow basket.* This is intended for use on wheel loader-type vehicles using a quick disconnect hitch. This basket bucket is for use in snow-loading operations and in function is similar to a standard bucket. The basket should range from 2.7 m to 5.1 m in width. The manoeuvring characteristics should correspond to a snow bucket. The construction should be of flexible steel weaving over a steel frame to achieve minimum weight without strength loss. The basket frame should be constructed to prevent deformation under maximum snow loads and normal operations.

Appendix 8

Related Reading Material

1. Copies of the following publications may be obtained from the National Technical Information Service, Springfield, Virginia, U.S.A. 22151:

— Pavement Grooving and Traction Studies, Report No. NASA 5P-507, dated 1969.

— A Comparison of Aircraft and Ground Vehicle Stopping Performance on Dry, Wet, Flooded, Slush, and Ice-Covered Runways, Report No. NASA TN D-6098, dated November 1970.

— Runway Friction Data for 10 Civil Airports as Measured with a Mu Meter and Diagonal Braked Vehicle, Report No. FAA-RD-72-6l, dated July 1972.

— Effects of Pavement Texture on Wet-Runway Braking Performance, Report No. NASA TN D-4323, dated January 1969.

— Porous Friction Surface Courses, Report No. FAA-RD-73-l97, dated February 1975.

— Laboratory Method for Evaluating Effect of Runway Grooving on Aircraft Tires, Report No. EAA-RD-74-l2, dated March 1974.

— Investigation of the Effects of Runway Grooves on Wheel Spin-up and Tire Degradation, Report No. FAA-RD-7l-2, dated April 1971.

— Environmental Effects on Airport Pavement Groove Patterns, Report No. FAA-RD-69-37, dated June 1969.

— The Braking Performance of an Aircraft Tire on Grooved Portland Cement Concrete Surfaces, Report No. FAA-RD-8O-78, dated January 1981.

— Braking of an Aircraft Tire on Grooved and Porous Asphaltic Concrete, Report No. DOT-FAA-RD-82-77, dated January 1983.

— Analytical and Experimental Study of Grooved Pavement Runoff, Report No. DOT-FAA-PM-83/84, dated August 1983.

— Surveys of Grooves in Nineteen Bituminous Runways, Report No. FAA-RD-79-28, dated February 1979.

— Modified Reflex-Percussive Grooves for Runways, Report No. DOT-FAA-PM-82-8, dated March 1984.

— The Correlation and Performance Reliability of Several Types of Friction Measuring Devices.

— Reliability and Performance of Friction Measuring Tires and Friction Equipment Correlation, Report No. DOT/FAA/AS-90-1, dated March 1990.

2. Evaluation of Two Transport Aircraft and Several Ground Test Vehicle Friction Measurements obtained for Various Runway Surface Types and Conditions, NASA Technical Paper 2917, dated February 1990, may be obtained from NASA, Code NTT-4, Washington, D.C., U.S.A. 20546-0001.

3. Copies of American Society for Testing and Materials (ASTM) Specifications can be obtained from ASTM, 1916 Race Street, Philadelphia, Pennsylvania, U.S.A. 19103.

END