SIERRA LEONE CIVIL AVIATION AUTHORITY

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Assessment of Runway Friction

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1 GENERAL

The Sierra Leone Civil Aviation Authority's Advisory Circulars contains information about standards, practices and procedures that the Authority has found to be an Acceptable Means of Compliance (AMC) with the associated Regulations.

An AMC is not intended to be the only means of compliance with a Regulation, and consideration will be given to other methods of compliance that may be presented to the Authority

Information considered directive in nature is described in this AC in terms such as "shall" and "must", indicating the actions are mandatory. Guidance information is described in terms such as "should" and "may" indicating the actions are desirable or permissive, but not mandatory

1.1 Purpose

(a) This AC provides information and guidance to aerodrome operators on the conduct of Runway Friction Assessment. It outline the procedures for undertaking runway surface friction assessments; and defines the criteria by which friction values should be assessed on runways under specified conditions.

1.2 Description of Changes

This is the second AC to be issued on this subject.

1.3 Reference

(a) SLCAR's Part 14A – Aerodrome Design and Operations Standards

(b) ICAO Doc 9137 - Airport Services Manual - Part 2 - Pavement Surface Conditions

(c) ICAO Doc 9137 - Airport Services Manual - Part 8 - Airport Operational Services

(d) ICAO Doc 9157 - Aerodrome Design Manual - Part 1 – Runways

1.4 Cancelled Documents

This document repeals and replaces the previous guidance prescribed in **SLCAA-AC-AATNS012 – ASSESSMENT OF RUNWAY FRICTION**

1.5 Definitions

For the purpose of runway surface friction assessment the following definitions apply:

Continuous friction measuring equipment (CFME) - A device designed to produce continuous measurement of runway friction values

Design objective level (DOL) - The friction level to be achieved or exceeded on a new or resurfaced runway

Maintenance planning level (MPL) - The friction level below which corrective maintenance action should be initiated

Minimum friction level (MFL) - The friction level below which information that a runway may be slippery when wet should be made available.

Portions of the pavement - A rectangular area of the runway width running the declared length, referred to as the 'central' trafficked portion and two 'outer' portions.

Runway surface friction tests - The assessment of friction carried out under conditions of self-wetting using a CFME.

2 INTRODUCTION

2.1 General

(a) 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 water on the runway and, particularly, when aeroplane take-off or landing speeds are high. This concern is more acute for jet transport aeroplanes 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.

(b) A measure of the seriousness of the situation is indicated by the action of 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 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 water-covered runways is contained in the Airworthiness Technical Manual (Doc 9051).

(c) Further, it is essential that adequate information on the runway surface friction characteristics/aeroplane 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 water and the runway becomes slippery when wet, the pilot should be made aware of the potentially hazardous conditions.

(d) 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 contaminants such as water, it cannot be overemphasized that the goal of the aerodrome operator should be the removal of all contaminants as rapidly and completely as possible and elimination of any other conditions on the runway surface that would adversely affect aeroplane performance.

2.2 Importance of Runway Surface Friction Characteristics/Aeroplane Braking Performance

(a) Evidence from aeroplane overrun and run-off incidents and accidents indicates that in many cases inadequate runway friction characteristics/aeroplane braking performance was the primary cause or at least a contributory 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.

(b) Adequate runway friction characteristics are needed for three distinct purposes:

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

(ii) 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

(iii) wheel spin-up at touchdown.

(c) With respect to either aeroplane braking or directional control capability, it is to be noted that an aeroplane, 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 y-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.

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

(e) On landing, runway surface friction is particularly 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 mechanically controlled anti-skid braking systems (installed in most current aeroplanes) and for obtaining the best possible steering capability. Moreover, the armed auto-spoilers 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 creating a potentially dangerous situation and possibly leading to tire failure.

(f) 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.

(g) To compensate for the reduced stopping capability 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 allowable cross-wind component is reduced.

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

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

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

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

  (i) the problem of determining runway friction characteristics in operationally meaningful terms; and

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

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

2.3 Need for Assessment of Runway Surface Conditions

(a) Runway surface friction/speed characteristics need to be determined under the following circumstances:

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

  (ii) 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;

  (iii) 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; and

  (iv) the slippery runway under unusual conditions, where additional measurements should be made when such conditions occur.

(b) The above situations may require the following approach on the part of the aerodrome operator:

  (i) 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.

2.4 Contaminant Drag

(a) There is a requirement to report the presence of water on a runway, as well as to make an assessment of the depth and location of 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, while the drag effects of the contaminant would assist aeroplane deceleration.

(b) 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 contaminated runway.

3 ASSESSMENT OF BASIC FACTORS AFFECTING FRICTION

3.1 Water Depth and Its Influence on Dynamic Aquaplaning

(a) The critical speed at which aquaplaning occurs depends on how it is defined. 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.

(b) 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.

(c) 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 23cm wheel.

(d) 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.

(e) 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 SLCAA-AC-AGA036 Rev00 – Runway Surface Condition Assessment and Reporting.

(f) 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.

(g) 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 827kPa. 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. 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.

(h) 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 section 3.3 below.

(i) 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.

3.2 Surface Contaminants

(a) The presence of fluid state contaminants such as 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 water-covered runways are contained in the Airworthiness Manual (ICAO Doc 9760).

(b) 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:

(i) fluid displacement drag;

(ii) wheel spin-down characteristics; and

(iii)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.

(c) When an unbraked tire rolls on a fluid-covered runway, the moving tire contacts and displaces the stationary runway fluid. The resulting change in momentum 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.

(d) 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.

(e) 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-

(f) 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.

(g) 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.

3.3 Surface Texture

(a) 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 microtexture. 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, macrotexture is primarily used to increase bulk water drainage, thereby reducing the tendency for aeroplane tires to experience 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 microtexture both have significant effects on wet friction coefficients, it can be reasoned that only general trends can be established using measurements of macrotexture only. Available data do show a general trend in favour of large macrotextures to increase wet friction coefficients.

(b) Section 3.1.26 of the SLCAR Part 14A requires 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.

(c) 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.

(d) 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.

3.3.1 Sand and Grease Patch Methods

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.

4 DETERMINING AND EXPRESSING FRICTION CHARACTERISTICS OF WET PAVED SURFACES

4.1 General

(a) 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.

(b) 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 generally determine the most suitable method to be used at a particular aerodrome. 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.

(c) 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 microtexture/macro textural 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.

(d) 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.

(e) Ideally, the distinction between good and poor runway surface friction characteristics when wet should be related to airworthiness criteria for the certification of aeroplanes.

(f) The criteria used for evaluating runway surfaces should be published in the 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.

(g) 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.

4.2 Measurement

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

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

  (ii) to assess the slipperiness of paved runways;

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

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

(b) 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.

(c) 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.

(d) Friction tests of existing surface conditions should be taken periodically in order to identify runways with low friction when wet. The Authority has defined its minimum friction level acceptable before a runway is classified as slippery when wet and this value is published AIP (Statement in green highlight is a recommended text). When the friction of a runway or a portion thereof is found to be below this reported value, then such information should be promulgated by a NOTAM. The Authority has also established 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.

(e) 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 1mm.

(f) 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.

(g) Even when friction has been found to be above the level set by the Authority 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.

(h) 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 promulgate this information and take corrective action.

(i) When conducting friction tests on wet runways, it is important to note that 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 macrotexture 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 macrotexture 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.

(j) An accurate measurement of the friction characteristics 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.

(k) The Authority has specified three (3) friction levels as follows:

  (i) a design level which establishes the minimum friction level for a newly constructed or resurfaced runway surface;

  (ii) a maintenance friction level below which corrective maintenance action should be considered; and

  (iii)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 4-1, which is based on experience with different friction-measuring devices, shows the criteria adopted by the Authority for specifying the friction characteristics of new or resurfaced runway surfaces, for establishing maintenance planning levels and for setting minimum friction levels.

(l) 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.

(m) 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.

(n) To minimize variations in the friction measurements 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 alone a track 5m 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.

(o) Continuous friction-measuring devices 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 4-1 Runway Surface Condition Levels

	Test Equipment	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)**	**(8)**
	Mu-meter Trailer	A A	70 70	65 95	1.0 1.0	0.72 0.66	0.52 0.38	0.42 0.26
	Skiddometer Trailer	B B	210 210	65 95	1.0 1.0	0.82 0.74	0.60 0.47	0.50 0.34
	Surface Friction Tester Vehicle	B B	210 210	65 95	1.0 1.0	0.82 0.74	0.60 0.47	0.50 0.34
	Runway Friction Tester Vehicle	B B	210 210	65 95	1.0 1.0	0.82 0.74	0.60 0.54	0.50 0.41
	TATRA Friction Tester Vehicle	B B	210 210	65 95	1.0 1.0	0.76 0.67	0.57 0.52	0.48 0.42
	RUNAR Trailer	B B	210 210	65 95	1.0 1.0	0.69 0.63	0.52 0.42	0.45 0.32
	GRIPTESTER Trailer	C C	140 140	65 95	1.0 1.0	0.74 0.64	0.53 0.36	0.43 0.24

4.3 Reporting

It is required to report the surface condition of a runway, guidance on this procedures of reporting runway surface condition is found in SLCAA-AC-AGA036 Assessment and Reporting of Runway Surface Conditions.

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:

(i) Damp - the surface shows a change of colour due to moisture.

(ii) Wet - the surface is soaked but there is no standing water.

(iii)Water patches - significant patches of standing water are visible.

(iv)Flooded - extensive standing water is visible.

4.4 Interpretation of Low Friction Characteristics

(a) 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.

(b) 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.

5 OPERATIONAL PRACTICES

5.1 Runway Friction Testing Overview

The aerodrome operator maintenance programme is required to "provide for the surface of paved runways to be maintained in a condition that provides good surface friction characteristics and low rolling resistance for aircraft".

5.2 Requirement for Friction Testing

(a) The SLCAR's Part 14A – Chapter 10 details the requirement for friction characteristics of runways under Section 10.2 - Pavements. The SLCAR's Part 14A requirements cover measurement of friction characteristics and corrective maintenance action.

(b) Runway surface types are off different characteristics and as such it requires individual aerodrome operators to closely monitor the friction levels. This monitoring assists in ensuring that the runway friction levels are kept to an acceptable level and assists in the planning of maintenance.

(c) A runway surface friction test is conducted under controlled conditions using self-wetting equipment to establish the friction characteristics of a runway and to identify those areas of a runway surface that may require attention.

(d) Friction measurements are specified for all hard-surfaced runways serving turbojet aeroplanes because the higher weights and operating speeds of turbojet versus turboprop aeroplanes make turbojet-braking performance on runway surfaces, particularly when wet, a significant safety concern.

(e) Consideration should also be given to measuring the friction characteristics of runways serving heavy turboprop aeroplanes (MTOW 15,000 kg or greater), that have runway take-off and landing distance requirements close to the limits of available runway length.

5.2.1 Friction Deterioration

(a) The skid-resistance of runway pavement deteriorates due to a number of factors, the two predominant ones being mechanical wear and polishing action from aircraft tyres rolling or braking on the pavement, and the accumulation of contaminants, chiefly rubber, on the pavement surface. The effect of these factors is directly dependent upon the volume and type of aircraft traffic.

(b) Other influences on the rate of deterioration are local weather conditions, the type of pavement, the materials used in original construction, any subsequent surface treatment and airport maintenance practices.

(c) Structural pavement failure such as rutting, cracking, joint failure, settling, or other indicators of distressed pavement can also contribute to runway friction losses. It is important that runway inspections identify any changes in surface condition so that appropriate and timely remedial action can be undertaken.

(d) Contaminants, such as rubber deposits, jet fuel, oil spillage, algae, and water, all cause friction loss on runway pavement surfaces. The most persistent contaminant problem is deposit of rubber from tyres of landing aircraft. This happens predominately at the touchdown areas on runways and can be quite extensive. Heavy rubber deposits can completely cover the pavement surface texture causing loss of aircraft braking capability and directional control, particularly when runways are wet.

5.2.2 Friction Testing Frequency

(a) Regular friction testing enables an aerodrome operator to build up an overview of the runway condition over a period of time to identify any deterioration. This enables runway maintenance to be planned and targeted to enable levels to remain above the specified minimum friction level (MFL). The testing should be performed on a regular basis with accurate readings performed on the same calibrated device.

(b) Initially, when setting up a runway friction testing programme, the frequencies outlined in Table 5-1 and Table 5-2 should be used. Aerodrome operators should monitor the results of friction tests and, if necessary, vary the interval between assessments based on the results.

(c) If historical data indicates the surface is deteriorating faster or slower than the rate used to establish the testing frequency, the frequency can be adjusted taking into account:

- (i) the type, mix and frequency of aircraft operating on the runway;
- (ii) the specific micro- and macro-texture characteristics of the pavement surface;
- (iii) the presence, extent and severity of surface contaminants especially rubber build-up;
- (iv) the existence of pavement surface problems which may directly affect friction levels;
- (v) pilot reports of low friction levels being experienced during aircraft braking;
- (vi) the frequency of past programs for the removal of surface rubber contaminants;
- (vii) any recent construction or maintenance of the pavement surface, and
- (viii) the results of past friction measurements.

(d) The objective is to ensure that, when the friction level has reached the maintenance planning level (MPL), maintenance can be arranged and completed efficiently and in a timely manner, to ensure the friction characteristics do not deteriorate below the minimum friction level (MFL).

(e) The aerodrome operator should record the justification for any variation from the recommended periodicity for assessments.

(f) When it is suspected that a runway has become slippery under other than normal wet conditions, or due to unusual surface conditions, additional friction testing may need to be undertaken. Information detailing the nature, extent and severity of any unusual slippery runway conditions should be promulgated by NOTAM to provide a cautionary warning.

5.2.3 Turbojet Aircraft Operations

(a) The operator of an aerodrome with significant jet aircraft traffic should schedule periodic friction testing of each runway that accommodates jet aircraft. It is recommended that every runway for jet aircraft be tested in accordance with criteria as shown in Table 5-1 below. Depending on the volume and type (weight) of traffic using the runway, testing may be needed more frequently, with the most heavily used runways needing testing as often as monthly, as rubber deposits build up.

(b) Each runway end should be evaluated separately, for example: Runway 21 and Runway03.

(c) Runway friction measurements take time, and while tests are being conducted, the runway will be unusable by aircraft. Since this testing is not time critical, a period should be selected which minimizes disruption of air traffic.

(d) Table 5-1 details the recommended frequency for friction testing for runways where turbojet aircraft operate. It is important the aerodrome operator assesses their own individual aerodrome needs.

Table 5-1 Friction testing frequency

Average number of turbojet movements on the runway per day	Minimum frequency of friction testing	Rubber Deposit Removal frequency
Less than 15	1 year	1 year
16 to 30	6 months	1 year
31 to 90	3 months	6 months
91 to 150	1 month	4 months
151 to 210	2 weeks	3 months
Greater than 210	1 week	2 months

5.2.4 Turboprop Aircraft Operations

(a) The recommended frequency depends on aircraft type, weight and number of movements. Table 5-2 details the recommended friction testing for runways where turboprop aircraft with a MTOW of 15,000kg or greater operate. It is recommended that for aerodromes serving turboprops less than this weight perform friction testing at least once every 3 years.

(b) Each runway end should be evaluated separately, for example: Runway 20 and Runway 0236.

Table 5-2 Friction testing frequency – Turboprop aircraft (MTOW 15,000kg or greater)

Average number of turboprop operations on the runway per day	Minimum frequency of friction testing
Less than 15	5 years
16 to 30	3 years
31 to 90	1 year

5.2.5 Testing Following Maintenance Activities

(a) The friction characteristics of a runway can alter significantly following maintenance activities, even if the activity was not intended to affect the friction characteristics. Therefore, a runway surface friction assessment should be conducted as soon as practicable, following any significant maintenance activity conducted on the runway. If possible this should be done before the runway is returned to service.

(b) If the runway surface friction assessment indicates that the friction characteristics of an area of the runway, that has been subject to maintenance work are poorer than anticipated or fall below the acceptable levels additional assessments, should be performed over a period of time to ascertain whether the friction characteristics remain stable, improve, or if additional work should be carried out.

5.2.6 Testing Following Reports of Poor Braking Action

Runway surface friction assessments should also be conducted following a period of poor braking action reports on a dry, damp or wet run surface, if there are visible signs of runway surface wear, or for any other relevant reason.

5.3 Friction Testing Process

(a) Runway friction testing requires the use of Continuous Friction Measuring Equipment (CFME) together with trained personnel to conduct the tests. If an aerodrome operator does not have CFME and trained staff to operate it, arrangements should be in place to access a unit with trained operators whenever testing is required.

(b) If a contractor is used it is important that that the CFME is appropriate for runway surface testing, and the operators are trained to perform runway friction testing.

5.3.1 Equipment Requirements

(a) There are a variety of CFME on the market, however, all use on the same principles to determine the runway friction characteristics. The Mu-Meter and the Grip Tester are the predominant makes used across the industry.

(b) Irrespective of whether the aerodrome owns the CFME or has hired a contractor, before conducting friction surveys the aerodrome operator should ensure:

  (i) the equipment has been serviced and maintained in accordance with the manufacturer’s requirements, and is in full working order;

(ii) the friction measuring system and components have been calibrated in accordance with the manufacturer's instructions and its performance has been confirmed to be within the manufacturer’s specified tolerances; and

(iii) for CFME fitted with self-wetting systems:

(1) the water flow rate is correct; and

(2) the amount of water produced for the required water depth is consistent and applied evenly in front of the friction measuring wheel(s)

(c) It is recommended that, before and after undertaking the runway friction tests, the CFME is checked on a defined test strip of pavement that is not used for aircraft operations. Comparison of the sample readings with previous results will quickly verify the CFME performance.

(d) Additional information on specifications for CFME can be found in ICAO Doc 9137-Airport Services Manual Part 2, Chapter 5.

5.3.2 Personnel Working on Aerodromes

(a) All personnel undertaking runway friction tests need to comply with the general requirements for personnel working on operational areas of an aerodrome, or be accompanied and supervised at all times by someone who does. In particular, they must:

(i) be familiar with, and follow the established procedures for working on an operational aerodrome;

(ii) be trained in radio procedures (radio telephony), including ATC phraseology and the importance of complying immediately with any instructions to vacate the maneuvering areas;

(iii) be provided with a two-way radio for communications with the air traffic services unit at the aerodrome; and

(iv) have a vehicle equipped with a flashing or rotating beacon or a chequered flag for day time testing, or a flashing or rotating beacon for night time testing

(b) Before any work starts personnel should be fully briefed operational procedures, method of work plans (MOWP) and safety plans, and any other matters relevant to the work being carried out.

(c) Advisory circular on the requirements for personnel working on operational areas of an aerodrome should be consulted.

5.3.3 CFME Operators

(a) The success of friction measurement in delivering reliable friction data depends heavily on the personnel, who are responsible for operating the equipment. It is important that CFME operators are fully trained and competent, to use the equipment and are aware of the critical factors affecting the accuracy of friction measurements.

(b) Where a contractor carries out the testing it is the responsibility of the aerodrome operator to be satisfied as to the competency and experience of the CFME operator.

(c) CFME operators must:

(i) have been trained to:

  (1) service and maintain the equipment; and

  (2) check its calibration and verifying it is working properly; and

  (3) operate the machine and carry out friction testing; and

(ii) understand:

  (1) runway friction testing procedures; and

  (2) requirements and procedures when working on operational areas; and

(iii) have been assessed as competent to carry out runway friction testing; and

(iv) where appropriate, received recurrent training and assessments

(d) Records must be kept as evidence that training and competency assessments have been completed.

5.3.4 Environmental Conditions for Friction Testing

(a) Environmental conditions can affect the friction testing results. The test should be conducted when:

  (i) the runway surface is dry, free from precipitation, and has no wet patches; and

  (ii) the ambient air temperature is conducive

(b) Dampness, fog and mist conditions may affect the outcome of the test and cross-winds may affect self-wetting testing.

(c) Where necessary, aerodrome operators should seek advice on any environmental issues from the CFME manufacturer.

5.3.5 Runway Surface Friction Testing Procedure

(a) Friction readings for the survey run are collected by the CFME along the entire pavement length. Several runs are made along the runway, offset on either side of the centreline, and in both directions.

(b) The runway is normally divided into zones 100 metres in length with an average friction value determined every 10 metres along a run, enabling a 100-metre rolling average to be calculated. Another method uses discrete averaging for interpretation immediately after the testing.

5.4 Location of Friction Testing Runs

(a) A runway surface friction assessment consists of two check runs supplementing a series of standard runs:

  (i) **Check Runs**

    (1) A check run is designed to confirm that the operation of the CFME is consistent throughout the full runway surface friction assessment and should be conducted before and after completion of the standard runs, under the same conditions.

    (2) A check run should be performed over the entire pavement length on a portion of the runway that does not traverse any other runs, and at a constant speed.

(ii) **Standard Runs**

(1) Starting with the run closest to the runway edge, a standard run should be carried out along the entire pavement length at a constant run speed, allowing for acceleration and safe deceleration. Table 3 defines the recommended location of each run for nominal width runways.

(2) The track(s) of the measuring wheel(s) should not run along the line of the pavement joints or longitudinal cracks.

Table 5-3 Recommended Format for Runway Surface Friction Assessment Standard Runs Based on Nominal Runway Width

Runway Width	Recommended lateral displacement of standard runs each side of the centreline (metres)					
18m	1,5	3,5	6			
23m	1,5	3	6	9		
30m	1,5	4	7	12		
45m	1,5	4	7	11	17	
60m	1,5	4	7	11	17	23

(b) Where a runway is not a standard width, the aerodrome operator should ensure that the spacing between the standard runs is of similar dimensions to the patterns illustrated in Table 5-2 above; that they run parallel to the runway centreline; and are laterally separated by a distance no greater than 6 metres.

(c) The run pattern for a runway with Touchdown Zone (TDZ) markings should be planned so as to include one run either side of the centreline to pass through the centre of the painted TDZ markings.

(d) If there is any reason to doubt the accuracy of the runway surface friction assessment, it should be repeated.

5.4.1 Friction Testing Work Schedule

(a) Ideally each runway direction should be tested separately, with friction test runs on either side of the runway centreline. The practice of one circular run for the whole runway results in only the friction values for one side of each direction of a runway being assessed.

(b) If there are operational difficulties in conducting bi-directional tests, the aerodrome operator may implement a series of single direction tests to complete the testing programme. Appropriate processes should be in place to ensure the tests in both directions are completed.

5.4.2 Low Friction Values

When friction values below maintenance planning levels are measured, additional friction runs should be performed outside the wheel path area, in order to assess the degree to which wear and contaminants have lowered friction levels in the centre trafficked area. A test track profile located 5 to 10 metres from the outer edge of the paved runway surface is normally optimum for the purposes of wear and contaminant comparison tests.

5.4.3 Vehicle Testing Speed

(a) The tests should cover the maximum area of the runway, subject to the test vehicle having sufficient area to accelerate to the required speed and decelerate and stop safely. Standard runs should be carried out along the entire pavement length at a constant speed, starting with the run closest to the runway edge.

(b) The friction test runs should be performed at two speeds, 65 km/h (40 mph) and 95 km/h (60 mph). The lower speed determines the overall mix of macro-texture and micro-texture/contaminant/drainage condition of the pavement surface. The higher speed provides a further indication of the condition of the surface's macro-texture alone.

(c) A complete survey should include tests at both speeds although operational requirements may limit this.

5.5 Evaluation of Friction Testing Results

5.5.1 Friction Assessment Levels

(a) There are three published friction levels for runways as described in section 4.2(k):

(b) The friction level values produced by different CFME vary slightly for any given runway surface friction characteristics; therefore, Table 4-1 indicates the correlation between the assessment criteria of CFME devices.

5.5.2 Action following Runway Friction Assessment

(a) The raw data from the friction test should be interpreted by trained maintenance personnel familiar with friction testing requirements.

(b) A report should be compiled from the raw data and compares the friction levels from the test against the published required friction levels. The report should also identify any areas where there are deficiencies, and make recommendations to address these.

(c) The aerodrome operator should review the results of each runway friction assessment and where appropriate take the following action:

   (i) If the friction level is below the MPL, maintenance should be arranged to restore the friction level, ideally to a value equal to or greater than the DOL.

   (ii) If the friction level is trending downwards, the aerodrome operator should consider increasing the frequency of assessments to ensure any further or rapid deterioration is identified in time for appropriate remedial action to be taken.

(iii) If the friction level is below the MFL, maintenance should be arranged urgently to restore the friction level. In accordance with SLCAR's Part 14A and, where appropriate a NOTAM should be issued advising that the runway may be slippery when wet.

(iv) If the friction level is significantly below the MFL, the aerodrome operator should consider withdrawing the runway from use for take-off and/or landing when wet.

(d) If there is any reason to doubt the accuracy of a runway surface friction assessment, it should be repeated.

5.5.3 Trend Analysis

(a) Friction testing results should be systematically recorded to allow the results to be monitored to identify trends and patterns. This enables analysis of the condition of the runway surface so timely preventative and/or corrective actions can be taken and, where appropriate, adjustments to the intervals between friction testing can be made. (See section 5.2.2).

(b) Any trend analysis must take into account the effects of using different CFME, equipment tyre wear and environmental factors. Effective interpretation of results can require normalization of test result data and factoring in issues that might affect the measurement data.

5.5.4 Rubber Removal

(a) One of the main causes of reduced runway friction levels is rubber deposits on the runway surface. There are various methods for rubber deposits removal, depending on the level of rubber deposits and the type of runway surface. Guidance on the removal of rubber can be found in SLCAR's Part 14A and section 5.17 of SLCAA-AC-AGA020 Rev01 Aerodrome Maintenance.

(b) Rubber deposit removal processes can impact on other aspects of the runway surface condition. Aerodrome operators should get specialist advice when necessary to ensure that rubber removal does not adversely affect other characteristics of the runway surface.

5.5.5 Records

(a) Aerodrome operators should keep records of all runway surface friction tests. The friction tests should be incorporated into the aerodrome maintenance plan, and used to monitor the overall health and condition of the runway surface.

(i) The following items should be recorded for each assessment:

(ii) Date and time of assessment.

(iii) Type of CFME used.

(iv) Name of operator.

(v) Runway assessed.

(vi) Runway number and runway direction.

(vii) Distance from the centreline and which side of centreline the run was performed.

(viii) Distance from threshold the run was performed.

(ix) Constant run speed (Km/h) for each run.

(x) Runway length.

(xi) Amount of water film used.

(xii) Surface condition (dry/damp/wet).

(xiii) Weather conditions and ambient temperature, and the runway surface and measuring wheel temperatures if available.

(xiv) Friction levels for each portion of the pavement. This can include average friction level for each third of the runway at each offset, direction, and speed.

(xv) Overall friction level for full length of the runway and, if required the 10m friction averages in the touchdown zones.

(xvi) A comparison of the results with any previous surveys conducted, providing the same CFME has been used.

(xvii) Evaluation of friction levels between the reference non-trafficked test strip and the trafficked runway during the current survey.

(xviii) Any evaluations of the reference non-trafficked test strip between successive surveys.

(xix) Any additional comments.

6 RUNWAY FRICTION-MEASURING DEVICES

6.1 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 (section 6.3 refers). However, consistent and reliable correlation between these devices and aeroplane stopping performance has not been achieved on wet surfaces. Measurements obtained by friction-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.

6.2 Criteria for New Friction-Measuring Devices

A set of criteria were developed by ICAO for the basic technical and operational characteristics of equipment used to measure runway friction. It was thought that the material would assist the planning of the development of new friction-measuring devices. However, there were 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. 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.

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

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

(c) **Mode of braking**. During friction measurement operations using:

   (i) 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

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

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

(e) **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.

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

(g) **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.

(h) **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).

(i) **Measured and recorded parameter**.

(i) 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.

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

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

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

(i) the first 100 m of the runway;

(ii) each 150 m increment; and

(iii)each one-third segment of the runway.

(l) **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.

(m) **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 ASTME1551 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 manufacturer's D-series (Slush cutter) or S-series (Disc tyre).

(n) **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 section 6.3.

(o) **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.

(p) **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.

(q) **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.

6.3 Some Frequently Used Runway Friction Measuring Devices

Below is a list of frequently used runway friction devices available in the market;

(a) Mux Meter

(b) Runway Friction Tester

(c) Skiddometer

(d) Surface Friction Tester

(e) Grip Tester

(f) Tatra Friction Tester

(g) Runway Analyzer and Recorder (RUNAR)

(h) Decelerometer

6.4 Correlation Between Friction-Measuring Devices

(a) The possibility of obtaining a useful degree of correlation between friction-measuring devices has been the subject of many trials in several countries 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 6-2).

(b) 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 4-1.

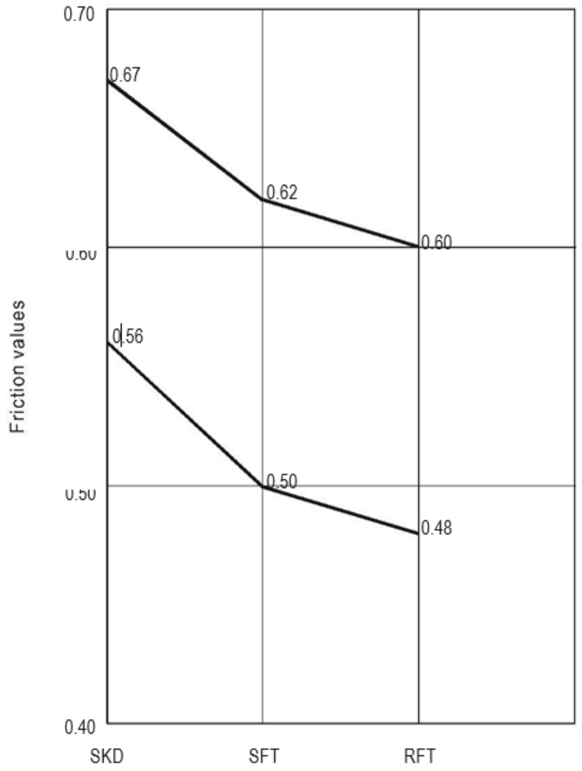
(c) Although some continuous friction-measuring devices use different tires or operate at a fixed braking slip or in yawed rolling test mode, tests have shown that their readings are reliable and correlate with each other when using self-water systems that apply a controlled water discharge in front 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.

Type of Equipment:	Time:	Location:	Program 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 Left Right	Rubber loss (grams)	
Total		
Tests conducted by Method of wetting Length covered by trace Starting at Distance of run from centre line Friction results		Towing vehicle (if applicable) Depth of water (mm) Test speeds Ending at

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 45m from center line giving lowest coefficient of friction (excluding paint markings)						

Figure 6-1 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 6-2 – Correlation chart for Friction-measuring device on artificial wetted dry surfaces

6.5 Correlation with Aeroplane Stopping Performance

(a) 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.

(b) 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, and rain-wet. 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.

6.6 General Discussion On Friction-Measuring Devices

(a) There are several friction-measuring devices in use today throughout the world. The devices listed in section 6.3 above provide a permanent and continuous trace of friction values produced on a strip chart for the entire runway length surveyed.

(b) 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 (section 4.3). 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.

(c) 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 manufacturer. 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.

7 PROCEDURES FOR CONDUCTING VISUAL INSPECTION OF RUNWAY MAINTENANCE SURVEYS WHEN FRICTION-MEASURING EQUIPMENT IS NOT AVAILABLE

7.1 Friction Survey Procedures

(a) 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.

(b) **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 7-1, 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.

(c) **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 7-2 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 7-2 represent values obtained from continuous friction-measuring devices that operate in the fixed braking slip mode. Table 7-3 shows a method for coding the condition of grooves in pavements, and Table 7-4 shows a method for coding the pavement surface type. These codes are provided as a short-cut method for preparing notes concerning the pavement surface condition.

(d) **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.

(e) **Measurement of pavement surface texture**. The following procedure is effective for measuring the macro-textural depth of pavements, but it will not measure the microtexture 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, representative 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:

(i) **Equipment.** On the left in Figure 7-1 is shown the tube which is used to measure the volume of grease which is 15 cm3. 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 7-2 gives the relation between the inside diameter of the tube and tube length for an internal tube volume of 15 cm3. The plunger can be made of cork or other resilient material to achieve a tight fit in the measuring tube.

(ii) **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 7-3. A general view of the texture measurement procedure is shown in Figure 7-4. 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.

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

$$\text{Texture Depth (cm)} = \frac{\text{Volume of grease (cm3)}}{\text{Area covered by grease (cm2)}}$$

$$\text{Average Texture Depth} = \frac{\text{Sum of individual tests}}{\text{Total number of tests}}$$

Table 7-1 –Frequency of Runway Visual Inspection Survey

Daily turbo-jet aircraft arrivals for runway end	Annual aircraft 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 2404	Once every 3 months
91 to 150	2405 to 3969	Once every month
151 to 210	3970 to 5535	Once every 2 weeks
Greater than 210	Greater than 5535	Once every week

***Note** - After calculating the first two columns according to the procedures given in Appendix 2 of this document, the airport operator must select the column which has the higher value and then select the appropriate value in the last column.*

Table 7-2 - 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 airport authority
Very Light	Less than 5%	Intermittent individual tire tracts; 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 6m 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 aircrafts 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 able 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 7-3 Alphanumeric coding for Groove condition

Pavement Surface treatment	Alpha Code	Numerical Coding with description
Groove type	H	0 – None 1 – 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 7-4 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

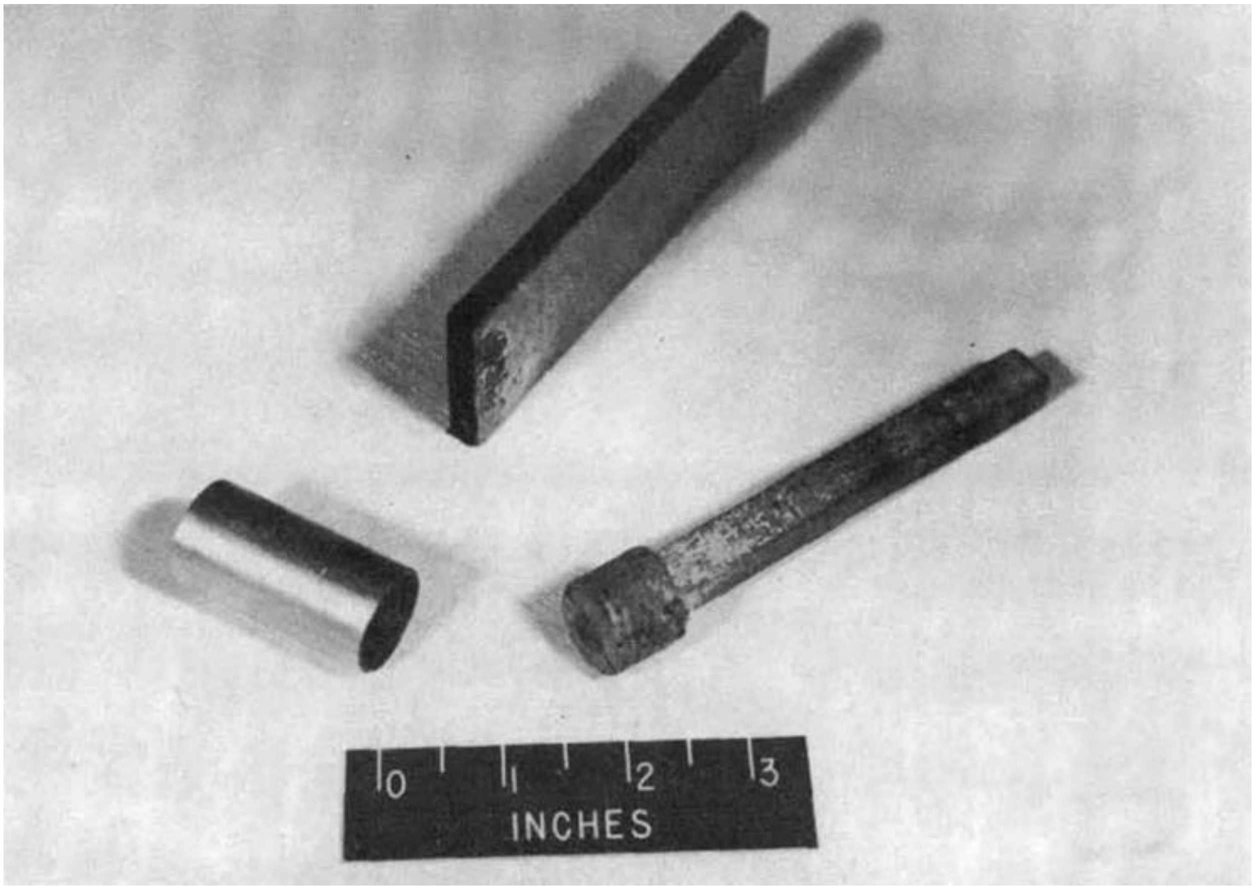


Figure 7-0-1 Grease-volume measuring tube, plunger and rubber squeegee

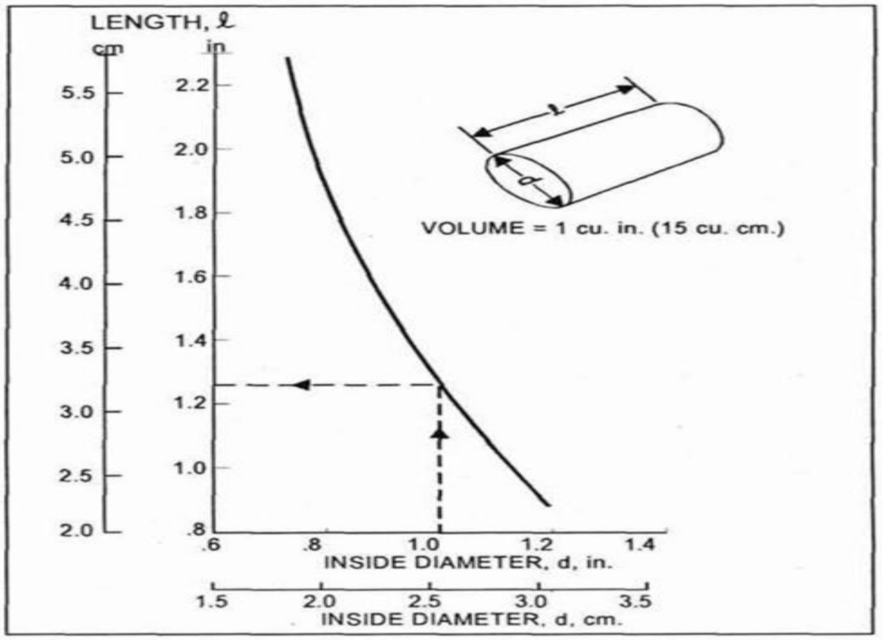


Figure 7-0-2 Measuring tube dimension to measure one inch

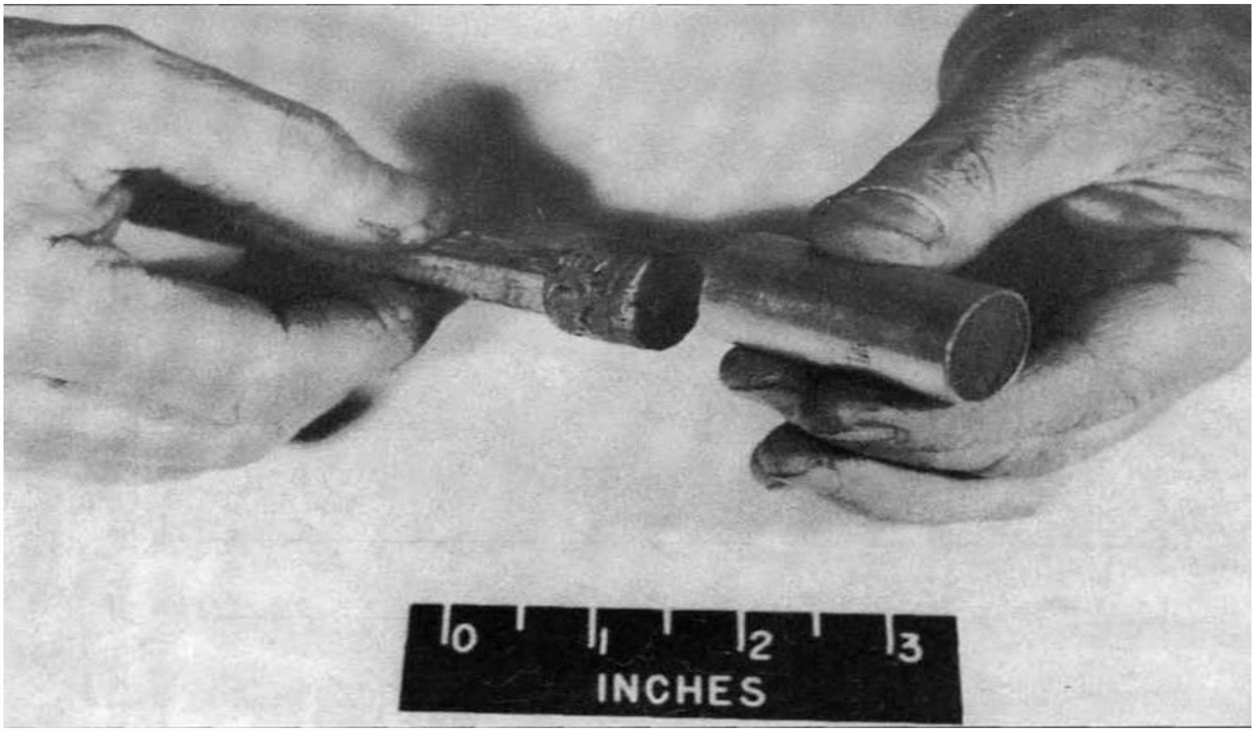


Figure 7--0-3 Measuring tube filled with grease

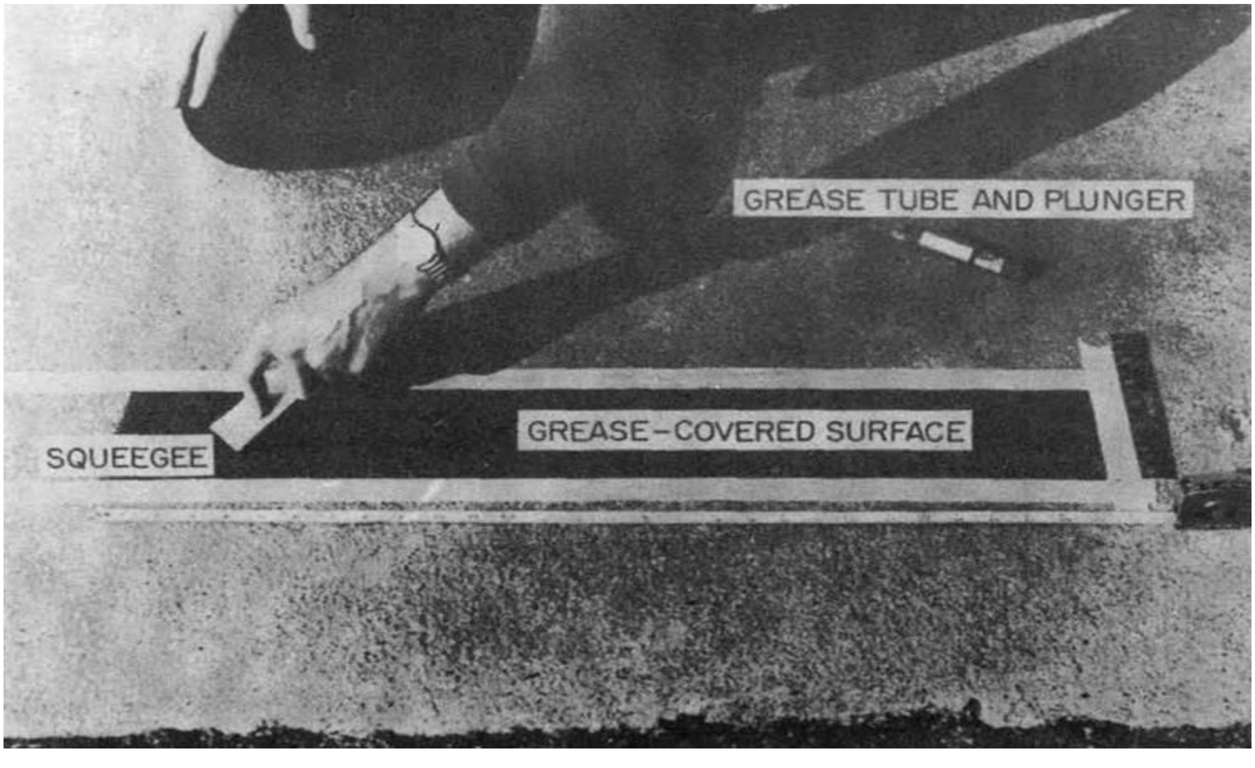
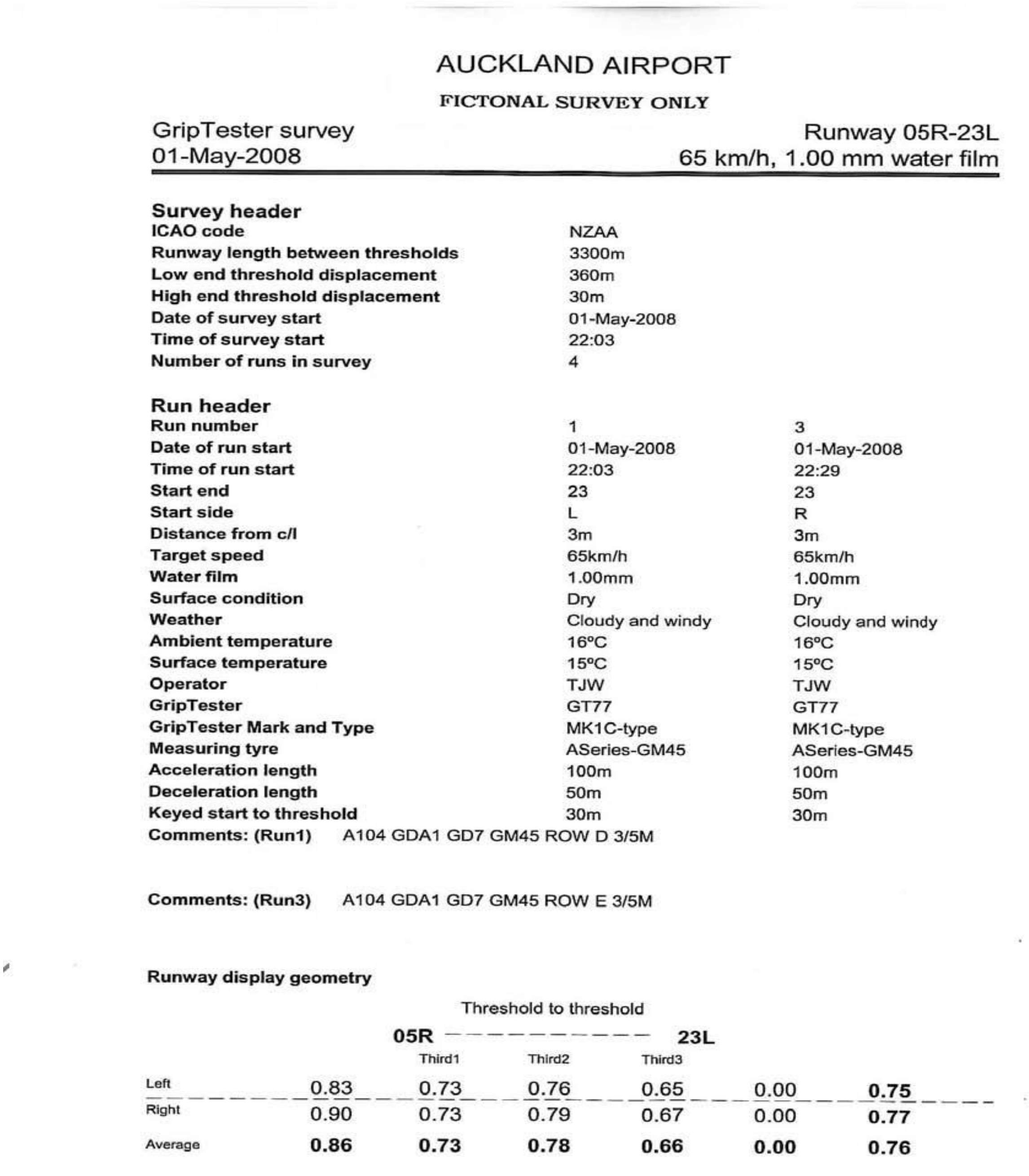


Figure 7-0-4 Illustration of apparatus used in grease application technique for measuring runway surface texture depth

APPENDIX 1 – SAMPLE FRICTION TEST REPORT

1. Sample Report

A sample friction test report showing typical test results follows.



AUCKLAND AIRPORT

FICTONAL SURVEY ONLY

GripTester survey
01-May-2008

Runway 05R-23L
65 km/h, 1.00 mm water film

Survey header

ICAO code	NZAA
Runway length between thresholds	3300m
Low end threshold displacement	360m
High end threshold displacement	30m
Date of survey start	01-May-2008
Time of survey start	22:03
Number of runs in survey	4

Run header

Run number	1	3
Date of run start	01-May-2008	01-May-2008
Time of run start	22:03	22:29
Start end	23	23
Start side	L	R
Distance from c/l	3m	3m
Target speed	65km/h	65km/h
Water film	1.00mm	1.00mm
Surface condition	Dry	Dry
Weather	Cloudy and windy	Cloudy and windy
Ambient temperature	16ºC	16ºC
Surface temperature	15ºC	15ºC
Operator	TJW	TJW
GripTester	GT77	GT77
GripTester Mark and Type	MK1C-type	MK1C-type
Measuring tyre	ASeries-GM45	ASeries-GM45
Acceleration length	100m	100m
Deceleration length	50m	50m
Keyed start to threshold	30m	30m

Comments: (Run1) A104 GDA1 GD7 GM45 ROW D 3/5M

Comments: (Run3) A104 GDA1 GD7 GM45 ROW E 3/5M

Runway display geometry

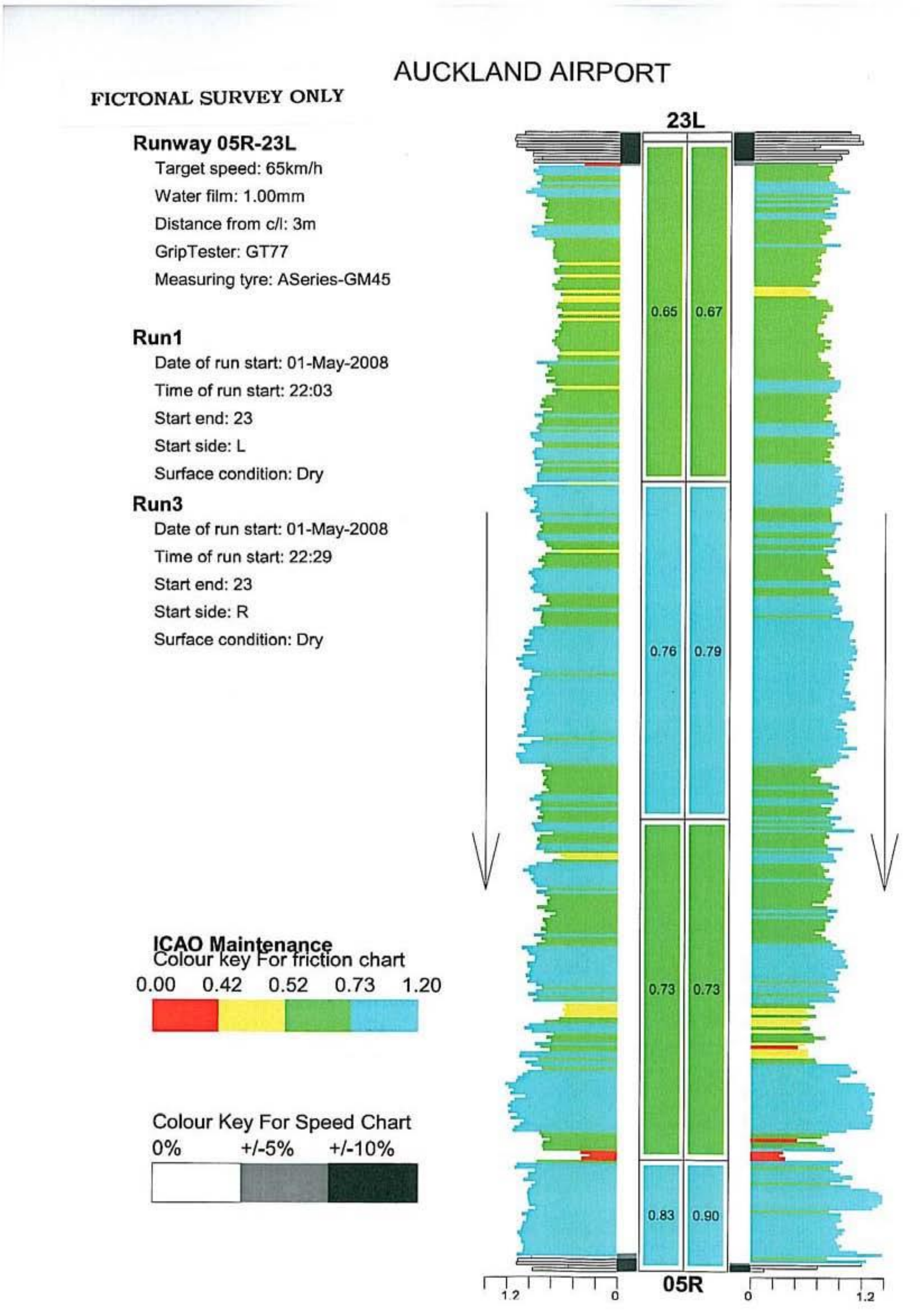
Threshold to threshold

05R ---------- **23L**

		Third1	Third2	Third3		
Left	0.83	0.73	0.76	0.65	0.00	**0.75**
Right	0.90	0.73	0.79	0.67	0.00	**0.77**
Average	**0.86**	**0.73**	**0.78**	**0.66**	**0.00**	**0.76**

Sample friction test report – Page 1 of 2

Sample friction test report



AUCKLAND AIRPORT

FICTONAL SURVEY ONLY

Runway 05R-23L

Target speed: 65km/h
Water film: 1.00mm
Distance from c/l: 3m
GripTester: GT77
Measuring tyre: ASeries-GM45

Run1

Date of run start: 01-May-2008
Time of run start: 22:03
Start end: 23
Start side: L
Surface condition: Dry

Run3

Date of run start: 01-May-2008
Time of run start: 22:29
Start end: 23
Start side: R
Surface condition: Dry

ICAO Maintenance
Colour key For friction chart

0.00	0.42	0.52	0.73	1.20
🟥	🟨	🟩	🟦	

Colour Key For Speed Chart

0%	+/-5%	+/-10%
⬜	▨	⬛

APPENDIX 2 – METHODS OF MEASURING/ASSESSING BRAKING ACTION WHEN NO FRICTION TEST DEVICES ARE AVAILABLE

1. Measuring of Braking Action by Braking a Truck or Car to a Full Stop

(a) 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.

(b) 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

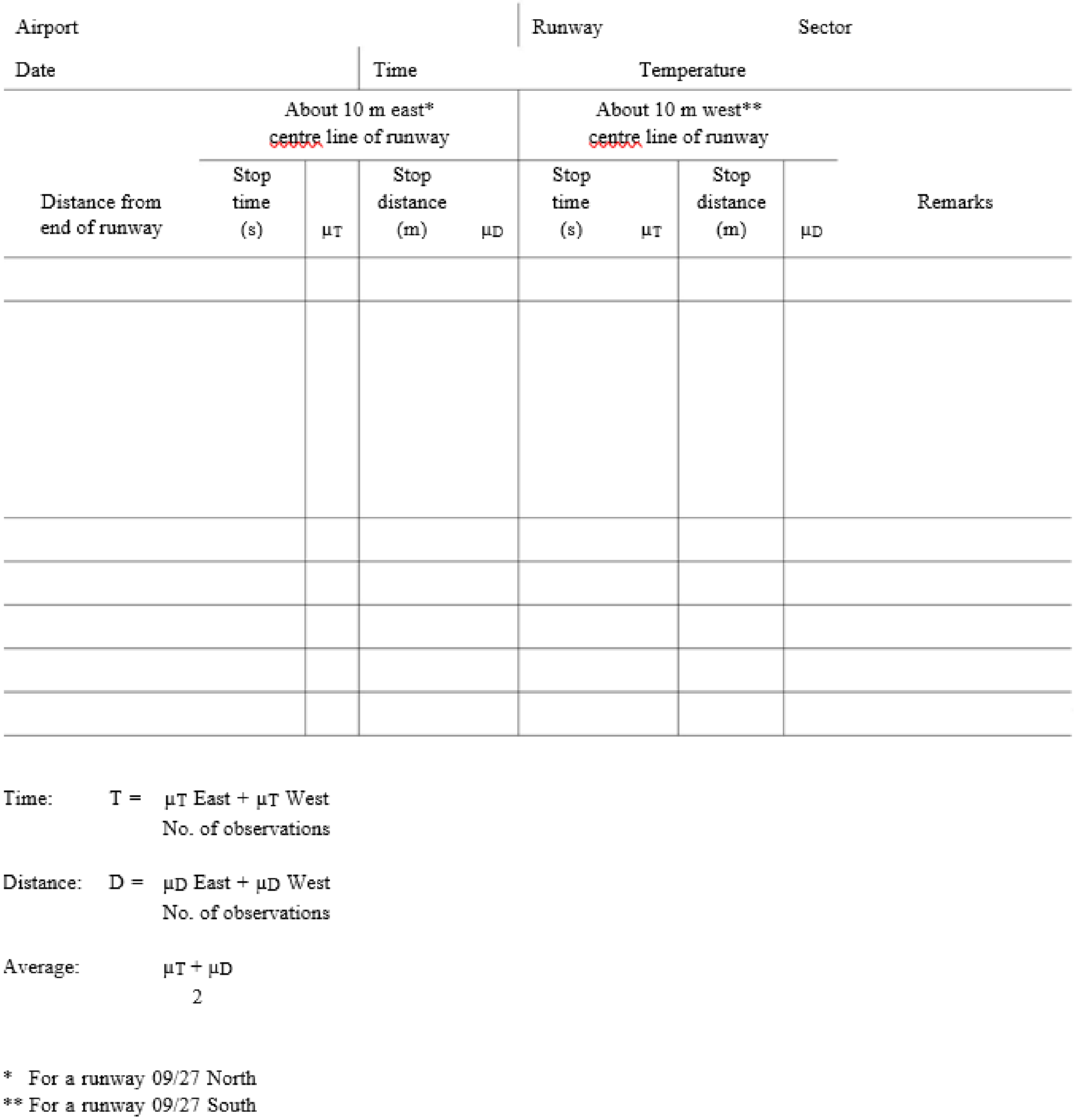
S = stopping distance, in m

t = stopping time, in s

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

(c) 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.

(d) 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. An example of a form to be used for recording and processing test results is given in Figure A2-1 below.



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)	μT	Stop distance (m)	μD	Stop time (s)	μT	Stop distance (m)	μD	Remarks

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

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

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

* For a runway 09/27 North

** For a runway 09/27 South

Figure A2-1 Example of schema that can be used when recording a friction test made with skidding wheels of a truck to a full stop from 40km/h