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International Runway Friction Index (IRFI)
Development Technique and Methodology

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16. Abstract

This report defines the International Runway Index (IRFI), which is part of a government/industry project called the Joint Winter Runway Friction Measurement Program (JWRFMP), led by Transport Canada and the U.S. National Aeronautics and Space Administration.

A statistical model was developed into ASTM Standard E 2100-00, *Standard Practice for Calculating the International Runway Friction Index*. The equation below represents a linear regression of the data for each friction measuring device to an IRFI reference.

$$_{IRFI} = a + b \cdot \text{device friction measurement}$$

where *a* is the intercept and *b* is the gradient that were determined by the regression to an IRFI reference device (primary reference) or to a master device that was calibrated to the IRFI reference device (secondary reference). This method thus harmonizes reported values of friction measurements to a common reference and units of friction measures worldwide. An Instrument de Mesure Automatique de Glissance, donated to the JWRFMP by Service Technique des Bases Aériennes (Paris), is currently being used as the reference and has been designated the International Reference Vehicle.

The average correlation (R^2) in 1998-99 was 0.85; in 1999-2000 it was 0.46; and in 2000-01 it was 0.73. The 1999-2000 data include Munich testing, where the snow conditions were poor. If Munich data are removed, the R^2 goes up to 0.81. The average sensitivity was 0.018 and the average standard error of estimate was 0.04.

Currently, the recommended procedure for harmonizing ground vehicle friction measurement data is outlined in ASTM Standard E 2100-00. The method requires annual calibration and typically reduces the present variations from a maximum of 0.2 down to 0.04.

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16. Résumé

Le présent rapport définit l'Indice international de la glissance des pistes (IRFI), dans le cadre d'un projet gouvernement-industrie appelé Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH), mené par Transports Canada et par la National Aeronautics and Space Administration (NASA) des États-Unis.

Un modèle statistique a été incorporé à la norme ASTM E 2100-00, *Standard Practice for Calculating the International Runway Friction Index*. L'équation ci-après représente une régression linéaire des données recueillies par chaque appareil de mesure du frottement, appliquée à l'appareil de référence IRFI.

$$_{IRFI} = a + b \bullet \text{appareil de mesure du frottement}$$

où *a* est l'ordonnée et *b* est le gradient, ces deux valeurs ayant été déterminées par une régression à partir de l'appareil de référence IRFI (référence primaire) ou par un appareil étalonné sur l'appareil de référence IRFI (référence secondaire). Cette méthode permet donc d'harmoniser les valeurs de mesure de frottement avec une référence commune et à des unités de frottement dans le monde entier. Un Instrument de mesure automatique de glissance (IMAG), donné au PCRGCAH par le Service technique des bases aériennes (Paris), est actuellement utilisé comme appareil de référence et désigné Véhicule de référence international (IRV).

La corrélation moyenne (R^2) était de 0,85 en 1998-1999, de 0,46 en 1999-2000 et de 0,73 en 2000-2001. Les données recueillies pour la campagne de 1999-2000 comprennent les mesures de frottement à Munich, où il y a eu peu de neige. Si on exclut les données de Munich, la corrélation moyenne (R^2) grimpe à 0,81. La sensibilité moyenne était de 0,018 et l'écart moyen d'estimation type, de 0,04.

À l'heure actuelle, la procédure recommandée pour l'harmonisation des mesures de frottement par le glissancemètre est décrite dans la norme ASTM E 2100-00. La méthode suppose un étalonnage annuel de l'appareil et réduit de 0,2 (maximum) à 0,04 les écarts actuellement observés.

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EXECUTIVE SUMMARY

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety, especially during winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying nature and qualities that contribute to reduced wheel braking friction capabilities. A service is warranted for runway condition reporting because the operational window for aircraft movement can change quite rapidly and frequently in the wintertime. Such a service includes measurement of tire-surface friction.

Measurements of friction were not calibrated to a common scale in the past. Also, being a non-dimensional ratio of forces, they were never associated with units of a scale, which could be another reason for the resulting differences. Ultimately, dynamic friction measurement results in the best accuracy, but the procedure has been limited to machine component calibrations. Research over the past four years has confirmed that different friction measuring devices report considerably different values, and this research has made significant advances to solve these problems. Methods of measurement are being improved to increase measurement quality, remove the uncertainties and provide better correlation to aircraft wheel braking.

This study was part of a government/industry project called the Joint Winter Runway Friction Measurement Program (JWRFMP), led by Transport Canada and the U.S. National Aeronautics and Space Administration. Support was received from National Research Council Canada, the U.S. Federal Aviation Administration, the Norwegian Civil Aviation Authority and France's Direction générale de l'aviation civile. Organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States also participated.

The JWRFMP objectives include:

- Compiling a database containing all test data available from a few selected and representative ground vehicles and aircraft that participated in the winter and summer runway friction programs.
- Using the data to determine a harmonized runway friction index: i.e., the International Runway Friction Index (IRFI).

The IRFI Method

This report describes the method developed and standardized by ASTM E 2100-00 *Standard Practice for Calculating the International Runway Friction Index.* Traditionally, regression techniques are used to find relationships between the reported friction values of pairs of devices. Such a technique assumes that one device's interaction with a surface is similar to another device's interaction with the same surface. A device or an algebraic transformation of reported friction values, such as the average friction of two or more devices, may be selected as a reference. All devices would then be compared to the reference device to establish harmonization constants, also called transformation constants. A simple linear regression, as shown in the equation below, is seen as a first step or an interim method, which can be applied by the aviation community in the near

future. The equation below represents a linear regression of the data for each device to an IRFI reference.

$$\mu_{IRFI} = a + b \bullet \textit{device friction measurement}$$

where *a* is the intercept and *b* is the gradient that were determined by the regression to the reference device. Past attempts have failed because the data were not acquired at the same time in the same wheel track. Also, the sample size was too small. Since 1998, the friction measurement and corresponding data collection have been carried out more systematically. Pairs of testers run in a wave pattern so that they measure the same surface within two minutes of each other.

In order to harmonize devices, they are calibrated with an IRFI reference to determine their *a* and *b* values and then these calibration values are used when making measurements to report μ_{IRFI}. An IRFI reference can be the International Reference Vehicle (IRV) or a master device that has been calibrated with the IRV. The JWRFMP uses an Instrument de Mesure Automatique de Glissance donated by Service Technique des Bases Aériennes (Paris) as its IRV.

Conclusions and Recommendations

The ASTM standard defines and prescribes how to calculate the IRFI for winter surfaces. The IRFI is a harmonized reporting index to provide information of tire-surface friction characteristics of the movement area to aircraft operators.

The IRFI is calibrated directly or indirectly to the IRFI reference device, thereby achieving harmonization of local friction devices of any airport to a common unit of measure, regardless of which local friction device was used.

The IRFI also can be used by airport maintenance staff to monitor the winter frictional characteristics for surface maintenance actions.

The method evaluates each 100 m (300 ft.) and averages them for each third of the runway. The IRFI method reduces the present variations of the 100 m surface lengths from as much as 0.2 down to typically 0.04. The sampling scheme of a full runway length (spot or continuous measurements) may yield additional variation.

Ongoing work has shown that the IRFI can be used to predict aircraft braking and will be reported in a separate document. Transport Canada has implemented a runway friction index called the Canadian Runway Friction Index (CRFI), which is based on only one ground friction measuring device. This index, based on an electronic recording decelerometer, correlates well to aircraft braking and is used in Canada to predict aircraft stopping distance.

SOMMAIRE

Connaître l'adhérence des pneus d'un avion au freinage est essentiel à la sécurité des opérations aériennes sur les aéroports. En hiver, principalement, les pistes peuvent présenter des contaminants de natures diverses qui réduisent l'adhérence à divers degrés. Les conditions de décollage/atterrissage l'hiver peuvent changer très rapidement, et à une fréquence telle que la constitution d'un service aéroportuaire de mesurage de la glissance des pistes est amplement justifiée.

Jusqu'à maintenant, la mesure du frottement n'était pas effectuée de manière uniforme. De plus, les valeurs de frottement n'étant pas exprimées par un ratio dimensionnel de forces, elles n'ont jamais été associées à des unités figurant sur une échelle, ce qui peut aussi expliquer les différences. À terme, la mesure du frottement dynamique donne une bonne précision, mais la procédure a été limitée à l'étalonnage des composants de la machine. Les recherches effectuées au cours des quatre dernières années ont confirmé que des appareils de mesure différents produisaient des valeurs très différentes. La présente recherche a cependant accompli des progrès significatifs pour régler ces problèmes. Les méthodes de mesure sont perfectionnées dans le but d'améliorer la qualité des résultats, d'éliminer les incertitudes et d'établir un meilleur rapport avec le freinage des aéronefs.

L'étude faisait partie de l'initiative conjointe gouvernement-industrie appelée Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH), sous la conduite de Transports Canada (TC) et de la National Aeronautics and Space Administration (NASA) des États-Unis. Le projet a reçu l'appui du Conseil national de recherches du Canada, de l'U.S. Federal Aviation Administration (FAA), de la Norwegian Civil Aviation Authority et de la Direction générale de l'aviation civile, en France. Ont également participé des organisations et des fabricants de matériel de plusieurs pays : Autriche, Canada, France, Allemagne, Norvège, Écosse, Suède, Suisse, États-Unis.

Parmi les objectifs du PCRGCAH :

- Créer une base de données d'essais de véhicules de mesure et d'aéronefs représentatifs qui ont participé aux campagnes de mesure du frottement des pistes menées l'hiver et l'été.
- Utiliser ces données pour établir un indice harmonisé de frottement des pistes, par exemple l'Indice international de la glissance des pistes (IRFI).

Méthode d'élaboration de l'IRFI

Le présent rapport décrit la méthode faisant l'objet de la norme ASTM E 2100-00, *Standard Practice for Calculating the International Runway Friction Index*, conçue pour élaborer l'Indice international de la glissance des pistes (IRFI). Habituellement, la technique de régression linéaire est utilisée pour calculer les rapports entre les valeurs de frottement mesurées par deux appareils. Cette technique repose sur l'hypothèse selon laquelle pour une surface donnée, l'interaction des deux appareils avec la surface est

la même. Comme référence, on peut sélectionner un appareil ou une transformation algébrique de valeurs de frottement mesurées, par exemple le coefficient de frottement moyen de deux appareils ou plus. Tous les appareils sont ensuite comparés à un appareil de référence de façon à établir des constantes de transformation. Bientôt, la communauté aéronautique pourra, comme première étape ou provisoirement, appliquer la régression linéaire simple illustrée par l'équation suivante.

$$\mu_{IRFI} = a + b \bullet \textit{appareil de mesure du frottement}$$

où *a* est l'ordonnée et *b* le gradient, valeurs déterminées par la régression à l'appareil de référence. Les tentatives antérieures se sont révélées infructueuses parce que les données n'étaient acquises ni au même moment ni dans la même trace de roue. De plus, la taille de l'échantillon était trop petite. La mesure du frottement et la collecte des données correspondantes doivent être effectuées de manière plus systématique. Deux appareils effectuent des passages en forme d'ondulations de sorte que la même surface est mesurée par les deux appareils dans un intervalle de deux minutes.

Dans le cadre de l'harmonisation, les appareils de mesure sont étalonnés sur un appareil de référence de l'IRFI. On a déterminé leurs valeurs *a* et *b*, dont on se sert ensuite comme valeurs de référence lors des mesures du coefficient μ_{IRFI}. La référence IRFI peut être le Véhicule de référence international (IRV) ou un étalon qui a été comparé au véhicule IRV. Le Programme conjoint de recherche sur la glissance des chaussées aéronautiques l'hiver (PCRGCAH) utilise comme IRV l'Instrument de mesure automatique de glissance (IMAG) donné par le Service technique des bases aériennes (France).

Conclusions et recommandations

La norme ASTM E 2100-00 définit les exigences relatives au calcul de l'Indice international de la glissance des pistes (IRFI) l'hiver. L'IRFI est un indice harmonisé destiné à informer les exploitants d'aéronefs des caractéristiques de frottement sur piste.

L'IRFI est comparé directement ou indirectement à l'appareil de référence IRFI, ce qui permettra d'harmoniser les appareils locaux en utilisant une unité de mesure commune sans égard au type d'appareil local employé.

Le personnel d'entretien aéroportuaire pourra également se fier à l'IRFI pour surveiller les caractéristiques de frottement des pistes en conditions hivernales aux fins de planification des activités d'entretien des chaussées aéronautiques.

La mesure porte sur des tronçons de piste de 100 m (300 pi). Une moyenne est établie pour chaque tiers de piste, pour chaque longueur de 100 m. La méthode de calcul de l'IRFI permet de réduire les variations courantes de 0,2 jusqu'à 0,04. L'échantillonnage d'une piste complète (mesures ponctuelles ou continues) peut produire davantage de variations.

Des travaux en cours ont démontré l'utilité de l'IRFI pour prédire les distances de freinage de l'aéronef. Cette application de la mesure du frottement des pistes fera l'objet d'un rapport distinct. Transports Canada a adopté un indice de glissance appelé Coefficient canadien de frottement sur piste (CRFI), basé sur les valeurs mesurées par un seul appareil, le décéléromètre électronique (ERD). Ce coefficient se prête bien à une corrélation avec le freinage des aéronefs; on s'en sert au Canada pour prédire la distance de freinage des aéronefs.

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DEFINITIONS AND NOMENCLATURE

Acronyms

ASTM	ASTM International
DGAC	Direction générale de l’aviation civile, France
FAA	Federal Aviation Administration, USA
JWRFMP	Joint Winter Runway Friction Measurement Program
IRFI	International Runway Friction Index
NASA	National Aeronautics and Space Administration, USA
NRC	National Research Council Canada
RUNAR	Runway Analyzer and Recorder manufactured by Norsemeter a.s., Norway
TC	Transport Canada

Definitions

device configuration, **n.** - a term used to designate the entire test system as used for any friction measurement. It includes, but is not limited to, type of device (force or torque measurements), tire type, size and inflation pressure, slip ratio, normal load and braking system control mode.

base surface, **n.** - the type of surface evaluated. There are four classes: (1) bare pavement dry, (2) bare pavement wet, (3) bare compacted snow, and (4) bare ice.

surface, **n.** - a generic term used in the act of reporting frictional characteristics. It includes the base surface class and the base surface condition.

compacted snow, **n.** - a compressed solid mass of snow that is sufficiently strong to prevent a normally loaded tire operating in a rolling mode from penetrating to the pavement or breaking up the surface.

ice, **n.** - water with or without contaminants frozen into a continuous solid body with or without cracks.

local friction device, **n.** - a particular friction testing device used at a given location to measure friction. The friction values evaluated with this device may be calibrated to IRFI values to provide harmonization.

master friction device, **n.** - a particular friction testing device used at a given location to calibrate local friction devices. The friction values of this device must be calibrated to IRFI values.

movement area, **n.** - that part of the airport (aerodrome) used for take-off, landing and taxiing of aircraft, consisting of the manoeuvring area and the apron(s).

IRFI reference device, **n.** - a particular friction measuring device selected as a benchmark or reference. It is used to calibrate any local or master friction device to permit local friction device values to be converted to IRFI values for selected base surfaces.

harmonization, **n.** - the transformation of the outputs of different devices used for measurement of a specific phenomenon so that all devices report similar values.

1.0 INTRODUCTION

Measuring the capability of a runway surface to provide aircraft wheel-braking action is fundamental to airport aviation safety. Pavement surface friction characteristics are important and especially need to be known during winter conditions. The different seasons, mainly winter, result in the possibility of the runway having contaminants of varying nature and qualities that contribute to reduced braking friction capabilities. In addition, because the operational window for aircraft movement can change quite rapidly and frequently in the wintertime, a service is warranted for the measurement of tire-surface friction. The measured results of such services in the winter have had serious deficiencies, which have been acknowledged by experts worldwide.

The equipment used and procedures followed in measuring winter contaminated surfaces do not report to a common unit of measure of surface friction. A value from one type of device at an airport does not necessarily provide the same information as a value from another device operated at another airport, even if the two devices are of the same type. In general, a simple transformation of measured values from one device to another has not been possible in the past.

In 1996, a multi-year government/industry study, called the Joint Winter Runway Friction Measurement Program (JWRFMP), was initiated by Transport Canada (TC) and the National Aeronautics and Space Administration (NASA), with support from National Research Council Canada (NRC), the U.S. Federal Aviation Administration (FAA), the Norwegian Civil Aviation Authority, and France's Direction générale de l'aviation civile (DGAC). Also participating are organizations and equipment manufacturers from Austria, Canada, France, Germany, Norway, Scotland, Sweden, Switzerland, and the United States. The primary objective is to perform aircraft and ground vehicle tests aimed at improving the safety of aircraft ground operations by finding the relation between ground friction measurement and aircraft braking. One of the program goals is flight crew recognition of less-than-acceptable reported runway friction conditions prior to the "go/no go" or the "land/go around" decision point. With this goal in mind, related studies were conducted to look at contaminant drag, effects of runway treatments on friction, and, especially, the harmonization of ground vehicle friction measurement. Harmonization will enable friction data to be reported to a unified common index worldwide, which will then be used to predict aircraft braking performance. This report addresses the methodology and development of a common harmonized index: the International Runway Friction Index (IRFI).

It is expected that dissemination, acceptance, and recommendation for implementation of the IRFI test method throughout the aviation community will be facilitated by several organizations. These include the International Civil Aviation Organization, ASTM International, the Joint Aviation Authority, the International Federation of Air Line Pilots Association, the Air Line Pilots Association, the Air Transport Association, and Airports Council International.

2.0 PROGRAM OBJECTIVE

In cooperation with other researchers from Transport Canada, NRC, NASA, DGAC and the FAA, the objective is to establish an International Runway Friction Index to harmonize all ground friction measurements so that the common values can be reported and used by airports around the world.

Program Sub-Objectives

- Compile a database containing all test data available on winter and summer runway friction measurements from different devices and tires, including data on aircraft tire braking performance.
- Use the data to develop a harmonized IRFI
- Correlate the IRFI to aircraft braking performance.

3.0 BACKGROUND-STATISTICAL MODEL

Traditionally, regression techniques would be used to find relationships between the reported friction values for pairs of devices. One device, or a statistical transformation of reported friction values, such as the average friction of two or more devices, may be selected as a reference. All devices would then be compared with the reference device to establish transformation constants. The model assumes that when the interaction of one measurement device with one surface changes, all other similar tire-surface interactions would change in a similar way under the same conditions. This is only true for devices using the same runway sampling techniques. Selective spot measuring on contaminated patches versus continuous full length runway measurements are not similar. Thus, it is valid only for 100 m segments of uniform surface material or where the sampling technique would not play a role.

The JWRFMP has shown that the statistical model gives good correlations with reasonable standard errors for ice and compacted snow surfaces, with the advantage that it is not necessary to identify the exact class of snow or ice contaminating the surface. The field test data sampling for the model includes ice, snow, and wet and dry winter surfaces in order to create a data set of sufficient range to enable linear regressions. A simple linear regression, called the IRFI, has been developed and is seen as a first step that now can be applied by the aviation community. This model is a linear regression of the data for each device to an IRFI reference device:

$$\text{IRFI} = a + b \bullet \text{device friction measurement}, \qquad (1)$$

where a is the intercept and b is the gradient, and where these constants were determined by regression with the reference device. Experience indicates that for this method to be successful and to collect good data, a rigorous test method must be followed by all participating devices. Data must be collected at the same time in the same wheel track. Since 1998, the data have been collected more systematically: pairs of testers made each run consecutively, or in a wave, in the same track, so that they measured the same surface within about two minutes of each other. Previous data were not collected in this manner, and it was found that the surface characteristics could change quickly enough so that regression analysis was not valid since the different testers had actually tested different surfaces.

4.0 THE IRFI METHOD

The local friction device can be harmonized in one of two ways: by conducting field testing with the IRFI reference device or with a secondary harmonized device called a master device. The JWRFMP uses an Instrument de Mesure Automatique de Glissance donated by Service Technique des Bases Aériennes (Paris) as its IRFI reference vehicle and calls it the International Reference Vehicle (IRV). The field test collects friction data for each surface class for which the local device can be used. When a local friction device has different selectable modes of operation (for example, fixed or variable slip measurement), each mode of operation is treated separately. The local friction device is operated according to the manufacturer's instructions for the device and run within the range of speeds for which it is to be harmonized. If there is a standard test method for the device, it should also be followed.

The minimum length of the surface segment to be used for producing a friction value is 100 m (300 ft.). These segments are combined to produce values for one third of a runway length. The friction values are reported digitally (with separate data series for each segment) in one file for the runway. The file has record(s) ordered by segments.

4.1 Method 1-Harmonization with the IRFI Reference Vehicle

The local device is harmonized to report an IRFI by measuring friction on surfaces with the IRFI reference vehicle. A minimum of eight surfaces covering a range of friction values from 0.1 to 0.7 as measured by the IRFI reference vehicle shall be included. Harmonization constants *a* and *b* are determined for the speed at which the local device normally operates.

The measurements with the local friction device and the IRFI reference device shall be taken on a segment within two minutes of each other.

Linear regressions are as follows:

$$FR_{ref} = a + b \bullet FR_{local} \quad (2)$$

where FR_{ref} is the friction value reported by the reference device and FR_{local} is the local device measured value. The harmonization constants for the device are *a* and *b*. The correlation coefficient of the regression and the standard error of estimate shall be reported. Typical values for devices that have been harmonized are given in Appendix A. These results were for specific local devices that were harmonized in the JWRFMP. They are not applicable to other local friction devices or to other test speeds, which must be calibrated with the device configuration for that device.

Subsequent measurements made by the local friction device can be harmonized using the regression constants of the device:

$$IRFI = a + b \bullet FR_{local} \quad (3)$$

Whenever the local friction device is modified, repaired or recalibrated, new harmonization constants shall be determined.

4.2 Method 2-Harmonization with a Master Device

The local device is harmonized to report an IRFI by measuring friction on surfaces with a master device that has been calibrated to the IRFI reference device. A minimum of eight surfaces covering a range of friction values from 0.1 to 0.7 as measured by the master device shall be included. Harmonization constants shall be determined for the speed at which the device normally operates.

The master device is harmonized by measuring friction on several base surfaces with the IRFI reference device. All surfaces shall be included. A minimum of five repeated runs on seven segments covering a friction range from 0.1 to 0.7 as measured by the IRFI reference device are to be included. The harmonization constants are determined at speeds at which the device normally operates. Test speeds shall be maintained within ±3 km/h (1.6 knots, 2 mph).

The measurements with the local friction device and the master device and for the master device with the IRFI reference device shall be taken on a segment within two minutes of each other.

A linear regression is of the form:

$$FR_{ref} = a' + b' \bullet FR_{master} \quad (4)$$

$$FR_{master} = a'' + b'' \bullet FR_{local} \quad (5)$$

Substituting equation 4 into equation 3 gives:

$FR_{ref} = a' + b' \bullet (a'' + b'' \bullet FR_{local})$ (6)

Then: $a = a' + b' \bullet a''$ and $b = b' \bullet b''$ (7,8)

where FR_{ref} is the friction value reported by the reference device for each 100 m segment, FR_{master} is the master device measured value for each 100 m segment, and FR_{local} is the local device measured value for each 100 m segment. The harmonization constants for the device are *a* and *b*. The correlation coefficient of the regression and the standard error of estimate shall be reported.

Subsequent measurements made by the local friction device can be harmonized using the regression constants of the device:

$IRFI = a + b\ FR_{local}$ (9)

Whenever the local friction device is modified or repaired, or changes its calibration, new harmonization constants shall be determined.

4.3 Calculation of IRFI

The runway is divided into segments (see Figure 1). The minimum length of the segment for local friction device measurement is 100 m and the maximum is one third of the runway length. The harmonized or corrected friction value for an individual segment is designated *irfi* (i.e., by italics and lower case) and $irfi = a + b\ FR_{local}$.

The value, IRFI, for each third of the runway or base surface is computed as a weighted average of the values as given by equation 10.

$$IRFI = \frac{1}{L} \Sigma(l_i \bullet irfi_i) \quad (10)$$

where L = total length of the one-third distance, m
l_i = the length of segment i, m
$irfi_i = irfi$ for segment i

When all segment lengths are equal, simple averaging will give the value for IRFI.

IRFI for other movement areas is computed the same way except they are not divided into thirds.

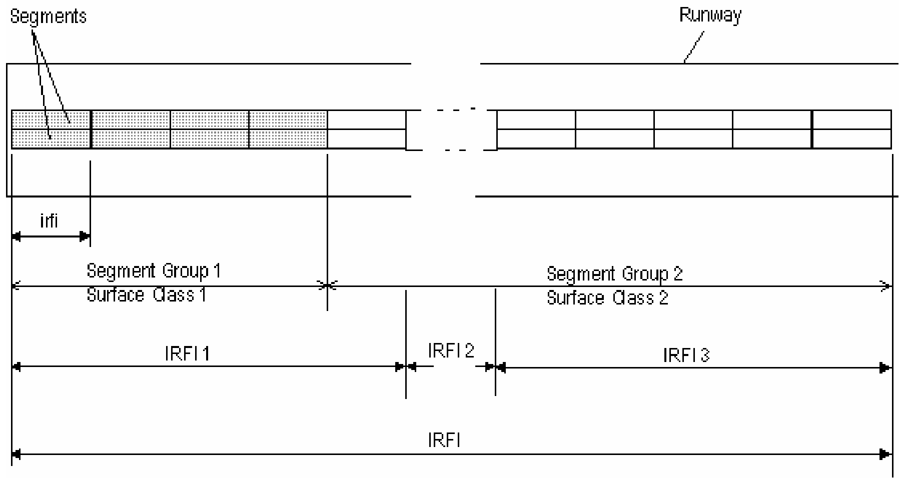

Figure 1. Illustration of a segmented runway

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5.0 CONCLUSIONS AND RECOMMENDATIONS

ASTM Standard E 2100-00 defines and prescribes how to calculate IRFI for winter surfaces. The IRFI is a standard reporting index to provide information on friction characteristics of the movement area to aircraft operators.

The IRFI is calibrated directly or indirectly to the IRFI reference device, thereby achieving harmonization of local friction devices to a common unit of measure, regardless of the local friction device used.

The IRFI can be used by airport maintenance staff to monitor the winter frictional characteristics for surface maintenance actions.

The method typically reduces the present variations from 0.2 down to 0.04.

A reference device, which is required for calibration, must be a dedicated device for this purpose only, and the aviation community must agree on its provision, ownership and services. The devices chosen for the exercises to demonstrate that IRFI is possible were only those that participated in the JWRFMP, and none of these was designated as a final IRFI reference device. All harmonization constants must be reworked when a permanent IRFI reference has been designated.

There is proof that the participating devices in the JWRFMP are not representative of the other devices even when they are of the same generic type. This suggests that harmonization constants must be determined and applied to individual devices, rather than to generic groups of devices, as was done in the past. To accomplish this, a master device can be calibrated to the IRFI reference device in order to serve as a secondary reference, and the manufacturer or owner of this secondary reference can then calibrate other devices to this master.

For any common scale of friction measure to work satisfactorily for the industry, annual harmonization meetings of devices must be arranged to determine the current harmonization constants, which will be valid only for a limited time: i.e. as long as the maintenance quality and product repeatability and durability will allow. The work in the JWRFMP so far has confirmed that friction devices do not report the similar values for the same surface and conditions unless they are harmonized on a regular basis, at least annually.

REFERENCES

1. A. Andresen and J.C. Wambold, "Friction Fundamentals, Concepts and Methodology," Transportation Development Centre, Transport Canada, TP 13837E, October 1999.

2. J.C. Wambold, C.E. Antle, J.J. Henry, and Z. Rado, "International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements", Final Report, World Road Association (PIARC), Paris 1995.

Appendix A. Table of Typical Harmonization Results from 1998–1999 Joint Winter Runway Measurement Program with IRV Used as the Reference

Device Description	Tire Type	Harmonization Constant a	Harmonization Constant b	Correlation Coefficient R^2	Standard Error of Estimate
Airport Surface Friction Tester SAAB 95*	Trelleborg AERO 690 kPa (100 psi)	0.0565	0.4264	0.78	0.023
FAA Trailer BV-11	Trelleborg T-520 690 kPa (100 psi)	0.0445	0.7635	0.83	0.052
TC ERD in Chevrolet 1500 truck		0.0879	0.8814	0.73	0.045
DND GripTester	ASTM E-1844	0.0001	1.1109	0.82	0.042
NASA Instrumented Tire Test Vehicle	Aircraft tire 26 by 6 inch	0.0907	1.0231	0.92	0.048
FAA Runway Friction Tester**	ASTM E-1551 690 kPa (100 psi)	0.0226	0.7262	0.98	0.034
Norsemeter RUNAR	ASTM E-1551 207 kPa (30 psi)	0.0504	0.3923	0.77	0.030
TC Surface Friction Tester SAAB 1979	ASTM E-1551 690 kPa (100 psi)	0.0598	0.7589	0.92	0.034
Munich Airport Surface Friction Tester	Trelleborg AERO 690 kPa (100 psi)	0.1261	0.6727	0.67	0.044

Reference: Wambold, J.C., et al., "Joint Winter Runway Friction Measurement Program (JWRFMP) 1997-98 Testing and Data Analysis," Transportation Development Centre, Transport Canada, TP 13836E, October 1999.

* 1998 data only

** Small number of data points

NOTES:
ERD = Electronic Recording Decelerometer
FAA = Federal Aviation Administration
NCAA = Norwegian Civil Aviation Administration
TC = Transport Canada
DND = Department of National Defence (Canada)