# Standard Practice for Correlations of Mu Values of Continuous Friction Measurement Equipment to Determine Maintenance Levels for Use at Airports [1]

This standard is issued under the fixed designation E2666; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This practice covers the method of calculating frictional values from correlations of continuous friction measurement equipment (CFME), using the Specification E1551 tire, for use in performing airport summer maintenance evaluations.

1.2 The practice is intended to provide a unified friction index of levels for use in harmonizing the output of devices.

1.3 Airport operators use a variety of CFMEs to assess the friction levels of their paved runway surfaces. The measurements are used to determine when the surfaces should be considered for or subjected to maintenance. However, many are built differently and produce different values when measuring the same pavement surfaces. This practice provides a method to harmonize these measurements so that the friction values generated can be used to determine the maintenance requirements as established by the operating authority.

1.4 The practice provides correlations for four maintenance levels of friction: New Design/Construction with grooves, New Design/Construction without grooves, Maintenance Planning, and Minimum Acceptable.

1.5 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.6 ASTM International takes no position with respect to the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

1.7 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

## 2. Referenced Documents

2.1 *ASTM Standards:*[2]

E1551 Specification for Special Purpose, Smooth–Tread Tire, Operated on Fixed Braking Slip Continuous Friction Measuring Equipment

E1960 Practice for Calculating International Friction Index of a Pavement Surface

E2100 Practice for Calculating the International Runway Friction Index

2.2 *Related Documents*[3]

FAA Advisory Circular AC/150/5320-12 Measurement, Construction, and Maintenance of Skid Resistant Airport Pavement Surfaces

Friction Tester Manufacturer's Instruction and Servicing Manuals

## 3. Terminology

3.1 *Definitions:*

3.1.1 *brake force coefficient (BFC), n*—filtered mean of a number of instantaneous friction readings divided by the normal force over a defined length.

3.1.2 *braking slip ratio, n*—ratio of relative braking slip RPM to identical unbraked wheel RPM. An equivalent definition is the ratio of the relative braking slip velocity to the horizontal velocity of the wheel axle.

3.1.3 *continuous reading, fixed slip measuring equipment (CFME), n*—an apparatus that can be moved over the test surface at the chosen test speed and that includes a test wheel, a system for retarding the test wheel and instrumentation for measuring the resulting frictional force or the wheel torque between the test tire and test surface.

[1] This practice is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.21 on Field Methods for Measuring Tire Pavement Friction.

Current edition approved Dec. 1, 2014. Published December 2014. Originally approved in 2009. Last previous edition approved in 2009 as E2666 – 09. DOI: 10.1520/E2666-09R14.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[3] Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, http://www.faa.gov.

3.1.4 *friction reading, n*—longitudinal force divided by normal load or torque on the test wheel generated by longitudinal force divided by load times tire radius (moment arm).

3.1.5 *reporting length, n*—defined length over which the BFC is calculated.

3.1.6 *standard test water film thickness, n*—water flow rate divided by the vehicle velocity times the width of application.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *certifying calibration, n*—verification of test equipment, calibration equipment (separate or built-in), calibration procedures and equipment operation, recommended to be performed once a year. This procedure records both as found values and adjusted values.

3.2.2 *field calibration, n*—primary force calibration or the equivalent carried out before each test or series of tests by a trained operator using calibration equipment supplied by the manufacturer.

3.2.3 *routine friction testing, n*—measurement of the friction of a surface under standardized test conditions, which normally includes a standard test speed and a rate of water flow which gives a standard test water film thickness.

3.2.4 *test tire, n*—standard tire for pavement friction testing.

3.3 *Acronyms:*

3.3.1 *CV*—coefficient of variation (standard deviation divided by the mean).

3.3.2 *CFME*—continuous friction measuring equipment.

3.3.3 *EF60*—device estimate of the IFI F60.

3.3.4 *F60*—IFI F60 as per Practice E1960.

3.3.5 *FM60*—IFI F60 maintenance level from the original MuMeter Mark II.

3.3.6 *FR60*—FR65(S) adjusted to a slip speed of 60 km/hr.

3.3.7 *FR65(S)*—CFME measurement at 65 Km/hr at its slip speed, S.

3.3.8 *FR95(S)*—CFME measurement at 95 Km/hr at its slip speed, S.

3.3.9 *FBS(60)*—back calculation for the device from the IFI value F60 giving by the friction classification calculated from the Mu Meter.

3.3.10 *FB65(S)*—FBS adjusted for speed from 60 km/hr to the devices slip speed (S) at 65 km/hr, and is the value that the CFME must measure to meet a maintenance level.

3.3.11 *IFI*—international friction index (Practice E2100) with values F60 and Sp.

3.3.12 *MPD*—mean profile depth.

3.3.13 *MTD*—mean texture depth.

3.3.14 *Sp*—IFI speed gradient as per Practice E1960.

3.3.15 *SD ERR*—standard error.

3.3.16 *SMp*—speed gradient for a maintenance level that goes with FM60.

## 4. Summary of Practice

4.1 Since the benchmark (FAA's Mark II Mu Meter) was retired in early 1990s, a new measure of friction had to be found that could be correlated back to the Boeing 727 friction requirements for the different maintenance levels. Fifteen years of NASA Wallops testing data was studied to find a measure that could be related to the Mark II Mu Meter. Of all the friction measurements made since 1993, only the International Friction Index (IFI)[4] (**1, 2**)[5] F60 values were found to be stable and repeatable over the 15 years. To establish a correlation between 1990 based values and the present, the IFI was employed. The IFI was developed to compare and harmonize friction measurements taken with different equipment to a common calibrated index expressed as calibrated wet friction at 60 km/h (F60) and the speed constant (Sp). Using data from a 1993 NASA friction workshop, the FAA's Mark II Mu Meter was used to determine the IFI friction values, called FM60 and SMp, associated with each of the maintenance classifications. These IFI friction values which are now fixed in time and can be used from 1993 forward to determine what a CFME must measure to satisfy each of the maintenance classifications.

4.2 A CFME is calibrated to IFI per Practice E1960. The IFI constant values (A and B) found for the CFME are used to determine what the CFME's must measure (FB65(S)) for each maintenance classification.

4.3 The FB65(S) for each classification of maintenance is then the friction level that CFME must measure to meet the maintenance level at 65km/hr.

4.4 A second order regression is made from the CFME measurements (FR65(S)) at 65 km/hr to its measurements (FR95(S)) on the same surfaces at 95 km/hr.

4.5 The second order regression constants (A, B and C) are then used to convert the 65 km/hr (40 mph) maintenance levels to 95 km/hr levels.

4.6 At least 5 runs should be made on at least 5 surfaces, whose friction levels cover the range of 0.2 to 0.7. Each surface shall be uniform in friction and texture. However; it is recommended that if more than five surfaces are available they should be used.

## 5. Significance and Use

5.1 *Introduction*—Mu numbers (friction values) measured by CFME can be used as guidelines for evaluating the surface friction deterioration of runway pavements and for identifying appropriate corrective actions required for safe aircraft operations. The original levels were based on the work of the FAA/AS-90-1 (**3**). The report states that based on friction values from a Mu Meter Mark II using Dunlop tires, and tests conducted by NASA in the 1970s using a Boeing 727, Table 1 of Mu Meter friction level classifications for runway pavement surfaces was established for friction measurements at test speeds of 65 Km/hr. Additionally, tests were conducted again with the Mu Meter Mark II outfitted with the Dico tire at 95 Km/h. Then a second order correlation was performed for the Mu Meter operating at 95 Km/h and at 65 Km/h resulting in the

[4] An ASTM International Standard methodology specified by Practice E1960 International Friction Index (IFI).

[5] The boldface numbers in parentheses refer to a list of references at the end of this standard.

**TABLE 1 Original Mu Meter Friction Classifications of Runway Pavement Surfaces for 65 km/hr Test Speed**

| Mu Value | Classification |
|---|---|
| 40 | Minimum |
| 50 | Maintenance Planning |
| 70 | New Design/Construction |

values shown in Table 2. These values were then fixed and used with correlations of other CFMEs to establish the present maintenance levels given in Table 3.2 of FAA Advisory Circular AC/150/5320-12. From the Wallops 1993 data, the IFI values were calculated and the 65 Km/hr data in Table 2 was used to calculate the FM60 value for each level. The data for the two speeds for the four CFMEs in the FAA report (**3**) were used to establish the SMp values for each level. Then a new level, New Grooved, was added based on the differences of grooved and un-grooved sites at the NASA Wallops test facility. Table 3 is a list of these values to be the standard values FM60 and SMp for any future calibration of CFME.

5.2 *Airports*—Routine testing is carried out in order to obtain data for scheduling remedial work on the runway surface. A single run on either side of the centerline may be regarded as sufficient or a set of runs covering the whole width of the runway may be preferred. At 3m spacing, the friction map which can be prepared from a set of runs of this kind provides excellent information on rubber buildup and surface polishing. Standard test speeds are typically 65 km/hr or 95 km/hr and standard test water film thickness is typically 1 mm.

## 6. Method for Determining CFME Friction Levels at 65 km/hr

NOTE 1—All calculations here are in Km/hr.

6.1 The CFME's slip speed is determined by multiplying the slip ratio times the vehicle speed of 65 km/h.

$$S = Slip\ Ratio \times 65\ or\ \%\ Slip \times \frac{65}{100} \tag{1}$$

6.2 Following Practice E1960, the FR60 value (for each calibration site tested) is calculated from the CFME measurement at 65 km/h called the FRS65. The Sp is calculated from the MPD measured for that site during calibration and S is per 6.1.

$$FR60 = FRS65 \times exp\left(\frac{(S-60)}{SP}\right) \tag{2}$$

6.3 Again per Practice E1960, a linear correlation of FR60 with F60 measured for all sites is performed to get the correlation constants (A and B), as well as the value of $R^2$ and the standard error, SD ERR.

**TABLE 2 Mu Meter Friction Classifications with a Dico Tire of Runway Pavement Surfaces for 65 km/hr and 95 km/hr Test Speed**

| Mu Value | | |
|---|---|---|
| 65 km/hr | 95 km/hr | Classification |
| 42 | 26 | Minimum |
| 52 | 38 | Maintenance Planning |
| 72 | 66 | New Design/Construction |

**TABLE 3 Recommended Friction Classification Levels from the Mu Meter for 65 km/hr**

| 65 km/hr | Mu Meter FR65(S) | SMp km/h | FM60 |
|---|---|---|---|
| Minimum | 0.42 | 77 | 0.289 |
| Maintenance | 0.52 | 120 | 0.370 |
| Construction | 0.72 | 161 | 0.493 |
| New Grooved | 01.00 | 185 | 0.547 |

$$F60 = A + B \times FR60 \tag{3}$$

6.4 Using the FM60 values from the original Mu Meter Mark II given in Table 3, the procedure is reversed using Eq 1-3 (with the A and B obtained in Section 6.3) to get the values for the CFME (FB65(S)) for that maintenance level at 65 Km/hr as follows:

6.4.1 First the back calculation FB60 is found from reversing the calculation of Eq 3 and using the A and B determined.

$$FB60 = \frac{(FM60 - A)}{B} \tag{4}$$

6.4.2 Then the value that the CFME must measure for that FM60 maintenance level is calculated from:

$$FB65(S) = FB60exp\left(\frac{(60-S)}{SMp}\right) \tag{5}$$

*where:*

*FR65(S)* = the CFME measurement at 65 km/h at its slip speed, S to meet that maintenance level,
*Sp* = the speed constant measured for the site during calibration per Practice E1960,
*FR60* = FR65(S) adjusted to a slip speed of 60 Km/hr,
*FB60* = the back calculation for the device from the IFI value FM60 giving by the Friction Classification calculated from the Mu Meter, Table 3,
*FB65(S)* = FB60 adjusted for speed from 60 Km/hr to the devices slip speed (S) at 65 km/h, and is the value for the CFME must measure to meet that maintenance level.
*SMp* = the speed gradient given in Table 3 for the maintenance level being calculated.

## 7. Method for Determining CFME Friction Levels at 95 Km/hr

NOTE 2—This method is what was used by the FAA (**3**) to establish the present Table 3.2 at 95 Km/hr.

7.1 A second order regression is made from the CFME measurements FRS65 at 65 km/hr to FRS95. Use the CFME measurements on the same surfaces at 95 km/hr to find the regression constants a, b and c. Also, $R^2$ and SD ERR are to be calculated.

$$FRS95 = a + b \times FRS65 + c \times FRS65^2 \tag{6}$$

7.2 The second order regression is then used to convert the 65 km/hr maintenance levels, FB65(S), to 95 km/hr levels FB95(S).

$$FB95(S) = a + b \times FB65(S) + c \times FB65(S)^2 \tag{7}$$

## 8. Report

8.1 The test report for each test surface shall contain the following items:

8.1.1 Date of friction and texture profile measurement,

8.1.2 Number of surfaces used for correlation,

8.1.3 Location and identification of the test surface,

8.1.4 Description of the surface types,

8.1.5 Observations of surface condition such as excessive cracking, potholes, etc,

8.1.6 The position of the friction measurement and profile on the surface, for example in relation to the wheel track, etc,

8.1.7 Identification of the friction and texture profile equipment and its operators,

8.1.8 Measurement speed,

8.1.9 Percentage of invalid readings eliminated,

8.1.10 Total length measured and the number of segments analyzed,

8.1.11 The IFI values, F60 and Sp for each test site,

8.1.12 The FR65(S) and FR95(S) for each test site,

8.1.13 The CFME friction level (FB65(S)) for the four maintenance levels for 65 km/hr and the $R^2$, SD ERR, and CV.

8.1.14 The CFME friction level (FB95(S)) for the four maintenance levels for 95 km/hr and the $R^2$, SD ERR, and CV.

## 9. Precision and Bias

9.1 *Precision*—The reproducibility using the CFME systems and test crews was found in the NASA Wallops Friction Workshops to vary, but the coefficient of variation (CV) (standard deviation divided by the average), was found to have an average of 0.065 with a standard deviation of 0.025. It is thus given that the CV is acceptable when it is less than 0.10 and considered good below 0.05.

9.2 *Bias*—There is no basis for determination of the bias in F60 and Sp. With respect to the average calibrated value, the CVs are given for each device in Tables 14 and 15 in (**2**).

9.3 *Regression Requirement*—The regressions are to be considered good if $R^2$ is greater than 0.85, fair between 0.75 and 0.85, and poor if it is less than 0.75. These levels are based on the average being 0.822 with a standard deviation of 0.03.

## REFERENCES

**(1)** Wambold, J. C., Antle, C. E., Henry, J. J., and Rado, Z, International PIARC Experiment to Compare and Harmonize Texture and Skid Resistance Measurements , Final report, Permanent International Association of Road Congresses (PIARC), Paris 1995.

**(2)** Wambold, J. C. and Henry, J. J., Correlations of Mu Values of Continuous Friction Measurement Devices for Use in Updating Table 3-2 of Advisory Circular 150/5320/12C, collection, analysis and reporting of friction data from the 2007-2008 wallops friction workshop, DOT/FAA/AR-XX/XX, Jan. 2008.

**(3)** Morrow, T.H., Reliability and Performance of Friction Measuring Tires and Friction Equipment Correlation, DOT/FAA/AS-90-1, March 1990.