



Designation: E3188 – 19

Standard Terminology for Aircraft Braking Performance¹

This standard is issued under the fixed designation E3188; 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 The terms and definitions listed provide a common set of definitions and concepts that have been agreed upon by the Society of Aircraft Performance and Operations Engineers. While historical reports and studies may use different terms, all concepts should be relatable to the definitions listed.

1.2 Several discussion sections are included to provide context. The definitions and discussions serve to formally capture industry best practices and common methods that relate to aircraft certification, aircraft operation, and airport operations under standard FAA and ICAO guidance.

1.3 *Units*—The values stated in SI units are to be regarded as standard. There are no SI units used in these definitions. New values relating to braking coefficients are described below.

1.4 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 FAA Documents:²

[AC 25-31 Takeoff Performance Data for Operations on Contaminated Runways](#)

[AC 25-32 Landing Performance Data for Time-of-Arrival Landing Performance Assessments](#)

[AC 91-79A Mitigating the Risks of a Runway Overrun Upon Landing](#)

¹ This terminology is under the jurisdiction of ASTM Committee E17 on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee E17.26 on Aircraft Friction.

Current edition approved Feb. 1, 2019. Published February 2019. Originally approved in 2019. DOI: 10.1520/E3188-19.

² Available from Federal Aviation Administration (FAA), 800 Independence Ave., SW, Washington, DC 20591, <http://www.faa.gov>.

[AC 150/5200-30D Airport Field Condition Assessments and Winter Operations Safety](#)

[2.2 Federal Aviation Regulation:³](#)

[FAR 25.109 Accelerate-Stop Distance](#)

3. Significance and Use

3.1 The terminology listed below allows for standardized and specific language to be given to concepts surrounding the identification of, recording, and communication of vehicle wheel braking. The terms are designed to specifically allow manufacturers, operators, regulators, research agencies, and investigative agencies the ability to communicate essential concepts in a manner that can be directly applied to operational requirements.

4. Terminology

4.1 Definitions:

aircraft braking action report, n —a report given describing a level of braking action using data from the aircraft.

aircraft braking coefficient, μ_{Aircraft} , n —the ratio of the deceleration force from the braked and unbraked wheels of a braked aircraft relative to the sum of the vertical (normal) force acting on the aircraft. Aircraft braking coefficient is determined by using the weight of the aircraft ($W-L$) and encompasses all the braking forces of all the gear, even those that are not braked.

DISCUSSION—The practice of calculating this type of braking coefficient value has been used in the past, most commonly with reference to Boeing aircraft. The industry is moving away from this practice, and modern guidance will most often refer to wheel braking coefficients.

aircraft braking simulation equipment, n —ground-based equipment that is used to simulate or model an aircraft braking system and its wheel braking coefficient.

airport friction measurements, n —the value obtained through ground measurement devices approved for use in measuring runway surface friction characteristics.

DISCUSSION—These machines are not required to utilize the same system components nor analysis methods as used for certified aircraft. Ground equipment runway friction coefficient values are normally the

³ Available from U.S. Government Printing Office, Superintendent of Documents, 732 N. Capitol St., NW, Washington, DC 20401-0001, <http://www.access.gpo.gov>.

result of two major classes of equipment. A continuous friction measuring device (CFME) normally applies a fixed slip into a continuously rotating tire to measure friction. A decelerometer (DEC) measures the deceleration force (in G's) associated with the braking of a vehicle. Measurements from both types of devices are normally given in numerical format but represent different values. It is always important to understand which device is being used and what the value the delivered number represents. The FAA has determined that there exists no correlation between these devices and wheel braking coefficients from airplanes.

DISCUSSION—Runway friction coefficient values are commonly referred to using the term “MU” or its associated Greek symbol, “ μ .” This is also a term used to describe wheel braking coefficient values for aircraft, although it is common to see aircraft terms associated with subscript qualifiers such as “ μ_{brakes} .” It is important to understand that runway friction values and aircraft braking values are not equivalent. It is considered a best practice to use the more specific terms listed in this document rather than the general term “MU” to avoid confusion.

anti-skid efficiency, n —a value, given as a percentage, that represents an anti-skid system’s ability to optimize the tire-to-ground friction coefficient close to the maximum value. This is usually taken as an average over time during friction limited braking.

assumed (predicted) wheel braking coefficient, n —a coefficient value that is used to predict braking performance.

DISCUSSION—The values listed in AC 25-32 allow the creation of predicted wheel braking coefficient values.

autobrakes, n —an automated aircraft control system that normally allows a flight crew to select a targeted deceleration rate to be achieved for the landing rollout.

DISCUSSION—This rate is normally obtained by modulating the wheel brakes as necessary to achieve the rate desired if the other forces acting to slow the aircraft do not by themselves achieve the desired deceleration.

DISCUSSION—Autobrake deceleration rates can be displayed as indexed numbers on a flight deck selector control. These numbers normally relate to fixed levels of deceleration that the aircraft as a whole is programmed to achieve. It is important not to confuse these deceleration rate values with runway friction values.

average braking coefficient, n —a braking coefficient number representing the average of all recorded values over a given time, distance, or change in groundspeed.

braking action, n —a means of describing the maximum capability of a vehicle’s braking system on a wet or contaminated surface that references a standardized reporting scale.

DISCUSSION—“Maximum capability” and “friction limited” are used interchangeably here. The term “capability” is used to reference subjective human observations, while the term “friction limited” is used as an engineering term. AC 150/5200-30D and AC 91-79A provide a relation between the descriptors and human observation, while AC 25-32 provides a relation between the descriptors and wheel braking coefficients. An example of the human observations is given below.

| <u>Braking Action</u> | <u>Deceleration or Direction Control Observation</u> |
|-----------------------|---|
| Good | Braking deceleration is normal for the wheel braking effort applied AND directional control is normal |
| Good to Medium | Braking deceleration OR directional control is between Good and Medium |

| | |
|----------------|---|
| Medium | Braking deceleration is noticeably reduced for the wheel braking effort applied, OR directional control is noticeably reduced |
| Medium to Poor | Braking deceleration OR directional control is between Medium and Poor |
| Poor | Braking deceleration is significantly reduced for the wheel braking effort applied, OR direction control is significantly reduced |
| Nil | Braking deceleration is minimal to non-existent for the wheel braking effort applied, OR directional control is uncertain |

DISCUSSION—AC 91-79A and other related FAA guidance referring braking observation guidance uses the terms “normal” and “reduced” braking in a specific context. In this case, “normal” is a level of braking action associated with a wet surface that meets established standards for runway friction maintenance. Under “normal” conditions, pilot control input would be supported by the relatively substantial directional and deceleration responses expected under standard wet runway conditions. “Reduced” braking occurs when deceleration and directional control is less than “normal.” This level of braking most often occurs when the runway surface is contaminated or when the surface cannot support normal wet friction standards. “Reduced” braking is then articulated through the series of terms that describe braking of a lower value than “good.”

DISCUSSION—It is important to note here how the philosophy of the NOTAM system intersects with that of the braking report. The NOTAM system is designed to only report non-normal conditions which, in this case, means a runway that is other than dry. This has the effect of creating three large classifications of braking action: dry (usually not reported), “good” for standard wet runways, followed by a series of classifications pertaining to “reduced” braking (medium, medium to poor, etc.).

friction-limited braking, n —a condition of aircraft ground deceleration performance where the amount of deceleration force that can be applied by the aircraft brakes is limited by the friction level of the runway surface. Any increase in command to the brake system will be limited by the anti-skid system.

friction-limited (aircraft/wheel) braking coefficient, n —a braking coefficient measured during conditions of friction-limited braking.

DISCUSSION—Standardized reporting scales such as those found in AC 25-32 reference wheel braking coefficients. It is understood that these values represent friction-limited braking and, as such, define the boundaries of the reporting scale referenced. When used in this manner, these values are used to calculate data that define an operational limit for an aircraft.

maximum aircraft wheel braking performance, n —any measurement that quantifies the highest limiting value of a wheel braking system under a given condition (good, medium, poor, etc.).

DISCUSSION—The customary language for describing wheel braking performance uses the “braking coefficient” value as a standard metric. Future technologies, however, may in fact use new forms of data and measuring devices to describe braking performance. Additionally, observations such as pilot braking reports rely on subjective criteria and are not dependent on coefficient analysis. The term therefore serves to describe an intended function of any process that achieves the result as defined above.

maximum tire-to-ground braking coefficient, n —the highest amount of wheel braking achievable for a given set of conditions over a range of slip ratios (0 to 1).

DISCUSSION—FAR 25.109 uses the term “maximum tire-to-ground wet runway braking coefficient of friction.” This term is specific to this FAR and references specific conditions regarding runway type, tire pressure, and ground speed as well as specific formulas.

mu slip curve, n —a graphical plot using the tire-to-ground friction coefficient in the y-axis and the slip ratio in the x-axis. These graphs display the relationship between slip and friction for a given surface. It can be used to display the characteristics of certain surfaces, as well as to show the designed function of an anti-skid system in regulating the brake pressure (and thus the slip ratio) to achieve the maximum tire-to-ground friction coefficient without letting the wheel lock up into a skid.

observed wheel braking coefficient, n —a wheel braking coefficient value that results from an actual event.

DISCUSSION—Post-incident analysis done by an investigative agency taken from recorded flight data would represent an observed braking coefficient.

pilot braking action report, PIREP, AIREP, n —a report describing a level of braking action resulting from the observations of a pilot.

DISCUSSION—The “deceleration or directional control observation” guidance such as that found in AC 91-79A is used to as an observation guide. In cases where braking reports are requested but no observation of maximum braking was observed, the phrase “braking not observed” should be used.

SCAP, n —acronym for Standardized Computerized Aircraft Performance; an industry standard developed by IATA, ATA, and several manufacturers for interfacing computer programming input/output features related to aircraft performance.

DISCUSSION—There are six (6) SCAP specifications: (1) takeoff, (2) landing, (3) climb-out, (4) inflight, (5) noise, and (6) APM (aircraft performance monitoring). SCAP specifications are applicable to civil, transport category airplanes.

slip ratio, n —the ratio between the speed of a rotating wheel and the speed of a vehicle.

DISCUSSION—As more force is applied by the brakes, the angular velocity of the wheel slows down with respect to the absolute velocity of the wheel axle. It is this difference in speed that is called “slip.” A frictional force is then created when the two bodies slide against each other. A slip ratio of 0 implies that the wheel is free rolling (no braking applied.) A slip ratio of 1 implies that the wheel is locked (not turning) but the wheel axle is still moving forward. The slip ratio can be defined by:

$$s = \frac{V_x - \omega R_R}{V_x}$$

where:

s = slip ratio (non-dimensional),
 V_x = velocity of the wheel axle,
 ω = angular velocity of the wheel, and

R_R = rolling radius of the wheel.

time-varying braking coefficient, n —a braking coefficient, whether it be wheel braking coefficient or aircraft braking coefficient, that varies over time with respect to the inputs required for its calculation.

tire-to-ground friction coefficient, n —the non-dimensional number determined by dividing the decelerating force of a specific tire by the vertical load on that tire.

DISCUSSION—The value is usually less than 1.0 and will vary in magnitude due to factors that may include:

- (1) Tire tread condition (new versus worn),
- (2) Tire inflation pressure,
- (3) Tire construction (bias versus radial ply; low versus regular profile),
- (4) Pavement texture,
- (5) Type and depth of contaminant,
- (6) Amount/level of braking slip generated (free rolling, 0 % slip; optimal slip ratio, 10 to 20 % slip; and locked wheel, 100 % slip), and
- (7) Forward tire speed.

torque-limited braking, n —a condition of aircraft ground deceleration performance where the amount of deceleration force that can be generated by the aircraft brakes is limited by the maximum torque capability of the wheel brakes.

wheel braking coefficient, μ_{Brakes} , n —the ratio of the deceleration force from the braked wheels/tires relative to the sum of the vertical (normal) forces acting on the braked wheels/tires. The wheel braking coefficient is the result of the combination of all functioning braked wheels.

4.2 Abbreviations:

AC—Advisory Circular

ATA—Air Transport Association (now known as A4A)

FAR—Federal Aviation Regulation

IATA—International Air Transport Association

SAPOE—Society of Aircraft Performance and Operations Engineers

SCAP—Standardized Computerized Aircraft Performance

4.3 Symbols:

R_R —rolling radius of the wheel

s —slip ratio (non-dimensional)

V_x —velocity of the wheel axle

ω —angular velocity of the wheel

5. Keywords

5.1 aircraft; anti-skid; braking coefficient; friction; MU; SAPOE; slip ratio

ASTM International takes no position respecting 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.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, at the address shown below.

This standard is copyrighted by ASTM International, 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959, United States. Individual reprints (single or multiple copies) of this standard may be obtained by contacting ASTM at the above address or at 610-832-9585 (phone), 610-832-9555 (fax), or service@astm.org (e-mail); or through the ASTM website (www.astm.org). Permission rights to photocopy the standard may also be secured from the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: (978) 646-2600; <http://www.copyright.com/>