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Standard Guide for Friction-Limited Aircraft Braking Measurements and Reporting¹

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1. Scope

1.1 This guide applies to any automated system that uses data from an aircraft to create an Aircraft Braking Action Report (ABAR) (see Terminology [E3188](#)). The system may be installed on an aircraft or operated remotely. This standard is intended to ensure that all ABARs created by automated systems meet a minimum level of quality and represent a standardized set of assumptions. This standard does not provide any guidance or means for the dissemination of an ABAR or related information.

1.1.1 Aircraft systems producing ABARs or ABAR-related flight crew alerts are covered by the appropriate regulatory guidance for aircraft certification.

1.2 This standard utilizes the terms and methods relating to aircraft anti-skid systems as documented in FAA AC 25-32.

1.3 *Units*—The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.4 *Risk Management*—Aircraft braking action reports contain information that may be used to reference the operating limits of an aircraft. Section 6 details the safety analysis and specific guidelines for airborne and remotely operated systems.

1.5 *Operational Use*—This standard does not address operational considerations nor recommend policies regarding the use of an aircraft braking action report.

1.6 *Mandating and Recommended Phrases*—To enhance comprehension and clarity, required and recommended tasks are listed with the following nomenclature:

1.6.1 The term “shall” is used to indicate a provision is mandatory. Such requirements are sequentially listed as “REQXX.”

1.6.2 The term “should” is used to indicate that a provision is recommended as a good practice. Such recommendations are sequentially listed as “RECXX.”

¹ This guide is under the jurisdiction of ASTM Committee [E17](#) on Vehicle - Pavement Systems and is the direct responsibility of Subcommittee [E17.26](#) on Aircraft Friction.

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1.7 This standard provides guidance for performing one or more specific functions. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this standard may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project’s many unique aspects. The word “Standard” in the title means only that the document has been approved through the ASTM consensus process.

1.8 *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.*

1.9 *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 *ASTM Standards*:²
 - [E3188 Terminology for Aircraft Braking Performance](#)
- 2.2 *FAA/EASA Guidance*:³
 - [FAA AC 91-79A Mitigating the Risks of a Runway Overrun Upon Landing](#)
 - [FAA AC 25-32 Landing Performance Data for Time-of-Arrival Landing Performance Assessments](#)
 - [FAA/AMC 25.1309 System Design and Analysis](#)
 - [14 CFR 121.344, Appendix M Airplane Flight Recorder Specifications](#)

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>. EASA documents may be found at <http://www.easa.europa.eu>.

2.3 RTCA Guidance:⁴

RTCA DO-178 Software Considerations in Airborne Systems and Equipment Certification

2.4 ICAO Guidance:⁵

ICAO Annex 6, Appendix 8 Flight Recorders

ICAO Doc 10064 Aeroplane Performance Manual

3.2.8 OEM—Original Equipment Manufacturer, commonly used to refer to aircraft manufacturers.

3.2.9 RCAM—Runway Condition Assessment Matrix

3.2.10 STC—Supplemental Type Certificate

3.2.11 TSO—Technical Standard Order

3. Terminology

3.1 Definitions:

3.1.1 *accuracy*—for the purposes of this standard, the term “accuracy” refers to the ability of data to truthfully represent an intended value.

3.1.2 *aircraft operator*—for the purposes of this standard, an operator represents both the management agency certified to operate a company engaged in flying transport category aircraft, as well as the flight crew certified to operate such aircraft.

3.1.3 *experimental certificate*—aircraft and related sensors that are operated under a state regulator’s designation of experimental.

3.1.4 *precision*—for the purposes of this standard, the word “precision” relates to the ability of a data source to repeatedly represent the same value for a given condition.

3.1.5 *tare run*—for the purposes of this standard, a defined movement of an airplane decelerating on a documented hard surface where there is an absence of wheel braking, thus providing a more direct indication of non-wheel-brake related deceleration forces.

3.2 Abbreviations:

3.2.1 14 CFR—Title 14 Code of Federal Regulations

3.2.2 AFM—Aircraft Flight Manual

3.2.3 AMC—Acceptable Means of Compliance

3.2.3.1 *Discussion*—Documents with AMC in the title are EASA documents, and are many times numbered the same as FAA documents to enable harmonization between countries.

3.2.4 EASA—European Union Aviation Safety Agency

3.2.5 FAA AC—Federal Aviation Administration Advisory Circular

3.2.6 ICAO—International Civil Aviation Organization

3.2.7 μ_{Brakes} *MU Brakes*—Aircraft Wheel Braking Coefficient (see Terminology E3188)

4. Summary of Guide

4.1 An aircraft braking action report (ABAR) is produced by an automatic system using aircraft data to describe the maximum capability of the aircraft’s wheel braking system on a wet or contaminated surface with reference to a standardized scale.

4.2 For an automatic system to produce an ABAR, it must perform the following functions. First, it must be able to isolate the forces of the mechanical wheel brakes from all other forces acting to decelerate the aircraft. It must then discriminate when the wheel braking is friction limited. The level of force produced by the friction-limited braking must then be mapped to a standardized scale. Finally, the entire system must meet minimum quality assurance standards. Fig. 1 shows the relationship between the aircraft ground deceleration forces.

4.3 The discrimination of wheel-braked forces is normally accomplished by creating an aircraft performance model of deceleration characteristics when no wheel brakes are applied. These modelled attributes are then subtracted from the total deceleration characteristics observed so that wheel braking contribution can be isolated. This model of how the aircraft decelerates without wheel brakes is validated through comparison to actual flight data of the same condition and cross checked with alternate calculation methods to validate for accuracy and precision.

4.4 Once the wheel-braked forces have been identified, the following functions are accomplished by the ABAR generating system. Changes to weight distribution and normal force during wheel braking operations are accounted for, friction-limited braking is identified, and data integrity is demonstrated as is overall quality assurance. Finally, the level of friction-limited wheel braking is mapped to a standardized scale.

4.5 The means of demonstrating compliance for such systems involve validation with actual flight data and the inspection of analysis methods. Of significance is the model created for the aircraft’s non-wheel-braked deceleration performance. This model is validated with actual flight data as it sets the baseline for system functionality. Other system functions may demonstrate compliance through analysis.

⁴ Available from RTCA, 1150 18th NW, Suite 910 Washington, DC 20036, <http://www.rtca.org>.

⁵ Available from International Civil Aviation Organization (ICAO), 999 Robert-Bourassa Boulevard, Montréal, Québec H3C 5H7, Canada, <http://www.icao.int>.



FIG. 1 Aircraft Ground Deceleration Forces

Upper Limit of Braking
Due to Friction

5. Significance and Use

5.1 The terminology within this guide references ASTM Terminology [E3188](#). These terms should be thoroughly familiarized before a review of this guide is accomplished.

5.2 U.S. and international guidance advocate that transport aircraft perform a time-of-arrival landing assessment for all runway conditions to include dry, wet, and contaminated surfaces. The function of this assessment is to provide an operator with a standardized means for anticipating the level of braking action upon landing. An aircraft braking action report is then created based on the actual level of braking achieved. This information can then be communicated for analysis.

5.3 The use of aircraft data to generate an aircraft braking action report is intended to mitigate human errors due to issues of training, experience, or cognitive bias that may occur with pilot braking action reports. For aircraft that use FAA AC 25-32 or equivalent (ICAO Doc 10064 and AMC 25.1592, for example) to assess landing performance, aircraft braking action reports can be considered applicable to a wide range of aircraft types and manufacturers.

5.4 The ABAR produced by such a system may not result in an observation representative of the entire prepared surface intended to be used for landing, deceleration, or both.

5.5 It is the responsibility of the aircraft and airport operator to create policies and procedures regarding the use of an ABAR. It is important to fully understand the capabilities and any limitations that may exist with such a system. It is the responsibility of the aircraft operator to ensure that proper training and system knowledge are in place prior to the use of these systems.

5.6 FAA and ICAO guidance use the term Aircraft Wheel Brake Coefficient or MU Brakes (see Terminology [E3188](#)) to define the reference distances to be used by the flight crew in accomplishing a time-of-arrival landing assessment. MU Brakes is also commonly used in research programs and accident investigations. While the use of this term is a standard industry practice, other means of quantifying aircraft wheel braking performance may be employed.

5.7 Aircraft of different manufacturers and type designs may use a variety of data sources. Therefore, this process of quantification cannot be universally detailed for all aircraft. This standard describes requirements for specific data, as well as categories of data that may be measured or inferred so that an appropriate calculation method may be employed.

5.8 This standard may be used to support the design and operation of a variety of intended functions. The specific description of each function will determine the compliance methods that should be followed.

NOTE 1—Intended functions may include the simple transmission of data, flight crew alerting, the discrimination of a simple boundary between two braking levels, or a multitude of braking levels.

5.9 There is a wide range of methods that may be used to show compliance. The party responsible for assessing an applicant's compliance should use this standard as a guide;

however, the specific methods deemed acceptable may be determined based on the specifics of the design.

5.10 This standard is intended to be applicable to any aircraft with an anti-skid system and available flight data. A nominal rate of data acquisition of 4 Hz represents requirements for flight data recorders. Data sample requirements are intended to allow older model aircraft and anti-skid systems enough information to demonstrate stable performance characteristics.

5.11 ABAR systems are intended to reflect a portion of the landing area that can reasonably be considered relevant for operational decision-making. It is incumbent on the end user to incorporate policies and procedures to appropriately utilize this information in a safety management process.

5.12 *Mapping Accuracy*—Compliance with this standard is intended to provide an ABAR produced by a system in which there is reasonable confidence that the reported braking action will be within $\pm$ one level of wheel braking, when using the six (6) categories of braking action reports as documented in FAA AC 25-32 or [10.2.2](#). For systems using fewer than six (6) levels of braking action, the standard for data precision will remain the same and the accuracy therefore increased.

NOTE 2—Dry runway conditions are not described using braking action.

5.13 Deviations from this standard may be considered acceptable if they are appropriately documented and justified.

5.14 The list of parameters included in [Annex A1](#) is categorized to maximize the ability of the designer to adhere to the philosophies documented herein. The list in this standard should be considered a minimum list of parameters normally available from an aircraft's data system. These parameters are then used in modeling aerodynamics, propulsion, and other forces. A method of direct measurement or alternate means of determining wheel braking characteristics may result in a deviation from this list.

6. System Safety Analysis

6.1 Aircraft braking action reports are not required for the design nor for the operation of an aircraft. As such, the information such systems produce is considered advisory in nature.

NOTE 3—An ABAR may contain information capable of conveying a wheel braking hazard that could have significant impact on operations. The impact may affect the recording aircraft itself or may be of use only to follow on aircraft, depending on the intended function of the system.

6.2 For on-aircraft systems, a system may provide ABAR-related analysis after the end of an operation and have no impact on the outcome of a landing or deceleration event. Other systems may input data to an alerting system and require flight crew action. The FAA/AMC 25.1309 system design and analysis classifications are recognized as follows:

6.2.1 For all systems, detected or undetected loss of ABAR reporting capabilities does not impact aircraft behavior and is considered to have a classification no greater than Minor.

6.2.2 For systems that have no impact on the outcome of a landing or deceleration event, undue (false or inadequate) indications are classified as no greater than [10.2.2](#).



6.2.3 For all other systems, the applicant shall perform an FAA/AMC 25.1309 analysis supporting their proposed classification.

6.3 *Software Criticality:*

6.3.1 For on-aircraft systems, software requirements are dependent on the intended function of the system (flight crew alert, other type of crew display, etc.) and are subject to appropriate certification requirements.

6.3.2 REQ 01—Remote systems shall demonstrate compliance with RTCA DO 178C guidance for Level E software.

NOTE 4—This guide does not address software security issues. Operators may have additional requirements for software development and security.

7. Aircraft Data

7.1 Data originating from aircraft can come in two forms: directly measured from sensors or inferred through analysis. Directly measured data can come from sources normally installed on a commercial-type design, specially installed for test purposes, or as part of an approved aircraft modification. The data is then used to perform various functions within an ABAR generating system. These functions can include analysis methods for the creation of inferred parameters, the creation of an aircraft performance model, inputs into the ABAR generating system, and as a quality assurance check. Certain data from onboard sensors falls under regulatory requirements specifically for flight data recorders (FDRs). Whether or not data requirements for FDRs meet the needs of an ABAR generating system depends on the intended function the data serves for that system. All data generated by the onboard sensors which are part of an OEM's type design must comply with various industry requirements such as TSO standards. These sensors typically exceed minimum requirements for FDRs. All data generated by onboard sensors included in a certified type design are considered "regulated sources."

NOTE 5—Minimum requirements for regulated data sources related to flight recorders can be found listed in 14 CFR 121.344, Appendix M and ICAO Annex 6, Appendix 8.

7.2 Data can come in two types: directly measured or inferred through analysis. Inferred data can result from methods unique to an applicant's ABAR generating system or from methods and sources that have been previously accepted by a regulatory authority (for example, for certification). The following requirements pertain to all data used in an ABAR generating system.

7.3 REQ 02—An applicant shall document that the aircraft data used in the operation of an ABAR generating system meets the minimum requirements as described in this section.

7.3.1 REQ 03—Knowledge of the aircraft's wheel braking performance shall be determined using data originating from onboard sensors.

7.3.2 REQ 04 Mandatory Data—The data parameters in **Annex A1** shall be used, at a minimum, to create a calculation of wheel braking performance. Data can be obtained through direct measurement or inferred through analysis.

7.3.3 REQ 05—The applicant shall list data parameters used which are in addition to those in **Annex A1**.

7.3.4 REQ 06 Data from Regulated Sources—An applicant shall document all data that comes from a sensor subject to certification, regulation, ICAO guidance, or combinations thereof.

7.3.5 REQ 07 Data from Non-Regulated Sources—An applicant shall document all data that originates from sensors that are not from regulated sources. These can include but are not limited to: sensors for experimental operating certificates, supplemental type certificates, and any non-airworthy sensors used for testing and research purposes.

7.4 The following guidance applies to the documentation of sensors used as data sources.

7.4.1 REQ 08—For regulated sources, instrument precision and accuracy shall be regarded as acceptable as a result of equipment certification standards with the following exception.

7.4.1.1 REQ 09—An applicant shall document the characteristics of an aircraft sensor (for example, sample rate, data range, accuracy, and resolution) when an ABAR generating system's precision and accuracy are defined as a function of the data taken from such sensors.

NOTE 6—Performance models may be constructed using methods and sources that are distinct from the mandatory parameters available from a normally configured type design. Paragraph 8.3 references these types of models. In such cases, where models are derived from methods and sources that have been previously accepted by a regulating authority, accuracy and precision of system output may be a function of the data input to the system.

7.4.2 REQ 10—For non-regulated sources, the sampling rate, data range, accuracy, and resolution of each sensor shall be documented.

7.4.2.1 REQ 11—The applicant shall demonstrate that data from non-regulated sources does not contribute to an error magnitude that exceeds the modelling error of the resultant calculations. (See Section 8 for guidance on modelling error.)

7.5 REC 01—Quality assurance data should be used to provide a confidence check for values of wheel braking performance that are derived from inferred data.

NOTE 7—The wheel braking characteristics that a system models may take various forms such as deceleration, distance, brake pressures, or wheel brake coefficients. It is intended that the primary means of describing wheel braking be checked by employing an alternate means of describing wheel braking to demonstrate that an equivalent outcome is produced. For example, if a system calculates a deceleration rate, that deceleration can be checked against actual aircraft data. However, deceleration values can also be derived from separate data, mapping the physical location of the aircraft during the same event. Using this separate source of positioning data, the deceleration values can be cross checked using the distance measured and change in groundspeed. In this case, the positioning data is not primarily used in the modeling but should be used to cross check the results.

7.6 *Inferred Data*—Data that represents information for which there are no sensors that provide a direct observation. An example of such data is thrust reverser force, which may be derived from engine N1 speed.

7.6.1 Inferred data may be the result of an OEM certification process, operational data analysis, or a specific test and evaluation process.