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Minimum Performance Requirements for Transport Airplane Wheel and Brake Assemblies Using Electric Power Actuation

RATIONALE

This document has been declared stabilized due to the fact that this document was utilized in the creation of TSO 135a, and as such is not to be changed. That is, it is the technical basis for the latest revision of the TSO 135a document.

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE A-5A Wheels, Brakes and Skid Controls Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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1. SCOPE

In lieu of TSO-C135, this SAE Aerospace Standard (AS) prescribes the minimum performance standards for wheels, brakes, and wheel and brake assemblies using electric power actuation for transport category (14 CFR Part 25) airplanes.

Testing is limited to that necessary to establish minimum performance related to strength, robustness, stopping capability, and energy absorption to ensure measurable, repeatable industry accepted standards for these aspects of wheel and brake performance.

The test parameters associated with electric braking actuation are defined around the state of the technology at this time, typically comprised of an Electro-Mechanical Actuator (EMA) controlled by a control system delivering electric power and effecting motor control. This document does not address qualification of the EMAs or brake assembly to the landing gear environmental threats including, but not limited to, EMI/HIRF, failure mode operation or other application specific performance, or the qualification of software or of complex custom micro-coded components, including but not limited to, Programmable Logic Devices (PLD) and Application Specific Integrated Circuits (ASIC).

1.1 Purpose

This document prescribes the minimum performance standards for wheels, brakes, and wheel and brake assemblies using electric power actuation to be used in lieu of certain corresponding requirements of Appendix 1 to the TSO-C135, Sections 3.3, 3.4, and 4.1 with approval of the Certifying Authority.

Compliance with this specification is not considered approval for installation on any transport airplane.

The Certifying Authority for the airplane for which the equipment is intended should be consulted for concurrence with the approaches proposed herein as an acceptable performance demonstration for the wheels, brakes, and wheel and brake assemblies for approved equipment.

1.2 Application

Compliance with this standard by manufacturers, installers, and users may be used as a means of assuring that the equipment will have the minimum capability to satisfactorily perform its intended function(s).

NOTE: Certain performance capabilities may be affected by airplane operational characteristics, brake control system interfaces, and other external influences. Consequently, anticipated airplane braking performance should be verified by airplane testing.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws or regulations unless a specific exemption has been obtained.

2.1.1 FAA Publications

Available from FAA, 800 Independence Avenuw, SW, Washington, DC 20591, Tel: 866-835-5322, www.faa.gov.

TSO-C135, Transport Airplane Wheel and Brake Assemblies, dated 5/2/02

Title 14, Code of Federal Regulations (14 CFR) part 25 - Airworthiness Standards: Transport Category Airplanes (§ 25.731, 25.733, 25.735, 25.1353 & 25.1529)

Advisory Circular (AC) 25-7A, Flight Test Guide for Certification of Transport Category Airplanes

2.2 Definitions

2.2.1 BRAKE LINING

Brake lining is individual blocks of wearable material, discs that have wearable material integrally bonded to them, or discs in which the wearable material is an integral part of the disc structure.

2.2.2 BOP - BRAKE OFF POSITION

BOP is a retracted EMA position that permits free rotation of the wheel and brake assembly after a brake application and release cycle.

2.2.3 BRWL - BRAKE RATED WEAR LIMIT

BRWL is the brake maximum wear limit to ensure compliance with 4.3.3, and, if applicable, 4.3.4 of this document.

2.2.4 D - DISTANCE AVERAGE DECELERATION

D = ((Initial brakes-on speed)^2 - (Final brakes-on speed)^2) / (2 (braked flywheel distance)). D is the distance averaged deceleration to be used in all deceleration calculations.

2.2.5 D_{DL} - RATED DESIGN LANDING DECELERATION

D_{DL} is the minimum of the distance averaged decelerations demonstrated by the wheel, brake and tire assembly during the 100 KE_{DL} stops in 4.3.2.

2.2.6 D_{RT} - RATED ACCELERATE-STOP DECELERATION

D_{RT} is the minimum of the distance averaged deceleration demonstrated by the wheel, brake, and tire assembly during the KE_{RT} stops in 4.3.3.

2.2.7 D_{SS} - RATED MOST SEVERE LANDING STOP DECELERATION

D_{SS} is the distance averaged deceleration demonstrated by the wheel, brake and tire assembly during the KE_{SS} Stop in 4.3.4.

2.2.8 EMA - ELECTRO-MECHANICAL ACTUATOR

The EMA is the brake subassembly, typically comprised of but not limited to, the ball screw or roller screw, electric motor, and gear train that converts electrical power to brake clamping force.

2.2.9 HEAT SINK

The heat sink is the mass of the brake that is primarily responsible for absorbing energy during a stop. For a typical brake, this would consist of the stationary and rotating disc assemblies.

2.2.10 I_{BMAX} - MAXIMUM BRAKE CURRENT

I_{BMAX} is the maximum current drawn by the brake in the most critical of the dynamic tests of Section 4 as determined by test or analysis of test results.

2.2.11 I_{SMAX} - MAXIMUM BRAKE SYSTEM CURRENT

I_{SMAX} is the maximum current the aircraft brake control system can deliver to the brake assembly in normal operation.

2.2.12 KE_{DL} - WHEEL/BRAKE RATED DESIGN LANDING STOP ENERGY

KE_{DL} is the minimum energy absorbed by the wheel/brake/tire assembly during every stop of the 100 stops design landing stop test in 4.3.2.

2.2.13 KE_{RT} - WHEEL/BRAKE RATED ACCELERATE-STOP ENERGY

KE_{RT} is the energy absorbed by the wheel/brake/tire assembly demonstrated in accordance with the accelerate-stop test in 4.3.3.

2.2.14 KE_{SS} - WHEEL/BRAKE RATED MOST SEVERE LANDING STOP ENERGY

KE_{SS} is the energy absorbed by the wheel/brake/tire assembly demonstrated in accordance with 4.3.4.

2.2.15 L_{BMAX} - MAXIMUM BRAKE LOAD

L_{BMAX} is the nominal maximum clamping load the brake is designed to generate with maximum brake control system command under normal conditions established by analysis or test.

2.2.16 L_{DL} - BRAKE DESIGN LANDING LOAD

L_{DL} is the average of the 100 peak clamping loads generated in the brake assembly during the KE_{DL} stop test of 4.3.2 as determined by test or analysis of test results.

2.2.17 L_{LMT} - BRAKE LIMIT LOAD

L_{LMT} is the maximum clamping load the brake structure may be subjected to in its operation which would not result in permanent deformation that would prevent it from performing its intended function. Conditions that may define L_{LMT} include, but are not limited to: L_{BMAX}; brake frame thermal effects in parking mode following a park brake application with a hot brake and subsequent cool down (e.g., fuse plug integrity test profiles prescribed in AC 25-7A); parking under normal conditions to the value required for compliance to §25.735(d); and, likely failure modes that may affect the load magnitude and potential re-distribution of load (e.g., EMA jam or EMA inoperative).

2.2.18 P_{BMAX} - MAXIMUM EMA BRAKE POWER

P_{BMAX} is the maximum power supplied to the brake during the most critical of the dynamic tests of Section 4 as determined by test or analysis of test results.

2.2.19 P_{SMAX} - MAXIMUM BRAKE SYSTEM POWER

P_{SMAX} is the maximum power that is available to the brake assembly from the aircraft brake control system.

2.2.20 PBC - PARKING BRAKE COMMAND

PBC is the configuration to which the EMAs are commanded following a high energy stop as defined by the airplane manufacturer associated with the parking brake applications in 4.3.3.5 and 4.3.4.5.

2.2.21 R - WHEEL RATED TIRE LOADED RADIUS

R is the static radius at load “S” for the wheel rated tire size at wheel rated inflation pressure (wheel unloaded). The static radius is defined as the minimum distance from the axle centerline to the tire/ground contact interface.

2.2.22 S - WHEEL RATED STATIC LOAD

S is the maximum static load (see §25.731(b)).

2.2.23 ST_R - WHEEL/BRAKE RATED STRUCTURAL TORQUE

ST_R is the maximum structural torque demonstrated in 4.3.5.

2.2.24 TS_{BR} - BRAKE RATED TIRE TYPE AND SIZE

TS_{BR} is the tire type(s) and size(s) used to achieve the KE_{DL}, KE_{RT}, and KE_{SS} brake ratings. TS_{BR} must be a tire type and size approved for installation on the wheel (TS_{WR}).

2.2.25 TS_{WR} - WHEEL RATED TIRE TYPE(S) AND SIZE(S)

TS_{WR} is the wheel rated tire type(s) and size(s) defined for use and approved by the airplane manufacturer for installation on the wheel.

2.2.26 TT_{BT} - SUITABLE TIRE FOR BRAKE TESTS

TT_{BT} is the tire type and size that has been determined as being the most critical for brake performance and/or energy absorption tests. The TT_{BT} must be a tire type and size approved for installation on the wheel (TS_{WR}). The suitable tire may be different for different tests.

2.2.27 V_{BMAX} - MAXIMUM EMA BRAKE VOLTAGE

V_{BMAX} is the maximum voltage applied to the brake assembly during the most critical of the dynamic tests of Section 4 as determined by test or analysis of test results.

2.2.28 V_{SMAX} - MAXIMUM BRAKE SYSTEM VOLTAGE

V_{SMAX} is the maximum voltage that is available to the brake assembly from the aircraft brake control system.

2.2.29 v_{DL} - WHEEL/BRAKE DESIGN LANDING STOP SPEED

v_{DL} is the initial brakes-on speed for a design landing stop in 4.3.2.

2.2.30 v_{RT} - WHEEL/BRAKE ACCELERATE-STOP SPEED

v_{RT} is the initial brakes-on speed used to demonstrate KE_{RT} in 4.3.3.

2.2.31 v_{SS} - WHEEL/BRAKE MOST SEVERE LANDING STOP SPEED

v_{SS} is the initial brakes-on speed used to demonstrate KE_{SS} in 4.3.4.

2.3 Terminology

2.3.1 Composition of Equipment

The words “equipment” or “brake assembly” or “wheel assembly,” as used in this document, include all components that form part of the particular unit.

For example, a wheel assembly typically includes a hub or hubs, bearings, flanges, drive bars, heat shields, and fuse plugs. A brake assembly typically includes a backing plate, torque tube, EMA(s), pressure plate, heat sink, temperature sensor, and other axle mounted components integral to the braking activity.

For the purpose of this specification, the interface boundaries of the equipment are the wheel and brake attachments to the landing gear and the electrical connectors to the aircraft brake control system.

It should not be inferred from these examples that each wheel assembly and brake assembly will necessarily include either all or any of the above example components; the actual assembly will depend on the specific design chosen by the manufacturer.

3. GENERAL DESIGN SPECIFICATION

3.1 Airworthiness

As specified in §25.1529, the continued airworthiness of the airplane on which the equipment is to be installed must be considered. See Section 5, titled “DATA REQUIREMENTS.”

3.2 Fire Protection

Except for small parts such as fasteners, seals, grommets, and small electrical parts that would not contribute significantly to the propagation of a fire, all solid materials used must be self-extinguishing. See also 3.4.5, 4.3.3.5, and 4.3.4.5.

3.3 Design

Unless shown to be unnecessary by test or analysis, the equipment must comply with the following:

3.3.1 Lubricant Retainers

Lubricant retainers must retain the lubricant under all operating conditions, prevent the lubricant from reaching braking surfaces, and prevent foreign matter from entering the lubricated cavity.

3.3.2 Brake Release and Wear Adjustment

The brake assembly and its control system must provide a suitable adjustment capability to maintain an appropriate running clearance throughout the entire heat sink wear and thermal range when no braking is commanded.

3.3.3 Wear Indicator

A reliable method must be provided for determining when the heat sink is worn to its permissible limit.

3.3.4 Dissimilar Materials

When dissimilar materials are used in the construction and the galvanic potential between the materials indicate galvanic corrosion is likely, effective means to prevent the corrosion must be incorporated in the design. In addition, differential thermal expansion must not unduly affect the functioning, load capability, and the fatigue life of the components.

3.3.5 Insulation Resistance

The equipment shall have an adequate insulation resistance level to ensure the design is robust to leakage current paths in accordance with established industry standards.

3.3.6 Dielectric Strength

The equipment shall have a suitable dielectric withstanding capability for the voltages and voltage surges to which it will be subjected in accordance with established industry standards.

3.3.7 Bonding, Grounding

The equipment shall employ suitable electrical bonding and grounding techniques in its design to protect ground personnel, and the equipment, from fault currents, and from the potentially high voltages that may be present, in accordance with established industry standards.

3.4 Construction

The suitability and durability of the materials used for components must be established on the basis of experience or tests. In addition, the materials must conform to approved specifications that ensure the strength and other properties are those that were assumed in the design.

3.4.1 Castings

Castings must be of high quality, clean, sound, and free from blowholes, porosity, or surface defects caused by inclusions, except that loose sand or entrapped gases may be allowed when serviceability is not impaired.

3.4.2 Forgings

Forgings must be of uniform condition, free from blisters, fins, folds, seams, laps, cracks, segregation, and other defects. Imperfections may be removed if strength and serviceability would not be impaired as a result.

3.4.3 Bolts and Studs

When bolts or studs are used for fastening together sections of a wheel or brake, the length of the threads must be sufficient to fully engage the nut, including its locking feature, and there must be sufficient unthreaded bearing area to carry the required load.

3.4.4 Environmental Protection

All the components used must be suitably protected against deterioration or loss of strength in service due to any environmental cause, such as weathering, corrosion, and abrasion.

3.4.5 Magnesium Parts

Magnesium and alloys having magnesium, as a major constituent, must not be used on brakes or braked wheels.

4. MINIMUM PERFORMANCE UNDER STANDARD TEST CONDITIONS

4.1 Introduction

The test conditions and performance criteria described in this section provide a laboratory means of demonstrating compliance with this document minimum performance standard. The OEM airframe designer/manufacturer must define all relevant test parameter values.

4.2 Wheel Tests

The wheel should be tested, results documented, and reported per Appendix 1 of TSO-C135, Sections 3.2, 4.1.1(a) and 4.1.4.

4.3 Wheel and Brake Assembly Tests.

4.3.1 General

4.3.1.1 The wheel and brake assembly, with a suitable tire, TT_{BT}, installed, must be tested on a testing machine in accordance with the following, as well as 4.3.2, 4.3.3, 4.3.5 and, if applicable, 4.3.4.

4.3.1.2 For tests detailed in 4.3.2, 4.3.3, and 4.3.4, the test energies KE_{DL}, KE_{RT}, and KE_{SS} and brake application speeds v_{DL}, v_{RT}, and v_{SS} are as defined by the airplane manufacturer.

4.3.1.3 For tests detailed in 4.3.2, 4.3.3, and 4.3.4, the initial brake application speed must be as close as practicable to, but not greater than, the speed established in accordance with 4.3.1.2, with the exception that marginal speed increases are allowed to compensate for brake clamping force release permitted in 4.3.3.4 and 4.3.4.4. An increase in the initial brake application speed is not a permissible method of accounting for a reduced (i.e., lower than ideal) dynamometer mass. This method is not permissible because, for a target test deceleration, a reduction in the energy absorption rate would result, and could produce performance different from that which would be achieved with the correct brake application speed. The energy to be absorbed during any stop must not be less than that established in accordance with 4.3.1.2. Additionally, forced air or other artificial cooling means are not permitted during these stops.

4.3.1.4 For brake stopping performance tests, the brake assembly must be tested using a control system and electrical power source providing representative characteristics of the actuating means to the EMAs, including limitations, specified for the aircraft braking system. I_{BMAX}, V_{BMAX} and P_{BMAX} shall not exceed the capabilities of the aircraft brake control system, I_{SMAX}, V_{SMAX} and P_{SMAX}, for which the equipment is intended.

4.3.1.5 For brake structural tests, the brake assembly may be tested with an alternate control system to that required for the brake stopping performance tests. The control system must be capable of structurally loading the EMA load path and brake structure to the static values required by the test conditions.

4.3.2 Design Landing Stop Test

4.3.2.1 The wheel and brake assembly under test must complete 100 stops at the KE_{DL} energy, each at the mean distance averaged deceleration, D, defined by the airplane manufacturer, but not less than 10 ft/s^2 (3.05 m/s^2). (see §25.735(f)(1)).

4.3.2.2 During the design landing stop test, the disc support structure must not be changed if it is intended for reuse, or if the wearable material is integral to the structure of the disc. One change of individual blocks or integrally bonded wearable material is permitted. For discs using integrally bonded wearable material, one change is permitted, provided that the disc support structure is not intended for reuse. The remainder of the wheel/brake assembly parts must withstand the 100 KE_{DL} stops without failure or impairment of operation.

4.3.3 Accelerate-Stop Test

4.3.3.1 The wheel and brake assembly under test must complete the accelerate-stop test at the mean distance averaged deceleration, D, defined by the airplane manufacturer, but not less than 6 ft/s^2 (1.83 m/s^2) (see §25.735(f)(2)).

This test establishes the maximum accelerate-stop energy rating, KE_{RT}, of the wheel and brake assembly using:

a. I_{SMAX} , V_{SMAX} and P_{SMAX}; or

b. The maximum brake current, voltage and power inputs consistent with the airplane's braking force limitations (e.g., tire/runway drag capability based on substantiated data).

4.3.3.2 For the accelerate-stop test, the tire, wheel, and brake assembly must be tested at KE_{RT} for both a new brake and a fully worn brake.

a. A new brake is defined as a brake on which less than 5% of the usable wear range of the heat sink has been consumed.

b. A worn brake is defined as a brake on which the usable wear range of the heat sink has already been fully consumed to BRWL.

The proportioning of wear through the brake for the various friction pairs for this test must be based on service wear experience or wear test data of an equivalent or similar brake. Either operationally worn or mechanically worn brake components may be used. If mechanically worn components are used, it must be shown that they can be expected to provide similar results to operationally worn components. The test brake must be subjected to a sufficient number and type of stops to ensure that the brake's performance is representative of in-service use; at least one of these stops, with the brake near the fully worn condition, must be a design landing stop.

4.3.3.3 At the time of brake application, the temperatures of the tire, wheel, and brake assembly, particularly the heat sink and EMAs, must, as closely as practicable, be representative of a typical in-service condition. Preheating by taxi stops is an acceptable means.

These temperatures must be based on a rational analysis of a braking cycle, taking into account a typical brake temperature at which an airplane may be dispatched from the ramp, plus a conservative estimate of heat sink temperature change during subsequent taxiing and takeoff acceleration, as appropriate.

Alternatively, in the absence of a rational analysis, the starting heat sink and EMA temperatures must be that resulting from the application of 10% KE_{RT} to the tire, wheel and brake assembly, initially at not less than normal ambient temperature (59 °F/15 °C).

4.3.3.4 A full stop demonstration is not required for the accelerate-stop test. The test brake clamping force may be released at a test speed of up to 23 mph (10 m/s). In this case, the initial brakes-on speed must be adjusted such that the energy absorbed by the tire, wheel and brake assembly during the test is not less than the energy absorbed if the test had commenced at the specified speed and continued to zero ground speed.

4.3.3.5 Within 20 seconds of completion of the stop, or of the brake clamping force release in accordance with 4.3.3.4, apply the Parking Brake Command (PBC) and maintain for at least 3 minutes (see §25.735(g)).

No sustained fire that extends above the level of the highest point of the tire is allowed before 5 minutes have elapsed after application of brake clamping force; until this time has elapsed, neither fire fighting means nor coolants may be applied.

The time of initiation of tire pressure release (e.g., by wheel fuse plug), if applicable, is to be recorded. The sequence of events described in 4.3.3.4 and 4.3.3.5 is illustrated in Figure 1.

4.3.4 Most Severe Landing Stop Test

4.3.4.1 The wheel and brake assembly under test must complete the most severe landing braking condition expected on the airplane as defined by the airplane manufacturer. This test is not required if the testing required in 4.3.3 is more severe or the condition is shown to be extremely improbable by the airplane manufacturer.

This test establishes, if required, the maximum energy rating, KE_{SS}, of the wheel/brake assembly for landings under abnormal conditions using:

a. I_{SMAX} , V_{SMAX} and P_{SMAX}; or

b. The maximum brake current, voltage and power inputs consistent with the airplane's braking force limitations (e.g., tire/runway drag capability based on substantiated data).

4.3.4.2 For the most severe landing stop test, the tire, wheel, and brake assembly must be capable of absorbing the test energy, KE_{SS}, with a brake on which the usable wear range of the heat sink has already been fully consumed to BRWL (see §25.735(f)(3)).

The proportioning of wear through the brake for the various friction pairs for this test must be based on service wear experience or wear test data of an equivalent or similar brake. Either operationally worn or mechanically worn brake components may be used. If mechanically worn components are used, it must be shown that they can be expected to provide similar results to operationally worn components. The test brake must be subjected to a sufficient number and type of stops to ensure that the brake's performance is representative of in-service use; at least one of these stops, with the brake near the fully worn condition, must be a design landing stop.

4.3.4.3 At the time of brake application, the temperatures of the tire, wheel, and brake, particularly the heat sink and EMAs, must, as closely as practicable, be representative of a typical in service condition. Preheating by taxi stops is an acceptable means.

These temperatures must be based on a rational analysis of a braking cycle, taking into account a typical brake temperature at which the airplane may be dispatched from the ramp, plus a conservative estimate of heat sink temperature change during taxi, takeoff, and flight, as appropriate.

Alternatively, in the absence of a rational analysis, the starting heat sink and EMA temperatures must be that resulting from the application of 5% KE_{RT} to the tire, wheel and brake assembly initially at not less than normal ambient temperature (59 °F/15 °C).

4.3.4.4 A full stop demonstration is not required for the most severe landing-stop test. The test brake clamping force may be released at a test speed of up to 23 mph (10 m/s). In this case, the initial brakes-on speed must be adjusted such that the energy absorbed by the tire, wheel, and brake assembly during the test is not less than the energy absorbed if the test had commenced at the specified speed and continued to zero ground speed.