requirements must be achieved. The mean deceleration must not be less than 3.1 m/s^2 (10 fps^2).

(2) *Maximum kinetic energy accelerate-stop.* The maximum kinetic energy accelerate-stop is a rejected take-off for the most critical combination of aeroplane take-off weight and speed. The accelerate-stop brake kinetic energy absorption requirement of each wheel, brake, and tyre assembly must be determined. It must be substantiated by dynamometer testing that the wheel brake and tyre assembly is capable of absorbing not less than this level of kinetic energy throughout the defined wear range of the brake. The energy absorption rate derived from the aeroplane's braking requirements must be achieved. The mean deceleration must not be less than 1.8 m/s^2 (6 fps^2).

(3) *Most severe landing stop.* The most severe landing stop is a stop at the most critical combination of aeroplane landing weight and speed. The most severe landing stop brake kinetic energy absorption requirement of each wheel, brake, and tyre assembly must be determined. It must be substantiated by dynamometer testing that, at the declared fully worn limit(s) of the brake heat sink, the wheel, brake and tyre assembly is capable of absorbing not less than this level of kinetic energy. The most severe landing stop need not be considered for extremely improbable failure conditions or if the maximum kinetic energy accelerate-stop energy is more severe.

(g) *Brake condition after high kinetic energy dynamometer stop(s).* Following the high kinetic energy stop demonstration(s) required by sub-paragraph (f) of this paragraph, with the parking brake promptly and fully applied for at least 3 minutes, it must be demonstrated that for at least 5 minutes from application of the parking brake, no condition occurs (or has occurred during the stop), including fire associated with the tyre or wheel and brake assembly, that could prejudice the safe and complete evacuation of the aeroplane.

(h) *Stored energy systems.* An indication to the flight crew of the usable stored energy must be provided if a stored energy system is used to show compliance with sub-paragraph (b)(1) of this paragraph. The available stored energy must be sufficient for:

(1) At least 6 full applications of the brakes when an anti-skid system is not operating; and

(2) Bringing the aeroplane to a complete stop when an anti-skid system is operating, under all runway surface conditions for which the aeroplane is certificated.

(i) *Brake wear indicators.* Means must be provided for each brake assembly to indicate when the heat sink is worn to the permissible limit. The means must be reliable and readily visible.

(j) *Over-temperature burst prevention.* Means must be provided in each braked wheel to prevent a wheel failure, a tyre burst, or both, that may result from elevated brake temperatures. Additionally, all wheels must meet the requirements of CS 25.731(d).

(k) *Compatibility*. Compatibility of the wheel and brake assemblies with the aeroplane and its systems must be substantiated.

(l) *Wheel brake temperature*. Equipment and structure that are essential to the safe operation of the aeroplane and that are located on the landing gear and in wheel wells must be protected from the damaging effects of possible wheel brake temperatures.

[Amdt 25/2]
[Amdt 25/14]

AMC 25.735 Brakes and Braking Systems Certification Tests and Analysis

ED Decision 2016/010/R

1. PURPOSE

This AMC (Acceptable Means of Compliance) which is similar to the FAA Advisory Circular AC 25.735-1 provides guidance material for use as an acceptable means, although not the only means, of demonstrating compliance with the requirements of CS 25.731 and CS 25.735. It also identifies other paragraphs of the EASA Certification Specifications (CS) that contain related requirements and other related and complementary documents.

2. RELATED REGULATORY MATERIAL AND COMPLEMENTARY DOCUMENTS

a. Related EASA Certification Specifications

PART-21 and CS-25 paragraphs (and their associated AMC material where applicable) that prescribe requirements related to the design substantiation and certification of brakes and braking systems include:

21A.303	Compliance with applicable Requirements
CS 25.101	General
CS 25.109	Accelerate-stop distance
CS 25.125	Landing
CS 25.301	Loads
CS 25.303	Factor of safety
CS 25.729	Extending retracting mechanisms
CS 25.733	Tyres
CS 25.1301	Function and installation
CS 25.1309	Equipment, systems and installations
CS 25.1322	Warning, caution and advisory lights
CS 25.1501	General: Systems and Equipment Limitations
CS 25.1541	Markings and Placards: General
CS 25.1591	Supplementary performance information

Additional Part-21 and CS-25 paragraphs (and their associated AMC material where applicable) that prescribe requirements which can have a significant impact on the overall design and configuration of brakes and braking systems are, but are not limited to:

21A.101	Designation of applicable certification specifications and environmental protection requirements
CS 25.671	General: Control Systems
CS 25.863	Flammable fluid fire protection
CS 25.1001	Fuel jettisoning system
CS 25.1183	Flammable fluid-carrying components
CS 25.1185	Flammable fluids
CS 25.1315	Negative acceleration (FAR 25.943)

b. Complementary Documents

Documents that provide appropriate standards for the design substantiation and certification of Brakes and Braking Systems are, but are not limited to:

(i) European Technical Standard Orders (ETSO)

ETSO-C47	Pressure Instruments - Fuel, Oil and Hydraulic
ETSO-C26c	Aircraft Wheels and Wheel-Brake Assemblies with Addendum I
ETSO-2C75	Hydraulic Hose Assemblies
ETSO-C62d	Aircraft Tyres
ETSO-C135	Transport Aeroplane Wheels and Wheel and Brake Assemblies

(ii) Advisory Circulars/Acceptable Means of Compliance

AC 25.1309-1A	System Design and Analysis
AC 25-7C	Flight Test Guide for Certification of Transport Category Airplanes
AC 21-29A	Detecting and Reporting Suspected Unapproved Parts
AC 91-6A	Water, Slush, and Snow on the Runway AMC 25.1591 The derivation and methodology of performance information for use when taking-off and landing with contaminated runway surface conditions.
AMC 20-115	Software Considerations for Airborne Systems and Equipment Certification

(iii) Society of Automotive Engineers (SAE) Documents

ARP 597C	Wheels and Brakes, Supplementary Criteria for Design Endurance - Civil Transport Aircraft
ARP 813A	Maintainability Recommendations for Aircraft Wheels and Brakes
AIR 1064B	Brake Dynamics
ARP 1070B	Design and Testing of Anti-skid Brake Control Systems for Total Aircraft Compatibility
AS 1145A	Aircraft Brake Temperature Monitor System (BTMS)
ARP 1619	Replacement and Modified Brakes and Wheels
AIR 1739	Information on Anti-skid Systems
ARP 1907	Automatic Braking Systems Requirements
AIR 1934	Use of Carbon Heat Sink Brakes on Aircraft
ARP 4102/2	Automatic Braking System (ABS)
ARP 4752	Aerospace - Design and Installation of Commercial Transport Aircraft Hydraulic Systems (Note: This document provides a wide range of Civil, Military and Industry document references and standards which may be appropriate.)

(iv) International Organisation for Standardisation (ISO) Documents

ISO 7137	Environmental Conditions and Test Procedures for Airborne Equipment.

(v) US Military Documents

MIL-STD-810	Environmental Test Methods and Engineering Guidelines.

(vi) The European Organisation for Civil Aviation Equipment Documents

ED-14G/RTCA DO-160G	Environmental Conditions and Test Procedures for Airborne Equipment.
AMC 20-115	Software Considerations for Airborne Systems and Equipment Certification.

3. RESERVED

4. DISCUSSION

a. Ref. CS 25.735(a) Approval

(1) CS 25.735(a) states that each assembly consisting of a wheel(s) and brake(s) must be approved. Each wheel and brake assembly fitted with each designated and approved tyre type and size, where appropriate, should be shown to be capable of meeting the minimum standards and capabilities detailed in the applicable European Technical Standard Order (E)TSO, in conjunction with the type certification procedure for the aeroplane, or by any other means approved by the Agency. This applies equally to replacement, modified, and refurbished wheel and brake assemblies or components, whether the changes are made by the Original Equipment Manufacturer (OEM) or others. Additionally, the components of the wheels, brakes, and braking systems should be designed to:

(a) Withstand all pressures and loads, applied separately and in conjunction, to which they may be subjected in all operating conditions for which the aeroplane is certificated.

(b) Withstand simultaneous applications of normal and emergency braking functions, unless adequate design measures have been taken to prevent such a contingency.

(c) Meet the energy absorption requirements without auxiliary cooling devices (such as cooling fans).

(d) Not induce unacceptable vibrations at any likely ground speed and condition or any operating condition (such as retraction or extension).

(e) Protect against the ingress or effects of foreign bodies or materials (water, mud, oil, and other products) that may adversely affect their satisfactory performance. Following initial aeroplane certification, any additional wheel and brake assemblies should meet the applicable airworthiness requirements specified in 21 A.101(a) and (b) to eliminate situations that may have adverse consequences on aeroplane braking control and performance. This includes the possibility of the use of modified brakes either alone (i.e., as a ship set) or alongside the OEM's brakes and the mixing of separately approved assemblies.

(2) Respecting brake energy qualification limits

The ETSO standard for wheels and wheel and brake assemblies includes an 'Accelerate-Stop Test' and a 'Most Severe Landing Stop Test' (if applicable), which establish the kinetic energy (KE) absorption capability of the brake assembly. The ETSO tests demonstrate the KE absorption capability of the brake with that brake at a predetermined (threshold) start temperature. Both of these tests are required to be performed on (new and worn) brakes with threshold temperatures that must 'as closely as practicable, be representative of a typical in-service condition'.

Two methods are permitted and accepted by the Agency to calculate the energy required to bring the heat pack to this representative thermal condition:

(a) by a rational analysis; or

(b) by the addition of a percentage of the KERT Wheel/Brake Rated Accelerate-Stop Energy: 10 % for 'Accelerate-Stop Test' or 5 % for 'Most Severe Landing Stop Test'.

A brake with an initial temperature higher than the threshold temperature has less KE absorption capability than it has at the threshold temperature. This could lead to the brake being unable to generate the required torque to stop the aeroplane in the available distance, or being unable to safely dissipate the additional thermal energy generated during the stop (hence, a risk of fire). Therefore, the applicant should ensure that the demonstrated brake KE absorption capability is not exceeded when the brake is installed on the aeroplane.

It should be demonstrated how the temperature thresholds, determined for the brake qualification testing, will not be exceeded.

Acceptable methods of demonstrating this include, but are not limited to, the following:

(a) use of brake temperature monitoring: by allowing the crew to check the brake temperature prior to a take-off, it can be ensured that that the brake temperature does not exceed thetemperature threshold of the demonstrated brake qualification testing, or

(b) use of brake cool-down charts: by establishing the cool-down rate of the brake heat sink, an estimate can be made that relates the energy absorbed by the brake to its temperature and also to the appropriate cool-down time.

Appropriate limitations have to be specified in the Aeroplane Flight Manual (AFM)

(3) Refurbished and Overhauled Equipment. Refurbished and overhauled equipment is equipment overhauled and maintained by the applicable OEM or its designee in accordance with the OEM's Component Maintenance Manual (CMM) and associated documents. It is necessary to demonstrate compliance of all refurbished configurations with the applicable (E)TSO and aeroplane manufacturer's specifications. It is also necessary to verify that performances are compatible for any combination of mixed brake configurations, including refurbished/overhauled and new brakes. It is essential to assure that Aeroplane Flight Manual braking performance and landing gear and aeroplane structural integrity are not adversely altered.

(4) Replacement and Modified Equipment. Replacement and modified equipment includes changes to any approved wheel and brake assemblies not addressed under paragraph 4a(2) of this AMC. Consultation with the aeroplane manufacturer on the extent of testing is recommended. Particular attention should be paid to potential differences in the primary brake system parameters (e.g., brake torque, energy capacity, vibration, brake sensitivity, dynamic response, structural strength, and wear state). If comparisons are made to previously approved equipment, the

test articles (other than the proposed parts to be changed) and conditions should be comparable, as well as the test procedures and equipment on which comparative tests are to be conducted. For wheel and brake assembly tests, the tyre size, manufacturer, and ply rating used for the test should be the same and the tyre condition should be comparable. For changes of any heat sink component parts, structural parts (including the wheel), and friction elements, it is necessary to provide evidence of acceptable performance and compatibility with the aeroplane and its systems.

(a) Minor Changes. Changes to a brake might be considered as a minor change, as long as the changes are not to the friction elements. The proposed change cannot affect the aeroplane stopping performance, brake energy absorption characteristics, and/or continued airworthiness of the aeroplane or wheel and brake assembly (e.g., vibration and/or thermal control, and brake retraction integrity). Technical evidence justifying a minor change should be provided.

(b) Major Changes. Changes to a wheel assembly outside the limits allowed by the OEM's CMM should be considered a major change due to potential airworthiness issues.

(c) Past history with friction elements has indicated the necessity of ongoing monitoring (by dynamometer test) of frictional and energy absorption capabilities to assure that they are maintained over the life of the aeroplane program. These monitoring plans have complemented the detection and correction of unacceptable deviations. A monitoring plan should be submitted to the cognisant Certification Office to ensure continued airworthiness of the product.

(d) Intermixing of wheel and brake assemblies from different suppliers is generally not acceptable due to complexities experienced with different friction elements, specific brake control tuning, and other factors.

b. Ref. CS 25.735(b) Brake System Capability

(1) The system should be designed so that no single failure of the system degrades the aeroplane stopping performance beyond doubling the braked roll stopping distance (refer to CS 25.735(b)(1)). Failures are considered to be fracture, leakage, or jamming of a component in the system, or loss of an energy source. Components of the system include all parts that contribute to transmitting the pilot's braking command to the actual generation of braking force. Multiple failures resulting from a single cause should be considered a single failure (e.g., fracture of two or more hydraulic lines as a result of a single tyre failure). Sub-components within the brake assembly, such as brake discs and actuators (or their equivalents), should be considered as connecting or transmitting elements, unless it is shown that leakage of hydraulic fluid resulting from failure of the sealing elements in these sub-components within the brake assembly would not reduce the braking effectiveness below that specified in CS 25.735(b)(1).

(a) In order to meet the stopping distance requirements of CS 25.735(b)(1) in the event of failure of the normal brake system, it is common practice to provide an alternate brake system. The normal and alternate braking systems should be independent, being supplied by separate power sources. Following a failure of the normal system, the changeover to a second system (whether manually or by automatic means) and the functioning of a secondary power source should be effected rapidly and safely. The changeover should not involve risk of wheel locking, whether the brakes are applied or not at the time of changeover.

(b) The brake systems and components should be separated or appropriately shielded so that complete failure of the braking system(s) as a result of a single cause is minimised.

(2) Compliance with CS 25.735(b)(2) may be achieved by:

(a) Showing that fluid released would not impinge on the brake, or any part of the assembly that might cause the fluid to ignite;

(b) Showing that the fluid will not ignite; or

(c) Showing that the maximum amount of fluid released is not sufficient to sustain a fire.

(3) Additionally, in the case of a fire, it may be shown that the fire is not hazardous, taking into consideration such factors as landing gear geometry, location of fire sensitive (susceptibility) equipment and installations, system status, flight mode, etc.

If more than one fluid is allowed for the hydraulic system, compliance should be addressed for all fluids.

c. Ref. CS 25.735(c) Brake Controls

(1) The braking force should increase or decrease progressively as the force or movement applied to the brake control is increased or decreased (refer to CS 25.735(c)(1)). The braking force should respond to the control as quickly as is necessary for safe and satisfactory operation. A brake control intended only for parking need not operate progressively. There should be no requirement to select the parking brake "off" in order to achieve a higher braking force with manual braking.

(2) When an automatic braking system is installed (refer to CS 25.735(c)(2)) such that various levels of braking (e.g., low, medium, high) may be preselected to occur automatically following a touchdown, the pilot(s) should be provided with a means that is separate from other brake controls to arm and/or disarm the system prior to the touchdown.

(3) The automatic braking system design should be evaluated for integrity and non-hazard, including the probability and consequence of insidious failure of critical components, and non interference with the non-automatic braking system. Single failures in the automatic braking system should not compromise non-automatic braking of the aeroplane. Automatic braking systems that are to be approved for use in the event of a rejected take-off should have a single selector position, set prior to take-off, enabling this operating mode.

d. Ref. CS 25.735(d) Parking Brake

It should be demonstrated that the parking brake has sufficient capability in all allowable operating conditions (Master Minimum Equipment List (MMEL) to be able to prevent the rotation of braked wheels. This demonstration is to be accomplished with the stated engine power settings, and with the aeroplane configuration (i.e., ground weight, c.g., position and nose-wheel (or tail-wheel) angle) least likely to result in skidding on a dry, level runway surface (refer to CS 25.735(d)). Use of ground idle thrust on the “other” engine is not mandatory, higher thrust levels may be used to prevent aeroplane motion due to the asymmetric engine thrust. Where reliable test data are available, substantiation by means other than aeroplane testing may be acceptable.

(1) For compliance with the requirement for indication that the parking brake is not fully released, the indication means should be associated, as closely as is practical, with actual application of the brake rather than the selector (control). The intent is to minimise the possibility of false indication due to failures between the brake and the point at which the parking brake state is sensed. This requirement is separate from, and in addition, to the parking brake requirements associated with CS 25.703(a)(3), Take-off warning systems.

(2) The parking brake control, whether or not it is independent of the emergency brake control, should be marked with the words "Parking Brake" and should be constructed in such a way that, once operated, it can remain in the selected position without further flight crew attention. It should be located where inadvertent operation is unlikely, or be protected by suitable means against inadvertent operation.

e. Ref. CS 25.735(e) Anti-skid System

(1) If an anti-skid system is installed (refer to CS 25.735(e)), then no single failure in the antiskid system should result in the brakes being applied, unless braking is being commanded by the pilot. In the event of an anti-skid system failure, means should be available to allow continued braking without anti-skid. These means may be automatic, pilot controlled, or both.

(2) Compliance with CS 25.735(e)(1) and (e)(2) may be achieved by:

(a) Failures that render the system ineffective should not prevent manual braking control by the pilot(s) and should normally be indicated. Failure of wheels, brakes, or tyres should not inhibit the function of the anti-skid system for unaffected wheel, brake, and tyre assemblies.

(b) The anti-skid system should be capable of giving a satisfactory braking performance over the full range of tyre to runway friction coefficients and surface conditions, without the need for preflight or pre-landing adjustments or selections. The range of friction coefficients should encompass those appropriate to dry, wet, and contaminated surfaces and for both grooved and ungrooved runways.

(c) The use of the phrase “without external adjustment” is intended to imply that once the antiskid system has been optimised for operation over the full range of expected conditions for which the aeroplane is to be type certificated, pre-flight or pre-landing adjustments made to the equipment to enable the expected capabilities to be achieved are not acceptable. For example, a specific prelanding selection for a landing on a contaminated low µ (friction level) runway, following a take-off from a dry high µ runway, should not be necessary for satisfactory braking performance to be achieved.

(d) It should be shown that the brake cycling frequency imposed by the anti-skid installation will not result in excessive loads on the landing gear. Anti-skid installations should not cause surge pressures in the brake hydraulic system that would be detrimental to either the normal or emergency brake system and components.

(e) The system should be compatible with all tyre sizes and type combinations permitted and for all allowable wear states of the brakes and tyres. Where brakes of different types or manufacture are permitted, compatibility should be demonstrated or appropriate means should be employed to ensure that undesirable combinations are precluded.

(f) The anti-skid function must be able to reduce braking for a wheel/tyre that is going into a skid, whether the braking level is commanded by the pilot or an auto-brake system if installed.

f. Ref. CS 25.735(f) Kinetic Energy Capacity

The kinetic energy capacity of each tyre, wheel, and brake assembly should be at least equal to that part of the total aeroplane energy that the assembly will absorb during a stop, with the heat sink at a defined condition at the commencement of the stop (Refer to CS 25.735(f)).

(1) Calculation of Stop Kinetic Energy.

(a) The design landing stop, the maximum kinetic energy accelerate-stop, and the most severe landing stop brake kinetic energy absorption requirements of each wheel and brake assembly should be determined using either of the following methods:

(i) A conservative rational analysis of the sequence of events expected during the braking manoeuvre; or

(ii) A direct calculation based on the aeroplane kinetic energy at the commencement of the braking manoeuvre.

(b) When determining the tyre, wheel, and brake assembly kinetic energy absorption requirement using the rational analysis method, the analysis should use conservative values of the aeroplane speed at which the brakes are first applied, the range of the expected coefficient of friction between the tyres and runway, aerodynamic and propeller drag, powerplant forward thrust, and, if more critical, the most adverse single engine or propeller malfunction.

(c) When determining the tyre, wheel, and brake assembly energy absorption requirement using the direct calculation method, the following formula, which needs to be modified in cases of designed unequal braking distribution, should be used:

$KE = 0.0443\ WV^2/N$ (ft-lb.)

where KE = Kinetic Energy per wheel (ft-lb.)

N = Number of main wheels with brakes

W = Aeroplane Weight (lb.)

V = Aeroplane Speed (knots)

or if SI (Metric) units are used:

$KE = 1/2\ mV^2/N$ (Joule)

where KE = Kinetic Energy per wheel (J)

N = Number of main wheels with brakes

m = Aeroplane Mass (kg.)

V = Aeroplane Speed (m/s)

(d) For all cases, V is the ground speed and takes into account the prevailing operational conditions. All approved landing flap conditions should be considered when determining the design landing stop energy.

(e) These calculations should account for cases of designed unequal braking distributions. "Designed unequal braking distribution" refers to unequal braking loads between wheels that result directly from the design of the aeroplane. An example would be the use of both main-wheel and nosewheel brakes, or the use of brakes on a centreline landing gear supporting lower vertical loads per braked wheel than the main landing gear braked wheels. It is intended that this term should account for effects such as runway crown. Crosswind effects need not be considered.

(f) For the design landing case, the aeroplane speed should not be less than $V_{REF}/1.3$, where V_{REF} is the aeroplane steady landing approach speed at the maximum design landing weight and in the landing configuration at sea level. Alternatively, the aeroplane speed should not be less than V_{SO}, the power-off stall speed of the aeroplane at sea level, at the design landing weight, and in the landing configuration.

(g) For the most severe landing case, the effects and consequences of typical single and multiple failure conditions that are foreseeable events and can necessitate landings at abnormal speeds and weights should be addressed. The critical landing weight for this condition is the maximum take-off weight, less fuel burned and jettisoned during a return to the departure airfield. A 30-minute flight should be assumed, with 15 minutes of active fuel jettisoning if equipped with a fuel jettisoning system.

(2) *Heat Sink Condition at Commencement of the Stop*.

(a) For the maximum kinetic energy accelerate-stop case, the calculation should account for:

(i) The brake temperature following a previous typical landing,

(ii) The effects of braking during taxi-in, the temperature change while parked,

(iii) The effects of braking during taxi-out, and

(iv) The additional temperature change during the take-off acceleration phase, up to the time of brake application.

(b) The analysis may not take account of auxiliary cooling devices. Assessment of ambient conditions within the operational limits established by the applicant and the typical time the aeroplane will be on the ground should be used.