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Superseding ARP597C

(R) Wheels and Brakes, Supplementary Criteria for Design Endurance Civil Transport Aircraft

RATIONALE

Revise the current ARP597C recommended practice to address the TSO-C135, the AS5663 and latest technology in the aircraft wheels, brakes and tires of Civil Transport Aircraft.

1. SCOPE

This document recommends supplementary design criteria to enhance endurance and reliability of transport aircraft wheels and brakes.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent 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 and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP813 Maintainability Recommendations for Aircraft Wheel and Brake Design

AIR1064 Brake Dynamics

ARP1619 Replacement and Modified Brakes and Wheels

AS5663 Minimum Performance Requirements for Transport Airplane Wheel and Brake Assemblies Using Electric Power Actuation

2.1.2 Federal Aviation Regulations

a. 14 CFR Part 25 Airworthiness Standards: Transport Category Airplanes - paragraph 25.731 Wheel and paragraph 25.735 Brakes and Braking Systems

b. 14 CFR Part 21 Subpart 0

c. TSO-C135 Transport Airplanes Wheels and Wheel and Brake Assemblies, dated May 2, 2002

2.1.3 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM B 117 Standard Practice for Operating Salt Spray (Fog) Apparatus

2.2 Definitions

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 of TSO-C135.

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 of TSO-C135.

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 TSO-C135.

3. DISCUSSIONS

The Federal Aviation airworthiness standards for civil transport wheels and brakes are defined in 2.1.2 (a). Certification procedures for products and parts are defined in 2.1.2 (b). The minimum performance standards for the design and testing of civil transport wheels and brakes are defined in 2.1.2 (c) and are used by vendors/equipment manufacturers to qualify wheel and brake assemblies. Minimum performance standards of other airworthiness authorities (e.g., Transport Canada, European Aviation Safety Agency and other Civil Aviation Authorities) may result in additional design requirements and tests. Aircraft manufacturer specifications impose additional design requirements and tests which address performance, endurance, and reliability of wheel and brake systems. Ratings of the wheel and the brake are defined in 2.1.2 (c). The references in 2.1.1 provide additional guidance.

4. TYPICAL WHEEL ENDURANCE REQUIREMENTS

4.1 TSO-C135 Requirements

The performance standards in TSO-C135 require a minimum roll test of 2200 miles at maximum static load of which 200 miles includes 15% of the maximum static load applied as side loads (100 miles with inboard directed side load and 100 miles with outboard directed side load). This criterion yields a minimum weight wheel of adequate strength.

4.2 Supplemental Requirements

The following supplemental requirements are recommended which are pertinent to wheel performance and/or endurance. Suggested tests linked to those requirements are proposed in Section 6. Over the years, additional design practices were applied to increase wheel endurance to approximately 25 000 roll miles. The present trend for commercial aircraft has been to increase wheel design life from 25 000 to 50 000 roll miles. The design life should be defined taking into account its impact on wheel weight and maintenance cost.

Recommended supplementary main wheel roll dynamometer test spectrums are discussed in Section 6. A 10 000 mile roll test with suitable scaled loads and pressures and an analytical assessment of temperature effects can give a realistic and practical assessment of wheel life and damage in service.

Actual wheel life can fall short of design goals due to corrosion, wheel softening, excessive bearing cup spinning damage, handling damage, and other causes. Supplemental tests to determine the effect of corrosion on wheel life have been conducted and are recommended. Temperature control for wheel, tire, axle, and other components should also be addressed in the aircraft manufacturer's requirements. Wheel endurance design practices should also include failure analyses of pressurized sections of the wheel (with and without corrosion) to assure that cracks result in safe tire pressure release. Wheel crack propagation studies should include consideration of maximum tire life (landings between overhauls) and realistic crack detection criteria. Non Destructive Test of the critical wheel areas is also recommended at frequent intervals. The effect of repeated brake heat exposure cycles on wheel fatigue life should also be considered.

Another important factor to be considered in wheel design is the tire. Tire brands (different manufacturers), new tire inflated profiles, tire constructions, tire type (bias or radial), new tires versus retreaded tires, and worn tire inflated profiles can result in changes in the tire induced wheel stress patterns. These may result in a change in the stress pattern for a given load and may change the fatigue critical location of the wheel. During aircraft development, consideration should to given by the design authority (aircraft manufacturer or systems integrator) responsible for the wheel, tire and landing gear specifications to account for simplified implementation of future changes and innovation. Accommodations for minor changes in wheel to tire interface, load characteristics, component weight, energy absorption characteristics and other integration parameters can significantly reduce the cycle time and cost of implementing changes to support operator needs.

Subsequent to aircraft certification, the design authority responsible for the tire specification should consider compiling key tire characteristics associated with aircraft certification requirements and identifying critical limits for each characteristic. This data set should be maintained to support simplified approval of future tire modifications and tire design innovations. Key areas of focus for the data set should include as example:

For each ground load case:

- Pressure
- Center of pressure shift
- Radius to ground
- Deflected tire profile
- Rim pressure profile
- Ground coefficient

For each braking and landing case:

- Energy absorption
- Ground Coefficient
- Stiffness and damping
- Spin-up load profile (landing cases only)

5. TYPICAL BRAKE ENDURANCE REQUIREMENTS

5.1 TSO-C135 Requirements

Specification TSO-C135 requires that wheel and brake assemblies meet basic performance and structural integrity requirements. The following is an abbreviated description of TSO-C135 requirements. With the advent of electric power actuation systems for commercial aircraft brakes, tailored TSO-C135 requirements have been provided in AS5663 and for such applications should be used in lieu of the following.

a. 100 Design Landing Stops (KE_{DL}): Deceleration is determined by airframe specification requirements and must be $\geq$10 ft/s^2 (3.05 m/s^2); "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 brake assembly parts must withstand the 100 KD_{DL} stops without failure or impairment of operations."

b. Two Accelerate Stops (KE_{RT}): Deceleration is determined by airframe specification requirements and must be $\geq$6 ft/s^2 (1.83 m/s^2). New and a fully worn brake must be tested. At the time of brake application, the temperatures of the tire, wheel, and brake, particularly the heat sink, must, as closely as practicable, be representative of a typical in-service condition. Within 20 seconds of completion of the stop, the brake pressure must be adjusted to the parking brake pressure and maintained for at least 3 minutes. “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 parking brake pressure; until this time has elapsed, neither fire fighting means nor coolants may be applied”.

c. One Most Severe Landing Stop (KE_{SS}): The conditions of this test are defined by the airplane manufacturer as the most severe landing braking condition expected on the airplane. This test is not required if the Accelerate Stop test is more severe or if the condition can be shown to be extremely improbable. The test must be performed on a fully worn brake. At the time of brake application, the temperatures of the tire, wheel, and brake, particularly the heat sink, must, as closely as practicable, be representative of a typical in-service condition. Within 20 seconds of completion of the stop, the brake pressure must be adjusted to the parking brake pressure and maintained for at least 3 minutes. “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 parking brake pressure; until this time has elapsed, neither fire fighting means nor coolants may be applied”.

d. Brake Structural Torque Test: Test conducted at 1.2 (single wheel) or 1.44 (multiple wheel) times maximum static load (S) times static loaded radius (R) of the tire at rated inflation pressure under load S on a fully worn brake. Note that the 1.44 factor contains an additional factor of 1.2 to account for occasions when the load of a wheel truck is distributed as much as 10 percent above its design distribution.

e. Yield - Hydraulic Brakes: “The brake must withstand a pressure equal to 1.5 times maximum brake pressure for at least 5 minutes without permanent deformation of the structural components under test”.

f. Overpressure - Hydraulic Brakes: "The brake with actuator piston extended to simulate a maximum worn condition" must sustain two times maximum brake pressure for at least 3 s.

g. Endurance Tests - Hydraulic Brakes: Brakes designed in accordance with TSO-C135 must sustain a total of 100 000 pressure cycles to a brake pressure level corresponding to the design landing (KE_{DL}) stops test and 5000 pressure cycles to maximum brake pressure. One fourth of each of the total cycles are conducted at piston extensions corresponding to 25, 50, 75, and 100% of wear limit. Static and dynamic leakage requirements must be met and no malfunctions are permitted.

5.2 Supplemental Requirements

The following supplemental requirements are recommended which are pertinent to brake performance and/or endurance. Suggested tests linked to those requirements are proposed in Section 7.

a. Brake Wear Tests: The brake test spectrums discussed in Section 7 and Tables 2 and 3 provide basis for service life estimates. Experience indicates that these tests can also provide valuable insight into vibration trends and other problems which could appear in service.

b. Vibration Testing: AIR1064 provides a description of brake and landing gear system vibration modes which can range from irritants where vibration might be sensed by passengers but does not impair braking performance, to destructive modes which can impair brake performance of individual brakes hence airplane stopping performance.

   The destructive vibration modes result from various friction component self-excitation mechanisms which are coupled to particular hydraulic, mechanical, and geometric system properties or from the clamp load modulation of the antiskid itself. Vibration levels which are high can trigger false antiskid signals hence impairing airplane stopping performance. Fretting at joints can also result and is one example of increased maintenance costs for the airlines.

   At a minimum, brake endurance requirements should include assessments of "walk", "squeal," "chatter," and "whirl" characteristics (reference AIR1064) with relatively new and worn brakes to assert that vibration control has been achieved. The methods of test and degree of simulation should include the brake systems, tire characteristics and the landing gear systems and be coordinated with the aircraft manufacturer.

   As stability of vibration modes can be influenced by friction components, control system algorithms, geometries and structural and damping parameters, significant changes may require additional analyses and/or retest and should be coordinated with the airframe manufacturer and, where applicable, airworthiness authorities. ARP1619 provides insight into certain "significant" change areas that need to be taken into account during the approval process of modified or replacement of brake and wheel assemblies. It should be noted that vibration characteristics might be pertinent to endurance of landing gear system components.

c. Expanded Endurance Tests: Experience indicates that increased brake structure endurance requirements are desirable for long life components in field service. An endurance test of 105 000 cycles from 50 psig to maximum brake pressure is recommended. The 105 000 cycles from 50 psig to maximum brake pressure can be used to meet the requirement of the TSO-C135. Test procedures and pass/fail criteria of TSO-C135 are recommended.

   For electric brakes, introducing a significant number of maximum load cycles over the cycles prescribed by AS5663 should be considered only after a review of the duty cycle. In the case of hydraulic brakes, the additional 105 000 high pressure cycles were found to be good design practice for brakes seeing a high parking brake pressure in their routine operation. Electric brakes may or may not use such a high force for routine parking given the flexibility of the technology.

d. Temperature/Creep: Wheel and brake design should include temperature/creep analyses to demonstrate compliance with aircraft manufacturer requirements and endurance objectives. Examples of typical components to be analyzed include wheel rotor drive beams and brake torque tube/backing plate assembly.

e. Static Torque: This test requirement is recommended in particular for carbon brakes which exhibit lower average and minimum static friction coefficients in comparison to steel brake friction couples. This test will verify that the brakes have adequate static torque when parked and during engine run up conditions to meet the requirements of 14 CFR 25.735(d).

f. Dynamic Torque: It is recommended that requirements include dynamic verification of wheel and brake assembly structure to an endurance spectrum taking into account the highest braking load(s) and numbers of load cycles which are expected to occur on the airplane. If a torque limiting system is used on the airplane, it is recommended that evaluations be conducted with the torque limiting system inoperative, and with failure modes as determined by the aircraft manufacturer.

6. TYPICAL WHEEL ENDURANCE TESTS

This section include two methods of defining laboratory tests for main wheel endurance testing, one method of defining main and nose wheels corrosion testing and a description of the objective of main and nose wheels missing tie bolt endurance testing.

For nose wheel methods 1 and 2 can also be used, however nose gear wheels may warrant a separate roll spectrum to account for increased normal force due to braking, towing, steering, and aircraft c.g. conditions as well as conditions noted for main wheels. Another consideration to take into account with dual nose wheels is the effect of non-perpendicular to the ground steering axis. This configuration, during steering activity, will unload one wheel and increase load on the other.

6.1 Method 1

The preferred method evolves from rational analyses which encompass representative operational conditions expected on specific aircraft models. The method of arriving at a laboratory test spectrum may include:

a. The airframe manufacturer's specification provides a spectrum of anticipated vertical, side and drag loads, and roll miles that might be typical for various operation conditions. These conditions may include:

(1) Push back

(2) Taxi-out

(3) Turns-out

(4) Taxi snubs out

(5) Brake turns out

(6) Takeoff roll

(7) Drift landing

(8) Landing roll

(9) Landing braking

(10) Brake turns in

(11) Taxi snubs in

(12) Turns-in

(13) Taxi-in

(14) Docking

The wheel design is based upon the aircraft manufacturer's load spectrum, tire-to-wheel loadings for the tire type, inflation pressure increase due to tire heating during rolling, and other factors. The objective might be that the wheel design is capable of the required roll life with 90% reliability and 90% confidence (based upon material static and fatigue data).

b. In order to reduce the roll test duration, the wheel and brake manufacturer(s) develop(s), in concert with the aircraft manufacturer, an accelerated roll test that simulates the cumulative fatigue damage of the design service life of the wheel. Typically, the accelerated laboratory roll test consists of rolling the wheel a minimum of 20% of the design service life of the wheel at increased loads. The loads are established by a combination of strain roll testing and analysis such that the cumulative fatigue at the critical wheel areas is equivalent between the test spectrum and the design spectrum. Care must be taken in selecting the loads to ensure that the failure modes of the wheel are not affected. It is typically an accepted practice to conduct routine maintenance, such as replacement of bearings, on the wheel throughout the test at intervals not less than the proportional design life of the affected part.

c. Wheel roll tests are then performed in the laboratory to verify that the wheel life has been met.

6.2 Method 2

This method, which may be adopted in lieu of the availability of an airframe manufacturer's spectrum, is illustrated in Table 1. Table 1 would replace the rational analysis in 6.1 (a). Accelerated roll test, as described in 6.1 (b), can also be used in this method in order to reduce roll test duration.

TABLE 1 - PERCENT RATED LOAD (MAXIMUM STATIC)

Roll Type	Radial	Side	Drag	% Total Roll Distance
Straight	100	--	--	75
Yawed	100	+30	--	1
Yawed	100	-30	--	1
Yawed	100	+15	--	5.5
Yawed	100	-15	--	5.5
Straight	100	--	20	10
Yawed	100	+10	15	1
Yawed	100	-10	15	1

6.3 Corrosion Testing

The corrosion test objective is to demonstrate that wheel critical areas, once corroded, should not lead to a failure before the number of cycles corresponding to several tire lives. The reduction of wheel life due to the effect of wheel corrosion should be accounted for in wheel design. Experience indicates that there are substantial variances in approaches to corrosion protection that are adopted by the various airlines. It is, therefore, recommended that corroded wheel conditions be accounted for in establishing the minimum life. Test procedures to verify the roll service life capability should include the following:

a. Prepare the wheel for corrosion testing by leaving bare (unanodized, etc.) those areas of the wheel (bead seat, flange, etc.) where failures may result in wheel burst. Other areas of the wheel (hubs, spokes, etc.) may need to be protected with applicable corrosion protection for a given wheel model to assure that failure occurs in critical areas under evaluation.

b. Subject wheel to salt spray exposure of ASTM B 117 before roll testing to yield corrosion pit depths of 0.020 to 0.030 in.

c. Subject the wheel to a roll test procedure representing multiple tire lives to demonstrate minimum service life capability. An accelerated roll test procedure could be used.