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

RATIONALE

This document has been reaffirmed to comply with the SAE 5-year Review policy.

1. SCOPE:

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

2. REFERENCES:

2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARP813	Maintainability Recommendations for Aircraft Wheels and Brakes
ARP1064	Brake Dynamics
ARP1619	Replacement and Modified Wheels and Brakes
AS8035	Minimum Performance Standards - Transport Category Aircraft Wheels and Brakes

2.2 Aircraft Manufacturer Specifications:

2.3 Government Publications:

Available from Standardization Documents Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-W-5013 Latest Revision Wheel and Brake Assemblies; Aircraft

TO PLACE A DOCUMENT ORDER: **Tel:** **877-606-7323 (inside USA and Canada)**
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2.4 Federal Aviation Regulations:

Available from Federal Aviation Regulations, Supervisor of Documents, U.S. Government Print Office, Washington, DC 20402.

a. FAR Part 25 Airworthiness Standards: Transport Category Airplanes - paragraph 25.731 Wheel and paragraph 25.735 Brake. Paragraphs 25.130 (a), (b); 25.1309 (a); and 25.143 (a)(1) also apply.

b. FAR Part 21 Subpart 0 Technical Standard Order Authorizations, TSO-C26c, Revision C or later.

3. DISCUSSIONS:

The Federal Aviation minimum performance standards for the design of civil transport wheels and brakes are defined in 2.4 (a). The design requirements and tests in 2.4 (b) are used by vendors/ equipment manufacturers to qualify commercial aircraft wheel and brake assemblies. Minimum performance standards of other certification agencies (e.g., CAA) 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 2.3. The references in 2.1 provide additional guidance.

4. TYPICAL WHEEL ENDURANCE REQUIREMENTS:

The performance standards in TSO-C26c 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.

Additional design practices were applied to increase wheel endurance to approximately 25 000 roll miles. The present trend for large commercial aircraft has been to increase wheel design life from 25 000 to 50 000 roll miles.

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 must 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. The effect of repeated brake heat exposure cycles on wheel fatigue life should also be considered.

4. (Continued):

Another important factor to be considered in wheel design is the tire type. With the advent of commercial aircraft radial tires, the construction of tires is of two basic types; i.e., radial and bias ply. The design and construction of radial ply tires is currently in a state of development, thus identical size tires from various manufacturers can exhibit markedly different loading patterns on a given wheel. Tire-to-wheel loading patterns should, therefore, be based upon tire type, manufacturer (construction), ply rating, tire size, and inflation pressure.

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.

5. TYPICAL BRAKE ENDURANCE REQUIREMENTS:

Specification TSO-C26c requires that wheel and brake assemblies meet basic performance and structural integrity requirements. The following is an abbreviated description of TSO-C26c requirements.

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

b. One Accelerate Stop (KE_{RT}): Deceleration determined by airframe specification requirements must be $\geq$6 ft/s^2. New or used friction components may be used, however this test has generally been a "new brake" test. No less than two landing stops (KE_{DL}) must be completed before this test and "the brake must be usable for taxi after the accelerate-stop test to KE_{RT}."

c. 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.

d. 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.

e. Endurance Tests - Hydraulic Brakes: Brakes designed in accordance with TSO-C26c must sustain a total of 100 000 pressure cycles to a brake pressure level corresponding to the design landing (KE_{DL}) stops test method used 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. Total leakage must not exceed 5 cc and no malfunctions are permitted.

5. (Continued):

The following supplemental requirements are recommended which are pertinent to brake performance and/or endurance. Vibration characteristics may be pertinent to endurance of landing gear system components.

a. Brake Wear Tests: The brake test spectrums discussed in Section 7 and Tables 2 and 3 provide bases 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. Brake Structural Torque Test: It is recommended for carbon brakes that TSO-C26c tests be conducted with carbon discs machined to the worn condition. This procedure assures that carbon discs in any configuration, when machined to estimated worn dimensions, will be capable of demonstrating TSO-C26c structural torque capability.

c. Worn Brake RTO: AS8035 recommends worn brake RTO testing. Worn brake RTO performance requirements are imposed by certain government agencies. These performance requirements can significantly impact endurance (brake life) levels, particularly with steel brakes.

d. Vibration Testing: SAE AIR1064 provides a partial 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. Vibration levels which are high, but not destructive, 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 "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 be coordinated with the aircraft manufacturer. As stability of vibration modes can be influenced by friction components, 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, certification agencies. ARP1619 provides insight into certain "significant" change areas.

e. 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. Test procedures and pass/fail criteria of TSO-C26c are recommended.

f. 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.

5. (Continued):

g. 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. Tests are recommended in Section 7 to demonstrate compliance with aircraft manufacturer requirements.

h. Dynamic Torque: It is recommended that requirements include dynamic verification of wheel and brake assembly structural endurance to 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:

The tests described in this section include two methods of defining laboratory tests for main wheel endurance testing.

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).

6.1 (Continued):

b. The wheel and brake manufacturer(s) develop(s) a laboratory roll test procedures that will approximate cumulative fatigue damages in critical wheel areas that result from the defined spectrum. Typically, the proposed laboratory roll test may be 10 000 miles for a "50 000 mile service life wheel." Strain roll tests are run and loads are adjusted such that the cumulative fatigue is the same for the 10 000 mile laboratory roll test and the 50 000 mile design based upon the aircraft manufacturer's spectrum.

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 (a). As stated, a proposed wheel roll test is formulated and tested such that the laboratory test roll miles (e.g., 10 000 miles) yields fatigue damage equivalent to that expected in airline service (e.g., 50 000 miles).

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

Nose gear wheels may warrant a separate roll spectrum to account for towing, steering, and aircraft c.g. conditions as well as conditions noted for main wheels. Another consideration with dual nose wheels is that the steering axis must be perpendicular to the ground plane or steering will unload one wheel and increase load on the other.

6.3 Corrosion Testing:

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 10 000 miles roll service life capability are to include the following:

a. Prepare the wheel half 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.

6.3 (Continued):

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

c. Subject the wheel to accelerated roll test procedures (e.g., 2000 roll miles) to demonstrate minimum service life (e.g., 10 000 miles).

7. TYPICAL BRAKE ENDURANCE TESTS:

The following tests are delineated to address certain of the supplemental requirements discussed in Section 5. Alternate test methods and procedures may be adopted by the aircraft manufacturer as applicable to individual airplanes.

7.1 Brake Wear Tests:

The tests outlined in Tables 2 and 3 are generally sufficient to establish steel and carbon brake life trends. The number of taxi stops and snubs is particularly important in assessing carbon brake life. For steel brakes, landing energies play a significant role in characterizing brake life. The different spectrums focus on the important variables to yield life estimates for each brake type.

7.2 Static Torque:

This test is recommended to ensure that the brakes have adequate static torque when parked and during appropriate engine runup conditions.

These tests should be conducted with:

a. Brake Wear Status: New and worn-in
b. Environmental Status: Dry and wet or high humidity exposure
c. Brake Pressure: Parking pressure
d. Static Torque Pulls: Cold and hot

These tests (a minimum of eight conditions) should be conducted to the wear spectrum conditions of Table 2 or 3 in a separate test series. It is recommended that one static pull be performed during every other landing sequence to permit reconditioning of friction surfaces.

8. BRAKE LIFE CHARACTERISTIC SPECTRUMS (SEE TABLES 2 AND 3):

The following tables may be used as a guide. A more specific test spectrum may be provided by the aircraft manufacturer based on the operational requirements of the specific aircraft model. It is recommended that testing include simulation of braking parameters associated with autobrakes if permitted by test equipment. Normal energy is based upon TSO-C26c, paragraph 4.2, Method I.