DOI: 10.2478/fas-2022-0008
FATIGUE OF AIRCRAFT STRUCTURES
Volume 2022: Issue 14, pp. 104-113

EFFICIENCY AND FATIGUE/ENDURANCE LABORATORY TESTS OF AVIATION FRICTION BRAKES

Zbigniew Skorupka
Łukasiewicz Research Network – Institute of Aviation (Ł-ILot),
Structures Testing Laboratory,
Al. Krakowska 110/114, 02-256 Warszawa, Poland

zbigniew.skorupka@ilot.lukasiewicz.gov.pl

Abstract

Brakes are one of the most important safety systems in moving vehicles and machines. In vehicles such as cars or motorcycles brakes are used for stopping, controlling speed, and sometimes changing direction of travel. In aircraft, the main function of brakes is to reduce landing speed. As landing is one of the most dangerous maneuvers in aircraft operation, brakes must be efficient and reliable in order to ensure safety of the crew, passengers, and cargo. The most efficient brakes nowadays are friction brakes where velocity is controlled by friction of a pair of specially designed materials, which ensure stable and high friction coefficient over the course of the required braking process. The process itself is the dissipation of energy during aircraft movement which generates very high temperatures in friction materials during the time of the braking process. The materials and the whole brakes have to be temperature resistant, and we must ensure braking parameters are stable during the whole process. The same principle relates to the endurance/fatigue of the brake assemblies which must be durable enough to survive as high number of braking cycles as possible without any failure, which can result in fatal consequences. Every friction pair and every newly designed brake assembly must be laboratory tested for efficiency and endurance/fatigue in order to be used in an aircraft or vehicle. In this paper, we present the basic set of laboratory tests in the scope of friction materials and brake assemblies. Results of the tests are used as confirmations/proofs of proper and safe operation of the brakes for use in vehicles, especially in aircraft but also in land-based vehicles.

Keywords: fatigue, endurance, brakes, friction material, landing gears, laboratory tests, dynamic testing
Article Category: research article

1. INTRODUCTION/BRAKING THE AIRCRAFT

Brake (https://www.merriam-webster.com/dictionary/brake) (Fig. 1) is a device for arresting or preventing the motion of a mechanism usually by means of friction. Braking itself is a process of using the brake. Brakes are used in every machine or vehicle which moves or in which the movement is a part of its operation, e.g., aircraft, cars, lifts, or cranes.

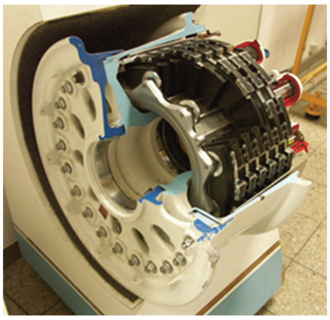

Figure 1. Example of aircraft brake.
Source: https://commons.wikimedia.org/wiki/File:Aircraft_brake_MD-11_cut-out_half-side.jpg

Friction brakes are most commonly used in vehicles and machines. Basically, a brake uses the friction phenomenon between surfaces of two materials by using a certain amount of force needed to generate and then maintain the desired effect.

Friction materials are designed to withstand high temperatures without losing stability of the process over the time of braking (brake appliance).

Other parts of the brake assembly must be durable/strong enough to work reliably through the high number of braking cycles due to the possible deadly consequences of the failure.

Figure 2. Normal operation of the brake.
Source: CharlieBay101 Aviation Broadcast Channel

Braking in the aircraft occurs mainly in two scenarios: landing (also during rejected takeoff [RTO]) and ground maneuvers.

Brakes are designed to operate safely and reliable for landing, which is the reference case of normal aircraft brake operation (Fig. 2.). The RTO case is considered as an emergency – brakes must ensure safety but can be destroyed in the process (Fig. 3).

Figure 3. Burning aircraft brake. *Source:* The Aviation Geek Club https://theaviationgeekclub.com/watch-this-video-featuring-a-c-5m-super-galaxy-experiencing-brake-fire-at-oshkosh-airventure-2019/

2. TESTS OF BRAKE SYSTEMS

Due to the regulation requirements, all brakes must be tested prior to use in order to prove their safe operation. The tests are carried out in stages:

- Friction pair materials are tested in order to collect data for ensuring its properties and to give feedback for brake assembly design (laboratory tests).
- Brake assemblies are tested in life-like conditions in order to prove their operation, assuming parameters and reliability in the number of braking cycles with highest possible parameters (in case of aviation: most energetic lading scenarios; laboratory tests).
- Brake assemblies are tested for repeatable cycles of operation (without braking – number of cycles of engaging/disengaging) in order to prove endurance/fatigue (laboratory tests).
- RTO test provides ultimate airfield results proving the safety of operation in emergency conditions.
- Brake tests are carried out on the aircraft in order to prove the real-time operation. Airfield tests are not in scope of this paper.

3. FRICTION MATERIALS TESTS – SAMPLE TEST DESCRIPTION

Usually, friction material tests are conducted in order to prove the properties of the friction pair (Fig. 4) by scaling down the braking process parameters from full-size brake to the model/sample size:

- Dynamic tests – in this case, there is a sequence of braking cycles (from 10 to >100). In the tests, the friction pair cannot fail or be destroyed. Parameters for the test are scaled from real brake with assumption of equality of the energy on the elementary area and equality of the sliding velocity between the friction pair surfaces.
- Static braking moment test – in this case, the braking force engages, and the pulling force (pulling moment to be exact) is applied until the rotation occurs. Test is repeated several (5–10) times.

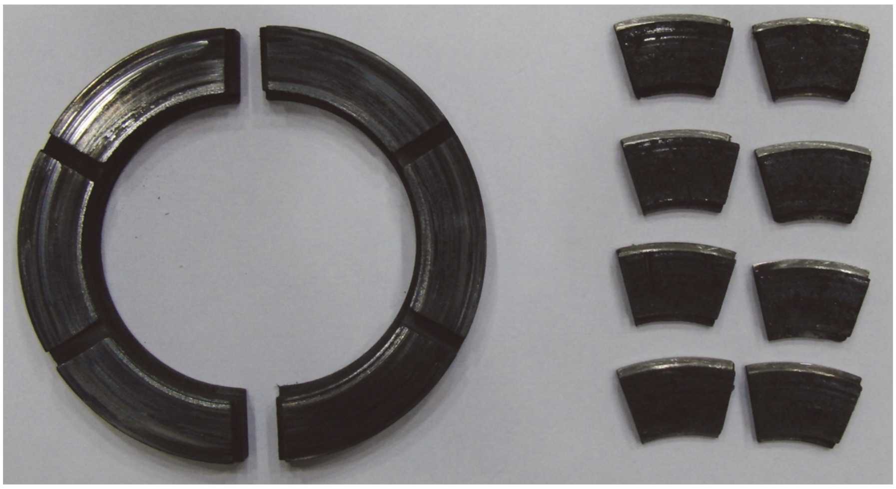

Figure 4. Friction materials/brake linings of aircraft brake.
Source: Landing Gear Laboratory, Ł-ILot.

Usually, test models/sample tests are performed using test stands called inertial dynamometers, which are capable of generating high amounts of energies to replicate the braking process. The main principle of the tests is the equality of braking energy dissipated (more precisely kinetic energy of the braking change into the heat) by the unit of area of the friction material used both in the model and in full size brake.

The IL-68 (Fig. 5) friction material testing machine owned by Structure Testing Laboratory (former Landing Gear Testing Laboratory) of Ł–ILot is the example of an inertial dynamometer.

Test stand parameters:

- Maximum drive shaft rotational velocity around 9000 rpm
- Moment of inertia (adjustable) of 0.154 up to 1.54 kg/m^2 (0.098 kg/m^2 step)
- Maximum load on the surface of the specimens 5.88 kN

Scope of tests: friction materials wear, friction pair behavior (parameters: braking torque, braking force, temperature, thermal endurance tests).

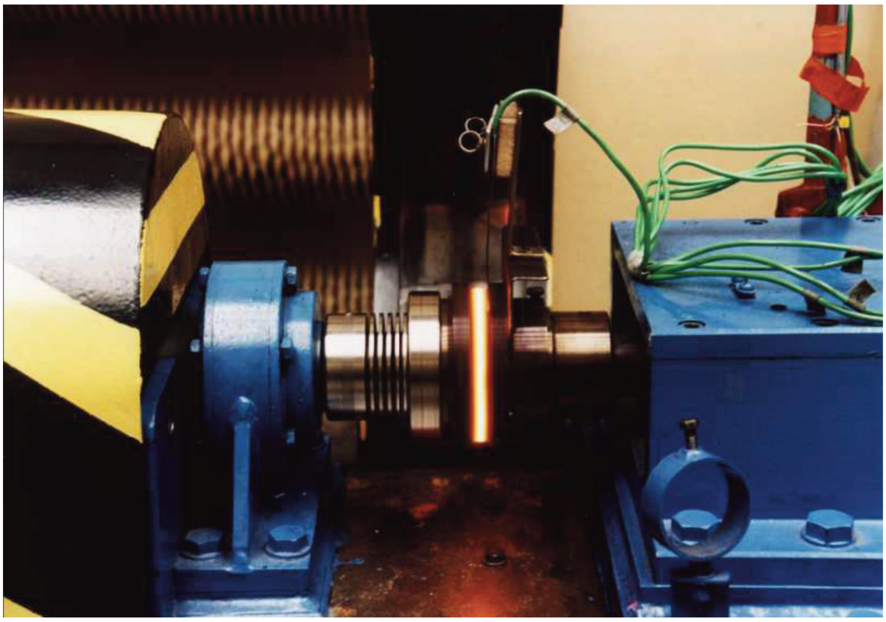

Figure 5. IL-68 friction materials dynamic test stand – test sample area.
Source: Landing Gear Laboratory, Ł-ILot.

An example of results from dynamic tests of aviation brake assembly performed using M3T/6T test stand is shown in Fig. 6:

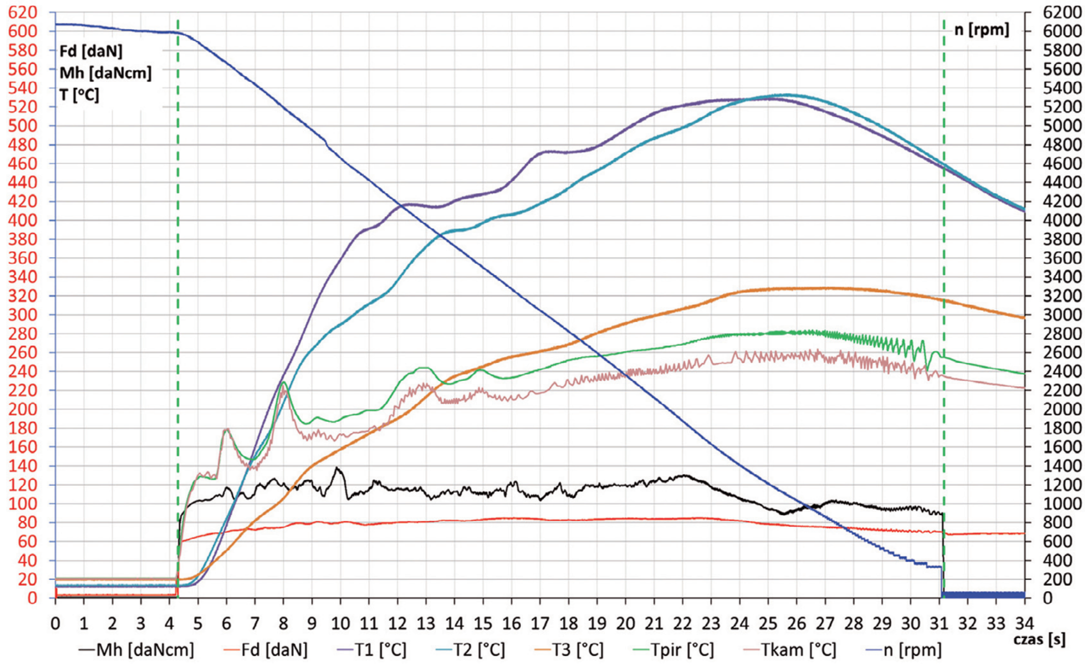

Figure 6. Example of friction material test results – test parameters: moment of inertia $I = 0.510$ kg/m^2, initial speed $n_s = 6000$ rpm, braking force $F_d = 70$ daN.
Source: Skorupka, Z. (2015). *Impact of Temperature on Braking Torque of Vechicle's Friction Brake*. Institute of Aviation.

4. BRAKE ASSEMBLY TESTS (FULL-SCALE BRAKE TESTS)

Exemplary brake assembly test compliant with ETSO-C26 regulations for aircraft compliant with part 23, 27, or 29 (CS – European, FAR – US, CAR - Canadian) regulations. Similar regulations are ETSO-C135 for part 25 compliant aircraft:

- Dynamic test resembling the real-life braking conditions – in this case, it is the energy, inertia, and braking speed. The test sequence contains 100 full braking cycles with one change of brake linings permissible per test sequence. The regulations only state that the brake must not fail in all of the tests, and the deceleration should be no less than 10 ft/s^2 (3.05 m/s^2). In many cases, the regulation requirements are extended by e.g., brake linings wear measurement, specific brake time requirement, or minimum braking moment (torque).
- Static test (brake structural test) – in this case, the brake is fully engaged and should withstand desired pulling force for 3 s. In other words, a wheel cannot move during the test time and brake cannot malfunction. Sometimes, this test is extended to the structure of the aircraft – the brake cannot cause removal of the landing gear out of the fuselage.

These types of tests are made using test stands capable of delivering the desired inertia – resulting in proper energy delivery – to the brake. There are a number of designs for such test stands. In Structure Testing Laboratory (former Landing Gear Testing Laboratory) of Ł–Ilot, the test stand is a drop test stand expanded with a rotating drum capable of a number of inertia levels.

Below there are exemplary M3T/6T test stand parameters:

- Maximum mass of test object including mounting parts 3T (it can be extended to 6.5T for wheel testing)
- Drum maximal rotational speed 800 rpm (peripheral 58.6 m/s)
- Drum moment of inertia (adjustable):
  - I1 = 294 kg/m^2; I2 = 550 kg/m^2; I3 = 588 kg/m^2; I4 = 843 kg/m^2.

Scope of tests: drop tests, shimmy and obstacle run tests, brake tests (Fig. 7.), and wheel roll-on tests.

Figure 7. M3T/6T test stand – example of an armored full-scale brake test.
Source: Landing Gear Laboratory, Ł-ILot.

An example of results from dynamic tests of aviation brake assembly performed using M3T/6T (Fig. 8.) test stand is shown in Fig. 9:

Figure 8. M3T/6T test stand – example aircraft LG test.
Source: Landing Gear Laboratory, Ł-ILot.

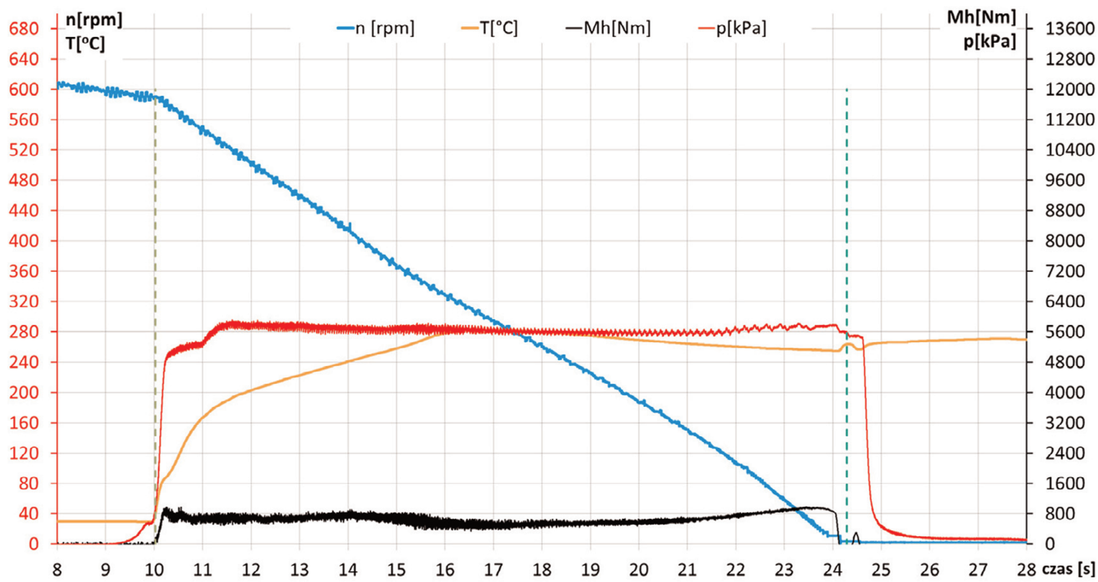

Figure 9. Example of full-scale dynamic brake test results – test parameters: moment of inertia $I = 588$ kg/m^2, initial speed $n_s = 600$ rpm, braking force $F_d = 11$ kN.
Source: Skorupka, Z. (2015). *Impact of Temperature on Braking Torque of Vechicle's Friction Brake*. Institute of Aviation..

5. ENDURANCE/FATIGUE TESTS

According to ETSO-C26 regulations, all of the newly designed hydraulic brake assembles must be endurance/fatigue tested:

The endurance test is a high number of work cycles (100,000 cycles for airplanes) with various levels of brake linings wear (25%, 50%, 75%, and 100%) using average pressure taken from dynamic tests or calculated. Moreover, the brake must be tested against the maximum allowable pressure for 5000 cycles. The brake assembly in this test is free (no dynamic braking) and must not leak (no more than 5cc according to regulations) or malfunction during the tests. The typical time of brake engage is 1 s or can be measured during the dynamic tests in laboratory or on the aircraft.

6. RTO TESTS

The mentioned above RTO is an emergency type maneuver that requires aircraft to stop just before taking-off due to onboard malfunctions or control tower command. The velocity of the aircraft would be near the takeoff speed as well as the mass of the aircraft which is full of fuel, which would be consumed during flight. The overall parameter values of the braking are higher than those during normal operational conditions during landing (e.g. CS 23.735, CS 25.735). Also, the aircraft must stop on considerably shorter distance than normally due to the distance already travelled during takeoff. This sets the strain on the brakes on a much higher level than that in usual operations. According to the regulations, aircraft brakes have to be able to dissipate the energy of the RTO even if they are destroyed during process. Usually, brake linings and other structural parts of the brake melt together into one lump, although there are some companies claiming that their brakes can be operational after RTO. Whether all brakes after RTO are considered as destroyed or not, they must be replaced before resuming operation of the aircraft, as well as the structural integrity of the landing gear and mounting nodes must be checked and confirmed to be within allowable limits.

The RTO test is done on the runway using the brakes with 10% left wear (CS-25 AMC 25.101(i)) in order to replicate most unfavorable circumstances during tests. To make the test as close to the reality as possible, it is advisable to hold firefighting for a few minutes, replicating the real airport fire brigade response time. This approach results with ignition (Fig. 10.) of the brakes due to the extremely high temperatures during RTO.

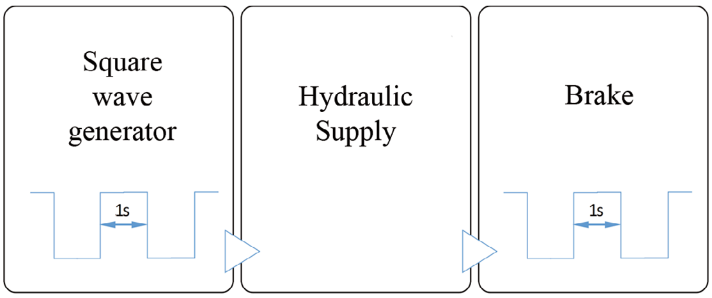

Figure 10. Diagram of brake caliper endurance test.
Source: Landing Gear Laboratory, L-ILot.

Figure 11. Burning brake in RTO test. RTO, rejected takeoff.
Source: https://youtu.be/KlpJTGAv2Oc

7. SUMMARY

- Every new designed brake must be tested before implementation;
- In aviation, tests are required by the regulations e.g., ETSO-C26 for smaller aircraft or ETSO-C135 for large aircraft;
- The scope of the tests is wide and covers the material testing as well as full-scale brake assemblies testing both in laboratory and in real operation conditions;
- The equipment and required researchers' experience for performing such tests are crucial in order to obtain reliable data. Structure Testing Laboratory (former Landing Gear Laboratory) of the L-ILot is capable of testing brakes for small and mid-sized aircraft, as well as testing the friction materials for brake usage.

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