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DYNAMIC FATIGUE TESTS OF LANDING GEARS

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ABSTRACT

Landing gears are one of the main components of an aircraft. The landing gear is used not only during take-off and landing but also, in most cases, during ground manoeuvres. Due to its function, the landing gear is also one of the key safety components of the aircraft due to dissipating landing loads acting on the aircraft. The mentioned loads come from both the vertical and horizontal speeds during touchdown and by the aircraft's losing the speed by braking. The landing gear is then loaded with constantly changing forces acting in various directions during every landing, with the only difference coming from their magnitude. The repeatable loading conditions cause significant wear of the landing gear. This wear can be divided into two categories, one is the wear of consumable parts such as the brake linings and the other is the fatigue wear of the structural components. The latter type of wear is much more dangerous due to its slow, and in many cases, unnoticeable progression. Fatigue wear can be estimated by numerical analyses – this method works with a great degree of probability on single components but due to the complexity of the landing gear as a whole it is not precise enough to be applied to the full structure. In order to evaluate the fatigue of the whole landing gear the best method accepted by regulations is the laboratory testing method. It involves a series of various drop tests resembling the real landing condition distribution. The aim of the tests is to check the fatigue wear of the landing gear and to prove its reliability for certification and/or operational purposes.

In this paper the author describes the basics of the landing gear fatigue wear, possibilities of its evaluation and presents laboratory dynamic method used for extensive tests in life-like operation conditions.

Keywords: fatigue, landing gears, laboratory tests, dynamic testing
Type of the work: Research Article

1. INTRODUCTION

Due to its function, the landing gear (Fig. 1.) is one of the key components of the aircraft by providing the repeatable ability of ground manoeuvring, taking off, and landing [2]. Landing gear is a critical part of the aircraft mainly due to its main function of dissipating the energy of landing and reducing loads acting on the aircraft's fuselage [3]. Landing loads come from both the vertical and horizontal speeds during touchdown and decelerating the aircraft by braking.

Loads/forces acting on the landing gear are constantly changing in various directions and magnitudes during every landing. The repeatable loading conditions cause fatigue – also called fatigue wear, which needs to be assessed and tested in order to determine the landing gear lifetime [1].

First stage of the landing gear lifetime evaluation is carried out during design phase when loads are estimated and potential weak spots of the final design are identified. The weak spots, in this case, are to be understood as parts of the landing gear mostly exposed to fatigue wear due to the design, functional, and manufacture limitations. The initial fatigue areas as well as probable failure rate are calculated both by the simple analytical tools and the finite method analysis (FEM or FEA). Even though the estimation of the fatigue by analyses works with a great degree of probability on single components, in many cases it is not precise enough for an assembled structure due to the complexity of the landing gear as a whole. In order to have the final proof of the landing gear fatigue over time (lifetime), proper tests need to be done due to the before mentioned inaccuracy of the numerical methods. Fatigue testing of the aircraft parts is required not only for the landing gear but also for other critical components of the aircraft such as wings/rotor blades and the fuselage.

The tests are not only the obligatory proof-of-safety and proof-of-operation of the landing gear but are also the verification of the numerical analyses as well as the real-life data collection for their improvement.

Fig. 1. Multiwheel Main Landing Gear (source: [7])

2. TYPES OF FATIGUE TESTS IN LANDING GEARS

Fatigue tests of the landing gears – as well as of all the other tests – range from the simplest to the most complex. The basic division of the tests is presented below:

- Single-component testing – one selected part is tested, isolated from its assembly. The tests are performed by using an equivalent set of loads applied to the areas of the part where they replicate real-life conditions. Loads are simulated by the specialized equipment capable of replicating their magnitude, component deflections, and the load application frequencies.

- Multi-component testing – the set of parts is tested in order to evaluate the fatigue of the connection areas or interactions between parts. Loads can be applied/ simulated as in a single component method or simulated by using the test stands which can replicate operation – landing, taxiing and take-off – of the aircraft by making the process self-generating under the initial conditions.

Test can be also divided by the nature of the load conditions:

- Quasistatic – the complete landing gear or its component is subjected to the full spectrum of loads in a quasistatic manner, which means that low frequency/speed loads are applied – e.g. load increase speed around 20 mm/s time of loading around 20 minutes. The tests are performed the same way as the static tests of landing gears but in higher quantity. Mainly – but not only – quasistatic tests are designed to replicate the braking and side forces acting on the landing gear. These tests can be done as single or multi-component tests (Fig. 2.).

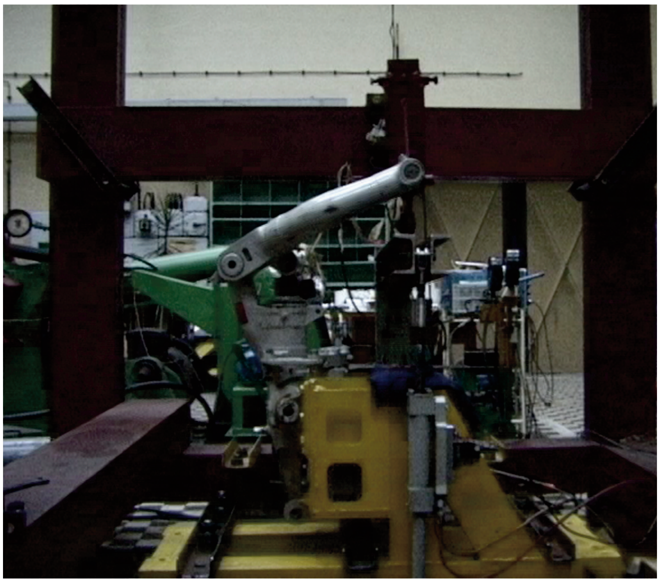

Fig. 2. Example of multi component quasistatic fatigue test (source: L-ILOT)

- Dynamic – the loads are of higher frequency and speed than in the quasistatic conditions – e.g. time of loading being around 0.3 seconds. As for landing gears, the method basically involves a series of various drop tests resembling the real landing conditions distribution or, if a proper test stand (Fig. 3. and 4.) is not available, the loads can be simulated using the specialized equipment. Simulation of the loads from landing requires a much more complex test stand than the drop tests one so this method is very rare though. In most cases tests are based on the landing cases (e.g. [6]) so the results are replicating the real-life conditions of the landing with the highest degree of probability achievable in a laboratory. These tests are typically performed in multi-component configuration but, rarely, it is possible to test a single component when special circumstances occur. This paper is only concerned with multi-component dynamic fatigue tests of landing gears.

Fig. 3. 10 Ton Drop Test Stand (Semi-Automatic)
(source: L-ILOT).

Fig. 4. 5 Ton Drop Test Stand (Automatic)
(source: L-ILOT).

3. INPUT DATA

For landing gear dynamic fatigue tests, some input data is similar to that needed for regular drop tests [4]:

- Landing speed (Horizontal and Vertical).
- Landing mass and Lift (Lift Force).
  - Landing scenario (two (non flared) or three (flared) point landing) [6].
  - Operational Landing Gear Parameters (e.g. pressures).
  - Characteristic dimensions.
  - Interval between the tests.

Input data different than in regular drop tests:

- Horizontal Velocity (Sink Speed) distribution – landing/touchdown.
- Load Factor Amplitude distribution – taxiing, take-off.

3.1. Sink Speed Distribution

The distribution is based on frequency of the sink speeds. It covers the landing conditions from lightest (smallest sink speed) to toughest (highest sink speed but usually not exceeding reserve energy conditions for specific landing gear).

The regulations-based distribution (e.g. MIL-A-8866C(AS)) is a mean of different recorded aircraft data and resembles the Gauss distribution where the toughest landings are the rarest.

The aircraft specific distribution is also used mostly when the landing gear is redesigned at some point of the aircraft service and there is a knowledge of the real landing conditions distribution taken from the actual operation of the aircraft. The aircraft specific distribution can be different from the regulations one especially for the training or military aircraft.

The distribution data is presented as the one sequence per number of landings (the most common is 1000). The sequence can be multiplicated to cover more landings. Example from MIL-A-8866C(AS) is presented in Tab.1 and in Fig. 5.

Tab. 1. Exemplary sequence of sing speed distribution according to MIL-A-8866C(AS) [5].

Sink Speed	**Frequency**	**Drop height**
f/s (m/s)	-	mm
1 (0.31)	57	5
2 (0.61)	170	19
3 (0.91)	271	42
4 (1.22)	252	76
5 (1.52)	153	118
6 (1.83)	66	171
7 (2.13)	22	231
8 (2.44)	7	303
9 (2.74)	1.5	383
10 (3.05)	0.5	474

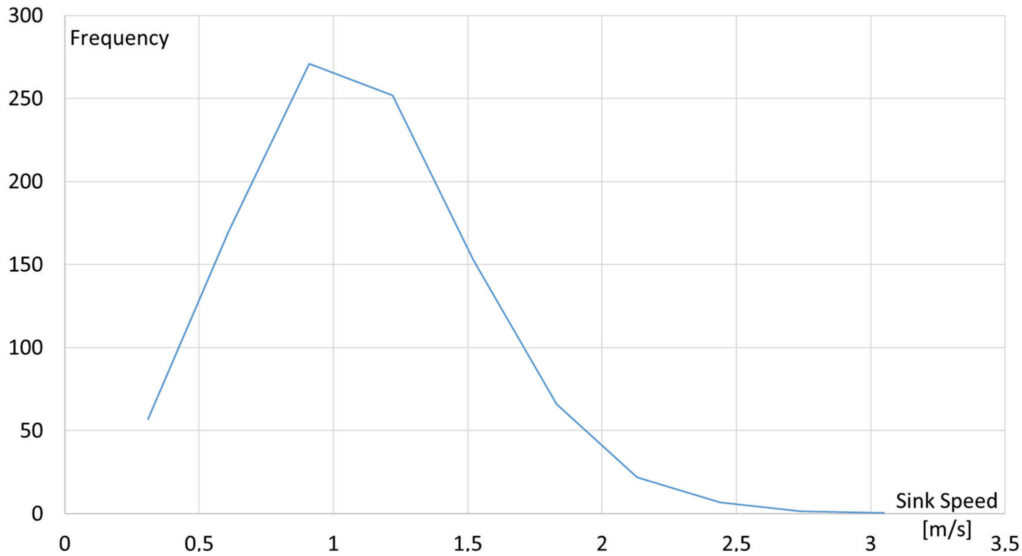

Fig. 5. Example of the sequence of sink speed distribution according to MIL-A-8866C(AS) (source: L-ILOT, [5]).

3.2. Load Factor Amplitude distribution

The Load Factor Amplitude distribution is based on the number of specific values (levels) of Load Factor Amplitude occurring during the taxiing, take-off or landing sequence. In one full sequence there are several levels of the Load Factor Amplitudes reached or overrun.

The Load Factor Amplitude test is made as the drop test in which one of the previously recorded levels of Load Factor Amplitude is achieved and would not be exceeded. The number of tests for each Load Factor Amplitude level is based on the number of its overruns recorded earlier.

If the specific data is not available it is possible to use the data from the regulations e.g. MIL-A-8866C(AS) where the mean distribution is given.

Tab. 2. Example of a sequence of Load Factor Amplitude distribution from L-ILot Landing Gear Laboratory

Load Factor Amplitude	**Number of Tests (Frequency)**
g	-
0.25	1000
0.55	1000
0.35	1000
0.25	1000
0.35	1000
0.25	1000
0.35	1000
0.25	1000
0.35	1000

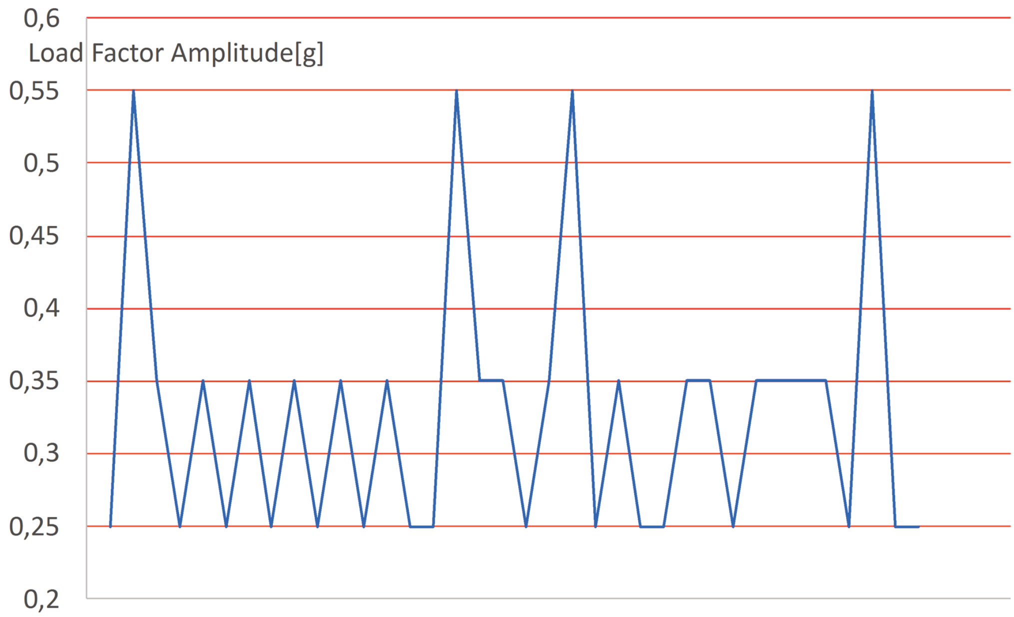

Fig. 6. Example of a sequence of Load Factor Amplitude distribution from L-ILot Landing Gear Laboratory.

Tab. 3. Example of a sequence of fatigue tests from L-ILot Landing Gear Laboratory.

Name of the Test	**Type of the Test**	**Configuration**
Taxiing, take-off	Dynamic	Levelled
Landing/Touch down	Dynamic	Three point (non flared)
Taxiing, take-off	Dynamic	Levelled
Braking, side load	Quasistatic	-
Landing/Touch down	Dynamic	Two point (flared)
Braking, side load	Quasistatic	-
Landing/Touch down	Dynamic	Two point (flared)
Braking, side load	Quasistatic	-
Landing/Touch down	Dynamic	Two point (flared)
Taxiing, take-off	Dynamic	Levelled

4. DYNAMIC TESTS – RESULTS AND FATIGUE EVALUATION

During the tests a number of parameters can be monitored and acquired (the symbols of the physical quantities shown in the Fig. 7. are in brackets):

- Pressures (Pa)
- Accelerations (load factors) (nz)
- Loads/Forces acting on the landing gear (Fz, Fx)
- Deflections (Uk, Ua)
- Landing Speeds (Vz)
- Stress/strain
- Material behaviour
- Temperatures

The results are presented in the same manner as the results from the regular drop test (Fig. 7.).

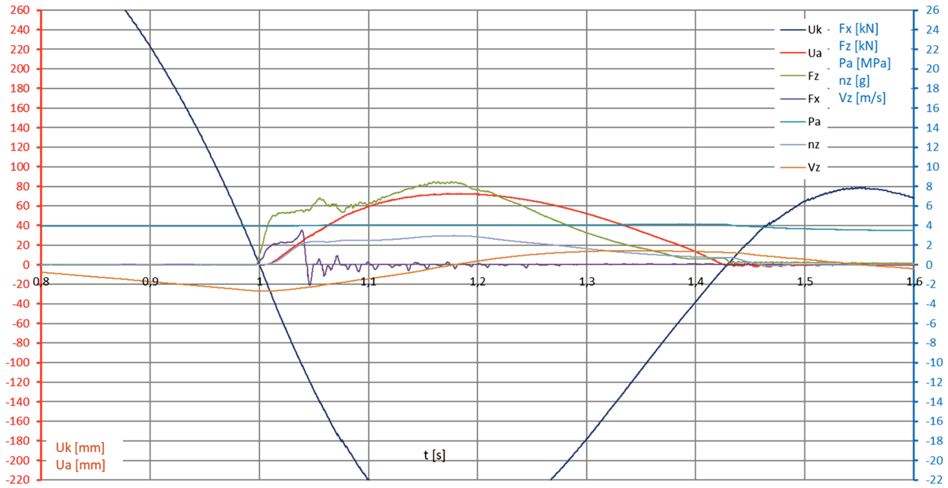

Fig. 7. Exemplary sequence of Load Factor Amplitude distribution
from L-ILot Landing Gear Laboratory.

Due to the number of the tests it is not necessary to record the data from every single test. The number of the recorded tests depends on the needs. However, nowadays the technical means in data recording and storage enable recording and storing a huge amount of data so if there is enough data storage available it is advised to record every test made. The results can be then utilized in a number of analyses, not only for fatigue assessment.

Also, the visual investigations are performed in order to evaluate the integrity of the Landing Gear. The visual investigations are usually connected with the:

- Number of tests performed – e.g. every 100th test.
- Toughness of the test – e.g. every test from the height over the established margin.
- Deviation of the recorded parameters – e.g. visible deviation of the loads between similar tests.

From the data recorded the fatigue evaluation is made. It can be done in various manners as needed but it has to provide answers to the questions about the fatigue wear occurrence and the lifetime of the Landing Gear. The simplest way to evaluate the fatigue is to observe the following:

- Change in output parameters – difference between reference test and selected test (usually made after sequence or when needed).
- Change in characteristic dimensions or operational parameters:
  - Breaks (tears, component separations, etc.).
  - Deformations.
  - Time to achieve the first fatigue indication.

The observations should be correlated with the number and parameters of the tests made. The usual procedure is to pause after a certain number of the tests and refer to the list above. If data is recorded and evaluated for every single test the first signs of the fatigue can be discovered earlier. Also, there are attempts to use the visual techniques for observation of the weak spots in order to catch the first signs of the wear – breaks – as soon as possible. Deformations can be discovered in real time by using specialized techniques such as high-speed video recording and motion analysis software.

5. SUMMARY

Dynamic testing of fatigue in landing gears is approved by the regulations as a method for evaluating the reliability, resistance and lifetime of landing gears.

The tests made in multi component or full-scale configuration are the closest simulation of the real-life Landing Gear operation and behaviour and due to that are the best method of fatigue evaluation.

Due to the nature of fatigue, tests must be performed in large numbers, which takes time and is very expensive.

The equipment and staff experience required to perform such tests are crucial in order to obtain reliable data. One of such laboratories is the Landing Gear Laboratory of the Lukasiewicz Research Network – Institute of Aviation.

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