ISSN: 1231-4005
e-ISSN: 2354-0133
DOI: 10.5604/12314005.1217202

AN ENERGY ABSORPTION DYNAMIC TEST OF LANDING GEAR FOR 1400 KG GENERAL AVIATION AIRCRAFT

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Abstract

Landing gear as one of the most crucial systems ensuring safe take-off and landing must be rigorously tested before first flight of each newborn aeroplane. In the static and dynamic tests strength, functionality and energy absorption capability of landing gear components (wheel, brake, shock absorber, support structure and retraction system) are verified. One of the most important is an energy absorption dynamic test. During drop, test campaign a landing gear damping system is not only verified but also optimized by changing parameters like: damping orifice diameter, geometry of gas and oil chambers and shock absorber and tire inflation pressures. This process often takes substantial amount of time because of influence of the mentioned parameters on landing gear energy absorption efficiency. Other factors like landing configuration spin up and spring back effects generated during wheel contact with the ground [1] also have to be considered in the energy absorption optimization process. The paper describes the landing gear drop test campaign and main challenges, which have to be overcome to achieve optimal dynamic characteristics of the system. The tested object was the main landing gear of the 1400 kg General Aviation aircraft certified in accordance with EASA CS-23 regulations. The drop test campaign was carried out in Warsaw Institute of Aviation Landing Gear Laboratory.

Keywords: *landing gear, energy absorption, drop test, shock absorber*

1. Introduction

Aircraft for the transport of people and goods have to meet a number of rigorous safety requirements before being allowed to fly. These specific requirements and regulations made by Aviation Authorities need to be considered at all stages of new aircraft development, from a concept to the final prototype manufacturing. Landing gear as one of the most important systems on aircraft, ensuring safe take-off and landing phases, also needs to be designed and tested according to aviation regulations such: FAA FAR (Federal Aviation Regulations), EASA CS (Certification Specifications), US MIL (Military Standards). Laboratory static and dynamic tests are one of the steps of the certification of a new aeroplane. Although the engineering world disposes of sophisticated numerical tools and methods to verify and optimize aircraft's components, still there is a necessity to carry out laboratory tests for complete confirmation that the designed system is suitable for flight. Dynamic drop tests are the most important ones for validation of both landing gear energy shock absorption ability and general functionality. All presented tests were performed in Warsaw Institute of Aviation's (WIA) Landing Gear laboratory.

2. Preparation for landing gear dynamic drop tests

Dynamic drop tests of the landing gear have to be carried out in accordance with Aviation Authorities regulations. Main landing gear (Fig. 4, 5) for 1400 kg small general aviation aircraft (AT-6) presented in this paper was tested in accordance with EASA Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes CS-23 [4]. The landing gear components must be carefully checked before dynamic tests and some of them like wheels and shock absorbers are tested individually. The shock absorber leakproofness, functionality and pneumatic characteristic are verified in quasi-static test performed on hydraulic press. The results from the quasi-static compression test allow assessing friction between shock absorber parts (load hysteresis) and comparing load versus piston displacement data with theoretical calculations. A small friction hysteresis shown in Fig. 1 is typical for compact shock absorbers designed usually for lever landing gear types.

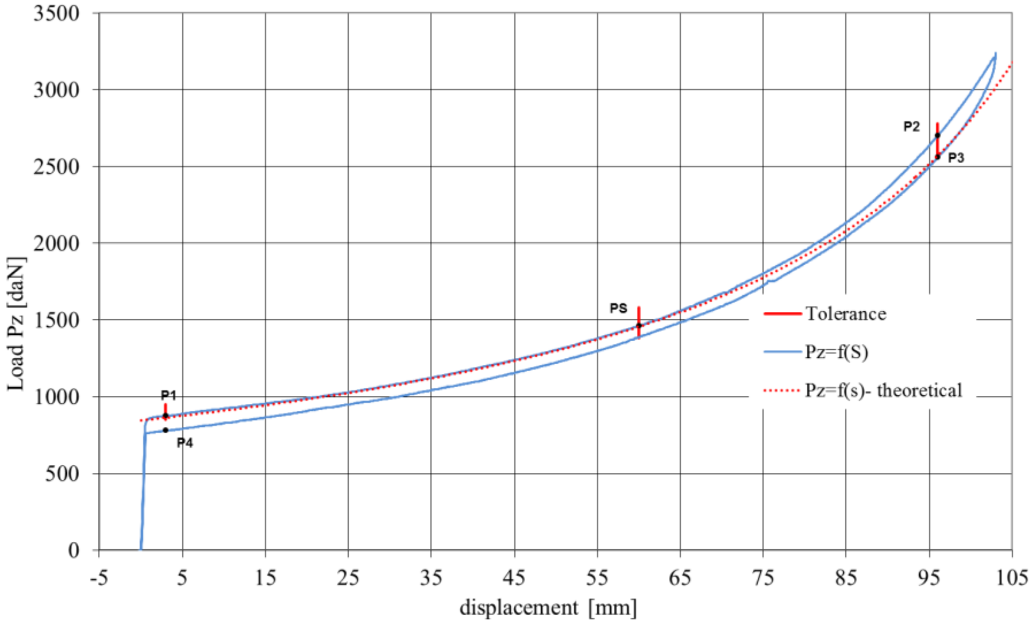


Fig. 1. Load versus displacement characteristics for the main landing gear shock absorber

The drop tests are carried out in the WIA Landing Gear laboratory 10-ton drop stand (Fig. 2). The test rig is equipped with pneumatic actuators for aeroplane lift force simulation and rotary actuator for spinning up the wheel. A group of data are measured during the test:

– total landing gear vertical displacement,
– shock absorber displacement,
– gas and oil pressures inside the shock absorbers,
– deceleration on vertical displacing car (drop carriage).

Fig. 2. 10-ton drop test stand

The whole landing gear system is fixed to a specially designed interface reflecting exact position of the gear in the aeroplane. Tests were performed according to test programme prepared based on requirements in CS-23 document. The parameters for the test are presented in Tab. 1.

Tab. 1. Parameters for the drop test of the landing gear for the 1400 kg small aircraft [3]

Parameter	Value	Units
Aeroplane landing mass	1400	kg
Effective weight to be dropped	687	daN
Limit vertical landing speed	2.94	m/s
Horizontal landing speed	40	m/s
Limit load factor for limit vertical speed	3.4	–
Tire inflation pressure	0.35	MPa
Maximum tire deflection during landing	80	mm
Shock absorber inflation pressure	6.0	MPa
Maximum shock absorber stroke	105.9	mm
Maximum wheel axle stroke for level landing (tail down landing)	231 (205)	mm

3. Dynamic drop test campaign

The energy absorption dynamic tests for the landing gear are divided into three stages:
- quasi-static tests,
- energy absorption optimization tests,
- limit and reserve energy absorption drop tests.

In the quasi-static test, complete landing gear is slowly loaded by lowering it on a tensometric plate up until maximum shock absorber displacement is reached for a given effective mass [2]. Vertical and horizontal forces, carriage and shock absorber displacements are measured. This test allows verifying landing gear assembly, guides correct installation and finds potential malfunctions both on the test stand and landing gear components. The quasi-static test results are shown in Fig. 3.

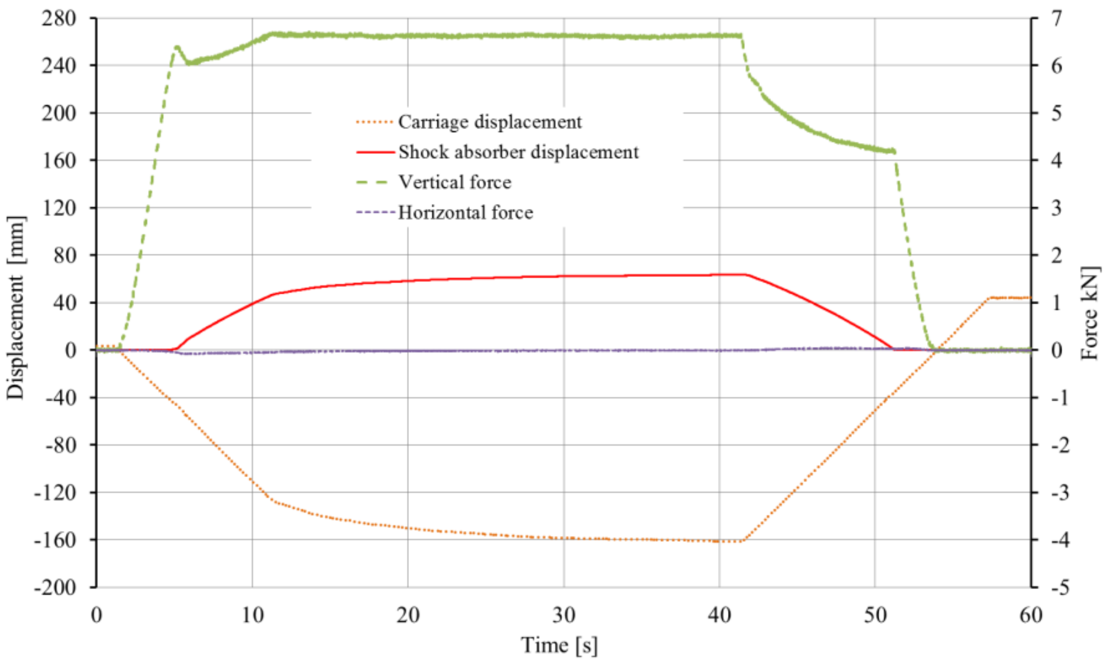


Fig. 3. Quasi-static test results for the 1400 kg small aircraft main landing

The energy absorption optimization test is the most laborious and time-consuming one. The aim of this test is to achieve the required limit of decent speed while not exceeding the calculated limit load factor. It is important to carry out the test in the most realistic way possible. In real landing conditions, an aeroplane's wheels are not rotated until they touch the ground and after touching the runway surface, they rapidly spin up causing significant loading on landing gear. In WIA's Landing Gear Laboratory, the effect of spin-up is achieved by using rotary actuator. The wheel is accelerated in the opposite direction to the flight direction to obtain adequate spin-up load. The lift force of the aeroplane during landing is simulated by pneumatic actuators. The CS-23 regulations [4] allow to carried out free drop test without lift force simulation and instead use calculated effective mass (dependence 1) but in that case carriage effective mass must be calculated and set up on the rig for every drop height. The dynamic optimization test is performed in many steps by increasing drop height gradually so using pneumatic actuators the time needed to complete the test can be significantly reduced. Two-dimensional landing conditions are taken into account during the test, level landing and tail down landing (Fig. 4).

$$M_e = M \frac{h + (1 - L)\, d}{h + d}, \tag{1}$$

where:
M_e – the effective weight to be used in the drop test,
h – specified free drop height,
d – deflection under impact of the tyre plus the vertical component of the axle travel relative to the drop mass,
M – mass for main gear units (kg), equal to the static weight on that unit with the aeroplane in the level attitude (with the nose wheel clear in the case of the nose wheel type aeroplanes),
L – the ratio of the assumed wing lift to the aeroplane weight ($L = 0$ for limit drop test).

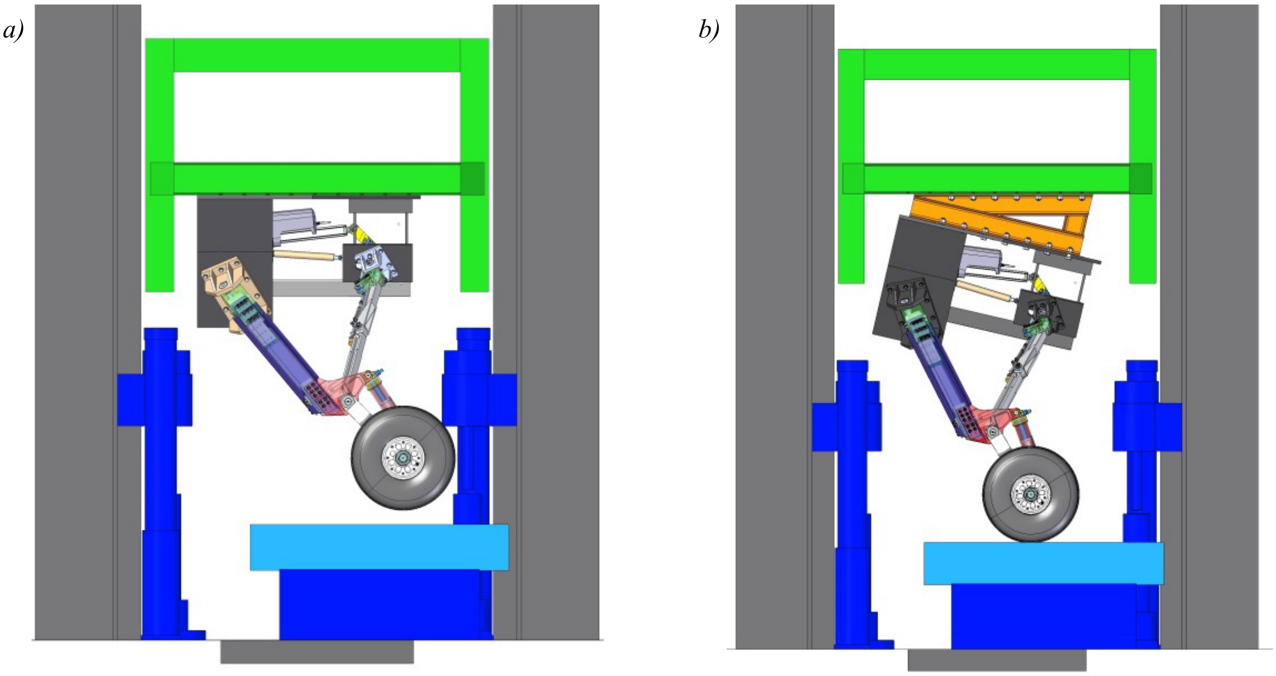
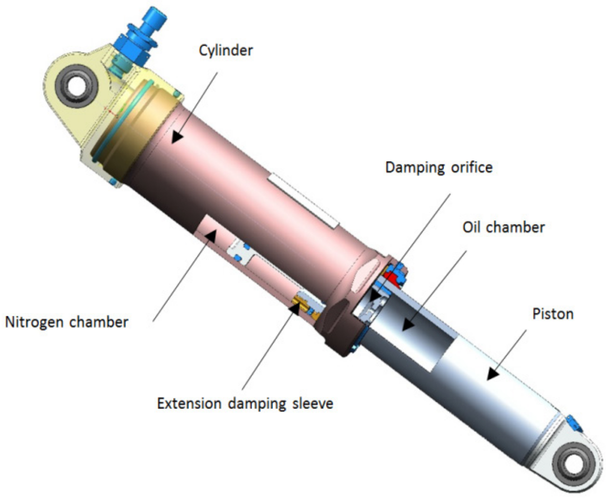


Fig. 4. Dimensional landing gear conditions: a) level landing, b) tail down landing

In the optimization process shock absorber, damping orifice diameter is changed (Fig. 5). Improving energy absorption efficiency for level landing often worsens energy absorption efficiency for tail down landing and vice versa. It is therefore important to analyse results from both level landing and tail down landing conditions in parallel and find a compromise that will allow meeting the test requirements. The parameters like shock absorber and tire inflation pressure are also changed during optimization. Sometimes slight change in those parameters can allow achieving required limit load factor. In some cases it is difficult to lower exceeded load factor and more complex action is needed like changing the gas chamber volume. That modification requires often changing the shock absorber design.

a)



b)

Fig. 5. Shock absorber for 1400 kg small aircraft main landing gear a), main landing gear just before reserve energy absorption drop test b)

The final stages in the drop test campaign are certification limit and reserve energy absorption drop tests. The tests are prepared in accordance with CS 23.723, CS 23.725 and CS 23.727 regulations and have to be performed in the presence of a Civil Aviation Authority representative (Civil Aviation Office of Poland, EASA, FAA). The limit drop test of the landing gear must prove that the limit factors selected for the design will not be exceeded. The target drop height for the presented landing gear was 440 mm and limit load factor 3.4 g. Maximum load factor equal to 3.39 was measured for chosen tail down landing configuration (tail down landing condition generates higher load factor). The landing gear is examined in detail for any malfunction or damage (parts yielding) after the limit drop test. If the gear is fully operational, the reserve energy absorption test is carried out. In this test the landing gear may not fail, but may yield. The decent velocity is 1.2 times the limit of decent velocity and wing lift force is equal to the weight of the aeroplane ($L = 1$). The target drop height for the presented landing gear was 634 mm. Maximum load factor equal to 3.67 was measured. There was not any plastic deformation or damage after the reserve energy absorption drop test and the landing gear was officially approved by Civil Aviation Office of Poland for flight. In Figs. 6, 7 and Tab. 2 the results from the drop limit and reserve energy absorption drop test are shown.

Tab. 1. Limit and reserve energy absorption drop test results for a 1400 kg small aircraft (AT-6) main landing gear

	Drop test results				
	Vertical force	Horizontal force	Carriage displacement	Shock absorber stroke	Load factor
	kN	kN	mm	mm	–
Limit drop test	16.14	6.63	311.9	99.6	3.02
Reserve energy drop test	18.35	6.19	324.3	101.9	3.67

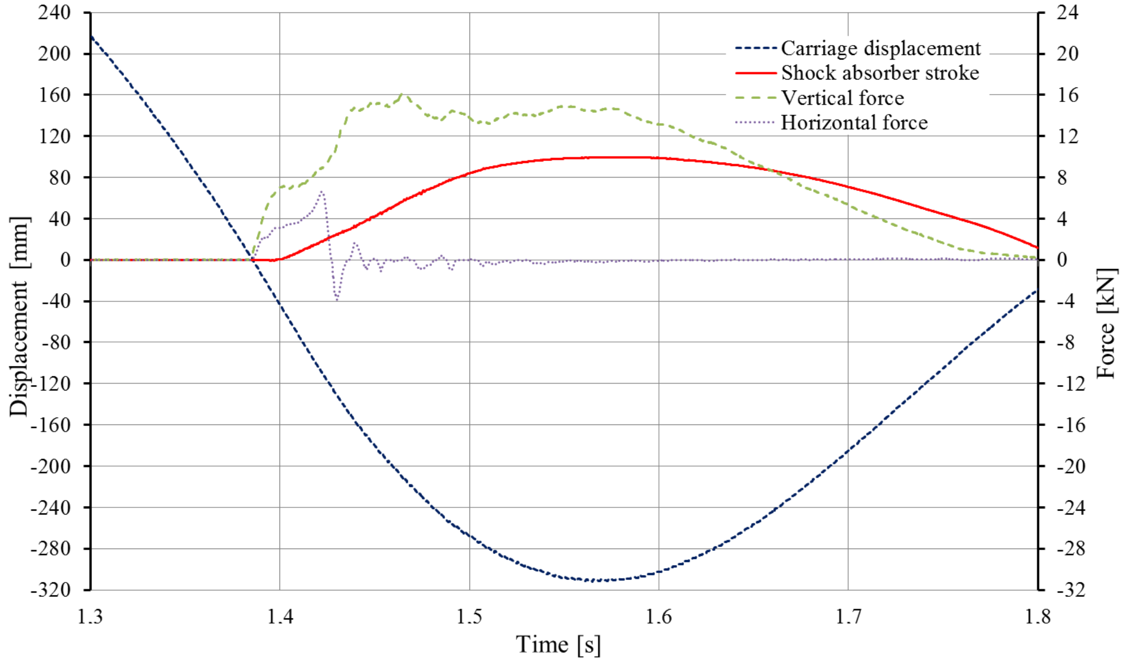


Fig. 6. Limit drop test results for a 1400 kg small aircraft (AT-6) main landing gear [5]

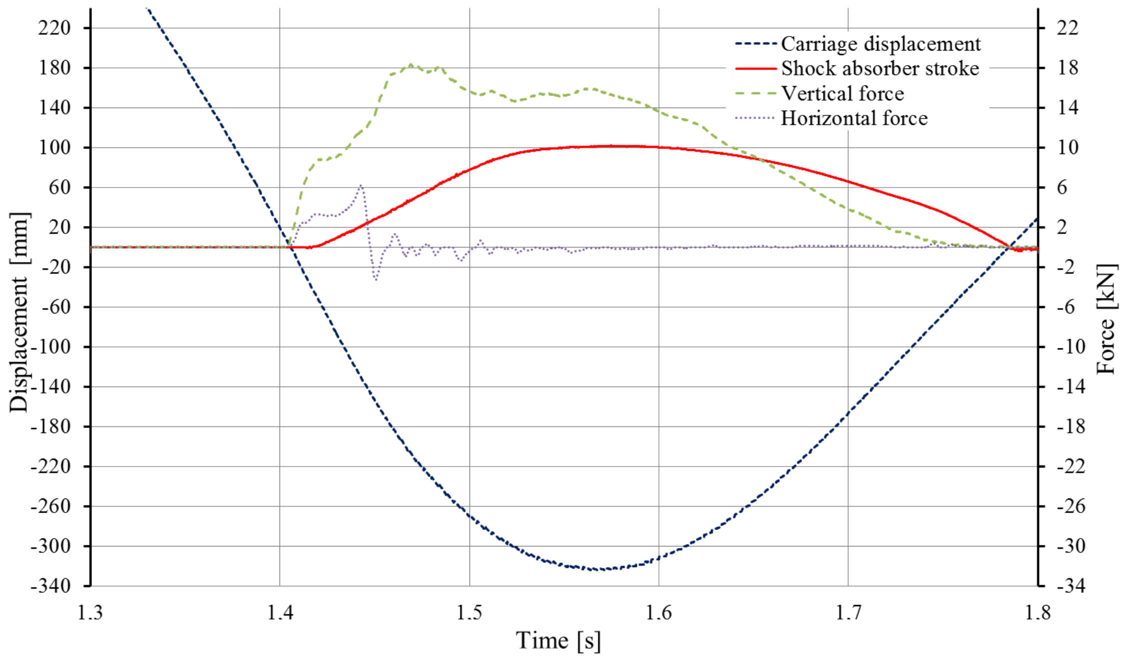


Fig. 7. Reserve energy absorption drop test results for a 1400 kg small aircraft (AT-6) main landing gear [5]

4. Summary

In this article, the energy absorption dynamic test campaign was presented. The aim of the tests campaign is to verify and optimize the landing gear energy absorption capability in order to meet requirements stated by Aviation Authority and described in EASA Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes CS-23 document. The most important in the landing gear limit drop test is to prove that the limit load factor selected for design will not be exceeded and for the reserve energy absorption test that the landing gear will not fail. In Warsaw Institute of Aviation Landing Gear Laboratory optimization and finally certification of main (presented in this article) and nose landing gear for 1400 kg small General Aviation aircraft

(AT-6) were carried out. The whole process generally consumes a substantial amount of work and time but WIA engineers having big experience and modern tools, which can greatly speed up all the process stages.

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