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LABORATORY INVESTIGATIONS ON LANDING GEAR GROUND REACTIONS (LOAD) MEASUREMENT

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Abstract

Ground reaction measurement in landing gear laboratory tests is used in order to gain knowledge about loads transferred to the aircraft structure. Ground reaction level is defined during aircraft design phase and it is required not to exceed limit value in real construction. Load from landing affect directly strength of aircraft structure especially mounting points what translates both strength of aircraft structure especially mounting points what translates both on safety and weight of the final design. Meeting the safety requirements is crucial in aviation regulations conformity. Landing gear ground reactions evaluation is performed during laboratory tests in order to meet the compliance with the ground load requirements assumed in design phase. Proper test method is crucial to prove the actual load. One of the methods is landing gear dynamic drop test where landing forces are measured. Force measurement is made in several ways according to test stand construction and test object specifics. In this article, three methods are described due to author's experience in landing gear tests. Proposed techniques cover two direct and one indirect force measurements. Direct approach is based on strain gauge measurement principle. One is a strain gauge plate fixed to the ground while the second one is based on strain gauges attached to landing gear mounting nodes. Indirect approach is based on the acceleration of the tested object, which by definition is correlated with the force applied to the structure. Obtained test results allow determining the kinetic energy absorbed by landing gear during drop test. In this article author also presented numerical integration of the time history data and compared them with simulation results in order to show equivalence of all three of the test methods and to prove correctness of the test initial conditions determination.

Keywords: *laboratory-testing, landing gear, load measurement, direct measurement, indirect measurement*

1. Introduction

In order to estimate level of ground reactions during touchdown of the airplane or helicopter it is needed to apply correct measurement technique. Taking into account that forces transferred from landing gear to the structure of the air vessel are crucial for the fuselage construction and for the safety of both passengers and cargo, its estimation must be made on the highest level possible.

Nowadays measurement of the forces is common and techniques used are well known, real problem is where to measure forces in order to obtain accurate values. There is number of techniques, which differ by both placement and type of sensor used.

According to the aviation regulations [7], forces ought to be measured in manner, which assures most accurate level of proof. It is not said where to make the measurement and what kind of sensors to use but it defines the need to prove the method.

2. Landing gear ground reactions (forces) measurement methods

There are three main Landing gear ground reactions (forces) measurement methods (approaches) used to determine ground its value (Fig. 1):

1. Direct approach based on strain gauges forces measurement on the ground plate mounted under the landing gear (Fig. 1). This kind of measurement can be used when there is a possibility of

mounting a flat surface under the landing gear. Plate measures all of the ground reactions acting on the landing gear even when wheel is spun up. Number of forces measured varies due to the plate design and can be limited to the one force – usually vertical (F_z) – or can cover more forces – usually vertical (F_z), horizontal (F_x) and side (F_y). Designs of strain gauge plates vary in sizes, strain gauge configurations or mechanical interface. Can be made directly for the desired measurements (tailored to fit specific needs) or be made as universal measurement devices covering as wide as possible range of laboratory needs. Plate based load measurement gives knowledge of sum of the forces acting in specific direction on landing gear without possibility of estimation their distribution between mounting nodes.

2. Direct approach based on strain gauges forces measurement [5] on the landing gear mounting nodes. This kind of measurement can be used in almost all of the landing gear test configurations but is more difficult to perform. Difficulty lies in measurement devices design – usually they are in the various shapes from pins resembling closely those used to the fuselage landing gear mounting or the bands or ties being mounted between fuselage and landing gear (Fig. 2.). Mounting nodes measurement approach is valid for all of the ground reactions acting on the landing gear even when wheel is spun up the same as for the plate measurement. Number of forces measured varies the same as in ground plate method. Measurement in landing gear mount nodes always needs tailored designs so is not as universal as the plate measurement. Most common advantage of the approach is the ability to measure forces even on not flat surface e.g. rotating drum and the possibility to estimate directly the distribution of forces to specific nodes if needed. In laboratory practice, both methods are seldom used together. Separate use of the ground and mounting points force measurement is dictated by the assumption that there is an equivalence of both direct measurement methods. Mounting node method can be used on an aircraft for real time force estimation; it can help to perform health monitoring (forces, fatigue, strength).

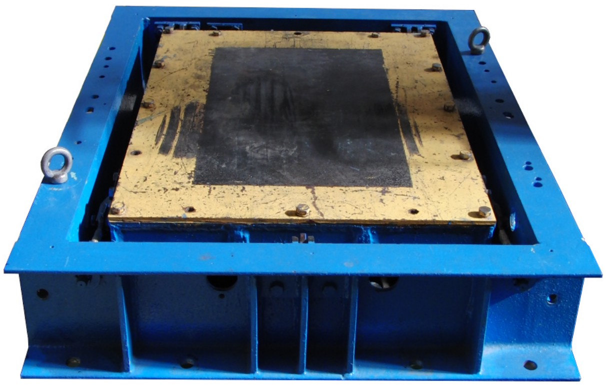

Fig. 1. Ground plate, source: ILot

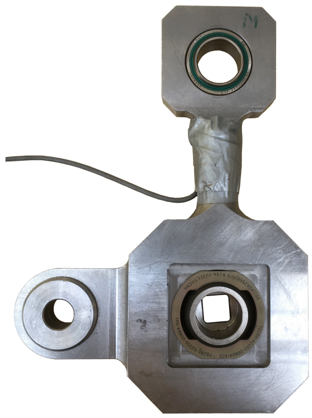

Fig. 2. Mounting node force measurement device (example) , source: ILot

3. Indirect approach based on the acceleration of the tested object. By definition, the force applied to the structure is equal to the object mass time's acceleration. It is therefore possible to calculate the load based on the acceleration measurements (Fig. 3). This approach is based on the indirect measurement principle, which leads to determination of the actual ground force value. Number of forces measured varies with the devices design the same as in direct methods. Number measured forces is most often limited by the transducers – best ones can measure acceleration on the one axis so best solution is to build three axis configuration out of separate devices, what is both space consuming and challenging to the mechanical accuracy of the transducers mount. Moreover, the measurement of the accelerations corresponding to the forces other than vertical gives not so accurate results in order to calculate horizontal and side

forces. Main difficulty in acceleration based load measurement is properly to mount the transducer to the test bench knowing that measurement itself is very sensitive to the mounting errors and can lead to obtain incorrect results (note that direct methods are much more resistant to the mounting errors – especially plate technique – due to devices design). It is necessary to say that acceleration measurement is most often used simultaneously with direct force measurement where possible (cross verification in order to prevent measurement errors), but there are tests where acceleration measurement is the only estimate of ground load.

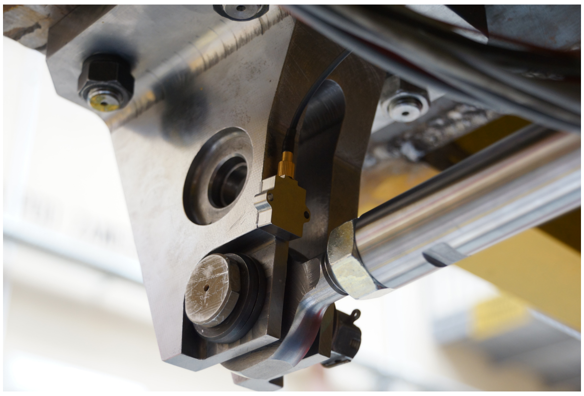

Fig. 3. Accelerometer mounted to the landing gear (example), source: ILot

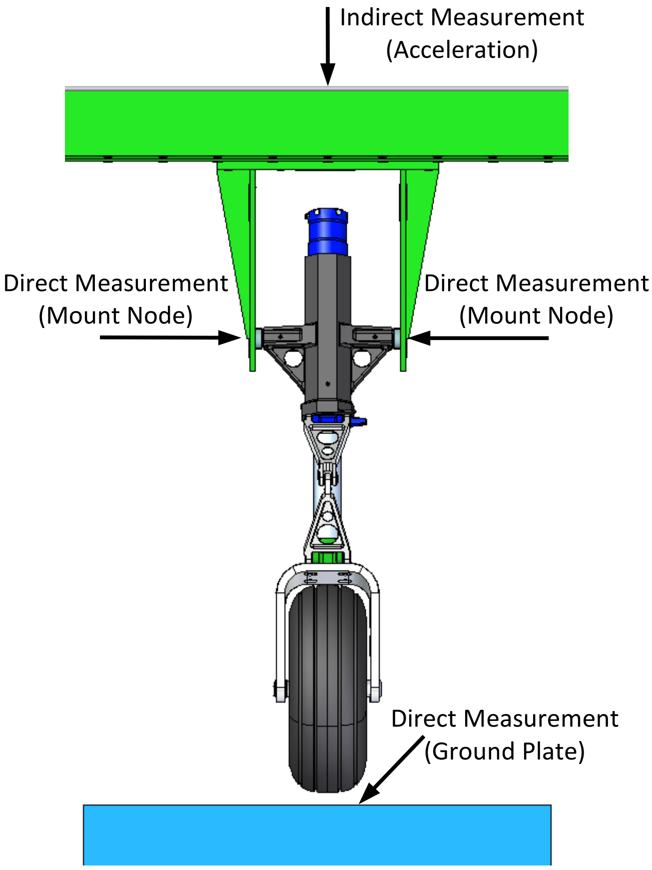

Fig. 4. Ground Loads (Forces) measurement techniques attachment schematic, source: ILot

3. Laboratory landing gear ground reactions measurement methods investigations

Forces acting on Landing Gear are at first calculated using preliminary aircraft parameters provided by the designer [1]. The results of the calculations accepted by the aviation authorities

(ULC in Poland, EASA in EU or FAA in USA) become the base for aircraft design. According to the aviation regulations, design assumptions have to be proven by laboratory tests or approved simulations. Nowadays both laboratory and in-flight tests are still the core source of aviation optimization and certification data.

For landing gear optimization and certification mainly one type of laboratory test called the drop test or dynamic test is used [3, 4]. Purpose of the test is to recreate, as closely as possible, real landing conditions in controlled environment. The test itself is basically a free fall of the landing gear with set weight and landing speed that resemble kinetic energy of landing. During touchdown phase of landing, some of the kinetic energy is dissipated [2] (i.e. converted to different forms) in the shock absorber and the rest is transferred to the aircraft's fuselage as forces – description of the landing process is the same for both laboratory tests and real-time conditions. Basic operation principle of the test stand (and the test itself as well) is described in aviation regulations e.g. CS-23.723, 725 – standardised approach assures that all laboratory tests (including certifications ones) will be carried out the same way and to be comparable to the tests of different aircrafts. Test stand detailed operation and design is therefore not described, so some of the design freedom is allowed as soon as the regulations are met. Warsaw Institute of Aviation Landing Gear Laboratory Test stands, where tests described in this article were conducted, allow carrying out complex tests for up to the 10T of landing mass on one landing gear [6].

General overview of the free drop test stand is presented in the Fig. 5.

Fig. 5. Free fall dynamic drop test machine example, Note the ground plate below the landing gear, source ILot

Note that for landing gear dynamic tests with initial drop speed (not only free fall where initial speed is zero), can also be performed, which results in higher landing speed without the need to build tall test stand in order to achieve desired speed. Higher landing speeds are often necessary in helicopter landing gear testing or in crush speeds testing.

Tests described in this article were performed using 10T drop test machine as standard free fall dynamic drop tests. Configuration of the test covered all three-load measurement methods: ground plate, mounting nodes and acceleration. Basic technical data of the test stand and measurement equipment used are shown in Tab. 1 and 2.

Tab. 1. 10T drop test stand technical data

N°	Name of parameter	Value
1.	Max. weight of tested object including mounting parts	10T
2.	Max. forces during the tests:	
	Vertical force	392 kN
	Horizontal force	196 kN
	Side force	157 kN
4.	Max. wheel spinning velocity	400 km/h (111 m/s)
5.	Max. sink speed	28.8 km/h (8 m/s)

Tab. 2. Basic data of measurement equipment used

N°	Measurement method	Device name	Principle of operation	Operation range
1.	Direct/Ground Plate	Custom made measurement plate	Tensometric	max 100 kN
2.	Direct/Mounting Node	Custom made mounting tie	Tensometric	max 100 kN
3.	Indirect/Acceleration	MEAS 4810A	Absolute accelometer (MEMS)	20 g dynamic range

Results of the tests shown that all of the direct force measurements results trend to be similar with no more than 5% error so the equality of method can be proven (ex. Fig. 6.). Described behaviour of the measurement results were recorded in all of the tests made. This can, due to the equivalence of direct load measurement methods, lead to the conclusion of possible wide usage of measurement pins or whole mounting nodes in real time node load monitoring during operation of the aircraft. This can be used (as stated earlier) for the health monitoring of the Landing Gear and its fuselage mounts as well as to help control/correct pilot behaviour during landing for training purposes.

Indirect (acceleration based) method results show similar trend as the direct ones (e.g. Fig. 6.) in drop tests without wheel speed (horizontal landing speed) – mainly as in rotorcrafts. When horizontal speed is present, error in measured load can reach up to 10% between direct and indirect measurement. This is still a satisfying result but is less precise than direct method. Indirect method therefore can be used where direct one cannot be. It is also very important to say that indirect method (acceleration) is very sensitive to the placement of the accelerometers in opposition to the force sensors, which are always placed where the force occurs.

5. Summary

Final analysis of the landing gear system during dynamic drop test indicates high efficiency of load measurement methods based on acquired data recorded from all of the measurement methods described above and proven equal – no more than 5% error for direct methods and 10% for indirect method compared with each other. It is also noticeable that acceleration measurements data usability for load calculations depends on proper installation of the transducer and correct estimation of the surroundings influence during the test, which is not so problematic in the direct force measurement due to much smaller sensitivity of measurement itself and arbitrary (landing gear design based) placement of the transducers in correct positions. Also acceleration

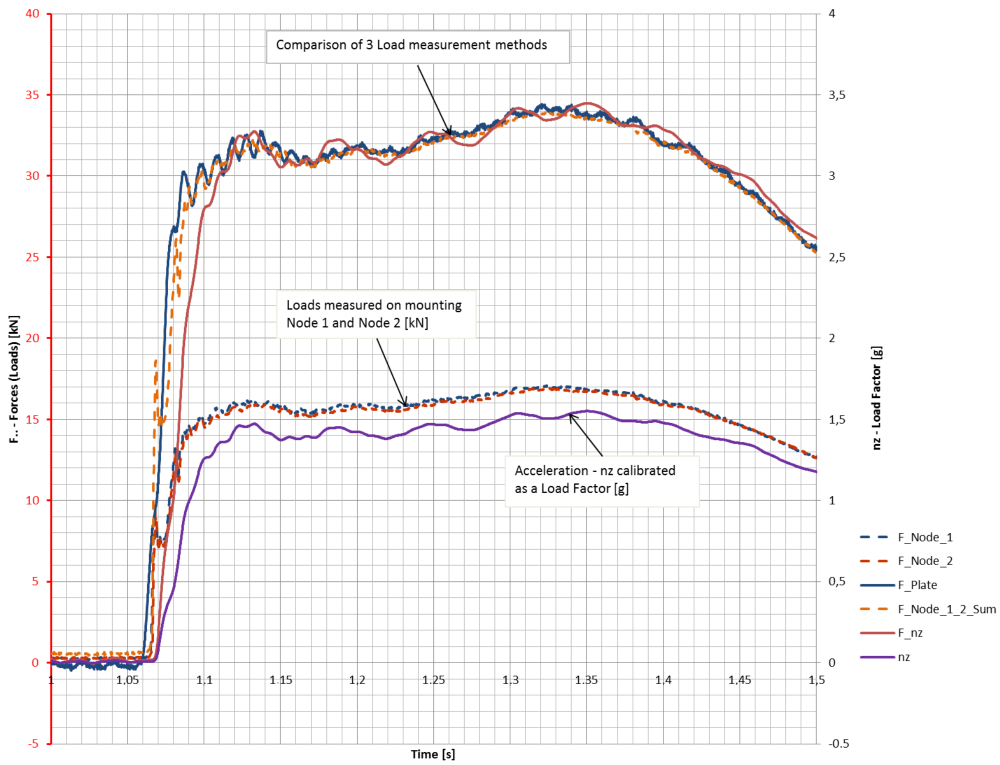

Fig. 6. Dynamic Drop Test results comparison (where F_node_X – force in mounting node, F_Plate – force measured by the ground plate, F_nz – force calculated from acceleration measurement, nz – acceleration measurement), source: ILot

measurement as standalone force/load measurement should be calibrated along with the force transducer in order to minimalize the measurement errors. If there is no possibility of doing so, placement of accelerometer should be preceded by precise test stand and landing gear mechanical design analysis.

All of the tests and analysis described in this article were performed in the Landing Gear Laboratory of Institute of Aviation in Warsaw (one of the few independent laboratories performing Landing Gear tests, optimization and scientific research in EU), Poland where the author works on daily basis.

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