INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

SELECTION OF DYNAMICS CHARAKTERISTICS FOR LANDING GEAR WITH THE USE OF NUMERICAL MODEL

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Keywords: Landing gear, numerical model, FEM, static and dynamic analysis

1. Introduction

Despite the amazing development of computer capabilities in recent years, it is still very difficult and expensive to create a model off overall aircraft structure. Usually less precise global model is used for preliminary analysis. More detailed analysis is conducted for extreme loaded units. Such a unit is landing gear. The primary purpose of the landing gear units is to absorb the impact energy of the aircraft when it lands and taxes. Landing is the most dangerous phase of aircraft flight. Therefore landing gear design comprises very difficult and responsible unit of overall project. This unit has to sustain appropriate strength to guarantee safety and fatigue life that assures the number of takeoff-lands prescribed in the technical specification.

Each type of aircraft needs a unique landing gear with a specific structural system, which can complete demands described by unique characteristics associated with each aircraft, i.e., geometry, weight, and mission requirements. They determine the design and positioning of the landing gear.

In the paper considerations are made for a tricycle landing gear, which belongs to a small transport aircraft with maximum take-off weight of 7000kg and landing weight of 6500kg. This aircraft is able to land on a grassy runway.

In general the landing gear can be divided according to four categories: load character, positioning of shock absorber and fork, attachment of wheel to fork character, positioning of wheel and fork. Each landing gear unit consists of: axle, shock absorber, fork and torque arm.

During landing of such a plane the main gear touches down on two points at first and then, after several seconds, the tire of the nose gear touches ground. The ground reaction acting on the landing gear is transmitted on the structure. When the aircraft lands, the force of impact is transmitted from the tyre to the axle. The first component compresses and the second bends the fork.

The paper discusses the methods used to the static analysis and presents a model, which allows determining the dynamics characteristics of the landing gear. The dynamic analysis is very important from the point of view of proper work of the landing gear. Appearing of the shimmy vibration during the take off can cause collapse of the aircraft. The numerical model of landing gear proposed by authors bases on a mathematical model which was applied to obtain dynamic characteristic of chosen parts of the unit. The analysis presented in this paper is the first part of wider considerations concerning numerical assessment of landing gear life.

2. Landing gear loading characteristics

A landing gear with a specific structural system is made for each type of aircraft. In general, the landing gear can be divided according to four categories: load character, positioning of shock absorber

and fork, attachment of wheel to fork character, positioning of wheel and fork. Each landing gear unit falls into: axle, shock absorber, fork, and torque arm.
Usually, at first the main gear touches down on two points. After several seconds the tire of the nose gear touches ground for aircraft with tricycle landing gear. The ground reaction acting on the landing gear is transmitted on the structure in the way described below. The internal loads acting on landing gear component are represented graphically on Figure 1.
When the aircraft lands, the force of impact is transmitted from the tire to the axle. This force consists of two components P_1 and P_2 . The first component P_1 compresses and the second P_2 bends the fork. Maximum bending moment will be close to the articulation-joining fork and strut. Only tension force acts on the torque arm.

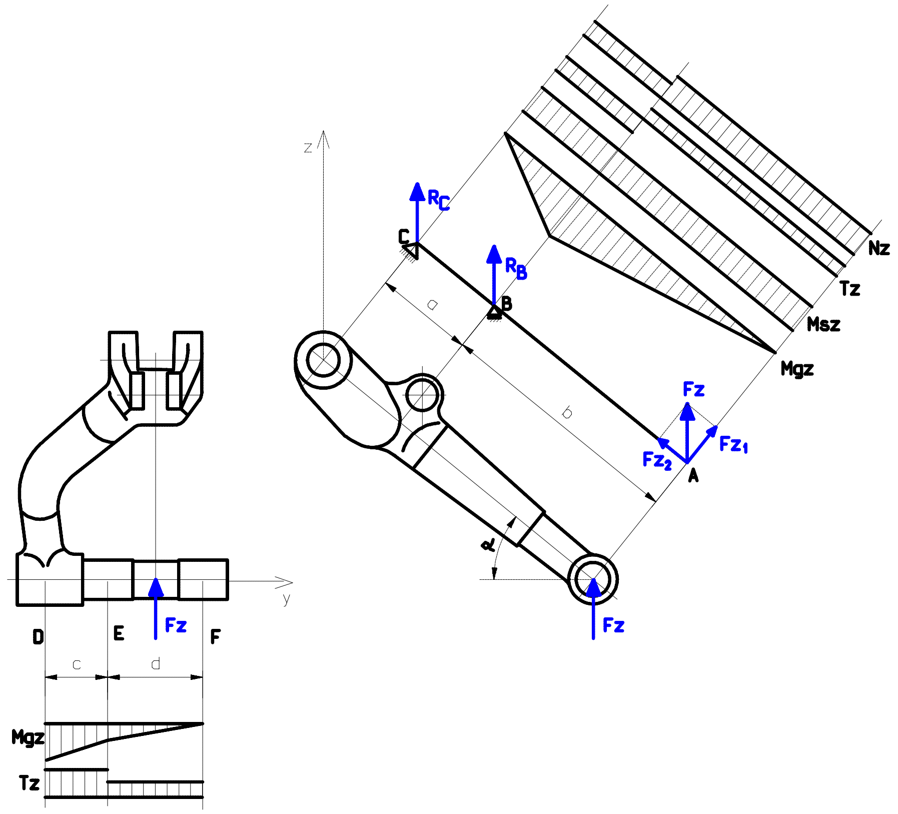

Figure 1. Half fork landing gear external load

The primary purpose of the landing gear units is to absorb the impact energy of the aircraft when it lands and taxes. The unique characteristics associated with each aircraft, i.e., geometry, weight, and mission requirements determine the design and positioning of the landing gear. Values of safe and failure loads are determining base upon FAR23 [FAR–23, 1966]. These values are used in the static analysis to check conducting landing gear safety factors. A load spectrum for given aircraft type, used to fatigue analysis and service life determination, for a given aircraft type is obtained experimentally or from aviation regulations. Drop test to limit loads was the base of determining the loads in the described case. Typical time course of measurement parameters during drops is shown in Figure 2.

3. Numerical analysis

3.1 Static calculations

The first step performed calculations of landing gear was performed in static conditions basing at values of forces presented on Figure 2. The scheme of half fork landing gear and results (distribution of reduced stresses) from this type of analysis are presented on Figure 3. During FEM calculations reduced load was applied to the node in the centre of one trunnion. Rigid elements were applied to carry out interaction of the outer cylinder of shock absorber axle and the fork. The maximum reduced stresses occurred in the region at the curve point of fork and predicted 779MPa (Figure 3a) for half fork landing gear.

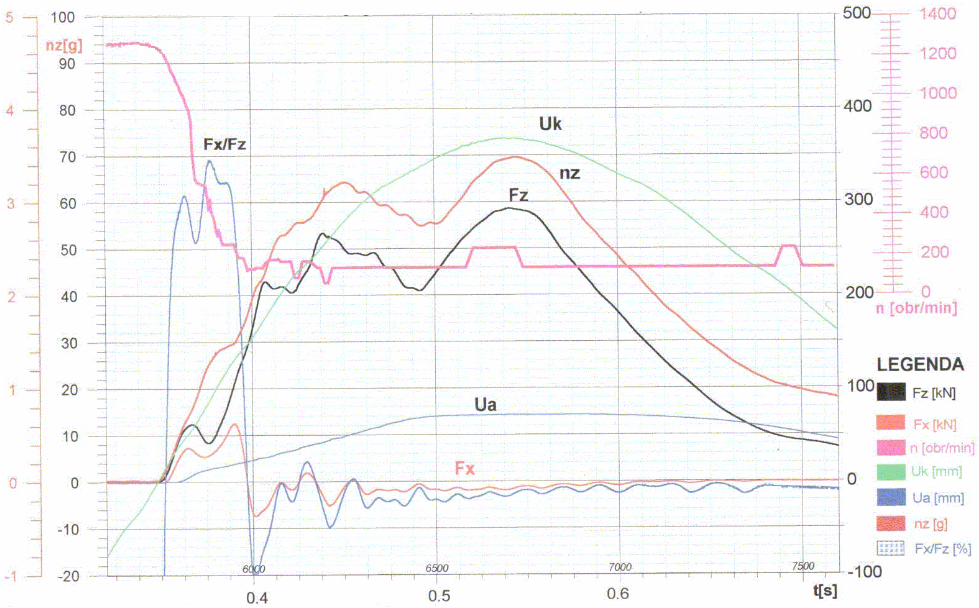

Figure 2. Dynamical characteristic of landing gear

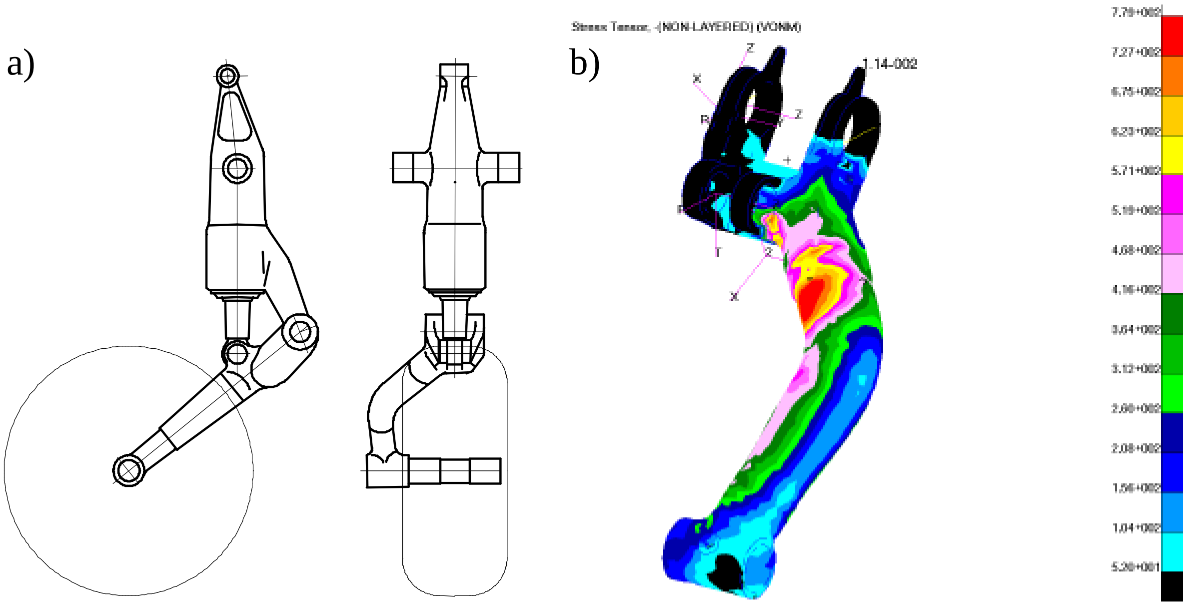

Figure 3. a) Half fork landing gear schema and b) distribution of reduced stresses

3.2 Dynamic calculations

Regulations concerning manufacture of aviation equipment require presenting a proof of the landing gear's resistance to shimmy vibrations before issuing a flight permit [Far-23,1966]. It is assumed in practice that positive results of laboratory tests and the prototype's ground tests are proof enough. Ground tests are conducted on the prototype of a plane. The complete set of laboratory and ground tests is proof enough of the landing gear's resistance to self-induced shimmy vibrations. However, the landing gear's prototype and costly tests are required. An optimal solution is to select the damping characteristic at design stage and limiting the tests only to evidential ones. It can be achieved thanks to a mathematical description of the phenomenon, as described below. The best solution to this problem is the numeric one. Shown below are all equations of motion and knots dealing with vibrations.

$$V^2\left(I_y \frac{d^2y}{ds^2} + I_{yz}\frac{d^2q}{ds^2} + \frac{i}{r}\frac{dq}{ds} \right) + ky = N \cos d\left(l - s\, l - r \cos d\right)y + \\ + N\left(h \cos d - s\, l \sin d - r \sin d \cos d\right)q + \left(al + s\, N \cos d\right) l - \left(b \sin d\right) f \tag{1}$$

$$V^2\left(I_{yz} \frac{d^2y}{ds^2} + I_z\frac{d^2q}{ds^2} + \frac{i}{r}\frac{dq}{ds} y \right) + M_{tl} = N \cos d\left(h - s\, h - r \sin d\right)y + \\ + N \sin d \left(h - s\, h - r \sin d\right)q + \left(a\, h + s\, N \sin d\right) l + \left(b \cos d\right) f \tag{2}$$

$$\frac{d}{ds}(l y + h q + l) = y \sin d - q \cos - j \tag{3}$$

$$\frac{d}{ds}(-y \sin d + q \cos d + j) = a l - b j + g (y \cos d + q \sin d) \tag{4}$$

Where V- progressive velocity of the plane, I – moments of inertia of a gear landing parts, α β γ – kinematics parameters of a tyre, λ φ χ – elastic parameters of a tyre, a b r h l ψ θ δ – geometric parameters of a landing gear, σ ρ – constants parameters from a test, N – normal force, Mtl – moments of a damping, k – stiffness of axle.

Presented equations are both universal and apply to each gear tested. It's necessary to formulate extra equations for each gear separately to describe a kinematics of a vibration damper.

The tests for self-induced shimmy vibrations resistance were applied to a new front landing gear of a transport aircraft (Figure 4). The gear is equipped with a hydraulic steering system that may be disconnected by the pilot. After disconnecting, the system can function as vibration damper and the landing gear becomes self-adjustable.

The full system of equations mentioned above was used for the numeric solution of the problem using computer programs. The remaining programs to the numeric solution were developed in Fortran by the authors.

One of the major objectives of this paper is the comparison between tests results and the numeric solution.

4. Summary and conclusions

In the paper, the numerical analysis of transport aircraft's landing gear was shown. The analysis presented in the first part of the paper is the first stage of larger considerations concerning numerical assessment of landing gear life. Determination of maximum landing gear service load was defined as a starting point of this programme. This was carried out by drop tests. Static stress analysis of line element FEM models were used to choose the most loaded components of landing gear. Further analysis was conducted for solid models of fork. The results of the stress analysis for those components identified as being subject to significant stresses are provided as part of the stress spectrum histories used in fatigue analysis. Values for elastic limit and tensile strength of applied materials were obtained through tests. If safety load is 1.5, value of stress as a function of safe load was assessed: σ = 1133MPa. Experiments have shown sufficient compatibility of calculation results and measurements. The differences are included in the 15% divergence, proving that applied models FEM are satisfactory.

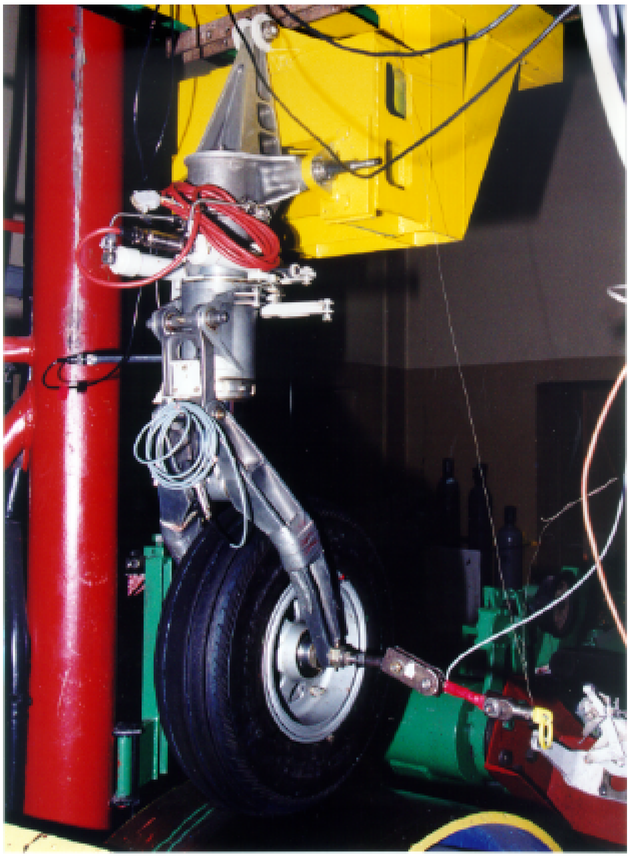

Figure 4. A gear landing during the test

In the second part of the paper numerical model is presented, which allow estimating some dynamics parameters. As the result of consecutive approximations, optimal landing gear's vibration damping was obtained. Such damping characteristic selection is time consuming and costly. It requires multiple assembling and disassembling of the damper and repeated tests under the same or similar conditions.

It was also shown that by means of numeric simulation, countermeasures against shimmy vibrations could be estimated at the design stage. However, the case of the apparent lack of influence of the damping characteristic on test results proves, that tests cannot be eliminated. The structure may contain hard to find "surprises" that will appear immediately in tests.

Construction of an analytical model of the shimmy phenomenon is actually quite simple. Two theories of tyre functioning were described [Clark,1974]. Both of them can be successfully applied to handling the shimmy problem as long as appropriate data, especially kinematics and rigidity parameters of the tyre used are available, what is of essential importance to the choice of the theory. It really is a serious problem. The laboratory of landing gear does not posses experimental stations for calculating all parameters. Therefore, the only reference is the literature [Clark,1974, Rogers, 1972, Horta,1999 and Pritchard,1999]. The paper also proves, that one should take advantage of the technological progress and analyze the structure by means of numeric simulation. It can also be handy for a better understanding of tests results on real objects. The analysis contributes to the optimization of the structure, concerning mass and strength criteria, thanks to the possibility of estimating loads to the structure. A properly conducted numeric analysis can shorten the test period significantly, limiting its range only to the probative tests, required for the landing gear's utilization permit to be issued. Therefore the costs of applying of new construction to exploitation are cut down. It is important to notice that owing to the progress in computer technology, simulation times of a single run in the case of shimmy amounts from a few to tens seconds, depending on the computer power and gear and tyre parameters, damping characteristic and initial conditions.

Numeric analysis at project stage will enable to specify the direction of structural changes to optimize the structure (e.g. load minimization). Thanks to numeric analysis it will be possible to evaluate the sensitivity of resistance of the structure at change of parameters [Morrison,1997]. For example, during utilization of the landing gear, tyre pressure may vary from nominal. In the case of a damaged tyre, the pressure may drop to environment pressure level. Because of the tyre getting hot or cold significant deviations from nominal pressure may occur. One may conduct tests of this parameters influence to the landing gear's resistance to self induced-vibrations. Numeric analysis is simpler and cheaper because we can indicate structural changes that will minimize pressure influence to movement stability.

In most of the structures the pilot may choose between steerable and self-adjustable landing gear. Then, a conflict between stability and steer ability requirements occurs. A stable gear may be hard to steer and vice versa, steer able gear may not be stable enough. Numeric analysis of stability which is the topic of this paper in connection with analysis of steer ability will enable to find a compromise at simultaneous optimization of loads and optimization of weight following, what is a basic requirement in aviation design.

To sum up – implementing the results of this paper to practice will allow to develop optimal structure, meeting all regulations and utilization requirements cheaper and faster.

Acknowledgements

This work was supported by the Polish Committee for Scientific Research under grants: 0T00A01417, 0T00B02421.

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