NUMERICAL TESTING OF LANDING GEAR SYSTEM FOR DIFFERENT DROP VELOCITIES

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Abstract

The FEM model of the landing gear was developed to determine efforts of individual structural members while simulating the landing-gear drop, and to investigate how the energy of such a system changes; also, to find what kinds of deformations occur in individual components, and to investigate into the effectiveness of the damping system. In the developed numerical model of the landing gear account was taken also of the support-wheel-related subassembly, which includes such elements as: the wheel pin, the wheel rim, and the tyre. All parts of this subassembly, belt in the tyre excluded, were represented with the flexible hexagonal elements. Results of numerical analyses for some selected drop tests and results from experiments carried out on a real landing gear confirm high quality of results gained from the dynamic simulation in the model of a complete landing-gear configuration. The advantage of the presented numerical method is applicability thereof to landing gear testing for the very wide range of drop velocities, what is impossible to be performed with other methods, including experimental testing work. Paper show the geometric model of the main landing gear, a discrete model with the shock-absorber model included, the fringe of the landing gear deformation at the final stage of touchdown phase respectively from experimental and numerical tests and the maps of maximum principal stresses and how they change within the area of the welded joint that connects the upper and lower levers of the main landing gear.

Keywords: *landing gear, numerical simulations, drop velocities, touchdown*

1. Introduction

The majority of mechanisms contain elements that move on relatively long distances or/and with relatively high speeds (linear or angular). That is why, modern engineers should add to their previous tasks (describing a project with values of geometric, dynamic and material parameters) a brand new one: simulating the behaviour of the machine that is currently designed. Numerical movement analysis should be examined already at the early stage of the product lifecycle, which is the design process. Numerical simulations are helpful in detecting all dangerous mechanisms conditions, what increases the safety and reliability of the maintenance process. The role of the aircraft undercarriage front gear (except being one of fulcrums) is to enable the pilot to maneuver the aircraft on the airfield, because of the capability of turning the front wheel (or wheels) on the surface [2, 8, 11]. The primary purpose of the landing gear units is to absorb the impact energy of the aircraft when it lands and takes off [1, 2]. 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. Majority of the fatigue numerical analysis and prediction of the landing gear's lifetime is limited to the linear analysis and the local phenomena appearing around a failure [5, 7, 9]

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. 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.

In the paper considerations are performed for a tricycle landing gear, which belongs to a small transport aircraft with maximum take-off/landing weight of 7500kg [6]. This aircraft is able to land on a grassy runway.

2. FE model details of a complete landing gear

A geometric model of a complete landing gear shown in Fig. 1 has been used to generate a totally deformable discrete FE model (Fig. 2) to investigate into the dynamics of the landing gear of a transport aircraft. What has been defined for individual solids of the geometric model, which represent particular sections of the landing gear, are the FE meshes, models of materials, and respective types and properties of finite elements that represent the modelled sub-assemblies. The sub-assemblies given consideration have been featured with materials characteristics that most often correspond with two materials: the 30HGSNA and the 30HGSA steels. Both kinds of steel are used in highly-loaded structures, e.g. in aviation. Mechanical parameters of the steel have been assumed using the following standards: PN-69/H-94010 and PN-72/H-84035 for the 30HGSNA steel and PN-89/H-84030 for the 30HGSA steel. Characteristics of the material used in the numerical model of a tyre of the main landing gear wheel correspond with those of a physical model of the BARUMTECH tyre of the following dimensions: 720 × 310, Model Y Tubeless – with the tyre pressure P_{op} = 0.55 MPa. For finite elements that describe the rubber of the tyre, the Mooney-Rivlin material model has been adopted [3, 4]. This model of the tyre-rubber material allows of gaining correct results within the range of large displacements and deformations.

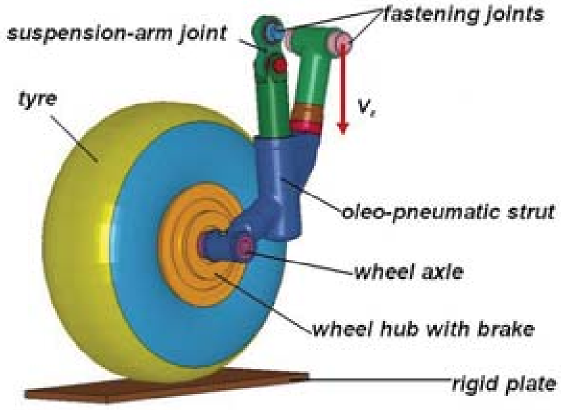

Fig. 1. The geometric model of the main landing gear

Solid elements of the HEX8 type have been used to model the following structural members of the landing gear: the lower and upper levers of the landing-gear strut, the suspension-arm joint with cup-and-ball joint assemblies – bearing races and pins, the piston rod of the shock absorber with rings and the stem fastening it onto the suspension-arm joint, the shock-absorber's sleeve, the wheel axle with a pin fastening it to the strut's lever, the landing-gear wheel hub, the brake stator and rotor discs, and the tyre (Fig. 2).

The model of a complete landing gear comprises 73146 finite elements of the HEX8 type. The complete model of the landing gear with the wheel included comprises 98009 nodes, 2760 surface elements of the QUAD4 type, and 120 MPC elements. Surface elements have been used to correctly describe the inner surface of the tyre. The elastic-and-damping system of the shock absorber has been replaced in the considered discrete model of the landing gear with a set of 40 elements of springs and dampers of linear characteristics [4, 11]. The set of 40 elastic elements and

40 damping elements have been joined directly to the nodes on the edges of additional rigid rings modelled between the cross-section of the bottom of the lower lever of the landing gear and that of the shock-absorber's end face. For each elastic element the same rigidity $K_{n=40}$ = 10.75 *N/mm* has been defined. On the other hand, for each damping element the same value of the viscotic damping $C_{n=40}$ = 2.65 Ns/mm has been defined. Fig. 2 illustrates implementation of the elements in the 3D model.

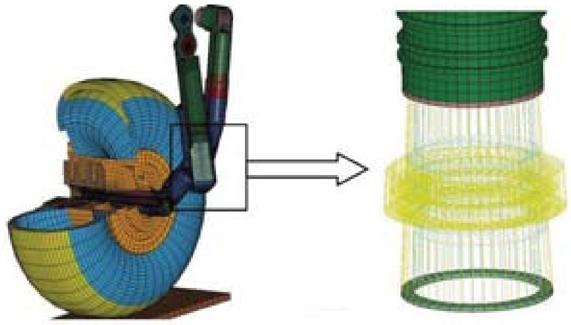

Fig. 2. A discrete model with the shock-absorber model included

In fact, reflected here in the 3D model particular structural members of the landing gear system keep mating to transmit loads through contacting one another. The mapping of the correct mating of the system's members in question requires that appropriate regions of contact are mapped in the numerical model. Twelve couples in contact that include surfaces of some structural members of the landing gear have been defined in the model. These are as follows: the wheel hub and the brake stator – two contact areas, the wheel axle and the bearing races of the wheel hub – three contact areas, the piston rod of the shock absorber and rings and the cylinder sleeve of the lever – four contact areas, the bearing races and pins of the cup-and-ball joint assemblies – two contact areas, and the upper lever of the strut and the fixing sleeve – one contact area.

3. Numerical tests description

The instance of the landing gear drop from some specific height, i.e. the case given consideration in the paper, was carried out under laboratory conditions on the drop–weight testing machine [6]. This corresponds to the touchdown when an aircraft lands on the tricycle landing gear, i.e. the nose wheel and the main gear, and the loads effected by the ground/pavement response are distributed on the nose wheel and both landing gear struts.

The objective of the numerical simulation in question was to define the dynamic characteristics of the landing gear, with the vertical-drop test represented (i.e. with no account taken of the forward speed). Numerical analyses were carried out to represent the drop test of the landing gear of an aircraft with the take-off/landing weight of 7500 kg. Numerical simulations of the touchdown were conducted for the parameters that corresponded with those typical of stand tests. They were as follows: m_r = 3325 kg – reduced mass that falls to the landing gear in question, equal to the weight, of all components of the dropped system, V_z = 1.74, 2.13 and 3.05 m/s – the tested rates of vertical descent of the aircraft at the moment of the tyre's touching the ground (Fig. 1), V_x = 0 m/s – the landing (horizontal) speed of the aircraft, h = 231 mm – the model-drop height, α = 0 deg – the angle of pitch of a given plane of the aircraft against the ground, P_{am} = 5 [MPa] – pressure of filling the shock absorber and P_{op} = 0.55 [MPa] –pressure of filling the tyre.

The FE model of the complete landing gear was applied to define the effort of particular components of the structure during the drop simulation, to examine how the energy of such a system was changing, and deformations that occur in the particular components of the complete aircraft landing gear. It is impossible to record most of these quantities during the tests. What should be emphasized is that the numerically represented test corresponded with the real time interval of the touchdown, i.e. 0.2 s.

Boundary conditions that correspond to those applied in the numerical-test variant under accomplishment were introduced in the landing-gear model. External constraints in the form of fixed pivot bearings were introduced in the nodes that attach the landing gear to the aircraft fuselage structure (i.e. central nodes on side surfaces of the upper pin and the upper-lever sleeve – Fig. 3). What results from numerical tests is a series of data that describe the mating of particular landing-gear structural components in contact areas. It refers to both the kinematics and the dynamics of the structure under consideration.

At the initial stage of the tests given consideration, numerical tests were performed to simulate the drop tests of the structure with associated masses representing reduced mass of transport airplane. Calculations were performed using the so-called direct-integration procedure, colloquially called the 'explicit integration' [4].

4. Results and discussion

In the main gear's structure many locations have been observed where local stress concentrations could initiate fatigue cracking [6]. However, it should be emphasised that the 3D model in question is an ideal model, with no account taken of any failure at any stage. Fig. 3 shows the typical deformation of the total landing gear system (mostly visible in the tyre) which is reached at the final stage of the drop test.

Fig. 4 shows the maximum principal stresses histories and how they change in elements distinguished within the area of the welded joint that connects the upper and the lower levers of the main landing gear. The map of the effort gained from the above-mentioned simulation explicitly confirms that within the area of the welded joint, which connects the upper and lower levers of the examined landing gear, considerable local stress concentrations occur. These observations confirm results of tests conducted on a real object. It has proved that stand tests which consisted in the reproduction of a complete operational cycle have resulted in the landing-gear failure.

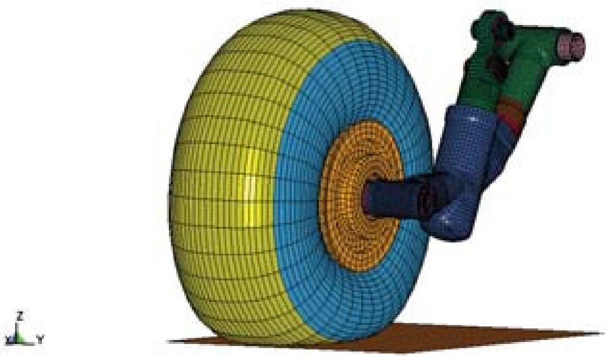

Fig. 3. The fringe of the landing gear deformation at the final stage of touchdown phase respectively from experimental [6] and numerical tests

The performance of elastic-and-damping elements, by means of which the landing-gear's shock absorber has been modelled, reaches the maximum value after approximately 0.18 s simulation. This observation has been confirmed with the analysis of the plot of the displacement of the shock-absorber's body against the cylinder's sleeve. The maximum value of the displacement of the shock-absorber's body against its cylinder's sleeve, found in the course of numerical simulation of the vertical drop of the main landing gear exposed to tests, has reached the value of 82 mm. The relative difference between the compared results does not exceed, therefore, 5% for drop test velocity V_z=2.13 m/s. The same high compatibility of numerical-analysis results and laboratory parameters of the drop test capable of recording has been also confirmed with the, e.g. reactive force recorded upon the drop-weight plate at the stage of touchdown. The maximum value of the vertical response recorded in a statical way (under the equivalent load that corresponds to the shock-absorber deflection of 82 mm) on the laboratory test stand has attained 39.5 kN. The maximum value of the vertical response found by means of numerical simulation of the drop has exceeded 45 kN. The compared values differ, therefore, by 12%, and only.

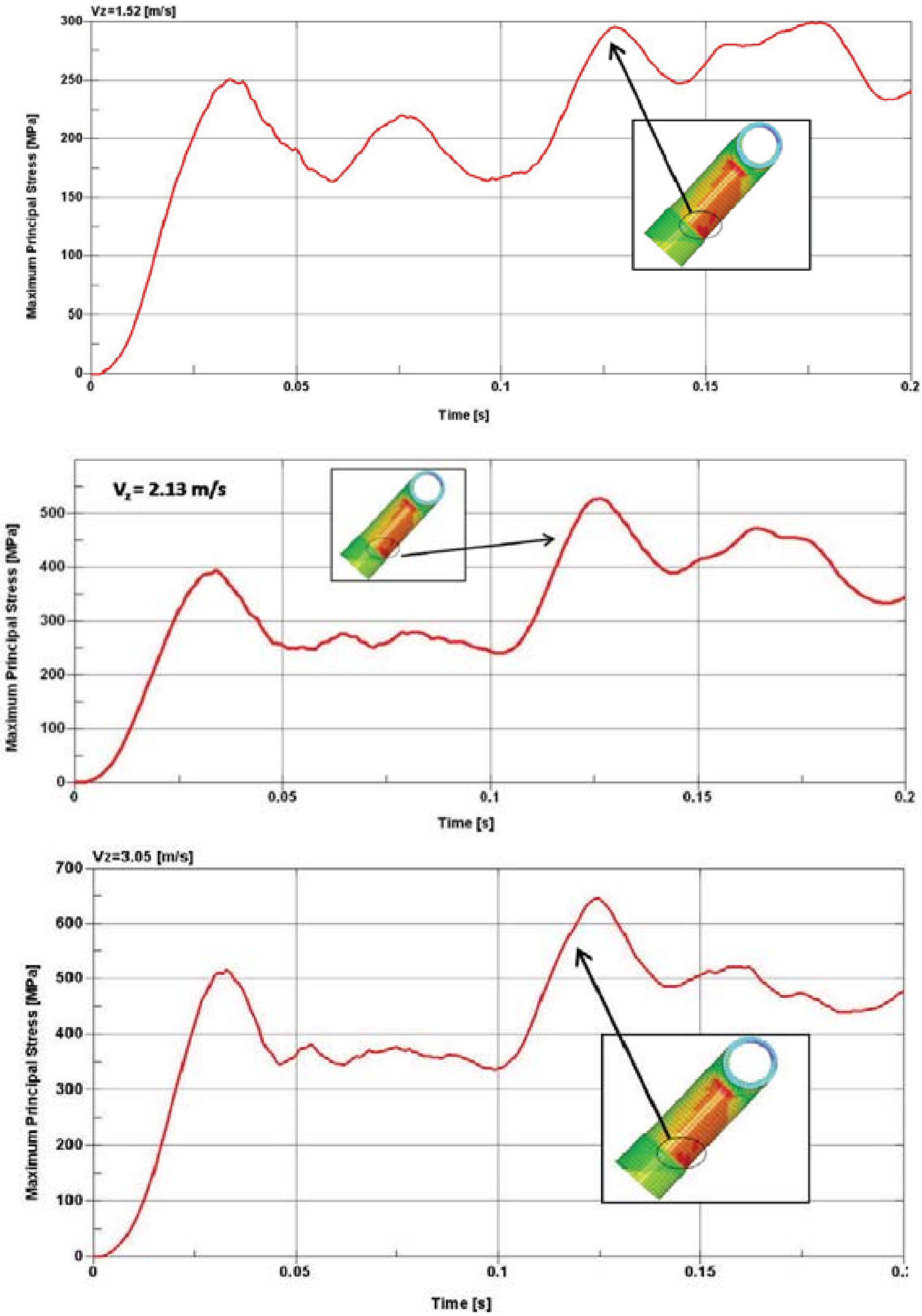

Fig. 4. The maps of maximum principal stresses and how they change within the area of the welded joint that connects the upper and lower levers of the main landing gear; the data recorded at the touchdown for three different drop velocities

5. Conclusions

The comparison of results obtained from numerical quasi-static and dynamic tests of the landing-gear structure has revealed numerous locations where stress concentrations could initiate, e.g. a crack in the material. Results of numerical analyses for some selected drop tests and results from experiments carried out on a real landing gear confirm high quality of results gained from the dynamic simulation in the model of a complete landing-gear configuration. Results of numerical analyses on how to represent different tests performed on a drop-weight testing machine will be used to generate a landing-gear model; operation-induced failures/damages to the system under consideration would be included.

Results gained from the simulation have proved how effective the 3D numerical model is and how many problems can be solved in the course of only one numerical run, e.g. the geometric and material non-linearities, the question of contact between mating components, investigation into kinematics of the landing gear, and investigation into the problem of dissipation (change) of energy in the whole system and the checking of possible failure influence on the structure behaviour, which can appear in some elements due to overload. The major advantage of the presented numerical method is applicability thereof to landing gear testing with artificially introduced flaws, what is impossible to be performed with other methods, including experimental testing work. This might include investigation into conditions hazardous to the operation of the landing gear. Furthermore, the method enables optimisation of values of some selected physical quantities of the landing-gear.

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