Dynamic Simulation of Transport Aircraft 3D Design Landing-Elastic Leg Shock Absorb ER Loads

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Global Journal of Computer Science and Technology (Special) Volume XIII Issue I Version I Year 2013

Abstract - **In the paper, dynamic simulation of landing impact of a large transport aircraft, based on a non-linear dynamical model that allows for touchdown analysis of an aircraft 3D landing is presented. The aircraft model is shaped as a multibody system with variable kinematical structure. The model includes discontinuous dynamics of the main landing gear shock absorber, tire dynamics and wheel spin-up effect. The aerodynamic loads are considered, too. Because of its great influence on an aircraft ground dynamical behavior and landing gear subparts loads determination, dynamical model of the main gear shock absorber is presented in more details. Based on the developed model, the touchdown impacts of a transport aircraft for different 3D flight-landing parameters (one gear landing cases) are simulated with the focus on the main gear shock absorbers loads determination.**

I. Introduction

During landing and taxi, a transport aircraft landing gear and parts of an airframe can be exposed to high dynamical loading. In the extreme situations even damages and loss of the stability of an airplane may be expected. Since during more common large airplane tail-down landing conditions all of dynamical loads are carried on the main gears first, dynamical characteristics of the main gear are of the most significant importance for the safe touchdown during which an airframe load factors should be kept in the prescribed range. However, when the most critical landing conditions and dynamic loads on the main gear are being determined, the simplifications are often made: an airplane aerodynamic loads are oversimplified, aircraft pitching and rolling motion are neglected or tire dynamics and wheel spin-up forces are not taken into consideration. Although the basic characteristics of a landing aircraft dynamical response can be determined by simplified linear dynamic analysis, the more accurate time simulation or determination of subsystems dynamical loads

Require full-scale nonlinear multibody approach. In the paper, an aircraft multibody model that allows for dynamic simulation of an aircraft landing cases as well as determination of the main gear dynamical loads is shortly described. The model includes aircraft aerodynamic loads, discontinuous dynamics of a shock absorber oleo-pneumatic element and an aircraft tire dynamics including wheel spin-up effect. Because of its great influence on aircraft ground dynamical behavior and landing gear subparts loads determination, dynamical model of the main gear shock absorber is presented in more details. Based on the developed model, the touchdown impacts of a transport aircraft for different 3D flight-landing parameters are simulated with the focus on the main gear shock absorbers loads determination.

II. System Study

a) Landing Aircraft Dynamical Model

i. *Multibody Dynamical Model*

The aircraft dynamical model that allows for non-linear dynamic simulation of 3D landing and taxi is designed as a multibody system with variable kinematical structure. The model comprises aircraft main body, a main landing gear consisting of two elastic legs with an upper part (the upper part of shock absorber + additional masses) and a lower par (the lower part of shock absorber + wheel and tire + additional masses) and nose landing gear consisting of two parts of the same structure. The upper part and lower part of landing gear is connected *via* non-linear force coupler, modeled according to the shock absorber dynamical characteristics. Another non-linear force coupler is added to model aircraft tire dynamics. The aircraft global multibody system and part of shock absorber assembly is depicted in Figure 1. Basically, global model possess 12 spatial degrees of freedom (DOF). During kinematical modeling it is assumed that landing gear elastic legs stay in upright vertical position and do not change their orientation during landing.

The designed model allows for dynamic simulation of an aircraft three-dimensional landing situations such as one-gear landing case, which may happen during lateral wind landing conditions.

ii. *Aircraft tire dynamics*

It is assumed that the main gear is equipped with the four tires of the conventional type, which are in use in the modern transport aviation. Mechanical properties of tires are estimated after and manufacturer data. The applied tire dynamical model considers its

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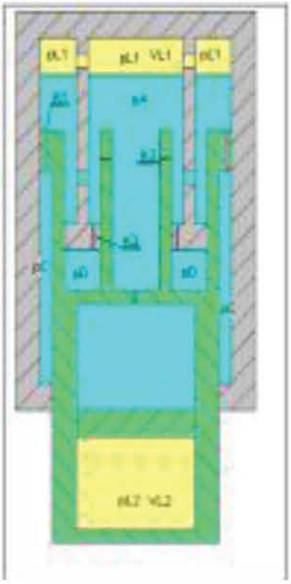
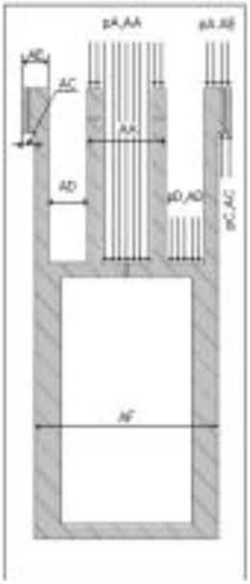
dynamical behavior (inertia effects, centrifugal growth of tire radius, side loads), but hysteresis effects is neglected for this type of simulations. A calculation of the tire contact dynamics spin-up force is based on tire variable slip-friction characteristics and a slippage factor defined according. It is assumed (and verified by the simulation results) that tire-bottoming deflections will not occur during analyzed motion.

III. System Environment

a) Landing Gear Shock Absorber

Most commonly, a telescopic main landing gear of a transport aircraft comprises a shock absorber of oleo-pneumatic type. Considering a contemporary design, it is a several stage unit and contains four chambers: a first-stage oleo-pneumatic chamber containing low pressure gas and hydraulic fluid, a recoil chamber and compression chamber containing hydraulic fluid and a second-stage pneumatic chamber that contains high pressure gas (nitrogen). The floating piston in the second-stage cylinder separates hydraulic fluid and high pressured nitrogen. During a compression stroke, the floating piston does not become active until the gas pressures of the first-stage and second-stage chambers are equal, which happens during system increased dynamical loading. Dynamical characteristics of the shock absorber are strongly influenced by the system of orifices that controls a hydraulic flow and by means of which net hydraulic resistance can be tuned. Considering different possibilities of the activation of floating piston and orifices as the absorber closes, it can be shown that four operation stages can be identified during the Compression stroke. During return stroke, primary control of the shock absorber recoil consists of the fluid flow from the recoil chamber into the oleo-pneumatic chamber and from the oleo-pneumatic chamber to the compression chamber. To prevent unit (and airplane!) excessive rebound, the orifices hydraulic resistance increases significantly during the absorber recoil stroke.



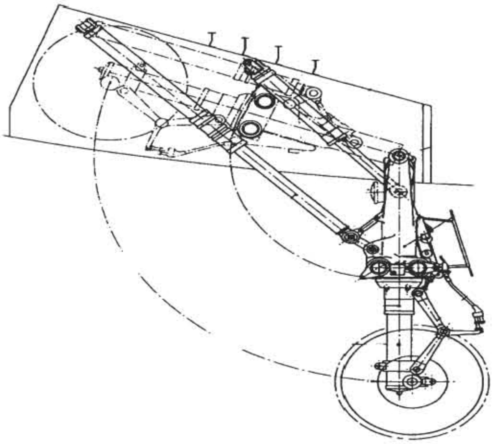


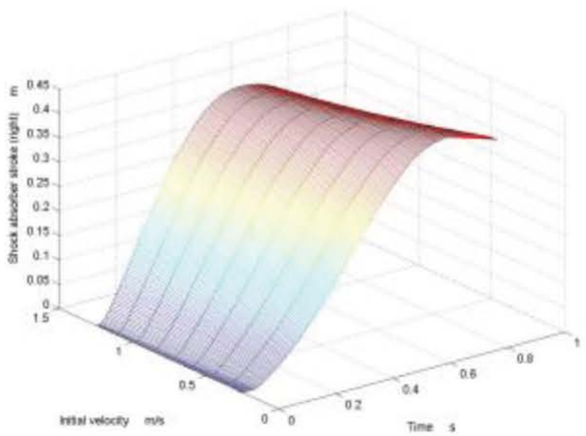
b) Mathematical Model

Since mechanical properties of the landing gear shock absorber are mainly determined by the pneumatic spring force and oleo (hydraulic) damping force, dynamical model of the absorber are presented in the overall multibody system as a force coupling element (highly non-linear!) consisting of these terms. All mechanical characteristics and geometrical data (AA, AC, AD etc.,), needed to establish the model mathematical relations, are assumed according to. The cylinder piston stick-slip friction phenomenon, the floating piston inertia effect and internal seal friction are neglected in the absorber dynamical model presented here.

c) Pneumatic spring force

Depending on the unit operation stage, the pneumatic spring force is determined by the initial inflation pressure in two nitrogen chambers and by the change of volume of the shock absorber (a unit current kinematical configuration). During modeling, it is assumed instantaneous gas compression ratio in accordance with the polytrophic law for compression. Since absorber high rate of compression is to occur during landing impact, the polytrophic exponential term is chosen as $n = 1.3$ during modeling of all internal processes. Having considered geometrical determinations of the gas chambers (volumes *VL1, VL2*) in dependence of unit kinematical configuration and after determination of initial gas inflation pressure, the net pneumatic force is expressed as a non-linear function of shock absorber stroke.





d) Hydraulic damping force

The hydraulic damping force results from the pressure difference associated with the flow through the system of orifices. It is assumed that jet velocities and Reynolds numbers are sufficiently large that the flow is fully turbulent (the orifice area is small in relation to the absorber diameter). As a result, the net damping force is expressed as a square function of the stroke velocity. Since during the compression stroke some orifices become active/inactive (orifices *K3* change their position as the absorber closes), the net hydraulic damping force is modeled via two stage discontinuous function of the absorber stroke velocity. Orifice hydraulic resistance damping coefficients *K1, K2, K3* (Figure 2) are estimated on the basis of orifice geometry and hydraulic fluid density according to. Prior to dynamic simulations of landing aircraft, the dynamical model of shock absorber has been validated by numerical dynamical simulations of landing gear drop test.

e) Landing Impact Shock Absorber Forces

On the basis of the presented aircraft dynamical model, the landing impact dynamic simulations were performed for different initial descent velocities in the range from

$$v\,z1 = 0.25\text{ms-1 to } vz1 = 1.25\text{ms -} \qquad (1)$$

The instant of touchdown of the elastic leg that comes first to the contact with the ground (right elastic leg) is chosen as simulation initial moment. A mass of the aircraft is assumed as 64500 kg and the horizontal velocity equals $v1$ = 67.5 ms-1 . The initial aircraft pitch and roll angles are 10o and 3o respectively, while the aircraft pitching and rolling velocity at the instant of touchdown is assumed to be approximately zero. It should be noted that landing impacts with the indicated touchdown parameters should not represent demanding landing cases for a modern transport airplane.

IV. RELATED WORK

a) Landing Gear Requirements

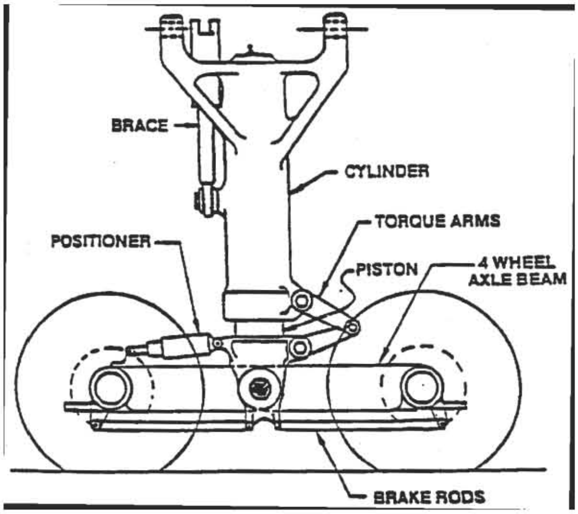
Aircraft landing gears fulfill the tasks of absorbing the vertical energy of the touch-down as well as providing a smooth ground ride before take-off and after landing. However, they perform a number of further duties which are less evident. Jenkins and Young have given a detailed presentation of these requirements which are summarized in.

The most important factors influencing the landing gear design are described in the following paragraphs. System weight is an important aspect in aircraft development. A subsequent major reduction in landing gear weight will be hard to realize because the landing gears are one of the few non-redundant load-paths in an aircraft, and any reduction in reliability from current fail-safe standards is not acceptable. Considering the progress in aircraft light-weight structural design and fuel efficiency the relative weight share of the landing gears can thus be expected to increase further. The position of the landing gears must be such that the aircraft will not tip over under static and tires depends on aircraft weight, maximum force per tire and maximum tire size, and is dictated by pavement bearing strength which may vary from airport to airport. Large civil transport aircraft as the A340, Boeing 747 and MD 11 reach loads of over 20 tons per tire on the main landing gears. During flight the landing gears of practically all modern transport aircraft are retracted. This requires restrictions on the landing gear positioning as these parts have to be stored in a limited space and must not collide with other systems. For this reason, landing gears often possess complicated kinematical layouts of the retraction mechanism for the storage in nacelles in wings and fuselage. Landing gears are usually retracted to the front so they can be released in case of a hydraulic failure and being pushed into position by the air flow, since landing gears have to carry the aircraft weight and have to absorb the energy of the landing impact, the fuselage has to be strengthened in the vicinity of the attachment points. Load alleviation is therefore also of importance for the dimensioning of the fuselage, especially at the attachment points and at the rear of the aircraft. For aircraft with a high maximum landing weight the bending moment resulting from the landing impact is often the critical design case for the rear fuselage. Therefore, comfort improvements obtained by the application of the results of this study must not result in higher attachment loads. Other load cases besides touch-down and rolling are also of great importance. On many airports aircraft are towed, either by push-rods or by special trucks. Cornering exerts high lateral loads on the landing gears.

These factors often lead to higher forces than those obtained at touch-down, especially in lateral and horizontal directions, and have to be taken into consideration as design loads. All requirements mentioned so far have to be met with a system that is one of the few aircraft parts which have no redundancies. And, as airlines look as well at acquisition costs as at DOCs (direct operational costs), the landing gear should be inexpensive and require minimum maintenance. The great number of requirements can only be fulfilled if comprehensive trade-off studies concerning space availability, weight considerations, and structural (stress-) evaluations are performed. Since a large number of engineering disciplines are involved in the suspension development, an integrated design of airframe and landing gears is essential for modern aircraft.

b) Landing Gear Configurations

Landing gears have developed from the simple skids of the first aircraft into the sophisticated and rather complex systems they are today. Originally, the spring function of the suspensions consisted only of the leg elasticity or solid springs. In the years after the First World War the oleo-pneumatic shock absorber became popular because it provided high efficiency by combining the desired spring and damping characteristics in a relatively small unit. At that time, the landing gear configuration with two main landing gears and a tail wheel was common, the most prominent. In the thirties, the retractable landing gear was introduced for reasons of reduced aerodynamic drag.



Since the generation of aircraft of the fifties the landing gear configuration of large transport aircraft has remained principally the same - a steerable nose landing gear and two, or more, main landing gears, one of the earlier aircraft with landing gears of that type being the Lock-head L-1049G Super Constellation, Other possible landing gear systems include floaters, skids, skis, track-type gears, and air cushions. They are applied in specialized aircraft but have found no wide usage. The nose wheel tricycle landing gear configuration has some important advantages when compared to the tail wheel type gear. First, the fuselage is level when the aircraft is on the ground, increasing visibility for the pilot at take-off and at ground maneuvers. Second, the center of gravity is located in front of the main landing gears which leads to a pitching moment of the aircraft at touch-down, automatically reducing lift. Furthermore, the aircraft is stabilized and the pilot can utilize the full brake power. On the other hand, aircraft with tail-wheel landing gear types have an initial angle of attack, allowing a shorter take-off distance. A major disadvantage of the conventional landing gear layout, though, is the fact that the requirements mentioned in section 2.1.1 restrict the designer's choice of landing gear location and layout. With aircraft becoming larger and the number of main landing gears increasing to three or even four, substantial limitations in the designer's freedom occur. The available envelope within which the landing gear has to be located to produce the ideal loading and stability characteristics may no longer be large enough to place the increased number of main landing gears in the fuselage and the wings. A good example is the A380 where the accommodation of four main gears with four- and six-wheel-bogies poses a demanding design challenge.

V. Conclusion

As result of performed dynamic simulations, a time evolution of the shock absorber stroke and total force in the left and right elastic leg during analyzed landing cases are presented in. Dynamic simulation results are presented for different initial descent velocities. It is evident that time diagrams of the shock absorbers' stroke and total force evolution are almost flat immediately after the touchdown. This is due to the fact that, since the shock absorber pneumatics acts as a set-up spring, it is still not active during this period and the tire dynamics affects the overall system motion dominantly. This is more emphasized for the lower initial descent velocities, since for the landing cases with larger touchdown descent velocities the set-up value is quickly reached and damping hydraulic component builds up very fast after the impact, provoking thus a big gradient of the absorber total force soon after the moment of touchdown. Of course, left shock absorber values have an additional time delay due to the fact that left elastic leg comes to the contact with the ground later on during landing process, depending on the aircraft geometry and rolling motion. The discontinuities visible at the shock absorber total force characteristics are due to the orifices different working regime (inactive/active K3 orifices) and due to the change of the absorber's pneumatic force at the point where floating piston of the second-stage pneumatic cylinder becomes active. As it can be seen, during simulated landing impacts the absorber stroke time evolution is within a range≈of 0.35 m. Since it is to be expected that the absorber maximum stroke equals 0.45 m approximately, no upper-point cylinder-piston collision occurred during analyzed landing cases.

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