NUMERICAL ANALYSIS OF A FRONT SUPPORT LANDING GEAR DYNAMICS AS THE EXAMPLE OF CHOSEN MCAD AND CAE SYSTEMS INTEGRATION IN THE CASE OF THE MILITARY TRANSPORT AIRCRAFT DESIGN

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Abstract

The paper presents the example of MCAD and CAE environments integration in the case of the military transport aircraft front gear dynamic analysis. The gear exact MCAD model is presented with the manner of its simplification. Simplified model is physically similar to the exact one: results of numerical static analysis are the same in both cases. To ensure the credibility of the dynamic analysis, a model kinematics one took place - the gear configuration changed ("airborne" - "airfield") with the measurements of chosen values. Simulation was verified with the real experiment results. The gear drop test has been simulated with the measurement of the fall-down velocity and absorber displacement. By the progressive results comparison of digital and real experiments, the stiffness-dumping values were attached to the spring/dumper Lagrange elements that simulate the behavior of the absorber gas-oil mixture. The gear model shock sensitivity has been analysed by simulations of landing process with gear invasion through chosen airfield obstructions. Aircraft fall-down velocity can be safely increased by 30% and it can operate on slightly damaged concrete airfields and rough surfaces. The shimmy vibration model sensitivity took place. It is proved that such a phenomenon can't appear during the correct aircraft maintenance.

Key words: *CAD/CAE integration, aircraft landing gears, dynamics*

1. INTRODUCTION

There are many integrated CAD/CAE engineering systems available at the market today. The most powerful and robust are called "high-end" environments (e.g. UGS Unigraphics NX4), but they are relatively expensive and – for the sake of their tools multitude – quite complex.

That is why in the case of majority industrial and educational enterprises, a bit less complicated computer systems are preferred. They are called "mid-range" ones and mostly exist as separate CAD and CAE environments. However, contemporary "mid-range" CAD solutions offer some CAE tools, but they enable only simple analysis in the limited range. Also "mid-range" CAE systems are equipped with CAD capabilities, but they are relatively poor – i.e. do not allow feature modelling.

The solution to this problem is the exact integration of separate CAD and CAE systems that allows easy and associative data transfer: model geometry is accurately prepared in CAD environment and then is exported to the suitable CAE one. Then, the appropriate engineering analysis takes place with the required accuracy. The paper presents the example of separate "mid-range" CAD and CAE environments integration, in the case of the dynamics analysis of the front support landing gear, designed for the brand new version of the military transport aircraft.

Aforementioned systems are: UGS Solid Edge (CAD) and MSC.visualNastran4D (CAE).

2. Object of investigation

2.1. The accurate MCAD model

The object of investigation is the 3D MCAD model of the front support landing gear, being the part of the military transport aircraft. It is the single wheel and single cylinder gear, constantly fixed to the aircraft fuselage (Fig. 1). On the basis of the manufacturer's detail drawings and drafting documents – the accurate 3D model of the landing gear has been created with the MCAD UGS Solid Edge system (Fig. 2). The aforementioned model is the assembly of more than 320 parts grouped in 12 subassemblies. The most important physical properties measurements took place (e.g. values of mass, its centre location, moments of inertia, orientation of principal axes, inertia matrix etc.) for every part, subassembly and the top-level assembly.

Fig. 1. The real object, investigated with numerical tools

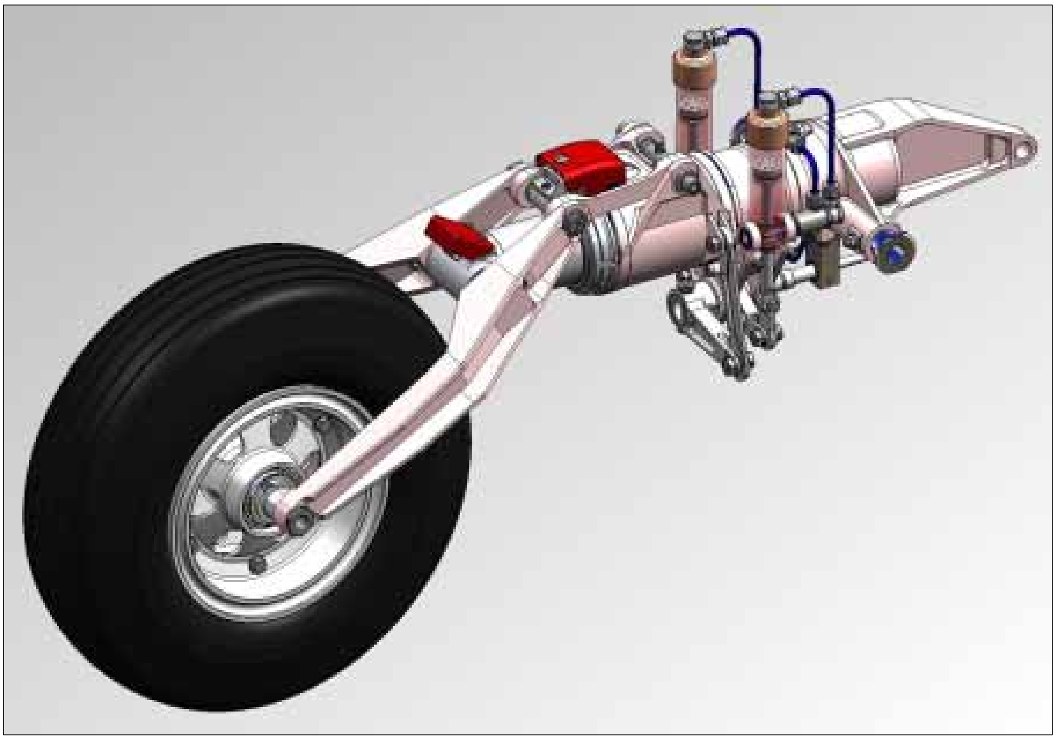

Fig. 2. The accurate 3D MCAD model of the military aircraft front support landing gear

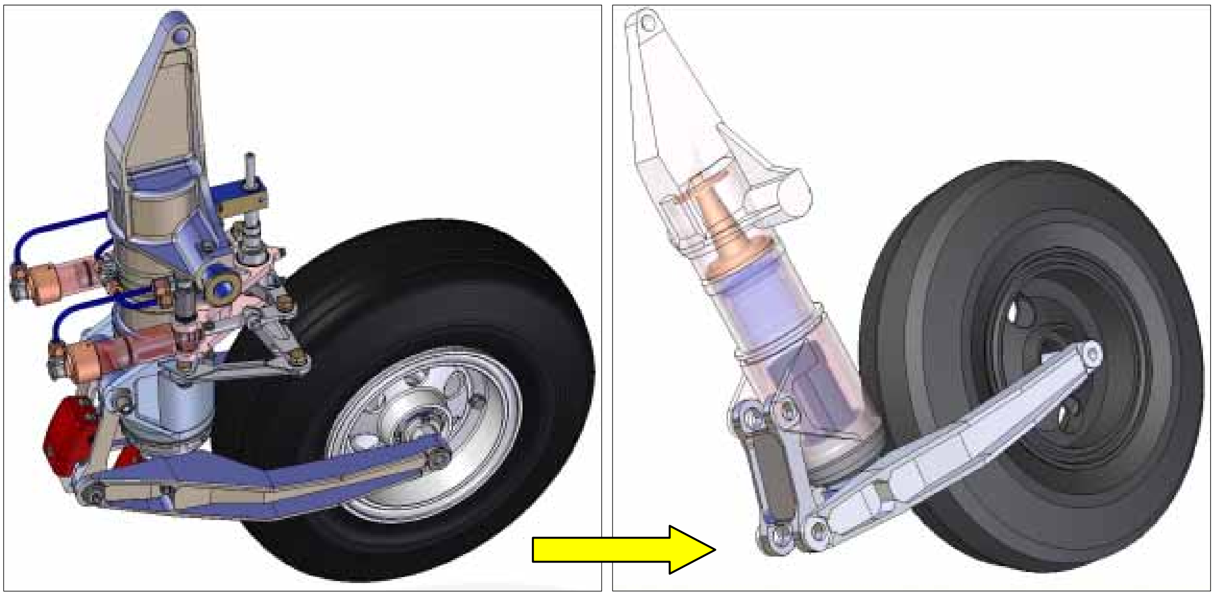

Fig. 3. The accurate MCAD model assembly simplification by non-important subassemblies deletion and replacing of important ones with simplified - geometry single parts

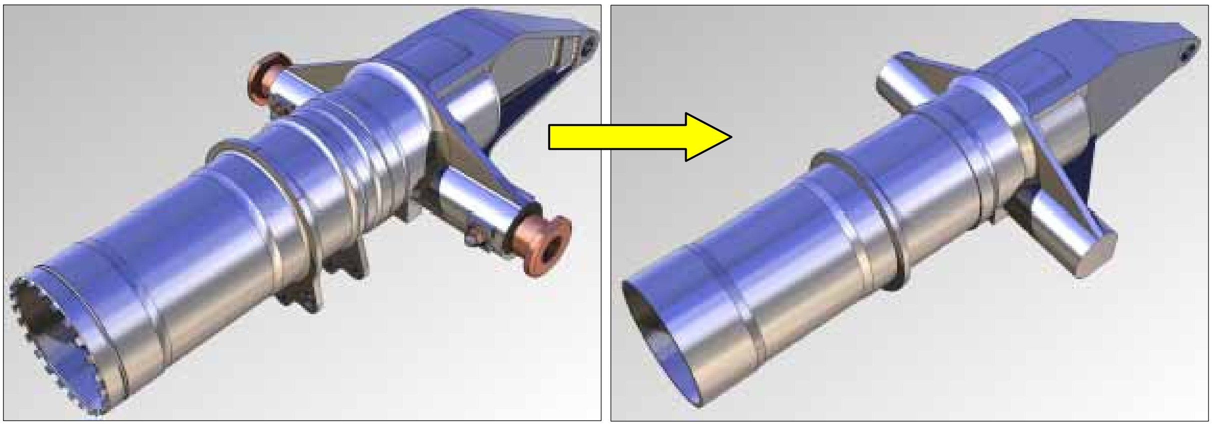

Fig. 4. A chosen subassembly (shock absorber cylinder) transformation into the simplified-geometry single part (design body)

The assembly is free to move with all degrees of freedom that can be found in the real front landing gear. It is claimed, the most important is the axial translation of the piston rod inside the shock absorber cylinder. Two extreme positions of the piston rod have been noticed and marked-up. They appear while the model changes its position configurations:

- the airfield position with the maximum fuselage load (the piston rod moves into the interior volume of the cylinder until the piston head mates with the bumper face of the stifle division),
- the airborne position (the piston rod moves out of the cylinder until the piston bumper mates with the face of the cylinder lower bumper).

2.2. THE MCAD MODEL SIMPLIFICATION

The model structure is considered to be relatively compound. Furthermore, the accurate MCAD model consists of many complex-shape parts and of subassemblies that do not influence the dynamic behaviour of the landing gear very much. For this reason - to ease CAD data transfer to the CAE environment – redundant subassemblies have been deleted out of the model structure (Fig. 3). Dynamically important subassemblies have been replaced with simplified-geometry single parts (Fig. 4). In this way the MCAD assembly model has been simplified significantly and contains only 8 parts that play role of the most dynamically important subassemblies: shock absorber cylinder, stifle division, cylinder bumper, piston rod, floating piston, coupler, front wheel and a pair of rocker arms. Previously measured physical properties of the accurate model have been attributed to a simplified model, so it is described with the same values of-among others– mass, moments of inertia, inertia matrix etc.

3. PRELIMINARY CAE ANALYSIS OF THE OBJECT OF INVESTIGATION

Suitably prepared MCAD model has been exported from the MCAD UGS Solid Edge system into the chosen CAE environment - MSC.visualNastran4D. As mentioned, both systems are capable to transfer data in two directions. While preparing preliminary CAE analysis, both systems integration has been very helpful for many reasons:

- all assembly relationships are transformed into real kinematics joints (constraints),
- necessary values of physical properties are stored in CAD system and transferred into CAE one,
- after any part geometry editing or its assembly relationships changing in CAD environment, CAE files became up-to-date automatically.

3.1. LANDING GEAR MODEL KINEMATICS ANALYSIS

If the accurate dynamics analysis is the aim, it is convenient to run a model kinematics analysis first. The general assumption was that the most important kinematics test was the analysis of position, displacement, velocity and acceleration of the front wheel, rocker arms and coupler during the axial translation of the piston rod with the constant velocity (Fig. 5). Received results were verified analytically with the positive effect. Such a model can be used for a very credible dynamic analysis.

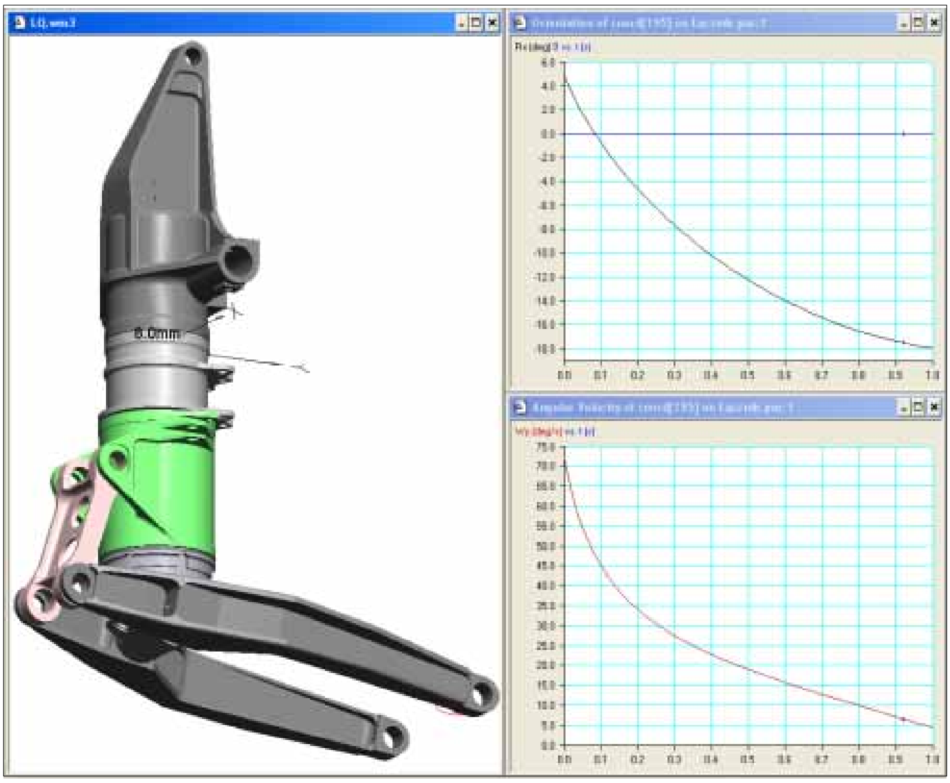

Fig. 5. CAE environment interface during the aircraft landing gear model kinematics analysis

3.2. MODEL ATTRIBUTING OF SUITABLE DYNAMICS PROPERTIES

In the CAE environment, the rigid front wheel (imported from the CAD system) model has been transformed into the deformable system (Fig. 6.a). On the circumference face of the wheel body multiple coordinate system were placed, as well as on the circumference face of the tyre outline. On the basis of these coordinate systems, spring-dumper elements were assembled. Tyre rubber material stiffness and dumping values were received out of the real tyre durability experiment (Fig. 6.b)

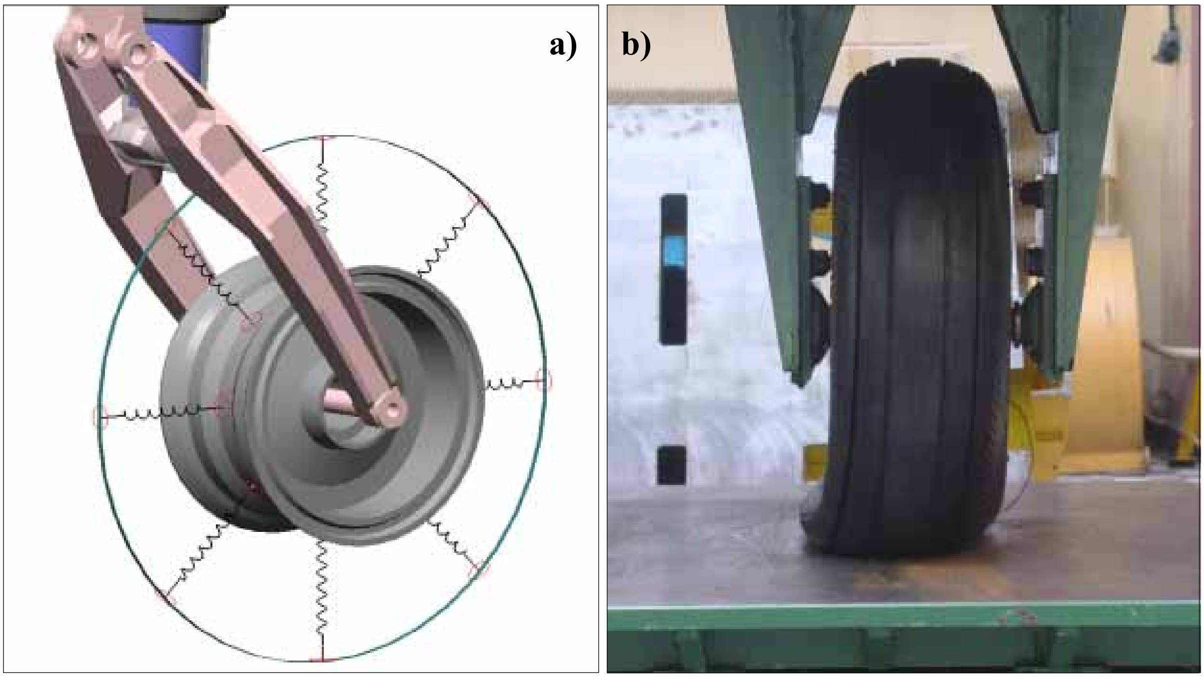

Fig. 6. Deformable tyre model (a), with necessary dynamics properties (stiffness and dumping) received on the basis of the real tyre durability investigations (b)

Furthermore, to find out values of stiffness and dumping in the case of the oil-gas mixture located inside of the shock absorber cylinder chamber, the numerical drop-down test was prepared (Fig. 7.a). The test idea is to drop the landing gear onto the load-measurement capable plate (according to appropriate FAR instructions). On chosen faces of the piston rod, the stifle division and the cylinder bumper (i.e. faces that mate while the model is its extreme position configurations – explained above) local coordinate system were placed. As before, between these coordinate systems, spring-dumper elements - Lagrange theory - were assembled (Fig. 7.b). It is truly difficult to achieve accurate information connected with stiffness and dumping properties of the oil-gas mixture, located inside the shock absorber cylinder. That is why necessary values were found approximately with the "next-iteration" manner. During the gear model drop-down numerical test, time-dependent functions were recorded. Theses functions are (among others): model falling down velocity, shock absorber displacement and the tyre outline deformation (Fig. 7.c).
The general assumption is that the approximately appropriate values of oil-gas mixture stiffness and dumping were found, where numerically recorded functions were possibly similar to adequate functions recordings, received on the basis of the real gear drop-down experiment.

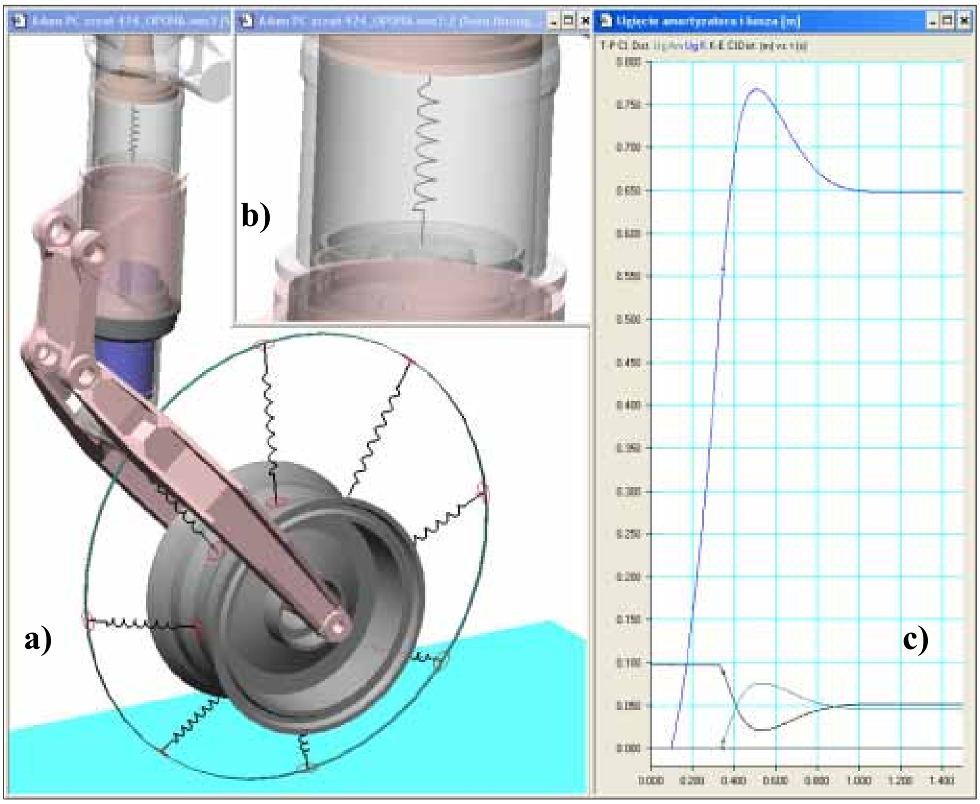

Fig. 7. Gear model drop-down numerical simulation: general view (a), spring-dumper element that responses possibly similar to the real oil-gas mixture (b), charts of functions in the case of model falling down velocity, shock absorber displacement and the tyre outline deformation

4. NUMERICAL SIMULATION OF THE AIRFIELD OBSTRUCTION GEAR INVASION

During the process of the aircraft design and maintenance, it is necessary to take into consideration the possibility of airfield obstruction gear invasion event. These obstructions are airfield cavities as well as foreign solid bodies laying on the airfield surface.

The reason the obstruction appears on the airfield surface may be:

- enemy units or terrorists squad hostile actions (e.g. aerial bombing or artillery fire can cause craters and cracks),
- natural forces of nature (e.g. wind blows can break tree branches that fall onto the airfield surface),
- incompetent airfield repair or maintenance (e.g. stones removal) by suitable technical service units.

Any gear damage after the obstruction invasion can cause the serious aircraft accident and be dangerous for people and cargo on board. That's why it is very necessary to evaluate acceptable size of airfield obstructions that will not harm the aircraft gear. Such investigation should be done at a possible early stage of the gear design process. If the gear is already in production, such an experiment allows the verification of the aircraft manufacturer's maintenance restrictions.

The most convenient way to run such an investigation process is the numerical analysis. Testing digital mock-ups is, first of all, cheaper and safer than real gears experiments.

While the numerical gear model dynamics features are possibly similar to the real gear, the next step was to design the airfield surface with the capability to generate following kinds of obstructions in user-defined distances from each other:

- rectangular cavities,
- rectangular cavities with rounded edges,
- wedge cavities,

- foreign rectangular solid bodies (Fig. 8),
- foreign wedge solid bodies,
- foreign cylinder solid bodies.

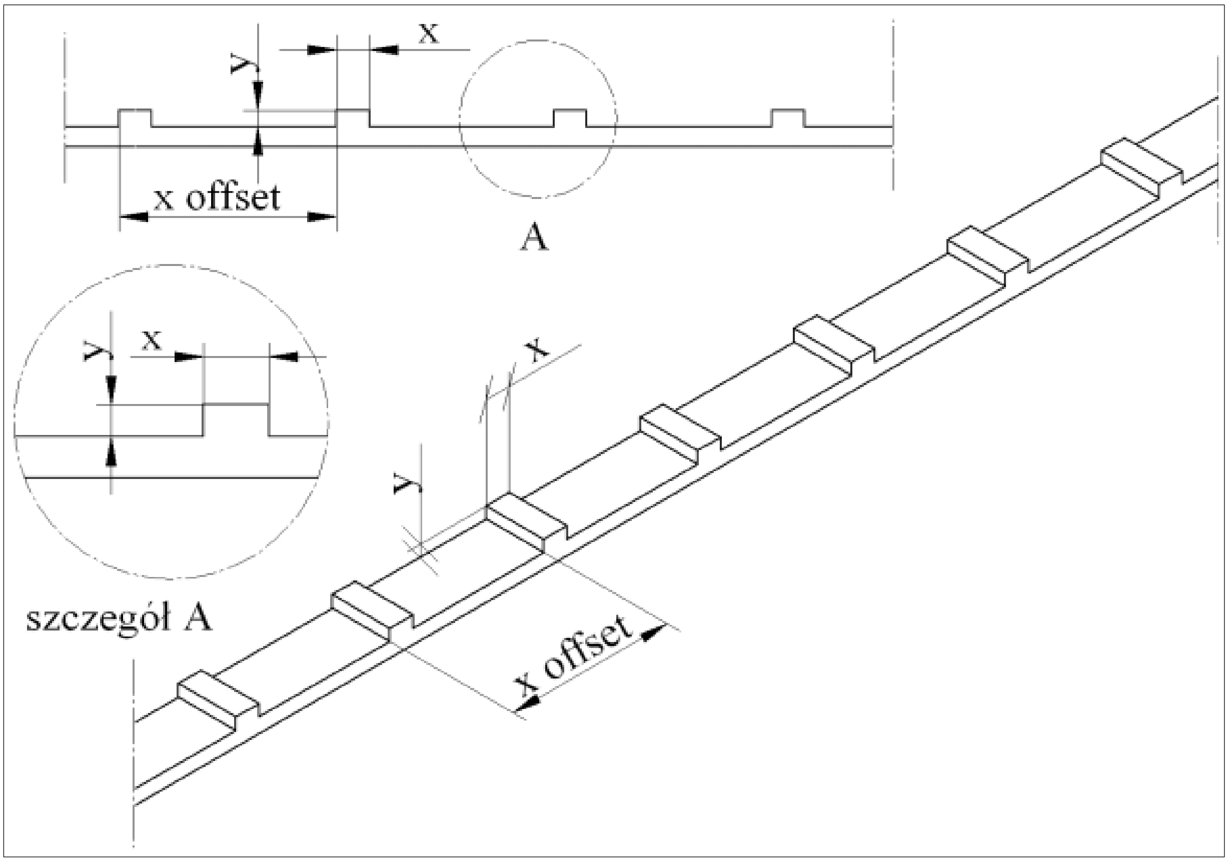

Fig. 8. The dimensions drafting of a chosen airfield obstruction geometry (set of foreign rectangular solid bodies)

Investigations of the gear model shock sensitivity after the obstruction invasion took place. So, the numerical simulation of aircraft landing on the damaged airfield was prepared. The total weight of the cylinder model was increased with the part of aircraft fuselage weight that additionally loads the front gear. Simulation step are described below:

- the gear model approaches the airfield model, being above it (in-air), with the standard landing horizontal velocity (30 m/s),
- the gears model simultaneously falls down at the airfield model with the maximum permissible vertical velocity (3 m/s),
- after the gear contacts the airfield its horizontal velocity is gradually decreased and the gear obstruction invasion process begins (type of airfield obstructions and distances between them are defined by a CAE system user before the simulation),
- CAE system measures and saves values of forces that appear in chosen kinematics joints as well as the influence of oil-gas mixture dumping on the gear model energy dissipation (Fig. 9).

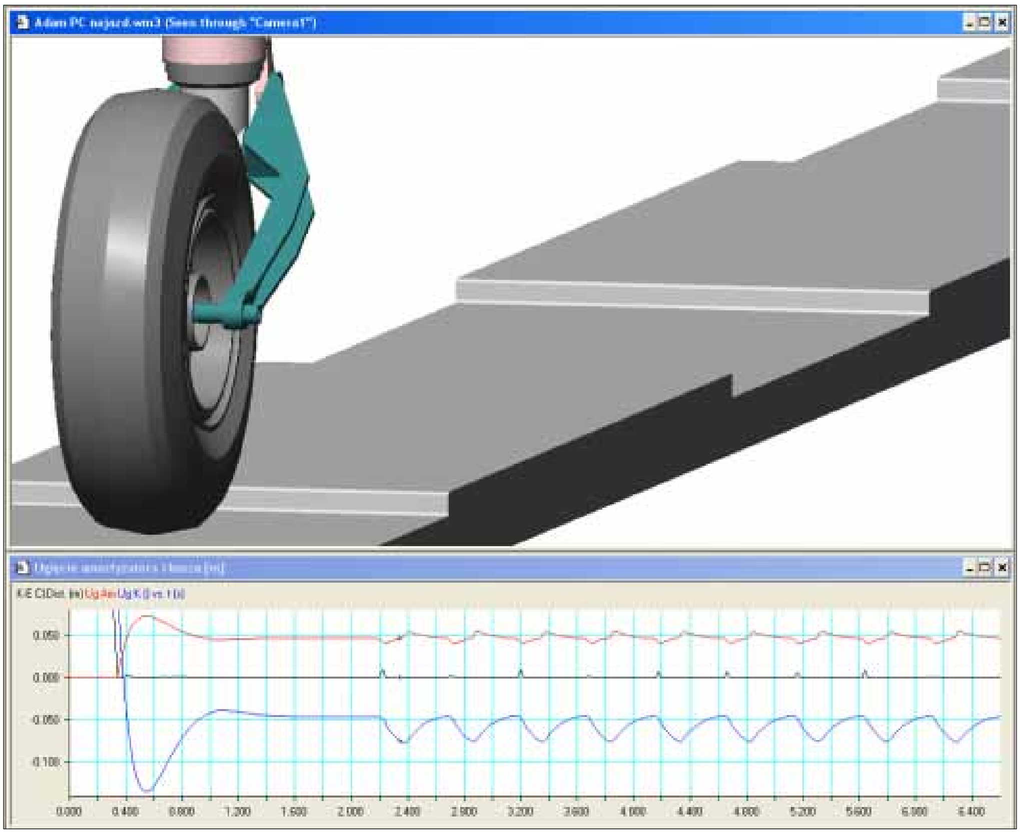

Fig. 9. Numerical simulation of the airfield obstruction gear invasion with the simultaneous measurement of forces that appear in chosen model kinematics joints

On the basis of simulation results analysis, it is proved that landing aircraft permissible vertical velocity can be increased of 30% more the aircraft manufacturer claims, with no serious differences in values of forces that appear in the gear kinematics joints.
Furthermore, it is also proved, that the aircraft equipped with such a gear can operate on slightly damaged concrete airfields as well as on makeshift and rough surfaces, even though the aircraft manufacturer instructions do not allow that.

5. Numerical analysis of Shimmy vibration model sensitivity

Before the landing gear is allowed for its maintenance, it is strongly recommended to verify its sensitivity for a Shimmy vibration appearance in chosen conditions. Such a vibration kind appears if improperly designed, manufactured or used gear runs on the airfield surface. The Shimmy vibration main feature is the fast changing amplitude and relatively high frequency, so the effect of Shimmy appearance may a serious damage or even destruction of the gear. This can be harmful for the aircraft and – even worse – for the people and cargo on board.
To proceed similarly to the real aeroplane laboratories, the model of the rotary cylindrical track has been design, and the model of the gear has been placed above it. The gear model is now pulled back from its equilibrium position according to its symmetry plane. The cylindrical track rotates with a suitable angular velocity to achieve the right linear velocity on the track-gear contact surface (the track circumference face). Then the gear model is dropped onto the track with a proper vertical velocity and the simulation gear model Shimmy vibration sensitivity begins.
The amplitude values of the gear model pendulum motion along its equilibrium position were recorded, as well as the angular motion frequency.

In the case of every model mass and track angular velocities combination (according to FAR instructions) the gear model returned to its equilibrium position in the acceptable time (Fig. 10). So, the conclusion is that in the case of such a gear the Shimmy vibration phenomenon does not appear.

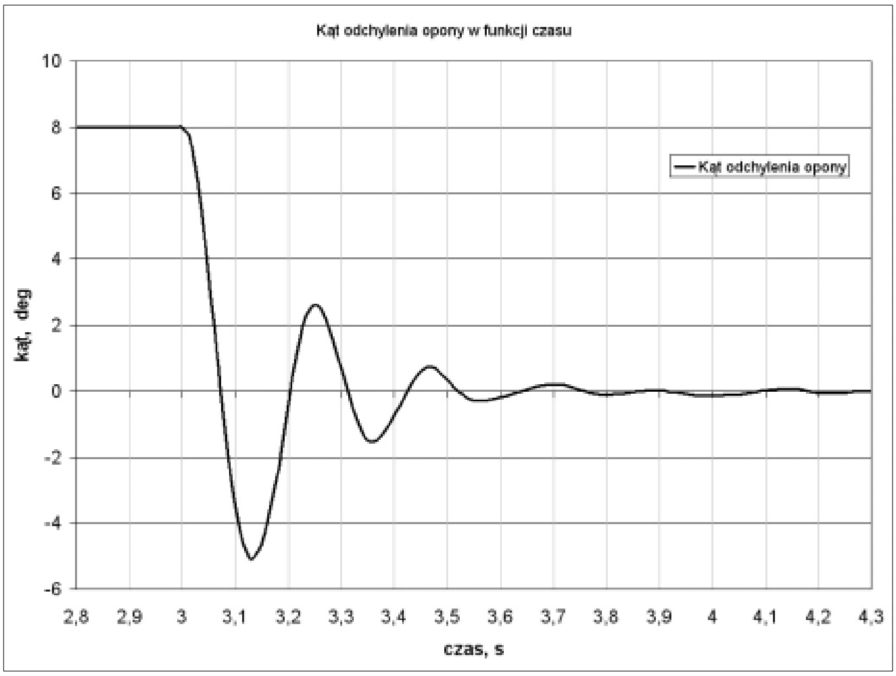

Fig. 10. The value of the gear model angular displacement relative to its equilibrium position, during the numerical investigations of the model Shimmy vibration sensitivity

6. CONCLUSIONS

A complex set of numerical experiments took place to evaluate military transport aircraft front support landing gear dynamics. The assumed goal was achieved with no need for expensive and complex fully integrated CAD/CAE "high-end" systems. Only quite cheap and easy to use "mid-range" environments were used: CAD (UGS Solid Edge) and CAE (MSC.visualNastran4D). Although they are separate environments, their capability of two directional data transfer was fully satisfactory.

Because of accurate gear modelling with the CAD system, all model important physical properties (for the sake of its dynamics) were calculated. That enabled simplifying of the gear model (to ease the CAD - CAE geometry transfer) and its attributing with necessary previously computed physical properties values. Durability properties of model deformable elements (tyre and cylinder oil-gas mixture) were defined relatively accurately.

On the basis of numerical investigations of the gear model dynamics, it is claimed that in the standard maintenance conditions the gear Shimmy vibration phenomenon does not appear.

Furthermore, it has been proved, that the aircraft equipped with the investigated landing gear can operate in a wider and more difficult range of conditions, than the factory instructions claim.

It means the aircraft maintenance purposes diversity is much more attractive for the military user, than the aircraft manufacturer initially assumed.

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