DYNAMIC STUDY OF AIRCRAFT GEAR BEHAVIOUR IN SOME UNUSUAL CONDITIONS

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Abstract: The paper presents CAE MBS analysis of aircraft front landing gear behaviour in unusual situations that can be caused by unpredictable obstacles. Numerical tools were applied, because real investigations can be relatively expensive and dangerous. One of unusual maintenance condition assumed increasing of the aircraft vertical velocity, caused by a loss of uplift forces (result of decreasing the horizontal velocity to shorten the airfield length needed to dissipate aircraft energy). The other analyzed maintenance condition assumed the aircraft landing with horizontal velocity, increased of a large percentage in comparison with its maximum value allowed by the aircraft manufacturer. Simulation also provided the gear dynamics analysis while crossing over obstacles placed on slightly damaged or makeshift airfield. During CAE tests, Lagrange spring/dumper elements used to simulate the behavior of deformable tyre and shock absorber oil-gas mixture. Simulations proved that increasing the vertical velocity of 25% and the horizontal one of 15% is safe for the aircraft and it can operate on damaged airfields. Investigations proved that aircraft maintenance conditions might be safely expanded, in comparison with its manufacturer suggestions. It enables the manufacturer to look for new and aircraft-safe applications that require special landing capabilities: Special Team Transport or Medical Evacuation.

Key words: CAE MBS simulation, aircraft landing gears, unusual maintenance conditions

1. INTRODUCTION

Contemporary real investigations of aircraft landing gears safety, during their maintenance in dangerous conditions should be provided rarely. Such tests can cause damage or destruction of investigated gears, aircraft structure, laboratory station and measurement equipment [11]. Real investigations are dangerous (for the aircraft crew and the plane) and expensive (tested gear can be harmed, dangerous conditions are difficult to simulate).

However, there is a need to estimate the gear behaviour in such conditions. Numerical experiments are the right solution. They enable the truthful prognosis combined with the highest safety and lowest costs – if the model is designed correctly. CAE tools provide perfect model geometry, accurate border conditions / results values and wider range of maintenance conditions possible to verify.

The paper presents the numerical experiment that allowed the investigation of aircraft front support landing gear dynamics with the assumption of its maintenance in dangerous conditions. The analysed gear is the part of Polish M-28 Skytruck military transport aircraft. Aforementioned conditions meant aircraft landing on a slightly damaged airfield with seriously increased values of horizontal and vertical velocities. These values were increased of quite large percentage, in comparison with maximum values, allowed by the aircraft manufacturer.

2. CAE TEST PREPARATION

To run simulations, the accurate CAD model of the investigated landing gear has been designed, simplified and exported to CAE environment [08] to prepare the MBS experiments (Fig. 1). Main shock-absorber parts have been connected with spring-dumper *Lagrange* elements to simulate the oil-gas mixture behaviour (Fig. 2a). Furthermore the deformable wheel tyre has been designed - mass points connected with spring-dumper elements as well (Fig. 2b). All stiffness and dumping parameters were based on previous real experiments results [09]. Such a CAE landing gear model was claimed as realistic enough to run simulations (many verification test were also executed with the positive results).

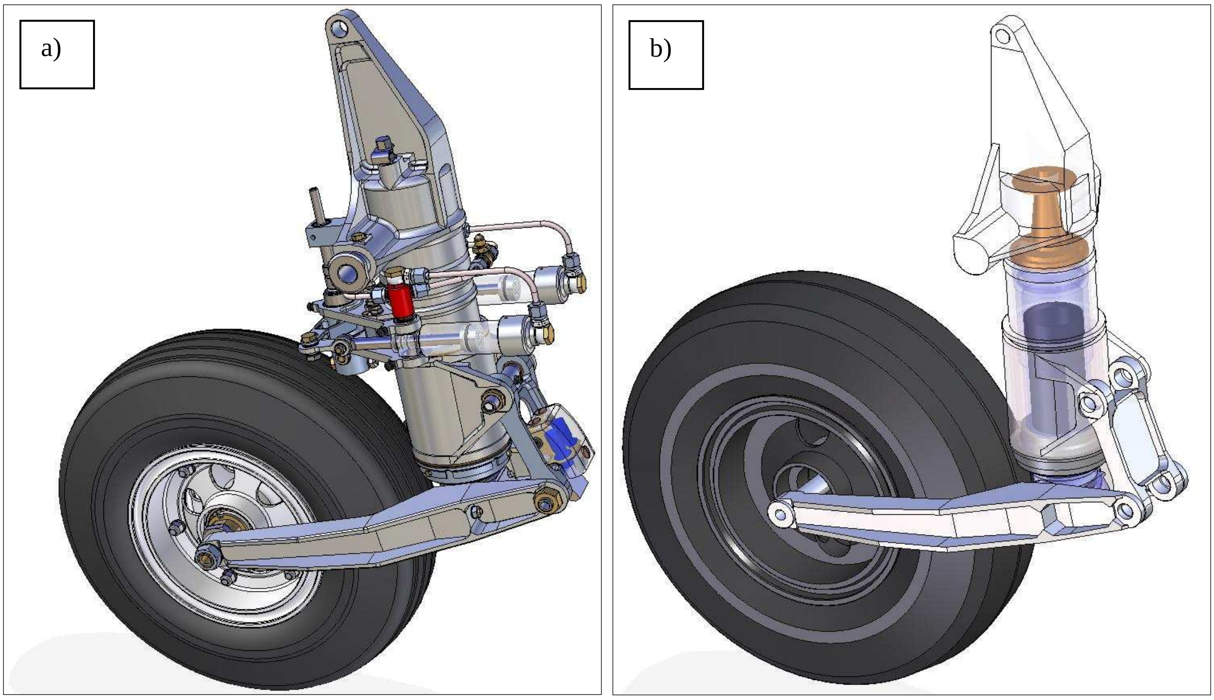

Fig. 1. CAD model of the investigated landing gear: a) accurate one, b) simplified model exported to the CAE MBS environment

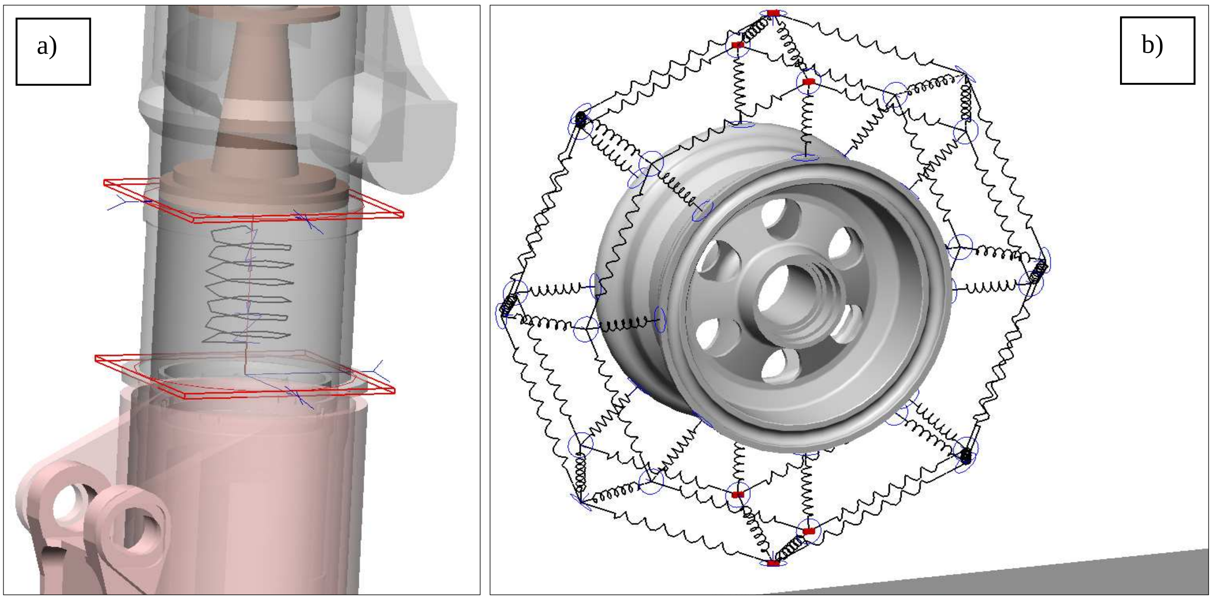

Fig. 2. Application of Lagrange spring-dumper elements to simulate the behaviour of: a) shock absorber oil-gas mixture, b) deformable wheel tyre

3. UNUSUAL MAINTENANCE CONDITIONS SIMULATIONS

3.1. LANDING WITH VERTICAL FALL-DOWN VELOCITY INCREASED

During the landing process, the aircraft horizontal velocity should be possibly low to shorten the airfield length needed to slow down and stop the landing vehicle (to dissipate its kinematic energy). Low horizontal velocity enables the flying crew to manoeuvre the aircraft precisely enough to reach the landing point accurately. Because of the aerodynamics, decreasing of horizontal velocity value means decreasing of wings-based uplift forces. Then, the aircraft vertical fall-down velocity increases dramatically [07]. In the M-28 case, the maximum allowed fall-down velocity is V_z = 3,05 m/s (Table 1). The manufacturer claims that landing with higher vertical velocities is dangerous for the gear structure and not allowed. However it's needed to verify the possibility of safe vertical velocity increasing - it would be the reason to expand the aircraft maintenance conditions. Shortening of needed airfield length would be the main advantage – expected for military transport aircrafts.

Table 1. Chosen M-28 aircraft safe landing parameters values, suggested by its manufacturer

No	Parameter	Label	Value
1	maximum vertical velocity	$V_{z\ dop}$	3,05 m/s
2	maximum horizontal velocity	$V_{x\ dop}$	38 m/s
3	minimum piston rod - stifle division distance	$L_{GT,PD\ MIN}$	3 mm
4	allowable „kangaroo" bouncing height	H_{kang}	0 mm
5	maximum shock absorber force load	$F_{a\ MAX}$	200 kN
6	needed airfield length	S_L	560 m

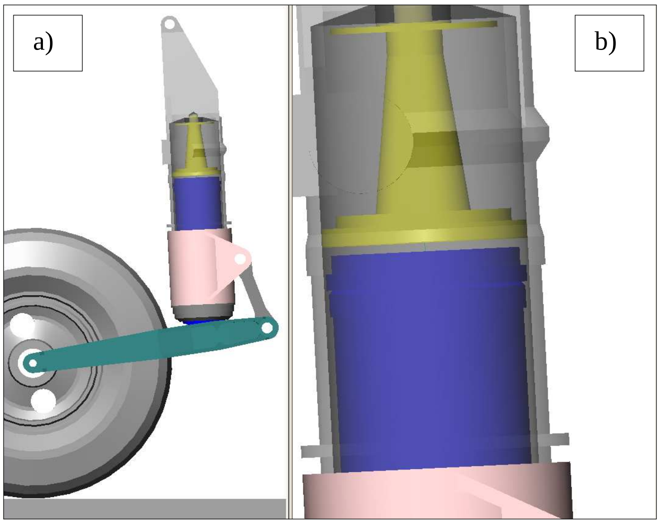

Fig. 4. Dangerous approaching of the piston rod top face to the stifle division, caused by the airfield touchdown with too high fall-down velocity: a) general view, b) detail view of the critical approach, where $L_{GT,PD}$ < 3 mm

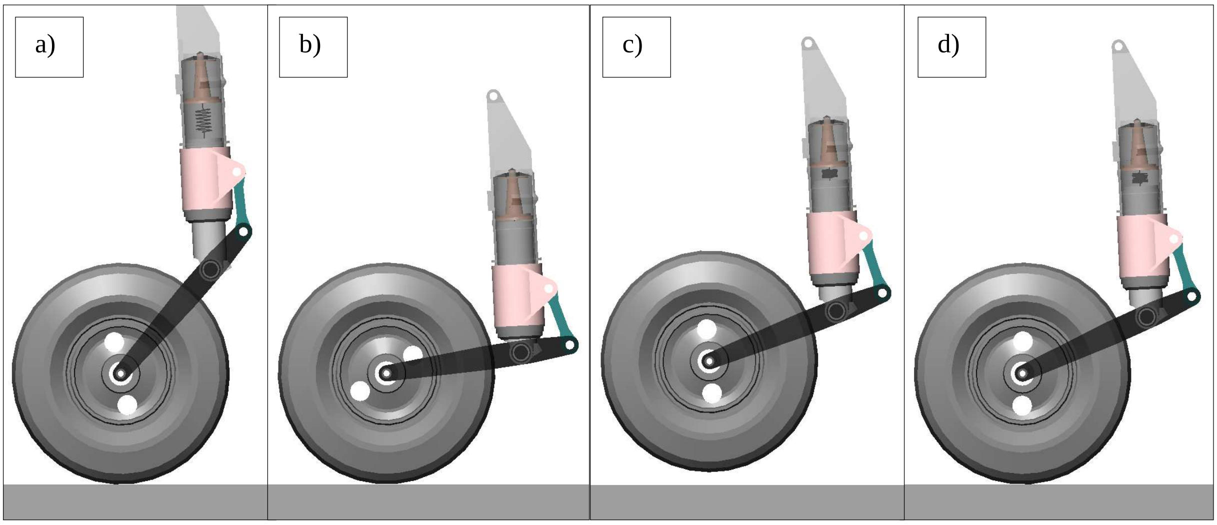

Fig. 5. Following steps of dangerous „kangaroo effect"- bouncing the gear back while landing with too high fall down velocity: a) airfield touchdown, b) large shock absorber load, c) the gear bounce with α-angle increasing, d) gentle touchdown

During the simulations of landing with increased vertical velocity, its maximum manufacturer-allowed value was increased of: 25%, 30%, 40% and 50%. The attention has been paid to the distance between shock absorber piston rod and stifle division (Fig. 4), the possibility of bouncing the gear back with α-angle increasing (the kangaroo effect – Fig. 5) and the force value that loads the piston rod during the aircraft-airfield touchdown. Simulation results with proper comments are presented in Table 2, recorded charts are shown on Fig. 6÷8.

Table 2. Comments and results of the aircraft-airfield touchdown simulation, with the assumption of large increasing of the vertical fall-down velocity (horizontal velocity is constant in all cases V_x = 38 m/s)

No	Value of vertical velocity: V_z	Assumed percentage increase of the allowed V_z value: **Δ**	Minimum piston rod-stifle division distance: $\boldsymbol{L_{GT,PD\ MIN}}$	The wheel bounce back height during the „kangaroo effect": $\boldsymbol{H_{kang}}$	Maximum measured force that loads shock absorber: $\boldsymbol{F_{a\ MAX}}$	Noticed gear risk level
1	3,05 m/s	0 %	8,6 mm	the phenomenon doesn't appear	154,833 kN	none
2	3,81 m/s	25 %	4,3 mm	the phenomenon doesn't appear	183,037 kN	none
3	3,96 m/s	30 %	3,1 mm	**147 mm**	**204,971 kN**	**high**
4	4,27 m/s	40 %	**1,2 mm**	**256 mm**	**229,192 kN**	**very high**
5	4,58 m/s	50%	**0 mm - collision, serious gear damage**	Not noticed before the damage	**257,232 kN**	**critical**

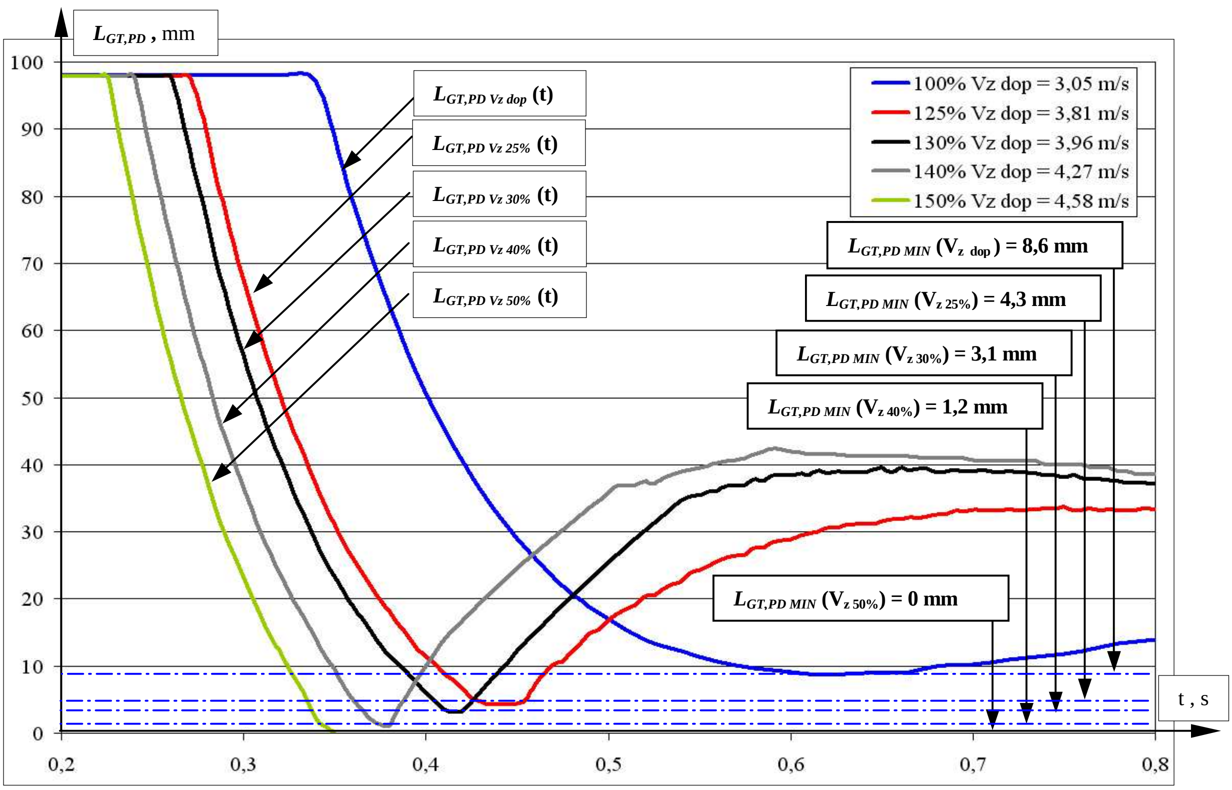

Fig. 6. Values of given $\boldsymbol{L_{GT,PD}}$*, parameters, measured during the CAE simulation of the aircraft landing with increased vertical fall-down velocity ((horizontal velocity is constant in all cases* V_x *= 38 m/s)*

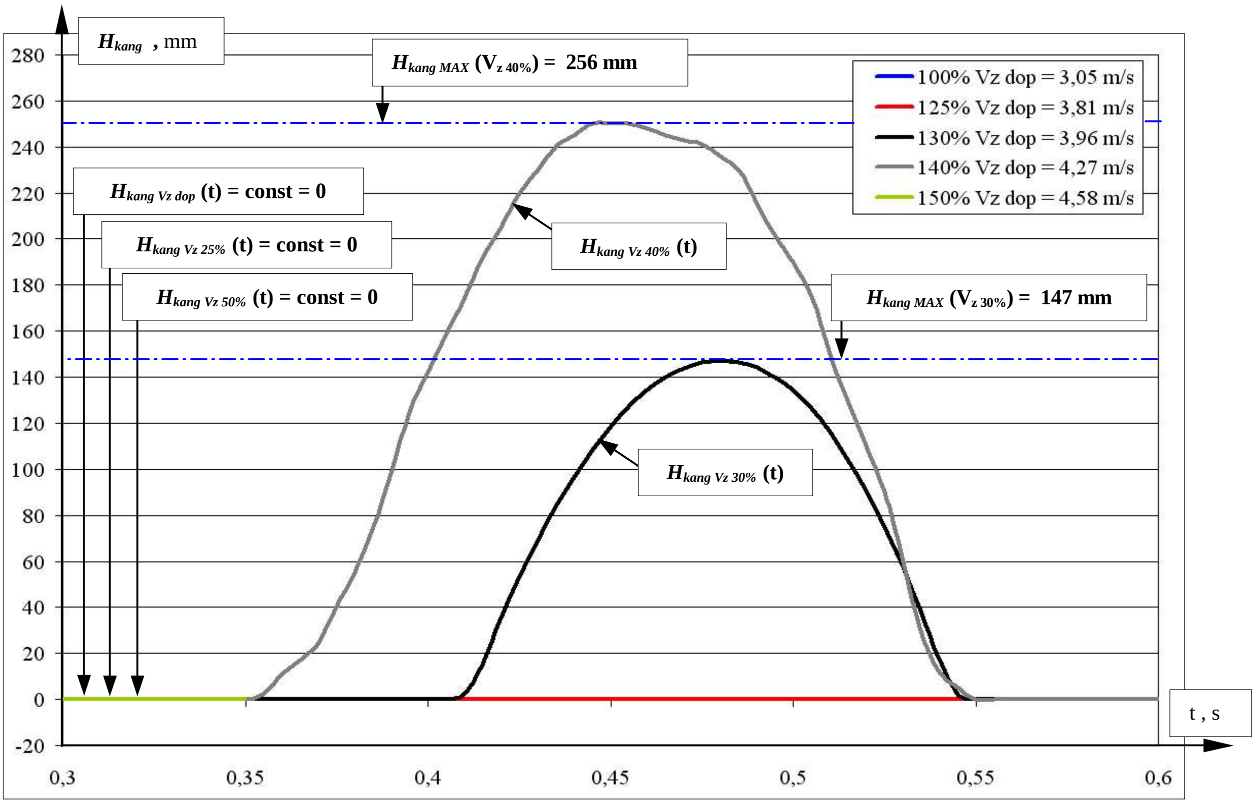

Fig. 7. Values of individual $\boldsymbol{H_{kang}}$ parameters, measured during the CAE simulation of the aircraft landing with increased vertical fall-down velocity ((horizontal velocity is constant in all cases V_x = 38 m/s)

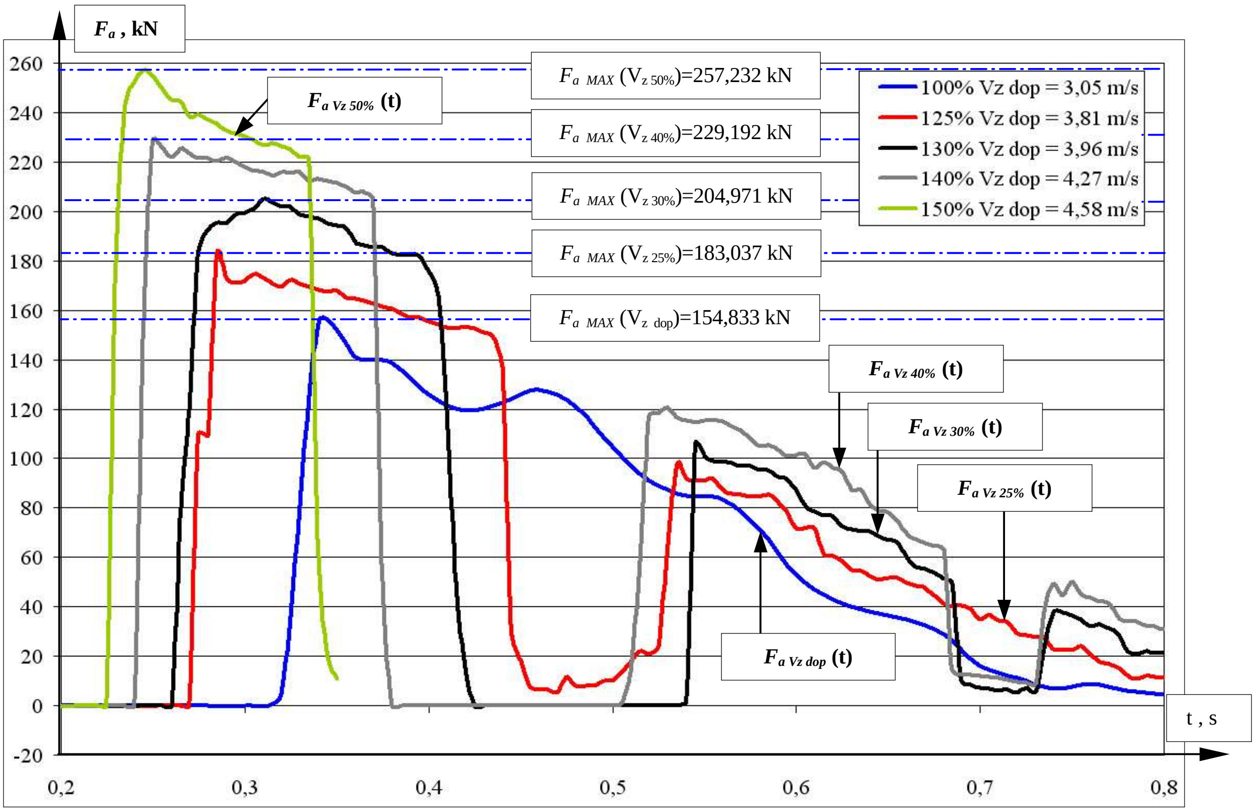

Fig. 8. Values of individual $\boldsymbol{F_a}$ parameters, measured during the CAE simulation of the aircraft landing with increased vertical fall-down velocity ((horizontal velocity is constant in all cases V_x = 38 m/s)

3.2. LANDING WITH VERTICAL FALL-DOWN VELOCITY INCREASED

The M-28's maximum vertical velocity while the aircraft–airfield touchdown is V_x = 38 m/s. The limit is explained by the manufacturer with large enough forces that appear within the gear shock absorber structure. Anyway, it's possible that in some cases such a velocity would be higher. The reasons may be aerodynamic or gear brakes damages (often while maintenance in the war zone). The conditions became truly dangerous if the airfield is slightly damaged, e.g. by the enemy bombing raid. It's needed to verify the safety of landing on damaged airfield with the increased value of the aircraft vertical velocity. If simulation results prove the possibility, it would be the reason to expand the aircraft maintenance conditions (to allow such an aircraft to operate on damaged or makeshift airfields.

For the sake of the simulation of landing on damaged airfield, the maximum allowed horizontal velocity was increased of: 10%, 15% and 20%. Examples of airfield obstacles, both cavities and bodies left on it, were created on the airfield model to make the landing gear cross over them (Fig. 9). The monitored value was the main load of the shock absorber, especially during the airfield obstruction wheel invasion. Simulation results with proper comments are presented in Table 3. The chart presenting exponentially - approximated values of the shock absorber main load values with assumption of chosen horizontal velocity increase case (Δ=15%) is shown on Fig. 10. The exponential approximation provides the influence of a shock absorber dumping on the aircraft energy dissipation. Maximum values of the investigated parameter occurred when the gear used to cross over the airfield given obstacle.

Table 3. Comments and results of the aircraft-airfield touchdown simulation (with the obstacles crossing over) with large increasing of the horizontal velocity (fall-down velocity is constant in all cases V_z = 3,05 m/s)

No	Value of horizontal velocity: V_x	Assumed percentage increase of the allowed V_x value: **Δ**	Maximum measured force that loads shock absorber: $\boldsymbol{F_{a\,MAX}}$	Exponential curve equation in the case of extreme $\boldsymbol{F_a}$ **(t)** values approximation	The influence of shock absorber dumping on the gear energy dissipation	Noticed gear risk level
1	38 m/s	0 %	154,833 kN	y = 156,93e-0,0925x	sufficient	none
2	41,8 m/s	10 %	159,125 kN	y = 162,69e-0,0752x	sufficient	none
3	43,7 m/s	15 %	171,893 kN	y =164,67e-0,0435x	sufficient	none
4	45,6 m/s	20 %	174,547 kN	y = 174,85e-0,0105x	**insufficient**	**very high**

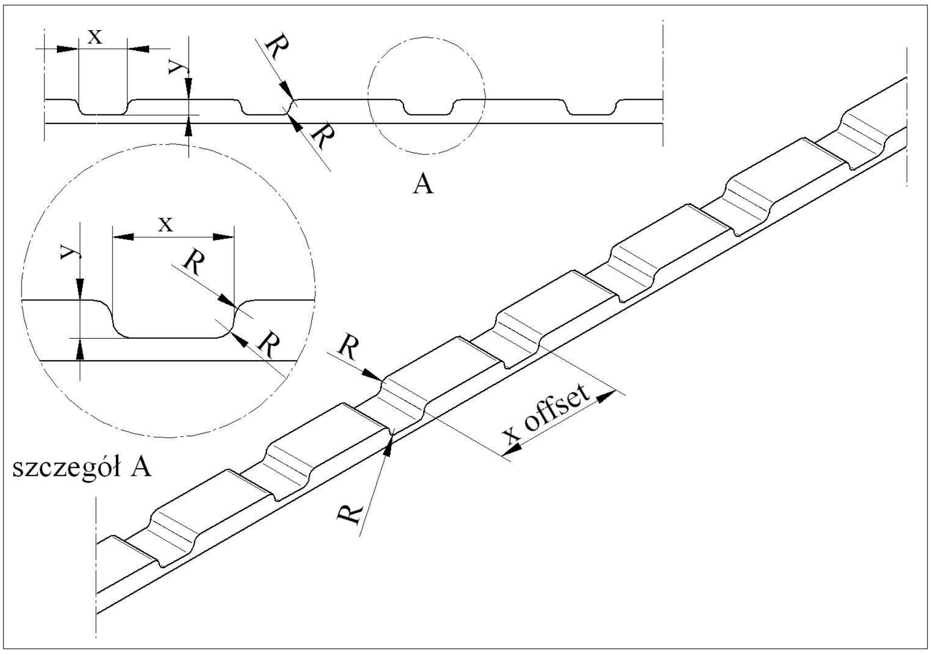

Fig. 9. Dimensioned geometry of a given airfield obstacle: rectangular-cross section cavity with rounded edges

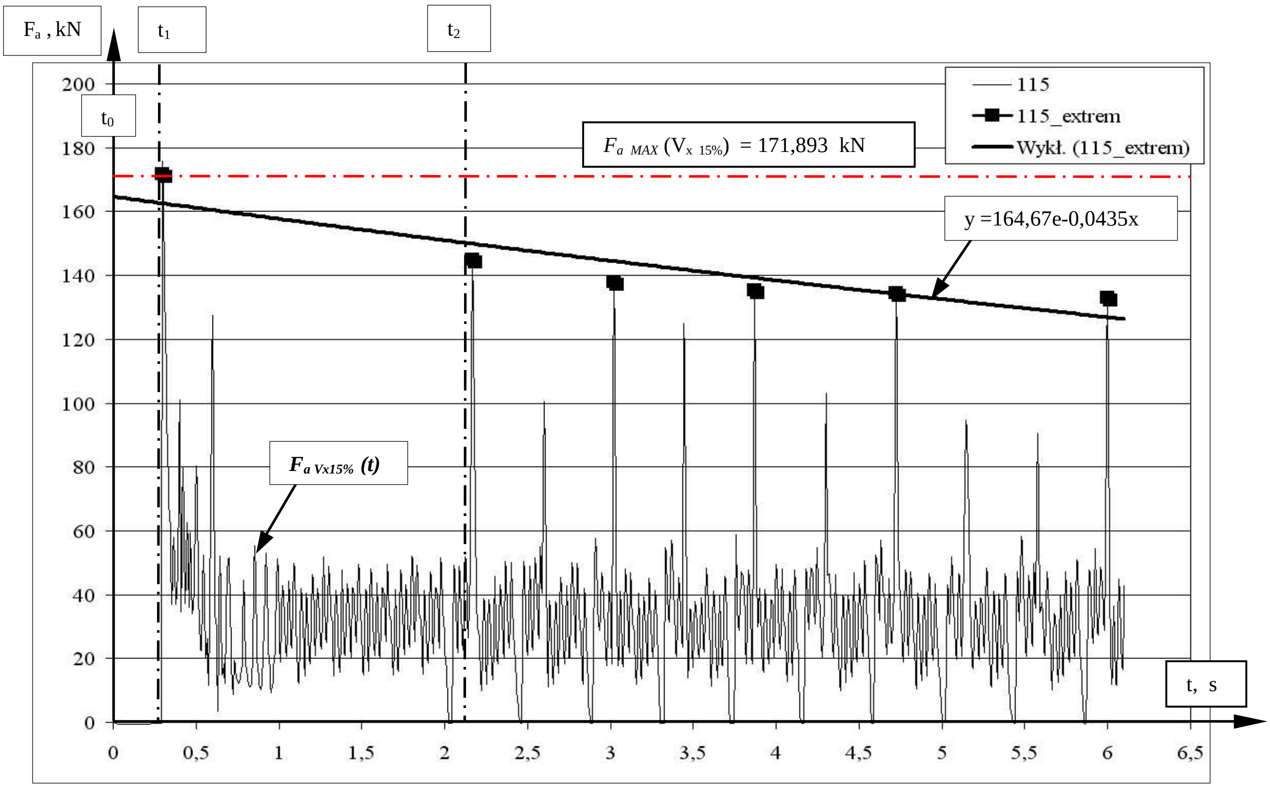

Fig. 10. Values of the F_a Vx 15% (t) parameter, during the simulation of landing with gear-airfield obstacles crossing over, with increasing of the aircraft manufacturer-allowed horizontal velocity by 15% (V_x = 43,7 m/s) (t_1 – airfield touchdown, t_2 –obstacle crossing over initialisation), V_z=3,05m/s

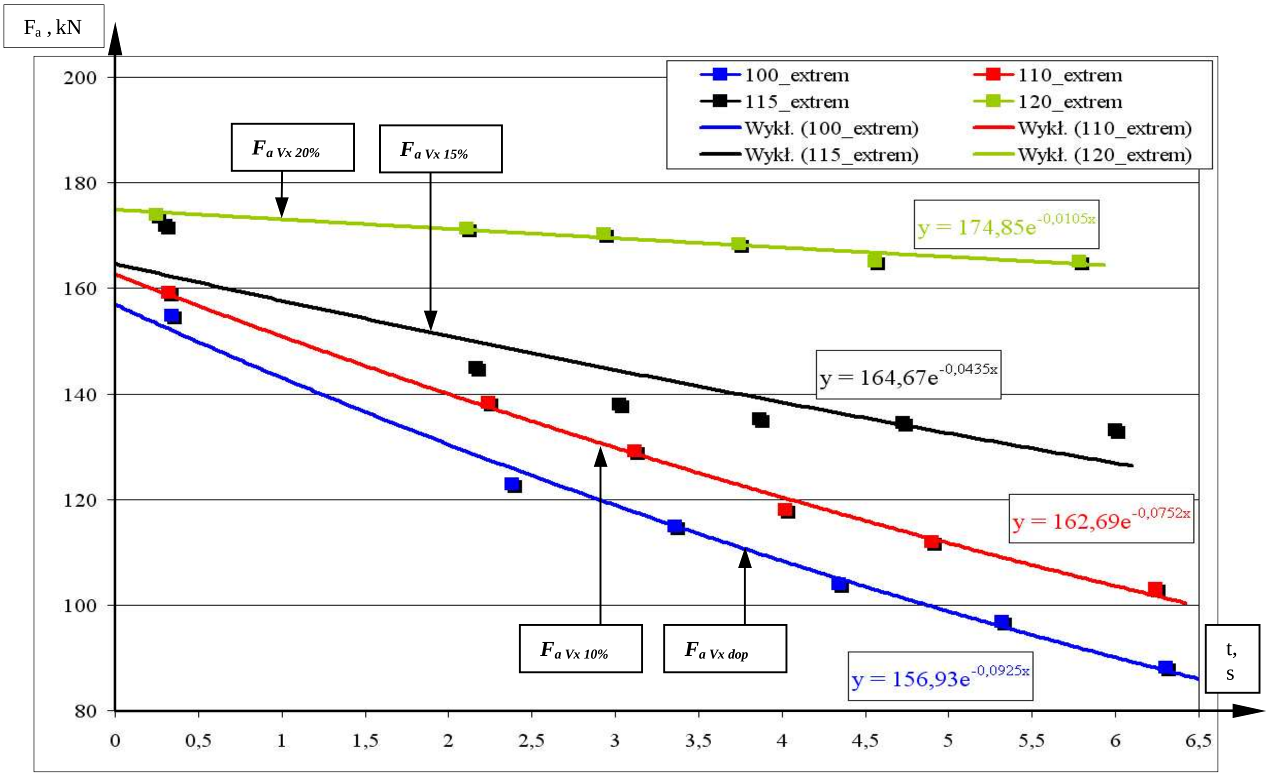

Fig. 11. Exponential approximation curves comparison in the case of investigated cases of aircraft landing with its horizontal velocity increasing (landing gear-airfield obstacle crossing over also assumed)

Values of a shock absorber load were measured and recorded in all investigated cases of aircraft landing horizontal velocity increasing. The results comparison is shown on a Fig. 11. The Fig. 12 presents CAE environment user interface, while the simulation running.

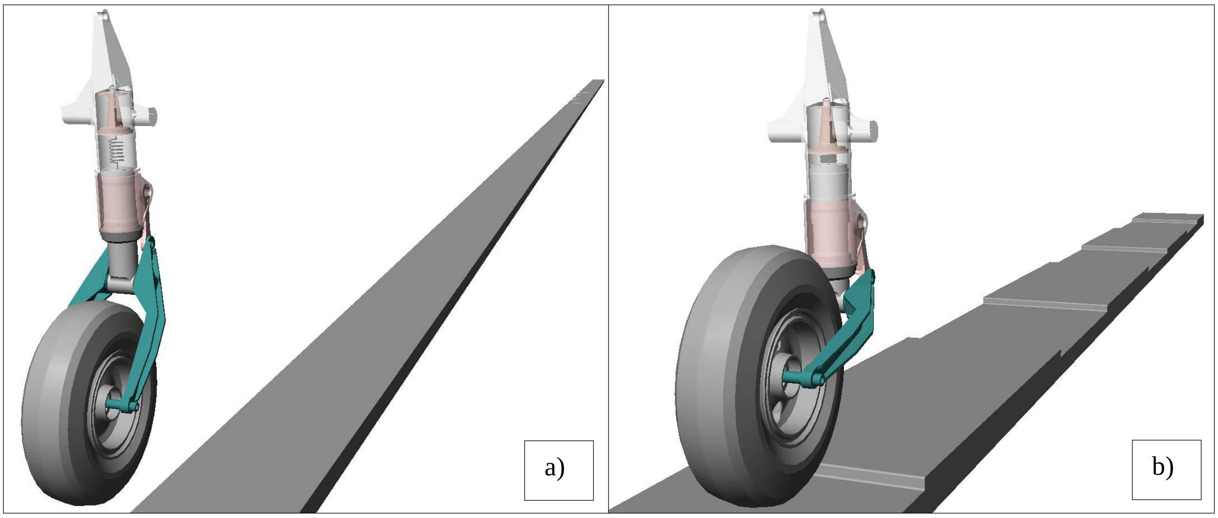

Fig. 12. CAE simulation chosen steps of aircraft landing on a slightly damaged airfield with horizontal velocity increased in comparison to the manufacturer-allowed value: a) airfield approach b) obstacle crossing-over

4. CONCLUSIONS

On the basis of simulation results, increasing the fall-down velocity of 25% (in comparison to the manufacturer-allowed value) is safe for the aircraft. Higher velocity values cause the piston rod hit the stifle division, kangaroo effect appearance and the shock absorber overloading. It has been also proved that M-28 landing on damaged airfield with the horizontal velocity increased by 15% is also safe. Further increasing of such a maintenance parameter caused gear structure overloading.

Executed CAE simulations shown that aircraft maintenance conditions may be safely expanded, in comparison with its manufacturer suggestions. The effect of landing with 25% increased vertical velocity can be impressive shortening of the airfield needed to dissipate the aircraft energy. Aircraft can also operate on makeshift airfields with higher horizontal velocity.
That's why simulations effects enable the aircraft manufacturer to look for brand new and aircraft-safe military applications that requires special landing capabilities, e.g. Special Team Transport or Medical Evacuation.

5. LITERATURE

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