A DESIGN AND NUMERICAL OPTIMIZATION OF A LANDING GEAR FOR 1400 kg (AT-6) TAKE-OFF MASS AIRCRAFT

Andrzej Tywoniuk, Rafał Jakubowski

Warsaw Institute of Aviation, Department of Transport and Energy Conversion
Krakowska Avenue 110/114, 02-256 Warsaw, Poland
tel.:+48 221883744, +48 221883880
e-mail: andrzej.tywoniuk@ilot.edu.pl, rafal.jakubowski@ilot.edu.pl

Abstract

One of the most important systems responsible for safe take-off and landing of aircraft is a landing gear system. Regardless of the configuration and the type of landing gear, its main function is to absorb energy from landing. The aim of this paper is to describe design and numerical optimization of modern tricycle-type, retractable landing gear system equipped with oleo-pneumatic amortization and mechanical emergency release. The landing gear was designed for a new prototype of 4 seats 1400 kg (AT-6) take-off mass aircraft in accordance with Certification Specifications for Normal, Utility, Aerobatic and Commuter Category Aeroplanes – CS-23. A complete design process from concept to final version was performed in Warsaw Institute of Aviation's Landing Gear Laboratory. Proposed retractable landing gear concept substantially reduces aerodynamic drag of aircraft. Although application of one retraction system for the left and right gear make the system more complicated, this solution significantly reduces weight. The authors, because of the project complexity, focused on most important aspects of the main landing gear design and described numerical optimization of chosen components like composite leg with main and upper aluminium fittings. Engineers involved in the project used SolidEdge software for 3D modelling, kinematics optimization and 2D documentation preparation. Strength and stiffness analysis was carried out using hand and numerical calculation methods – FEMAP with NX Nastran and Hyperworks software.

Keywords: landing gear, aircraft, design, finite element method, undercarriage

1. Introduction

Landing gear is one of the most important systems in aircraft, responsible for safe take-off, landing and taxiing at the airport. Regardless of the type of airstrip (manufactured or natural surface), configuration of the landing gear and amortization systems (spring, rubber, or oleo-pneumatic), its main role is to absorb energy from landing.

The type of landing gear depends on the aircraft design and its intended use. Three basic configurations of landing gear are commonly used: tail wheel-type landing gear (also known as a conventional gear), tandem landing gear and tricycle-type landing gear [2].

The use of tricycle-type landing gear gives following benefits:

– allows to use high effective brakes without nosing over when braking, so landing speed can be higher,
– pilot have better visibility from the flight deck,
– prevents from ground-looping of the aircraft, such as with tail wheel-type landing gear [1].

The landing gear system presented in this paper was designed for the 4-seat, 1400 kg take-off mass aircraft, classified as a light aircraft according to CS-23 regulations. The tricycle-type landing gear configuration consists of two main wheels with brakes, and steerable nose gear. Examples of aircraft with tricycle-type landing gear are shown in Fig. 1.

The component of static load existing at the main gear units in this configuration is about 80-90% of total load of aircraft. The scheme of load calculation procedure for nose landing gear type is shown in Fig. 2.

Fig. 1. Tricycle-type landing gear (EM-11C Orka and I23-Manager aircraft) [4]
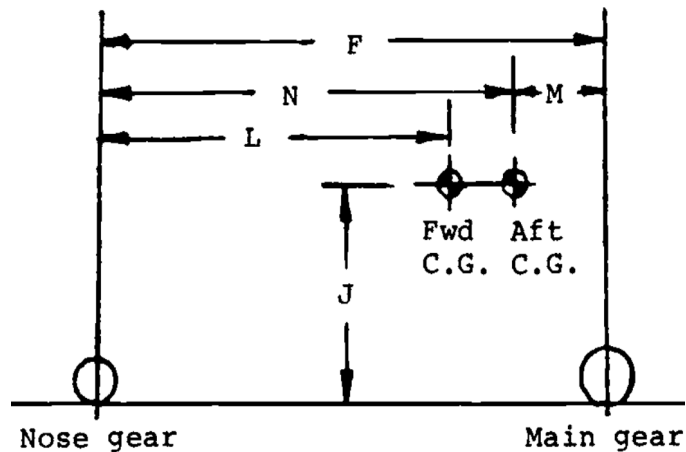

Fig. 2. Diagram for nose landing gear type load calculation [1]

Simple formulas for static load calculations are:

$$MLG_{SLmax} = \frac{W(M-F)}{2F},$$
(1)

$$NLG_{SLmax} = \frac{W(F-L)}{F},$$
(2)

where:
MLG_{SLmax} – Main landing gear maximum static load,
NLG_{SLmax} – Nose landing gear minimum static load,
F, N, L, J, M – geometrical dimensions,
W   – aircraft weight.

The main and the nose landing gear were designed and optimized in Warsaw Institute of Aviation's Landing Gear Department. The basic requirements for the project were tricycle-type landing gear, retractable (main to the back of fuselage, nose to the front), oleo-pneumatic amortization, mechanical emergency release, accordance with EASA CS-23 document.

2. Main landing gear design

Landing gear department engineers used SolidEdge software for 3D modelling, kinematics optimization and 2D documentation preparation.
Main landing gear [Fig. 3] consists of:
− composite leg with main and upper aluminium fittings,
− aluminium lever connected to the wheel and shock absorber,
− shock absorber, the most important part of the gear from energy absorption point of view,

- drag strut with locking system, used also for retraction,
- hydraulic brakes,
- electric retraction system with pneumo-mechanical emergency release (one for both main landing gear units,
- yoke – with connection to two struts (for use one retraction system for both legs).

Tab. 1. Main landing gear parameters (source: Institute of Aviation)

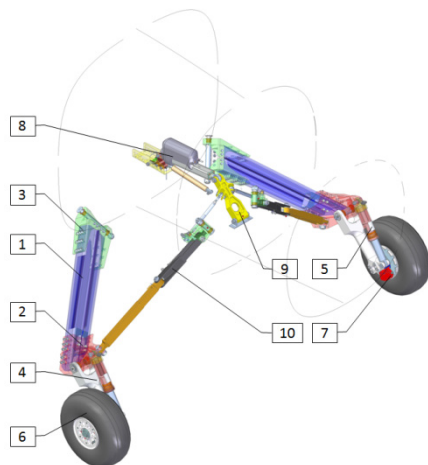|	
Total main landing gear weight	80.5 kg
Maximum deflection of shock absorber	105 mm
Type of shock absorber	oleo-pneumatic
Weight of shock absorber	2.67 kg
Composite leg weight with main and upper fittings	14.3 kg
Type of retraction system	electric with pneumo-mechanical emergency release
Type of brake	hydraulic disc brake

Fig. 3. AT-6 main landing gear: 1-composite leg, 2- main fitting, 3- upper fitting, 4- lever, 5-shock absorber, 6- wheel, 7- brake, 8- electro-actuator, 9- yoke, 10- drag strut (source: Institute of Aviation)

The oleo-pneumatic shock absorber type used in presented landing gear system has the highest operational energy dissipation efficiency (up to 85%). It consists of two chambers separated by floating piston. One chamber is filled with hydraulic fluid and the second with nitrogen. Energy of landing aircraft is dissipated in compression stage when hydraulic fluid is pressed through the damping orifice and nitrogen is compressed. Highly compressed nitrogen may cause a rapid extension of the shock absorber, which not only can result in a harsh bounce of the aircraft after touchdown but also a destructive collision between shock absorber's parts at the end of the stroke. To prevent that potential failure of the energy absorbing system additional damper restraining the flow of fluid during the extension stage was implemented.

Another landing gear component participating in energy dissipation process is a pneumatic tire. Although the tire energy dissipation efficiency is much lower (47%) comparing to shock absorber efficiency (85%), it significantly affects performance of the amortization. The main landing gear is equipped with Beringer JAB02-HE-6 tire, selected after loads, touchdown speed and required braking distance analysis.

Retractable landing gear substantially reduces aerodynamic drag of aircraft. Applied in the project one retraction system for the left and right gear units reduces weight. In the retraction

process, extending electric actuator pushes the yoke connected with both drag struts by the lock links. The link first open the down-lock mechanism and after breaking the drag strut, landing gear is retracted. Signals from electric limit switches installed on drug strut and fuselage structure inform the pilot if the landing gear is in released or retracted positon. The main landing gear in released and retracted position is shown in Fig. 4.
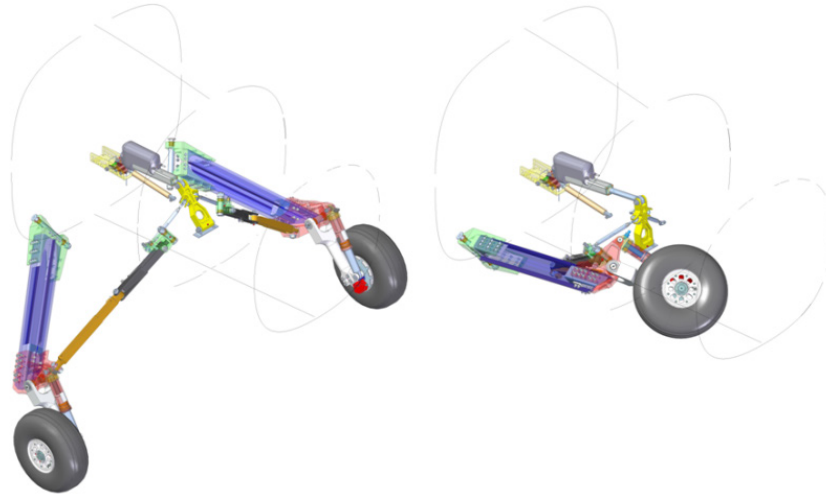

Fig. 4. AT-6 main landing gear – released (on the left) and retracted (on the right), (source: Institute of Aviation)

In case of electric power or actuator failure, pneumo-mechanical emergency release system can be used. Fig. 5 shows retraction system with emergency release. The link (6) needs to be pulled and then sliding attachment part (2) of electric actuator is moved by pneumatic cylinder. The electric actuator moves to the left, pulls the yoke (4) and the landing gears goes down.
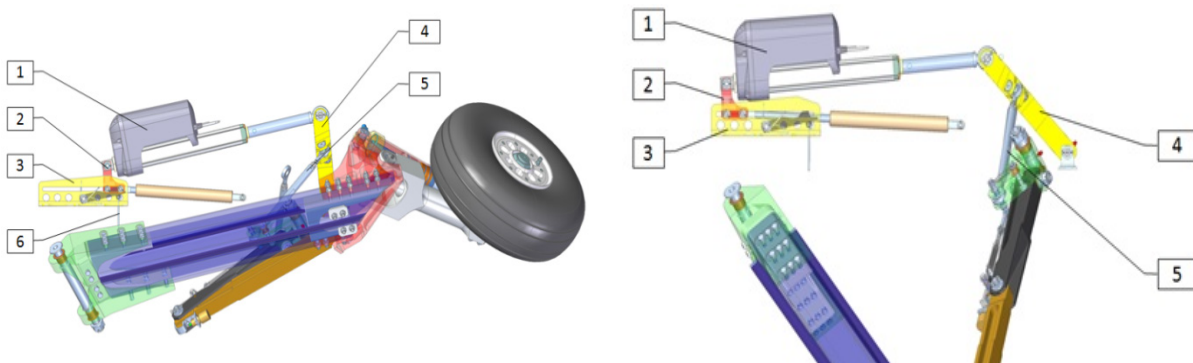

Fig. 5. AT-6 main landing gear emergency retraction system: 1- electric actuator, 2- sliding attachment part, 3- guiding part, 4- yoke, 5-lock link, 6- link (source: Institute of Aviation)

3. Stress and stiffness analysis

Each part of a newly designed landing gear system has to be investigated by stress analysis to prove its strength for specific load cases. The analysis can be carried out using hand calculation techniques or numerical solutions like finite element method. In the case of landing gear system presented, its parts were checked for ground loads specified in Certification Specifications for Normal, Utility, Aerobatic and Commuter Category Aeroplanes – CS-23. The CS-23 document describes basic landing cases, braked roll loads, towing loads and supplementary conditions for main and tail/nose landing gear [3]. It is important for properly interpret each specification's section in order to correctly carry out the stress analysis. In Fig. 6, basic landing conditions and guidelines for ground loads calculations are described.
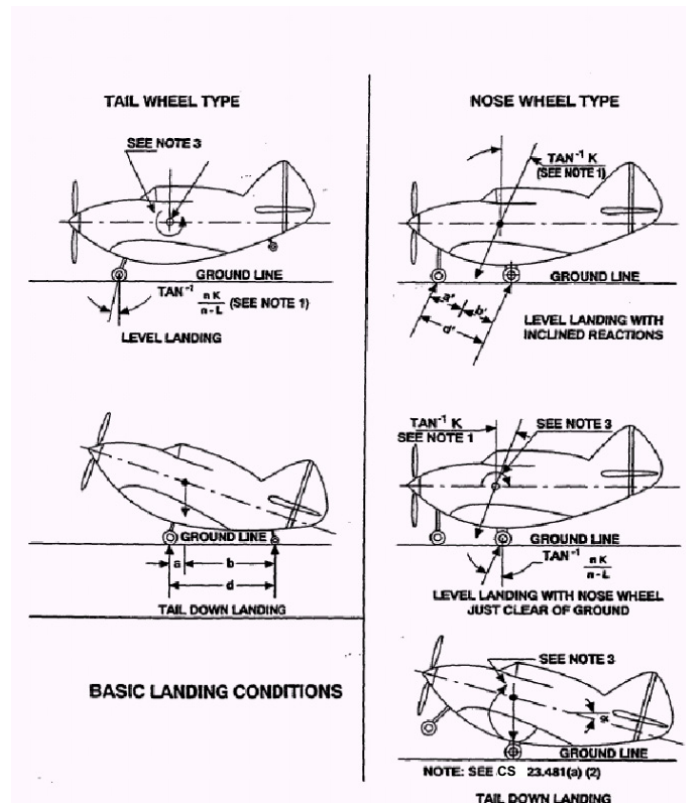
Fig. 6. Basic landing gear conditions for tail and nose wheel type aeroplane [3]

Strength analysis of described landing gear was carried out using both hand and numerical calculation methods. For geometrically complex parts FE calculations were made using FEMAP with NX Nastran and Hyperworks software [5, 6]. The stress criterion for parts being analysed is:

$$\sigma_{red\ max} = \sigma_{dop} \leq \frac{R_m}{n_s}, \tag{1}$$

where:

$\sigma_{red\ max}$ – maximum Von Mises stresses,

σ_{dop} – limit stress,

R_m – ultimate tensile strength,

n_s – safety factor equal to 1.5.

In the Fig. 7 and 8 the example of FE model of main landing gear including main fitting (Fig. 3 position 2) and Von Mises stresses results are presented. The main fitting was designed using 2024 aluminium alloy with ultimate stress equal to R_m=420 MPa.
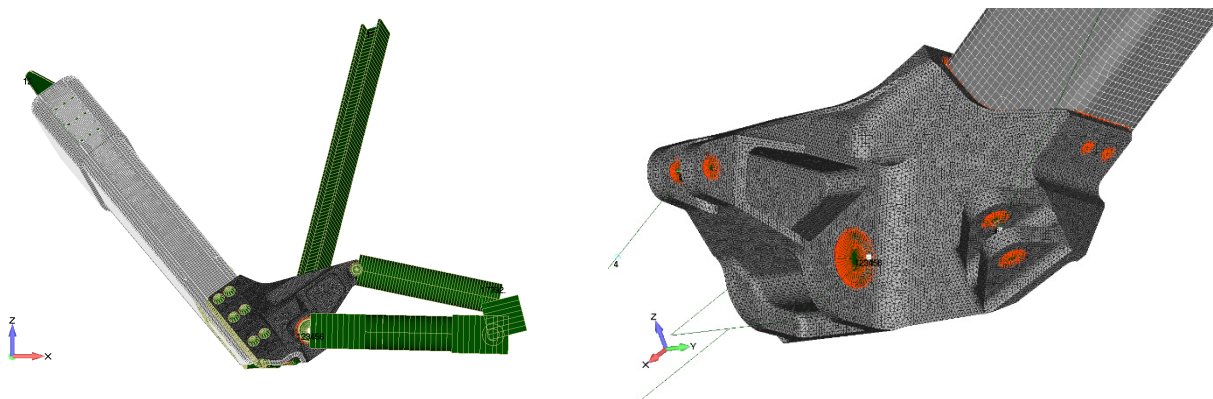

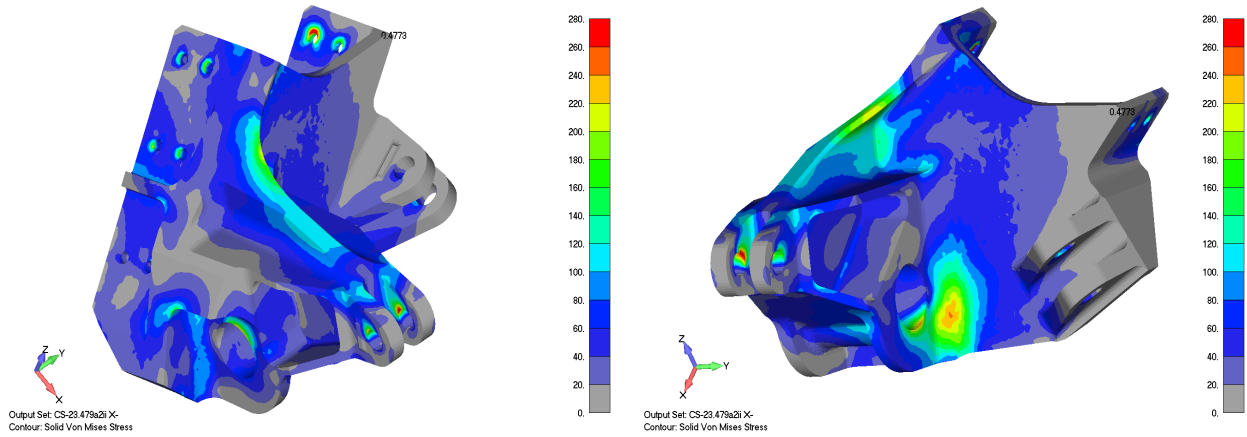*Fig. 7. Finite element model of AT-6 main landing gear*

Fig. 8. Von mises stresses results for main fitting

The undercarriage leg was one of the part checked in details using FEM (Fig. 3, position 1). The basic requirement for the composite leg was its high stiffness due to a necessity of preserving stable wheel traction during landing and taxing. High stiffness of the leg also improves energy absorption efficiency of the whole landing gear system. The geometry and configuration of the main landing gear dimensioned the leg. It was necessary to oversize the structure of the leg in order to obtain required stiffness. Numerical calculations were carried out using Hyperworks software package. The FE model of the leg was prepared using plate elements with plies layout and orientation accurate representation (Fig. 9). The bonded joint connecting upper and lower part of the leg was modelled by using solid elements (Fig. 9). Rigid elements were used for simplified representation of arm, strut and landing gear fittings (Fig. 10). The total displacement of the wheel axle is shown in Fig. 11 and results are summarized in the Tab. 2.
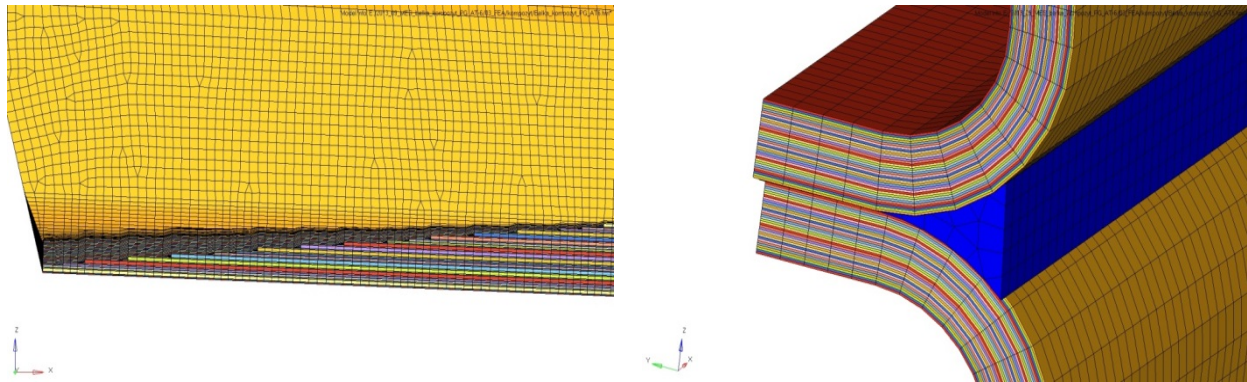

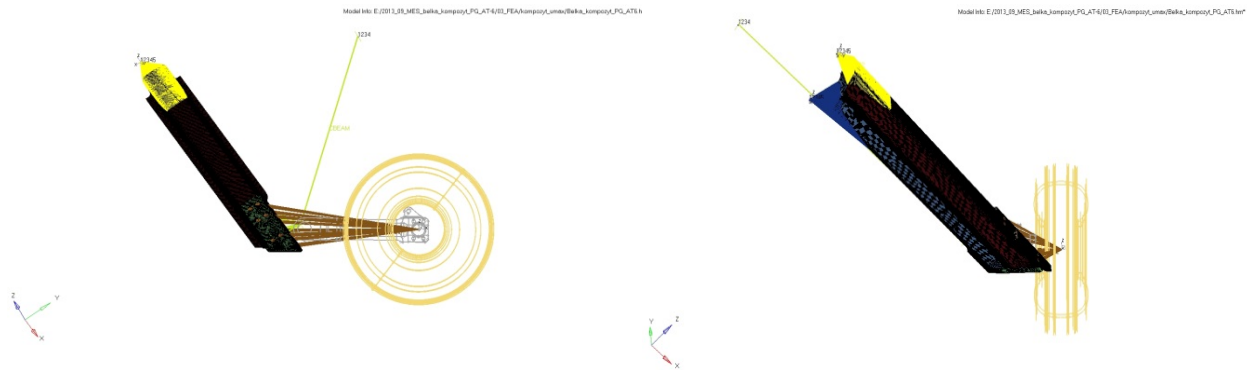*Fig. 9. Plies layout representation in numerical model of AT-6 main landing gear undercarriage leg*

Fig. 10. Finite element model of AT-6 main landing gear undercarriage leg
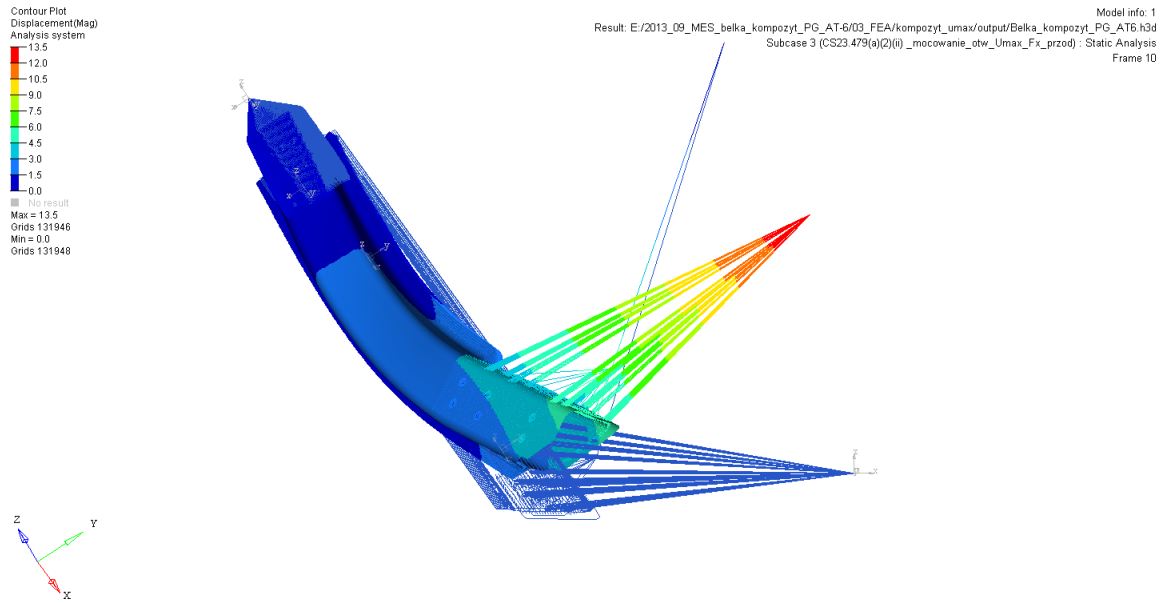
Fig. 11. Total displacement of AT-6 main landing gear undercarriage leg

Tab. 2. Displacement and rotation results for AT-6 main landing gear undercarriage leg

Load case	Displacement [mm]				Rotation [°]			
	Total	x	y	z	Total	x	y	Z
CS23.479(a)(2)(ii), spin-up	11.6	1.8	-3.8	11	1	-0.4	-0.9	-0.2
CS23.479(a)(2)(ii), spring-back	13.5	1.4	-6.7	11.6	1.35	-0.1	-1.2	-0.6

4. Summary

A design and numerical optimization of a landing gear for 1400 kg (AT-6) take-off mass aircraft presented in this paper helps to understand the complexity of the system, which is the aircraft undercarriage. All design requirements defined by the client have been met. The correctness of the landing gear design, especially its shock absorption capability was confirmed by full laboratory functional and dynamic drop test campaign (presented in other paper). Big experience of the Warsaw of Aviation landing gear design team in combination with modern engineering tools used in the project allowed for fast delivery of the prototype. Utilization of finite element method software packages significantly helped to reduce mass of landing gear system, and eliminated the necessity of making costly changes in the prototype.

References

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[6] HyperMesh 11.0 User Guide, Altair.