



SIMULATION STUDY OF A COMPOSITE LANDING GEAR OF ULTRALIGHT AND VERY LIGHT AIRCRAFT

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Received 09 August 2021, accepted 24 November 2021, available online 25 November 2021.

Key words: landing gear, aircraft vehicles design, knowledge-based design, drop test analysis, mechanical engineering, material engineering.

A b s t r a c t

There is a need to design new, lighter aircraft structures, which has a direct impact on the safety and costs of aircraft maintenance. One of basic parts of an aircraft is its landing gear, whose main functions are to enable taxiing, safe landing, take-off, and to assist the remainder of ground operations. Landing gear failures are usually related to metallurgy, processing, environment, design, and causes of overload. These are conditions that can be prevented using modern methods to calculate the strength of such a landing gear in various conditions. The paper presents stages of a simulation study of the fixed three-wheeled spring landing gear for an ultralight aircraft. Analysis of forces acting on the landing gear during drop test and their implementation by numerical computer methods allowed for the creation of a model in the CAD (Computer-Aided Design) tool and its FEA (Finite Element Analysis). These results were compared between a modeled classic spring landing gear and the one made of composite materials. The further goal of the research will be to build a drop test stand for a small landing gear used in airplanes and drones. This method has a significant impact on simplifying the design of the landing gear, its modeling, and optimization.

Introduction

The paper presents the stages of a simulation study of the fixed three-wheeled spring landing gear for an ultralight aircraft. The main assumptions of the paper are the type of landing gear mounting, the type of aircraft, and the layout of the landing gear, i.e. two rear wheels and the front one.

The limitations of the tested structures are the minimum load capacity, deflection, and thus the dissipation of the impact force during the drop test and landing, structure weight, and feasibility. The issues of attention are elaborated further in the text.

The landing gear analysis was performed based on mathematical equations developed based on applied mechanics. Shape optimization is an engineering problem, while the selected materials and their analysis are related to material engineering. Moreover, the analyzes were performed based on IT techniques. For the design purposes, the Zenith STOL CH701 aircraft was selected for which the landing gear was analyzed. This is a very popular aircraft in the world. It is well-known construction, but this model of an airplane is still produced (*Introducing the Zenith...* 2021).

For the aircraft to be admitted to air traffic, it must meet the requirements. Based on the CS-VLA and the general principles of designing the landing gear, calculations were made to determine the force acting on the landing gear during the drop test (*Easy Access Rules...* 2018). All the parameters adopted for the calculations were based on the data of the CH701 aircraft.

The landing gear is a very important structural element of an aircraft, as it is the only mechanical system in an aircraft that is adapted to contact with the ground, and its durability determines whether the aircraft lands safely. There are different types of landing gears in aviation. The article focuses on a three-wheeled beam-type landing gear. These landing gears are made of various materials such as steel and aluminum.

Due to the necessity to carry out a practical analysis, a design of a measuring stand is developed, the purpose of which is to compare the results obtained by mathematical analysis and by an analysis carried out in specialized software used in the aviation industry.

Figure 1 shows the scope of work needed to optimize the existing landing gear and use new material and shape for it. This work is focused on the steps marked with a red rectangle. These are the stages related to the initial design phases.

The next phases that will be carried out will present dynamic dependencies that should be met during dynamic analysis. The dynamic analysis will cover the entire landing gear, including wheels and tires. The first step is a static analysis of the chassis beam itself, which I focused on in this article. Landing gear failures account for many of all defects reported in general aviation. These errors are usually related to material properties, processing, environment, design,

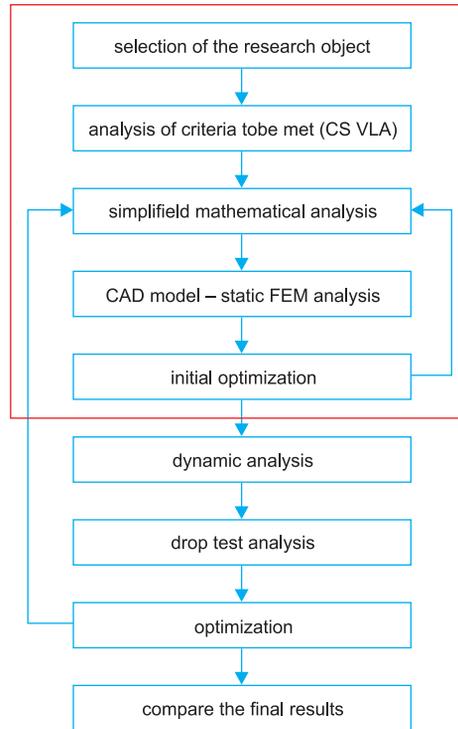


Fig. 1. Multidisciplinary approach to designing an airplane spring landing gear

and causes of overload. These are conditions that can be easily prevented by applying good engineering practices and maintenance practices that are usually well established in the aerospace industry (GUDMUNIDSSON 2013).

Landing gear efficiency depends on the damping system which is used in the landing devices. Highly effective rubber or hydraulic shock absorbers have high drag and weight. As a result, general aviation aircraft do not often use such damping devices. The most commonly used is the spring landing gear. Such a landing gear practically does not absorb impact energy and requires attention during landing. Of course, tires absorb some part of the energy, but it is a very small one and may not even be taken into account during the efficiency calculations. The shape and material of the spring used to have a direct impact on the performance of the selected landing gear (*Aircraft Landing Gear...* 2018).

The main approach reported in the paper is to perform FE (Finite Element Analysis) for the CAD (Computer-Aided Design) model of the Zenith STOL CH701 landing gear, using the calculations and recommendations contained in the CS-VLA.

This research aims to investigate ways of improving the efficiency of a general aviation airplane spring landing gear. The following tasks were solved to achieve

this goal: the laws of deformation of a standard metal spring and a similar composite spring were determined, the maximum load factor was compiled based on of values presented in the literature (RAYMER 1989) and an analysis of the landing gear mass change was made.

Landing Gear of General Aviation Planes

The main functions of the landing gear are to enable taxiing, safe landing, and take-off, support for the remainder of the safe landing and ground operations. Currently, the most commonly used system is the “three-wheel” landing gear. With a three-wheeled landing gear e.g. in front of the main wheels, the airplane is stable on the ground and can land at a large angle of attack. Usually ultralight and very light airplanes use a fixed landing gear (RAYMER 1989).

Many general aviation aircraft use steel, aluminum, or composite spring to pick up and dampen the impact. Spring is popular because it is mechanically simple, usually light, and requires no maintenance.

The advantages of composite landing gear brackets are that they are lighter, more flexible, and non-corrosive. As the plane lands on the ground, the springs bend upward, dispersing and transferring the shock load to the airframe at a speed that will not deflect the plane.

Requirements for landing gear of ultralight and very light planes

Requirements to the landing gear conditions for planes of little weight categories are described by special specifications (*Easy Access Rules...* 2018). Ultralight planes with MTOW (Maximum Take-off Weight) less than 450-600 kg must meet national documents of different countries. This class is regulated in the European Union Certifications Specifications for Very Light Aircraft (CS-VLA) (*Easy Access Rules...* 2018) and is limited to MTOW 750 kg. These requirements state that the calculated descent velocity, in meters per second, equals:

$$V_z = 0.51 \sqrt[4]{\frac{mg}{s}} \quad (1)$$

where

- m – MTOW (Maximum Take-off Weight),
- s – wing area,
- g – gravitational acceleration.

The vertical landing loads determined as a result of such a landing also must be recalculated in accordance with CS-VLA for lateral and frontal landing loads. The effectiveness of the landing gear on the aircraft should also be verified by performing drop tests from a height:

$$h = 0.0132 \sqrt{\frac{mg}{s}} \quad (2)$$

According to CS-VLA, the height of the free drop test should be in the range from 0.235 m to 0.75 m. As a result, the drop test is often the main design case of landing gear loading.

Taking into account that the requirements for the landing gear of ultralight aircraft are simpler than very light ones, they were not considered in this research.

Object of investigation

The considered STOL CH701 aircraft (Tab. 1) for which the landing gear was analyzed (Fig. 2) was selected for the analysis test. Designed for off-runway operations, the all-metal CH701 (Fig. 3), has many features that contribute to the aircraft's capabilities. The main difference of this aircraft is its ability to take off and land from very short distance.

For this, the wing of the aircraft has a very powerful aerodynamic devices: non-retractable slats and flaps.

Table 1

General characteristics and performance of CH701
General characteristics of CH 701
Wing area: 122.0 sq ft (11.33 m ²)
Max takeoff weight: 1,100 lb (499 kg)
Fuel capacity: 20 US Gal (76 L)
Powerplant: 1 × Rotax 912 four-cylinder liquid-cooled piston engine, 80 hp (60 kW)

Source: based on *Introducing the Zenith...* (2021)

The main landing gear consists of wide wheels with hydraulic brakes (Fig. 2) attached to a leaf spring. The spring is made of aluminum alloy. There are recesses on the spring in the places where the spring is attached to the fuselage. Those are stress concentrators from the strength point of view. The wheels are covered with mudguard to prevent dirt from the wheels from getting onto the propeller during off-runway operations.



Fig. 2. CH-701 plane
Source: courtesy V. Dudnik

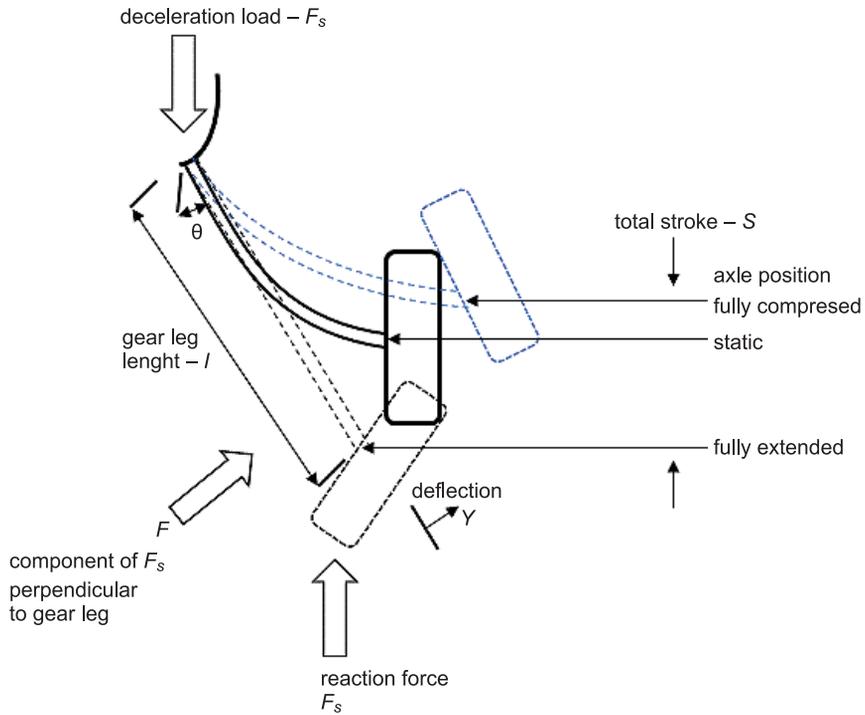


Fig. 3. Solid spring gear deflection
Source: based on RAYMER (1989).

Analysis based on simplified mathematical model and aircraft parameters

The shock absorber is represented by a leaf spring type, which depends on the elastic properties of the landing gear legs and normal force during contact with the ground. The diagram of the action of forces is presented in Figure 3.

For this example were calculated the reaction force F_s and a total stroke S .

$$F_s = \frac{WN_{\text{gear}}}{2}g \quad (3)$$

where:

- W – MTOW,
- N_{gear} – gear load factor,
- g – Earth's acceleration.

Gear load factor was taken from table data, for general aviation (RAYMER 1989):

$$N_{\text{gear}} = 3$$

The value of the force calculated from formula (3) is expressed as:

$$F_s = 7,342.8 \text{ N}$$

Then the total stroke is calculated for the aluminum and composite landing gear.

$$S = F_s(\sin^2\theta) \frac{l^3}{3EI} \quad (4)$$

where:

- θ – angle,
- l – length,
- E – Young modulus,
- I – moment of inertia.

It should be taken into account that different materials have different densities and Young's moduli. This has an impact on deflecting the landing gear leg during ground operations.

For the paper, a chassis made of 7075 T6 aluminum and Carbon Fiber Reinforced Polymer (CFRP) were considered. It should be emphasized that in this article CRFP was treated as an isotropic, homogeneous material, it is an introduction to the subsequent calculations, detailing the anisotropy of composite materials.

$$S_{\text{aluminium}} = 34.15 \text{ mm}$$

$$S_{\text{compostice (carbon fiber)}} = 16.42 \text{ mm}$$

Analysis based on a detailed virtual 3D model

The analysis was performed in SolidWORKS® using the simulation static analysis module. In the beginning, supports have been added that are represented by the green arrows in Figure 4. They mark the places of supports – for both the landing gear cases, these are places where the landing gear connects to the plane. The landing gear is mounted in clamps at the fuselage. In the places where the clamps are to contact the beam, planes have been added, where the bindings have been added so that the beam also bends in the middle, which is in line with the actual deformations. Figure 5 presents mesh application.

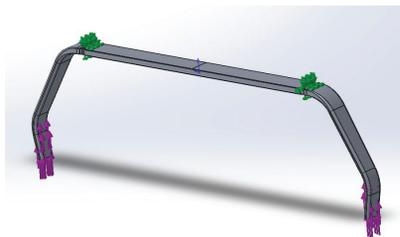


Fig. 4. Load and supports

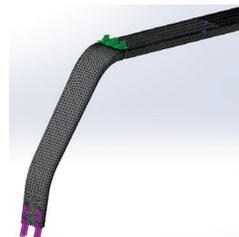


Fig. 5. Mesh application

Then loads were added. The force directions coincide with those in the plane, while the value was calculated using the analytical method. The purple arrows represent the force of F_s , calculated from formula (3), which is 7,342.8 N.

Then the material was selected, which is the aluminum alloy 7075 T6 and Carbon Fiber Reinforced Polymer. Again, to facilitate introductory calculations, isotropic properties of the composite material were assumed. Then the FEA mesh was selected, and the stress analysis was performed according to von Mises and deformation analysis.

For the analysis, a fine standard mesh was used with the size of one element: 8.5 mm and tolerance of 0.424 mm because it gives the most accurate results and the computation time is not significantly extended.

Table 2 shows a comparison of the analysis for an aluminum alloy beam for different mesh sizes.

Table 2

Dependence of the accuracy of the results on the size of the mesh

The global dimension of the mesh element [mm]	Mesh tolerance [mm]	Stress [MPa]	Displacement [mm]
33.95	1.69	208	22.72
18.25	0.91	227	23.02
8.48	0.42	216.5	23.17

Comparison of results for landing gear analysis from different materials

The von Mises maximum stress criterion is based on the von Mises-Hencky theory, also known as shear energy or maximum strain energy theory. Concerning the principal stresses σ_1 , σ_2 , σ_3 the von Mises stress in SolidWORKS® is expressed as (Dassault Systemes. 2019):

$$\sigma_{\text{Mises}} = \sqrt{\frac{[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2]}{2}} \quad (5)$$

The theory assumes that a plastic material starts to deflect at the point where the von Mises stress becomes equal to the stress limit. In most cases, the yield point is used as the stress limit. However, the SolidWorks® software allows using the maximum tensile strength or a user-defined stress limit.

$$\sigma_{\text{max.}} = \frac{\sigma_{\text{material}}}{k} \quad (6)$$

where

- $\sigma_{\text{max.}}$ – maximum allowable stress,
- σ_{material} – ultimate tensile strength for each material,
- k – safety factor, for landing gear $k = 1.5$ (RAYMER 1989).

The paper assumes that the maximum stress is the limit for a given material. The maximum stress for each material was calculated according to formula (6). For the landing gear, the FEA simulation was used for two materials – aluminum alloy 7075-T6 and CRFP. Static analysis was performed for the previously modeled landing gear. The parameters of the considered materials are presented in Table 3.

Table 3
Parameters of the considered materials

Type of spring	Young's modulus [GPa]	Weight [kg]	Volume [m ³]	Density [kg ³ /m]	σ_{material} [MPa]	$\sigma_{\text{max.}}$ [MPa]
Aluminium 7075 T6	71.7	13.7	0.00489	2,810	505	336.7
CFRP	150	7.8	0.00489	1,600	1,500	1,000

Source: based on INAGAKI (2000).

This analysis presents a static simulation of the landing gear deflection and von Mises stress under a given force F_s . The results in the form of reduced stresses and resultant displacements are presented in Table 4.

Table 4

Comeparison of results				
Type of spring	von Mises reduced stress		Resultant displacement	
	min. [MPa]	max. [MPa]	min. [mm]	max. [mm]
Aluminium 7075 T6	0.005	208	0	22.72
CFRP	0.01	265	0	11.23

Figures below are von Mises stress static analysis (Fig. 7) and displacement (Fig. 8) figures for a beam made of 7075 T6 aluminum. The place of stress is concentrated under boundary conditions.

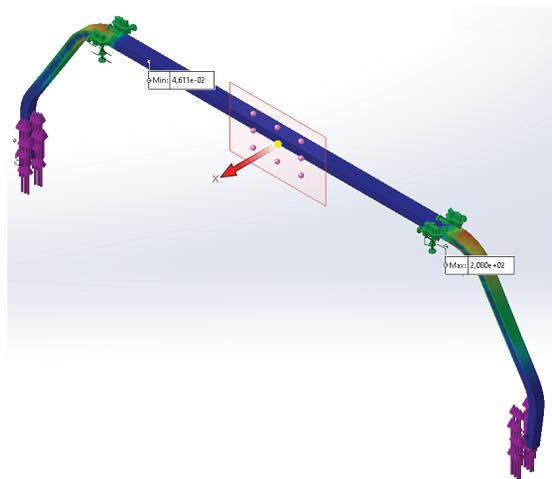


Fig. 6. Reduced stress according to von Mises – aluminum alloy

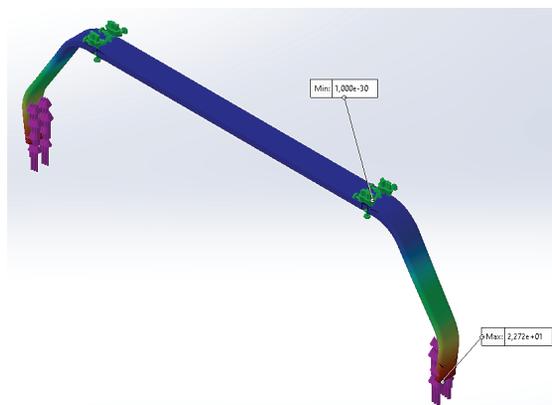


Fig. 7. Resultant displacement – aluminum alloy

The comparison of simulation results of the von Mises and displacement analysis are shown in Table 5.

Table 5

Comparison of calculation results

Type of spring	σ [MPa]	von Mises reduced stress Max. [MPa]	Deformation of lowest point [mm] – calculated	Deformation of lowest point [mm] – from FEA
Aluminum 7074 T6	336.7	208	34.15	22.72
CFRP	1,000	265	16.32	11.23

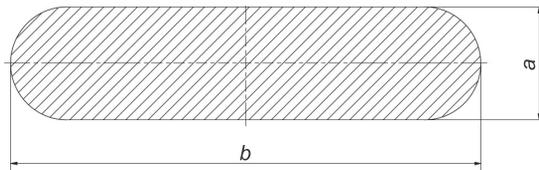


Fig. 8. Cross-section of the landing gear beam profile

Further analysis of the designed landing gear beam required interference with the shape of the profile used in the structure. Figure 8 shows the cross-section of the profile used in the analyzed beam. Its dimension is constant along its entire length and one of the main assumptions is to keep the b dimension constant. This assumption is required by the method of attaching the landing gear beam to the aircraft fuselage. The results of the analysis were obtained for the elements whose dimension was changed are presented in Table 6. The analysis shows the values of maximum deformations, displacements, and mass of the designed element.

Table 6

Results for changed thicknesses of the profile used

Profile thickness a [mm]	Maximum Stress [MPa]	Maximum Displacement [mm]	Mass [kg]
25	268.6	11.24	13.94
20	354.8	20.4	11.06
18.5	401.4	24.5	10.37
17	491.6	30	9.51

Conclusions

The presented transdisciplinary analysis concerns a simulation study of a composite landing gear of ultralight and very light aircraft. Limitations and rules that very light airplanes must meet were reviewed, and the object of investigation was selected. Based on the literature review, mathematical calculations of the aircraft parameters necessary for the drop test analysis were performed.

Computer-Aided Design (CAD) models were subjected to Finite Element Analysis (FEA) in the SolidWORKS® program, loading with previously calculated forces. At the same time, mathematical analysis was still carried out. The results of the mathematical analysis and FEA for the deformation of the landing gear were they are not identical due to the approximations used in the mathematical calculations. Some elements and factors important from the point of view of FEA, such as the fixing method, were omitted in the mathematical calculations. Based on the analysis presented above, comparative results of the landing gear for the two isotropic materials under consideration were obtained. The obtained results allowed for unequivocal determination of specific parameters for both types of the landing gear. The analysis showed that the landing gear made of CFRP showed less weight, greater resistance to reduced stress, and, as a result, less deflection of the beam. The results of the mathematical and computer analysis are presented in Table 3.

The maximum von Mises stresses for both the materials are less than the maximum calculated stresses. It should be noted that the SolidWORKS® program indicated the maximum reduced stresses in the places of the added supports, it is related to the problems of designing boundary conditions and results from measurement errors using the FEA method.

The highest stresses that occurred beyond the abovementioned points of support were respectively 137.7 MPa for the aluminum alloy 7075 T6 and 136.6 MPa for CFRP. It can be seen that the chassis made of CFRP is stiffer and lighter.

The next step in the analysis should be to analyze the CFRP material as a non-homogeneous anisotropic one, determining the orientation of the fibers. This will allow to improve the damping properties of the landing gear springs, to optimize its shape and further weight reduction.

The landing gear beam made of CRFP seems to be a better alternative for light aircraft, where the weight of all components is very important. Future research will be focused on improving the composite landing gear model and performing more advanced calculations taking into account the structure of this composite beam, the method of carbon fiber reinforcement, and the resulting anisotropy of local beam properties. In further studies, dynamic and simulation analysis for the drop test of a beam made of both materials will be carried out.

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