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ISSUES IN DESIGNING OF MECHANICAL PARTS MODELS IN CAD PROGRAMS

Paweł Grygorcewicz* and **Konrad Raczko**
Materials and Structures Research Center, Łukasiewicz Research Network, Institute of Aviation,
Al. Krakowska 110/114, 02-256 Warsaw, Poland

Abstract
The article describes methods of creating mechanical parts in 3D programs, together with presenting very significant issues that emerge during the designing process employed in this creation, the main goal being to show the most important factors playing a role in the design process. Resultantly, it is ascertained that the most important factors needing to be considered by a designer are, inter alia, mass of the parts, strength, and kind of material. The article indicates the different types of parts used in different load cases, the objective being to explain various aspects relevant to design. The parts were different in particular in their nature of work and purpose. The article also presents illustrations after finite element method (FEM) analysis. It was important and interesting to observe how the stress in the tested parts was distributed under load and how the structure changed when the used material changed. The stress had a very large influence for the design of every airplane part; a case in point would be the illustration available from the lever example. The main role of this article is to describe different designing factors that could help a specialist create new designs in the future.

Keywords: designing; design; model 3D; mechanical parts; lever; support
Type of the work: research article

1. INTRODUCTION

The purpose of this article is to show the design process associated with the designing of parts using 3D programs. After optimisation, these parts could find application in real machines, airplanes and vehicles. The first part that was considered was the force actuator support. The designing factors have been demonstrated by using the support as an example. The support was created to transfer large forces through the actuator to the ground during working. The support was attached to the cylinder. This design was created to move large elements. The support consists of the following parts: support, bolts, shaft, nuts and washers. This part was designed in the Solid Edge 2019 Siemens 3D application.

It is also necessary that the designer should always consider the most important factors influencing the prototype [1]. Sometimes it is difficult to reconcile conflicting demands, for example costs with quality. The role of the designer would be to choose the best solution, as well as ascertain the compromises that it might be necessary to make. The main factors influencing the design of the parts are: weight, compatibility and flexibility, reliability and durability, ease of installation and maintenance, low-cost operation and low-cost components. All of these factors were considered in designing a prototype of a different part [2]. A presentation of the important factors during the designing process is provided below.

* Corresponding Author: pawel.grygorcewicz@ilot.lukasiewicz.gov.pl
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These are the main factors and their considered features:

- Geometry: Dimensions, height, width, length, diameter, space requirement, the number, arrangement, connection, extension and enlargement;
- Kinematics: Type of motion, rotation, speed and acceleration;
- Forces: Direction of the force, the frequency of the force power, weight, load, strain, stiffness, elasticity, strength, mass, stability and resonance frequency;
- Energy: Power, efficiency, loss of energy, friction, ventilation, state, pressure, temperature, heating, cooling, power connected, power and energy conversion;
- Material: Material flow and transport material, physical and chemical properties of the product of the input and output materials, materials in accordance with the regulations, and quality;
- Signal: The input and output of measured values, the shape of the signal, indication, supervision and control instruments;
- Safety of exploitation: Direct safety technology, safety systems, safety and environment;
- Ergonomics – man–machine interdependence: Support, the amount of operating positions, means of handling, comfortable seating, the lighting and the type of industrial application;
- Production: Restrictions on the part of the plant, the largest feasible size, the preferred method of production, means of production, attainable quality, tolerances and the percentage missing;
- Control: It is possible to measure and verify; specific rules (norms and prescriptions of the various levels of the organisation DIN, ISO, etc.);
- Installation: Special installation prescriptions, assembly, building, assembly on place, and foundation;
- Transport: The limitations kind of lift, profile rail or road transport types, the permissible size and weight, and the manner and conditions of transport of consignments;
- General use: Low noise, wear and tear arising from the use and disposal of land, and the place of use (e.g. sulphur vapour atmosphere, tropical climate);
- Service: Redundancy maintenance jobs, the number of maintenance activities, the time required for maintenance, inspection, replacement and repair, coating and cleaning;
- Costs: Maximum allowable costs of production, the cost of utilities, investment and depreciation;
- Deadline: Completion of design and development, site-based intermediate steps, and delivery.

In our examples of parts, not every factor from this list was important. The factors were mentioned to show the complexity of designing with regard to different issues.

2. SUPPORT PART

The first example in our article is the support part, which was designed specifically with regard to this function. Its main role is to transfer the force from actuator to the ground. The building of the support is shown below (Fig. 1).

The building of the support encompasses the following elements:

- main body,
- shaft,
- fastening screws,
- nuts,
- washers.

The red arrow in the illustration (Fig. 2) indicates the force applied by the actuator cylinder on the support. The main purpose of the designed structure was to transfer forces in such a way that the support bolted to the ground and stably transmitted all forces. As the reader can see, the forces have been closed in such a way that it has become possible to transfer loads without damaging the support.

Ribs and shelves were added during the construction to provide support in the most loaded areas. The main body was welded – the reason being that such a pattern of construction, among various types of production, offers the simplest design in conjunction with the lowest cost.

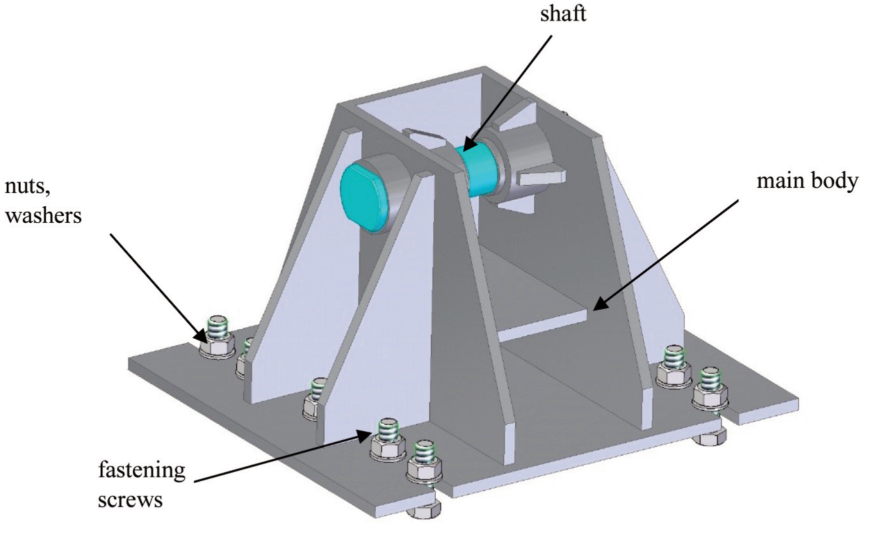

Figure 1. Force actuator support.

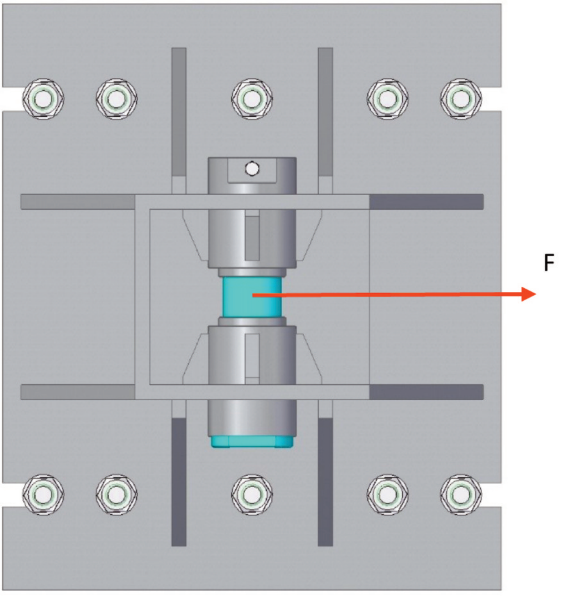

Figure 2. Force actuator support – the force direction.

In this example, two factors were considered very important in terms of influencing the cost, namely production and installation to the ground. The installation is needed to ensure safety during the functioning of the system device. The position of the support simply had to be changed.

Since the profitability of the enterprise, as well as the project's individual profitability position, is a main factor motivating any undertaken activity, the cost of production is naturally an important factor almost universally; and the cost of production is connected exclusively with material costs and costs of tooling on machine.

The most important dimensions of the support have been presented below to enable the reader to more easily imagine the size of the part. The height of the support was about 460 *mm*; the width was about 800 *mm* and length was about 680 *mm*. The main role of the support was to ensure the point of mounting the actuator to the ground. The actuator pulled large mass. The amount of force was about F = 22 kN. Elucidating the complexity of the mechanisms that were conducted for the support is not comprised in the aim of this article; so, the authors mainly focussed on the support.

Nowadays, it is possible to execute the entire design process using a computer aided design (CAD) process, by using specialised programs such as Solid Edge. During the design process, every part of the future design is modelled in 3D using the above-mentioned program. This allows the user to make changes easily and to adjust the model as needed. In this phase, models are used to check the design, to gain a better understanding of problem areas, to display kinematics and to evaluate the whole mechanisms. After the completion of 3D modelling, the next step is the creation of design documentation: assemblies drawings and technical recommendations [3].

2.1. Finite element method (FEM) support analysis

The support finite element model was created in MSC.Patran. FEM analyses were performed in MSC.Nastran solver. The main body was modelled by deploying a first-order 3D 8-node brick solid elements hexahedral type. The main body was fixed in the mounting fastener holes by constraining all three translational degrees of freedom (dof 123) characteristic of solid finite elements (Fig. 3) [4].

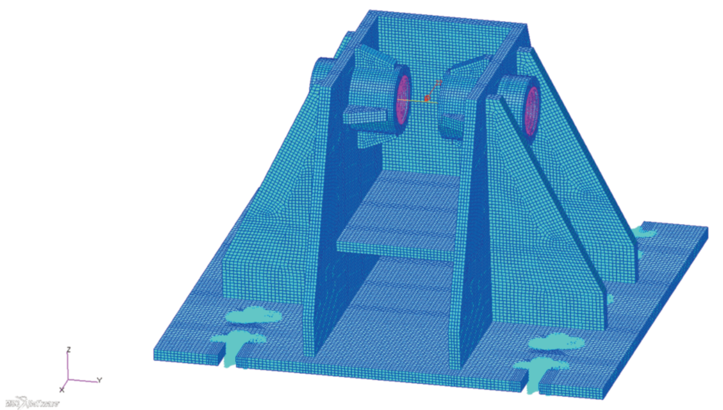

Figure 3. Boundary conditions and general load application.

The bolt was modelled by using beam elements; and contact between the main body holes and the bolt was simulated by using rigid body elements RBE and nonlinear GAP elements and a clamp bolt end (Fig. 3). It was assumed that the support would have been made of steel S355, which had a yield strength equal to 335 MPa.

During the designing phase, the support model 3D was optimised. As can be seen in Fig. 4, the higher levels of stress occurred in different areas. The material was stronger than the stress in support. The special ribs were designed to ensure that the part intended for maximal exposure to the stress would be capable of withstanding the same. In this example, this part was used on the machine in a laboratory.

For this reason, and others, for instance the value assumed by the concerned factor, the mass of this part was not considered the most important criterion. [4]. However, in other cases, especially pertaining to the parts used in airplanes, the mass is one of the most important parameters.

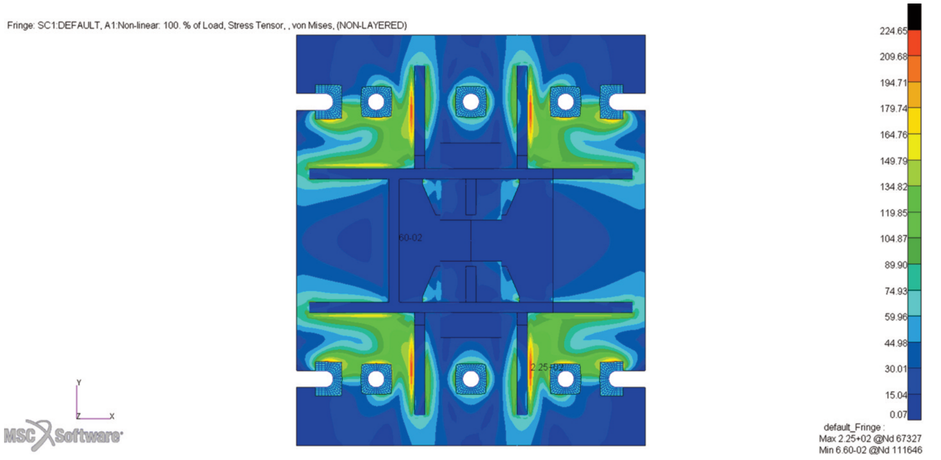

Figure 4. Distribution of von Mises stress in force actuator support.

In this example, the most important parameters were strength, the easy production, availability of material and chip production method. For example, it is for this reason that welding and machining were required to be carried out for the support in such a way that the formation of planes would be ensured.

The analysis produced an answer that the part seemed to be sufficient for the forces for which the part was designed. The analysis was very important and indispensable because the designer needed to ensure the level of stress in the designing part. The highest stress in this example was σ_{max} = 225 MPa, and is below the yield strength for the material of force actuator support (Fig. 5).

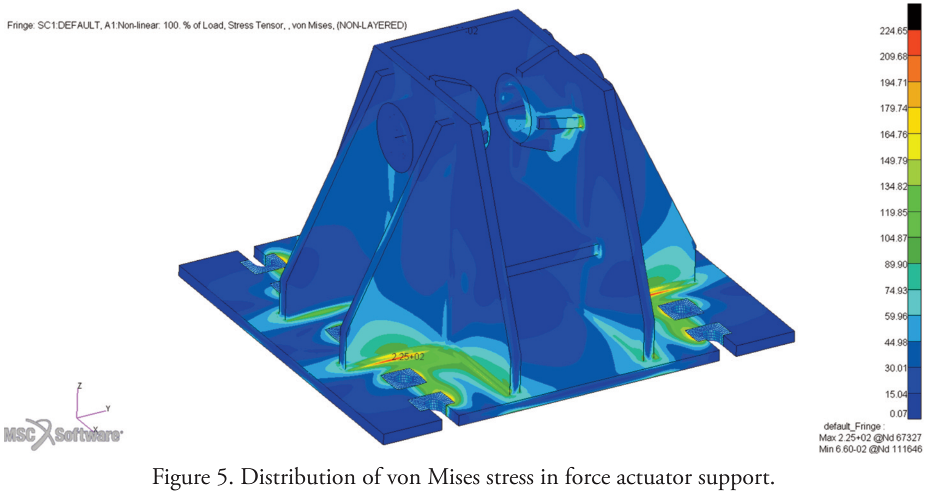

Figure 5. Distribution of von Mises stress in force actuator support.

The final results are shown in the article. Initial changes were connected with thickness of walls and ribs. The final design was achieved through a few iterations of calculation and design changes.

3. LEVER PART

The lever is the other example of the designing part. The lever was designed as the part of the main landing gear for an airplane. This part was designed using the 3D-modelling-capable Solid Edge 2019 application. The aluminium material 7075 was firstly chosen for application in this part. In this example, the strength of aluminium material 7075, which was considered in making the relevant computations, was R_m = 538 MPa (Fig. 6).

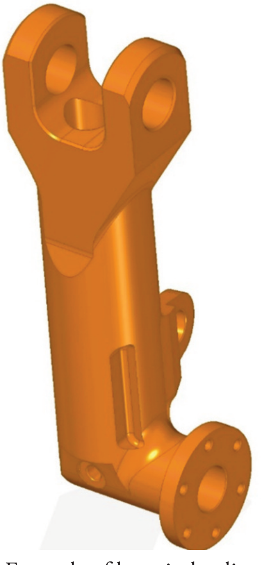

Figure 6. Example of lever in landing gear.

The mass of the aluminium lever was 7.735 kg. The aluminium material ultimate tensile strength was R_m = 538 MPa.

The FEM analyses were made in a few stages. These analyses mainly aimed to maintain the ability to endure the loads and the forces that were generated during work.

The evolution of lever design was allowed to proceed simultaneously with the mass and strength optimisation. Thereafter, all changes occurring in the lever design were connected with kinematics changes taking place in the full landing gear and airplane, and in agreement with the main designer of the airplane.

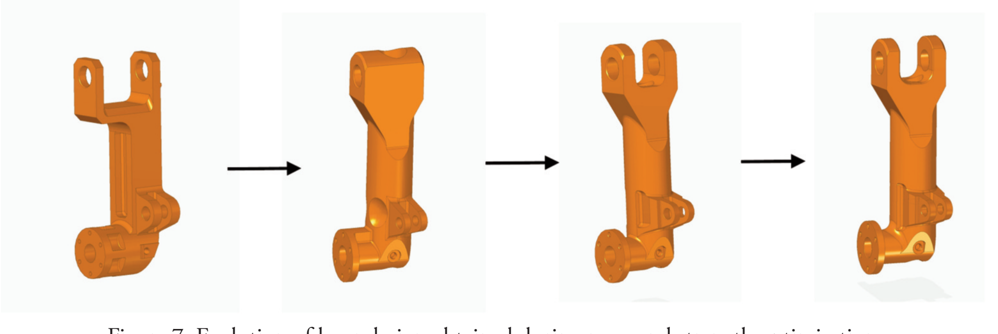

Figure 7. Evolution of lever design obtained during mass and strength optimisation.

It is really amazing what the lever looked like in its earlier stages. These design changes are shown above (orange part; Fig. 7). In the first stages, the designing was rather rough. In the last phase, the lever was optimised to aluminium alloy. The most important factors considered in the process of designing the lever were: geometry, kinematics of landing gear, forces, weights, loads, strength, material, costs, and methods of production.

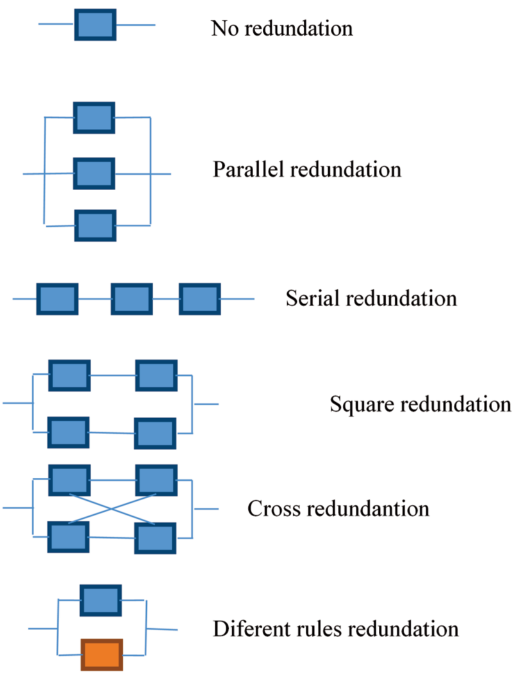

Figure 8. The redundant systems [6].

During every phase of the designing process, the part was changed. Weak points were reinforced and eliminated. Due to decreased mass and successive elimination of lesser points from the design, every iteration seemed to produce a better result in comparison with the one immediately preceding it.

Both parts, lever and support, are with no redundation, which ensures that the failure of the part results in a whole system brake [5].

Sometimes there are used systems with redundation, implying that if the part brakes, the other part would take control over the full process (Fig. 8).

4. FEM LEVER ANALYSIS

The lever finite element model was created in MSC.Patran. The FEM analyses were performed in MSC.Nastran solver [7]. The lever was modelled based on and used first-order 3D 4-node tetrahedral solid elements. The component was modelled as an integral part of the main landing gear. It was attached with appropriate boundary conditions to the rest of the main landing gear components made of beam elements [4]. All contact areas between the lever body holes and bolts were simulated. There were used rigid body elements RBE and nonlinear GAP elements including clamp bolt ends (Fig. 9).

Several calculations were carried out until the designer achieved a satisfactory level of stresses in the lever in relation to the weight of the part.

As mentioned above, in this example, owing to the fact of the lever needing to be deployed in an airplane, there were different aspects of designing that assumed a particular importance during this phase, including, primarily, weight and reliability. The maximum stress in the lever was about σ_{max} = 382 MPa (Figs 10 and 11).

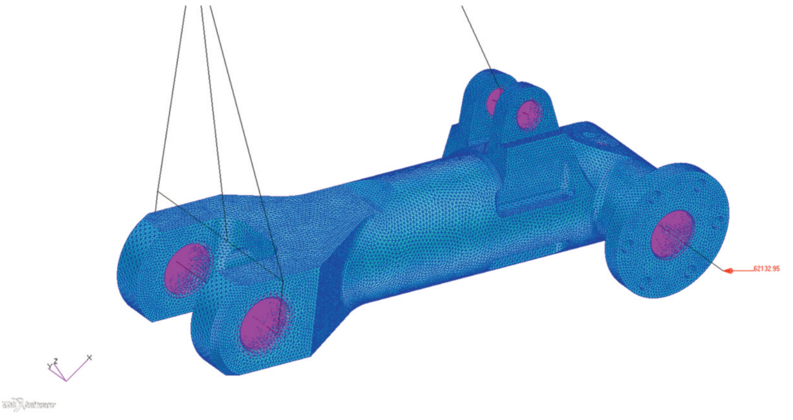

Figure 9. Lever boundary conditions and general load application of the main landing gear. Lever as a part of the entire main landing gear model.

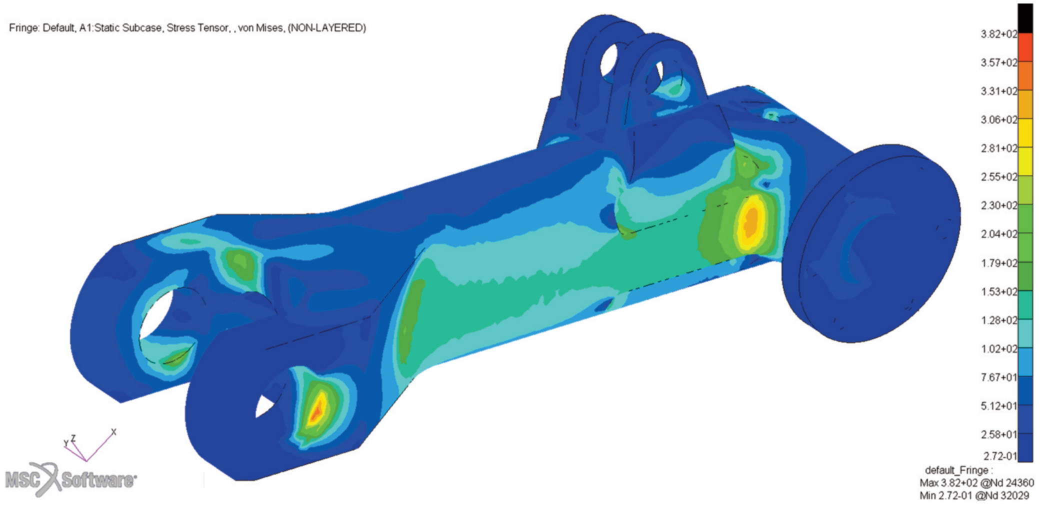

Figure 10. Lever after FEM analysis – distribution of von Mises stress in aluminium lever. FEM, finite element method.

The lever shown above (Fig. 11) was designed from 300M steel. In this example, 300M steel having an ultimate tensile strength of R_m = 1800 MPa was deployed. In this example, the mass of the lever was 8.807 kg. This steel is a very popular material that is used in different landing gear designs in Western countries. So far as our designing methodology is concerned, other materials, too, have been used in the past in our Landing-gear Department.

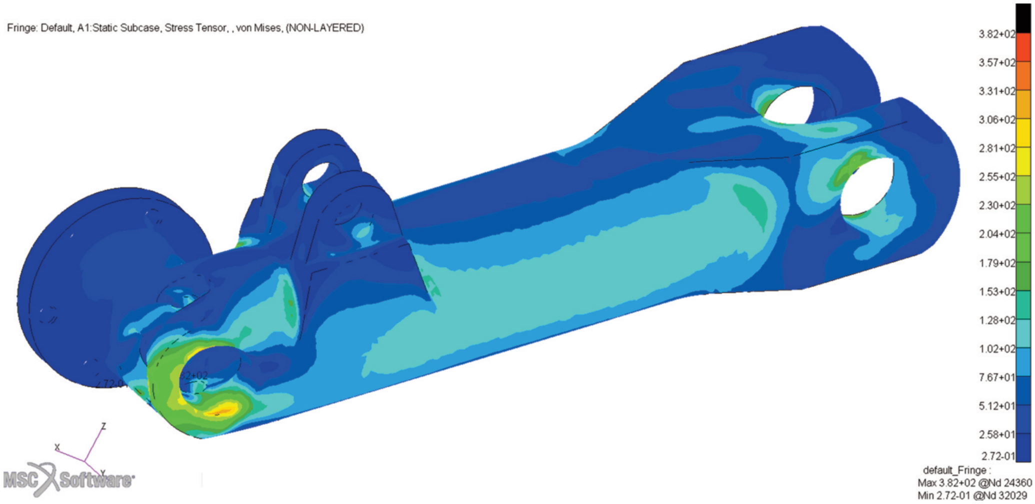

Figure 11. Lever after FEM analysis – distribution of von Mises stress in aluminium lever.
FEM, finite element method.

Maximum stress in the steel lever was about 1160 MPa. This is illustrated in Figs 13–14.

Figure 12. Design of lever from steel material.

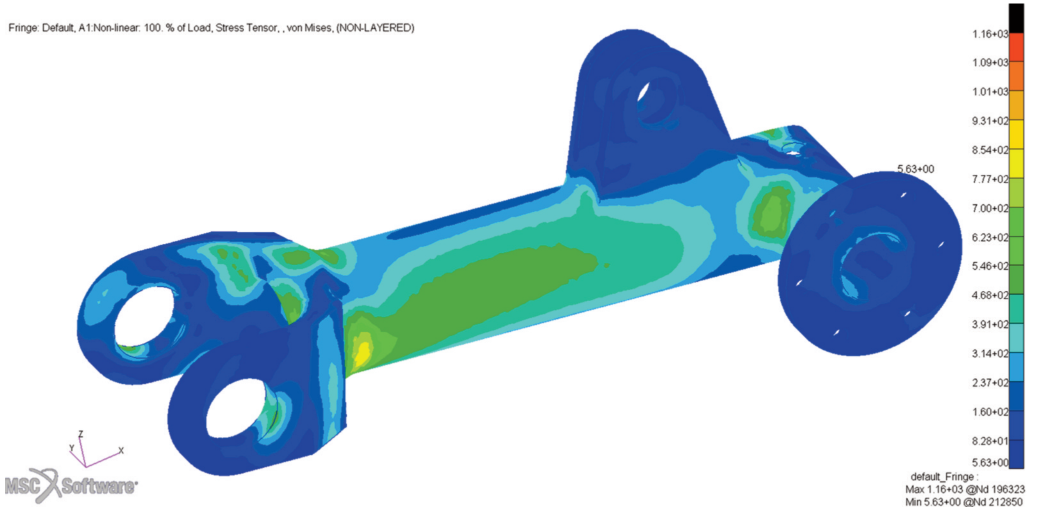

Figure 13. Distribution of von Mises stress in steel lever – spring back, U_{max} (U_{max} denotes max. deflection of the shock absorber).

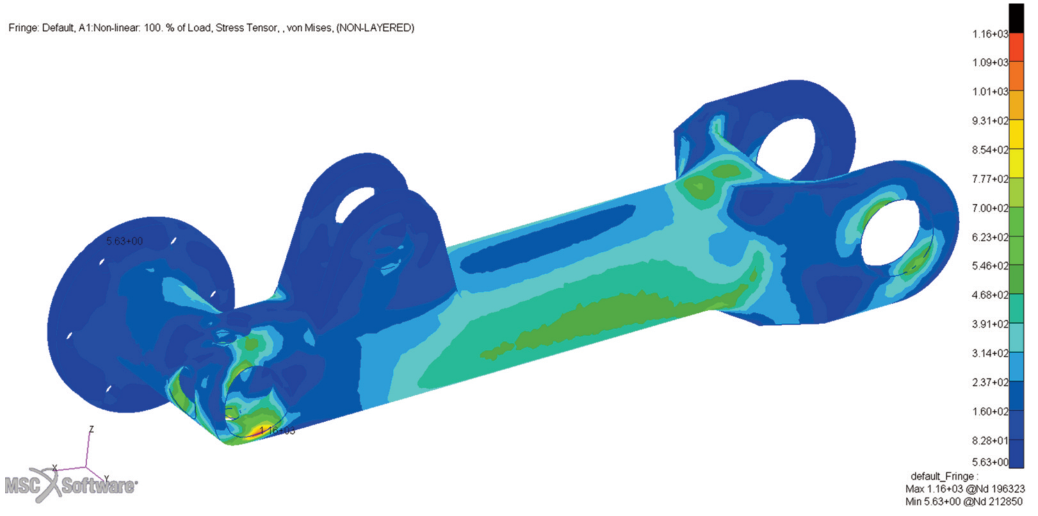

Figure 14. Distribution of von Mises stress in steel lever – spring back, U_{max}.

One of the reasons behind changing the material of the lever from aluminium alloy to steel was the possibility to reduce the space occupied by the landing gear in the airplane. The hiding space limited the possibility of mounting large objects. Parts masses seemed nearly the same. It was very significant that for steel, all flanges as well as facets were thinner, and therefore bolts as well as axles could have been shortened. Steel was much more durable than aluminium alloy, and for this reason, the faces in steel were thinner. Steel was preferred due to fatigue strength and the risk of intercrystalline corrosion.

In this example, the lever was a part of the main landing gear, which was designed for airplanes, and thus certain select factors were very important, namely mass, strength and material [8]. The first of the mentioned factors was very important due to cost of fuel during flying, which could have been very expensive. If the parts are lighter, the trips undertaken by the airplane will be more efficient as well as cost-effective. The second of the mentioned factors – namely, strength of the parts – was optimised, too, because during landing, high forces would be operational from the ground to the main landing gear. During calculation of the strength of the part, the required safety factor was included, in adherence with airplanes' certifications specifications (CSs). Both these factors were the most important during designing.

The third factor – flawless production of the part intended for application in an airplane – had to be perfect. Scratches or damages were unacceptable. For this kind of airplane part, special materials were used, such as steel 30HGSA or 300M, or aluminium alloys.

In the normal designing process, sometimes there are many changes of design, and then the whole part could come to be characterised by a need for change. For example, this could happen when there are changes in kinematics or hiding space. In this example, the whole design needed to be redesigned. Sometimes, there was a need to undertake a complete redesigning of the main landing gear, and in such cases, the iteration process of designing needed to be carried out from the beginning.

The installations of the different designed parts were the critical points during the assembly phase. For example, different groups designed landing gears, fuselage, engines, wings and many other components. These issues had been discussed and established. All these facts had been taken into account during designing parts in different areas [9].

5. CONCLUSIONS

In the presented article there were shown the designed parts and the optimisation of these parts. The issues connected with designing were mentioned to enable visualisation of the different aspects of designer problems. This designing process in its entirety is very important from the perspective of safety, because there is a need to prepare the designed part in such a way that it could be suitably deployed in airplanes without violating potential safety concerns. The parts that are used in airplanes need to be without damage, well-produced, strong, corrosion-resistant and light-weight. In this article, the authors have demonstrated mainly the issues pertaining to the designing of two different parts. As the reader would be able to see, there were many factors related with the design that exercised an influence upon the parts. All these aspects were shown in consideration of the examples of force support and lever. The main role in machines for these two different parts are specific and characteristic. For this reason, every solution would be different. Very significantly, the airplane components whose manufacturing simulations were produced as part of the present study were designed according to Certification Specifications for Normal, Utility, Aerobatic, and Commuter Category Aeroplanes CS-23, and accordingly included the required safety factors. The verification of proper designing of the prototypes parts was conducted in a laboratory.

Every part was analysed in Nastran, and this is very important because validating the conceptual fidelity of the designing process is vital. In the absence of such an analysis employing Nastran, using only laboratory testing to verify the designing process could have been very expensive and time-consuming [10].

After the designing phase, the parts and lever were produced and tested in a laboratory, where the design was verified. In our case, the Lukasiewicz Institute of Aviation Landing Gear Laboratory was used for the testing of the designs generated for our new landing gear prototype. For main landing gears, the following tests were the ones mainly carried out: drop tests, braking tests and test of functionality. The tests were performed in special test stands, such as the Mlot 3T with treadmill and the Mlot 40T drop-machine; but more information about these stands will be provided in other articles by the present authors.

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