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Numerical Structural Analysis of Main Landing Gear System Using ANSYS

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التحليل الإنشائي العددي لنظام معدات الهبوط الرئيسية باستخدام برنامج *ANSYS*

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Abstract

The structural analysis of titanium (Ti) and aluminum (Al) alloys was conducted using ANSYS. The analysis studied the mechanical properties of these alloys including deformation, stress and strain characteristics under operational loads. The analysis showed that the total deformation of Ti Alloy (2.33 mm) is smaller than that of Al alloy (3.66 mm), indicating that the former alloy exhibited higher structural stability and lower susceptibility to yielding. It was also found that both alloys experienced similar maximum principal stresses of ~23MPa. Moreover, the uniform stress distribution observed for both alloys indicated structural stability and reduced suitability to localized failure. Both Von Mises and principal stress analysis, confirmed the high strength of the alloys under tensile and compressive loads.

The equivalent elastic strain of Ti alloy (0.2 mm/mm) is smaller than that of Al alloy (0.3 mm/mm), which is in agreement with the elastic moduli of both alloys. These results confirm that Ti alloy is suitable for critical aerospace applications where high strengths, reduced deformations and high resistance to fatigue are required. Due to its higher energy absorption and deformation, Al alloy was found to be more suitable for applications where energy dissipation is more desirable compared to structural rigidity. Finally, the structural analysis revealed the importance of material selection in aerospace engineering based on specific performance and safety regulations.

Keywords: Main landing gear, Finite element analysis, Von Misses stresses.

الملخص

يُسلط التحليل البنيوي لسبائك التيتانيوم والألومنيوم الذي تم إجراؤه باستخدام برنامج ANSYS الضوء على السلوكيات الميكانيكية المميزة لهذه المواد تحت الأحمال التشغيلية، مع التركيز على خصائص التشوه والإجهاد والانفعال. كشفت النتائج أن سبيكة التيتانيوم أظهرت أداءً بنيوياً أعلى مع تشوه إجمالي أقل بلغ 2.33 مم مقارنة بـ 3.66 مم لسبيكة الألومنيوم. وهذا يُظهر تمتع سبيكة التيتانيوم بسلامة بنيوية أعلى وقابلية أقل للانبعاج. أظهر تحليل الإجهاد أن كلا السبيكتين تعرضتا لإجهادات رئيسية قصوى متشابهة (~23 ميجا باسكال)، مع توزيع موحد للإجهاد، مما يساهم في تعزيز متانة البنية وتقليل حالات الفشل الموضعي.

تطابقت نتائج الإجهاد المكافئ مع تحليل الإجهاد الرئيسي، مما أعاد تأكيد قوة السبائك تحت أحمال الشد والضغط. كما أظهرت سبيكة التيتانيوم انفعالاً مرنًا مكافئًا أقل (0.2 مم/مم) مقارنة بسبيكة الألومنيوم (0.3 مم/مم)، بما يتوافق مع معامل مرونتها الأعلى وخصائصها الميكانيكية المتفوقة. تشير هذه النتائج إلى أن سبائك التيتانيوم أكثر ملاءمة للتطبيقات الحرجة في مجال الطيران، وخاصة في أنظمة هبوط الطائرات التي تتطلب قوة عالية وتشوهاً أقل ومقاومة للإجهاد. في المقابل، فإن سبيكة الألومنيوم، مع قدرتها الأعلى على امتصاص الطاقة ولكن بتشوه أكبر، قد تكون أكثر ملاءمة للتطبيقات التي تُعطي الأولوية لتشتيت الطاقة بدلاً من الصلابة البنيوية. كما تؤكد هذه الدراسة على أهمية اختيار المواد بناءً على متطلبات الأداء والسلامة المحددة في هندسة الطيران.

الكلمات المفتاحية: معدات الهبوط الرئيسية، تحليل العناصر المحددة، إجهادات فون ميزس.

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1. Introduction

The Main Landing Gear System is one of the most significant sub-systems of an aircraft being utilized during take-off, landing, and ground operations. Its purpose is to provide support to the aircraft while it is taxiing, taking off, or landing. Shock absorbers, wheels and tires, and axel beams form the main components of an aircraft landing gear. The safety and reliability of an aircraft operation fundamentally depends on the structural integrity and functionality of the landing gear system. A landing gear must withstand very large compressive stresses and impact energy during these operations. These components are subjected to casual jolts of loads and stresses, particularly during take-off when forces are extreme. For this purpose, the design of a landing gear must accommodate significant loads and stresses while ensuring low weight to optimize aircraft performance [1, 2].

The landing gear system is a constituent setup system of complicated assemblies and parts to form an aircraft and controls its weight which affect the aerodynamic response of an aircraft. Structural analysis assists in weight reduction while increasing functionality and retaining the original purpose of the system. This helps improve the general energy used by the system to operate efficiently which leads to aircraft fuel efficiency and overall vehicle operation performance. Evaluating the structural strength of an aircraft landing gear over its life span is also important. The analysis assists in designing the lifetime of the system components.

Conducting a structural analysis of the landing gear system is very important for safety and security concerning reliability, performance, and safety of aircraft operations. A detailed structural analysis guarantees that all these stresses are appropriately dealt with and controlled without failure keeping both the aircraft and the people onboard safe. Some historical data [3–5] show that there was quite a number of landing gear system failures which culminate to the failure of the entire aircraft system.

Perkasa et al. [6] conducted a structural strength analysis of the retractable main landing gear of an unmanned aircraft vehicle. Their analysis specifically addressed the impact loads that arise from vertical landing speed. The study employed the finite element method to evaluate the landing gear's strength across various loading conditions. They concluded that assessing the structural integrity of landing gear against vertical landing impact loads, using finite element analysis, is a vital step in its design and evaluation. Gopalakrishnan et al. [7] described an exhaustive case study on the numerical simulation of the course of operation of the toggle assembly of aircraft landing gears. The simulation indicated that this component performs satisfactorily with respect to the strength criteria. This is vital considering that the landing gear experiences considerable cumulative fatigue during taxi, take-off and landing cycles. A noteworthy outcome from the investigation is the consideration of the use of aluminum instead of steel for the toggle assembly. The results indicated that even if steel is removed, the performance of the assembly will still be satisfactory since it will lighten the load without trading off strength. Udayakumar et. al [8] emphasized the necessity of grasping the working principles concerning the operations of landing gear systems. This aspect is important in the design and engineering work within the aircraft industry for the purpose of safety and effectiveness. The investigators noted the different types and arrangements of landing gears available in the aviation industry. This study looked into common failure mechanisms of the landing gear and provided suggestions on their functional and structural reliability which is essential in the optimization of aircraft performance and safety. Yadav et. al [9] studied the stress distribution of the nose landing gear for STOL aircraft. The researchers were able to demonstrate the use of SOLIDWORKS for modeling and ANSYS for performing numerical simulations. They modeled the torsional and bending stresses of the landing gear during operational and extreme load conditions to analyze stresses distribution and deformation. They found that the gradient of the runway greatly affects the mechanical stresses and displacement that would take place under these operational conditions. Ni et. al [10] performed finite element analysis on the aircraft landing gear shock strut made of Ti-6Al-4V material. The analysis revealed that the maximum deformation occurs at the connection point between the inner and outer cylinders of the piston rod. The simulation results provide a valuable foundation that can be used for subsequent optimization and further processing of the landing gear design.

The objective of this study is to conduct a structural analysis of landing gear using ANSYS simulation. The simulation assessed in evaluating the structural integrity and performance of the landing gear system under loading condition. This research aimed to; (1) calculate the static load distribution among landing gear parts to ensure structural safety against operational loads, (2) calculate stress concentrations via Finite Element Analysis (FEA) for determining potential failure sites hence ensuring safety margins, and (3) examine two candidate materials (titanium alloys (6Al-4V) and aluminum alloys (7075-T6)) based on their mechanical properties like strength, fatigue life and Young’s modulus to ensure operational loads performance.

2. Computational

2.1 The Physics

In structural analysis using ANSYS, the normal and shear stresses of the main landing gear are described using the three-dimensional stress tensor in equation 1. Determining these stresses is crucial for ensuring that the landing gear can safely support the aircraft during landing, taxiing, and takeoff [11]. These stresses were calculated at each element node, enabling identifying areas of high stress concentration, such as near mounting points or where the gear interfaces with the wheel and strut.

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$$\sigma = \begin{bmatrix} \sigma_{xx} \ \tau_{xy} \ \tau_{xz} \\ \tau_{yx} \ \sigma_{yy} \ \tau_{yz} \\ \tau_{zx} \ \tau_{zy} \ \sigma_{zz} \end{bmatrix} \qquad (1)$$

where:
σ_{xx} , σ_{yy} , and σ_{zz} are the normal stress acting on the x, y, and z planes, respectively.
τ_{xy}, τ_{yx}, and τ_{xz} are the shear stresses caused by tangential forces.
The maximum and minimum normal stresses acting on the landing gear under various loading conditions were determined from the principal stresses. The stresses were used to evaluate the gear's performance under extreme loads, such as hard landings or emergency braking, as they directly correlate with failure theories like von Mises and Tresca criteria. The principal stresses are derived from the stress tensor by solving the eigenvalue problem [11]:

$$\det(\sigma - \lambda I) = 0 \qquad (2)$$

where λ are the principal stresses.
Analyzing the deformation of the main landing gear is another critical parameter as excessive deformation may compromise the stability and safety of aircrafts. Material properties (e.g., Young's modulus, Poisson's ratio), loading conditions, and boundary constraints influences the deformation. In this work, the total deformation was computed as the resultant displacement of each node in the finite element model under applied loads.
In simulation with ANSYS, stress and strain are defined by Hooke's Law for elastic materials [11] as in equation 3:

$$\varepsilon = C^{-1}\sigma \qquad (3)$$

where ε is the strain tensor, and C is the stiffness matrix.
Finally, by solving equations 1 through 3, it was able to calculate the strain field, integrate it over the geometry, and ultimately output the total deformation.

2.2 Geometry

The design of the main landing gear shown in figure 1 was adapted from that of the Airbus A330. SpaceClaim was used to modify and integrate the geometry of the landing gear to match the design goals and constraints of this study. This was achieved by extracting parts from the base models, scaling each component for proportionate accuracy, and designing new parts to fill in any gaps or to improve functionality.
The design was performed systemically to maintain consistency across all dimensions while preserving the structural and mechanical integrity of the model. For components that required large scale modifications which didn't exist in the base models SpaceClaim's tools were used to create custom geometries which were then aligned with the overall design goals and constraints.

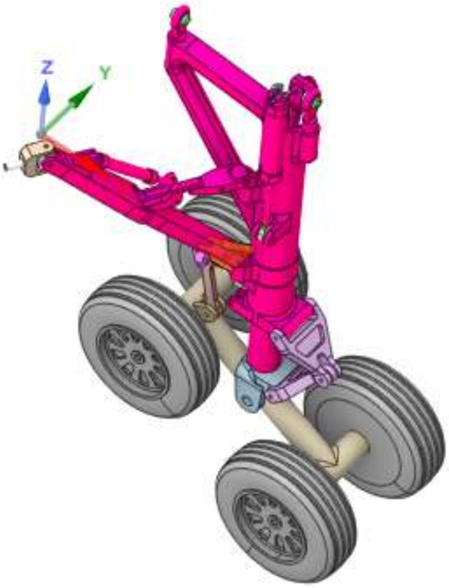

Figure 1. Model geometry.

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Once the CAD model was complete it was subjected to a very detailed preparation stage which is required prior to analysis. The geometry was cleaned up by removing unnecessary features such as small fillets or holes that would complicate meshing and don't greatly affect the results. Moreover, all parts which may have been out of tolerance or had gaps that would break the model's integrity were excluded from the model. In this stage the model was also simplified without losing accuracy. For instance, surface texturing which has little effect on the structure as a whole was omitted. Finally, the refined geometry was divided into different regions into which the material properties and boundary conditions were assigned.

2.3 Materials Selection and Properties

Once the geometry was created, appropriate materials properties such as Young's modulus, Poisson's ratio, yield strength were assigned to the components under study. The appropriate selection of these mechanical properties allowed for precise examination of the response of the system under different loading conditions representing real-world scenarios. This approach would improve the accuracy of the simulation results which in turn would help in the selection of the right material for the design and ultimately improve the safety and reliability of the landing gear system. In this study, high-strength titanium (annealed Ti-6Al-4V) and aluminum 7075-T6 were investigated. These materials will be referred to as Ti alloy and Al alloy here after and their mechanical properties (sourced from the extensive materials library available in ANSYS software) are listed in table 1.

Table 1. Mechanical properties of Ti alloy and Al alloy.

Property	Ti-alloy	Al-alloy
Young's modulus (GPa)	110	71
Poisson's ratio	0.3387	0.33
Bulk modulus (GPa)	~110	~76
Shear modulus (GPa)	44	26
Ultimate tensile strength (MPa)	900-950	510-570
Ultimate compression strength (MPa)	~970	~510-570

After setting the materials properties, the model was meshed as seen in Figure 2. The model consists of 90,055 nodes and 15,759 elements with a tetrahedral mesh of a 0.005 meter scale. It should be noted here that the quality of the mesh significantly affects the accuracy of the results. Fine mesh does improve accuracy but at the cost of greater computational resources. In the meshing process the complex geometry was simplified by removing the tires focusing only on the structural aspects of the landing gear.

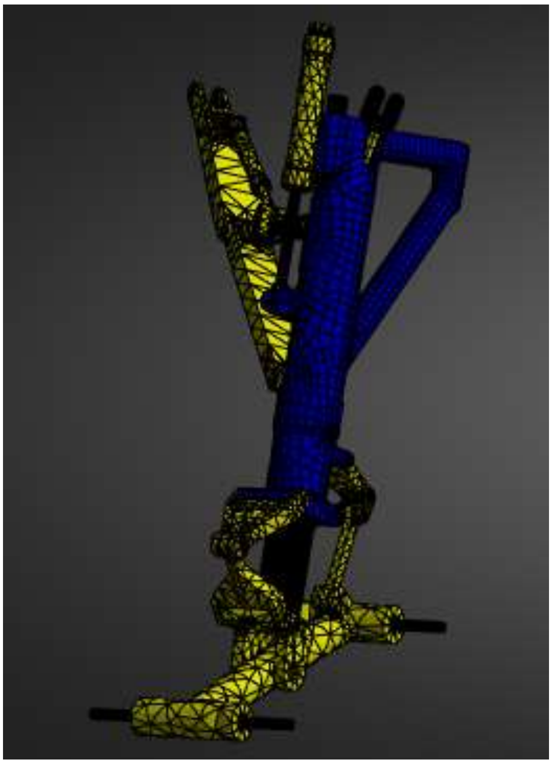

Figure 2. Geometry meshing.

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2.4 Applying Boundary Conditions and Loads

In FEA for landing gear systems, a realistic boundary conditions and loads were used. These boundary conditions include the support points of the landing gear at the aircraft attachment points. The applied load represented the critical operational conditions (takeoff, taxi and landing) which include vertical and lateral forces. For takeoff the weight of the aircraft (representing the load the main landing gear has to support) plus dynamic factors like acceleration, breaking forces and ground reactions are included in total load estimation. At take off the main gear supports about 85 to 90% of the aircraft's total weight while the nose gear supports the other 10 to 15% [6].

As shown in figure 3, a static load of 1000 kN was applied to one end of the main landing gear structure to model real world loading condition. In FEA a proper boundary conditions were applied to truly represent the landing gear's operating environment. At the landing gear's mount points all degrees of freedom were restricted by applying fixed supports condition. The applied load was uniform over the specified area to replicate weight transfer and dynamic impact at touch down condition. This design allowed for complete stress distribution, deformation and identification of potential failure points within the landing gear.

After completely setting up appropriate mesh, material properties, boundary conditions, and loading condition, the static structural analysis was performed. The governing equations of the finite elements were solved providing the results of maximum principal stresses, total deformation, and equivalent elastic strain. These results are presented here as contour plots and deformation animations allowing for the general assessment of the performance of the main landing gear.

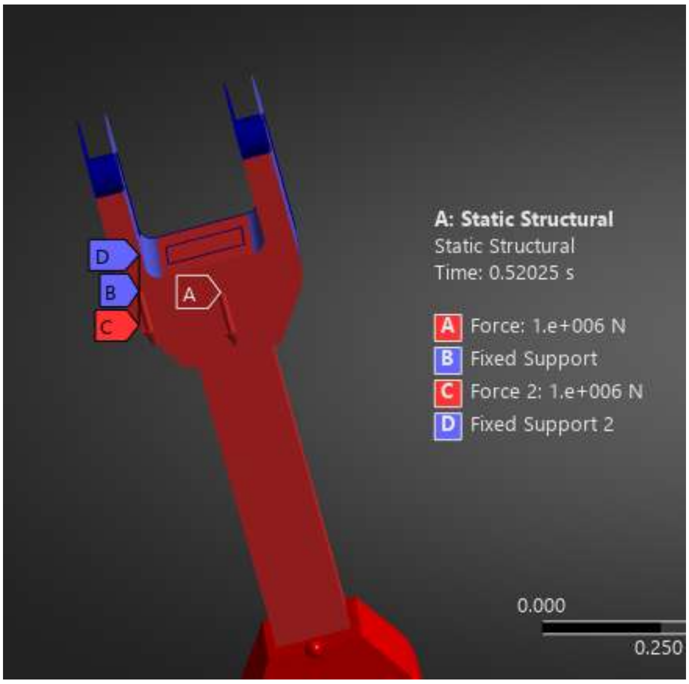

Figure 3. Load and boundary conditions**.**

3. Results and Discussion

The deformation characteristics of Ti alloy and Al alloy under the applied load obtained from FEA structural analysis is shown in figure 4. For the Ti alloy, the total maximum deformation was 2.33 mm occurring at the base of the shock absorber. This is expected as the stress is concentrated at the shock absorber due to high load transfer as a critical structural role of this component within the landing gear system. The total maximum deformation of the Al alloy was 3.66 mm localized at the shock absorber as well. The minimum deformation on Ti alloy and Al alloy was 0.25 mm and 0.4 mm, respectively.

The higher deformation of the Al alloy indicated the increased susceptibility to yielding while the Ti alloy exhibited better structural stability under the exact loading condition. It could be argued that although Ti alloy showed better strength and lower deformation, the Al alloy could be considered for those applications that require high energy absorption capabilities.

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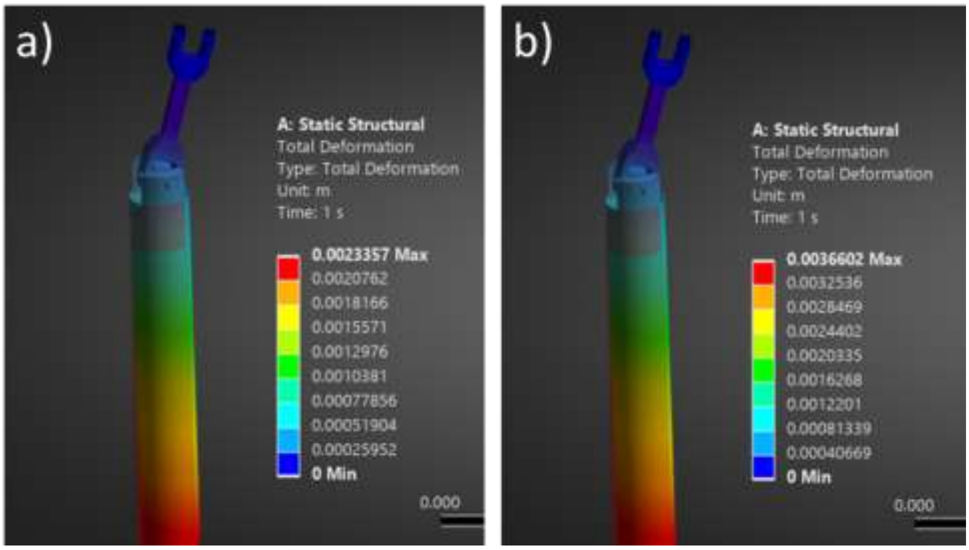

Figure Total deformation of (a) Ti alloy and (b) Al alloy**.**

The maximum principal stresses for the Ti and Al alloys under normal operating conditions are shown in figure 5. Both alloys were found to have very similar maximum principal stresses indicating their great strength and ability to distribute the applied loads. This could be attributed to the high tensile strength and the high modulus of elasticity of these alloys making them better at resisting deformation and stress concentration. The analysis also revealed a very even stress distribution which in turn reduces localized failures and as a whole improves the structural integrity and durability of the landing gear. The maximum principal stress for each alloy was about 23 MPa located at the fixture where stress concentration is greatest due to aircraft weight and landing impact. The minimum principal stress of both alloys was about 0.54 MPa.

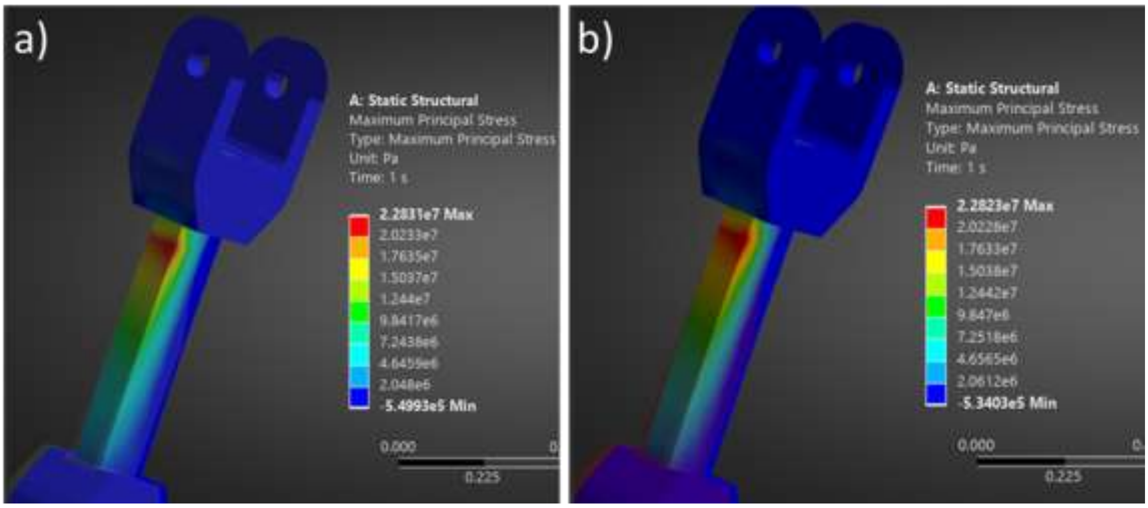

Figure 5. Maximum principal stresses of (a) Ti alloy and (b) Al alloy**.**

In the design of an aircraft's main landing gear, both maximum principal stresses and von Mises (equivalent stresses) are used for the evaluation of the structure's performance and safety under various loading conditions. Although these terms are related to stress analysis, they represent different concepts and it is important for proper results interpretation to understand that. The maximum principal stress is the greatest value of normal stress at a given point in a material and in a certain direction. That is the highest tensile or compressive stress a material would experience. On the other hand, the von Mises stress, is a single number that is used to represent the effect of all stress components (normal and shear) in a way that is related to material's yield criteria. During failure analysis of ductile materials, von Mises stress is usually used based on the theory of energy distortion [12].

It is expected in some scenarios such as high stress concentration and cases of pure tension or pure compression that the results of equivalent stress match those of maximum principal stress.

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For example, if the stress state is dominated by one principal stress (pure axial stress) the maximum principal stress may be very close to the von Mises stress. Also, in a uniaxial stress state the von Mises stress is the same as the magnitude of the maximum principal stress. Similarly, in the case of pure tensile or compressive loading without great shear the maximum principal stress and von Mises stress may agree. In this case both magnitudes may provide the same idea of stress severity. Finally, if the material of the landing gear is ductile where yield is the main failure criteria of concern, von Mises may be the better choice and in some simple stress states the results may agree very closely.

The equivalent stress or von Mises stress behavior of Ti and Al alloys is shown in figure 6. The analysis indicated that both alloys exhibited similar low equivalent stress (~22 MPa). This result could be attributed to their superior strength and high ability to withstand applied loads without yielding.

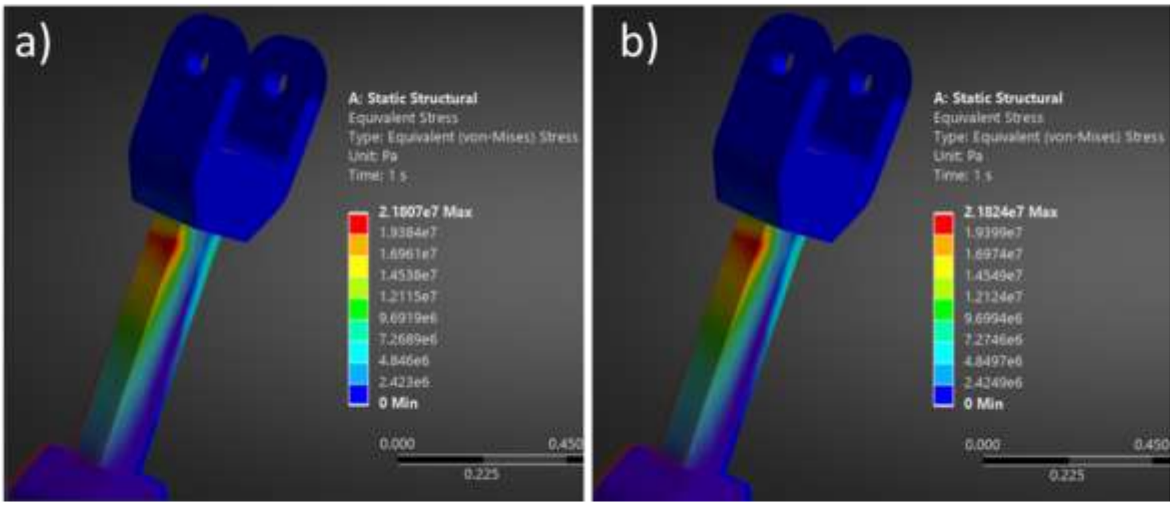

Figure 6. Equivalent stresses of (a) Ti alloy and (b) Al alloy**.**

The structural analysis provided valuable insight into the elastic strain performance of Ti and Al alloys under operational load (Figure 7). It was found that the Ti alloy had a lower equivalent elastic strain (0.2 mm/mm) than that of the Al alloy (0.3 mm/mm) which in turn emphasizes that the former has better mechanical performance and ability to handle greater loads with less deformation. It was also found that the lower strain in the Ti alloy which is a result of the high elastic modulus and strength makes this alloy very suitable for aerospace components operating under repeated loading and high stress. It was also noted that the higher equivalent elastic strain of Al alloy (0.3 mm/mm) is a result of its lower modulus of elasticity (high energy absorption) and higher tendency to deform under similar loading conditions.

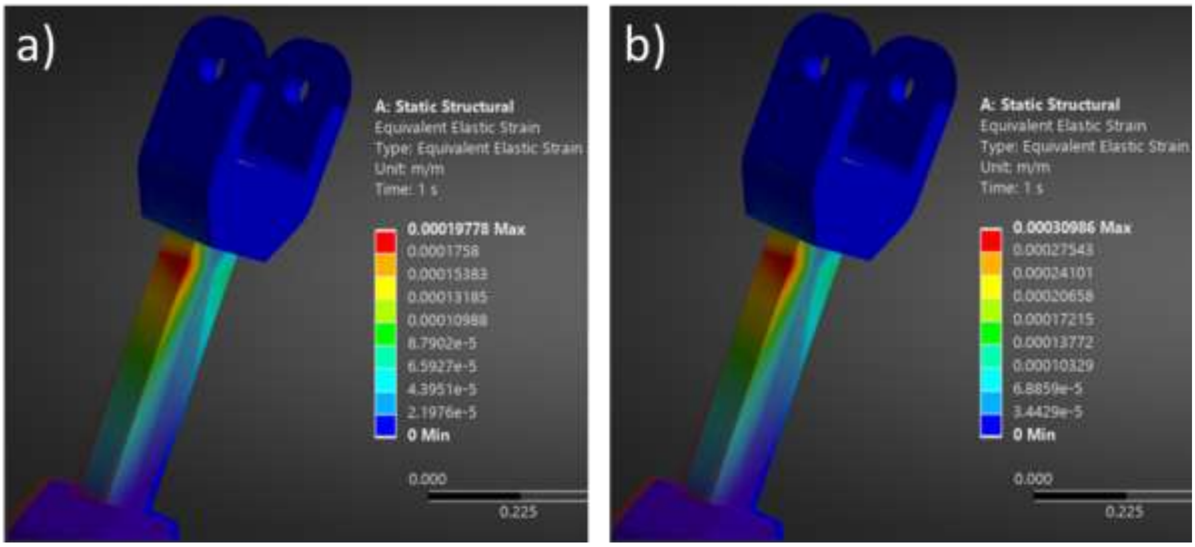

Figure 7. Equivalent elastic strain of (a) Ti alloy and (b) Al alloy.

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4. Conclusions

The structural analysis of main landing gear using ANSYS has revealed that the Ti alloy exhibited better mechanical properties making it a great choice for critical aerospace parts like main landing gear. Under normal operation conditions, Ti alloy showed better structural stability with lower deformation (2.33 mm as compared to 3.66 mm for Al alloy). While the performance of both alloys was comparable in terms of maximum principal stress (stress distribution and resistance to failure) of about 23 MPa, Ti alloy was found to have a lower elastic strain (0.2 mm/mm compared to 0.3 mm/mm for Al alloy) reflecting its greater performance under cyclic. Al alloy was found to experience higher deformation and strain suggesting its better energy absorption ability. In general, Ti alloy is the material of choice if strength is the priority in aerospace systems and Al may be considered if the design requires higher energy absorption. Finally, the analysis highlights the importance of materials selection based on the specific performance and safety requirements in aerospace engineering.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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