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A Novel Design and Structural Analysis of Spring Landing Gear for Unmanned Air Vehicles

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ABSTRACT

Aircraft are subjected to an impact load during landing. This situation becomes more important for unmanned aerial vehicles that are remotely controlled and must serve in extreme conditions. Because the landing gear should absorb this impact load as much as possible and prevent damage to the unmanned aerial vehicle body and its components. In this study, a landing gear design was developed for unmanned aerial vehicles that can absorb more impact load during landing. Numerical analyzes were performed to determine the fatigue life and the maximum impact load that the developed design could withstand. In addition, a conventional landing gear was modeled and the results were compared. The properties of 7075-T6 Aluminum alloy were used as the landing gear material. As a result of the finite element analyzes made with Ansys software, it had been understood that the newly designed landing gear could absorb more energy than the conventional landing gear. It had also been determined that it could be used at values up to 3700N impact load

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INTRODUCTION

Automatic landing, take-off and taxiing are the most important parts of the flight in autonomous flights of unmanned aerial vehicles [1]. The landing gear of the unmanned air vehicle (UAV) is vital. The main task of the landing gear is to provide support during takeoff and landing. The landing gear that carries the main load of the aircraft varies according to the structural configuration of the aircraft. For this reason, it is necessary to improvement landing gears that are desired to have features such as minimum stress and strain, long life and high performance [2]. The landing gear also acts to absorb and dissipate kinetic energy during landing, reducing impact loads on the air-frame [3]–[5]. Therefore, parameters such as stress, deformation, type of material, lightness, strength, stability and stiffness are essential for accurate analysis in the design of the landing gear [6], [7].

While designing and developing landing gear for unmanned aerial vehicles, parameters such as stress, deformation and fatigue that will occur during use have to be considered. Swati and Khan [8] made designs to reduce the weight of the landing gear. Two designs (Model1 and Model 2) were created and they analyzed by using Ansys software. In Model1 and Model2 design, the maximum equivalent stress was 461.7 MPa and 542.2 MPa, respectively. Moreover, the weight of Model2 (13.174 kg) was lower than Model1 (20.089 kg). However, stress factor of safety of Model1 (1.33) was lower than the allowable value (1.5) for aviation. Wibawa [9] investigated the effect of fillet radius on static stress and fatigue life of the main landing gear for UAV aircraft. Analyzes were performed in Ansys Workbench software. In the landing gear design, the radius was changed to 120, 130, 140 and 150 mm. Aluminum alloy 6061 was used as the landing gear material. It was observed that as the fillet radius of the design increases, higher the von-Mises stress and lower the fatigue life. Pradesh et al. [10] evaluated the landing gear in terms of stress and fatigue using different conventional materials (Al Alloy 7075, Alloy Steel 4340, Ti-6Al-4V, Ti-6Al-6V-2Sn, and Ti-10V-2Fe-3Al) by using Ansys software. Ti-10V-2Fe-3Al alloy has the highest safety factor and minimum stress value compared to other materials. Chen and Huang [11] analyzed the material of the landing gear in the Ansys software by selecting a glass fiber-reinforced composite.

The glass fiber-reinforced composite material was compared with the aluminum alloy material, which is the original material of the landing gear. Maximum stress and deformation parameters were investigated. In the plate- or tube-shaped designs, the maximum stress and deformation of the composite material is four times higher than the aluminum alloy. Aluminum alloy 7075-T61 and bi-directional carbon fiber materials have been widely used as the landing gear of the UAV. Durmusoglu [12] made an impact analysis because the landing gear was subjected to an impact loading during the landing of the aircraft. Aluminum 7075-T6 and titanium (Ti553) were used as materials. According to the analyzes made in Ansys, better fatigue life and lower total deformation of the titanium alloy material was obtained. Chen et al. [13] performed a numerical analysis of aluminum alloy and carbon fiber reinforced composites used in landing gear of light sport aircrafts (LSA). Maximum stress and deformation were examined in landing gear of different shapes (plate and column shapes). The lowest maximum strain, less deformation and the lowest maximum stress were obtained with aluminum alloy under static load. Column-shaped aluminum alloy landing gear showed the best performance under static load. Yildirim et al. [14], [15] examined the original and modified version of a landing gear in Ansys software. Three different aluminum alloys (7075 T6, 2024 T3 and 6061 T6) were used in this study. The best material was determined as aluminum alloy (6061 T6). Das et al. [16] investigated the effect of aluminum alloy material (6061 T6) on the deformation and natural frequency on the landing gear. As a result, the maximum frequency was found to be 974 Hz causing a deflection of 403.59 mm with aluminum alloy (6061 T6). Sonowal et al. [17] used Aluminum alloy (6061-T6) material in a landing gear, and analyzed with Ansys. The maximum stress was determined as 252.7 MPa. The stresses from impact landing with this material were within the safety range. As a result, this material was suitable for use in the landing gear. Yetkin and Koca [18] investigated the effects of shaft radius and moment on stress and deformation of the landing gear. As the shaft radius increased, the maximum stress decreased and the maximum deformation increased. In addition, as the moment applied to the cylinder of the landing gear increased, the maximum stress and maximum deformation increased. Al-bahkali [19] designed the landing gear of UAV's in two different models. It was evaluated for a total of thirteen cases under different speeds and forces for both models. Modeling was done by using ABAQUS. AA7075-T6 was used for both models. As the landing speed increased, the von-Mises stress value increased in both models. It was observed that the maximum stress values were lower in model two under all cases. Rajesh and Abhay [20] looked at the stress and deformation of a landing gear they designed under static load acting (17650 N) and impact load acting (67032 N). Aluminum 2024 and steel were used as materials. In the static and impact analysis results, the von-Mises value of the steel material was higher than the aluminum alloy material while the deformation value of the steel material was lower than the aluminum alloy material. Gokulraja et al. [21] analyzed an aircraft landing gear in Ansys with three different materials (Titanium Alloy (Ti553), Al 7075 T6 and Carbon Composite). Lower total deformation was obtained in titanium alloy material. Moreover, it was stated that the landing gear with titanium material could withstand more impact load. Jeevanantham et al. [22] designed the landing gear of Boeing 747 aircraft in ANSA software and then analyzed it by using Ansys software. In the study, Aluminum Alloy 7075, Steel 4340, Ti-6AL-4V, Ti-6AL-6V-2Sn and Ti-10Al-2Fe-3V materials were compared. The maximum stress and deformation values of the landing gear designed using Ti-10Al-2Fe-3V material were very low.

In this study, a new spring type landing gear was designed that could absorb more impact load compared to the conventional landing gear. The 3D models of landing gears were drawn by using Solidwoks and then they imported to Ansys software for numerical analysis. The stress, deformation, strain energy and fatigue properties of the conventional and designed landing gears under different loads (2760-4140N) were evaluated.

MATERIALS AND METHODS

Design of UAV Landing Gear

In this study, a new leaf spring type landing gear that can absorb more impact energy was designed for unmanned aerial vehicles. The 2D technical drawing of the conventional landing gear used as a reference in order to compare the results obtained in the studies was given in Fig. 1 (a). The technical drawing of the designed landing gear and its assembled views on the unmanned aerial vehicle were shown in Fig. 1 (b) and (c), respectively. As could been seen from Fig. 1 (b) and (c), the designed landing gear could flex both horizontally and vertically along the wheel axis when the unmanned aerial vehicle lands on the ground. The models were drawn using SolidWorks® software.

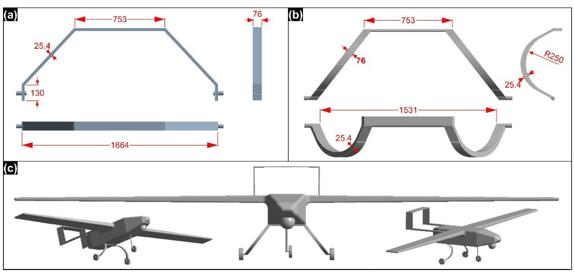

Figure 1. 2D geometries of the (a) conventional and (b) newly designed landing gear. (c) an UAV assembled with newly designed landing gear.

Meshing and Boundary Conditions

The drawn landing gears were imported into the Static Structural module of the ANSYS® software for finite element analysis (FEA). In this study, it has been tried to generate high quality meshes in order to obtain more realistic results. For this, in the mesh process, 6.35 mm volumetric tetrahedral meshes were used, and mesh sizing was applied to ensure that the average mesh element quality was above 85%. As seen in Fig. 2 (a) and (b), number of nodes was 2853663 and 327948 for conventional and new designed landing gears, respectively. Moreover, number of elements was 191868 and 220186 for conventional and new designed landing gears, respectively. In order to investigate the response of the landing gear in the most severe condition, the load situation at the first touchdown on the runway during the landing of the UAV were taken into account. As could been seen in Fig. 2 (c) and (d), forces were applied separately and equally from both of the wheel shafts (B and C). In literature, it was stated that UAVs land at normal glide angle between 3 to 10 degrees [17]. Therefore, in this study, the landing angle was assumed to be 10 degrees and loads were applied at an angle of 10 degrees with the Y-axis (see Fig. 2 (d)). The upper part of the landing gear in contact with the fuselage of UAV was defined as fixed support (D). Moreover, standard earth gravity (9806.6 mm/s2) was applied on the -Y axis.

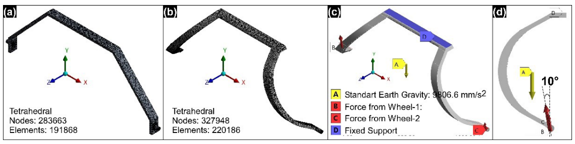

Figure 2. Meshing and boundary conditions. Tetrahedral finite element meshes for (a) conventional and (b) new designed landing gears. (c) and (d) load and boundary conditions.

Load and Material

There is a simple empirical formula for determining the impact load acting on the UAV landing gear (Equation 1) [9].

$$F \times \Delta t = m \times Vf \quad (1)$$

Here, F, Δt, m and Vf are the impact load (N), impact time (s), mass of UAV aircraft (kg) and landing speed (m/s), respectively. In this study, in accordance with the literature, the impact time (Δt) was determined as 0.5 s [23]. Considering the stall speed of 20 m/s, the landing speed (Vf) was chosen as 25 m/s. From this point, the impact load (F) of 2760 N was calculated for a 55.2 kg (m) UAV. Therefore, the initial load was applied as 2760 N. Then, as seen in Table 1, the load was increased gradually, and the impact loads acting on the landing gear were found to be 64.4, 73.6 and 82.8 kg, respectively, at 3220, 3680 and 4140 N load conditions. Under these conditions stress and fatigue analysis for conventional and newly designed landing gears were made.

In the experimental studies, Aluminum 7075-T6 alloy with a density of 2.85 g/cm3, a possion's ratio of 0.33, a yield strength of 503 MPa and an ultimate strength of 572 MPa was used as the landing gear material [24], [25]. The reason for using 7075-T6 Aluminum alloy material as the landing gear material was load life cycles, maximum static load capacity, optimal static strength and corrosion resistance. This material has been widely using in the aerospace industry [26], [27].

Table 1. Loads and codes.

Design	Load (N)	Code
Conventional	*2760*	*C1*
	3220	*C2*
	3680	*C3*
	4140	*C4*
New Design	*2760*	*N1*
	3220	*N2*
	3680	*N3*
	4140	*N4*

Aluminum alloys are generally ductile materials, and it is reported that the use of Gerber's mean stress theory is appropriate for fatigue life predictions of ductile materials [9]. Therefore, in this study, since 7075-T6 aluminum alloy was chosen as the landing gear material, Gerber's mean stress theory was used in fatigue analysis under zero-based loading conditions. The S-N curve for 7075-T6 aluminum alloy was given in Fig. 3.

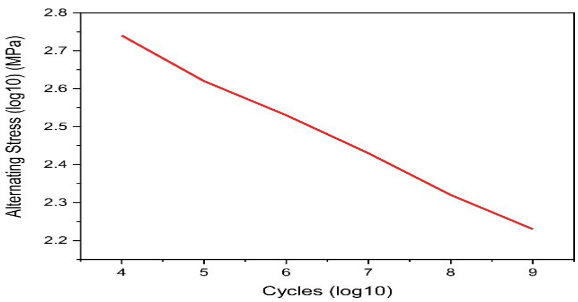

Figure 3. S-N curve for 7075-T6 aluminum alloy.

RESULTS AND DISCUSSION

Static Stress, Deformation and Strain Energy Analysis

The equivalent (von-Mises) stress distributions that occur at different loads shows in Fig. 4 (a-d) - the conventional design and Fig. 4 (e-f) - the newly designed landing gear. Maximum values of stress distributions were given in Table 2. As could be seen from the distributions in Fig. 4, the maximum stresses were concentrated in the shoulder regions of the landing gears in both conventional and new design. While the maximum stress values occurred in conventional design vary between 120.94 and 182.35 MPa, they were in between 229.67 and 347.46 MPa in new design. This means that under the same loading

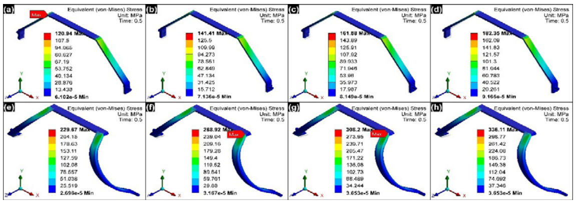

Figure 4. Equivalent (von-Mises) stress distributions. (a) C1, (b) C2, (c) C3, (d) C4, (e) N1, (f) N2, (g) N3 and (h) N4.

conditions, the maximum equivalent stress value of the new design landing gear was approximately 90% higher than the conventional design. Additionally, these maximum stress values were lower than the yield stress value of 7075-T6 Al alloy (503 MPa). Therefore, it was suitable for use under the specified loading conditions. The factor of safety for stress (FSS) values obtained by dividing the yield stress to the maximum equivalent stress value were shown in Table 2. Generally, these values were above "1.5". However, as a result of loading 4140 N, FSS value was calculated as "1.45" in the new design landing gear. On the other hand, it was stated that the minimum stress safety factor value should be "1.5" according to the Federal Aviation Regulations (FAR) standards [25]. Therefore, the new design was not suitable for the minimum stress safety factor allowed for use under the 4140 N loading condition of the landing gear. As could be seen in Table 2, both total and directional (Y-axis) deformation increased (about 22% and 27%, respectively) with the increase of load in accordance with the resulting stress values. At the same load values, more deformation occurred in the new design landing gear. This is an indication that the new design landing gear can absorb more impact energy. As a matter of fact, as seen in Table 2, both the maximum and total measured strain energy values were higher in new design landing gear than in conventional landing gear. Under the same loading conditions, as a result of the landing impact, the newly designed landing gear contains around 28% more total strain energy than conventional landing gear. This situation shows that more impact energy can be absorbed. Because the new design landing gear could be deformed more elastically along the Y-axis than the traditional design thanks to its geometry.

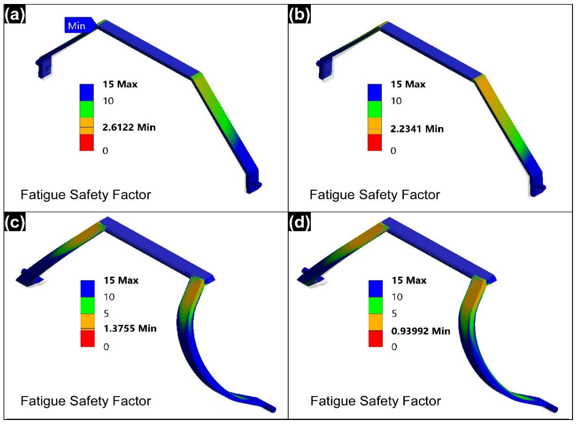

Figure 5. Fatigue safety factors for (a) C1, (b) C4, (c) N1 and (d) N4.

Fatigue Analysis

Fatigue analysis was performed to investigate the response of conventional and newly designed landing gear under cyclic loading conditions. Fatigue life analysis could be thought of as an estimate of the number of flight cycles until damage occurs by crack propagation. As seen in Table 2, the fatigue lives of the C1-C4 and N1-N3 landing gears was higher than 5e8 cycles. This means that the landing gears have a life of more than 500000000 cycles under the given loading conditions. Also, the fatigue safety factors of these landing gears were greater than "1". Therefore, there was no problem in terms of fatigue life of the new design landing gear under 2760, 3220 and 3680 N loading conditions. However, the fatigue life and safety factor of the new design landing gear at 4140 N loading condition (N4) were 1.41e8 cycles and 0.94, respectively. Therefore, the new design landing gear was not safe to use in this loading condition (4140 N). Consistent with these results, as seen in Table 2, the highest alternating stress value (191.38N) occurred under N4 loading condition. In Fig. 5 (a-d), fatigue safety factor distributions were given for conventional and newly designed landing gear at 2760 and 4140 N loading conditions. As expected,

Table 2. Total deformation, directional deformation (along Y axis), strain energy, stress safety factor, fatigue life, fatigue safety factor and alternating stress values for landing gears.

Code	*Max.*				*Total*	*Min.*			
	Equivalent Stress (MPa)	*Total def. (mm)*	*Directional def. Y axis (mm)*	*Strain Energy (mJ)*	*Strain Energy (mJ)*	*Stress Safety Factor*	*Fatigue Life (cycle)*	*Fatigue Safety Factor*	*Alt Stress (MPa)*
C1	120.94	16.34	10.61	3.80	13334	4.16	5e8	2.61	61.154
C2	141.41	19.10	12.41	5.19	18224	3.56	5e8	2.23	71.802
C3	161.88	21.86	14.20	6.80	23874	3.11	5e8	1.95	82.60
C4	182.35	24.63	15.99	8.63	30287	2.76	5e8	1.73	93.55
N1	229.67	19.98	13.54	6.55	17135	2.19	5e8	1.37	119.66
N2	268.92	23.37	15.83	8.98	23430	1.87	5e8	1.17	142.33
N3	308.20	26.76	18.11	11.80	30712	1.63	5e8	1.03	166.15
N4	347.46	30.15	20.40	15.00	38976	1.45	1.41e8	0.94	191.38

the minimum fatigue safety factor regions were concentrated in the shoulder areas of the landing gear, in line with the equivalent stress distributions given in Fig. 4. As a result, it had been understood that the newly designed landing gear, which could absorb more impact energy, was suitable for use under 3700 N load.

CONCLUSION

In this study, the design and numerical analysis of an UAV landing gear that could absorb more impact load during landing were made. The newly designed landing gear and the conventional landing gear were analyzed by using Ansys software. Aluminum 7075-T6 material properties were used as the landing gear material. Analyzes were made under different loading conditions to find the maximum load limit that the design could withstand. The obtained findings were listed in the following items.

- The maximum stresses were concentrated in the shoulder regions of both conventional and new design landing gear.
- Under the same loading conditions, the maximum equivalent stress value of the new design landing gear (229.67 – 347.46 N) was approximately 90% higher than the conventional design (120.94 – 182.35).
- Under the same load conditions, more deformation of the new design landing gear (about 22%) occurred compared to conventional landing gear depend on the increase of the load in accordance with the stress values.
- Under the same loading conditions, the newly designed landing gear obtained approximately 28% more total strain energy than conventional landing gear.
- It was understood that there was no problem in the use of the new design landing gear up to 3700N load in terms of fatigue life and fatigue safety factor.

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CONFLICT OF INTEREST

Authors approve that to the best of their knowledge, there is not any conflict of interest or common interest with an institution/organization or a person that may affect the review process of the paper.

AUTHOR CONTRIBUTION

All the work in this study were performed equally by the authors.

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