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Design Optimisation Of Landing Gear's Leg For An Un-Manned Aerial Vehicle

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ABSTRACT:
The landing gear is a structure that supports an aircraft on ground and allows it to taxi, take-off, and land. In fact, landing gear design tends to have several interferences with the aircraft structural design. Now a days the weight of landing gear has become an important factor. Efforts are being made to reduce the weight of the aircraft and consequently increase the payload. This paper presents an approach to optimize the design of landing gear's leg of an Unmanned Aerial Vehicle (UAV) made of ASM7075-T6 material adopted from Aerospace Specification Metals(ASM). First the structural behavior is tested using the structural analysis when subjected to behavior constraints. Optimization process is carried out iteratively to minimize thickness of landing gear's leg which results in the minimum weight of landing gear.

1.0 INTRODUCTION:
Each type of aircraft needs a unique landing gear with a specific structural system, which can complete the demands described by unique characteristics associated with each air craft. The landing gear is the component that supports an aircraft and allows it to move on the ground. Conventional landing gear is one of the types among the landing gear where the gear legs are arraigned in tricycle fashion. The tricycle arrangement has one gear strut either back or front and two main gear legs. The main gear leg comprises a simple single piece of aluminum alloy spring leaf type which is bolted at the bottom of the fuselage.

The design and development of a landing gear encompasses several engineering disciplines such as structures, mechanical systems, aerodynamics, material science, and so on. The conventional landing gear design [1] and development for aerospace vehicles is based on the availability of several critical components/systems such as forgings, machined parts, mechanisms, sheet metal parts, electrical systems, hydraulic systems, and a wide variety of materials such as aluminum alloys, steel and titanium, beryllium, and polymer composites. As the science of materials is progressing continuously it is natural that the use of new materials will replace older designs with new ones. Energy absorption and crashworthy features are the primary design criteria that govern the development of landing gears. The impact force on landing gear has been discussed by Flugge [2] considering both the landing and taxiing impact forces and neglected the drag force acting on it. The crack generation in the landing gear components was observed by Fujimoto [3] and the basic causes of damage were found to be processing operations, latent material defects, mechanical damage and crack growth developed at corrosion pits. The aircraft landing gear simulation was analyzed by Derek Morrison et al. [4] by performing two types of analysis. The first is kinematic evaluation of front nose gear and other is the structural study of main landing gear for a light weight aircraft. The approach for modeling and simulating landing gear systems was proposed by James Daniels [5] devolved a nonlinear model of an A-6 intruder main gear, the simulation and validation was performed against the static and dynamic test data. A discussion has been done on problems facing by the aircraft community in landing gear dynamics, especially in shimmy and brake-induced vibration by Jocelyn Pritchard [6], experimentally validated and characterized the shimmy and brake-induced vibration of aircraft landing gear. The design analysis of Light Landing Gear was presented by Amit Goyal [7]. In the development phase, conducting a rigorous non-linear stress and buckling analysis was carried out and also conducting various experimentations on different combinations of loads and orientations. Noam Eliaz et al. [8] discussed failure of beams of landing gear during operation. During replacement of a wheel on the aircraft, a crack was found on the rear axle bore of the left-hand main landing gear truck beam. The aero structure analysis on ME 548 was analyzed by Dave Briscoe [9] verified that the vonmises and deflections of landing gear and also proved that results given by the ANSYS and SOLID WORKS software are not same because of improper meshing of components. The specific constrained layer damping applications for cantilever-loaded steel spring landing gear was investigated by Oraig Gellimore [10]. This work involves validation of the cost efficient design of traditional landing gear damping devices when used in constrained layer damping. The dynamic analysis of landing gear for critical work conditions by applying finite element analysis was analyzed by Jerzy Malachowski [11].

The design of light landing gear by conducting structural analysis and design optimization was analyzed by Essam Albahkali and Mohammed Alqhtani [12] by conducting experiments on landing gear using impact analysis.

Review of literature survey on different types of landing gears shows that landing gear is analyzed for safety of the structure and effort was made to identify the faults occurring in them. However there is limited literature available on conventional landing gear made of ASM7075-T6 material. The present study deals with the structural analysis and optimization of landing gear's leg made of ASM7075-T6 material and the analysis was carried out using ANSYS (Version 13).

2.0 GEOMETRICAL MODEL:

The undercarriage or landing gear in aviation is the component that supports an aircraft on the ground and allows it to land. Conventional landing gear consists of two wheels adjacent to the aircraft's centre of gravity and a third wheel at the tail. This type of landing gear is most often used in older generation aviation airplanes and now a days it is used in UAV.

The following are assumptions to be considered for analysis

- The material is assumed to elastic and homogenous.
- The analysis has been carried out with in elastic limits.
- Both Solid (pipe element) and shell elements are used for analysis.
- Rigid Body Element (RBE3) connection is used for load transfer.

Figure 2.1: Landing gear legs

Figure 2.1 shows the model of gear legs chosen for analysis which have been used for Ceanna140, RV-8 type vehicles and at present these are used in UAV.

The weight of landing gear's leg considered for analysis was taken as 6 kg.

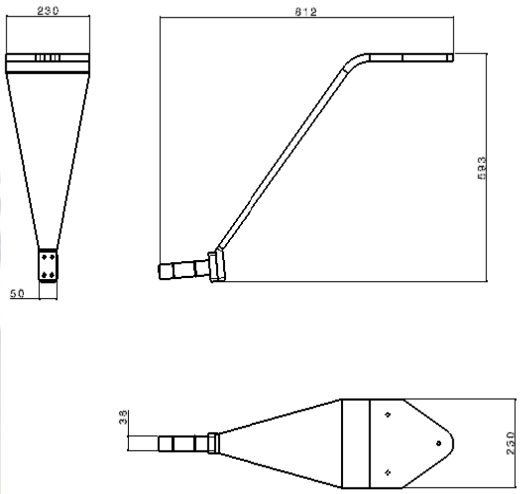

Figure 2.2: Geometry of landing gear's leg

The data required for designing and weight of landing gear leg has been taken from "Grove Aircraft Landing Gear Systems Inc", which is a complete custom landing gear company manufactures ready to bolt component design for customer requirements to individual aircrafts.

2.1 MATERIAL PROPERTIES:

The main consideration when designing landing gear is to decide the type of material to be used. Aluminum alloys have played a dominant role in aircraft components for many decades. They offer good mechanical properties with low weight. Among the aluminum alloys, the 2024 alloy and 7075 alloy are perhaps the most used. 7075 alloys (7075-T6, T6510) have higher strength than the 2024 but lower fracture toughness. 2024-T3 alloy is used in the fuselage and lower wing skins, which are prone to fatigue due to applications of cyclic tensile stresses. For the upper wing skins, which are subjected to compressive stresses, fatigue is less of a problem, and 7075-T6 alloy is used. 7075 aluminum alloy's composition roughly includes 5.6-6.1% zinc, 2.1-2.5% magnesium, 1.2-1.6% copper, and other materials like silicon, iron, manganese, titanium, chromium, and some other metals are used less than one percent. The Table 1 shows material properties of T7075-T6 alloy.

Table 1: Material properties of T7075-T6 Alloy

Property	Value
Density	2850 kg/m^3
Yield Strength	490 N/mm^2
Allowable Stress	392 N/mm^2

2.2 LANDING GEAR LOADS:

The design loads applied on aircraft are lift load, drag load, side load and torsion load. Lift is the upward force created by the air flow as it passes over the wing, drag is the retarding force (back ward force) that limits the aircrafts speed, side load is the opposing acting in inward direction of gear leg and torsion load is applied when the air craft structure rotates. Table 2 shows general design loads considered to test the landing gear's leg.

Table 2: Landing Gear Loads (Design Loads)

Type of load	Value
Lift Load	1000 N
Drag load	450 N
Side load	260 N
Torsion Load	20,000 N-mm

With the above all specifications the model was designed in CATIA (Ver-11), meshed in HYPERMESH (Ver-12) and the results are viewed in ANSYS (Ver-13).

Figure 2.2: 3D-meshed model of landing gear's leg

Figure 2.2 shows the 3D model of the landing gear's leg which is meshed in HYPERMESH and applied the boundary conditions. The applied boundary conditions for the model are as follows,

- Fixing the gear leg at bolting portion in all directions.
- The loads such as lift, drag, side and torsion are applied in respective directions..
- Gear leg and axle component are glued to make a single component.

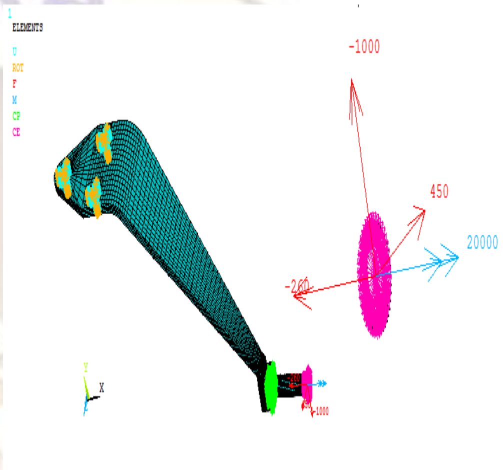

Figure 2.3: Loads applied on landing gear's leg

The maximum possible loads which are given as design loads are applied through RBE3 connection at the axle end spreading to wheel base. The units are taken in such a way that translational forces are in newton and torsion moment is represented in newton-millimeters. The colour code is used to represent the problem boundary conditions.

3.0 STRUCTURAL ANALYSIS:

There are several types of structural analysis which play an important role in finding the structural safety under stress and deformation. From that the basic structural safety of the component can be found by analyzing the structure for static and dynamic loading conditions.

3.1 STATIC ANALYSIS:

A static analysis is used to calculate the effects of steady loading conditions on a structure, while ignoring inertia and damping effects, such as those caused by time-varying loads. This analysis has been done by applying static loads and results are presented for the displacements and vonmises stresses, because vonmises stress theory is the main failure theory to find the failure of the components or factor of safety in the problem.

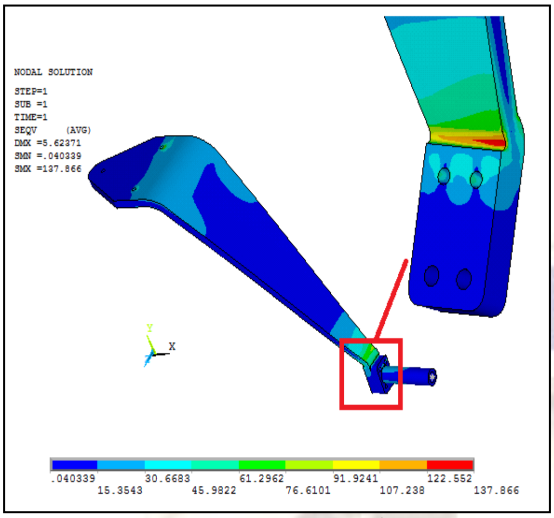

Figure 3.1: Vonmises Stress plot of the structure

Figure 3.1 shows developed vonmises stress in the structure. The maximum vonmises stress is 137.866 N/mm^2. The obtained stresses are less than yield stress of the material, so structure is safe for the given loads. The maximum displacement is 5.62371 mm. Maximum displacement is taking place at the loading region.

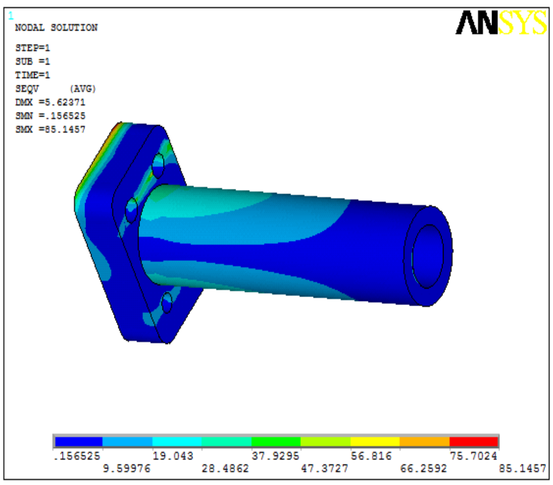

Figure 3.2: Vonmises stress plot of axle component

Figure 3.2 shows the maximum vonmises stress in axle component is 83.1457 N/mm^2. This result of static analysis shows the maximum stresses are occuring at the connection region between the members. The stress obtained is much less the allowable stress of the structure. The maximum stress are observed near the curvature connecting to the wheel axle.

3.2 SPECTRUM ANALYSIS:

In number of instances (e.g. earthquakes, wave loading) dynamic loading is random in nature and static methods are used to represent them. One of such measure is response spectrum. This represents the response of an equivalent single degree of freedom system, to a prescribed random dynamic loading. The response is typically expressed as displacement across of range for a particular value of damping. The spectrum analysis is one in which the results of a modal analysis are used with a known spectrum to calculate displacements and stresses in the model. The landing gear leg is further analyzed for spectrum response. Initially modal analysis is carried out to find the dynamic stability of the structure. Spectrum analysis has been carried out at spectrum loading conditions.

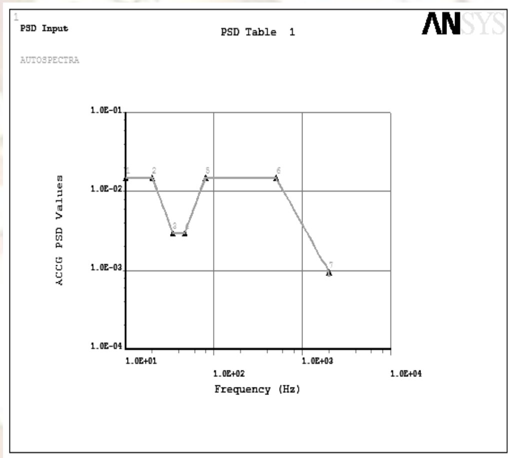

Figure 3.3: Modal analysis plot of landing gear's leg

Figure 3.3 shows Power Spectral Density (PSD) outputs in G^2/Hz for the landing gear vibration with change in frequency. It indicates random vibration loads on the landing gear. The modal frequencies are extracted up to the spectrum frequency and these are required to calculate the resultant effect of modal spectrum vibration. The initial frequency of 52.115 Hz is corresponding to a speed of 3126.9 rpm. This speed indicates resonance condition if the structure is excited with 3126.9 rpm of the air craft.

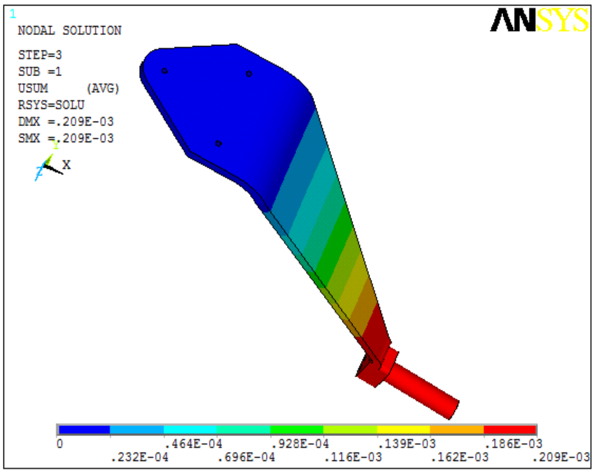

Figure 3.4: Displacements plot of spectrum analysis

The result of spectrum analysis using Single-Point Response Spectrum (SPRS) analysis shows maximum displacement of 0.209 mm which is due to combined modal and spectrum loads. Maximum displacement is observed at the axle end. This is due to cantilever nature of the support. The status bar indicates the varying displacements in the structure.

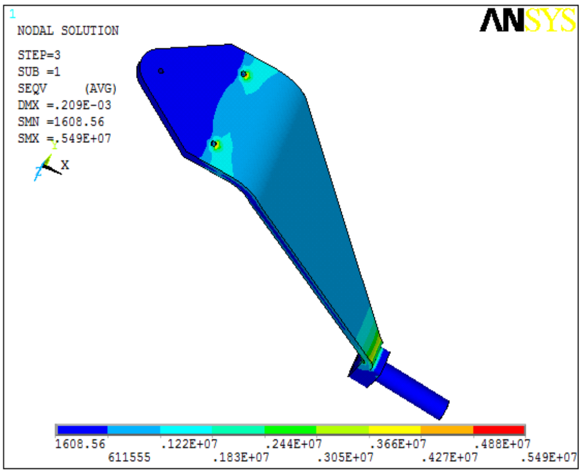

Figure 3.5: Vonmises stress plot for spectrum analysis

Figure 3.5 shows spectrum response of the landing gear due to the given spectrum loads. Maximum stress of 5.49Mpa can be observed in the problem. The results viewed by ANSYS solver are 1σ or one standard deviation values. These results follow a gaussian distribution. The interpretation is that 68.3% of the time the response will be less than the standard deviation value. We can scale the result by 2 times to get the 2σ value which gives 95.91% and 3σvalues 99.7% of the time. The default results are for maximum stress condition for 1σ value. By multiplying 3 times the 1σ values, 16.47 Mpa stress is obtained. But this stress is much smaller than the allowable stress of the material, hence the structure is completely safe for the given loads.

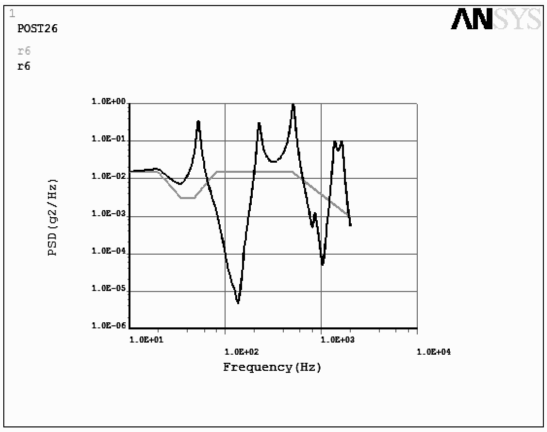

Figure3.6: Response plot of spectrum analysis

Figure 3.6 shows dynamic amplification of the input to the output response of the systems. The uncontrolled vibration on gear leg lies between 100 to 750 Hz.

4.0 WEIGHT OPTIMISATION OF THE LANDING GEAR'S LEG:

The static and spectrum results indicate that the obtained stresses are low when compared to allowable stresses of the material, hence there is a possibility for optimization of the landing gear's legs thickness. The model with shell elements is considered for the analysis. Various regions are created by splitting and by varying thickness. The thicknesses are supplied as the real constants which can be easily optimized based on the optimization cycle satisfying the design requirements. Totally 11 regions were created with different thickness parameters for optimization. The analysis is limited to main landing gear part. Since the axle dimension depends on wheel diameter and suspension, so the axle part is not considered for optimization.

In ANSYS optimization the zero-order method which is an advanced method in sub problem approximation technique with random design generation type optimization tool performs multiple loops, with random design variable obtains values at each loop. A maximum number of loops with a desired number of feasible loops can be specified. This tool is useful for studying the overall design space, and for establishing feasible design sets for subsequent optimization analysis.

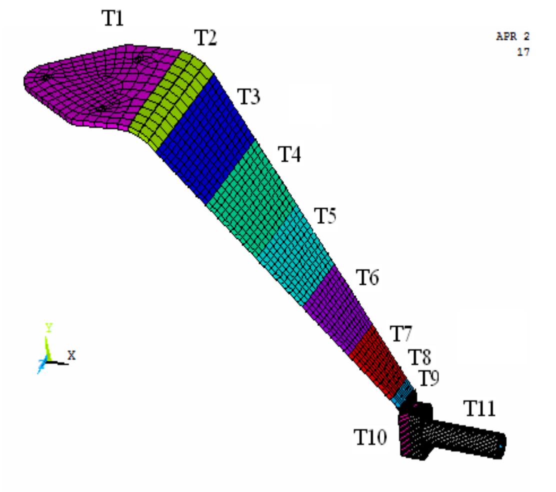

Figure 4.1: Splitted model for weight optimization analysis

A number of iterations were performed by varying the thickness of the component and the results are obtained with different sets of feasible thickness data. The lowest design thickness data obtained in iterative process is optimized for gear's leg.

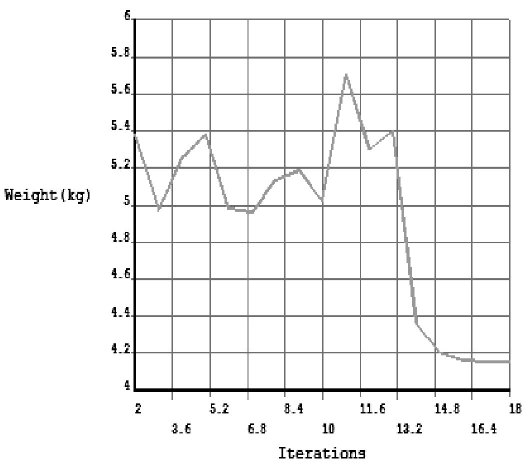

Figure 4.2: Variation of weight of the structure with iterations

Figure 4.2 shows variation of weight and vonmises stresses to the iterations. At the beginning iterations the weight is not reduced and the reduction of weight can be observed at the end of the iteration cycles.

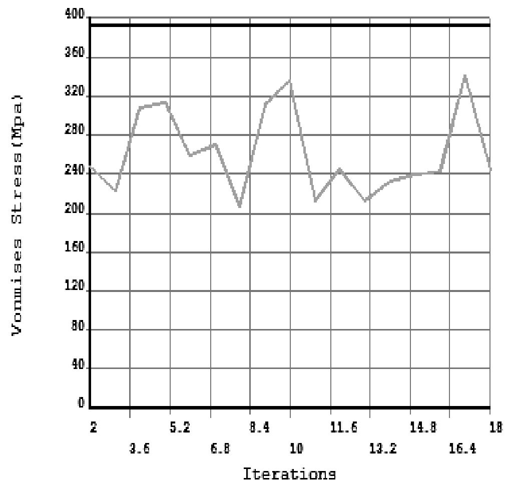

Figure 4.3: Variation of vonmises stress with iterations.

Figure 4.3 shows the variation of vonmises stress to the iterations. It can be observed that the variation in vonmises stress is not much predominent for varying thickness. This is due to redistribution of loading region. The feasible optimized set obtained by iteration process is tabulated in Table 3.

Table 3: Optimized feasible data of gear leg thickness

THICKNESS LABLES	THICKNESS VALUE (mm)
T1	9.0108
T2	9.0111
T3	9.0173
T4	9.0112
T5	9.0124
T6	9.0129
T7	9.0133
T8	9.0135
T9	13.839
T10	15.948
T11	13.870

The maximum vonmises stress is around 244.178 Mpa as shown with red colour. The obtained stresses are minimum at the top region and are increasing towards the connecting region between main landing gear to the wheel axle. Initial weight of 6 kg is reduced to 4.1538 kg by the final optimization cycle for the given loads. So reduction of 1.8462 kg can be observed.

5.0 CONCLUSIONS:

A CAD model of landing gear's leg for unmanned aerial vehicle was made and discretized in to finite element mesh using HYPERMESH. Design loads were applied through RBE3 connection in respective directions. Static and spectrum response analysis were conducted in ANSYS. The obtained stresses are much lesser than the allowable stresses of the material. So design optimization is carried out to reduce the weight of the component. The landing gear's leg weight was reduced by iterative process using design optimization analysis in ANSYS from 6 kg to 4.1538kg for the given loading conditions. A reduction of 1.8462 kg can be observed which amounts to almost 30% reduction of weight.

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