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Strength Optimization of Landing Gear's Leg for Aerial Vehicle using ANSYS Solver

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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. Present research is going in the weight of landing gear has become an important factor and efforts are being made to reduce the weight of the aircraft landing gear to consequently increase the payload. This thesis presents an approach to optimize the weight of landing gear's leg for an Un-manned Aerial Vehicle (UAV) made of aluminum ASM 7075 material adopted from aerospace specification materials. A cantilever type conventional landing gear's leg is chosen for analysis. The model is drafted in CATIA V5, meshed in ANSYS Mesh tool and software and analysis is carried out in ANSYS solver. Loads are applied through a rigid boundary condition & screw boundary connection. First the structural behavior of the component is analyzed by performing static and random analysis when subjected to behavior constraints.

Optimization process is carried out iteratively to optimize the structural parameters of the component. Weight of landing gear's leg is optimized using ANSYS optimization and less stress concentrated areas in design is identified using ANSYS shape optimization module. A new optimized landing gear's leg with reduced weight is modeled with same material properties, boundary conditions and design loads. The behavior of component is checked using structural analysis which includes static and random vibration (PSD) analysis.

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 von-mises 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 material and the analysis was carried out using ANSYS (Version 16).

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 present 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 Boundary condition & Screw Boundary connection is used for load transfer.

Figure 2.1: Geneva Aerospace Dakota UAV

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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.

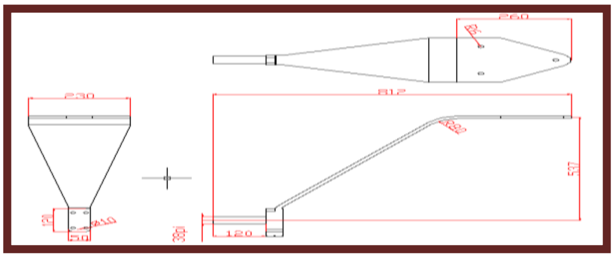

Figure 2.2: Geometry of landing gear's leg

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.

2.2 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. The Table 2.1 shows general design loads to test the landing gear's leg.

Lift force$F_L = C_L * A * \frac{\rho u^2}{2}$

Drag force $F_D = C_D * A * \frac{\rho u^2}{2}$

C_D= 0.15

C_L=0.75

Density of air ρ=1.15kg/m^3

Velocity of landing gear = 500Km/hr = 139m/s

Area of landing gear = 603*230 mm^2 = 0.1387m^2

Note: - Area of landing gear is measured using CATIA software.

Lift force = 1154 N

Drag force =540 N

Momentum lode = 20000 N-mm

Side Thrust lode = 230 N

Table 2.1: Landing gear's leg loads (Design Loads)

Type of load	Value
Lift Load	1154 N
Drag load	540 N
Side load	230 N
Torsion Load	20,000 N-mm

With the above all specifications the model was designed in CATIA (Ver-21), meshed in ANSYS workbench mesh tool (Ver-16).

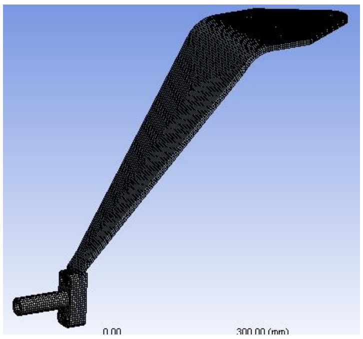

Figure 2.2: 3D-meshed model of landing gear's leg

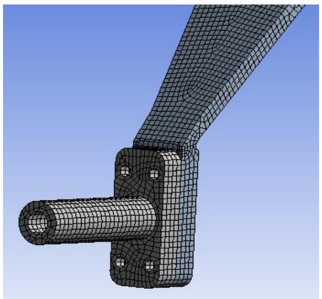

Figure 2.2 shows the 3D model of the landing gear's leg which is meshed in and applied the boundary conditions.

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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.
- Landing gear's leg and axle component are glued for making a single component.

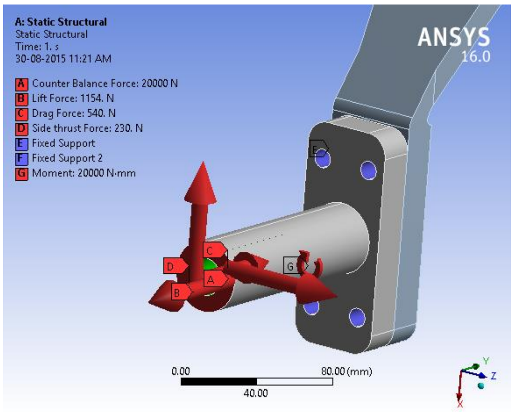

Figure 5.4: Applied loads on landing gear's leg

Figure 5.4: applied loads on landing gear's leg. The maximum possible loads which are given as design loads are applied through rigid boundary condition & Screw boundary 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 color 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:

Static analysis is the first and foremost aspect of strength analysis of landing gear leg. Static equivalent von-misses stresses and the deflection of landing gear leg components are determined with the given load data and constraints by satisfying equilibrium equations. Both material and geometrical linearity is considered in the analysis. A static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects.

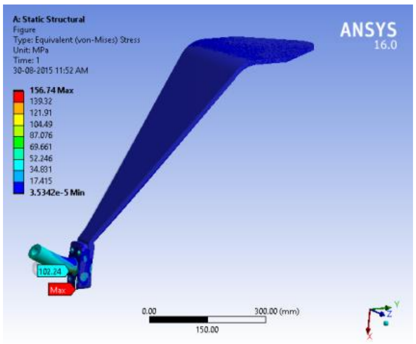

Figure 3.1 shows developed von-mises stress in the structure.

Figure 3.1 shows the maximum von-mises stress is 156.74 N/mm². The obtained stresses are less than yield stress of the material, so structure is safe for the given loads. By observing the von-mises stress plot of static analysis the stress levels throughout the structure is almost equal and a small portion at bottom corner of the component has highest stress concentration.

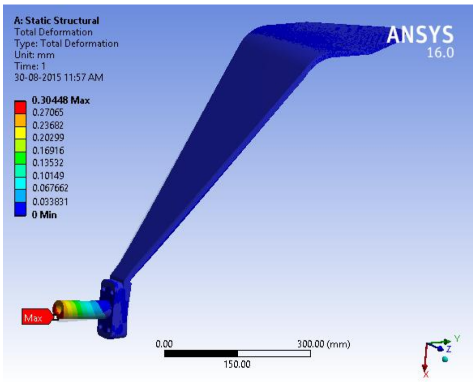

Figure 3.2: Displacement plot of the structure

Figure 3.2 shows displacement in the structure. The Maximum displacement is 0.3044 mm which can observe at the loading region which is at the wheel base of the axle component.

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3.2 RANDOM 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 random. 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 random 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 random response. Initially modal analysis is carried out to find the dynamic stability of the structure. Random analysis has been carried out at random loading conditions.

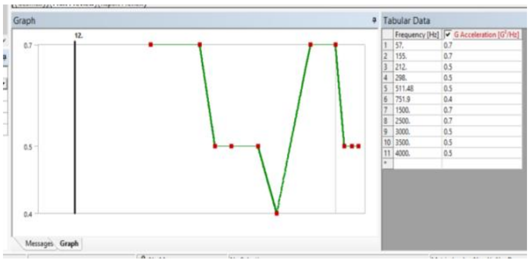


Figure 3.3: Random input plot of landing gear's leg

Figure 3.3 shows base excitation plot obtained Power Spectral Density (PSD) outputs in G^2/Hz for the landing gear's leg 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 57.141 Hz is corresponding to a speed of 3200 rpm. This speed indicates resonance condition if the structure is excited with 3200 rpm of the air craft.

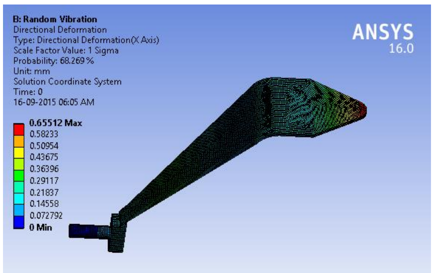


Figure 3.4: Displacements plot of random analysis

The result of spectrum analysis shows maximum displacement of 0.65512 mm and the displacement plot shown in figure 5.10, 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.

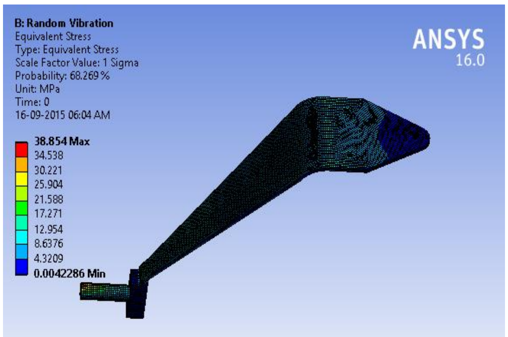


Figure 3.5: Von-mises stress plot for random analysis

Figure 3.5 shows the von-mises stress plot of the landing gear due to the given spectrum loads. The maximum stress of 38.854 Mpa can be observed in the component. 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. The scale factor of result is doubled to get the 2σ value which gives 95.91% and tripled to get 3σ values gives 99.7% of the time.

The default results are for maximum stress condition for 1σ value. By multiplying 3 times the 1σ values, the obtained displacement is 1.93 mm and 116.47 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.

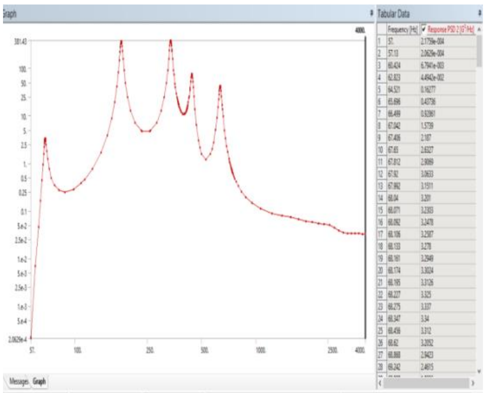


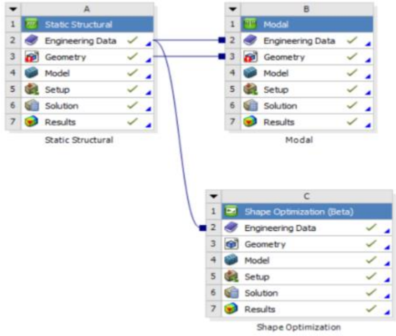
Figure3.6: Response plot of random analysis

Figure 3.6 shows dynamic amplification of the output response of the systems. The uncontrolled vibration on gear leg lies between 50 to 750 Hz.

4.0 WEIGHT OPTIMISATION OF THE LANDING GEAR'S LEG:

The static and random 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.



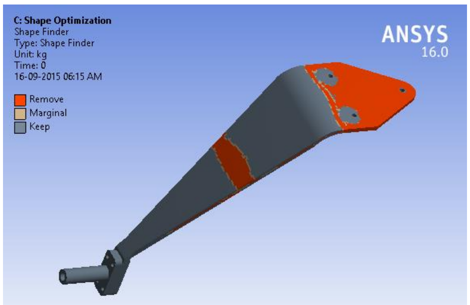


Figure 4.1: Shape optimization (Shape finder plot) analysis

Shape optimization is carried out iteratively to find out possible cut off regions which are useful to reduce the weight of the component from selected area. The process is carried out iteratively and the output plot in figure 4.1 shows that the colors other than red color can be removed from the geometry. The topology optimization shows that there is a scope to remove the material at the top side and bottom side of landing gear's leg which leads to reduce the weight of the component.

Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Target Reduction	41. %
Suppressed	No
Results	
Original Mass	5.6633 kg
Marginal Mass	6.0544e-002 kg
Optimized Mass	3.2711 kg

Figure 4.2: Variation of weight of the structure with iterations

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Figure 4.2 shows variation of weight and von-mises 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.

Object Name	*Shape Finder*
State	Solved
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Definition	
Target Reduction	41. %
Suppressed	No
Results	
Original Stress	156.74 Mpa
Optimized Stress	238.42 Mpa

Figure 4.3: Variation of von-mises stress after optimization

Figure 4.3 shows the variation of von-mises stress to the iterations. It can be observed that the variation in von-mises stress is not much predominant for varying thickness. This is due to redistribution of loading region. The feasible optimized sets obtained by iteration process are tabulated.

5. STRUCTURAL ANALYSIS FOR OPTIMIZED MODEL

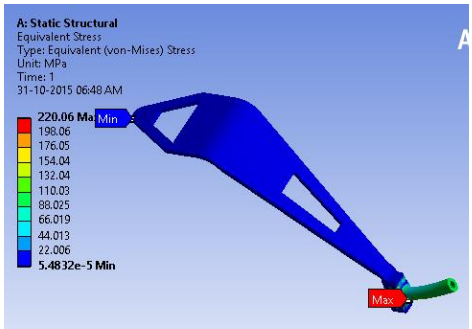

Figure 5.1 shows developed von-mises stress in the structure.

The maximum von-mises stress is 220.06 N/mm². The obtained stresses are less than yield stress of the material, so structure is safe for the given loads. By observing the von-mises stress plot of static analysis the stress levels throughout the structure is almost equal and a small portion at bottom corner of the component has highest stress concentration. The maximum displacement obtained by conducting static analysis is 0.3799 mm.

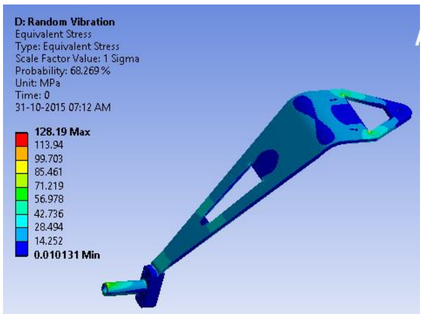

Figure 5.2: Von-mises stress plot for spectrum analysis

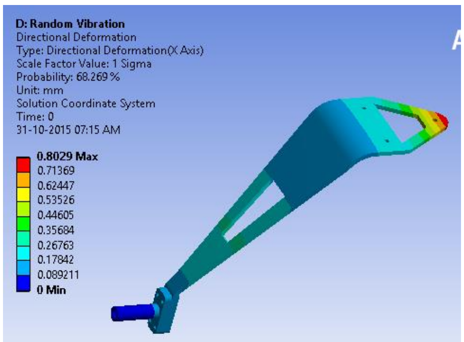

Figure 5.3: Directional Deformation in X axis plot for spectrum analysis

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The result of spectrum analysis using Response Spectrum analysis shows maximum displacement of 0.8029 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 5.2 shows spectrum response of the optimized landing gear's leg due to the given spectrum loads. Maximum stress of 128.19 Mpa can be observed in the problem. The results viewed by ANSYS solver are 1σ or one standard deviation values. By multiplying 3 times the 1σ values, 280.23 Mpa stress and 2.4 mm displacements are obtained. But this stress is much smaller than the allowable stress of the material; hence the structure is completely safe for the given loads.

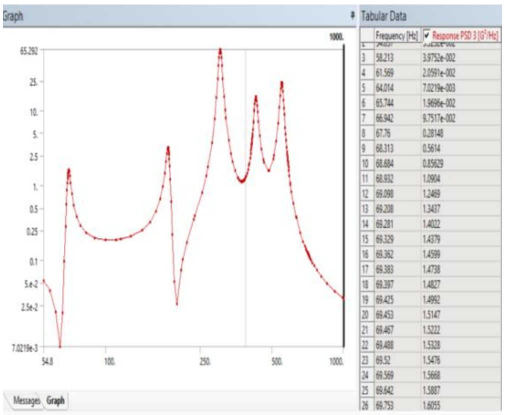

Figure 5.4: Response plot of random analysis for optimized model

Figure 5.4 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.

6.0 CONCLUSIONS:

A CAD model of landing gear's leg for unmanned aerial vehicle was made and discretized in to finite element mesh using ANSYS. The following results are made from structural and optimized analysis on conventional type landing gear's leg.

- Landing gear's leg model is drafted in CATIA, meshed in Ansys workbench 16 and analyzed using ANSYS software's.
- Static analysis is performed in ANSYS to determine maximum displacement and maximum von-mises stress.
- Random analysis is carried out to obtain the frequency response of the landing gear's leg.
- Optimization is carried out to identify the areas where material can be removed without affecting the safety of the design.
- Optimized model is tested for static and spectrum analysis to conform reduction of landing gear's leg weight.

From the above analysis they 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 5.6699 kg to 3.11kg for the given loading conditions. A reduction of 2.33 kg can be observed which amounts to almost 40% reduction of weight.

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