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Design optimization of rear uprights for UniMAP Automotive Racing Team Formula SAE racing car

M Azmeer¹, M H Basha^{1*}, M F Hamid², M T A Rahman¹ and M S M Hashim¹

¹Mechanical Engineering Programme, School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia.

²School of Mechanical Engineering, Universiti Sains Malaysia, Engineering Campus, 14300, Nibong Tebal, Penang, Malaysia

hafifbasha@unimap.edu.my

Abstract. In an automobile, the rear upright are used to provide a physical mounting and links the suspension arms to the hub and wheel assembly. In this work, static structural and shape optimization analysis for rear upright for UniMAP's Formula SAE racing car had been done using ANSYS software with the objective to reduce weight while maintaining the structural strength of the vehicle upright. During the shape optimization process, the component undergoes 25%, 50% and 75 % weight reduction in order to find the best optimal shape of the upright. The final design of the upright is developed considering the weight reduction, structural integrity and the manufacturability. The final design achieved 21 % weight reduction and is able to withstand several loads.

1. Introduction

Formula SAE is a design competition for students that provide opportunity to enhance engineering and project management skills by applying learned classroom theories in a challenging competition. The goal for teams is to develop a small formula-style race car that conforms to the rules and regulations that have been set-up by the organizer. In the competition, a lighter car accelerate quicker and requires shorter stopping distance than heavier car so, reduction in vehicle mass becomes increasingly important to improve acceleration performance. Furthermore, FSAE competition has no minimum weight requirement, so the weight reduction benefits essentially have no limits. A reduction in the weight of the vehicle also improved the vehicle handling performance [4]. Therefore, it would be a great advantage for the team if the weight of the vehicle components is reduced.

Upright has a greater weight compared to the tie rod, control arm and ball joint, it will give a greater impact in reducing the weight of upright compared to other parts [3]. Therefore, a weight reduction on the upright is essential. Upright is an important component in a vehicle which it is used to hold the hub for the wheel and connects the upper and lower control arms. Furthermore, it also carries the power thrust from tie rod to the stub axle and hence it must be very strong, rigid and also as light as possible. The objective of this work is to reduce the weight and cost, while maintaining the structural strength of the upright. A shape optimization had been performed and the strength of the upright had been observed.



2. Methodology

2.1. Base Design

The CAD model of the base design upright has been developed using CATIA V5. The upright with the mass of 3.027 kg consists of stub hole, tie-rod mounting points, upper arm and lower mounting points as shown in Figure 1. The material used is steel, with its properties as shown in table 1.



Figure 1. Base design of upright

Table 1. Property of steel

Property	Value
Young's Modulus	2×10^{11} Pa
Poisson Ratio	0.3
Bulk Modulus	1.667×10^{11} Pa
Shear Modulus	7.692×10^{10} Pa

2.2. Static structural analysis

By using converted “.STP” file format, the CAD model of the upright is imported to ANSYS WORKBENCH and the meshing process started. Fine element size and hundred percent relevance were selected to obtain better mesh quality. Analytical calculation was done to determine the magnitude of force and moment under 2g braking, 2g cornering and 2g bumping. Table 2 shows the combination of these forces and moments form a critical load which was used to observe the maximum deformation and stress of the upright.

Table 2. Forces and moments values

Condition	Moment and Force
Axial force (Braking), 2g	559.150 N.m
Lateral force (Cornering), 2g	615.026 N.m
Vertical force (Bumping), 2g	2001.24 N
Critical situation (Combination of Braking, Cornering and Bumping)	Moments 559.150 N.m, 615.026 N.m Force 2001.24N

2.3. Shape optimization

Shape optimization is a method to modify structural shape into optimal shape. Topology analysis is used to find the best optimal shape under specified constraints. Shape optimization of the upright was done using 25%, 50% and 75% target reduction in order to determine which exact region and trusses that need to be kept or remove without making the structure fail. The optimized mass for every reduction were also recorded.

3. Result and discussion

3.1. Static structural analysis of the base design

Static analysis of the upright has been done under critical load condition which all the force and moment happen at once as shown in figure 2. The result of the analysis is shown in table 3. Based on this result, the maximum deformation and stress value was good enough to avoid failure in structure. Furthermore, the distribution of stress was also everywhere well below the yield strength of the material.

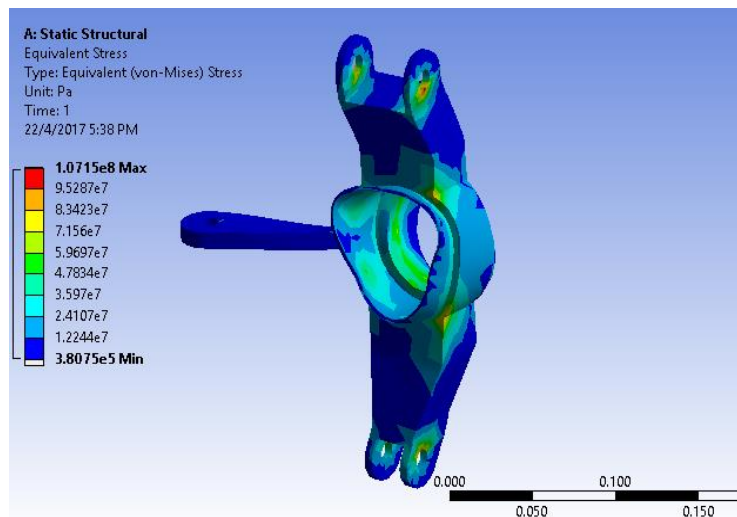


Figure 2. Stress analysis (Von-Misses) of the upright

Table 3. Static structural analysis result of the base design upright

Result	Value
Maximum stress	1.0715x10 ⁸ Pa
Total Deformation	2.8618x10 ⁻⁵ m
Safety Factor	Min 2.3332 Max 15
Equivalent Elastic Strain	0.00057939

3.2. Mass reduction

The base mass of the upright is 3.027 kg. As shown on figure 3, by starting with target reduction of 25%, the mass of upright is reduced to 2.3023kg and no significant difference in the shape of upright formed. While, for target reduction of 50% as shown in figure 4, the mass of upright is reduced to 1.5292 kg and some different in the shape begin to formed. Lastly, for target reduction of 75%, the

mass of upright is reduced to 0.77621 kg and significant different in the shape had formed. Based on figure 5, the shape formed after the material been removed for 75% percent reduction can be clearly seen. The shape formed indicates that the design maintain it strength by using “X” shape trusses. Therefore, the “X” shape trusses will be used in designing a new optimized design of upright.

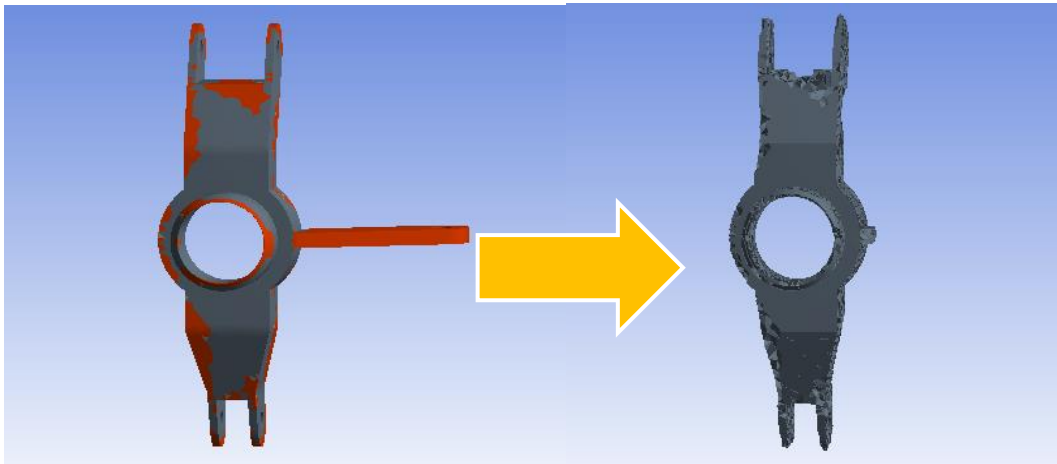


Figure 3. Shape optimization for 25% target reduction

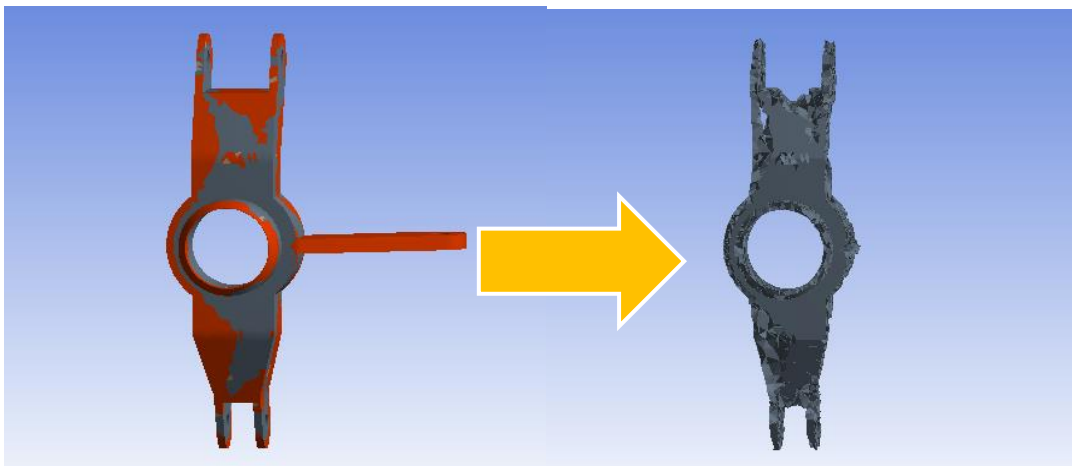


Figure 4. Shape optimization for 50% target reduction

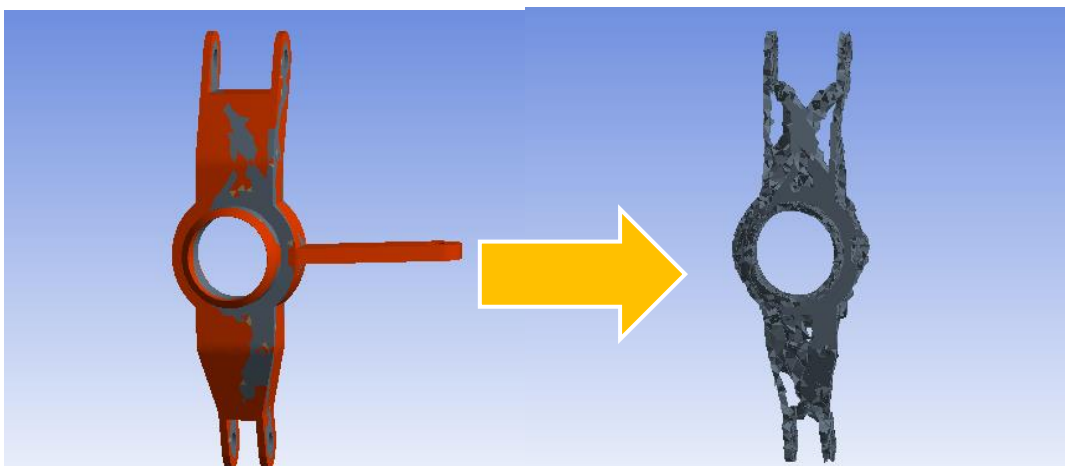


Figure 5. Shape optimization for 75% target reduction

3.3 New Optimized Design

Based on figure 3 ~ 5, the design cannot be used directly because shape optimization is only a tool to indicate the potential geometry changes and allow user to determine where material can be removed without adversely affecting the strength of the overall structure. So, a new design must be created to replace the trusses design in Figure 5. For fabrication purposes, the upright design as shown in figure 6 had been choose because of its advantages in low cost, easy to fabricate and availability of material. Besides that, with the help of “X” shaped trusses, the mass of the new optimized design has become 2.3863kg which is about 21% target reduction. This mass reduction show that shape optimization is very useful tool in making an improvement to a certain design.

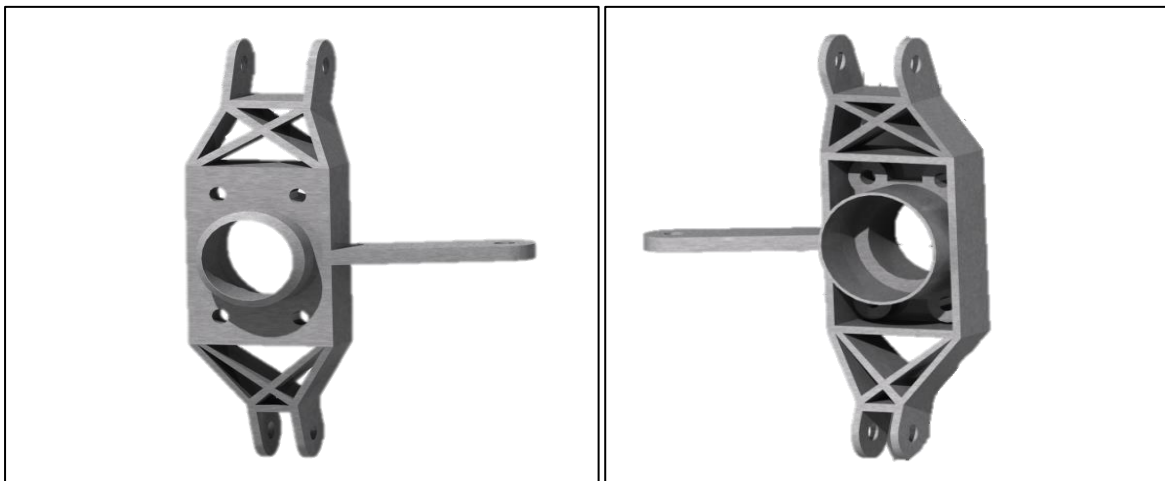


Figure 6. New optimized design

3.4 Static Structural Analysis of New design

Structural analysis of the new optimized design is done as shown in figure 5, with the same condition as stated in table 2. The result of the analysis is shown in table 4. Based on the results, the maximum stress value was good enough to avoid failure in structure. Furthermore, the distribution of stress was also everywhere well below the yield strength of the material.

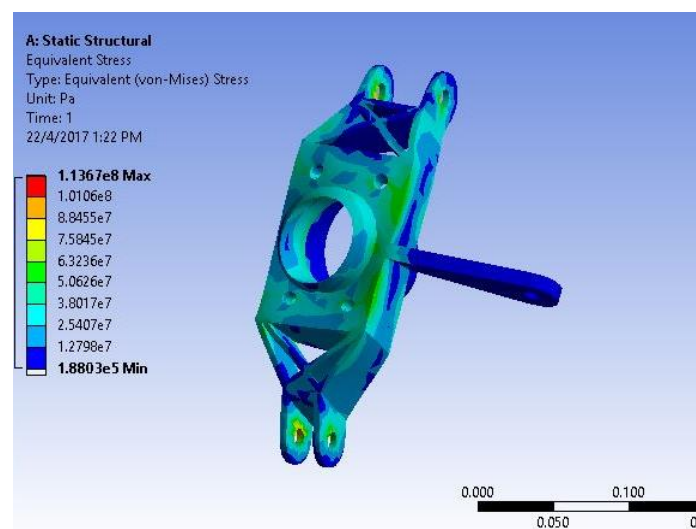


Figure 7. Stress analysis (Von Misses) of the new optimized upright

Table 4. Static structural analysis result of the new optimized upright

Result	Value
Maximum stress	1.1367x10 ⁸ Pa
Total Deformation	6.4769x10 ⁻⁵ m
Safety Factor	Min 2.1993 Max 15
Equivalent Elastic Strain	0.00059006
Mass of upright	2.3863

4. Conclusion

Shape optimization had been performed and the mass of the upright was reduced by 21%. Maximum stress and deformation are within control. The shape optimization gives small change in deformation when several loads are applied, which means that change of volume and shapes does not influence significantly to stiffness of the structure. Therefore, the total weight of the vehicle has been reduced, as well as, costs and materials used. This will improve the fuel efficiency, handling and carbon emission.

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