Topology Optimisation of an Automotive Knuckle

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1. Abstract

Weight reduction and ease of manufacturability through additive manufacturing are in increased focus in Industry than ever before. This objective can be realized by the use of advanced design and analysis strategy during the design phase of the interested component. Structural optimization is a method that aims to optimize the design and material of a component or a body for a given set of constraints. Especially, Topology and Shape optimization based on Finite Element Analysis have been widely used to optimize the distribution of material in a body, in the initial design phase. Off Road and Racing vehicles built by students for competitions such as SAE E-Baja require structural components that are less in weight yet have high stiffness. The purpose of this project is to carry out topology optimization on the Steering Knuckle of a fully electric All-terrain vehicle using Altair Hyper works and Solidthinking Inspire.

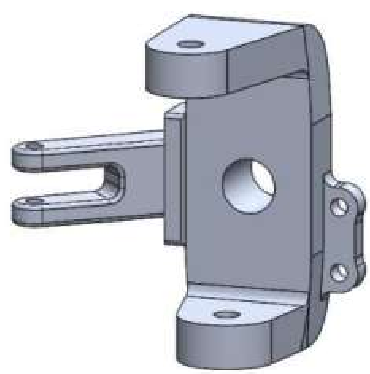
2. Introduction

Topology optimization is a mathematical method that optimizes material distribution within a given design space of a component, for a given set of loads, boundary conditions and constraints with the goal of maximizing the performance of the system and optimizing design volume, weight and material usage. The design after topology optimization can attain any shape within the design space, instead of dealing with predefined configurations as in shape and sizing optimization methods. Topology optimization uses a finite element method (FEM) to evaluate the design performance and identify the major load bearing and other crucial points in the design space. The design is optimized using mathematical programming techniques such as the optimality criteria algorithm and the method of moving asymptotes or non-gradient-based algorithms such as genetic algorithms. Topology Optimization has a wide range of applications in aerospace, mechanical, bio-chemical and civil engineering domains. It is mainly used in the conceptualisation stage of the design process. The result obtained from topology optimization is generally difficult to manufacture with conventional manufacturing techniques because of the resultant free form structure of the component. Recent advances in manufacturing techniques such as additive manufacturing has helped in a more mainstream application of topology optimization. Topology optimization was first proposed in 1900 (Mitchell 1904). It was primarily used for two purposes: shape optimization and layout optimization. The most common method of topology optimization is homogenization method where it is assumed that the microstructure of the component's materials is homogeneous [1]. Topology optimization was then popularized by Bendsoe and Kikuchi in 1988. The main objective of topology optimization is to identify the amount and placement of material in the design space to obtain maximum structural performance with minimal cost [2]. Topology optimization was first invented for mechanical structures but has since spread into other related domains such as fluids, acoustics, electromagnetics, optics, etc. The method involves repeated analysis and design update steps, which is guided by mathematical gradient computation. Topology optimization can be done by adopting either of the following two approaches: by shape optimization or density optimization (using elemental or nodal densities).

3. Unoptimized Component

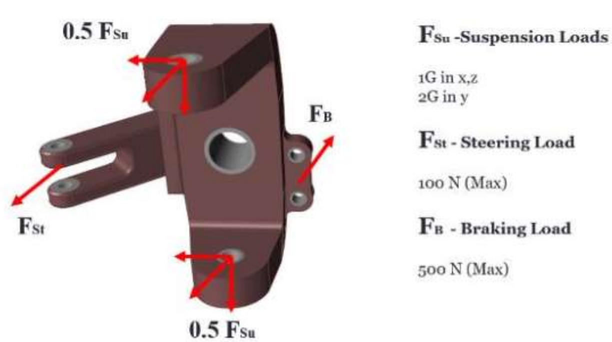
The existing knuckle in the fully electric ATV is made of Al 6061.This model is simulated for the various loading conditions as follows.

- Axial Load - Axial load is a force measured along the lines of an axis. Axial loading occurs when an object is loaded so that the force is normal to the axis that is fixed. Tensile and Compressive loads are the two major axial loads acting on the knuckle
- Bending Load - When the weight of the vehicle acts on the knuckle then this load exists. This force tends to bend the steering knuckle outwards, away from the centre line.



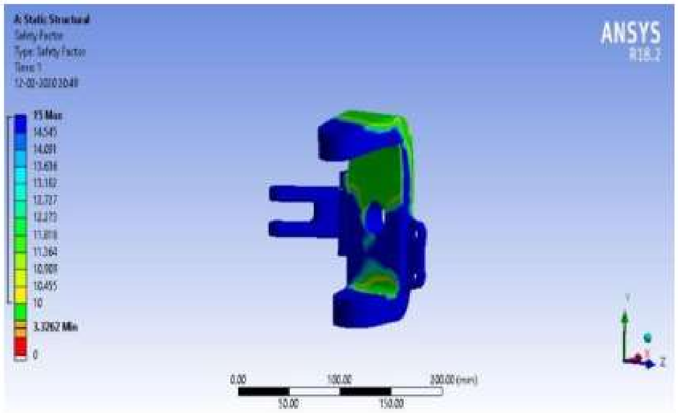
3.1. Finite Element Analysis

ANSYS Workbench is used to analyse the existing component. Element size of 5 mm is chosen as the mesh size. The loading conditions are as shown in Fig 3, where 1G represents the force corresponding to the weight of the entire vehicle, it being 2900 N.



3.2.Results and Discussion

The existing design is over engineered, which causes unwanted mass to be present in the component. A minimum safety factor of 3.3 is obtained [Fig.4] which is very high when compared to the Industrial Standard of 2.0 – 2.5. Thus, the component can be optimized to result in weight reduction without affecting other steering and suspension parameters in the design.

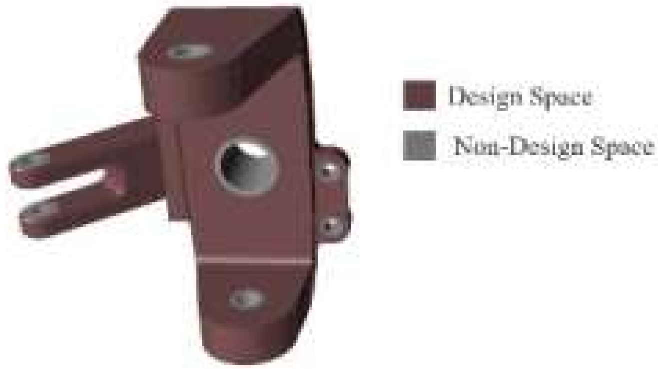


4. Optimization of the Knuckle

I*nspire* is a simulation tool that enables users to ensure a quality, dependable and optimized design prior to any prototyping or production. The factors considered for the tool selection are ease of use, required features, solution accuracy and speed, validation and availability. Various other solvers such as *ANSYS, OptiStruct* were also considered. In *ANSYS*, we can define objectives easily and apply controls to ensure that manufacturing requirements are met, minimum material thicknesses are set and exclusion areas are defined. This tool is used after complete unoptimized design of product and provides high quality support during optimization. *OptiStruct* is a structural solver with comprehensive, accurate and scalable solutions for linear and nonlinear analyses across statics and dynamics, vibrations, acoustics, fatigue and Multiphysics disciplines. Based on the capabilities and features of the three software tools, Altair Inspire was decided as the best suited tool for our application of topology optimization. We have used the nodal density-based approach in *Altair Inspire* software.

4.1. Design and Non-Design Space

For any component under Topology Optimization, specification of the Design space is important. Design space is the region of the topology where optimization has to be done. Usually, this does not include mounting regions or functional bodies in an assembly file. Figure 5 shows the design and non-design space in our knuckle.



4.2. Simulation Results for Various Percentage of Volume

For this optimization, 10 trials have been performed. Each trial is done by varying the percentage of volume of design space to be optimized. The values were 5%, 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50%. The same loading conditions as given in Figure 3 are loaded in this setup. The following are the isometric view of the topology results for each trial in ascending value.

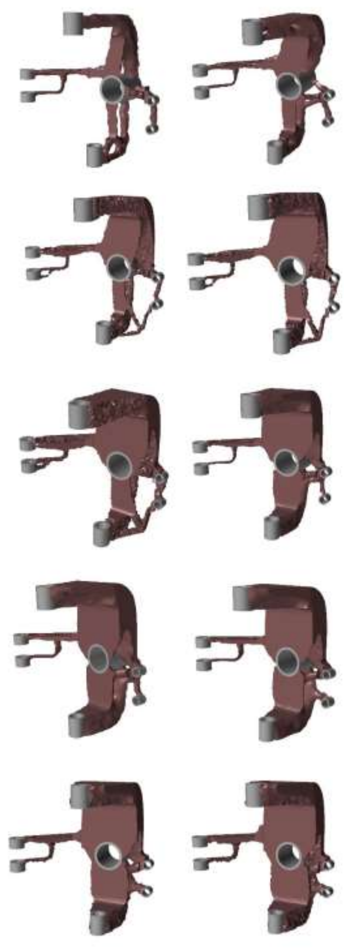


Table I. Results of trials

%volume	Mass (kg)	Factor of safety
5	0.155	0.78
10	0.20351	1.096
15	0.24665	1.33
20	0.29802	1.502
25	0.37088	1.654
30	0.40447	2.162
35	0.47168	2.353
40	0.50	2.418
45	0.55139	2.5777
50	0.60802	2.663

5. Linear Interpolation

The novelty in our work is to find the exact percentage of volume at a Safety Factor of 2.0, which would afterwards increase when design realization is being done.

5.1. Linear Interpolation in MATLAB

Using interpolation, the user can iterate in between the known range of values, find missing values, smooth existing data, make predictions etc. Here the interpolation is used for finding the value of volume percentage corresponding to Safety Factor 2.0 from the input data set of percentage of volume and safety factor from the previous trials. There are several built-in functions provided by MATLAB for interpolation like interp1, interp2, interp3, intern, spline, p-chip etc. Interp1 is the most widely used inbuilt function for 1-D data interpolation where it used to interpolate the unknown values from the known dataset.

MATLAB code

```
% Percentage of Volume vs Factor of Safety
% Percentage of Volume - x
% Factor of Safety - y
x = [5,10,15,20,25,30,35,40,45,50];
y = [0.78,1.096,1.33,1.50,1.65,2.16,2.35,2.42,2.58,2.66];
plot(x,y,'-o');
grid;
y_value = 2;
print(interp1(y,x,y_value));
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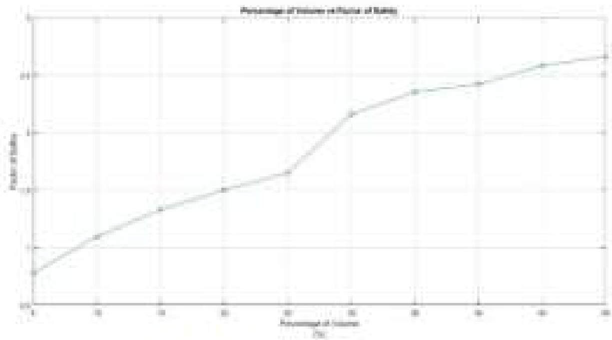
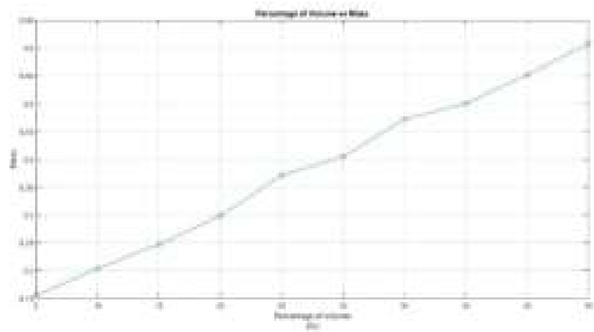
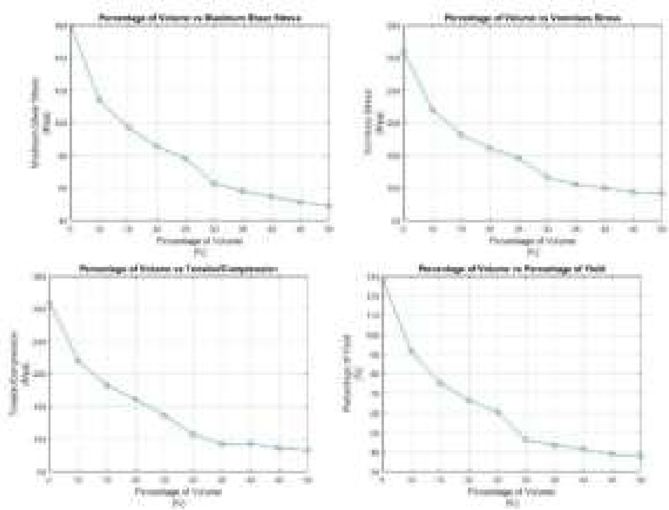


Graph 1. Percentage of Volume vs Factor of Safety



Graph 2. Percentage of Volume vs Mass in Kg

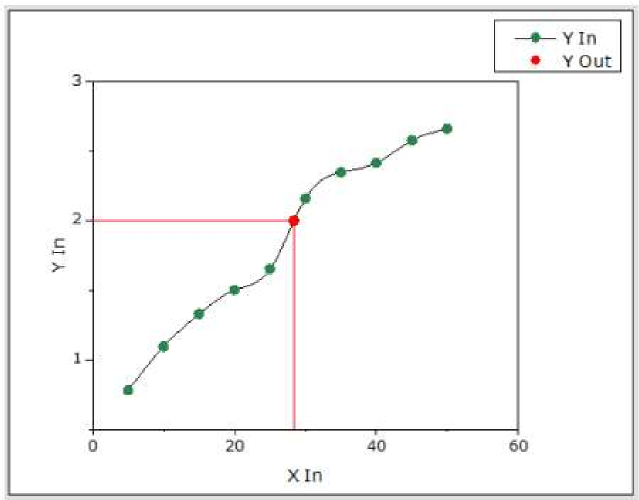


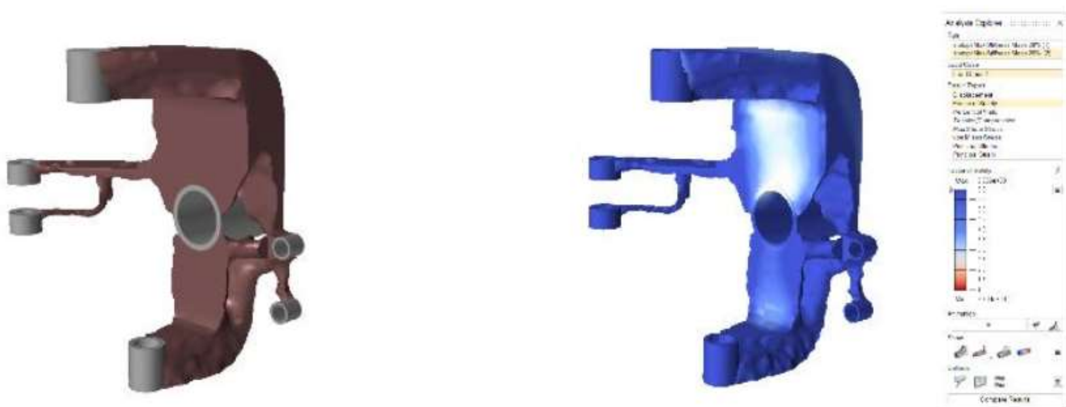
5.2. Results and Discussion

Graph 3 shows the interpolation done for finding the percentage of volume corresponding to Safety Factor 2.0 Graph 3. Interpolation Thus, by noting from the graph, the ideal volume to be considered is 28.4%. This value is again given as input in a new trial in the Altair Inspire Software and topology is obtained.

5.3. Design Realization

Using PolyNURBS modelling, the finite element mesh model is manually converted into a 3D printable Solid Block.





6. **Conclusion**

Using multiple trials of topology optimization and then linear interpolation, an effective design of 43% Mass reduction with a safety factor of 2.5 is obtained. This novel and probabilistic technique will cut down precise unwanted material costs and manufacturing costs, especially when using Metal Additive Manufacturing.

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