# Optimization and Finite Element Analysis of Steering Knuckle

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## ABSTRACT
This Steering Knuckle is one of the critical components of vehicle which links suspension, steering system, wheel hub and brake to the chassis. It undergoes varying loads subjected to different conditions, while not affecting vehicle steering performance and other desired vehicle characteristics. This paper focuses on optimization of steering knuckle targeting reducing weight as objective function, while not compromising with required strength, frequency and stiffness. A vehicle steering knuckle undergoes time-varying loadings during its service life. Fatigue behavior is, therefore, a key consideration in its design and performance evaluation. This research program aimed to optimized best use of material for the steering knuckle and compare analysis of steering knuckles made from two materials i.e. cast iron which is recently using and aluminium alloy which is suggested material.

## Keywords
Shape Optimization; Types of materials; weight reduction; Static analysis

## 1. INTRODUCTION
Reducing mass of vehicle components will contribute towards overall mass reduction of a vehicle, lower its energy consumption demand, therefore, will improve its fuel efficiency. Material resources will be saved too.The employment of light alloys aimed at weight saving is becoming a stringent need in the transport industry due to the environmental and social pressure. Fuel consumption and exhaust emissions are in fact strongly dependent on car weight and for such a reason, the automotive industry is looking at both innovative process technologies which make use of light alloys and new design methodologies. On such a base, after a brief analysis of the approach to be adopted for meeting the environmental goal.

In this investigation, steering knuckle is used as component for study. Steering knuckle is one of important component of vehicle which is connected to steering, suspension and brake to chassis of vehicle. Fuel consumption and exhaust emissions are directly dependent on engine efficiency and car weight. Engines have already reached a remarkable efficiency and so the improvement possibilities are limited. Concerning the weight reduction, the improvement field is by far wider. In fact it has been demonstrated that weight saving has a strong influence on fuel consumption reduction if seen not only on the single vehicle but considering the fleet economy. There are two ways of meeting these goals:

1) Optimising the component design employing the same material.
2) Replacing traditional materials with lighter ones.

In the first case, it is important to acquire high knowledge of employed materials and processes in order to exploit at maximum their capabilities. Relating to the material replacement, the automotive industry is looking at innovative process technologies, new design methodologies, development of light alloy applications.

Optimization methods were developed to have lighter, less cost and may have better strength too. Many optimization types, methods and tools are available nowadays due to the revolution of the high speed computing and software development, from which I select shape optimization which gives the best use of material for a body. Typically this involves optimizing the distribution of material so that a structure will have the maximum stiffness for a set of loads the image steering knuckle

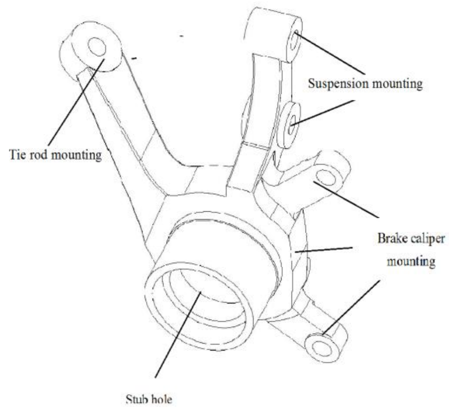


**Fig.1. Steering Knuckle**

## 2. LITERATURE REVIEW
Purushottam Dumbre et al. [June2014], “Structural Analysis of steering Knuckle for Weight Reduction”-In this paper, authors used steering knuckle for study. Weight reduction of steering knuckle is the objective of this exercise for optimization. Typically, the finite element software like OptiStruct (Hyper Works) is utilized to achieve this purpose. For optimization, Nastran/Ansys/Abaqus could also be utilized. The targeted weight or mass reduction for this exercise is about 5% without compromising on the structural strength. Topology optimization can be used to reduce the weight of existing knuckle component by 11% while meeting the strength requirement, with limited design space given with or without change in material properties.

2.2: Viraj R. Kulkarni and Amey G. Tambe [2013], “Optimization and Finite Element Analysis of Steering Knuckle”-In this paper, authors focuses on optimization of steering knuckle targeting reducing weight as objective function, while not compromising with required strength, frequency and stiffness. Taking into consideration static and dynamic load conditions, structural analysis and modal analysis were performed. Finite element model was developed in HyperWorks and the finite element model was solved using RADIOSS solver. OptiStruct solver was used for performing Topology Optimization to minimize the amount of material to be used and setting geometric parameters as design variables.Optimization method used in this study in reducing the mass of the existing steering knuckle to 53.33%. This implies the first CAD model was over designed. Even if slightly optimized model would been investigated observing results the reduction of mass would have definitely been over 10%. The maximum stresses and displacement is within control and yielding a factor of safety around 2.8 to 3 necessary for such a crucial part in an automobile. Displacement is under 0.08mm and frequency obtained is at higher range thus eliminating cause of resonance. Considering the results obtained from optimization, geometric model was modified and iterated until satisfactory results were achieved.

2.3: Razak I. H. A. et al. [July2013], "Modelling, Simulation and Optimization Analysis of Steering Knuckle Component for Race Car"- In this paper, authorsaimed to A light weight and optimized design of steering knuckle is proposed to be used for an EIMARace car; a small high-performance formula-style car, with suitable material selection as well as valid finite element analysis and optimization studies. First part of this study involves modeling of steering knuckles and analysis of the stresses and displacement under actual load conditions. A CAD and FEA software; SolidWorks, is applied for modeling as well as for static analysis studies. Shape optimization is the second part of this study, utilizing solid Thinking software from Altair Engineering packages. As the ultimate aim of this study is to reduce mass of the existing knuckle with target to achieve low fuel consumption, selection of the best material and simple geometry are crucial. Aluminum 6061-T651 alloy (yield strength 276 MPA) was found to be the best material for the component due to the good physical and mechanical properties as well as light weight. Obtain the best use of material for the component was justified in reducing the weight of existing knuckle to 45.8% while meeting the strength requirement. The minimal weight of the steering knuckle component may contribute to the reduction of the overall weight of the race car thus may improve the fuel efficiency as well as the overall performance.

2.4: Mehrdad Zoroufi and Ali Fatemi [2004], "Fatigue Life of Competing Manufacturing Processes: A Study of Steering Knuckle"-In this paper author research program aimed to assess fatigue life and compare fatigue performance of steering knuckles made from three materials of different manufacturing processes. These include forged steel, cast aluminium, and cast iron knuckles. In light of the high volume of forged steel vehicle components, theforging process was considered as base for investigation. Monotonic and strain-controlled fatigue tests of specimens machined from the three knuckles were conducted. Static as well as baseline cyclic deformation and fatigue properties were obtained and compared. In addition, a number of load-controlled fatigue component tests were conducted for the forged steel and cast aluminium knuckles. Finite element models of the steering knuckles were also analysed to obtain stress distributions in each component. Based on the results of component testing and finite element analysis, fatigue behaviours of the three materials and manufacturing processes are then compared iron reached 37% and 57% of forged steel ultimate tensile strength, respectively. The percent elongation of cast aluminium and cast iron were found to be 24% and 48% of the forged steel, respectively. Component testing results showed the forged steel knuckle to have about two orders of magnitudelonger life than the cast aluminium knuckle, for the same stress amplitude level. This occurred at both short as well as long lives. Comparisons of strain-life fatigue behaviour of the three materials indicated that the forged steel provides about a factor of 20 and 4 longer lives in the short-life regime compared to the cast aluminium and cast iron, respectively. In the high-cycle regime, forged steel resulted in about an order of magnitude longer life than the cast iron, and about a factor of 3 longer life, compared to the cast aluminium.It is concluded that the forged steel knuckle exhibits superior fatigue behaviour, compared to the cast iron and cast aluminium knuckles.

2.5: Wan Mansor Wan Muhammad et al. [Feb2012], "Design Improvement of Steering Knuckle Component Using Shape Optimization".-In this paper finite element software, HyperWorks which contains several modules is used to achieve this objective. HyperMesh was used to prepare the finite element model while HyperMorph was utilized for defining shape variables. For optimization purpose, OptiStruct was utilized. The improved design achieves 8.4% reduction of mass. Even though there are volume reduction and shape changes, maximum stress has not change significantly. This result is satisfactory considering using optimization in shape only, with limited design space given and no change in material properties. Optimization method used in this study succeeded in reducing the mass of existing knuckle component to 8.4%. Even though there are volume reduction and shape changes, maximum stress has not change significantly. This result is satisfactory considering using optimization in shape only, with limited design space given and no change in material properties. Other vehicle components, similarly, have the potential to be reduced with respect to mass using shape optimization. Therefore, the overall weight of the vehicle can be reduced to achieve savings in costs and materials, as well as, improve fuel efficiency and reduce carbon emissions to sustain the environment.

2.6: Kamlesh Lalsaheb Chavan et al.[June2014], "Mass Reduction For Steering Knuckle Arm in a Suspension System Through Topology Optimization in CAE".-In this paper, author studied thefailure during sudden severe loading caused due to abuse or due to continual and repetitive usage while driving for extended timelineover the life of the component. The challenge posed for the Design Engineer is to recreate the actual conditions during the analysis phase and determine the best material or the specifications of the component that would be most suited to the given application. The current Design challenge for the Steering Knuckle Arm is to generate the most optimal configuration of the component Design for the given input conditions of loading. The Sponsoring Company is working on the soon-to-be launched automotive model and is expected to take this task to completion through the use of CAD (CATIA or UG) for creating the geometry and further use the CAE tools (HyperWorks/Optistruct/ or suitable) for conducting analysis for the component. The Test Report/s for the component would form a basis for verifying the results with the Analytical method of analysis. For validating the Design of the component, a good match of the corresponding readings is desired. Typically, depending on the type of Test and the application, an error margin or about 5 to 20% could be considered close towards validating the proposed Design.

# 3. MATERIAL SELECTION

There are several materials used for manufacturing of steering knuckle such as S.G. iron (ductile iron), white cast iron and grey cast iron. But grey cast iron mostly used. Forged steel are most demanding material for this application.

The steering knuckle which I modelled is made up of cast iron. Now a day's automobile industry has put effort to use aluminium alloy as an alternative. Due to low weight of this material, it can reduce fuel consumption and CO2 emission. So as per literature survey I found the material which can be used for manufacturing of steering knuckle which is Aluminium 2011 T3 Alloy.

**Table 1: Physical and Mechanical Properties Of Aluminium 2011 T3 alloy**

| | |
|---|---|
| Young's Modulus | 7.1e+4 Mpa |
| Poisson's Ratio | 0.33 |
| Density | 2770 kg/m3 |
| Ultimate tensile strength | 310Mpa |
| Yield Strength | 280Mpa |

**Table 2: Physical and Mechanical Properties Of Cast Iron**

| | |
|---|---|
| Young's Modulus | 1.1e+005 Mpa |
| Poisson's Ratio | 0.28 |
| Density | 7200 kg/m3 |
| Ultimate tensile strength | 240Mpa |
| Yield Strength | 280Mpa |

# 4. 4. DESIGN OF CAD MODEL

CAD model of steering knuckle was developed in 3D modelling software CREO 2.0. it consists of stub hole, brake calliper mounting points, steering tie-rod mounting points, suspension upper and lower A-arm mounting points. Knuckle design mainly depends on suspension geometry and steering geometry.

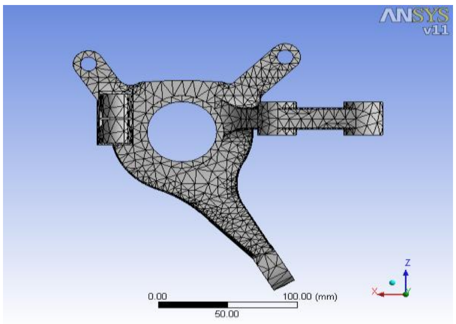


**Fig.2: meshing**

**Table3: Nodes and Elements of model**

| | |
|---|---|
| NODES | 18577 |
| ELEMENTS | 9337 |

# 5. STATIC ANALYSIS

There are two types of load acting on knuckle i.e. force and moment. This knuckle is designed for vehicle of 1480 kg weight. Braking force acting on it produces moment.by measurement perpendicular distance is 94mm

For calculating breaking force acting on one wheel we have to distribute weight of vehicle for four wheels so that we get vehicle weight acting on one wheel. i. e. 1480/4 = 370 kg for one wheel

Breaking force = 1.5g ( g = 9.81m$^2$/s)

=1.5*9.81 = 14.715 m/s$^2$

=14.715 *370

= 5444.55kgm$^2$/s

=5444.55 N

Moment = breaking force * perpendicular distance

= 5444.55* 94

= 511787.7 Nmm (for one wheel)

This moment is acting on steering knuckle where break caliper is mounted. Brake calliper is mounted at three location therefore distributing momnt at three point,

Moment = 51187.7/3

= 170596 Nmm

# 6. FORCE

For calculating force acting on steering knuckle, we required loading conditions which is given as follows

Table 4: loading conditions

| LOADING CONDITIONS | |
|---|---|
| Braking force | 1.5g |
| Lateral force | 1.5g |
| Steering force | 50N |
| Load on knuckle hub in X-direction | 3g |
| Load on knuckle hub in Y-direction | 3g |
| Load on knuckle hub in Z-direction | 1g |

Since all load in X, Y, and Z direction are perpendicular to each other, the resultant of all the forces s given by,

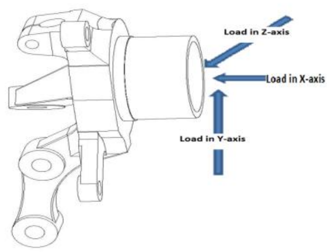


**Fig.3: Direction of load**

$$F = \sqrt{X^2 + Y^2 + Z^2}$$

X = Y = 3g = 3*9.81*370 = 10889.1 kgm/s$^2$ ie N

Z = 1g = 1*9.81*370 = 3629.7 N

$$F = \sqrt{10889.1^2 + 10889.1^2 + 3629.7^2}$$

= 15821.5 N

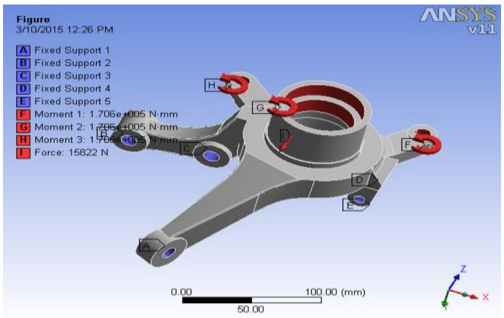


**Fig.4 Boundry conditions (Al alloy)**

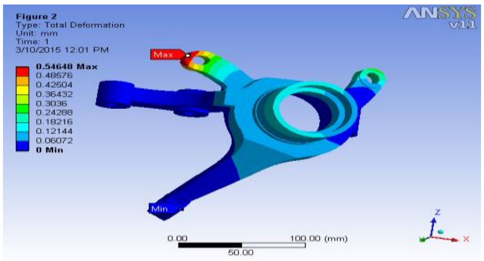


**Fig.5: Total Deformation (Al alloy)**

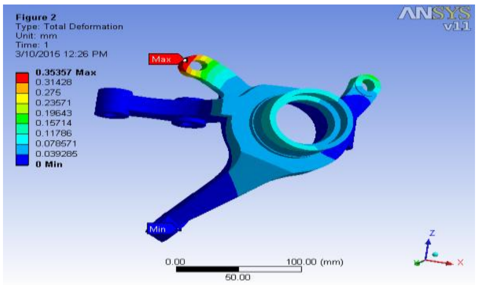


**Fig.6: Total Deformation (Cast Iron)**

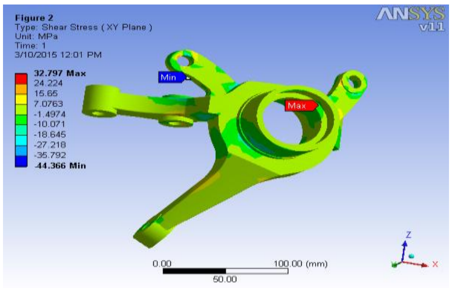


**Fig 7.: Shear stress (Al alloy)**

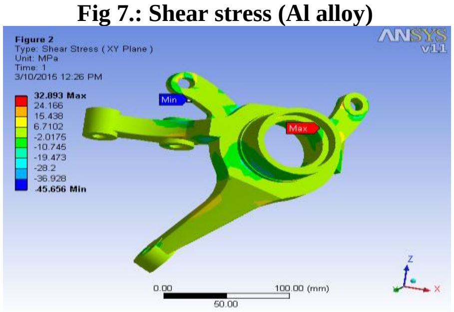


**Fig 8: Shear stress (Cast Iron)**

## 7. SHAPE OPTIMIZATION

Shape optimization is technique to modify the structural shape based on predefined shape variables to obtain optimal shape. Size optimization defines ideal component parameters, such as material values, cross-section dimensions and thicknesses. Shape optimization is different from topology optimization in that it is used once the component's topology has already been defined. Topology optimization is used to generate material layout concepts whereas shape optimization refines and improves the topology within the concept. In shape optimization, the outer boundary of the structure is modified to solve the optimization problem. The purpose of a shape optimization analysis is to find the best use of material for a body. Typically this involves optimizing the distribution of material so that a structure will have the maximum stiffness for a set of loads. In this paper, shape optimization of knuckle was done by using Ansys Workbench Shape Optimization. Here objective function is to reduce weight of knuckle. Design constraints are applied as in static analysis.

## 8. RESULTS AND DISCUSSION

Initial model of knuckle is shown in Fig.5. It has maximum Stress 353.18MPa. After applying load and design constraints shape optimization was performed. Fig. 7 shows material which can be removed from model (shown in orange) after optimization. The objective of the research is to reduce the mass (represented by reduction volume) using shape optimization. The mass reduction for the front knuckle was found to be 19.35%, compared to the currently used model. Optimized model is shown in fig.7.

Original weight of steering knuckle is = 2.6474 kg

Final optimized mass of steering knuckle using aluminium 2011 t-3 alloy replacing cast iron material is 0.86448kg ie 67% weight is reduced.

From original weight 2.6474 kg, 1.78292kg wt is reduced to get 0.86448kg wt. The equivalent stress is less than youngs modulus as compare to cast iron and shear stress is also less than shear stress of cast iron. From these entire result aluminum alloy can be selected.

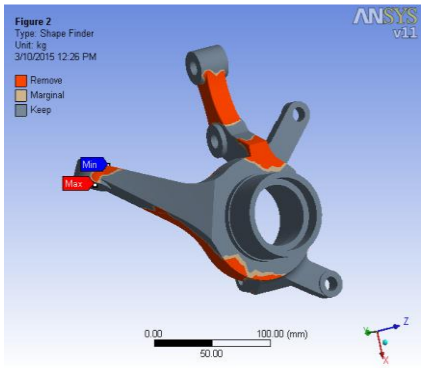


**Fig.9: After Shape Optimization**

## 9. CONCLUSION

Shape optimization method used in this study in reducing the mass of knuckle by 67%. Also factory of safety is between 3 to 4. Maximum stress and displacement are within control. This optimization process also gives small change on the displacement. It means that change of volume and shapes doesn't influence significantly to stiffness of the structure. Therefore, the overall weight of the vehicle can be reduced to achieve savings in costs and materials, as well as, improve fuel efficiency and reduce carbon emissions to sustain the environment.

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