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Design and Manufacturing of Knuckle Hub for Formula Student F1 Car

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Abstract - The steering knuckle is a vital part of a vehicle's suspension and steering system, linking the wheel hub to the suspension arms and steering linkage. In the context of student formula cars, weight reduction and structural strength are crucial design objectives. This study aims to design a lightweight and durable steering knuckle using high-strength materials while maintaining performance and safety. A 3D model of the knuckle was created in SolidWorks 2022, and static structural analysis was performed using ANSYS Student Version 2022 R2. The knuckle was subjected to realistic loads including vertical vehicle weight, longitudinal braking forces, and steering reactions. Among various materials studied—Aluminum 6061-T6 and Mild Steel A36, Aluminum 7075-T6 was selected due to its high strength-to-weight ratio and fatigue resistance. The simulation results confirmed that the component meets structural and safety requirements under expected loading conditions. The final design achieves a good balance between weight and durability, making it a suitable choice for high-performance student racing applications.

Keywords: *Steering Knuckle, Aluminum 7075-T6, Static Analysis, SolidWorks 2022, ANSYS 2022 R2, Student Formula Car, Lightweight Design*

1.INTRODUCTION

Knuckle:
The knuckle is a critical component of the wheel assembly that integrates the suspension and steering systems. It provides mounting points for essential elements such as wishbones, tie rods, bearings, and the brake caliper

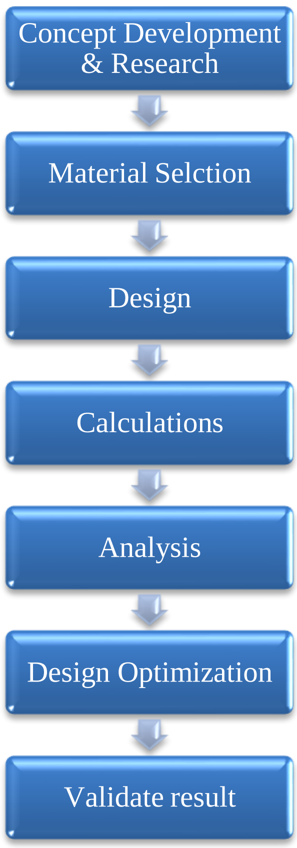
Hub:
The hub serves as the interface between the wheel and the knuckle, enabling smooth wheel rotation while supporting the vehicle's load.

Bearing:
The bearing is an integral component of the wheel assembly, press-fitted into the knuckle, which allows the hub to rotate freely while minimizing friction.

Caliper:
The caliper is a component mounted on the knuckle that houses the brake pads. It generates friction against the disc, resulting in the deceleration and stopping of the vehicle.

Lock Nut, Circlips, and Locking Plate:
The lock nut, circlips, and locking plate are safety-critical components that secure the assembly under dynamic conditions, preventing unintentional loosening or displacement.

1.2 Methodology



1.3 Material selection

The steering knuckle must be designed to withstand the forces and moments arising from vehicle dynamics such as braking, acceleration, steering, and road irregularities. To achieve optimal ride quality, it is essential to minimize the vehicle's unsprung mass. Therefore, the objective of this study is to design a lightweight wheel assembly. Material selection plays a critical role in achieving this goal, with the focus on identifying materials that offer high strength-to-weight ratios. In this paper, we propose the use of Aluminum 7075-T6 and compare its performance against Aluminum 6061-T6, Mild Steel A36, and Stainless Steel AISI 304.

Aluminum 7075-T6

Aluminum 7075-T6 is primarily composed of 5.6–6.1% Zinc, 2.1–2.5% Magnesium, and 1.2–1.6% Copper, along with trace amounts of elements such as Silicon, Iron, Manganese, Titanium, and Chromium. This alloy is known for its exceptionally high specific strength, making it a strong candidate for structural components like the steering knuckle. As shown in the table below, Aluminum 7075-T6 exhibits significantly higher yield and tensile strengths compared to other commonly used materials

Young's Modulus (GPa)	71.7
Density (g/cc)	2.81
Shear Modulus (GPa)	26.9
Poisson's Ratio	0.33
Ultimate Tensile Strength	572
Yield Tensile Strength	503

Table No.1.3.1

Aluminum 6061-T6

Aluminum 6061-T6 consists primarily of 0.80–1.20% Magnesium and 0.40–0.80% Silicon, along with other elements such as Iron (up to 0.70%), Copper (0.15–0.40%), Chromium (0.04–0.35%), Zinc (up to 0.25%), Titanium (up to 0.15%), and Manganese (up to 0.15%). While this alloy offers excellent weldability, it is relatively less suitable for applications like steering knuckles, which require materials with superior machinability and higher strength. Compared to Aluminum 7075-T6, Aluminum 6061-T6 has lower yield and tensile strengths. However, due to its low copper content, it demonstrates good corrosion resistance

Young's Modulus (GPa)	68.9
Density (g/cc)	2.7
Shear Modulus (GPa)	26
Poisson's Ratio	0.33
Ultimate Tensile Strength	310
Yield Tensile Strength	276

Table No. 1.3.2.

Mild Steel A36

Mild Steel A36 primarily consists of 0.25–0.29% Carbon, 0.20% Copper, 97% Iron, 1.03% Manganese, 0.04% Phosphorus, 0.20% Silicon, and 0.05% Sulfur. It is one of the most cost-effective materials among those considered and is readily available in the market. However, it has a significantly higher density, resulting in a poor strength-to-weight ratio when compared to Aluminum 6061-T6 and Aluminum 7075-T6, making it less desirable for lightweight applications such as steering knuckles.

Young's Modulus (GPa)	200
Density (g/cc)	7.8
Shear Modulus (GPa)	79.3
Poisson's Ratio	0.26
Ultimate Tensile Strength	500
Yield Tensile Strength	250

Table No.1.3.3

All the materials discussed are commonly used in applications requiring high tensile strength and toughness. Among these, aluminum alloys are particularly well-suited for wheel assembly components due to their low density and adequate yield strength. The reduced weight of aluminum alloys contributes to decreased fuel consumption and improved vehicle efficiency. Specifically, Aluminum 7075-T6, being both lighter and stronger than Aluminum 6061-T6, is an ideal choice for manufacturing components such as the knuckle, hub, and brake disc

1.3. Design

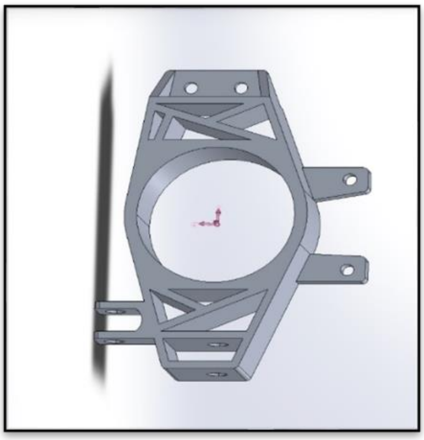


Fig.1.3- 3D Model

2.Force Calculations

The knuckle is a critical component of the wheel assembly, press-fitted onto the spindle and serving as the mounting point for the A-arms, brake caliper, and tie rod. Due to these multiple mountings, the knuckle is subjected to complex and varying forces during vehicle operation. It experiences fully reversed stresses during turning maneuvers, as well as significant loads during braking and acceleration. Therefore, brittle materials are unsuitable for this application. Aluminum 7075-T6, with its high strength-to-weight ratio and superior endurance limit compared to other aluminum alloys, is an excellent choice for manufacturing the knuckle. Its properties enable the production of strong yet lightweight knuckles capable of withstanding dynamic stresses. The material properties are summarized as follows:

$$\text{Endurance Limit} = 160\ \text{N}/mm^2$$

$$\text{Syt} = 503\ \text{N}/mm^2$$

$$\text{Density} = 2800\ \text{kg}/m^3$$

2.1 Determining the forces acting on the Knuckle:

Longitudinal Forces during Braking: During braking, the vehicle's weight shifts from the rear to the front, causing a load transfer that impacts the front suspension components. This load transfer exerts forces on the knuckle through the A-arm mounting points, affecting its structural performance.

Considering,

Maximum acceleration of 1g = 9.81 m/s^2

Force at the front side = mass at the rear side of the vehicle × acceleration

Let the mass at the rear side of the vehicle be 0.7 times the total weight Mass at the rear side of the vehicle=0.7 × 236 =165.2kg

Force = 165.2 × 9.81

Force = 1620 N

Now force on 1 wheel $=\frac{1620}{2}$=810 N

Lateral Forces: -

Lateral forces are because of two reasons – centrifugal force and lateral load transfer from outside to inside while turning. The centrifugal force is considered as follows:

Let the vehicle take a turn of 6m turning radius and at a speed of 30kmph

r = turning radius =6m

v= 30 kmph = $\frac{30\times5}{18}$ =8.3333 m/s

Centrifugal Force $=\frac{\text{m}\times v^2}{r}$

$=\frac{0.7\times236\times8.333^2}{6}$

=1911.88 N

Now consider if all the weight at the front side comes on the wheel assembly the force will be Force due to lateral load transfer =0.7 ×236 × 9.81 =1620.6N

Vertical load acting on each wheel:

Vertical load = 82.6 × 9.81=810.31N

Friction Force = Coefficient of Friction ×
Vertical Load= 0.6 × 810.306

$$= 486.18 \text{ N}$$

Braking Torque = Frictional Force × Radius of tire

$$= 486.1836 \times 0.33$$

$$= 160.44 \text{ N.m}$$

Force Exterted on Caliper Mounting

$$=\frac{Braking\ Torque}{Distance\ from\ center\ of\ spindle}$$

$$=\frac{160.44}{0.062}$$

=3000.2 N

2.2 Designing and determining the dimensions:

The bolts are standard parts and have a defined value of yield strength. All bolts used in the Wheel Assembly are made up of a minimum of 8.8 Grade.

$$\text{Syt} = 580 \text{ N}/mm^2$$

$$\text{Factor of Safety} = 2$$

For selection of bracket bolt size:

Shear Force acting on these bolt

$$= \sqrt{Longitudinal\ foce^2 + Centrifugal\ force^2}$$

$$=\sqrt{\left(\frac{810}{2}\right)^2 + \left(\frac{1911.88}{2}\right)^2}$$

$$= \sqrt{405^2 + 955.94^2}$$

=1252.65 N

$$\text{Shear stress on bolts} = \frac{\text{Syt}\times 0.5}{Factor\ of\ safety}$$

$$= \frac{580\times 0.5}{2}$$

Shear stress on bolts = 145 N$/mm^2$

$$\text{Now,Shear stress on bolts} = \frac{\text{Force}}{Area}$$

$$145 = \frac{1252.65}{\left(\frac{\pi}{4}dc^2\right)}$$

$$dc^2 = \frac{1252.65\times 4}{145\times\pi}$$

dc =4.6 mm

$$d = \frac{\text{dc}}{0.8}$$

$$d = \frac{4.6}{0.8}$$

d=5.86 mm

For selecting bracket bolt size as **M8**

For selection of Caliper mount bolt size:

$$\text{Shear stress on bolts} = \frac{\text{Syt}\times 0.5}{Factor\ of\ safety}$$

$$= \frac{580\times 0.5}{2}$$

Shear stress on bolts = 145 N$/mm^2$

Now,

$$\text{Shear stress on bolts} = \frac{\text{Force}}{Area}$$

$$145 = \frac{3000}{\left(\frac{\pi}{4}dc^2\right)}$$

$$dc^2 = \frac{3000\times 4}{145\times\pi}$$

dc=5.132mm

$d = \frac{dc}{0.8}$

$d = \frac{5.132}{0.8}$

d=6.41 mm

For selecting Caliper mount bolt size as **M8**

2.3 Selection of bearing

At the front wheels the type of forces which acts are radial as well as axial forces. This is due to the reason the vehicle load acts on the wheel as well as axial thrust acts while cornering. Thus, it becomes important to use a bearing which can sustain radial as well as axial forces.

Data for Bearing Selection:

Radial Load = Fr = (1620.6+810) = 2430.9N

Axial Load = Fa = 1911.88 N

Equivalent Load = Fe = (X Fr + Y Fa)

$$\frac{Fa}{Fr} = \frac{1911.88}{2430.9} = 0.785$$

$$\frac{Fa}{Co} = \frac{1911.88}{9800} = 0.2$$

For $\frac{Fa}{Co}$ ratio the value of 'e is 0.37' According to the V.B.Bhandari design data book

Therefore,

$$\frac{Fa}{Fr} > e$$

So,

X=0.56 and Y=1.2

Equivalent Load = Fe = (X Fr + Y Fa)

$Fe = (0.56 \times 2430.9 + 1.2 \times 1911.88)$

Fe = 3655.56 N

Assuming,

Speed = 1200rpm

Bearing life =L= 5,000hr

L=5000*60*1200

L=360 million Revolutions

$L = \left(\frac{C}{Fe}\right)^n$

The value of n is 3 for the ball bearing

$360 = \left(\frac{C}{3655.56}\right)^3$

$C = \sqrt[3]{360} \times 3655.56$

C=26004.8 N

C=26 kN

As per the above data we have to select the bearing which can sustain the above loads.

So, from the NTN bearing catalogue we have selected 6815ZZ bearing which is having,

Internal diameter = 75mm

Outer diameter = 95mm

Width = 10mm

4. ANALYSIS

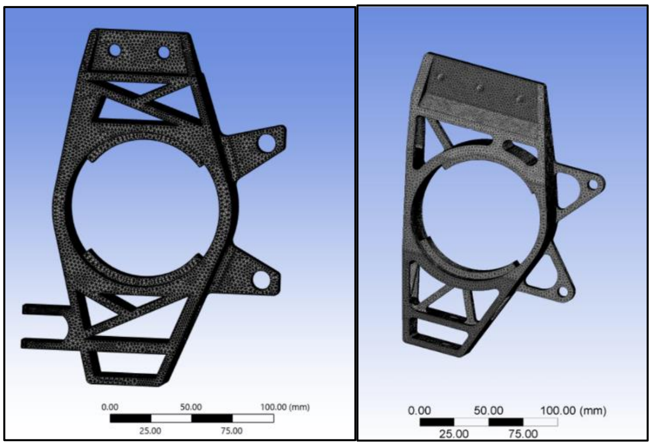


Fig.4.1 Meshing of Old and New Knuckle

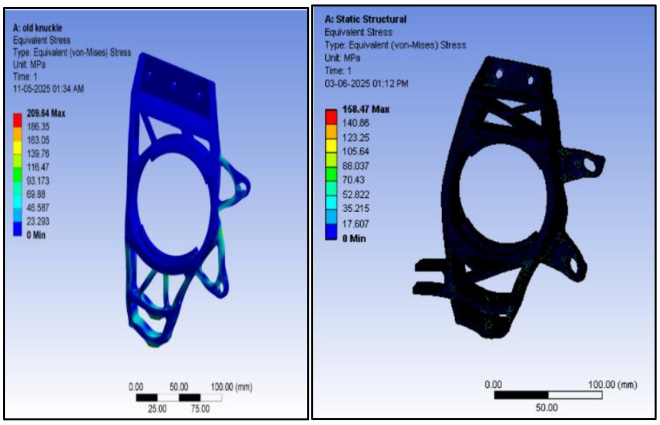


Fig.4.2 Equivalent Stress of Old and New Knuckle

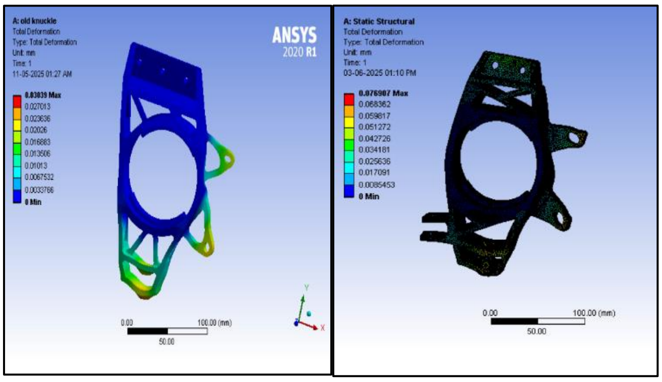


Fig.4.3 Total Deformation of Old and New Knuckle

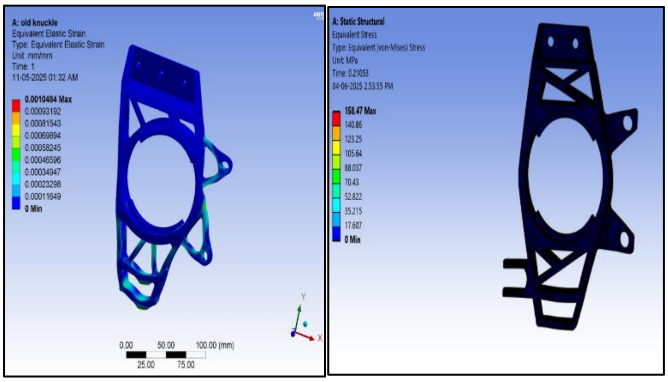


Fig.4.4 Equivalent Elastic Strain of Old and New Knuckle

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6. CONCLUSION

A lightweight upright assembly with the required stiffness is achieved through optimized design calculations and a simplified structural configuration. The selection of Aluminum 7075-T6 plays a crucial role in minimizing the weight of the upright component without compromising its strength or hardness. Structural analysis of the upright was performed using ANSYS software, and the results confirmed that stress and deformation values remained within acceptable limits. This indicates that the upright assembly meets the necessary stiffness and durability requirements under operational loads, resulting in a favorable strength-to-weight performance ratio

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