

Design, Analysis and Fabrication of Wheel Assembly for Formula Type Automotive



Honey Bhural, Saurabh Bhatnagar, Sarthak Nautiyal, Vipin Kaushik, Sumit Sharma, Rahul Sindhvani, and Punj Lata Singh

Abstract This paper reviews design, analysis and fabrication of wheel assembly for infinity motorsports, a Formula Society of Automotive Engineers (FSAE) team of Amity University Noida, with accordance to rules and safety regulation of FSAE. Wheel assembly is the system which connects the suspensions from the chassis to the wheels; in doing so, it has multiple purposes to be fulfilled and experiences immense forces while doing so. The tests run on the previous year car provided the merits and demerits of the previously used wheel assembly. It showed the room for improvements which in turn paved the path to work for finding a more efficient material and designs. The further changes in the design were made according to the test results of Formula Bharat 2019 competition, and improvements were made for Formula Bharat 2020. The plan included various step-by-step procedure, i.e. running various tests and iterations on previous year vehicle and other research papers, checking the room for improvement, making changes in the design, doing calculations and analysis to check the result of various forces which wheel assembly faces and on the overall car in different working conditions and finally assembling all the components for performing satisfactory test runs.

Keywords FSAE vehicle · Suspension, materials, vehicle dynamics · Component packaging

1 Introduction

If all the systems of a vehicle are working as they are desired to, then only it is said to work efficiently. There are two types of masses in a vehicle, i.e. sprung and unsprung masses. Sprung masses are the masses which are damped by a damping system. The

H. Bhural · S. Bhatnagar · S. Nautiyal · V. Kaushik · S. Sharma · R. Sindhvani (✉)
Department of Mechanical Engineering, Amity School of Engineering and Technology, Amity University, Noida (U.P), Noida, Uttar Pradesh 201313, India
e-mail: rsindhvani@amity.edu

P. L. Singh
Civil Engineering Department, Amity School of Engineering and Technology, Amity University Noida (U.P), Noida, Uttar Pradesh 201313, India

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wheel assembly and the wheels together comprise of unsprung masses as it is not damped by the spring.

The ability of a formula car to compensate during a turn and providing maximum control to the driver depends on many factors such as suspension, aerodynamics and weight distribution. The weight of unsprung mass also affects this ability, and the less the unsprung mass the more the stability of the car [1].

Furthermore, reducing the weight of the wheel assembly would provide with a greater fuel economy, and also as per FSAE rules, air intake can have a maximum of 20 mm opening, so to provide more power from the engine to the tires will increase power output [2].

A decent wheel assembly can continue such powers over a more extended time-frame. In this manner, it is required to structure the wheel get together thinking about every one of these components. A disappointment of any segment of wheel components implies a damage of car and may likewise be dangerous for the driver. Along these lines, most extreme consideration must be concerned while structuring the wheel components. Target of improvement is consistently to locate most ideal and reasonable measurement. It is on the grounds that improvement does not constantly mean lessening measurements, but it likewise means discovering the measurements which will only enough to support the powers.

1.1 Function

There are multiple functions which a wheel assembly serves firstly suspension pickup points to connect the chassis to the wheel. The current design also facilitates adjustable camber angle according to the vehicle performance on track which is a suspension parameter, and the front and rear track width can also be adjusted by adding shims in between the suspension mounting on the upright [3].

Depending upon the driving wheels, it also connects the transmission system to the wheels, i.e. the axle. As a rear wheel drive approach is suitable for formula type automotive, we have to make two sets of designs, one in front and another in rear compensating additional space for axle's tripod to deliver power to the wheels [4].

It also provides brake rotor mounted on the hub, brake calliper mounted on upright, and to link steering arm to the steering tie rod coming from the rack for actuation according to the Ackerman geometry.

1.2 Components

The wheel assembly comprises two major components that are:

- The hubs which is the rotating part,
- The uprights which is the fixed part.

The minor components are as follows:

- **Thrust bearings:** They are rotary bearings which are used for axial loads.
- **Steering arm:** It is a rod which connects the upright to the rack and pinion.
- **Suspension mounts:** These are mounts separately made and then fitted on uprights for A-arm connection.

Figures 1 and 2 show the exploded view of wheel assembly revealing various components of it.

In contrast to the weight of tie rod, control arms, and ball joints, the weight of the wheel assembly is much greater, so it is essential to reduce the weight of complete wheel assembly for better performance of the vehicle without compromising the structural stiffness and strength of the assembly as it experiences various dynamic and static loads [4].

Wheel Hub

As shown in Fig. 3, the motivation is to transfer force and join wheel to the suspension and keep the wheel turning uninhibitedly. On the off chance that the centre is set in drive hub, engine power travels from centre point to wheels. The centre points additionally hold brake rotor so as to move braking force to the haggly vehicle.

Fig. 1 Exploded view of WA without wheel

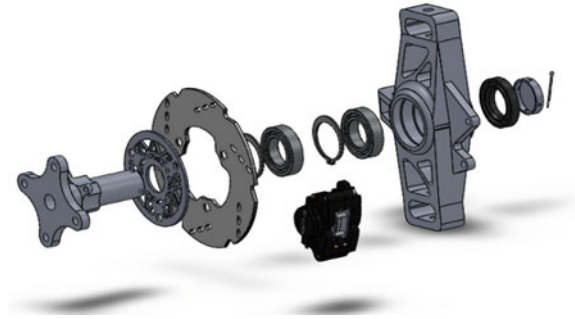


Fig. 2 Exploded view of WA with wheel

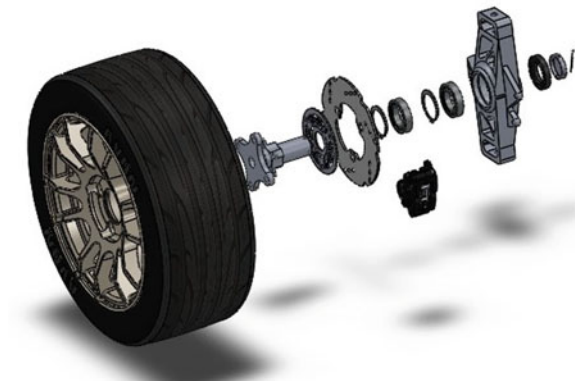
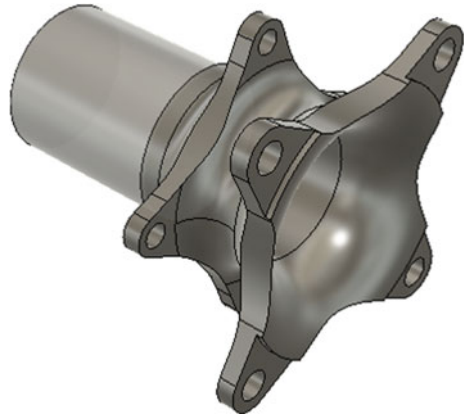


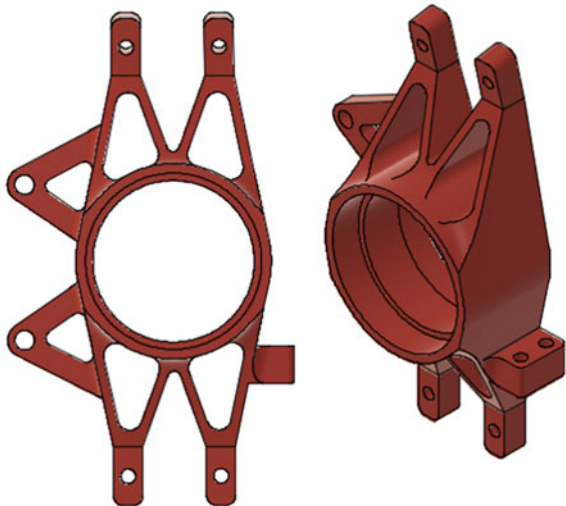
Fig. 3 Wheel hub



Upright

As shown in Fig. 4, it is a necessary vehicle element which associates suspension segments between the haggle vehicles. It gives a connection between up and low rotating conjunctures. The upstanding interfaces parts, for instance, the A-arms, guiding tie pole, springs, dampers, brakes, tires and at the back it associates the axles. The uprights must be adaptable and unbending enough to withstand deviations, and some may happen at the same time for instance during slowing down and a corner.

Fig. 4 Upright



2 Methodology Used

2.1 Review of Current Wheel Assemblies

Various wheel assemblies are reviewed which are available in the market or the wheel assembly previously used assemblies used by other competing teams in their formula student cars.

Constraints: There are always some constraints present that had to be kept in mind for any design before even starting the design. Some of the constraints according to which the designing and manufacturing had to take place are as follows,

Physical constraints: As wheel components are covered by wheel itself, wheel assemblies' dimensions should be kept within the space pocket that is been provided by the wheel rims, and no contact of the assembly and rims should be there other than the bolted connection. As discussed, the wheel assembly serves multiple purposes for the suspension, brake and steering department, and we are required to design so that their geometries and components are not to be changed.

Material constraints:

We have a wide range of materials that can be used for the design, but as we are a student team, we also have a tight budget to work with, and without compromising the properties of the materials needed, we also have to stay on the budget. Hence, a budget constraint on material selection according to the team funds has to be considered.

Manufacturability: The manufacturing technique that is feasible and readily available is three-axis CNC machining. The wheel assembly is a highly critical part which undergoes various forces, to endure these forces we need to have a stiff and durable design, and still the complexity of the design should be kept to minimum so that it does not take much of the time in CNC machining which will increase the machining cost if not been checked [5].

2.2 According to Formula Bharat 2020 Rulebook

Formula Bharat Rulebook is revised every year keeping in mind the development going on in the current world. The design dimensions and parameters are done keeping in mind these rules. These rules are there for designing an optimum and safe component.

According to rule T.1.7.1, the minimum diameter of wheel that can be used is 203.2 mm (8 inches).

According to rule T.1.3.3, the suspension pickup points should not have any play and must be visible for inspection [6].

Further design and analysis are done on software like Fusion 360, SolidWorks, Ansys and HyperWorks keeping in mind the factor of safety.

Table 1 Materials and their properties

S.No.	Material	Properties
1.	Titanium	Density as 4.506 g/cc M.P. of 3038.4 °F (1670.1 °C) B.P. of 5949 °F (3286 °C) Mohr’s number as 6
2.	Aluminium 7075	Density as 2.81 g/cc Tensile strength of 572 MPa Yield strength of 503 MPa Melting point of 477–635 °C
3.	Alloy Steel	Density as 7.85 g/cc Tensile strength as 744.9 MPa Yield strength as 471.02 MPa Melting point at 1427 °C

Table 2 Properties - Al 7075 T6

1	ρ	2.794 g cm ⁻³
2	E (Young’s mod.)	71.02 GPa
3	V (Poisson ratio)	0.326
4	K (Bulk mod.)	69.63 GPa
5	G (Shear mod.)	26.688 GPa
6	S_{ut}	565.367 A

3 Material Selection

Optimum material selection with cost of material and material properties is done and is shown in Table 1. The material selected should handle the forces faced by wheel assembly during cornering, turning, acceleration and braking. The material should also be cost efficient and lightweight [7].

As shown in Table 1, the material decided to be taken is Aluminium Alloy 7075-T6 as it has a high strength to weight ratio and better fatigue properties than the other lightweight aluminium alloys such as 6061-T6 [8, 9].

The properties use for the analysis was as follows:

Material properties of Al 7075-T6 properties are as shown in Table 2 [10, 11].

4 Calculations and Analysis

4.1 Forces Faced by Knuckle [12, 13]

In this section, longitudinal force for braking and flank forces is explained. Force due to steering on steering arm and on calliper mounting point (braking torque) is also explained below.

Longitudinal force (Braking).

When applying brakes, all the components of vehicle apply force on the front. Its right hand impacts the knuckle.

Consider Max. acc. of 1 g, i.e. 9.809 m/s^2

On front, force = rear mass of vehicle \times acc.

Assumption weight distribution 40 front 60% rear

Force = $.6 \times 300 \times 9.809 = 1765.81 \text{ N}$

Lateral weight distribution is 1:1, so force on a single wheel = $1765.81/2$

Thus, longitudinal force = 882.9 N

Flank (Lateral) forces.

Sidelong powers occur because diffusive power and horizontal burden travel along out to inside of vehicle. The outspread power is taken as pursues.

Assumption turning radius is 6 m, and speed is 30 km/h

$r = 6 \text{ m}$

$v = 30 \text{ km/h} = 8.3333 \text{ m/s}$

Centrifugal force = $mv^2/r = (0.4 \times 300 \times 8.3333^2)/6 = 1388.77 \text{ N}$

The front weight is = 120 kg

If it gets transferred to one side = $120 \times 9.81 = 1175.5''$

Force due to steering on steering arm [14, 15].

As indicated by the controlling exertion, the power on guiding arm was discovered to be 1165.52 at a point of 8.5560. Subsequent to settling these powers.

force due to steering on steering arm = 1165.52 N

Force on calliper mounting point (braking torque).

Radius (upper calliper mount) = 89.21 mm

Radius (lower calliper mount) = 60.332 mm

Min. radius will experience max. force. Hence,

force (lower arm) = Torque/Radius = $130000/60.233 = 2158.28 \text{ N}$

Figure 5 contains the FBD of upright in which various forces acting on it are shown.

4.2 Analysis of Upright

Figure 6 shows the stress analysis of upright done in Fusion 360 with factor of safety.

Figure 7 shows the stress concentration in the upright when deformation occurs due to applied forces.

4.3 Bolt

Selecting bolt for up and down bracket (knuckle).

They are standard and contain characterized estimation of yield quality. All bolts utilized are comprised of at least 8.8 class.

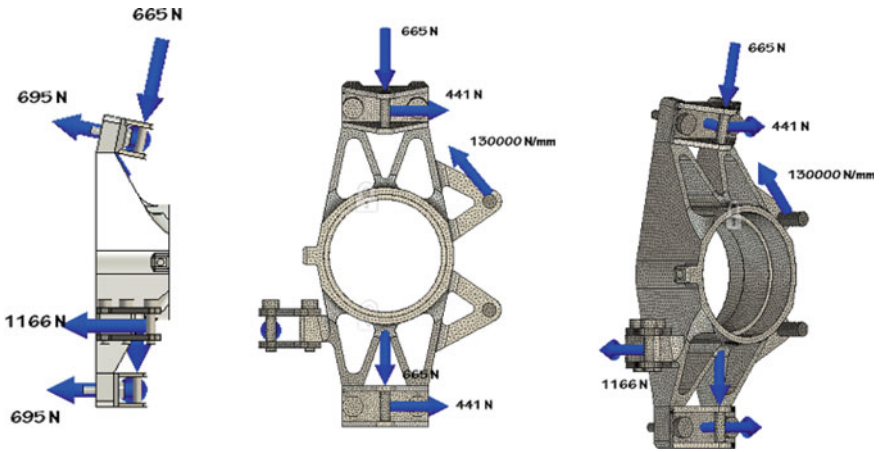


Fig. 5 FBD of upright

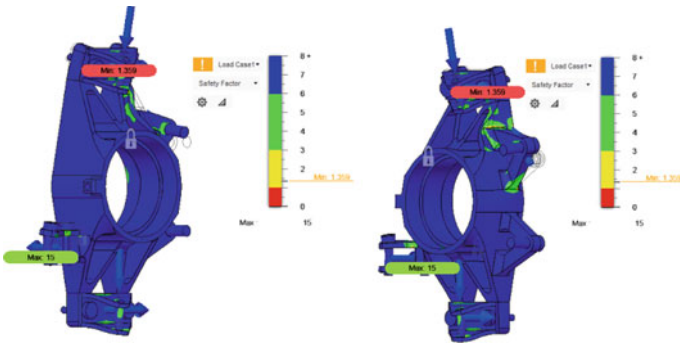


Fig. 6 FOS of upright

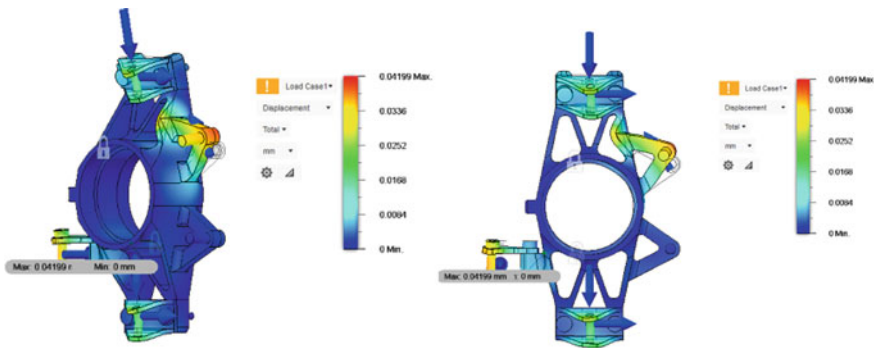


Fig. 7 Upright deformation

$$S_{yt} = 580.11 \text{ N/mm}^2$$

$$FOS = 2.0$$

$$\text{“Shear force} = \sqrt{4422 + 6952} = 823.64 \text{ N”}$$

$$\text{“Shear stress} = T = (S_{yt} \times 0.5)/2 = 145 \text{ N/mm}^2\text{”}$$

$$\text{Now, } T = F/A$$

$$145 = 823.64/(2 \times 0.785 \times dc^2)$$

$$dc^2 = 1.9016 \text{ mm}$$

$$d = dc/0.8$$

$$d = 1.9016/0.8$$

$$d = 2.37 \text{ mm}$$

“M8 size of bolt is used for knuckle”

Selecting bolt for Calliper Mounting.

$$\text{Shear stress on bolts} = T = (S_{yt} \times 0.5)/2 = 145 \text{ N/mm}^2$$

The force is given by

$$\text{Now, } T = F/A$$

$$145 = 2158.23/(2 \times 0.785 \times dc^2)$$

$$dc^2 = 4.3533 \text{ mm}$$

$$d = dc/0.8$$

$$d = 4.3533/0.8$$

$$d = 5.44 \text{ mm}$$

“M8 size of bolt is selected for calliper mounting.”

Selecting bolt for Steering Arm.

$$\text{Shear Stress on bolts} = T = (S_{yt} \times 0.5)/2 = 145 \text{ N/mm}^2$$

The force is given by

$$\text{Now, } T = F/A$$

$$145 = 1165.52/(2 \times 0.785 \times dc^2)$$

$$dc^2 = 2.2621 \text{ mm}$$

$$d = dc/0.8$$

$$d = 2.2621/0.8$$

$$d = 2.821 \text{ mm}$$

“M8 size bolt is used for steering arm.”

Selecting bolt for wheel.

$$\text{Shear stress on bolts} = T = (S_{yt} \times 0.5)/2 = 145 \text{ N/mm}^2$$

The force on the steering arm is given by

$$\text{Now, } T = F/A$$

$$145 = 880/(2 \times 0.785 \times dc^2)$$

$$dc^2 = 2.99 \text{ mm}$$

$$d = dc/0.8$$

$$d = 2.99/0.8$$

$$d = 3.74 \text{ mm}$$

Thus, taking the wheel bolt size as M12.

Selecting bolt for Brake Disc.

$$\text{Shear stress on bolts} = T = (S_{yt} \times 0.5)/2 = 68.75 \text{ N/mm}^2$$

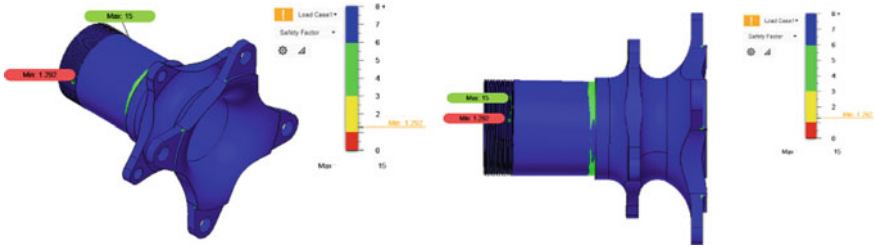


Fig. 8 FOS of wheel hub

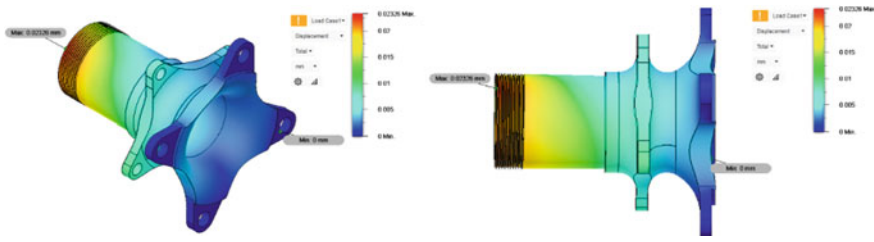


Fig. 9 Displacement of hub

The force is given by

$$\text{Now, } T = F/A$$

$$68.75 = 879.89 / (2 \times 0.785 \times dc^2)$$

$$dc^2 = 2.99 \text{ mm}$$

$$d = dc / 0.8$$

$$d = 2.99 / 0.8$$

$$d = 3.74 \text{ mm}$$

Thus, taking the bolt size as M8 [16].

Analysis of Hub.

Figure 8 shows the stress analysis of wheel hub with its factor of safety.

Figure 9 shows the stress analysis of the displacement of the wheel hub.

4.4 Stress Conc. on Wheel Components

Figure 10 contains the stress conc. of wheel components combined together with its FOS. Figure 11 contains the stress conc. of the displacement on the wheel components.

Fig. 10 FOS of wheel components

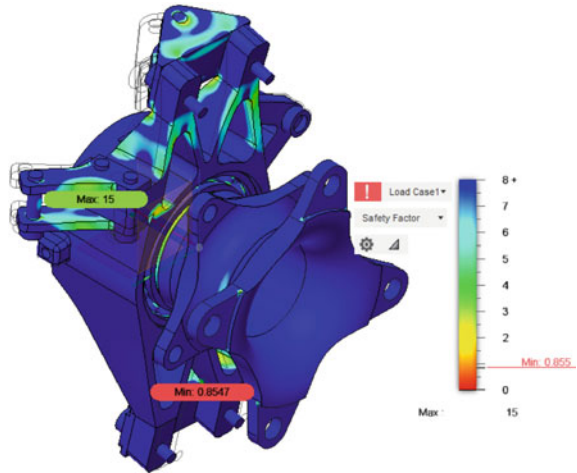
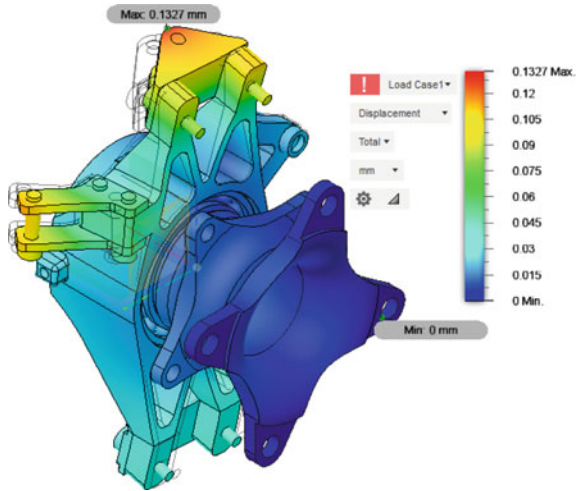


Fig. 11 Displacement of wheel assembly



5 Result, Discussion and Conclusion

The in-depth study to ultimately arrive at the final design for the wheel assembly and its analysis was reviewed by this paper. We observed an inter-department cooperation and communication, and the needs and parameters provided by different department meet with great efficiency. We achieved greater stability and ease of manoeuvrability for the driver due to using Al7075 T6 as the unsprung mass of the vehicle was highly reduced. The new design had many valuable changes from the previous ones as it has suspension mounting point separately attached with the uprights, and it gives versatility for it to be used with different chassis just by changing the mounts. Also

the steering arm is being assembled separately, and it gives room for adjustment for toe in and out depending upon the vehicle performance on track. The reduction in overall dimension of the wheel assembly provides a wider range of rims to be attached to the chassis. The compact size of the upright helped in the proper mounting of A-arms, connecting rods and callipers and in turn lowering the centre of gravity, which is considered a key component while designing a fast-moving automobile. Being able to use 10" rims helped us in attaining better stability and lower centre of gravity. The system also granted ease of installation, adjustability and ease of serviceability which is very helpful when the work is to be done at a faster pace. This design helped to fulfil all the areas of improvements observed from the previous design and test runs.

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