Automotive Suspension Final Report

Lauren (Jingya) Luo

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1 Layout Drawing

1.1 Hub

1.1.1 Overview

The goal of the hub is to provide a mount for the wheel to the suspension. The hub is attached to the wheel and the brake disc via bolts, and houses an angular contact ball bearing(3207 A-2RS1) and a groove ring(Smalley DNH-72) that holds the bearing in place. A sketch of hub side view with location of ball bearing and groove ring is shown in Figure 1. Various views of hub are shown in Figure 2.

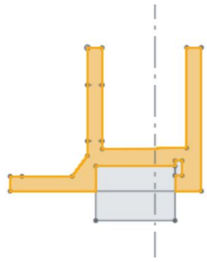
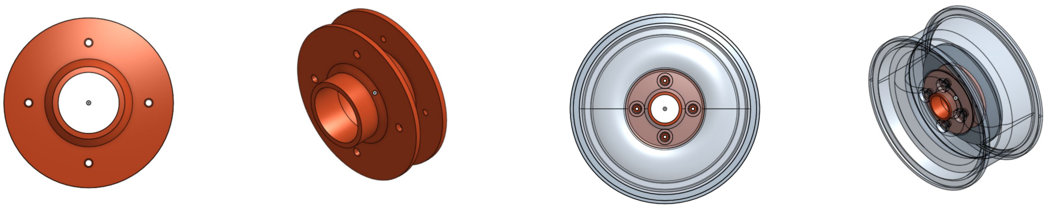


Figure 1: Upper half side view sketch of hub(highlighted). Gray parts are the bearing and groove ring(smaller rectangle on right side) location



(a) (b) (c) (d)

Figure 2: Views of hub. (a) hub front view (b) hub isometric view (c) assembly front view (d) wheel, hub, and brake disc isometric view

1.1.2 Material

The hub is **strength-limited** because our primary concern is the material yielding from applied moment due to friction from the ground to the wheel to the hub. Therefore, minimizing density of a beam with section area free, we find aluminum alloy to be a suitable material. Aluminum alloy is general chosen over steel due to ease of machining and lighter weight. Aluminum alloy 6082T6, specifically, is chosen. The hub can be lathed from a 6" diameter round bar.

1.1.3 Critical Calculations

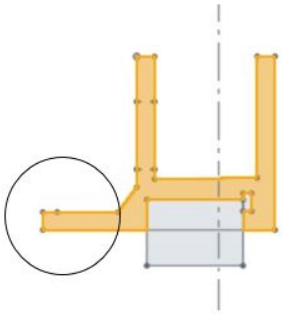
To ensure the hub can withstand the forces from the wheel without failing, we did some simple calculations to find the thickness of the ledge that inserts into the wheel(circled in Figure 2(a)), where the most force will be experienced. We simplified the hub into a cylindrical beam with an inner hole. Taking R as the outer radius, r as the inner radius, the hub would have a moment of inertia shown in equation 1.

$$I = \frac{\pi}{4}(R^4 - r^4) \tag{1}$$

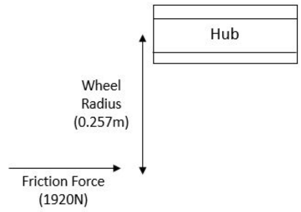
The hub experiences max force when a wheel is turning, and centripetal force equivalent to the friction force is applied to the bottom of the wheel towards the center of the vehicle. As a result, the centripetal force generates a moment on the hub. The hub can then be modeled like a beam in bending using equation 2. A force diagram is of the scenario is shown in Figure 2 (b).

$$\frac{\sigma_y}{y} = \frac{M}{I} \tag{2}$$

σ_y for Aluminum alloy is 280MN, Moment (M) is the product of friction force and wheel radius, y is the outer radius of the hub (65mm, constrained by inner wheel dimensions), and I is shown in equation 1. Solving for the maximum possible inner radius, r, we get that inner radius r can have values less than 64.9mm.



(a)



(b)

Figure 3: (a) Ledge of hub circled is the focus of force calculations. (b) Force diagram of calculations

1.1.4 Bolt Calculations

There is a set of bolts/fasteners required for securing the wheel to the hub, and another set securing the hub to the brake disc. The general force diagram is shown in Figure 4.

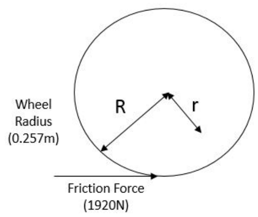


Figure 4: Force diagram for bolt calculations. R is wheel radius, r is bolt radius.

The friction, resisting moment generated by the bolts is shown as equation 3, where μ is roughly estimated to be 0.5, r is the bolt radius, and F_n is the total normal tension force. The friction, resisting bolt moment must also be equal and opposite to the friction moment of the wheel, as shown in equation 4.

$$F_r = \mu * F_n * r \tag{3}$$

$$F_r = \text{Wheel Friction Force (F)} * \text{Wheel Radius (R)} \tag{4}$$

Therefore to find the normal tension force of each bolts f_n give N bolts, we use equation 5.

$$f_n = \frac{F * R}{\mu * r * N} \tag{5}$$

Due to the wheel design, four bolts must fasten the wheel to hub are a fixed radius 54mm away. Using equation 5, each bolt must have tension force of at least 4.575kN. With a safety factor of 3, I chose M8 bolts for security. Since the bolt is smaller than the size of the holes in the wheel, washers will be used on the wheel side to help secure the bolt in place. The bolt will be a fastener bolt, with the hub holes threaded, to help with ease of assembly.

To ensure the fastener bolt does not "tear out" of thread, we must examine the shear stress, τ_r, on thread root of the screw using equation 6, 7, and 8.

$$\tau_r = \frac{1.25 * f_n}{\pi * d_r * L} \tag{6}$$

$$d_r = d_nom - 1.73p \tag{7}$$

$$L = 4 * p \tag{8}$$

where p is pitch of the screw, d_nom is nominal size of the screw. τ_r must less than $\frac{1}{2} * R_{0.2}$ for a 12.9 grade screw to be safe from "tear out".

In this case, τ_r is 62.88 N/mm^2, $\frac{1}{2} * R_{0.2}$ is 529.6 N/mm^2 referencing the databook chart, so the condition is satisfied.

For the attachment of hub to brake disc, more liberty can be taken with the radius and number of bolts. In this design, I chose to position the bolts the same radius and number as the wheel-hub bolts for ease of drilling. Instead of M8 bolts, I chose to use M6 bolts instead. The safety factor does not have to be as high since I am able to use nuts and bolts for this assembly, in which case if a bolt breaks, it is easier to replace.

To ensure a bolt does not "tear out" from a nut, we must examine the shear stress, τ_n, on thread root of the screw using equation 9. τ_n must less than $\frac{1}{2} * R_{0.2}$ for a 12.9 grade screw to be safe from "tear out".

$$\tau_n = \frac{1.25 * f_n}{\pi * d_n om * L} \tag{9}$$

In this case, τ_n is 75.75 N/mm^2, $\frac{1}{2} * R_{0.2}$ is 529.6 N/mm^2 referencing the databook chart, so the condition is satisfied.

1.1.5 Hole and Shaft Fits

Hole	Shaft	Fit	Description
Wheel and Hub	M8 Bolt	Tap drill hole for M8 bolt	For a fastener fit.
Hub and Brake Disc	M6 Bolt	Clearance hole for M6 bolt	Nut and bolt fastening.
Wheel	Hub	Clearance fit H7g6	Fastener bolts secures the wheel onto the hub, so a tight fit is not required. Loser fit allows ease of changing wheels.
Hub	3207 A-2RS1 ball bearing	Press fit P6 housing	Tolerance for bearing specified by manufacturer, therefore only hub housing tolerance specified. Press fit require to ensure relative motion(outer bearing turns with the axle).

1.2 Brake Disc

Brake disc shape was mostly set as we knew it had to fit within the braking caliper, designed for a brake disc diameter of 240mm, and attach to the hub, which require 4 holes for M6 bolts. An isometric view of the brake disc is shown in figure 5.

Figure 5: Isometric view of brake disc. Radius of holes were designed for M6 bolts.

1.2.1 Material

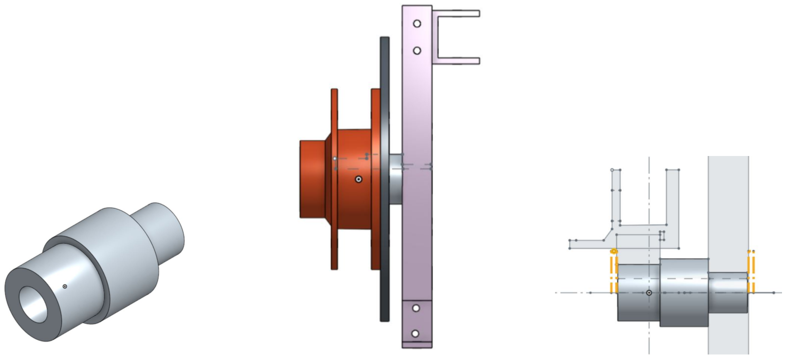
The brake disc is **strength-limited** because our primary concern is the material yielding from applied force of the caliper. The material must also have a high melting point, as braking will heat up the material significantly. When minimizing density of a flywheel, we find both aluminum alloy and steel to be suitable materials. In this scenario, I went for steel because steel has a higher melting point and lower thermal conductivity than aluminum. Looking at the databook, ENG9 steel seems appropriate as it has relatively low thermal conductivity compared to other steels, and it is wear resistant. The downfall is that ENG9 is harder to machine. However, a brake disc does not have a complicated geometry.

1.3 Axle

The Axle is a stationary rod which also acts as a mounting point for the upright. Key features to be wary of while designing the axle:

- Axle should not extend beyond the hub or axle. Otherwise the central bolt would not be able to apply a compression force, with the help of washers, to the assembly on the axle.
- Widest part of the axle should only be in contact with inner rim of the ball bearing in hub. This ensures the axle is stationary, and does not feel a shear force from the outer bearing, which rotates with the wheel.

Figure 5 shows various views of the axle and its assembly.



(a) (b) (c)

Figure 6: Views of axle. (a) axle in isometric view (b) Right view of axle assembly with the hub, brake disc, and upright mounted (c) Sketch includes the axle, sketch of the hub, and sketch of the upright. The yellow highlighted parts are locations of washers. The dark grey dotted line shows the hole which a bolt fits through.

1.3.1 Material

The axle is **strength-limited** because our primary concern is the material yielding from applied force of the wheel and the upright. Therefore, minimizing density of a beam with section area free, we find aluminum alloy to be a suitable material. Aluminum alloy is general chosen over steel due to ease of machining and lighter weight. Aluminum alloy 6082T6, specifically, is chosen. The axle can be lathed from a 2" diameter round bar.

1.3.2 Critical Calculations

The critical calculation for the axle lies in choosing the bolt which compresses the assembly of the hub/bearing and the upright together. A force diagram of the proposed scenario is shown in figure 7.

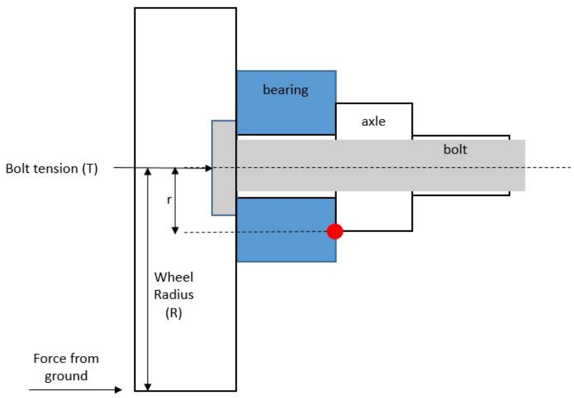


Figure 7: Force diagram for axle bolt calculations. Red circle is point of most applied force on the axle. R is wheel radius, r is distance from point of applied force to the center of the bolt. T is bolt tension.

Assuming max force is applied when the ground exerts of friction force of 1920 N (F_r), on the ground, inwards towards the assembly. The axle, held by the bolt, would have max pressure applied to the lower shoulder indicated by the red dot in figure 5. The opposite shoulder would theoretically experience 0 force. The job of the bolt, therefore, is to exert a force (T) that counters the force applied to the point. Therefore, to solve for the force required to be exerted by the bolt, equation 10 must be satisfied.

$$T * r > F_r * (R - r) \tag{10}$$

For this design, the chosen values were: Force from the ground F_r to be max 1920N, radius of the wheel R to be 0.257m, and the distance of the red dot in figure 5, r, to be 0.021m. r is chosen such that the axle is only in contact with the inner rim of the ball bearings, as mentioned above. The yielded bolt tension was a minimum of 21.58kN. With a safety factor of 3, I chose to design around a M16 bolt.

1.3.3 Hole and Shaft Fits

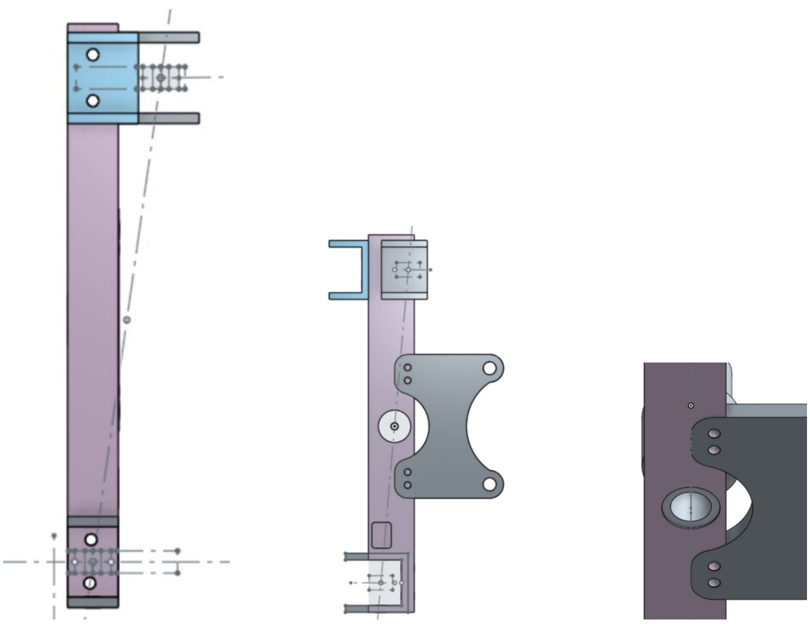
Hole	Shaft	Fit	Description
Axle	M16 Bolt	Clearance hole for M16 bolt	Clearance fit allows components to be easily slid onto the axle. The M16 bolt and nut secures all components in place.
3207 A-2RS1 ball bearing	Axle	transition/drive fit m6	There needs to be enough hold such that the axle can make sure the inner bearing does not rotate with the wheel. However, press fit shaft tolerances were not offered by the manufacturer. m6, a drive transition fit, was the tightest fit for the part.
Upright	Axle	slide/location fit H7h6	Axle and upright should have no relative motion between the components. However, since there will be a bolt and nut securing the upright onto the axle assembly, a tighter fit is not needed.

1.4 Upright

The upright is the attachment structure of the wheel assembly to wishbones, caliper, and steering arm. Key features to be wary of while designing the upright:

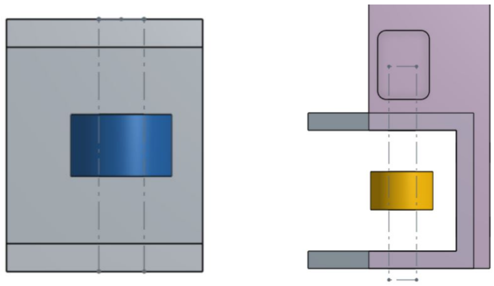
- From side view, there is a king pin axis of 8 degrees and a scrub radius of 30mm, which the upper and lower wishbone attachment points lie.
- From the front view, there is a caster angle of 5 degrees through the center of the wheel, which the upper and lower wishbone attachment points lie.
- Upright must also hold up and attach the braking caliper.

The upright is kept in a rectangular bar shape to minimize machining of complicated geometry. Brackets are used to hold the upper and lower wishbones, allowing a bolt to act as a shaft through the middle of bearings, as shown in Figure 9. A bracket is also designed for holding the steering arm. An attachment piece on the side holds the braking caliper in place. All brackets are held onto the upright using two M6 bolts, which is more than enough to withstand the pulling forces from the wishbones(approximately 5kN). Two M10 bolts are used to secure the caliper to the upright-caliper attachment piece.



(a) (b) (c)

Figure 8: Views of the upright. (a) side view of the upright showing the king pin axis and location of wishbone bearings in gray dotted sketches (b) back view of the upright showing the caster angle and location of wishbone bearings in gray dotted sketches (c) Embedding of upright-caliper attachment piece in the main structure of upright.



(a) (b)

Figure 9: Views of upper and lower wishbone brackets. (a) Upper wishbone bracket with the relative placement of bearing. The gray-dotted sketch indicated the location of an M8 bolt, through the bracket and bearing acting as a shaft. (b) Lower wishbone bracket with the relative placement of bearing. The gray dotted sketch indicates teh location of M8 bolt, through the bracket and bearing acting as a shaft. The rectangular hole above the bracket, machined into the upright, provides access to secure a bolt onto the M8 bolt.

1.4.1 Material

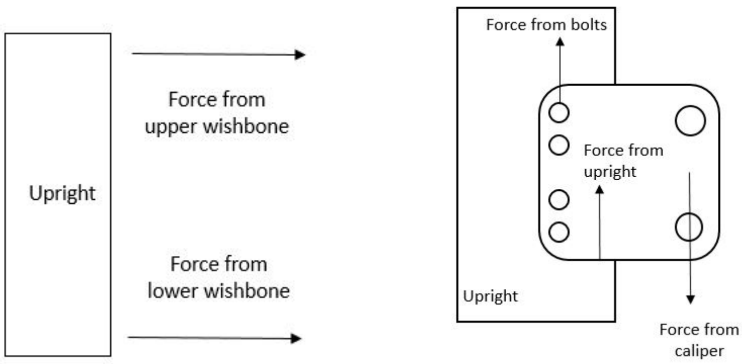
The main upright is **strength-limited** because our primary concern is the material yielding from applied moment due to the upper and lower wishbone. Therefore, minimizing density of a beam with section area free, we find aluminum alloy to be a suitable material. Aluminum alloy is general chosen over steel due to ease of machining and lighter weight. Aluminum alloy 6082T6, specifically, is chosen. The hub can be cut(using bandsaws)and milled from a 3" by 2" flat bar.

The brackets attached to the upright should also be machined from aluminum mostly because it is light weight and easier to machine and bend. Brackets can be made by cutting (using bandsaw) and bending 0.25" metal sheets. Holes can be drilled either using mill or drill press.

The attachment piece from the caliper to the upright can be machined milled from an aluminum sheet of 0.375". The thickness is required for be supported by the upright from potential downward pull from the caliper.

1.4.2 Critical Calculations

There are two sets of calculations to consider: The thickness of the upright and the design of the caliper attachment. The force diagram for the two structures are down in figure 10.



(a) (b)

Figure 10: (a) Upright force diagram for calculating thickness (b) Upright force diagram for justifying caliper attachment design

As figure 10(a) shows, the upright experiences force from the pulling of the upper and lower wishbone on two ends. With the upright simplified to the basic structure of a rectangular beam, the scenario can be analyzed as a beam in bending, governed by equation 11.

$$\frac{\sigma_y}{y} = \frac{M}{I} \tag{11}$$

The moment M is the greater of the upper and lower wishbone resultant force(in this case, upper wishbone force of 4885.9N a distance 0.121 m from center of the beam), calculated in the appendix. y is the most outside surface, therefore $2 * y$ is the thickness of the beam. I, the moment of inertia for a rectangular bar is shown in equation 12. The width of the beam (d), for this design, I chose to be 35mm such that it can hold the axle and the bottom wishbone bearing shaft with sufficient material on both side. σ_y of aluminum alloy 6082T6 is 280 MN/m^2

$$I = \frac{(2 * y)^3 * d}{12} \tag{12}$$

Combining equation 11 and 12, we yield a minimum beam thickness (2y) of approximately 20mm. In the design, I used an upright of 25mm thick to add a safety factor of 1.25.

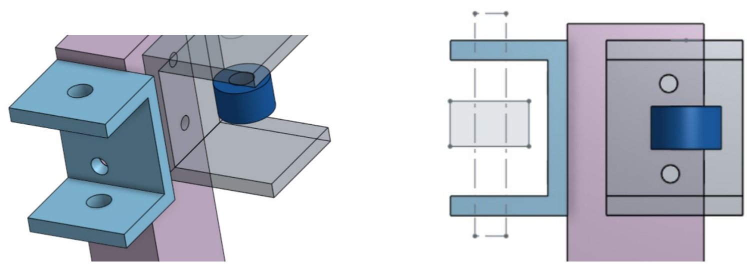
As figure 10(b) demonstrates, the connection piece between the upright and the caliper experiences a significant force from the braking of the disc. The max possible force experienced can be approximated from a balance of torque between max friction force applied to the wheel diameter of the wheel, 1920N * 0.257m (radius of the wheel), and the friction force applied by the caliper, positioned 0.07275m from the center. Therefore, the maximum forced can be applied from the caliper is approximately 6.8kN. The force experienced by the bolts attaching the caliper and the attachment piece to the upright experiences a force downwards, as shown in figure 10(b). The primary purpose and design of bolts, however, is not to withstand force in such direction. Therefore, the design decision of embedding the caliper attachment piece into the bracket, as shown in figure 8(d), was strategic. This way, the upright as well as the bolts provide support for the caliper attachment piece, as portrayed in figure 10(b).

1.4.3 Hole and Shaft Fits

Hole	Shaft	Fit	Description
Upright and Brackets	M6 bolts	Clearance hole for M6 bolt	Nut and bolt assembly made to secure bracket onto the upright. Bolt is sufficient for tightening.
Upright and Caliper	M10 bolts	Clearance hole for M10 bolt on upright. Caliper hole predetermined (transition)	To allow max security, M10 bolts are used to fill the caliper hole and to withstand large forces acting on the caliper while braking.
Brackets and 21C-WZ08 bearings	M8 bolts	Transition hole for M8 bolt through the bearings, clearance hole for M8 bolt through the brackets	M8 is a bolt size that will fit through the selected bearings for the wishbone with slight movement.
Upright	Axle	slide/location fit H7h6	Axle and upright should have no relative motion between the components. However, since there will be a bolt and nut securing the upright onto the axle assembly, a tighter fit is not needed.

1.5 Steering Arm

The steering arm ideally is in parallel with the upper wishbone, and controls the steering of the wheel. I conveniently located the steering arm on the same plane as the upper wishbone bearing, secured onto the upright using a bracket as shown in Figure 11. A bolt will also go through the bracket, holding the steering arm in place. The material and machining method of the steering arm bracket is similar to the wishbone bearing brackets. Two M6 bolts are used to secure the bracket onto the upright.



(a) (b)

Figure 11: (a) isometric view of steering arm bracket, in parallel plane with the upper wishbone bracket. M8 bolt clearance hole drilled through top and bottom, M6 bolt clearance hole drilled through bracket and upright for attachment. (b) front view of steering arm bracket showing the relative location of steering arm assembly. Potential steering arm bearing represented by a gray shaded rectangle, and an M8 bolt represented by gray dotted lines.