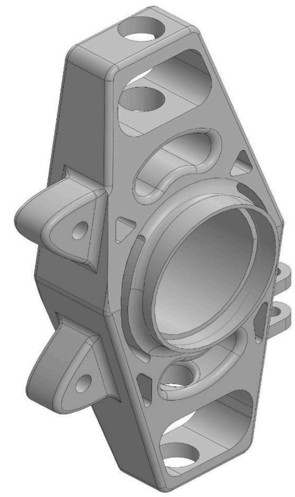
FSAE Upright Design

Soham Saha, Application for Highlander Racing, February 13, 2023

Background



The "Upright" or "Knuckle" in the context of formula student cars, refers to a critical component of the suspension assembly. The upright connects the wheel hub to the suspension arms and is responsible for the load transfer between the wheels and suspension. Brake calipers are also mounted on the upright as well as the steering arm. Given these requirements, the geometry of the upright determines several aspects of the vehicle's performance in regards to handling and cornering. When designing a suspension upright it is important to acknowledge the effects of the geometry while keeping in mind the upright must withstand great forces and be lightweight.

The key aspects of the upright's geometry include the *kingpin inclination angle* (KPI) , *caster angle,* and *camber.* The KPI has an effect on steering as the wheel is raised or lowered while turning, producing a self centering effect. When cornering with a KPI angle, the outside wheel is loaded greater than the inside wheel with respect to the corner due to the camber produced by the turn.This causes an imbalance of forces between wheels which requires the uprights to be able to withstand high forces.

The caster angle (positive in this case) causes the opposite effect in camber during cornering, and reduces the load on the outside wheel. A large caster angle will cause a stiffer steering and suspension with more road feel whereas a small caster angle will result in a steering that feels loose. An appropriate caster angle will result in stability at high speeds along with good steering response. As the designs pertain to a performance race car, driver comfort is not the top priority.

From the given suspension assembly, the KPI, caster, and distance between suspension ball joints were measured and the upright was designed to fit the given specifications. The KPI was measured to be 5.01 degrees (+), caster was measured to be 3.33 degrees (+) and vertical distance between suspension ball joints was 84mm. These values were at the center of the CAD design and kept in mind throughout the design process.

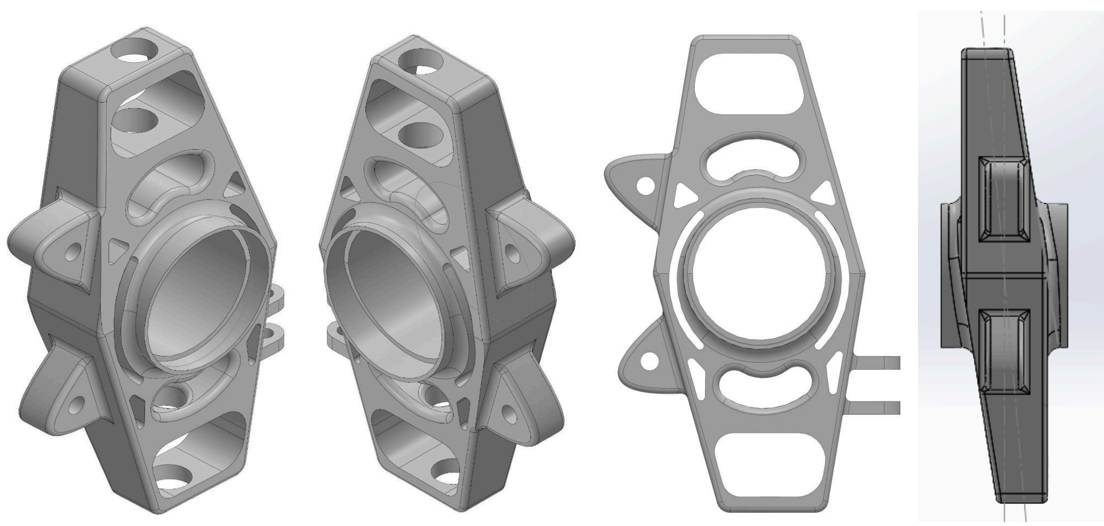
Design Process and Features

This design took much inspiration from the provided example designs as well as research on other school's designs. Based on the research conducted, it appeared that there were two schools of thought in designing an upright.

The first was to design the upright around a single extruded boss, cut slots and holes as necessary, adding any additional features required (“brick design”). The second was to design the upright around the main bore hole and create extruded or swept features around it for support and additional function (“spiderweb design”). After analyzing the tradeoffs/skills required for both it was decided to move forward with the former.

After creating the initial extrusion, the first step was to cut spaces for the suspension ball joints. The height and width of the joints were measured from the given assembly and slots were cut accordingly. Holes for the mounts were created based on the axis shown in the side view. The mounts are in line with the KPI and Caster measurements to ensure they meet the specifications. After determining the physical location of the mount holes, excess material was taken off from the side profile view. Then additional slots were created to reduce weight while maintaining structural integrity of the design. A variety of slots were used to remove material as shown in the front view. Lastly the brake caliper mount and steering arm was added in. To complete the design filets were added all around the part.

Final Design *(isometrics, front, side)*



As with any design, this project underwent several iterations. The primary changes over time were the size and shapes of the slots and the amount of material removed from the side view.

Material Choice

Based on the research conducted, two potential candidates for materials were chosen. 7075-T6 Aluminum, and 6061-T6 Aluminum. Both are different versions of tempered Aluminum alloy and are excellent candidates for the job. The notable differences are in the cost and the strength. While the 7075 alloy offers higher strength overall, its cost is higher as well and may possibly be out of budget for a formula student project. 7075 is typically used in the context of aerospace engineering where very strong lightweight materials are necessary. 6061 still has an impressive strength to weight ratio and so was selected for this design.

Category	Tensile Strength	Cost/KG	Hardness (Brinell)	Young's Mod.
7075-T6	503 MPa	$5.20	150	71.7
6061-T6	276 MPa	~$3.00	95	68.9

After configuring the 6061-T6 aluminum alloy, the mass of the part was calculated to be 0.464 KG, with the center of mass located 2mm off the z axis from the center of the bore hole.

Simulation

To create a viable simulation a sample worst case condition was conceived. Suppose the vehicle is cornering and accelerating out of the corner. This as mentioned previously would cause excessive load on the wheel on the outside corner in the form of both vertical and lateral forces. To ensure the upright will survive the condition in real life it is best to assume 100% load transfer onto the upright. In physical terms this means that the suspension coil is fully compressed and so all the excess forces are borne by the upright.

If we take the mass of the vehicle to be 300kg, (comparable to typical formula student vehicles), assume lateral forces to be 2G and vertical forces to be 3G, we get

Lateral: 300kg * 2 * G ~= 6000N
Vertical: 300kg * 3 * G ~= 9000N

These forces would likely never be experienced by any single upright in a real scenario, but in the case of simulation it is safe to overestimate the amount of load experienced.

As these forces are transferred through the tire's contact with the ground, a dummy hub was created for the purposes of transferring loads to the upright as shown. The forces were directed to the hub from the origin of the assembly which was mated to be axially coincident to the center of the hub at a typical tire radius distance (254 mm).

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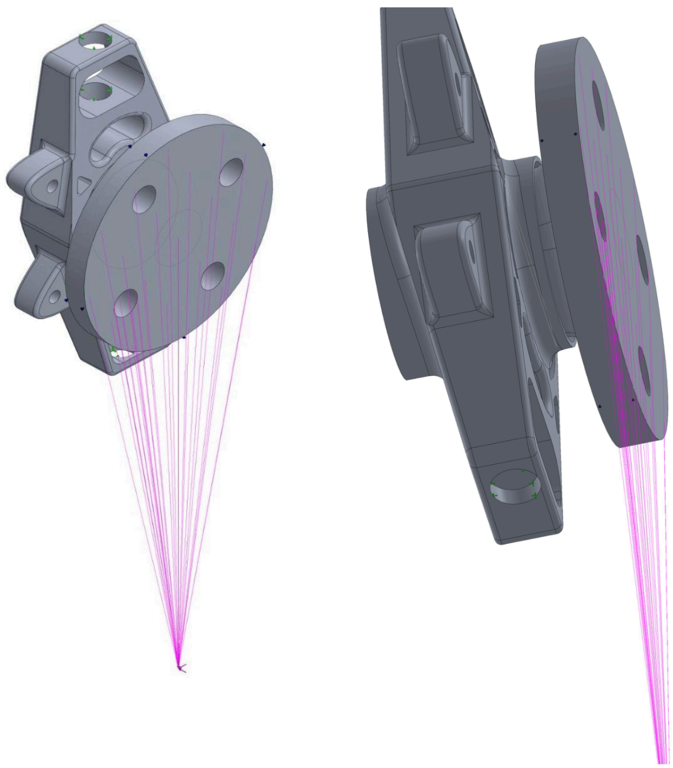
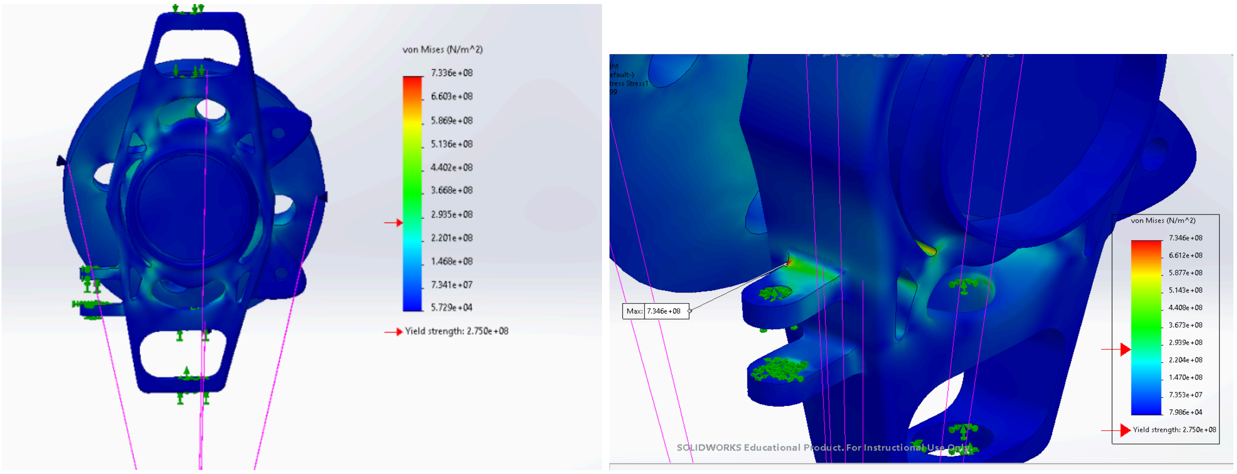
The 3 forces (XYZ) are vectored to the origin and mapped to the face of the hub. The Hub is mated to the upright

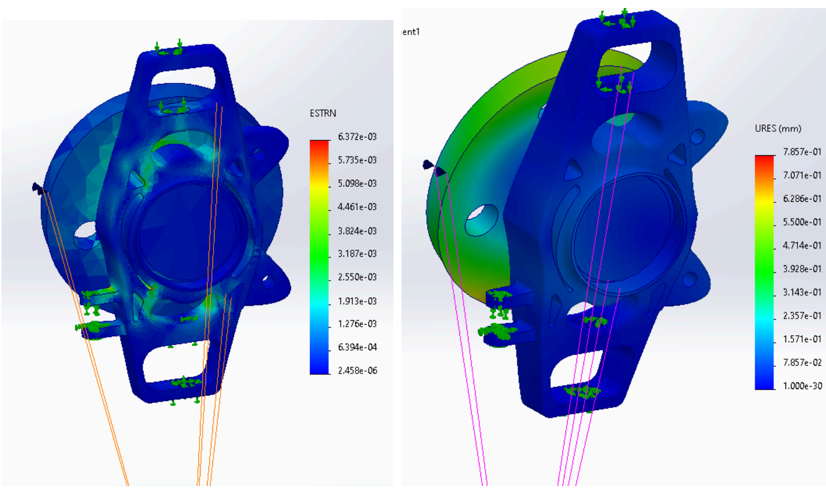


The suspension mounting holes were constrained in the following simulation along with the steering mounting holes.

Results

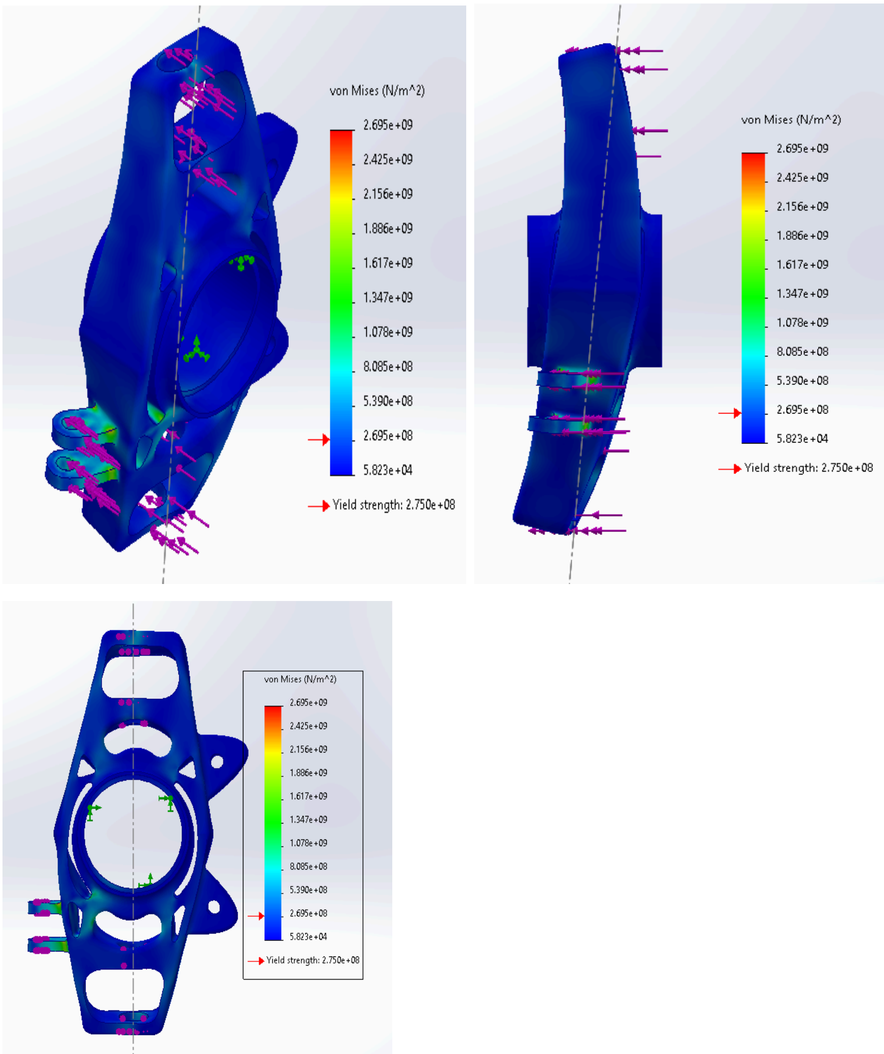


^ vonMises stress from backside and closeup view. Steering arm had the most stress.

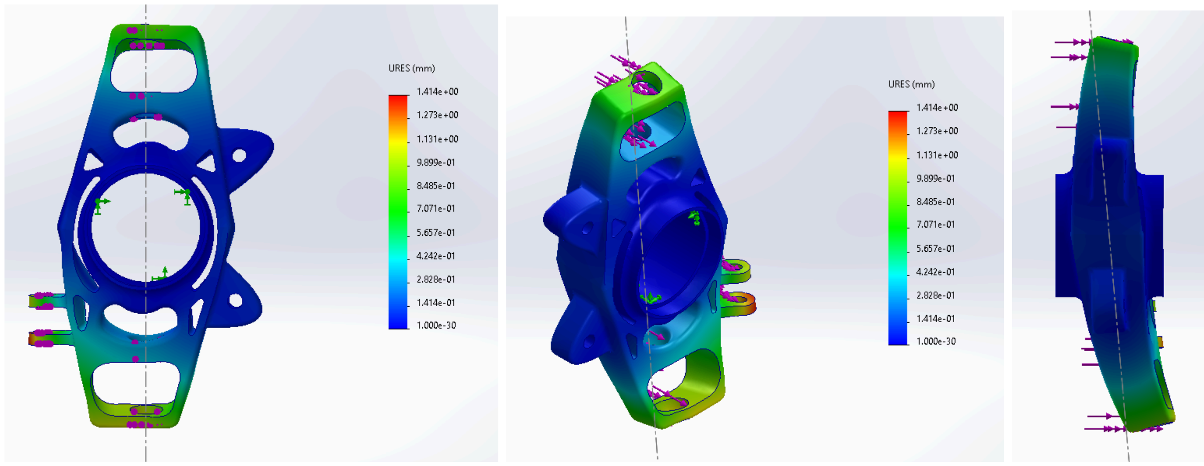


^ strain and displacement. Strain was around narrow parts of the body adjacent to the slots. Displacement on the upright was minimal.

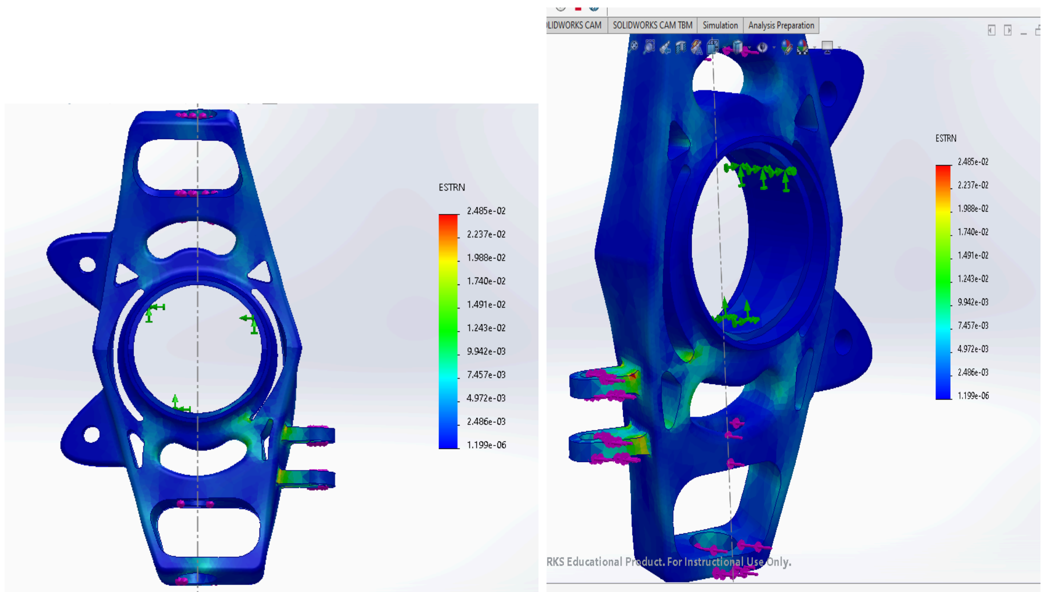
A second FEA simulation was conducted in which the forces and constraints were reversed. The center bore was held constrained while directional lateral forces of 6000N were applied to both suspension mounts and the steering arm. This study highlighted many design flaws that were not shown in the primary analysis. This FEA severely deformed the upright, and showcased several areas of future improvement. The suspension mounting holes were deformed off the axis of the KPI while the center maintained the majority of its integrity. Although the forces experienced were exaggerated, it is important to take these results into consideration when designing future iterations of the upright.



Von mises stress simulation 2.



Displacement was large on the extremities of the part



Strain on simulation 2. Strain was mostly near the steering arm as this feature was the least reinforced structurally.

Improvements

Based on the FEA, it is clear that this design was lacking in a few areas. Primarily the extremities of the upright were not reinforced well as material was cut away to lower the weight. As the material was cut from the side profile at an angle, as you got closer to the top or bottom, more material was cut off. This led the upright to deform under extreme lateral stress. In a real life scenario this would cause the wheel to misalign severely and be quite dangerous for the driver. That said, it would be unlikely that any single upright would experience the sorts of forces placed on it during the FEA.

Another area of improvement would be changing the size/placement of the lower triangular slots. These slots were initially created to reduce weight while maintaining structural integrity, but the FEA highlighted the weak points. Changing the position of these slots to areas less affected by forces can reduce weight while maintaining the safety of the structure. Additionally, altering the shape of these slots to remove less material may be beneficial.