Rationale

Our team is designing a recumbent motorcycle featuring a carbon tubing trellis frame, an electric fuel injection engine, hub centered steering, and a coilover suspension system. My project is designing a recumbent frame design built from a center beam with a composite tubing structure connected with laminated lugs.

Recumbent motorcycles allow for a lower center of gravity, increasing cornering performance and stability. Being recumbent also allows for an upright sitting position, contrary to the conventional straddle position, providing additional comfort. Recumbent position also decreases the normal cross section to the direction of motion, also increasing fuel efficiency. Fairings can be added to further decrease air and wind resistance.

A major design choice is to follow a “canoe” design. The main structural member of the frame will be an aluminum H beam, whereupon the carbon fiber structure will be attached to. Refer to Figure 2 in Technical Drawings. A single beam reduces weight while providing an uninterrupted support member that is very strong. The rest of the frame will be built from carbon fiber tubing connected with laminated lugs. Carbon fiber tubing is significantly lighter, allowing for better agility. The lugs will be for alignment, and composite fabric will be wrapped around both the tubing and lugs, creating a strong, one piece frame.

Working Principles

A trellis frame derives its name from frame tubes constructed into triangles. The frame will be fully modeled in a CAD software like Fusion 360, from which the alignment lugs can be modeled and dimensions for the tubing measured. Fusion 360 also offers the benefit of Static Stress Analysis, which can provide results on stress, displacement, reaction force, strain, contact pressure, and more. From those results the frame can be modified additionally before construction begins.

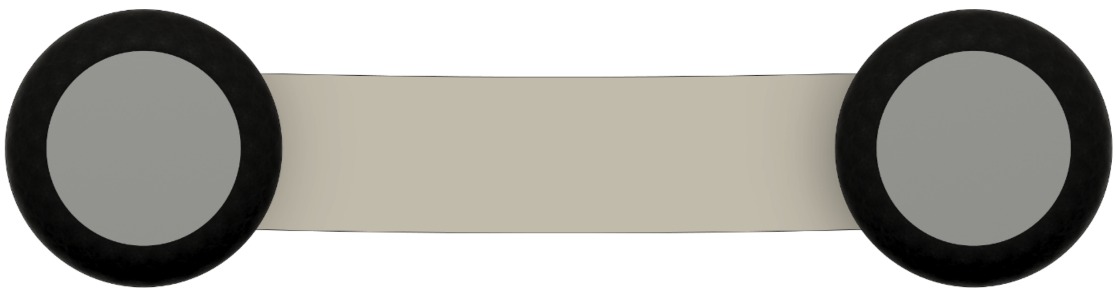
The alignment lugs will be 3D printed out of TPU (thermoplastic polyurethane). TPU filaments come in a variety of hardness levels, measured in Shore A hardness scale. The alignment lugs will need to be flexible enough to take up any slack in aligning the tubing, but also stiff enough to make alignment possible to begin with. 85-95A TPU filament will provide the characteristics needed while being affordable and readily available.

Carbon fiber is the material of choice for the tubing, selected for its high strength to weight ratio. Prepreg and braided tubing are commonly available. Prepreg offers better beaming strength, while braided offers better torsional strength. A combination of both will be used on the frame.

To assemble the frame, the tubing will be dry fitted into the alignment lugs. Once the whole frame is assembled, woven carbon fiber tape will be used. The carbon fiber fabric tape will then be wrapped starting on the tubing then overlapping onto the lugs, following its geometry. Epoxy resin will then be used to bond everything together. Compared to polyester or vinylester resin, epoxy offers the strength needed to not limit the properties of carbon fiber. With this construction technique, the frame is essentially one piece, offering no additional stress points at the seams of the lugs.

Criteria for Success

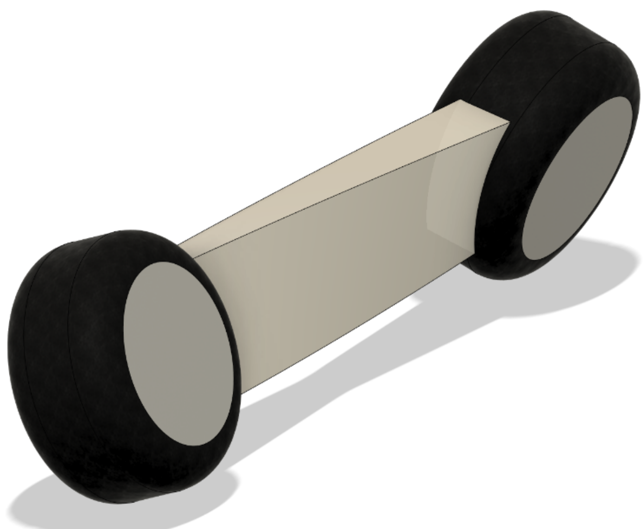
Beaming stiffness: With the front and back carbon fiber suspension mounting secured in place, a weight of 150 kg will be placed on the aluminum H beam. A deflection of under 2 cm will be acceptable. See figure below.



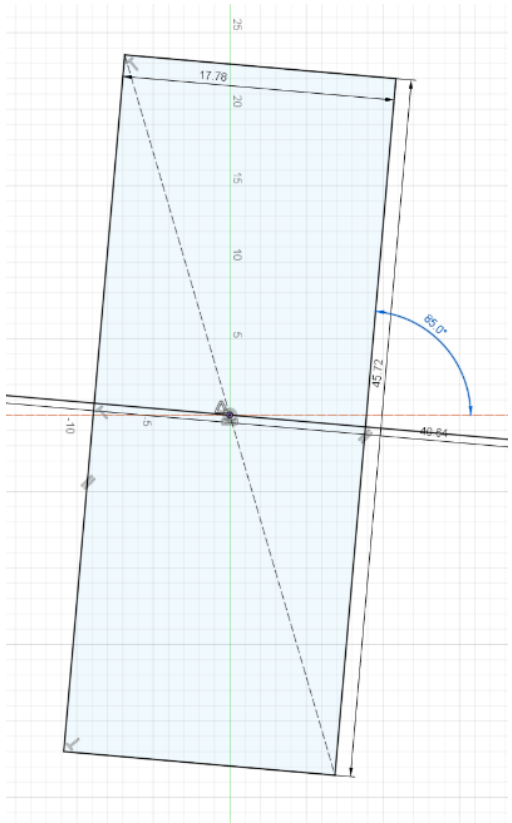
This frame has a 2 cm deflection at the center, which is acceptable.

Torsional stiffness: The nature of two wheels mitigates the four wheel torsional force when one wheel would go over a bump while the other stays on the ground. This results in the frame twisting. However, front and rear wheel steering during a turn would camber the wheel in different directions, whereupon a torsional force would be applied to the chassis. See figure below for illustrative explanation. Adapted from a torsional stiffness test of four wheel vehicles, the rear of the chassis would be fixed in place, and a beam would go under one frame member and over another. A force of 100kg would then be applied to one end of the frame, causing the frame to twist. A deflection of under 5 degrees measured from vertical would be acceptable. See sketch below.

When the vehicle turns, the wheel camber in different directions.



This would cause the rigid aluminum frame to also want to twist with the wheels, causing torsional stresses. This is a severe exaggeration of a lack of torsional stiffness.



This is a front view of the frame at one end, where a maximum of 5 degree angle measured from vertical would be deemed acceptable.

Goal

In year one of this project, a frame from a 4x4 substituting the aluminum H beam and wooden dowels substituting carbon fiber tubing should be built using the same manufacturing technique of alignment lugs and composite fabric wrap.

Contingency

If Stress Analysis in Fusion 360 does not work or takes more than two weeks to implement, a balsa wood model will be built to roughly serve the same purpose to stress test the frame in torsional and beaming stiffness.

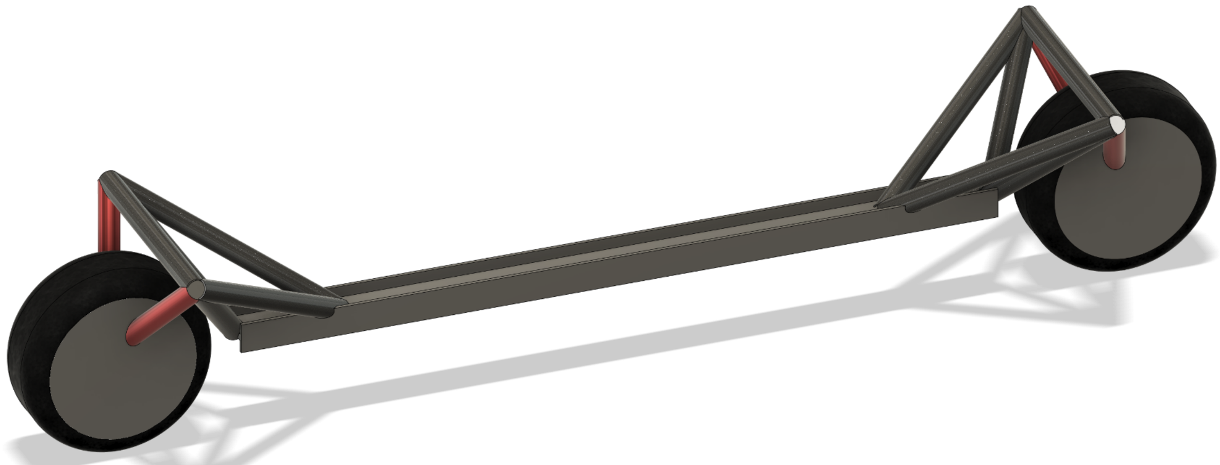
If the TPU filament proves to be difficult to print or has other issues, PLA could be substituted, although alignment may be more difficult with the more brittle lugs.

When 150 kg of weight is applied to the chassis, the lugs have two possibilities of failure. The first type of failure is the lugs may become permanently distorted but locks out. The second type of failure is the lugs failing catastrophically, snapping at the joint. Both of these can be mitigated by running a series of tests to see the failure load of the lugs depending on how much composite fabric is wrapped around before a chassis is built. If a lug does deflect more than optimal in the chassis more composite fabric can be wrapped around the joint.

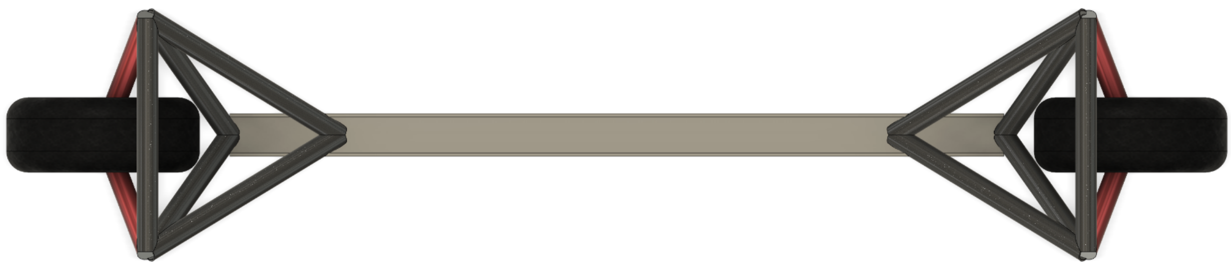
Major Milestones

By the end of February, a model of the chassis including mounting location for all critical components should be completed. Lugs should be modeled and printed, and the m materials cut to dimension.

Technical Drawings and Instructions



Angled View



Top Down View

Side View

Front View

Color coding:

Carbon Fiber: Frame tubing, made out of 5.08 cm (2 in) diameter tubing.

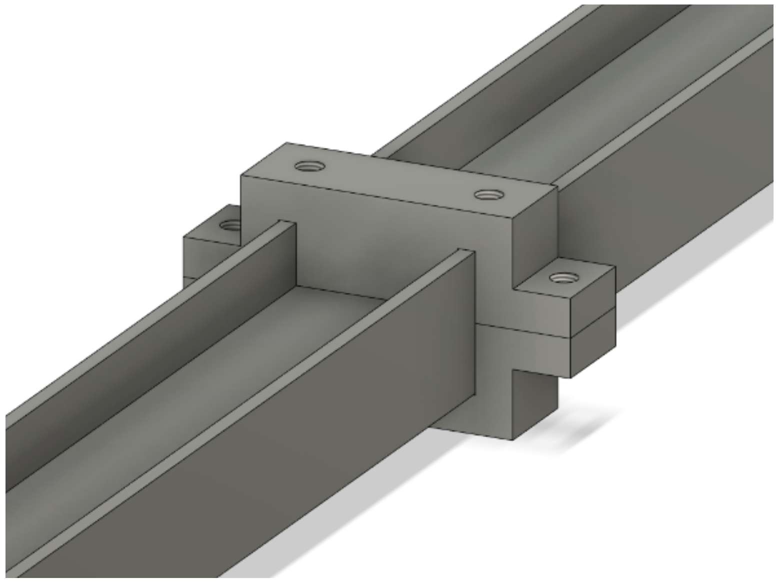
Red: Suspension, full extension 30.48 cm (12 in), fully compressed >22.86 cm (9 in).

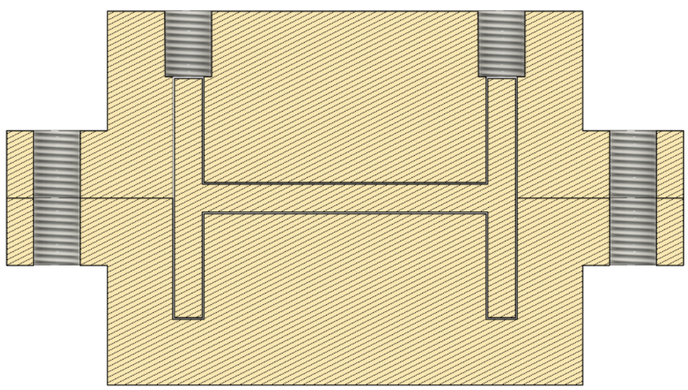
Not pictured are the alignment lugs, engine mounting bracket, and the steering hub.

Alignment lugs will be modeled next, see below for the engine mounting bracket.

Concordances

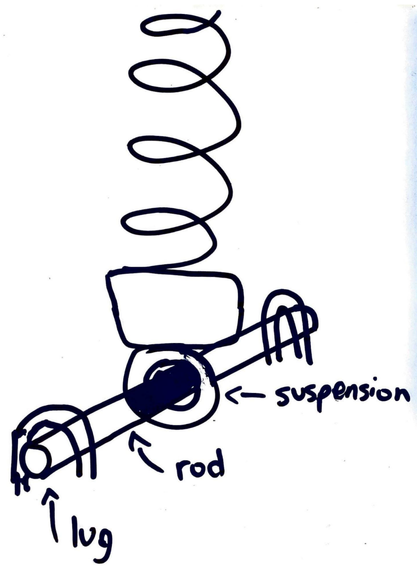
Engine: A three piece clamp will be modeled around the engine mounting spacing dimensions and the H beam. Two pieces will clamp around the H beam, while a third plate will be mounted on top with the correct mounting holes for the engine. See figures below. The physical engine mount should be ready by early March.





This shows the cross section of the mounting bracket to be attached to the aluminum H beam. This utilizes flanges with M16 hardware to clamp onto the beam. Not illustrated is the third plate that can be of any size to be mounted onto the top threaded holes.

Suspension: Special lugs will be modeled for suspension mounting, with a socket that allows for a rod to go through both the lug and suspension mounting point. See figure 6. The physical mount will be ready by late March.



Steering: Hydraulic lines will be run along frame members and the suspension. No special preparations are needed. This will be ready whenever suspension is mounted.

List of Materials

1. 4in x 4in x 8ft Lumber (1): https://www.homedepot.com/p/4-in-x-4-in-x-8-ft-Premium-2-and-Better-Douglas-Fir-Lumber-441856/202094374 - $13.42ea
2. 2in x 2in x 48in Dowel (10): https://www.homedepot.com/p/6456U-2-in-x-2-in-x-48-in-Pine-Round-Dowel-10001813/203334076 - $13.46ea
3. Woven Fiberglass Tape 3” - 50 yd roll 220-B (1): https://www.fibreglast.com/product/Woven_Fiberglass_Tape_217 - $47.95ea
4. System 2000 Epoxy Resin Gallon (8lbs) 2000-B (1): https://www.fibreglast.com/product/System_2000_Epoxy_Resin_2000 $169.95ea

5. Shore 90A TPU (1): https://www.amazon.com/Polymaker-PolyFlex-Filament-Flexible-Printing/dp/B09MTCG38B $39.99ea

Working plan

Day 1-7: Work on finishing the final frame model.

Day 7-14: Model the alignment lugs and use the Static Stress Analysis in Fusion. Implement any necessary adjustments. Order the materials needed.

Day 14-21: Print out the alignment lugs.Cut the dowel and 4x4 to the correct dimensions, and do a rough line up with the lugs.

Day 21-28: Begin the fiberglass and vacuum bagging process.

Day 28-35: Clean up the frame and inspect/repair anything necessary.