EGA-334 Mechanical Engineering Design 3

Stage 2 Report

Group 22

[redacted]

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Key notations:

Symbol/Notation	Section	Definition
Det	FMEA	Chance of detection
FEA	All	Finite Element Method
FMEA	All	Failure Modes and Effects Analysis
FOS	FEA	Factor Of Safety
PCB	All	Printed Circuit Board
Occ	FMEA	Occurrence
PLA	All	Polylactic Acid
RPN	FMEA	Risk Priority Number
RC	All	Remote Control
Sev	FMEA	Severity
CoM	FMEA	Centre of mass
MVM	FEA	Maximum Von Mises
LHS	Individual reports	Left Hand Side
RHS	Individual reports	Right Hand Side

Explanation of design

The main objective for this design is to create a fully functioning RC Car with metal detecting capabilities that can operate at an extended range over various terrains of differing topologies. The target audience for this RC car product is for anyone with mobility issues such as the elderly or the physically disabled, however this may appeal to a broader range of enthusiasts as well such as children or general hobbyist.

To achieve this goal, several design challenges had to be overcome to provide a design with the greatest off-road capabilities achievable. These design challenges include, but are not limited to:

- Suitable ground clearance – as the terrain is non uniform, a clearance between the bottom of the chassis and the ground was essential to the operation of the product to be able to facilitate enough the traversing of the environment without obstruction to the undercarriage.
- Tight turning circle – with the unpredictability of the paths that it may incur, being able to avoid such obstacles quickly and easily would be optimal for this use case.
- Drive train – having a high torque is critical to the operation of the vehicle due to the previously mentioned rough terrain encountered having potential to have a sharp gradient. This would also be a benefit to operation on loose terrain such as sand or gravel.
- Structural integrity – impact probability for this design is high, therefore it is vital that the components are protected to a suitable IP rating, as well as can withstand any impact force coming from external sources.
- Weight saving and distribution – being able to function effectively begins with the correct management of weight. Having a large weight could lead to sinking or hinder the optimal performance of the car, and a poor center of mass location could cause tipping or ineffective traction.

Our design was successful in meeting most of these conditions, but not all. Our IP rating was not met, with the difficulty of sealing parts that house large components being a major reason for this failure. Furthermore, during the design process, other targets were prioritized over this rating, such as component space allocation hindering the efforts to create a sufficient seal. Similarly, the weight saving goal was not reached either, however it was not missed by a great margin. Once more, other priorities took precedence such as stability and rigidity of the structure and a powerful enough drivetrain being of a large enough size.

Alternatively, in terms of success, many of the criteria were met. Our design met all other criteria of the PDS, proving that the design is a realistic and valid creation for our use case. This leaves us with much room for improvement for potential future designs. Firstly, the two failures identified should be actioned, with greater thought going into the designs weight and where it holds too much material for the load it is expected to undertake. An example of a part exhibiting this is the wheel design. Whilst it performs at the level required of it, it could perform at a similar level whilst reducing the weight and intelligent planning of its load paths through its structure. Moreover, through adjustments of the battery mount, a much more secure seal could be achieved around the part making the car far more resilient and matching the PDS requirements.

Table 1: PDS

ID	Requirements	Origin	Class (M/O/E/B)	Acceptance criteria to pass	Been met (Y/N)
Regulation / Safety Requirements					
1.1	Use reclaimed materials.	Reclaimed materials can be used if they are mechanically meaningful.	M	100% utilized for the body work.	Y
1.2	High durability.	Must have a suitable FOS of >2 for manufactured parts & >4 for reclaimed materials.	M	FEA simulation >2 and >4 for the corresponding materials.	Y
1.3	Water Resistant.	Product must withstand sand, water, and dirt due to use case being in beach environment.	M	Exceeds IP53 rating.	N
Technical / Design Requirements					
2.1	Easy to assemble & disassemble.	It must be possible to remove electrical components and replace them using housing tools.	M	Assembly within a 15-minute period, without the use of glue.	Y
2.2	Low weight.	The car does not exceed the specified weight requirements & components are designed with light weight in mind. Non-essential & non-functional parts of the car must be removed without damaging the strength of the structure.	M	Total weight is <1.1kg. Passes FEA simulations whilst using a mass equivalent to a third of the combined weight of the other components.	N
2.3	Withstand load tests.	Must be able to withstand vertical force through roll cage, maximum cornering load through front axle and crash test.	M	Pass following loads, based on the group's calculated maximum acceptable force. (1.25x for crash structure).	Y
2.4	Cornering Mobility.	Vehicle must be able to enter between the circles and complete a left-hand circle followed by a right-hand circle.	M	Two circles of 1.2m inside diameter and 1.8m outside will be created. The centre of the circles will be 1.5m apart.	Y
2.5	Suitable dimensions.	Must not exceed 180mm width & 340mm length.	M	A template has a rectangular hole cut in it. This must fit over the whole car including tyres down to ground level.	Y
2.6	Material must have suitable mechanical properties.	High yield strength, resistant to corrosion and extreme temperatures.	M	Pass stress analysis FEA simulations.	Y
Manufacturing Requirements					
3.1	Standard BSI components required.	Metrics must be kept consistent to maintain standards and tolerances.	E	Metric drawings and measurements taken at standard.	Y
3.2	Consider environmental implications.	Use suitable manufacturing processes which have a limited or decreased impact on the environment.	B	Used recycled materials that can be manufactured with low carbon footprint.	Y
3.3	Appropriate Material selection.	Use suitable material with properties that affect a component part's strength and infill percentage.	M	Proof of resources used to analyze properties. E.g. Granta EduPack.	Y
Materials					
4.1	Recyclable.	All manufactured parts are suitable for recycling bins.	M	All parts can be discarded in recycling bins via the Swansea.gov guidelines.	Y
4.2	Durable.	All materials can withstand direct impacts.	M	Passes collision tests with minimal damage.	Y

Process	Potential Failure Mode	Potential Failure Effects	Sev	Potential Causes	Occ	Current Controls	Dec	RPN	Action Recommended	Actions Taken	Sev	Occ	Det	RPN
Crash Structure	Unsuitable height clearance from ground.	Crash structure contacts the terrain.	7	Angle of attack from the rear axle. Height of attachment to the front of the car.	5	Calculation of the angle of attack. Design of impact surface.	2	70	Account for 9-degree angle of attack for the connection hub or shorten/offset the outer radius (impact surface).	No actions taken as steering was lowered.	7	5	2	70
	Shearing from the attachment points to the chassis.	Catastrophic failure of the connection.	10	Weak connection points (wrong choice of attachment).	3	Right angle geometry to increase thickness from 5mm to 10mm of the bolt and nut attachment to chassis. Multiple connection points.	1	30	Add additional M3 bolts. Increase size of connection points. Increase hole distance from edge.	Interference fit substituted bolts due to high stress concentrations on central bolt hole in FEA. ID 1.2	10	3	1	30
	Fails to designed failure mode. Does not crumple uniformly through structure.	Energy is not absorbed by crash structure and transferred to the chassis.	9	Shape or infill percentage chosen incorrectly, unsuitable for testing loads.	2	Uniform thickness of outer radius and symmetrical spokes.	4	72	Prototype various infill patterns and shapes.	Material properties used was 25% Tri Hex pattern during load case studies. Iterated until FOS>2 when subjected to 1.25 x (average crash force). ID 1.2, 2.3, 2.6, 3.3	9	2	4	72
	Dimensioning obstructs the assembly of part to the chassis	Physically cannot attach crash structure to the car.	8	Incorrect tolerances and dimensions on drawings. Poor printing imperfections. (Levelling, calibration & spool quality.)	2	+-0.1mm connection arm tolerance. Design with roll cage for fit. +-0.5mm tolerance between connections.	2	32	Close consultation with chassis and roll cage designers. Physical printing and assembly of part to verify no obstructions.	22mm Fillets optimise surface area on chassis, allowing roll cage and steering space for attachments. ID 2.1, 2.5,3.1	8	2	2	32
Chassis	Too much weight reduction causing the structure to fail.	Cause the chassis to snap or deform.	10	Honeycomb region is too large. Thin structures create stress on unsupported sections.	2	Chassis design avoids weak points in the structure. Perform FEA of the chassis design.	2	40	Consider each reduction and examine weak points causes - perform FEA after changes.	Honeycomb area reduced by a significant amount across the entire chassis. ID 1.2, 2.6	10	1	2	20
	Poor weight distribution	Vehicle fails the steering test causing damage to components.	4	Components heavily off centre.	6	Space provided for chassis to allow for the components to be centrered and spaced effectively.	3	72	Calculate CoM with components. Does it affect car's function?	Majority of components with a significant weight contribution located in the centre or rear of the chassis. ID 2.2	6	3	3	54
	Bad attachment of components to the chassis.	Failure at attachment points causing components to detach.	8	Too much stress placed on too few attachment points from the forces of the components.	3	Structure design allows sufficient attachment points for each component.	2	48	Provide sufficient attachment points for each component.	Increased number of attachment points to the chassis for the steering, drivetrain, and crash structure.ID 1.2	8	2	1	16
	Chassis lacks space and support for all the components.	Capability of the vehicle limited, and function may be stopped.	8	Poor management of the placement of components on to the chassis.	4	Regular communication with other group members to maximise the chassis surface area for component allocation.	2	64	Team updates, check how this affects space management of the chassis before making changes.	Part locations moved around, and chassis length increased to maximise space. ID 2.5	8	1	1	8
Roll cage	Roll cage does not withstand vertical load or horizontal load	Product is insufficient for intended use, broken components, total failure.	9	Roll cage is not strong enough, poor design.	4	Regular visual checks, safe use of product. Thicker beams, larger fillets, higher infill.	2	72	Safety manual, stronger construction with fillets and strong density/infill.	FEA used to test and strengthen vertical load bearing parts. ID 1.2	6	3	2	36
	Roll cage interferes with other components	Product cannot be constructed, repaired, or modified.	10	Poor communication. Lack of CAD assembly, no prototyping.	1	Virtual CAD assembly of components and prototypes.	1	10	Team communication. CAD assembly and prototyping to test installation.	CAD assemblies and pre-planning. ID 2.1	10	1	1	10
	Roll cage does not securely fit onto chassis.	Cannot be installed, product is insufficient.	9	Poor communication. Printing imperfections (calibration, levelling etc)	1	Virtual CAD assembly of components and prototypes.	1	9	Team communication. CAD assembly and prototyping to test installation.	CAD assemblies and 3D printed prototypes used to evaluate fits. ID 2.1, 3.1	9	1	1	9
	Does not increase the cars structural integrity (stiffness in twisting)	Car does not have good strength, potentially unstable construction.	3	Does not fix onto chassis securely, poor fit.	1	Virtual FEA testing and prototypes. Connection to chassis is secured with suitable tolerances.	3	9	Communicate with team during designing. Stronger, secure connections.	Designed in line with chassis and has many strong connection points to transfer impacts. ID 2.3	3	1	2	6

Table 2: FMEA

Drive train	High Levels of vibration throughout component	Vibration causes connections to fail, PLA to crack	10	PLA layers incorrectly adjoined	3	Targeted design to best adhere to the target manufacturing process. Designing with intent to allow for intolerances in the manufacturing process.	3	90	Testing prototypes and iterative improvements in targeted design to accommodate for the PLA printing process.	Testing of all bearing/ fixture joints prior to the printing production of full assembly.	8	3	3	72
	Excess power causes failure in motor mount	Motor breaks free rendering the component unusable	9	Mount not suitable to withstand necessary loads from motor	3	FEA force simulation to understand the loads which the part must withstand to operate.	2	54	Simulation and extensive testing on prototypes	Isolated motor mount prototype printed prior to full part to ensure the thickness and connections are suitable for use case. ID 2.6	6	3	2	36
	Torque in rear axle causes excess displacement in mounts.	Rear axle mounts fail, and system does not rotate rear wheels	9	Mount not suitable to withstand necessary loads from motor	3	Over engineering of adjoining features to accommodate for excess loads.	3	81	Simulation of loads exerted on rear axle mounts.	Forces proved to be overrated so weight reduction measures were undertaken to this feature.ID 2.2	5	3	3	45
	Housing seals have inadequate IP protection	Dust/ debris enters moving parts causing damage and failure	6	Seals not tested before assembly	2	Tight tolerance fitment joints between housing and lid components incorporated into the design.	3	36	Fine layer thickness used for printing adjoining seals and fitments	Fine layer (0.12mm) used for sealing faces. Additional fastening joints incorporated to allow a tighter fit. ID 1.3	3	2	3	18
Steering System	Misalignment of the Ackermann angle	Will cause understeering or oversteering	8	Incorrect calculation of the Ackermann angle Incorrect tolerance (too large)	2	Ackermann angle calculated and current tolerance of +-0.5mm	5	80	Hand calculations that have been checked and peer assessed	Re-calculated the angle after the chassis design had been updated. ID 2.4	5	1	2	10
	Geometry of servo arm connection point too weak to withstand the load.	Steering would be ineffective as connection would snap under the load	10	Overall geometry of connection is too small and too high	8	Testing of 3D prototypes as the geometry of the current connection has not taken into consideration of the torque	1	80	3D testing has been applied with the torque from the servo (1.6-2kg/cm)	Added a paper clip to the servo connection arm as it would provide with the correct strength and fit. ID 1.1	10	2	1	20
	Weak and few connection points	Shear force would cause failure at the bolted connection	10	Not enough connections Placement of the connections	2	2 connections that are symmetrical through the vertical axis of the chassis	3	60	Additional connections to be added along the entire steering system	Additional 2 connections added in parallel to provide greater strength. ID 1.2	10	1	3	30
	Angle of attack increasing the load at front of system, causing increased stress	Wheel alignment would flair outwards	6	A centripetal force is applied through friction to the wheel axle	3	Increased thickness of the axle and shorten to withstand the bending forces	2	36	Switch position of steering with the controller at the front of the car. Position the axle underneath the chassis to reduce the angle.	Increased the length of the steering arm by 27.5mm to level out the chassis, resulting in additional support to the underside of the chassis. ID 2.5	6	1	2	12
	Restricting turning circle due to chassis and crash structure design	vibrations will cause abrasion of materials and stress at the lever arm connection points	4	Miscommunication cause incorrect geometry of parts	2	Testing of CAD assembly between the wheels, bearings, and rear/front axle. Ensuring tight fit.	3	24	Physical verification will be needed to determine that it can turn to 30 degrees	Location of steering was pushed towards the front of the chassis as it was in the way of the ESC and the battery ID 2.3, 2.4	4	2	2	16
Wheels	Wheels do not account for bearing slippage	Bearings will slip out rendering the wheels immobile	10	Wheels do not account for the secure fit of the bearings	3	Testing of CAD assembly between the wheels and bearings. Ensuring tight fit.	4	120	Create 3D printed design and test fit over the supplied bearings. Achieve tight tolerance (0.1 mm)	Create new wheel design that has a secure tolerance fit (0.1mm) around the bearings.	10	3	4	120
	Wheels are unable to withstand specified loads	Wheels will crumple/break/crack under test loads.	10	Wheel design is not strong enough	2	FEA analysis and force simulation. And use improved iteration of initial design.	5	100	Use SolidWorks to simulate the test loadings to produce a design that withstands the specified loading.	FEA testing and simulation. Ensure design withstands load requirements. ID 1.2	10	2	5	100
	Wheels cannot achieve a secure attachment onto the axle	Wheels will fall off and the Rc car will not be able to move	10	Failure to design strong connection to axle (lack of communication with axle designers)	1	Clear communication with steering and drivetrain designers. Ensure proper connection method of attaching the wheels to the axles.	2	20	Achieve Tolerance fit of 0.1mm. Test this using 3D printed parts of the axle, wheels, and the supplied bearings.	Achieve tight tolerance fit (0.1mm) onto the front + rear axles. ID 3.1	10	1	2	20
	Wheels cannot be easily removed and fitted onto the axle	If wheels cannot be attached/removed easily, design may fail assembly	8	Wheel dimensions are either too big or too small	2	Testing of CAD assembly between the wheels, bearings, and rear/front axle. Ensuring the correct fit.	2	32	Using initial 3D printed design parts, test the ease of wheel assembly several times	Accurate dimensions. Clear communication with steering and drivetrain designers. ID 2.1,3.1	8	2	2	32

Table 2 (Continued): FMEA

Group management report

During my time in my group, I have learned how to effectively communicate with my team and how to set goals. I also learned how to time manage and coordinate with my teammates as we had to plan working hours in between other coursework and external factors. As the team leader, I established what the objectives were for my leading period and had 2 updates each week as a group where we shared our progress and ideas for the next stage. With my lead, the team progressed by improving designs with feedback from the presentation and the FMEA.

When people were unavailable for group or supervisor meetings, notes were always taken and shared around so everyone was on the same page. We also kept the Microsoft Teams directories as tidy as possible so we can backtrack and find files easily.

Unfortunately, communication was not perfect, and some goals were left unfulfilled for a long time. Some components were physically incompatible with each other, and the overall design had some significant misalignments. On the other hand, definitive connection points had been established early, so most components could be adjusted freely without worrying about incompatibility issues.

We also did not stick to the Gantt chart plan very well, which was not a problem until the 3D printing phase. Unfortunately, one of the 3D printers was not printing perfectly, and with little time left I had to prioritise and plan the printing as efficiently as possible to print out nearly all the parts in the last 2 days. I had to weigh out which features had priority if it came down to a last-minute decision.

Thankfully, I was able to print everything we needed, and a backup of some extra pieces.

Key design features

The connections between each part of the roll cage are exclusively friction fits. This makes 3D printing the connections very reliable and allows for easy connectivity without relying on clips (which are weak connection points and can break over time). The friction fits are also stronger than clips because the impact loads are directly transferred from one piece to the other.

- The friction fit is also easier to line up with slots. Troubleshooting a peg-in-hole connection post processing would be more difficult, with a weaker connection and more parts.

- Dovetail joints were highly considered for the three parts, but unfortunately there was no orientation which transferred the vertical and horizontal impacts between each part effectively, as a key goal of the roll cage was for each of the three parts to share the loads as much as possible.

- The current orientation of friction fits was selected because it spreads the vertical and horizontal loads as evenly as possible between the five connection points.

- There are five large connection points between the roll cage and chassis. This is beneficial for transferring impacts evenly and increases strength of the roll cage by having fewer weak points.

If I were to remake the roll cage, I would add extra material beside the attachment points so that it can lineup with the chassis flush on all sides. I would also make the middle piece weaker and more dependant on the front and rear because this would cut down on weight and thus cost.

FEA analysis of component subject to load cases

Before analysing iterations for the roll cage, a mesh independency test was performed to find the optimal mesh parameters.

Initially, 5 connection points were established with the chassis. Two in the front, one in the rear, and one on the left and right. PLA material was applied using material properties found from previous studies[1].

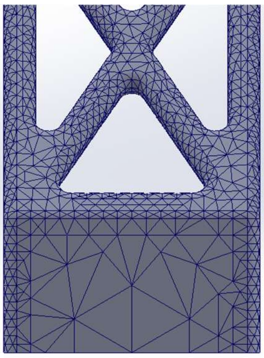


Figure 4 - Large and small triangles on the right face of the roll cage.

The element size growth ratio used a high value of 3 and the minimum number of elements in a circle was 8. This allowed for smaller elements to analyse smaller details, such as the fillets, more accurately. Larger surfaces on the models used less triangles while still being accurately represented, so this minimised computing power needed and the wait times between testing.

The minimum element size was varied and plotted against the maximum Von Mises value, converging at 17.9MPa.

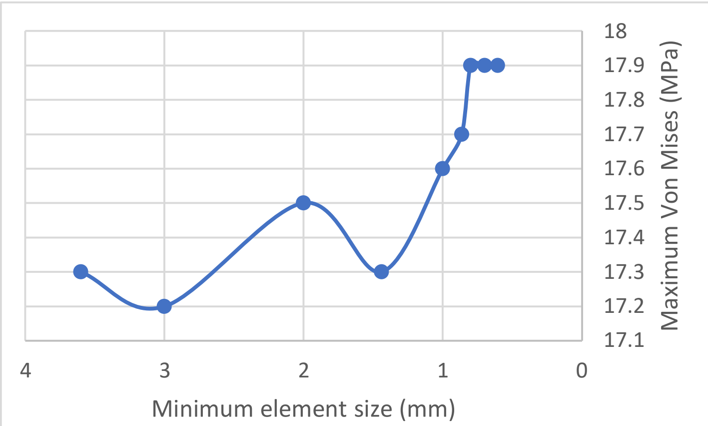


Figure 5 - Graph confirming mesh independency.

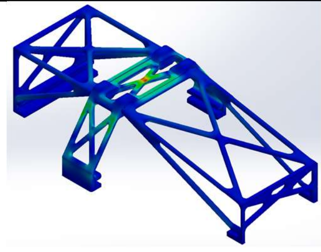
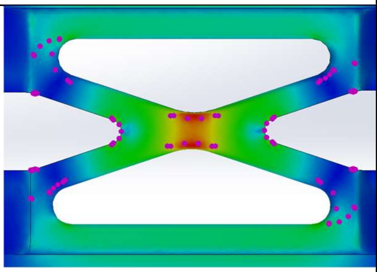
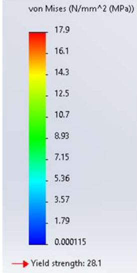
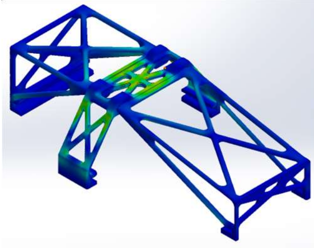
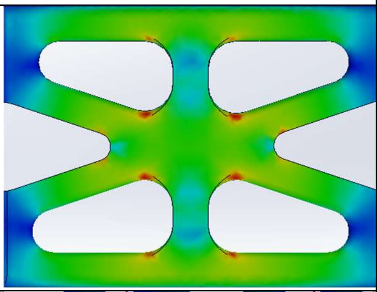
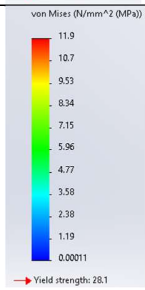
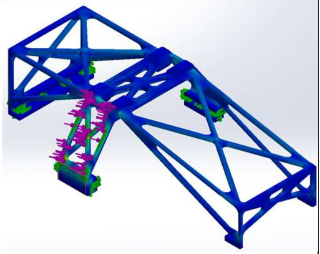
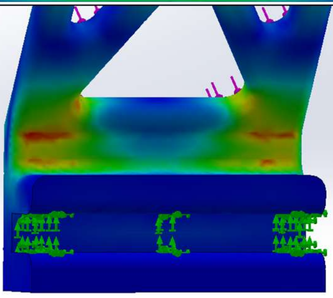
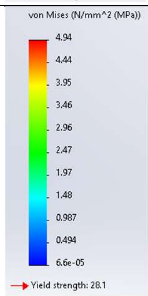
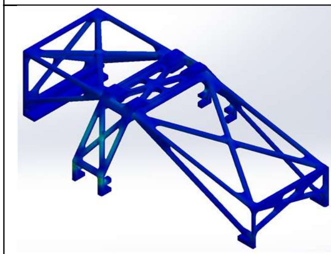
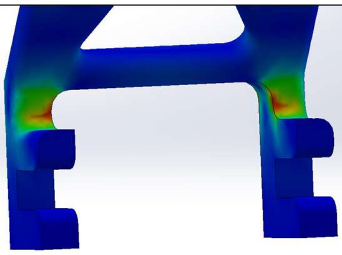
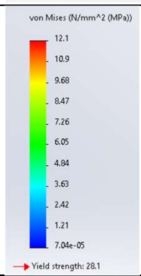
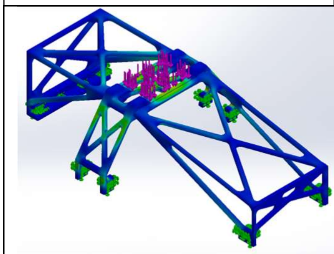
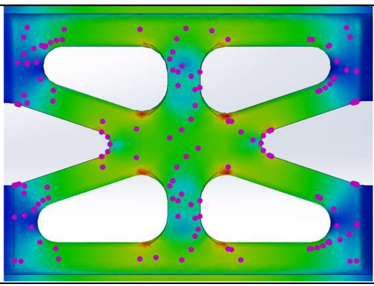
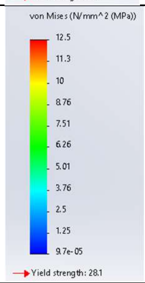
The mesh independency testing and the first FEA study used the vertical dump static load as this is the larger impact force and it affects the most area on the roll cage, meaning any crucial changes are noticed with just one simulation.

I chose to use the upper, larger faces of the side of the roll cage for the side impact because lower down would lead the forces directly into the chassis. This location also allows the roll cage to disperse the load along more of its body and so gives a more insightful simulation. The vertical dump load was also used on the larger face to disperse the forces.

The models were assessed under two static loads. The value for the side impact static load was calculated from the change in momentum before and after the collision, and the vertical dump is 1.25x larger than the side impact. The static loads are 82.5N on the side impact and 103.125N at the top surface.

[1]: Rismalia M, Hidajat SC, Permana IGR, Hadisujoto B, Muslimin M, Triawan F. Infill pattern and density effects on the tensile properties of 3D printed PLA material. Journal of Physics: Conference Series. 2019 Dec;1402:044041.

FEA Analysis

Isometric view of model	Highest stress area	Max Von Mises	Values	Analysis
			Top load: 1.6 FOS 17.9MPa	Iteration 1: FOS is far too low because here is a large lack of support for top impact.
			Top load: 2.4 FOS 11.9MPa	Iteration 2: Beams are added with larger fillets on the top face to dissipate top load.
			Side load: 5.7 FOS 5.764MPa	Iteration 2: FOS is too high. There is lots of unnecessary material here.
			Side load: 2.3 FOS 12.1MPa	Iteration 3: Split the connection points in the middle and filleted the side faces to reduce material.
			Top load: 2.2 FOS 12.5MPa	Iteration 3: After changing the side faces, top load still has a 2.2 FOS.