GNG5140 Initial Prototype Analysis and Test Results

Assignment D
Modular Ultralight eV Prototyping

Submitted by

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March 9th, 2023

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Abstract

UO Super mileage is a student organization at the University of Ottawa that competes in the highly regarded Shell Eco-Marathon program. The aim of the club is to design and build the most energy-efficient electric vehicle possible and to provide undergraduate and graduate students with the opportunity to enhance their engineering skills through hands-on experience. Over the years, the team has taken part in the prototype car category, which involves creating smaller vehicles that only require functional components and don't have any added features. However, more recently, they have stepped up to the urban concept category, where they face new design and production challenges such as optimizing the manufacturing process to create the chassis frame adapters. The process must be robust, economical and efficient in terms of material usage, among other important factors.

Our group, which is part of the Engineering Design course (GNG5140) at the University of Ottawa, will be providing support to the UO Super mileage club in selecting the most suitable manufacturing process for their vehicles. In this report, we begin by clearly defining the design problems and presenting some examples of existing solutions for reference. Additionally, we provide comprehensive technical information on the various manufacturing processes that will be evaluated and compared in order to determine which is the best fit for the club's needs in terms of design, mechanical requirements, and budget constraints.

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List of Acronyms

Acronym	Definition
SAE	Society of Automotive Engineers
CNC	Computer numerical control
CAD	Computer-aided design
FDM	Fused Deposition Modeling
CFRP	Carbon Fiber Reinforced Polymer
OD	Outer Diameter

1 Introduction

The University of Ottawa's SAE Supermileage team has constantly worked to improve its energy-efficient automobiles. We have been tasked with finding alternate ways of spare part production that are cost effective, time efficient, and simple to learn. We are focused mostly on traditional manufacturing techniques, from which we will methodically seek inspiration and work towards the needs of our Super mileage team. We gathered public materials from multiple SAE Supermileage teams and determined the processes employed, such as water jet cutting, CNC machining, Additive fabrication, and casting. Some pieces must be extremely exact, and their production will be beyond the scope of this project. We had a thorough discussion with our team members and decided to focus more on casting processes (with possible future development) and, secondly, the process of additive manufacturing. We will be able to best develop a better solution and bring about a revolutionary change in low-cost manufacturing using the information gained from the collected resources.

2 Global Solution Concept

The following flow chart illustrate overall solution process to achieve best possible solution.

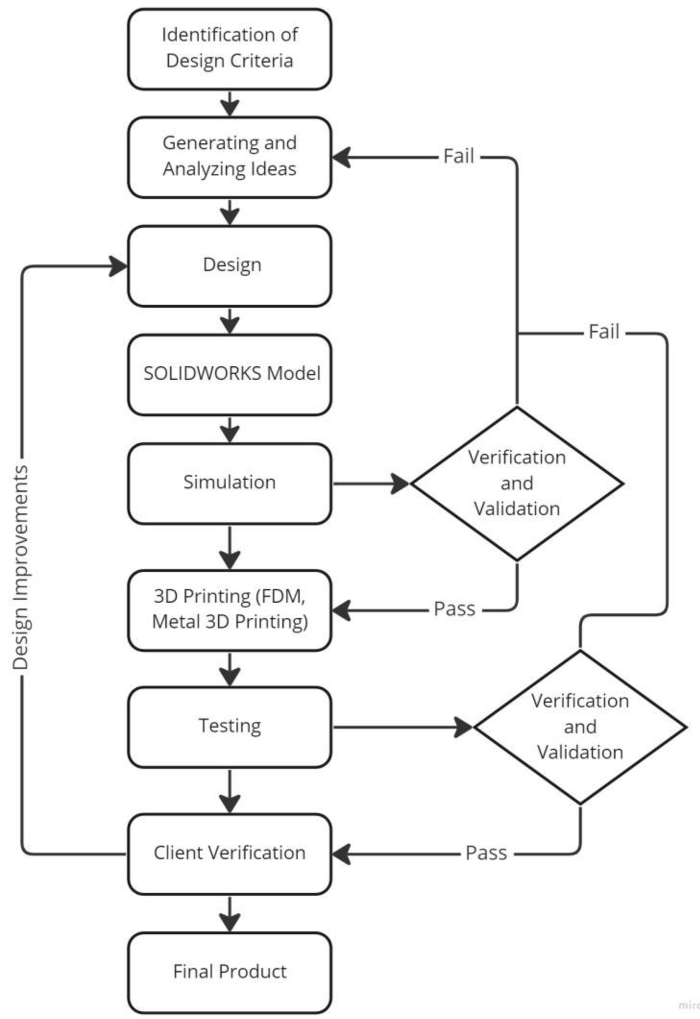


Figure 1: Global Solution Concept

The design is the design of semi-permanent joints for the frame of a super-milage car.

Here, Solution phase includes total three types of prototypes:

1. SOLIDWORKS Model
2. 3D printed using FDM printer
3. 3D printed using metal printer

The physical model is first printed using FDM 3D printer and then by metal 3D printer to save the cost of prototyping and hence, the overall project cost.

2.1 SOLIDWORKS Model

It is the model based on the design created using 3D modeling software SOLIDWORKS.

2.2 Physical Prototype

Physical prototype is the unit, which connects with the tube of a super-milage car frame. The assembly of the units (according to the configuration of the tubes in the frame) is the joint.

Following is the connection between the components of the system.

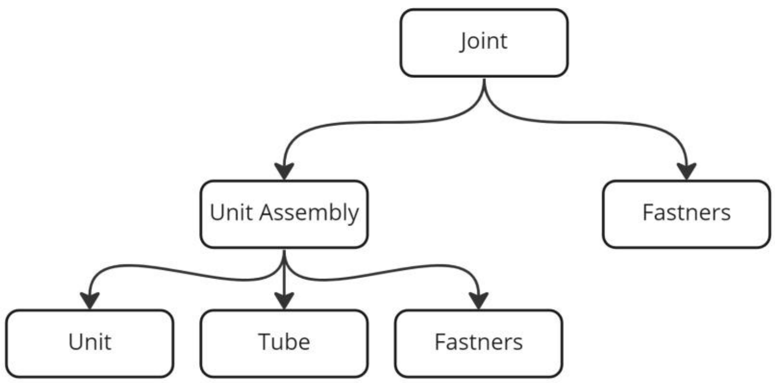


Figure 2: Connection Between Components

3 Prototype and Test

3.1 Design Criteria and Assumptions

For this joint design, based on client requirements and analysis of the problem, following design criteria are considered.

1. Joint is design for the tube having OD of ½”.

2. Direct Loading

   The frame structure of the car is considered as the truss. So, the body weight of vehicle along with the weight of the driver is transmitted through truss members (tubes) to the joint, which will act as a direct loading.

3. Impact Loading

   During the competition there might be instances when driver have to apply the brakes suddenly, which will create impact on the overall car and hence, on the joint.

4. Bending

   The tube of the frame is connected with the joints from both the sides and due to weight of the pipe, there is a bending load on the joint.

Assumptions

Here, we have taken two assumptions,

1. Joint will not fail by bending

   The density of the CFRP tubes is 1.8g/cm^3, so, bending due to self-weight of the CFRP tubes is negligible [1].

2. The thickness of the joint

   The basic of joint strength is that – the strength of the joint must be greater than equal to the material being joined using that joint [2]. According to the standard size the thickness of the ½” tube is 0.122” (≈ 3 mm) [3].

3.2 Prototypes

First, the 3D model is created by considering design criteria and assumptions.

In the initial stage of design, we have assumed the thickness of the joint wall to be 5 mm to account for the factor of safety. With this assumption 1st 3D model of the single unit is created, and simulation is performed. After analyzing the results of simulation, we modified the design. The testing results and analysis are shown in the next section of testing.

Both the designs with their physical prototype are shown below.

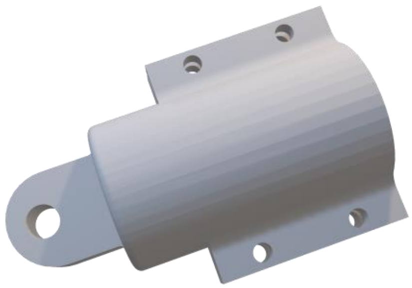


Figure 4: 1st Unit Design

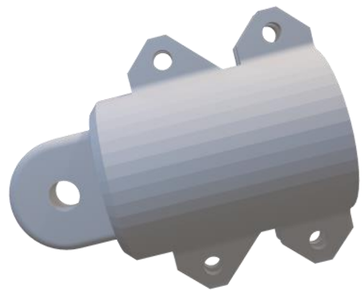


Figure 3: Modified Unit Design

Figure 6: 1st Unit - FDM 3D Printed

Figure 5: Modified Unit - FDM 3D Printed

3.2.1 1st Unit Design and Physical Prototype

1st unit design is starting point based on benchmarking.

- This design is created to carry out simulation and to take corrective action in coming designs.
- Moreover, FDM 3D printing of the 1st unit is carried out in order to better understand the 3D printing parameters and after manufacturing processes like removing raft, removing structure etc.

3.2.2 Modified Unit Design and Physical Prototype

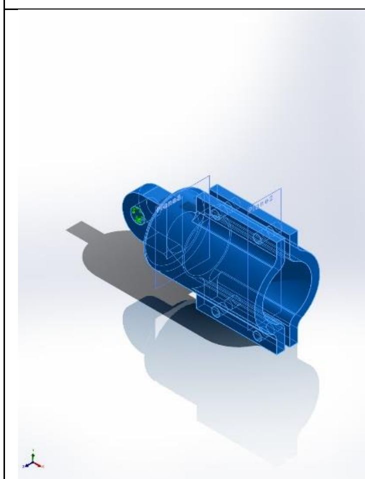
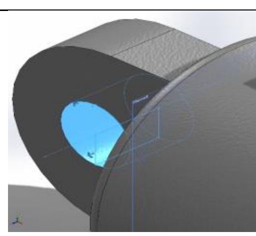
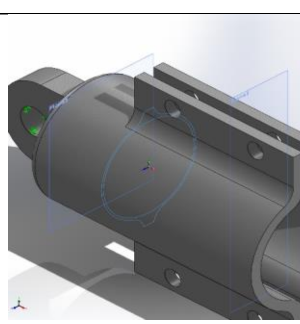
This is the modified design based on the 1st unit design.

- This design is done to reduce the weight of the unit, which eventually affects the total cost of manufacturing.
- Additionally, design for manufacturing aspects is taken into consideration to reduce the amount of support material while 3D printing, to reduce the problems of removing structure and to reduce the weight of the unit.
- 3D model is used for simulation to perform destructive testing like strength testing and physical prototype will be used for fit testing and for validating the assumptions.

3.3 Testing

In the simulation, considering the worst-case scenario is that the impact load and the direct load are simultaneously acting on the joint, so we set the loading force as 7,000N (Appendix A). If the part doesn't deform or the stress is relatively small comparing to the material strength, then the part is considered pass the test, if the value is way off the strength, then it is failed the test in simulation.

Table 1: 1st Unit Material Properties and Constraints [4]

Model Reference	Properties
	Name: **TI64(3DP)** Model type: **Linear Elastic Isotropic** Yield strength: **7.3e+08 N/m^2** Tensile strength: **8.45e+08 N/m^2** Elastic modulus: **1.048e+11 N/m^2** Poisson's ratio: **0.31** Mass density: **4,318.06 kg/m^3** Shear modulus: **3.189e+08 N/m^2**
	**Entities: 1 face(s)** **Type: Fixed Geometry**
	**Entities: 1 face(s)** **Type: Apply normal force** **Value: 7,000 N**

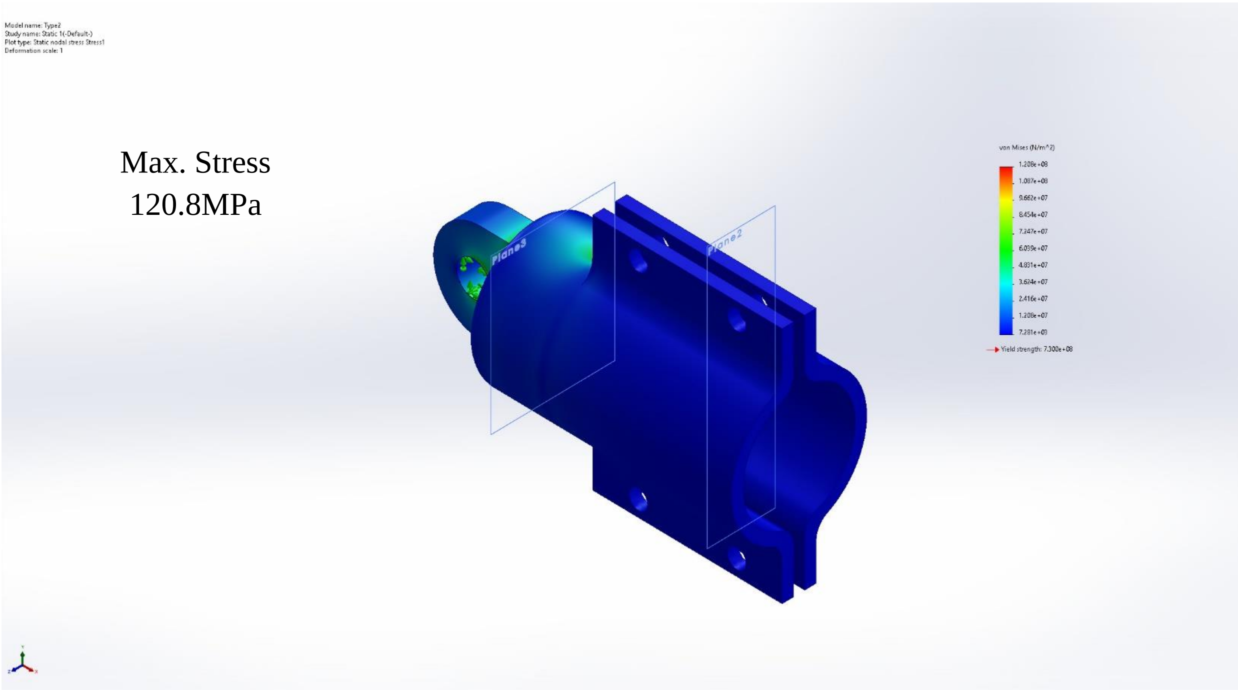


Figure 7: 1st Unit - Stress Result

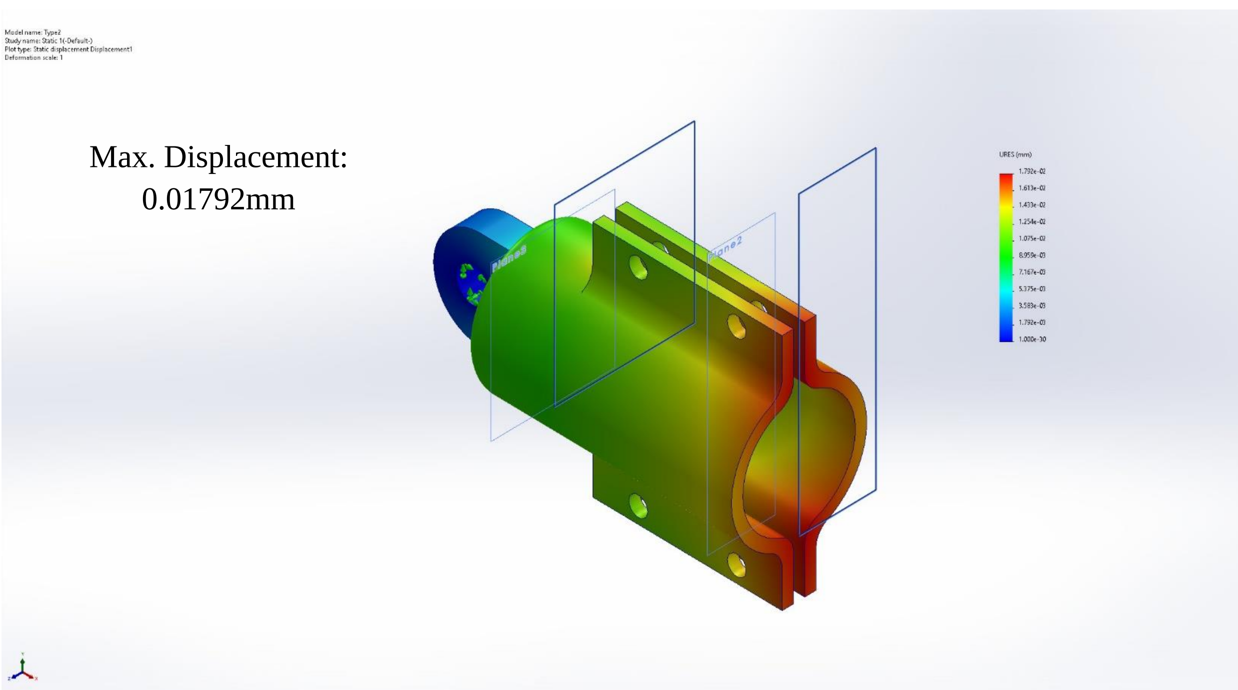
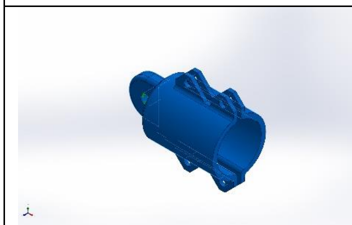
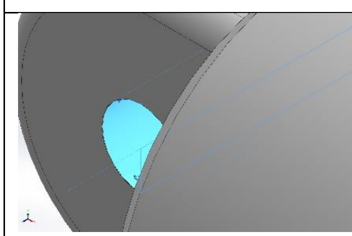
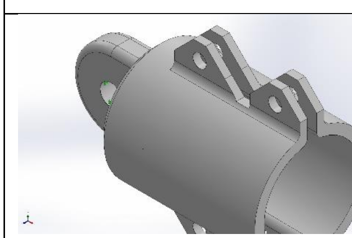


Figure 8: 1st Unit - Displacement Result

In the first iteration, we found out this design is more than enough for our application, so we decide to reduce the thickness, total length and try to reduce the overall weight of the joint

Table 2: Modified Unit Material Properties and Constraints [4]

Model Reference	Properties
	Name: **TI64(3DP)** Model type: **Linear Elastic Isotropic** Yield strength: **7.3e+08 N/m^2** Tensile strength: **8.45e+08 N/m^2** Elastic modulus: **1.048e+11 N/m^2** Poisson's ratio: **0.31** Mass density: **4,318.06 kg/m^3** Shear modulus: **3.189e+08 N/m^2**
	**Entities: 1 face(s)** **Type: Fixed Geometry**
	**Entities: 1 face(s)** **Type: Apply normal force** **Value: 7,000 N**

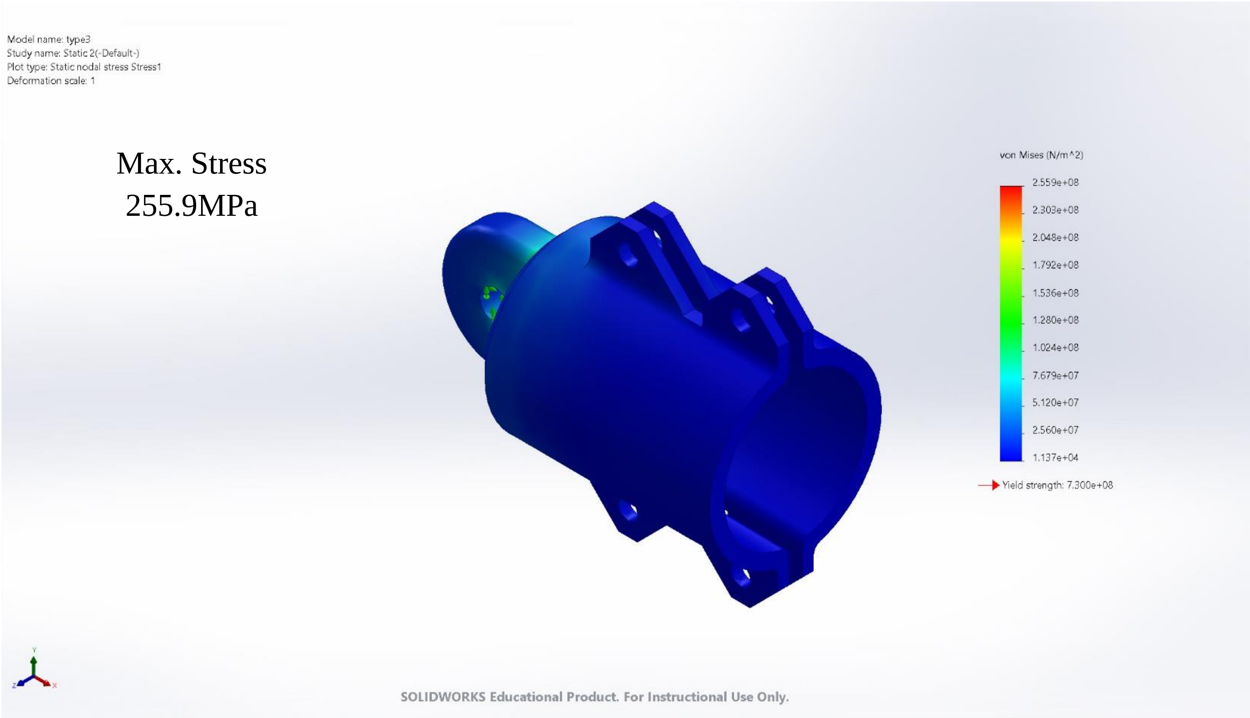


Figure 9: Modified Unit - Stress Result

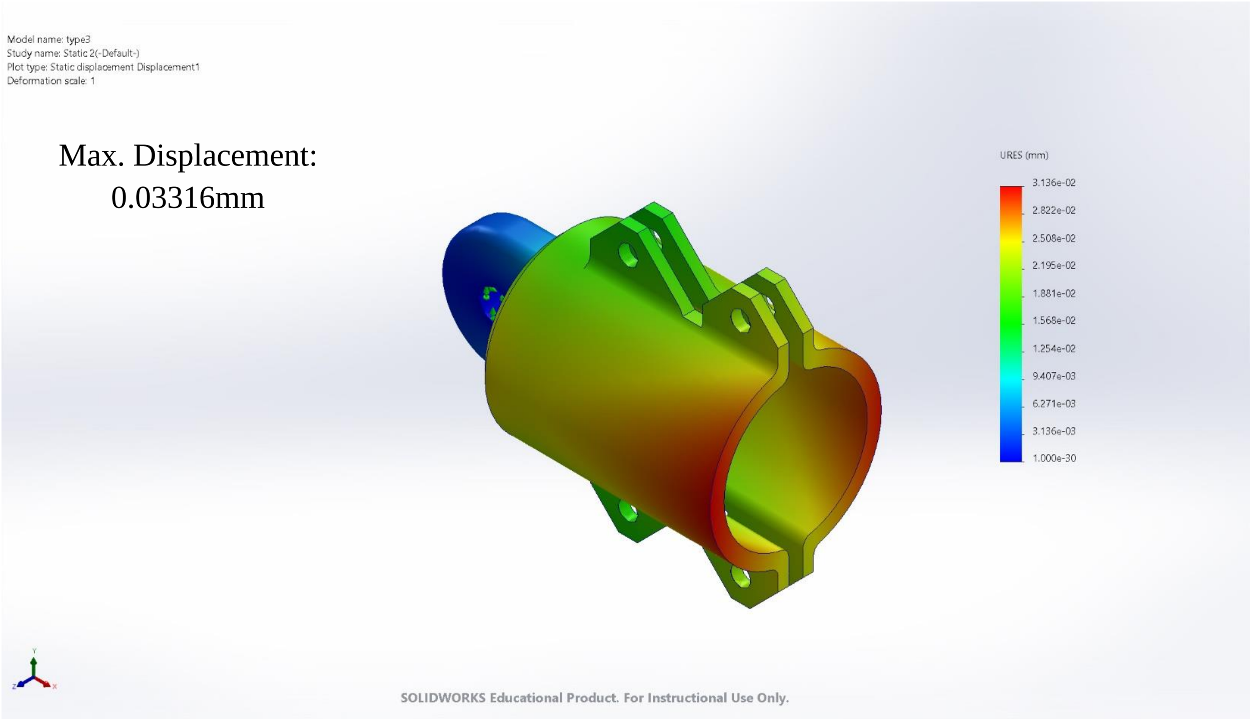


Figure 10: Modified Unit - Displacement Result

3.3.1 Comparison Between Expected and Actual Results

Table 3: Comparison Between Expected and Actual Result

		Expected Result	Actual Result
1	Strength	> 580 MPa	780 MPa
2	Diameter of The Tube to be Join	1/2", 5/8"	1/2”
3	Max Speed	45 Km/h	Safe to Impact Loading
4	Weight of Vehicle	300 Kg	Safe to Direct Loading
5	Recommended Weight of Vehicle	100 Kg	Safe to Direct Loading
6	Maximum No of tubes at joint	< 8	Not done
7	Corrosion Resistance	✓	✓
8	Fit	Transition	Not done

3.4 Bill of Material

Table 4: Bill of Material

Item	Quantity	Cost per unit	Total cost	Links
Titanium (140 g)	140g	$1.00/g	140.00 USD = 193.63 CAD	
M5 Nuts	4	$0.625 each	$2.50	https://www.homedepot.com/p/5-mm-0-8-Stainless-Steel-Metric-Hex-Nut-2-per-Pack-801008/204274112
M5 Bolts	4	$1.25 each	$5.00	https://www.homedepot.com/p/Everbilt-M5-0-8-x-40-mm-Class-8-8-Zinc-Plated-Hex-Bolt-801408/204273659
M8 Nuts	1	$0.625 each	$0.625	https://www.homedepot.com/p/Everbilt-M8-1-25-Stainless-Steel-Metric-Hex-Nut-2-Piece-per-Bag-842328/204836106

M8 Bots	1	$2.75 each	$2.75	https://www.homedepot.com/p/M8-1-25-x-40-mm-Class-8-8-Zinc-Plated-Hex-Bolt-801698/204273588
Total Cost			$204.505	

4 Project Plan

Below is the updated project plan.

	Name	Assignee	Status	Start date	Due date
1	Modular Ultralight eV Prototyping - A		New	11/01/2023	18/04/2023
2	1. Initiation				
3	Team Contract	Anuj Shah	Completed	11/01/2023	20/01/2023
4	2. Planning				
5	2.1Setting up Project and Goals	Sina Ghazali	Completed	24/01/2023	26/01/2023
6	2.2Budget	Tony Tsang	Completed	24/01/2023	26/02/2023
7	2.3Communication Plan	Vishwadath Ayyappan	Completed	20/01/2023	23/01/2023
8	2.4Risk Management plan	Anuj Shah	Completed	24/01/2023	27/01/2023
9	2.5Project Plan(PD A)	Sina Ghazali	Completed	13/01/2023	19/01/2023
10	3.Execution				
11	3.3PD B	Tony Tsang	Completed	24/01/2023	30/01/2023
15	3.5 PD C	Sina Ghazali	Completed	08/02/2023	16/02/2023
19	3.6 PD D	Anuj Shah	Completed		
20	3.6.1 Detailed design	Tony Tsang	Completed	17/02/2023	27/02/2023
21	CAD Drawing	Anuj Shah, Tony Tsang	Completed	20/02/2023	24/02/2023
22	Draft	Sina Ghazali, Tony Tsang, Anuj Shah, ...	Completed	17/02/2023	20/02/2023
23	Simulation	Tony Tsang, Anuj Shah	Completed	24/02/2023	27/02/2023
24	3.6.2 Prototype 1	Anuj Shah, Sina Ghazali, Tony Tsang, ...	Completed		
25	With Features				
26	Non Permanent	Anuj Shah, Sina Ghazali	Completed	01/03/2023	04/03/2023
	Permanent	Tony Tsang, Vishwadath Ayyappan	Cancelled	01/03/2023	04/03/2023
28	Without Features				
29	Non Permanent	Tony Tsang, Vishwadath Ayyappan	Completed	28/02/2023	02/03/2023
30	Permanent	Anuj Shah, Sina Ghazali	Cancelled	28/02/2023	03/03/2023
31	FDM Printer	Vishwadath Ayyappan, Anuj Shah, To...	Completed		07/03/2023
32	3.6.3 Testing and simulation	Tony Tsang	In Progress	06/03/2023	09/03/2023
33	3.6.4 BOM	Sina Ghazali, Vishwadath Ayyappan	Completed	27/02/2023	06/03/2023
34	3.7 Client meet 3	Anuj Shah	New	08/03/2023	10/03/2023
35	3.8 PD E	Anuj Shah	New	13/03/2023	22/03/2023
39	3.1 PD A:Client Meeting Preparation	Anuj Shah	Completed	16/01/2023	18/01/2023
40	3.2Client Meet1	Vishwadath Ayyappan	Completed	24/01/2023	24/01/2023
41	3.4 Client meet 2	Anuj Shah	Completed	16/02/2023	16/02/2023
42	3.9 PD F: Final Project Presentation	Tony Tsang, Anuj Shah	New		29/03/2023
43	Design Day	Sina Ghazali, Vishwadath Ayyappan	New		03/04/2023
44	4.Monitoring and Control				
45	4.1 Project objectives	Tony Tsang	New		
46	4.2 Quality of deliverables	Vishwadath Ayyappan	New		
47	4.3 Project performance and cost	Anuj Shah	New		
48	4.4 Schedule status	Sina Ghazali	New		
49	5.Closing				
50	5.1 PD H: Video and user manual	Sina Ghazali, Tony Tsang, Anuj Shah, ...	New	04/04/2023	18/04/2023
	Total: 33 tasks				

5 Conclusion and Recommendations

The report provides the details about the initial prototype and the simulation results of the same.

The following conclusion and recommendation are drawn from the results,

1. The design is given safety which more than enough, so, there is a room for the improvement in the design.
2. The quality of the 3D printing depends on the design of the model as well as on the parameters of printing.
3. Using FDM 3D printing for the initial prototyping will result in reduction in the overall cost.
4. While using 3D printing carefully set the parameters of the printing otherwise it will be the waste of time and money.
5. While performing the simulation is important that input the correct and logical values, which inline with the actual system.
6. We need to measure the printed parts carefully to accommodate the tolerances of design and the actual parts.

6 Bibliography

[1] "jinjiuyi.net," JINJIUYI, 29 10 2022. [Online]. Available: https://www.jinjiuyi.net/news/carbon-fiber-tube-advantages-disadvantages-applications.html#:~:text=The%20density%20of%20carbon%20fiber%20tube%20produced%20and%20processed%20is,2..

[2] T. Gerhard and C. Friedrich, "Mechanical fastening of carbon composite tubes, numerical calculation of axial loading capacity and experimental verification," *ELSEVIER*, no. 67, pp. 391-399, 2014.

[3] "clearwatercomposites.com," CLEARWATER COMPOSITES, [Online]. Available: https://www.clearwatercomposites.com/products/carbon-fiber-tubes/round/std-mod-round/?filter_nominal-od-range=1-000-1-999.

[4] "Desktop Metal," [Online]. Available: https://www.desktopmetal.com/uploads/BMD-MDS-Ti64-210803.

7 Appendix

Direct loading

Weight 300Kg

Gravity take 10

And we take half as a safety measure.

$$F_{direct} = mg$$

$$m = 300 \text{ kg}$$

$$g = 10\ ms^2$$

$$F_{direct} = \frac{300\ \times 10}{2}$$

$$F_{direct} = 1{,}500\ N$$

Direct loading

Impact

45km/h- to 5 km/h in to sec

Weight is 300 including driver

$$F_{impact} = m\frac{v-u}{t}$$

$$m = 300kg$$

$$v = 45km/h$$

$$u = 10km/h$$

$$t = 2s$$

$$F_{impact} = 300\frac{45-10}{2}$$

$$F_{impact} = 5250N$$

$$F_{total} = F_{direct} + F_{impact}$$

$$F_{total} = 6750N \approx 7000N$$