APSC 103
Phase 3: Project Proposal

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"We do hereby verify that this written report is our own individual work and contains our own original ideas, concepts, and designs. No portion of this report has been copied in whole or in part from another source, with the possible exception of properly referenced material."

02/19/202

Executive Summary

The Queens Racing Formula SAE team has expressed interest in updating their current subframe. The current vehicle employs a one-piece steel subframe to fortify its components. While effective, this system adds unneeded weight to the car, effectively reducing the car's performance. To address the issue, the team has set forth plans to develop a detachable lightweight subframe that will lighten the load of the car while providing support for the powertrain package, rear suspension, and rear wing.

To fulfill such intentions the team has developed a variety of solutions. Each of which will be meticulously tested and analyzed to ensure the final proposal integrates seamlessly with the car and meets the outlined requirements. The first features a trapezoidal design, supported by two parallel trusses to provide additional support. The use of trusses and multiple mounting points makes it the most structurally sound option; however, weight is sacrificed in order to do so. The second shares similar attributes to the first but takes a more rectangular shape. This design also features a truss system that extends up into the second mounting point providing more structure to the subframe. This design is an improvement on the first in terms of size, however, due to the nature of the design the manufacturing process will be far more tedious. Lastly, a less structurally supportive prototype was developed which reduced the mass of the subframe substantially. This frame takes a congruent trapezoidal shape enlisting structural stability without sacrificing mass. To validate the feasibility of each subframe design, the team has also employed a detailed computer-aided design (CAD) model for each with the intention of conducting finite element analysis (FEA)-guided simulations. These simulations will provide a deeper analysis of the performance of the subframe under a variety of conditions, providing insight into potential improvements within the prototype to ensure the final product is as effective as possible.

In addition, to demonstrating feasibility, the team will provide a cost, mass, and safety analysis of the prototype, along with insight into the scheduled manufacturing process to ensure that the final prototype matches the outlined constraints and expectations for the project in a cost-effective and efficient manner.

Table of Contents

List of Tables and Figures

Section 1: Problem Definition and Scope

The Queens Racing Team is an established member of the Formula SAE series with a focus on designing, manufacturing, and competing with open-wheel cars [1]. The vehicle features a steel frame to reinforce each of the pieces within the vehicle. However, excess steel contributes to the weight of the vehicle which has ramifications for its performance. In hopes of improving the acceleration and control of the vehicle, a detachable subframe must be designed to reduce weight while providing mounting points for the powertrain package, rear suspension, and rear wing. To demonstrate the feasibility of the product, detailed CAD models and subsequent FEA-guided simulations are required. Additionally, the cost, mass, and a brief description of the manufacturing processes must be provided to ensure it meets the outlined constraints.

Stakeholders

Relevant stakeholders in the design and decision-making process include the client, being the Formula SAE Team, the sponsors for the team, as well as other teams involved in the Formula SAE team. The client poses the greatest influence in the design process as they determine the constraints, functional requirements, and attributes of the rear subframe. The design of the rear subframe must adhere to these factors. The team must also ensure that the client is consulted regularly to influence the decision-making for the design of the rear subframe. The client, members of other design teams, as well as the drivers must be consulted to ensure the rear subframe follows the preconceived expectations for performance and safety. Conflicts may arise in the decision-making process if different members of the team have opposing needs for the rear subframe. Furthermore, the sponsors of the Formula SAE Team are considered stakeholders for the project as they make Queen's Racing possible. Although they are not concerned with the rear subframe's design, they are concerned with the overall performance of the car. Additionally, competing teams will have a stake in the performance of Queens Racing, as a lighter car will increase speed, leading to greater competition. The closer the racing, the more teams will push each other to innovate and improve their designs.

Constraints

The project is constrained by many key considerations. The subframe must be easily manufactured, durable, cost effective, and adhere to the pre-existing mounting points on the chassis. For the design to be realistic, it needs to be manufacturable by Queen's students. The design can incorporate uses of CNC milling, waterjet cutting, welding, and drilling. The manufacturing of the subframe must be limited to these methods. The rear subframe will also be connected to the rest of the chassis at specific points and must adhere to that limitation. The subframe must feature a mounting point for the rear wing, powertrain package, and rear suspension. Teams are also judged based on the cost of the car, so the rear subframe must be cost effective while still being durable enough to participate in all events during the competition calendar. Finally, it must be lighter than the current subframe which is 29.6kg.

Functional Requirements and Attributes

The Queen's Formula SAE team is interested in an updated rear subframe design for the current iteration of the vehicle. To meet the client's needs the subframe must:

- be detachable from the rest of the frame.
- provide mounting points for the engine, powertrain, and suspension.
- display high stiffness and demonstrate a moment force less than 5N and a shear force less than 25 N through Torsional Rigidity testing [12].
- have minimal manufacturing cost compared to other options.
- have a lower mass then the current subframe.
- a factor of safety of 2 or greater.

Scope

To ensure a quality solution to the problem, while also adhering to the time and resource restrictions, the team determined a project scope. This consists of creating a CAD model of the rear subframe, a list of materials, performing a cost breakdown, providing instructions on assembly, discussing safety, and if resources allow, using Finite Element Analysis (FEA) on the rear subframe. This scope ensures the team will be challenged in producing a feasible solution to the rear subframe with the necessary information to manufacture it. The scope could be expanded to include a prototype of the rear subframe, but this surpasses the skill level of the team and time constraints. It would also provide a safety risk to the team members, as the assembly methods can be dangerous to those who are not properly trained. Within the project scope, the team will not be able to address sustainability factors such as the carbon footprint related with obtaining materials and manufacturing the rear subframe.

Section 2: Information Summary

To centralize and condense the information gathered in the previous phase an information summary is necessary. First focusing on the materials and properties that are important in the creation of the rear subframe design. The research yielded 2 materials that out preformed the others: 4130 Steel and 6061 Aluminum. Docol Tube R8 was also considered although little quantitative data was available. In terms of the properties of the 2 materials; strength, weight, durability, cost, usability, and safety all must be considered. The tensile strength of 4130 Steel being 440 to 980 MPa that being larger than 6061 Aluminum which spans between 76 to 370 MPa. The Fatigue Strength of the steel is between 320 and 660 MPa whilst the aluminum's strength is between 58 to 110 MPa. The Shear Strength of the steel is from 340 to 640 MPa, and between 84 to 210 MPa for the aluminum. The 4130 Steel is denser having a density of 7.8 g/cm^3 compared to the 6061 Aluminums 2.7 g/cm^3 [6]. With 6061 Aluminum having a significantly lower weight the benefits should be mentioned. For an internal combustion engine vehicle, a reduced weight of 100 kg lowered the fuel consumption by 0.3-0.5 L/100 km. This being 6-8% less fuel used before the weight reduction [7]. For durability, maximum mechanical temperature can be considered; with the steel having a max at 420 °C and the aluminum's max being at 170 °C [6]. The cost of 6061 Aluminum is notably more expensive than the 4130 Steel [15]. To understand the safety of the designs methods such as Von Messes Stress, finite element analysis, displacement analysis, and a factor of safety calculation can be performed [8]. For safety, a recommended tubing size for steel from the

FSAR Rules is a cross-sectional area of 91 mm, diameter of 25 mm, and a wall thickness of 1.2 mm. Whereas for aluminum the rules recommend a minimum wall thickness of 1.2 to 2 mm [11].

The next portion of the information summary revolves around evaluating the shape and structure of the proposed designs. A scholarly journal focuses on assessing trapezoids and square prisms comparing them with their cracking load, P_{cr}; deflection at cracking, Δ_{cr}; maximum deflection,Δ_u ; cracking torque,T_{cr}; twist at cracking, ρ_{cr}; ultimate torque, T_u; and maximum twist, ρ_u [3].

Table 1: Evaluation of principal tests on different shapes; B-23 being a square prism and B-06 a trapezoidal prism.`

Specimens	P_{cr}, kN	Δ_{cr}, mm	P_u, kN	Δ_u, mm	T_{cr}, kN.m	φ_{cr}, rad	T_u, kN.m	φ_u, rad
B-23	60	6.85	149	35.77	100.20	0.001	248.83	0.058
B-06	27	1.14	193	58.81	45.09	0.001	322.31	0.107
B-16	15	2.52	214	64.55	25.05	0.001	357.38	0.149
B-17	39	0.77	155	36.49	65.13	0.005	258.85	0.198
B-18	47	0.80	198	36.99	78.49	0.002	330.66	0.203
B-19	45	0.39	171	44.32	75.15	0.002	285.57	0.201

As made evident through the table the trapezoidal prism possesses stronger resistance to the listed forces in comparison to the square prism.

Section 3: Conceptual Designs

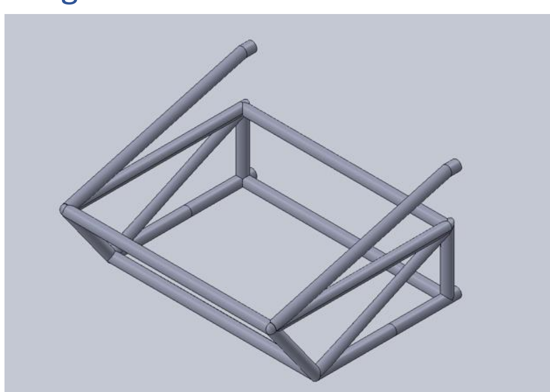

Figure 1: Option one, a trapezoidal design with cross bracing and a support bar to connect the frame to the rear subframe.

Design one is a trapezoid shaped design, with cross bracing across two parallel opposite sides for extra support. This design is made of steel tubing with aluminum tubing used on the cross bracing. The aluminum was chosen to help reduce weight as it's lighter. The steel being used in all three designs is 4130 steel tubing which is the same material that is being used in the rest of the frame. This can help reduce the cost of the rear subframe as they can reuse pieces that aren't being used and order a larger amount of tubing in bulk. As mentioned in the Information Summary, this steel is strong enough for the requirements of the rear subframe. The fact that it is used in the other parts of the frame is an added level of reassurance that it is strong enough for our purposes as it has been used by Queen's Racing before. The aluminum being used in this design is used minimally, as aluminum is more expensive than the steel tubing. It is also harder to work with and weld compared to the steel, hence why it was used in fewer places. While it’s not a primary concern, ease of manufacturability is still important in the design of the rear subframe. Of all the three designs, this design is the hardest to manufacture because of the amount of material and different materials. There are two more pieces of tubing connecting the far corners of the rear subframe to the rest of the frame. This design uses the most material out of the three designs so will be the heaviest but will also be the most secure.

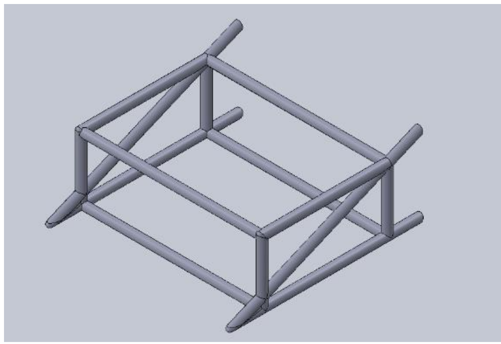

Figure 2: Option two, a rectangular design with a cross brace going through two sides, connecting the rear subframe to the frame.

The next design is like the first in many ways, however rather than having one slanted side all four sides create a rectangle. It again has cross bracing across two of the sides however the cross bracing extends through both corners it connects to. One corner is a connection point to the rest of the frame, and the other extends to the base, and extends slightly, making the base a little longer. The sides with the diagonal supports will be the same sides as the suspension mounting points, to help carry that load. As with the first design it will be made of steel tubing, however this time it will be the entire prototype. This model is in the middle of the two other designs, as it uses more material that the third design, but less than the first. It has a cross brace like the first design but is made with all steel like the third design. Because of the angle of the where the cross brace meets the base, this design is the hardest to manufacture out of all three designs. Also, having the cross brace go through both corners of the rectangle make it harder to manufacture and help distribute loads at the same time. It lies in the middle of the two other designs when it comes to safety too, as it has cross bracing, however the connection point to the rest of the frame is on that same bar, so it carries more load compared to the cross brace of option one.

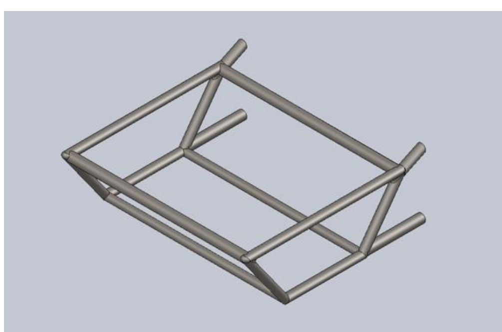

Figure 3: Option three, a trapezoidal design with no cross bracing, made entirely of steel tubing.

The final design is the simplest, as a trapezoid like the second design, but with two slanted sides rather than just one. The biggest difference between this one and the other designs is that it has no cross bracing, so it has the least support but also the least amount of material, so it will be the lightest. This is the biggest factor when comparing this design to the others. Safety is the primary concern for this project as someone will be operating the car and others will be racing against it, so we must ensure it abides by all the proper safety regulations. We do not know how much safer or less safe this design is compared to the others as minimal testing and evaluation has been done on any of the designs. This means the team must make an estimate on whether we think this design is safe enough until the Finite Element Analysis and all testing has been done. After all testing has been done, thew necessary changes will be made to the chosen design to ensure safety. The entire subframe will be made of 4301 steel tubing, as is being proposed in the rest of the designs.

Section 4: Decision Making

To decide the most effective option for the use case the team has evaluated each of the 3 design concepts based on weight, safety, cost, and ease of manufacturability.

The first design is a very safe and viable option. Due to the additional support provided by the internal trusses of the structure and the use of the strong material in a trapezoidal silhouette this concept has a high safety rating. Subsequently, the design suffers in terms of cost and weight due to the additional material used. This option weighs in at around 12kg, which is significant and does not improve upon the current option. The second shares similar prospects, although sacrificing more strength and therefore safety for less material. Thus, resulting in lighter weight and more cost-effective solution. This option has a mass of 11kg, cutting down nearly a full kg from the previous design. Despite the improvements in terms of weight and cost, due to the importance of safety the team decided against the solution as the improvements did not outweigh the risks. Option 3 is the lightest solution with a mass of only 7.7kg. This is nearly half the mass of the original design. In order to do this, the design makes sacrifices in terms of safety, but even with the high weighting localized to the safety criteria, the benefits in performance, and cost surpassed the risk, and despite being theoretically less safe that the other 2 options the subframe will be an improvement on the previous subframe and should satisfy the requirements set out within the project scope. The official weighted matrix utilized during the design process is located below in Table 2. Each set of factors have a corresponding weighting which was decided upon by the group based on the importance of the factor. Then each of the options were evaluated to determine the best design.

Table 2: Weighted Evaluation Matrix of the 3 Proposed Designs

Criteria	Weighting	Option One	Option Two	Option Three
Weight	0.3	2	3	4
Safety	0.4	5	4	3
Cost	0.15	2	3	4
Ease of Manufacturability	0.15	3	2	4

Total	1	3.35	3.25	3.6

The results concluded that option 3 was the best option for the project. Option three is the lightest as it has the least amount of material with option one being the heaviest because of the amount of material. Subsequently option 3 will be the most cost-effective option due to the materials being used. Option 3 utilizes solely steel tubing, whereas the other 2 options feature aluminium alloys, and trusses as supports which are significantly more expensive. Additionally, option 3 is the easiest to manufacture. Option three has the least amount of material and is made up entirely of steel making for a straightforward construction process. Whereas Option one and two utilize more material and are partly made of aluminum which is more difficult to weld and construct the prototype with. After contrasting each option with the criteria option three scored the best with a total score of 3.6, and performed best in all the categories but safety, where it was the worst with a score of 3. Option one was second best with a score of 3.35, where it was worst in weight and cost, but best in safety with a score of 5. Option two was the worst of the three options, as it was the worst in ease of manufacturability, and was average in all the other categories. As a result, option 3 is the best design.

Section 5: Design Proposal

5.2 Proposed Design

The final design developed for the detachable subframe for the Queens Racing Team's open-wheel car consists of a trapezoidal prism with two slanted sides, and no cross-bracing (trusses). The design will be made of lightweight and durable 4130 steel tubing, to provide sufficient support to counter forces that the subframe may encounter. The design can be seen in Figure [4].

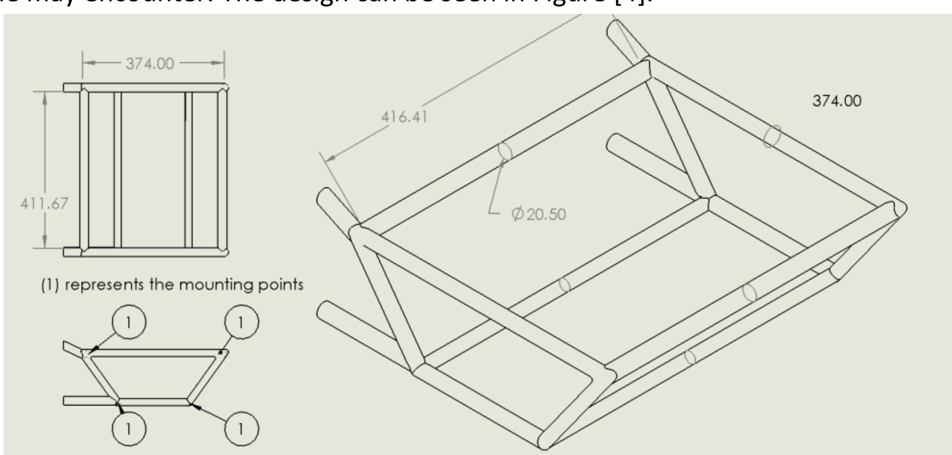

Figure 4:Cad drawing of the final design with dimensions

Due to the structural characteristics of the trapezoidal prism it serves as a very strong catalyst for the rear subframe. Due to the wide top and narrow base of the shape any forces acting on the tubing will be distributed throughout the structure reducing the stress experience on each point. [2] Additionally, the tapered sides provide strength to resist torsional forces experienced by the subframe. The nature of the shape allows for a larger moment of inertia, when contrasted to other shapes such as rectangles, with

the same perimeter, which provide greater resistance to rotational forces which the subframe will encounter. [3]
The design is made of 4130 steel tubing, which is a relatively lightweight and durable material that can effectively resist forces that the subframe may encounter during use. The subframe's primary function is to support the powertrain package, rear suspension, and rear wing, which can experience forces such as bending and torsion. The symmetrical configuration, higher tensile strength, and high modulus of elasticity lend 4130 steel tubing to counter all torsional and bending forces applied to the trapezoidal silhouette. [4] Furthermore, 4130 steel tubing is a cost effective at roughly $10.50/ft of 4130 steel tubing [15] and relatively lightweight solution with a mass of only 7.7kg.
The location of the mounting points has been mapped in figure [4]. The mounting points for the rear suspension will remain in the same locations and enlist the same mounting method to ensure the integration of the part is as smooth as possible for all stakeholders. However, the mounting points to the rest of the frame must be re-designed, as currently it is welded - not detachable. A set of removable frame bungs inspired by the Suspension Solutions Design Team at California Polytechnic State University will be used to allow for seamless removal of the rear subframe. [5] The conceptual frame bungs have been modeled using CAD and are depicted in figure [5].

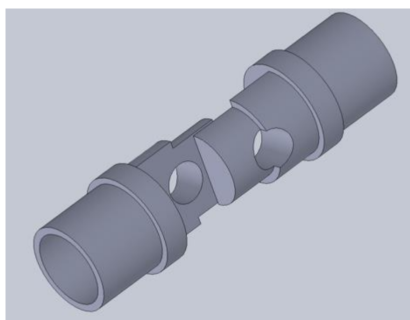

Figure 5: Cad model of removable frame bungs

5.2 Project Costs and Manufacturing Requirements

The scope of the project suggests that no prototype needs to be developed but rather a CAD design rear subframe, along with a cost analysis and finite element analysis must be conducted to ensure the solution meets the outlined problem set. As a result, the project presented requires no additional funding. Should the project require an additional prototype the manufacturing process involves CNC machining and laser cutting, which is a precise and efficient process that ensures that the final product meets the design specifications. Additionally, access to welding devices are required as well as methods to produce parts required for the final submission. The required parts are outline within the bill of material in table 3 below.

Table 3: Bill of Materials

4130 STEEL TUBING	**LASER CUTTING MACHINE**	• **SOLID WORKS LICENSE**
8X BUNGS	**CNC MACHINE**	• **COMPUTERS**

5.3 Societal Cost and Benefits

This project has significant impacts on society, both positively and negatively. On a small scale, by reducing the weight of this car, the Queens Formula team will see better performance while becoming more fuel efficient. In the grand scheme, the significant performance improvement displayed by the Queens Racing car will inspire others to do the same, thus having a much larger impact on the carbon emissions produced in the sport. On the contrary, there are many costs which coincide with the project. These costs include matter waste from old frames, carbon and material emissions during the manufacturing process of the new subframe, as well as the energy and technology which is used during the design stages of the project.

Section 6: Modeling, Analysis, Testing and Evaluation

All modeling, analysis, and testing of the rear subframe will be performed in Solidworks. The success of the design will be tested through multiple simulations: Torsional Rigidity, Von Mises Stress, and Factor of Safety. These simulations will determine if the requirements outlined in section 1 are met, and if further iterations of the design are required. An evaluation rubric is provided in Appendix I: Testing and Simulation Evaluation Rubric

Table 4 in appendix I. The rubric grades the results from each test on a scale from 0-3. The scoring works as follows:

3 - The subframe testing surpassed the required values and no iterations are necessary. Depending on the test, the determining values in the rubric may be unrealistic.

2- The subframe testing met the required values. No iterations are required, but depending on the values, iterations would improve the design.

1- The subframe testing was on the threshold of required values. Iterations are required to create a more feasible design.

0- The subframe testing did not meet required values. Major iterations are required to create functional design.

Explanations for the values that determine the scores are discussed in each test summary below.

6.1 Torsional Rigidity

Torsional rigidity is an object's resistance to twisting when a torque is applies to a component and is dependent on the geometry of the object. As the torsional rigidity increases, the torque required to twist the component increases [10]. Torsional rigidity is one of the most important tests to perform on a chassis [12].

To perform this simulation, the rear suspension connection points will be selected and translations in the x and y direction will be prohibited while rotational movements will be allowed. A force of 300N will be applied to the chassis in opposite directions to simulate torsion, as well as self-gravity will be applied to account for the weight of the chassis. This simulation will provide a stress and displacement analysis which will present the moment and shear forces each beam is experiencing. The moment must be less than 5Nm and the shear less than 25N [12].

6.2 Von Mises Stress

The Von Mises Stress Theory states that a material will yield when the Von Mises Stress becomes equal to the stress limit. At this point, the material stops behaving elastically and begins to show plastic behaviour [13]. The Von Mises Stress increases when the principal stresses have a greater difference [13]. As it is crucial that the subframe maintains its shape, this analysis will provide valuable information on what forces the subframe can withstand before surpassed the stress limit.

To perform this analysis, The connection points will be fixed, and a force will be applied to the subframe. This analysis will provide values of the Von Mises Stress at different points along the beams of the subframe. These values will be compared to the known yield strength of 4130 steel (435 MPa [6]) to determine if the stress is within the safe range. Since the possible forces acting on the subframe are not known, the subframe will be tested until failure to determine the maximum force.

6.3 Factor of Safety

Factor of Safety (FoS) refers to the load capacity of a design or the required margin of safety for a component. A FoS of 1 indicates that the component will fail when the design load is reached. A FoS of 2 indicates that the components will fail at double the design load, and a factor of safety less than one is not viable [14].

After the Von Mises Stress analysis is performed, and the maximum force is found, a Factor of Safety plot will be added to the simulation. The plot will highlight areas on the frame with the appropriate FoS value. The areas of concern will be where the FoS value is less than or equal to one. Other values are acceptable but the possible additional loading in those areas must be considered to determine if the FoS value is acceptable.

Section 7: Project Plan

Both the Table 5: Work Break down structure and Figure 6Figure 6: Gantt Chart for proposed timeline to the end of the year can be found in Appendix II: Project Plan where tasks and a timeline are given. Potential risks and how to mitigate them will be discussed here and not within Appendix II: Project Plan.

There are several risks involved with multiple tasks, which will affect everything as the timeline is all connected. Finite element analysis, FEA, poses the largest threat at disturbing the progress of the plan. Due it being not only CPU and GPU extensive, but also being a lengthy process that must be learned. To prepare to combat any issues that may arise with FEA all members will learn how to use FEA from tutorials from Dassault Systemes and look for any alternatives outside of Solidworks. Multiple computers will be found that can preform the FEA in case issues present themselves. The FEA will be done far in advance giving time to resolve issues and allow other tasks to begin well before they need to be completed.

Another possible issue revolves around the connection between the mass analysis, cost analysis, and assembly process. For each subsequent task, the previous one must be completed. It will be made imperative that the mass analysis is completed in a manner that allows the cost analysis to be finished in advance for the assembly process. If this is not done properly the 3 tasks have the potential to be rushed or not done in time. To prevent this communication and consideration between all members will be made even more important.

The last issue focuses on any changes that may need to be made to the final design if failing the structural or safety tests. Currently, the design chosen is the lightest; clearly this will increase the risk of failing the tests. Although this can easily be combatted by using cross bracing or increasing the thickness of tubing if needed. In contrast, if the designs exceed the requirements to pass the tests parts will be looked to be changed to 6061 aluminum to reduce the weight. If any changes are made revised cost analysis, mass analysis, assembly processes, FEA, and safety and structural tests will be needed. Due to this, the evaluation of the solution will be done within a timeframe allowing for any revisions that must be done.

Section 8: Team Contract and Organization

Communication and Attendance

1.1 All team members must attend all meetings on time where their attendance is expected. Some of these exemptions include sickness, injury, significant personal and familial matters.
1.2 The assumed meeting times will be every Tuesday between 11:30 a.m. to 1:30 p.m. and every Wednesday between 12:30 p.m. and 2:30 p.m. This is subject to change depending on the weekly circumstances.
1.3 If a team member cannot attend a meeting, it is their duty to inform the team a reasonable time ahead of the meeting, preferred if 24 or more hours before any meeting. Repercussions that will result from a failure to meet this condition will be decided and agreed upon by all team members.
1.4 If a team member cannot attend a meeting for a reason that does not fall in line with the aforementioned exemptions, refer to 1.1, the member is required to provide reason and an understandable explanation as to why they are unable to be present.
1.5 Members should respond to messages regarding any assignments within the APSC 103 curriculum.

Individual Member Responsibilities

2.1 Each member has the duty to complete the required work assigned to them, with consideration for the member’s time personal life or time restrictions, within a reasonable time frame before the due date allowing the team time to review and edit.
2.2 Team members are expected to work to the best of their ability.
2.3 Team members are expected to give assistance to other members if needed and justified.

2.4 Failure to repeatedly not complete the given work, or failure to reach the set standards will cause consequences as decided upon by the team. The consequences will be unanimous and must be fair through the understanding of the given situation.

Team Acknowledgements

3.1 All team members are expected to treat one another, and others involved with the project in a respectful manner with consideration for others' culture, identity, ethnicity, or orientation, as legislated by the Ontario Human Rights Commission.
3.2 All members are expected to attempt to give an equal amount of input and time to the project.
3.3 All members of the team are expected to evaluate one another with fairness and honesty in any team and individual evaluation surveys.
3.4 All team members acknowledge the expectation that they complete their work in a timely manner well before the due dates for Phase 1, Phase 2, Phase 3, and Phase 4.

By signing, you agree to follow the terms listed within the contract. A Failure to work inside the parameters of the contract can and will result in consequences.

Signed by: Cameron Dawson Tyler Dhanpaul Kate Vanderlaan Isabel Vranesic Joshua Westlake

Section 9: Conclusion

The trapezoidal design was chosen as in the evaluation matrix it scored the best and met the requirements of the project in the most ideal way. As the goal of the project is to make the rear subframe as light as possible, this design was by far the best. This concept utilizes the least amount of material but remain a very safe option. The final design chosen is not too dissimilar to the current subframe, where there is no cross bracing. If after all the testing and simulations on SolidWorks prove the rear subframe requires extra reinforcement, the team will add more bracing to ensure it is safe for the driver. The testing on the chosen design will be a torsional rigidity test where the only movement allowed is rotation and a Von Mises stress test to test the forces the frame can withstand while holding it’s shape. A factor of safety test will be done to test how safe the rear subframe is. This is the most important one, as the driver must be safe with the final design. This is the biggest disadvantage compared to the other designs as it is the least safe option, however this can be changed in the future. The biggest advantage to this design is that it is the lightest and easiest to manufacture. For this design, the cost of any design is not a consideration, as Queen’s Racing already has all the materials to build the final design, and the group is not building a model of the design. Because the material used in the final design is the same as that in the rest of the frame, Queen’s Racing already has the correct steel tubing from other projects. This means there is no cost of materials, shipping and taxes, and the team has been informed that there are no labour costs.

References

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[3] M. M. MohamedSalih and A. R. Yousif, "Experimental study on torsional behavior of thin- and thick-walled RC box-girders using BFRP bars and steel stirrups under combined torsion-shear-moment," *Structures*, vol. 36, pp. 549–564, 2022. [Accessed: 19-Feb-2023]

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Appendix I: Testing and Simulation Evaluation Rubric

Table 4: Evaluation Rubric for Testing and Simulations

	Score			
Test	**3**	**2**	**1**	**0**
Torsional Rigidity	No moment or shear force experienced by the subframe	Moment less that 5Nm and shear less than 25N	Moment equal to 5N and/or shear equal to 25N	Moment greater than 5N and shear greater than 25N
Von Mises	Significantly less than 435 MPa. (335 Mpa)	Less than 435 MPa	Equal to 435 MPa	Greater than 435 MPa
Factor of Safety	Greater than 10	Greater than 2	Equal to 1	Less than 1

Appendix II: Project Plan

Table 5: Work Break down structure

Task	Length (Days)	Person (Lead)	Date to Complete
Client meeting	1	Everyone	01/13/23
Draft Phase 1	3	Everyone	01/15/23
Research on Light Weight Materials	14	Cameron	01/26/23
Research on Strong Materials	14	Tyler	01/26/23
Research on Formula SAE Rules and Regulations	14	Josh	01/26/23
Research on Safety	14	Kate	01/26/23
Research on Miscellaneous	14	Isabel	01/26/23
Draft phase 2	5	Everyone	01/28/23
Analyze solid works	7	Kate	01/29/23
Prepare proposal presentation	5	Everyone	02/12/23
Create at least 1 possible rear subframes	7	Everyone	02/14/23
Compare materials	6	Tyler	02/14/23
Pick final material	2	Everyone	02/15/23
Preliminary Cost Analysis	5	Josh	02/19/23
Draft Phase 3	5	Everyone	02/19/23
Bill of Materials	1	Josh	02/19/23
Modeling	4	Josh	02/19/23
Pick Final Design	7	Everyone	02/19/23
Assembly and Manufacturing Process Research	5	Cameron	02/28/23
Find Max Budget	1	Cameron	02/28/23
Mass analysis	6	Josh	03/06/23
Final Cost Analysis	5	Josh	03/06/23
Determine assembly process	9	Cameron	03/06/23
Week 9 client status report	3	Isabel	03/15/23
Factor of safety calculations	5	Kate	03/16/23
Finite element analysis	7	Tyler	03/18/23
Experimental Testing/Results	4	Everyone	03/22/23
Evaluate Solution/Any Changes	2	Everyone	03/23/23
Draft phase 4 for PM	6	Everyone	03/27/23
Edit Phase 4	6	Everyone	04/01/23
Prepare final presentation	5	Everyone	04/27/23

Project Start: Jan 9, 2023

Display Week: 6

TASK	Team Lead	PROGRESS	START	END
Phase 3				
Analyse Solid Work	Kate	100%	1-30-23	2-6-23
Prepare Proposal Present	All	100%	2-7-23	2-11-23
3 Rear Subframe Option	Everyone	100%	2-5-23	2-13-23
Compare materials	Tyler	100%	1-30-23	2-6-23
Pick Final Material	Tyler	100%	2-7-23	2-9-23
Pick Final Design	Isabel	100%	2-7-23	2-9-23
Preliminary Cost Analysis	Josh	100%	2-9-23	2-14-23
Draft Phase 3	All	100%	2-12-23	2-17-23
Phase 4				
Week 9 Client Status Rep	Isabel	0%	3-15-23	3-18-23
Mass Analysis	Josh	0%	3-6-23	3-12-23
Final Cost Analysis	Josh	0%	3-6-23	3-11-23
Determine Assembly Proc	Cameron	0%	3-6-23	3-15-23
Safety Calculations	Kate	0%	3-16-23	3-21-23
Finite Element Analysis	Tyler	0%	3-18-23	3-25-23
Draft Phase 4 for PM	All	0%	3-21-23	3-27-23
Edit Phase 4	All	0%	3-28-23	4-3-23
Final Presentation	All	0%		

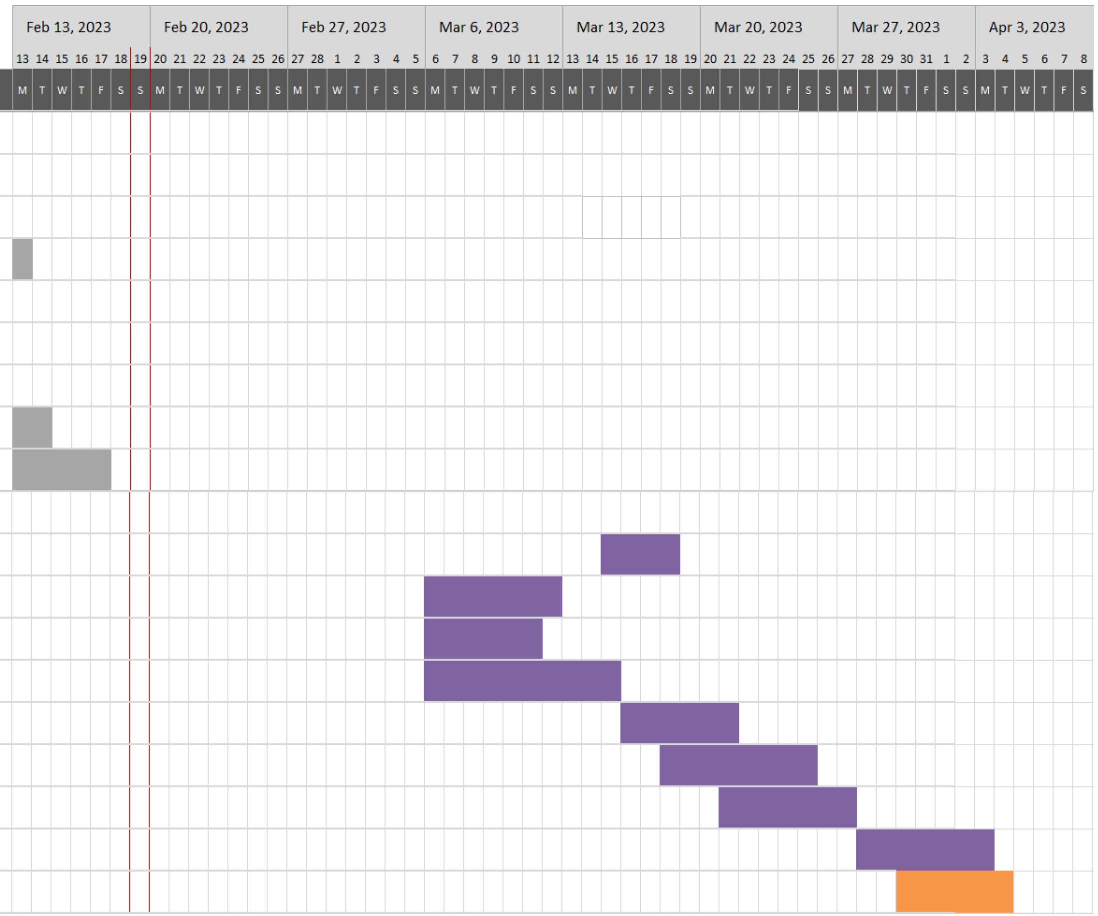

Figure 6: Gantt Chart for proposed timeline to the end of the year

Appendix III: Individual Contributions

Table 6: Individual Contributions from Each Team Member

Task	Description of Activity	Activity Duration (Hours)	Individual Responsible For Activity
Executive Summary	Outline of the report, summarizing the problem definition and key design decisions	2 hours	Josh
Section 1: Problem Statement and Scope Definition	Review feedback from phase 2 and edit problem statement. Add quantifiable values to determine project success	1 hour	Kate
Section 2: Information Summary	Summary of all key information which was gathered during research stage	3 hours	Cameron
Section 3: Conceptual Design Solution	Discuss the three proposed design options, and their similarities and differences as well as the advantages and disadvantages.	4 hours	Isabel
Section 4: Decision Making	Discuss the advantages and disadvantages or each rear subframe option.	5 hours	Everyone
Section 5: Design Proposal	Describe the design that was decided on, and discussed the costs and manufacturing requirements	4 hours	Josh
Section 6: Modeling, Analysis, Testing and Evaluation	Research and determine what testing should be conducted. Determine	6 hours	Kate

	evaluation rubric with quantifiable values.		
Section 7: Project Plan	Breakdown of the timeline, key milestones, and potential risks which may influence the project	3 hours	Cameron

Appendix IV: Self Evaluation

iteria	Level 8 8 points	Level 7 7 points	Level 6 6 points	Level 5 5 points	Level 4 4 points	Level 3 3 points	Level 2 2 points	Level 1 1 point	Cri Score
Problem statement and scope									/ 8
Information summary									/ 8
Conceptual design solutions									/ 8
Decision making									/ 8
Design proposal									/ 8
Modeling, testing, analysis and evaluation									/ 8
Project plan									/ 8
Overall proposal									/ 8

Total	/ 64