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Team 503: Formula 1/10th

8/28/2017



# Abstract

The abstract is a concise statement of the significant contents of your project. The abstract should be one paragraph of between 150 and 500 words. The abstract is not indents.

*Keywords*: list 3 to 5 keywords that describe your project.

# Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

# Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

* Paragraph 1 thank sponsor!
* Paragraph 2 thank advisors.
* Paragraph 3 thank those that provided you materials and resources.
* Paragraph 4 thank anyone else who helped you.

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# Notation

|  |  |
| --- | --- |
| A17 | Steering Column Angle |
| A27 | Pan Angle |
| A40 | Back Angle |
| A42 | Hip Angle |
| AAA | American Automobile Association |
| AARP | American Association of Retired Persons |
| AHP | Accelerator Heel Point |
| ANOVA | Analysis of Variance |
| AOTA | American Occupational Therapy Association |
| ASA | American Society on Aging |
| BA | Back Angle |
| BOF | Ball of Foot |
| BOFRP | Ball of Foot Reference Point |
| CAD | Computer Aided Design |
| CDC | Centers for Disease Control and Prevention |
| CU-ICAR | Clemson University - International Center for Automotive Research |
| DDI | Driver Death per Involvement Ratio |
| DIT | Driver Involvement per Vehicle Mile Traveled |
| Difference | Difference between the calculated and measured BOFRP to H-point |
| DRR | Death Rate Ratio |
| DRS | Driving Rehabilitation Specialist |
| EMM | Estimated Marginal Means |
| FARS | Fatality Analysis Reporting System |
| FMVSS | Federal Motor Vehicle Safety Standard |
| GES | General Estimates System |
| GHS | Greenville Health System |
| H13 | Steering Wheel Thigh Clearance |
| H17 | Wheel Center to Heel Pont |
| H30 | H-point to accelerator heel point |
| HPD | H-point Design Tool |
| HPM | H-point Machine |
| HPM-II | H-point Machine II |
| HT | H-point Travel |
| HX | H-point to Accelerator Heel Point |
| HZ | H-point to Accelerator Heel Point |
| IIHS | Insurance Institute for Highway Safety |
| L6 | BFRP to Steering Wheel Center |
|  |  |
|  |  |
|  |  |

# Chapter One: EML 4551C

## 1.1 Project Scope

**Project Description**

Project F1TENTH is an open-source project intended to foster interest and critical thinking about the rapidly developing field of autonomous systems by utilizing a preexisting 1/10th scale RC chassis and implementing various autonomous components such as LiDAR, cameras, speed controllers, and more to develop a platform that can be used for autonomous systems research and education. Originally founded by the University of Pennsylvania in 2016, the project has since expanded its participation to various researchers, engineers, and enthusiasts. The purpose of this project is to develop our own iteration of an F1TENTH vehicle to be used by researchers and students studying autonomous algorithms and providing them with a robust and engineered platform for their algorithm implementation.

**Project Objective**

The objective of this project is to design and fabricate a well-engineered 1/10th scale vehicle chassis that can house various autonomous driving components while taking into consideration clearly defined mechanical engineering metrics such as center of gravity, moment of inertia, fluid flow about the chassis, and even more parameters.

**Key Goals**

A key goal is to create a foundational body design that is scalable. Mechanical properties of the chassis should be consistent across different iterations of the chassis. Another key goal is to determine an optimal material choice to prioritize strength and minimize overall weight. Our final key goal is for each of the design iterations to have guaranteed repeatable metrics. A key aspect of achieving scalability is ensuring that manufacturing processes are streamlined for efficiency. Guaranteed repeatable metrics, such as the Center of Mass and Moment of Inertia, are fundamental to achieving precise control and stability in various applications. Ensuring these metrics remain consistent from one body iteration to another is vital for maintaining control algorithms, optimizing vehicle dynamics, and achieving desired performance outcomes. Ultimately, these objectives reflect a commitment to delivering high-quality products that meet the exacting standards of our sponsor.

**Primary Market**

Intended primary market for the project is the Resilient and Autonomous Lab at Florida State University. Professor Dr. Anubi is seeking the establishment of a developed autonomous F1/10th platform as a research tool.

**Secondary Markets**

Beyond initial intention, the platform will be used to instruct students in courses as a base point. Another secondary market would be F1/10th open-source project consumers that can access the development of these F1/10th cars. Hobbyists who are interested in the F1/10th project have also been identified as a secondary market. The work done on this project could also be marketed to the remote-controlled car community in general.

**Assumptions**

These assumptions act to limit the scope of the project to assure the team’s effort is not spread too thin. The design will give repeatable results able to be implemented on multiple chassis without performance variation. The current design of the vehicle chassis is not expected to change, all designs will be made for a single chassis that may be duplicated. The product will be designed primarily for engineering professors and their students. A high degree of competency with the produced system is expected of the consumer. The vehicle body will be able to endure some abuse in a racing environment but is not expected to hold up to large impacts. The vehicle body will be modular, and separate body portions can be replaced and iterated without changing others. Mass is a crucial factor in vehicle design, minimizing mass will be a major focus.

**Stakeholders**

The stakeholders of this project consist of the F1TENTH, FAMU-FSU College of Engineering, as well as Senior Design Coordinator Dr. Shayne McConomy, and Academic Advisor Dr. Moses Anubi. F1TENTH is the sponsor for the project. Furthermore, F1TENTH’S partner Locomotion is also interested in the project since their mission statement is to innovate fully autonomous vehicles. Dr. McConomy, Dr. Anubi, and the FAMU-FSU College of Engineering are represented in the project. Therefore, they are all interested in the project.

## 1.2 Customer Needs

Team 503 conducted a meeting with the customer and sponsor, Dr. Anubi, discussing the needs and wants for the Formula 1/10th project. These customer needs will be the design parameters and foundation for the product which Team 503 designs and develops. These questions were asked during the first meeting with the sponsor to establish an initial basis for the project, and then some supplementary questions were asked via a follow-up email to clear any confusion and miscommunication between Team 503 and the sponsor. The customer's questions, their response to them, and how Team 503 interpreted their response in an engineering context are listed below.

Table 1: Customer Responses and Interpreted Needs

|  |  |  |
| --- | --- | --- |
| **Question** | **Response** | **Interpreted Need** |
| What are the goals for this project? | The designed mechanical properties such as Moment of Inertia and Center of Mass should be consistent across different chassis. Variation in length is undesirable. The design should be easily scalable. | The F1/10th vehicle chassis has definite mechanical metrics and is easily reproducible. |
| What problems do you experience commonly with this type of project? | Time. It seems to take too long. It would be great if you can get it done in a timely manner | The design of the chassis will be constructed in a timely manner. |
| What kind of extra components or attachments need to be considered? | Expect the chassis components to remain the same | All iterations of the chassis will contain the same components. |
| What do you like about the chassis so far? | The ability to fully control the design of the platform is great. | The design of the chassis is unique and modular. |
| What do you dislike about the chassis so far? | The separate chassis are not identical. Control instructions are not able to be transferred simply between different chassis easily. | Designs produced will bear repeatable results. |
| What kind of different iterations would you like to see? | Many design iterations may not be reasonable under the time restraints present, but worthwhile, well-engineered iterations will be expected. | Iterative design will be necessary during this project. Excessive iterations may be counterproductive. |
| Is it fair game to reference competitor’s cars or from any vehicle features you want? | Prefers well engineered solutions to aesthetic design. F1 car designs are great to draw from, well-engineered with years of Research and Development behind them. | The final design may be inspired by other effective designs. The function of the body will be more important than the form. |
| What are some featuring the car should have in the final design? | No fancy features. Just the simplest working design. | The design will be simple yet effective. |
| Would you prefer we work off the current chassis design or start completely from scratch? | I don’t have a preference on this. Anything you like is fine. | The project may be referenced with a current chassis design or from scratch. |
| What do you see in other F1TENTH builds that you would like us to implement? | Nothing really. I think the building we have now may be good. Select one that works best according to your criteria. | The current build for the car is effective. |
| How modular would you like the car to be? | A fixed chassis with easily replaceable components. | The car will have a fixed chassis with accessible and replaceable components. |
| Would you like the final product to be plug-and-play or assembly based? | Plug-and-play. | The final product will feature a plug-and-play design. |
| What extreme loading cases will the chassis need to withstand? | Crashes, top speed, cornering/accelerating/braking forces, transport. | The chassis will withstand crashes and be practical while the vehicle is in motion. |
| What setting will these cars be used in? | Competition and teaching settings | The final product may be utilized in competition and teaching settings. |
| What components need to be accessed most frequently? | Batteries and the onboard computer. | Power supply and onboard computer may have higher accessibility. |

The design team tried to ask questions that could clearly define a direction for the project. The customer responses proved to be highly informative and have allowed the team to begin on the path to producing a product that is satisfactory for the customer. A few of customer needs that standout include the need for clearly defined mechanical metrics, the need for consistency between iterations, and the need to keep the preexisting components the same. The overall take-away from the customer’s needs is to develop a car that has defined and quantitative mechanical metrics such as center of gravity, center of mass, component positioning, etc., a car that is easily reproducible and identical to the car before, and a car that is robust and versatile enough to undergo various racing conditions, such as high speeds, sharp turns, and potential crashes.

## 1.3 Functional Decomposition

**Introduction**

The functional decomposition process was employed to transform the project scope details into more precise, specific requirements that are essential for the project's success. By establishing basic level functions for the F1TENTH scale car chassis, the group will be able to identify the system's targets and metrics. In completing the functional decomposition, the group ensures that each functional component contributes to the overall quality and functionality of the chassis.

**Data Generation**

The functions listed below in Figure 1 were determined by analyzing questions such as what is crucial for the F1TENTH project, what functions affect one another, and what functions are not needed for research and development. Some of the questions that helped determine what the functions are for the project are “What kind of different iterations would we like to see?” and “How modular would we like the car to be?” Knowing what each function can do and what is correlated increases efficiency with good organization with the understanding of the F1TENTH project. By looking at the key goals, customer needs, project scope, and interpreted answers, the answers for the functions are listed as a flow chart below:

**Flow Chart Reasoning**

The functional decomposition hierarchy chart, seen in Figure 1, is broken down into four major systems: *movement, structure, utilization, and protection*. The *movement* system encompasses all functions pertaining to the movement of the car. The *structure* system covers the stability and positioning of the components within the chassis, as well as the material of the design. The *utilization* system covers the accessibility of the components as well as the intended use of the components. The *protection* system covers crash durability and user handling of the car.

The F1/10th vehicle chassis was broken down in the four systems based on the primary objective with aligning key goals and interpreted need from customer evaluation. Interpreted from evaluation was a need of a chassis with definite mechanical metrics that is easily reproducible. As designed for competitive use, the limiting factors from F1/10th competition will remain in consideration to metrics.

Movement is divided into two subsystems: Suspension and steering. Under suspension, the functional interaction of the chassis to the limitation of body roll and other stabilizations of the entire vehicle can be seen such as dampening vibrations and ground clearance. When steering the vehicle there is also the functional requirement for clearance of the chassis during max turn radius.

The chassis structure system is divided into five subsystems: Compact, aerodynamic material, vibration, and fixed. With consideration of compactness and constraints, there is an ability to utilize and optimize the consumption of available space by the chassis keeping in mind necessary components. Competitive use of vehicles entails the use of aerodynamic design benefits in downforce generation and drag force limitation. The structural integrity of chassis material ensures the weight capacity to support components and withstand collisions. Aside from suspension dampening occurring in collaboration with chassis, the dampening of vibrations can be future induced by the selected materials and structure. A fixed structure will ensure components to be fixed to their mounting points and enable rotations in all axes.

Utilization is composed of subsystems access and components. User interaction with the components is prioritized when testing or making adjustments that will require the chassis to enable components to be easily accessible and ports to not be obscured.

In conjunction with other systems, protection system divides into the subsystems: crash and user handling. Upon collisions or roll overs, there is assurance that components will be protected, and chassis will remain intact. Fabrication considers the safety of the user from any sharpy extrusion or electrical grounding with exposure to high voltages.

**Connection to Systems**

The objective of the functional decomposition hierarchy was to create as many functions as possible that satisfy the customer's needs. As you descend the hierarchy, the specificity of the system increases. The first tier of the hierarchy which includes movement, structure, utilization, and protection are unique yet relative functions that are general enough to capture necessary functions. Each tier 1 system can’t exist without the other when discussing functions of a vehicle chassis. The next tier are more specific subsystems such as aerodynamics, steering, components, and more. These subsystems were implemented to create a more organized and translatable set of functions. Shown below in Table 2, the functional decomposition cross reference chart is a chart comparison of various functions as they relate to the overall system. The tally is useful in determining which function will take priority in the design process. The “X”indicates the given function that is correlated to. Some functions may relate to multiple systems as shown in Table 2:

Table 2: Functional Decomposition Cross Reference Chart

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **System Functional Decomposition** | | | | |
| *Function* | *Movement* | *Structure* | *Utilization* | *Protection* |
| Limits Body-Roll | X |  |  |  |
| Dampens Vibrations | X | X |  |  |
| Clears Ground | X | X |  |  |
| Clears Maximum Turn Radius | X |  |  |  |
| Contains Cables |  | X |  |  |
| Utilizes Free Space |  | X | X |  |
| Limits Length, Width, and Height |  | X |  |  |
| Influences Fluid About Body |  | X |  |  |
| Generates Downforce |  | X |  |  |
| Supports Weight of Components |  | X |  |  |
| Withstands Forces from Crashes |  | X |  | X |
| Dampen Component Vibrations |  | X |  |  |
| Fixes Components to Chassis |  | X | X |  |
| Allows for Rotation About All Axes |  | X |  |  |
| Allows for Easily Accessible Input/Output Ports |  |  | X |  |
| Allows for Components to be Used as Intended |  |  | X |  |
| Protect Against Collisions |  |  |  | X |
| Protects Against Roll-Over |  |  |  | X |
| Protects User from Sharp Extrusions or High Voltages |  |  |  | X |

**Integration**

The first functions split into multiple sub-systems which are movement, structure, utilization and protection. The movement and structure will work together as it will utilize power for movement, as well as physical forces of the structure affecting the movement. Protection and support also relate with one another as the structural integrity of the chassis will determine how durable the car is with unexpected damage. Utilization and support correlate with accessibility to components and the structure design to access them. The four functions all relate to one another, but it is crucial that they are split into smaller sub-systems to help organize the workload while also knowing what component affects the other.

**Action and Outcome**

The main action for the design to perform is to provide a stable and accessible platform for the components in the F1TENTH car. This platform should not inhibit the motion of the F1TENTH car and should be able to survive extreme loading cases such as high-speeds, cornering, acceleration and deceleration, crashes, and transport.

The customer needs the design to allow free movement of the F1TENTH car. The wheels need to be able to steer the car without colliding with the frame. The steering arc and suspension travel of each wheel should be free to move through their entire travel without colliding with the chassis. The weight of the car cannot cause it to bottom out during normal maneuvers. If the chassis design weighs too much, the suspension on the F1TENTH car will not behave correctly. The suspension system of the subframe is designed to perform best with a specific load which will limit the system's mass. Overloading the system with too much mass will cause the springs to compress undesirably and the system will become underdamped and oscillate undesirably. The chassis design should arrange the components so that the F1TENTH car has favorable handling characteristics. The steering geometry is pre-determined on the F1TENTH subframe, so the center of mass should be kept as low as possible to limit the rolling moment acting on the car during acceleration, braking, and cornering. The outcome of a lower center of mass will be a decrease in the weight shift from front to back or side to side during acceleration/braking and cornering, respectively.

The customer also needs a design which can be easily transported and handled so the vehicle is not easily damaged. The design should act to protect the components of the car and present obvious points where the chassis can be lifted from. This will provide the customer with assurance that the design is sufficient in its structural integrity.

The customer has requested that the components of the F1TENTH car be easily utilized. The design should allow easy access to all components of the car, with special attention paid to the components that need to be most easily accessible, which the customer identified as the battery and the onboard computer. The design will give access to all the F1TENTH car’s components by utilizing organization techniques to arrange the components within the chassis, so they are not blocked by less important components.

The protection of the components within the chassis as well as of the chassis itself during operation of the F1TENTH car was also emphasized by the customer. The structure of the chassis will allow a system to be attached to the extremities of the chassis which can reduce the stress of an impact in a crash. Combined with the emphasis on a robust structure, this impact reduction system's outcome will be to protect the components and the chassis of the F1TENTH car.

*Figure 1. Functional Decomposition Hierarchy*A diagram of structure and utilization

Description automatically generated

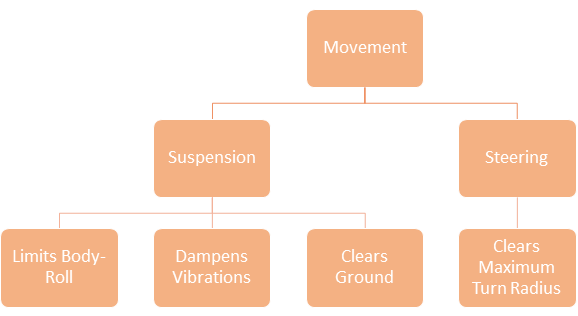
Figure 2. Movement Subsystem, Functional Decomposition Hierarchy

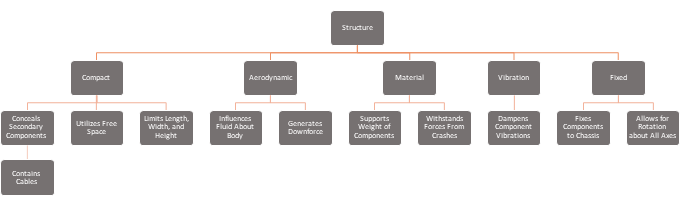
Figure 3. Structure Subsystem, Functional Decomposition Hierarchy

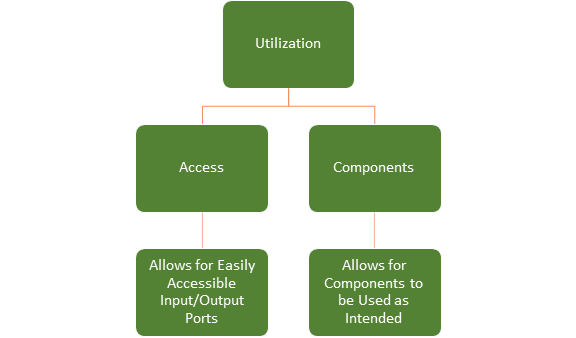
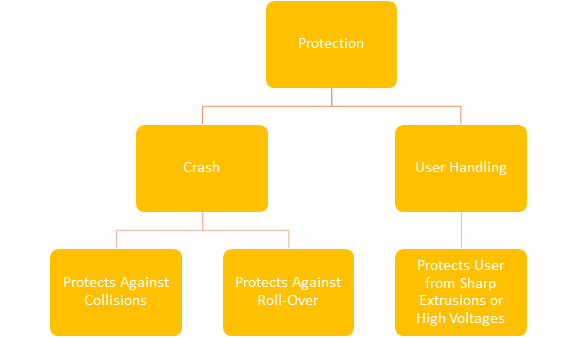
Figure 4. Utilization Subsystem, Functional Decomposition Hierarchy

Figure 5. Protection Subsystem, Functional Decomposition Hierarchy

## 1.4 Target Summary

The functional decomposition is a breakdown of functions in a hierarchical format that includes all of the functions the project should include, based on the needs of the customer. The following targets and metrics were created to be quantifiable goals for each of the functions to reach.

**Movement System Targets and Metrics**

In relation to the Movement system, the limitation of the body roll of the F1/10th vehicle is targeted to remain below 5 degrees of rotational angle. This ensures preventative measures from rolling over the vehicle. Given the load applied on the vehicle when in motion, the ground clearance targeted at 1.6cm preventing scraping or damage to undercarriage and other components from excessive vibration. When making a turn, the vehicle will necessitate the ability to move freely or have sufficient clearance to achieve a maximum wheel turn of 30 degrees.

**Structure System Targets and Metrics**

Falling under the Structure system is the “Withstands Forces from Crashes” function. The decided target would be 150N. This was calculated with the assumed mass of the vehicle multiplied by the maximum acceleration of the vehicle. The number was calculated at 112N. However, it was decided that the target would be 150N with a safety factor of 1.34. Another function listed is “Supports Weight of Components”. The decided target would be 12N. This was calculated with the mass of the vehicle along with the mass of the components, cables, and connectors.

**Utilization System Targets and Metrics**

Frequent utilization of ports implies a targeted lack of port obstruction within 5 cm distance for cable access. Components like Lidar also need unobstructed views in all directions, within a 360-degree field of vision.

**Protection System Targets and Metrics**

In the realm of the protection system, the designated metrics align with predefined targets to ensure the vehicle's safety and performance. For collision protection, the chassis must withstand a force of 150 N, determined through calculations involving a constant top velocity of 70 mph and a vehicle weight of 3.6 kg. In addressing rollover protection, the specified target is a Static Stability Factor (SSF) of 20. To enhance user safety, strict targets are set: limiting energy dissipation to 70 Amperes (A) and maintaining a sharpness level of 0 meters on the vehicle. These targets and metrics are pivotal in guiding the vehicle design process, emphasizing safety considerations for collision, rollover incidents, and user protection.

**Targets and Metrics Derived Outside of Functions**

There were several targets and metrics that did not fall under a function category because they needed to be defined before other targets and metrics could be. This category mainly contains the vehicle dimensions. Mass is one of the most important metrics used to define other metrics such as the forces during turning, in a crash, and the body roll in a turn. Metrics from the prefabricated subframe were defined by taking measurements from the subframe. The mass of the subframe was 1.44kg, wheelbase was 26cm, total length was 42.5cm, front and rear track width were both 7cm, total width was 20cm, ground clearance with no load was 1.6cm, steering angle was ±30deg, and the reported top speed from the manufacturer was 31.3m/s.

**Method of Validation**

Validating the newly made targets ensures accuracy for future accomplishments within the project. The methods that will be utilized in validating the targets are as follows: Utilizing 3D software such as CREO Parametric can help with looking for displacement on fixed components on the chassis, port clearance, and clears ground. To ensure there will be no errors within the targets, using formulas and clear calculations will help with validation. With validation, errors can be reduced which will lead to less issues with future testing. Without it, it can create multiple problems that can hold back the team as well as the sponsor. Finally, validation can also help with choosing the correct concept in the future. Methods such as using the House of Quality for concept selection can drastically change which concept will be used for the project which solely depends on the target values/engineering characteristics.

**Derivation of Targets and Metrics**

The targets and metrics were derived from the functions in the functional decomposition. For every system, several functions have a metric assigned to them by determining what unit of measure would show best how well the function will be accomplished. These metrics were then assigned a target value that the team believes will characterize good performance in the final design. Many of these targets are found by a direct measurement from the vehicle subframe, or a calculation based on those measurements.

Certain targets are solid targets, which are more critical. Some solid targets are those directly measured from the vehicle subframe. The targets that are derived from these data are also of a higher importance as they will determine the handling characteristics of the vehicle. One such example is the static stability factor, which is assigned a target of 20. This is the ratio of forces in the vertical direction such as downforce and weight to forces in the horizontal direction such as lateral force and centripetal force felt while going around a corner. The downforce and weight of the vehicle should cause a moment about the outside tires 20 times greater than the centripetal force in order to ensure the car does not roll, and the inner tires maintain sufficient traction.

Other targets are soft targets, such as utilizing free space, concealing secondary components, and containing cables to name a few. These were added to be able to have a quantity attached to these functions, but are not as important to the performance of the car.

**Discussion of Measurement**

Measurements were taken from the prefabricated subframe using a tape measure for longer lengths, and calipers where possible. Angle measures such as body roll and steering were measured using a protractor and a reference line. For body roll, a protractor was attached along the center of rotation of the subframe and measured against a vertical reference to determine how many degrees the vehicle rolled over when the body came into contact with the ground.

**Summary and Catalog**

Table 3. Targets and Metrics of Critical Functions

|  |  |  |  |
| --- | --- | --- | --- |
| **System** | **Critical Functions** | **Target** | **Metric** |
| Movement | Limits Body-Roll | ±5 [deg] | Rotation Angle |
| Clears Maximum Turn Radius | ±30 [deg] | Steering Angle |
| Structure | Limits Height | 18 [cm] | Height |
| Supports Weight of Components | 12[N] | Weight |
| Withstands Forces from Crashes | 150 [N] | Force |
| Dampens Component Vibrations | Ns/m | Damping Coefficient |
| Allows for Rotation About All Axes | 360 [deg] | Rotation Angle |
| Utilization | Allows for Easily Accessible Input/Output Ports | 5 [cm] | Port Clearance |
| Protection | Protects Against Collisions | 150 [N] | Force |
| Protects Against Roll-Over | 20 [N\*m/N\*m] | Static Stability Factor |
| Non-Function Targets | Vehicle Dimensions | 26 [cm] | Wheelbase |
| 20 [cm] | Total Width |
| 31.3 [m/s] | Maximum Speed |
| 1.44 [kg] | Subframe Mass |
| 3.6 [kg] | Vehicle Mass |
| ±30 [deg] | Steering Angle |

Table 3 consists of the critical functions of the project, and their respective targets and metrics. It was important to declare these initial targets in order to better determine the direction of the design process. With these targets and quantifiable metrics in mind, the team is better suited to satisfy the needs of the customer and successfully carry out the functions of the project. The critical functions discussed for these targets and metrics were determined to be the most imperative targets to be achieved to create a well-engineered chassis for the F1TENTH vehicle. Defining a target for weight and crash protection are some of the most important design goals to take into consideration when designing any type of vehicle. Knowing the customer needs, the functions of the project, and now the targets the design needs to achieve, provides a necessary foundation for the design of the project.

## 1.5 Concept Generation

Concept generation is crucial in the design process. There are multiple methods on how to come up with concepts, such as morphological charts, anti-problems, and crap shoots. The team came up with 100 design concepts that provide solutions for the project. The list is located in Appendix D.

**Concept Generation Tools**

Of the multiple methods that can be utilized to generate concepts for the project, Team 503 used ideation and a morphological chart. Ideation is the formation of ideas and concepts, and Team 503 conducted a brainstorming session to generate 50 concepts for the chassis design of the F1TENTH vehicle. The next 50 concepts were generated using a morphological chart. The morphological chart was constructed using critical functions of the project and listing out possible parameter choices for each function. Concepts were generated using different combinations of these parameters as Team 503 saw fit.

**Medium Fidelity Concepts**

Team 503 chose five concepts from the list of generated concepts to act as their medium fidelity concepts. These were concepts that the team thought to satisfy most of the required functions but didn’t feel were strong enough to represent a final design for the project.

Table 4: Medium Fidelity Concepts

|  |  |
| --- | --- |
| **Concept #** | **Description** |
| 2 | A car that has cable chambers to organize cords, cables, and wires. |
| 17 | Quick Release Shell Chassis design for quick access and maintenance to internal components. |
| 19 | Recessed Camera Housing Chassis Design for camera protection. |
| 22 | Implement a moving mass inside the chassis to change the center of mass of the car. This allows the car to make tighter turns by keeping the force distribution on the inner and outer wheels closer to 50/50 during a turn. |
| 53 | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increase Spring Stiffness. |

**High Fidelity Concepts**

Team 503 chose three concepts from the generated concepts to act as their high fidelity concepts. These concepts were determined to satisfy many of the required functions for the project and could confidently represent a final design.

Table 5: Medium Fidelity Concepts

|  |  |
| --- | --- |
| **Concept #** | **Description** |
| 12 | Centralized Electronics Hub Chassis that houses the computer, LiDAR, and other sensors for easy maintenance. |
| 55 | Screwed Down, Uniform Mounting Holes, Rely on Subframe Bumpers, Dampening on Fasteners, Increase Spring Stiffness. |
| 61 | Roll Cage Chassis |

## 1.6 Concept Selection

After the generation of 100 different concepts for a possible design of the project, it was necessary to decide which concept would be the “winner.” The winner would be the design concept that Team 503 would move forward with in designing. The team used a number of concept selection techniques to determine which concept would be the most appropriate to satisfy the objective of the project. These techniques include: binary pairwise comparison, house of quality, pugh charts, and analytical hierarchy process.

**Binary Pairwise**

The following is the binary pairwise classification of the various customer requirements defined for the project.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Customer Requirements** | **1** | **2** | **3** | **4** | **5** | **6** | **Total** |
| 1. Strong and Resilient | - | 1 | 1 | 1 | 1 | 1 | 5 |
| 2. Defined Mechanical Metrics | 0 | - | 1 | 1 | 1 | 1 | 4 |
| 3. Each Production is Identical | 0 | 0 | - | 0 | 1 | 1 | 2 |
| 4. Improved Vehicle Handling | 0 | 0 | 1 | - | 1 | 1 | 3 |
| 5. Modularity of Components | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 6. Ease of Access to I/O and Battery | 0 | 0 | 0 | 0 | 1 | - | 1 |
| Total | 0 | 1 | 3 | 2 | 5 | 4 | n - 1 = 5 |

Table 6: Binary Pairwise

The binary pairwise matrix compares the importance of one customer requirement vs. another. The column and row titles are identical, however the intersecting box between different customer requirements contains either a 1 or a 0. If the row customer requirement is considered more important than the column, a number 1 will denote this triumph, and a zero would denote the opposite. The “Total” column in green is the ranking of the importance of the customer requirements, 5 being the most important and 1 being the least, with the customer requirement finishing at 0 being removed. Team 503’s customer requirements ranked from most important to least important is strong and resilient, defined mechanical metrics, improved vehicle handling, each production is identical and, ease of access to I/O and battery.

**House of quality**

The House of Quality tool evaluates how well the different functions of the F1TENTH Car align with our customer needs. It highlights the features and compares them to the customer’s requirements. By considering the importance assigned by the customer to each requirement, the tool ranks how effectively the most critical Engineering Characteristics or functions that the F1TENTH Car should prioritize to best fulfill the customer’s requirements. From the House of Quality table shown below we can see that our most important functions are: *Protect Against Rollover, Clears Maximum Turn Radius, Limits Height,* and, *Protects Against Collisions.* The least important functions are: *Dampens Components Vibrations, Influence Fluid About Body, Allows for Easily Accessible I/O Ports* and, *Generates Downforce.* This process aids in a more thorough assessment of concept viability. Sometimes, a concept might seem superior at first glance, but when we consider the importance assigned to each characteristic, the true picture emerges. Weighting the characteristics helps reveal whether a concept is genuinely superior or if certain key features make it more viable and aligned with the desired outcomes.

|  |  |  |
| --- | --- | --- |
| # | **Customer Requirements** | **Engineering Characteristics** |
| 1 | Strong and Resilient | Limits Body Roll |
| 2 | Defined Mechanical Metrics | Clears Maximum Turn Radius |
| 3 | Improved Vehicle Handling | Limits Height |
| 4 | Each Production is Identical | Supports Weight of Components |
| 5 | Ease of Access to I/O and Battery | Withstands Forces from Crash |
| 6 | - | Dampens Component Vibrations |
| 7 | - | Handles Rough Treatment |
| 8 | - | Allows for Easily Accessible I/O Ports |
| 9 | - | Protects Against Collisions |
| 10 | - | Protects Against Roll-Over |
| 11 | - | Ground Clearance |
| 12 | - | Influences Fluid About Body |
| 13 | - | Generates Downforce |

Table 7: Customer Requirements and Engineering Characteristics

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Engineering Characteristic | | | | | | | | | | | | | | |
| Improvement Direction | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Units | | deg | deg | cm | N | N | N | deg | cm | N | N\*m/N\*m | cm | m/s | N |
| Customer Requirement | IWF | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | #11 | #12 | #13 |
| #1 | 5 | 1 |  | 1 | 9 | 9 | 3 | 9 | 3 | 9 | 9 | 1 | 1 | 1 |
| #2 | 4 | 3 | 3 | 9 | 1 | 1 |  |  |  |  |  | 3 | 1 | 1 |
| #3 | 3 | 9 | 9 | 9 | 3 |  | 1 |  |  | 3 | 9 | 9 | 3 | 9 |
| #4 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| #5 | 1 |  |  |  |  |  |  | 3 | 9 |  |  |  |  |  |
| Raw Data  (572) | | 44 | 39 | 68 | 58 | 49 | 18 | 48 | 24 | 54 | 72 | 44 | 18 | 36 |
| Relative Weight | | 7.7 | 6.8 | 11.9 | 10.1 | 8.6 | 3.1 | 8.4 | 4.2 | 9.4 | 12.6 | 7.7 | 3.2 | 6.3 |
| Rank Order | | 7 | 9 | 2 | 3 | 5 | 13 | 6 | 11 | 4 | 1 | 8 | 12 | 10 |

Table 8: House of Quality

**Pugh Charts**

For the corresponding pugh charts, initially the open-source vehicle model by F1TENTH was used as the datum concept. The engineering characteristics selected for the charts were taken from the previously top 5 ranked results from the House of Quality. Within the pugh chart, concepts are to be deemed better (+), worse (-), or same (S) as the datum. Resulting from the comparison between concepts and datum against the engineering characteristic was four concepts tying with most pluses. The tying four concepts include: Recessed Camera housing chassis, screwed down mag., screwed down uniform mount., and the roll cage chassis. These resulting concepts have an improvement in the top engineering characteristics compared to the open-source model.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| x | | Concepts | | | | | | | |
| Engineering Characteristics | [F1TENTH Open Source Vehicle Model](https://f1tenth.org/build) | #2 | #17 | #19 | #22 | #53 | #12 | #55 | #61 |
| Protects Against Roll-Over | - DATUM - | + | S | + | + | + | S | + | + |
| Limits Height |  | - | - | - | S | - | - | - | - |
| Supports Weight of Components |  | S | S | + | S | + | S | + | + |
| Protects Against Collisions |  | S | - | + | S | + | S | + | + |
| Withstands Forces from Crash |  | S | - | + | S | + | + | + | + |
| Total Pluses |  | 1 | 0 | 4 | 1 | 4 | 1 | 4 | 4 |
| Total Satisfactory |  | 3 | 2 | 0 | 4 | 0 | 3 | 0 | 0 |
| Total Minuses |  | 1 | 3 | 1 | 0 | 1 | 1 | 1 | 1 |
|  |  | Datum | No | Yes | No | Yes | No | Yes | Yes |

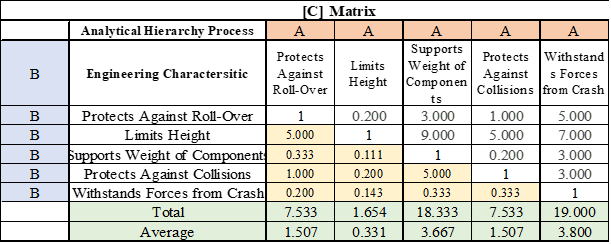
Table 9: Pugh chart Open-Source Vehicle Model Datum

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Concepts | | | |
| Engineering Characteristics | Cable Organizer Chamber Chassis | #19 | #53 | #55 | #61 |
| Protects Against Roll-Over | - DATUM - | + | + | + | + |
| Limits Height | S | S | S | S |
| Supports Weight of Components | S | + | + | + |
| Protects Against Collisions | + | + | S | + |
| Withstands Forces from Crash | + | S | S | + |
| Total Pluses | 3 | 3 | 2 | 4 |
| Total Satisfactory | 2 | 2 | 3 | 1 |
| Total Minuses | 0 | 0 | 0 | 0 |
|  |  | Yes | Yes | No | Yes |

Table 10: Pugh chart Cable Organizer Chamber Chassis Datum

Subsequently, one of the concepts from the open-source vehicle model pugh chart was selected as the new datum. The concept was chosen from the resulting values closer to the satisfactory compared to the original datum, not necessarily better or worse. Either cable organizer chamber chassis or centralized electronics hub chassis were options as they tied for satisfactory, for the table Cable Organizer Chamber Chassis was chosen. With selecting datum, the secondary pugh chart was to compare the top four concepts against engineering characteristics to determine the top three competing concepts.

**Analytical Hierarchy Process**

The Analytical Hierarchy Process (AHP) was utilized to compare the importance of the engineering characteristics used in the Pugh Chart. A comparison was made between all of these characteristics, using a scale of 1-9 (Fig.6) to determine the relative importance of any two engineering characteristics in the lens of importance to product success. This initial comparison chart (Table 11) gives a score for each engineering characteristic’s relative importance.Table 11: Initial Comparison [C] Matrix

A black and white text on a white background

Description automatically generatedFigure 6: Rating Factor Explanation.

The [C] Matrix is then normalized as shown in Table 12, making all the sums of the important factors equal to one for each engineering characteristic, which provides a clearer value to compare the importance of each characteristic.

A screenshot of a computer screen

Description automatically generatedTable 12: Normalized [C] Matrix

A consistency check is performed to ensure that the values used in the initial comparisons are not biased. The value of the consistency ratio is expected to be below 0.1 for a consistent, unbiased [C] matrix. A value of 0.086 was achieved for the consistency ratio, which is within the targeted range (Table 13).

A screenshot of a table

Description automatically generatedTable 13: Consistency Check

The next step taken in the AHP was to bring in the best concepts from the Pugh chart and assign them a value based on how well each fulfills the engineering characteristics and accounting for the critical weights from the norm[C] matrix. This is called the [Pi] matrix (Table 14).

A screenshot of a computer

Description automatically generatedTable 14: [Pi] Matrix

The result of the AHP is a table which gives a value for each design that describes how well it fulfills the engineering characteristics from the House of Quality. These alternative values (Table 15), show that the concept which best fulfills all the engineering characteristics from the Pugh Chart is the Roll Cage Chassis design, which has the highest alternative value by almost 3 times the other concepts.

A close-up of a list of words

Description automatically generatedTable 15: Alternative Value Matrix

The result of the AHP when applied to an F1TENTH car is that a roll cage chassis is the best conceptual design of those presented by Team 503.

**AHP EC**

AHP EC or Analytical Hierarchy Process Engineering Characteristics is very similar to AHP shown above. However, instead of comparing concepts with concepts, it is comparing concepts to concepts with the engineering characteristics in mind. The AHP EC is a table with concepts on both vertical and horizontal cells. The top of the table has a listed engineering characteristic. Engineering characteristics are taken into account for deciding which concept is more important.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **[C] Matrix for Protect Against Roll-Over** | | | | | |
|  | **Analytical Hierarchy Process** | **A** | **A** | **A** |  |
|  |  | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | Recessed Camera Housing Chassis | Roll Cage Chassis | **Average** |
| **B** | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | 1 | 0.333 | 0.200 | 0.511 |
| **B** | Recessed Camera Housing Chassis | 3.000 | 1 | 0.333 | 1.444 |
| **B** | Roll Cage Chassis | 5.000 | 3.000 | 1 | 3.000 |
|  | **Total** | 9.000 | 4.333 | 1.533 | 4.956 |
|  | **Average** | 3.000 | 1.444 | 0.511 |  |

Table 16: AHP EC [C] Matrix for Protect Against Roll-Over

As shown in Table 16, one of the AHP EC tables is given as an example. The whole table is for the purpose of one engineering characteristic: Protect Against Roll-Over. The vertical cells and horizontal cells are both the listed concepts. Adding a 1 in the cell represents equality, as they are the same concept. This is shown diagonally down for each concept. If the column is more important than the row, then a big number is placed down. If the row is more important than the column, then a reciprocal number is placed down. The scoring factor is 1, 3, 5, 7, and 9, where 1 is equal, 3 is least important, and 9 is the most important. The average is taken both vertically and horizontally.

There is a normal matrix that uses the total sum of the column and divides it by the cell. The equation is listed below:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **norm[C] Matrix for Protect Against Roll-Over** | | | | | |
|  | **Analytical Hierarchy Process** | **A** | **A** | **A** |  |
|  |  | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | Recessed Camera Housing Chassis | Roll Cage Chassis | **Design Alternative Priorities {Pi}** |
| **B** | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | 0.111 | 0.077 | 0.130 | 0.106 |
| **B** | Recessed Camera Housing Chassis | 0.333 | 0.231 | 0.217 | 0.260 |
| **B** | Roll Cage Chassis | 0.566 | 0.692 | 0.652 | 0.633 |
|  | **Total** | 1.000 | 1.000 | 1.000 | 1.000 |

Table 17: AHP EC norm[C] Matrix for Protect Against Roll-Over

The matrix is used to find the Design Alternative Priorities. The priorities help the team find out which design is best. As shown in Table 17 above, the table is a norm matrix that divides the previous total of the original matrix to the selected elemental cell. The quotient is displayed in the corresponding cell of the norm matrix. The total is then added up, equaling to 1.000. The Design Alternative Priorities are calculated with the equation listed below:

Finally, there is a consistency check table to calculate the consistency ratio or {CR} for short. The table uses values such as Weighed Sum Vector {Ws}, {Pi}, {Ws}. /{Pi}, Average Consistency {λ}, and Consistency Index {CI}. There is a new consistency check table for each engineering characteristic.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Consistency Check | | | | | |
| Weighed Sum Vector {Ws} = [C]{Pi} | {Pi} | Cons = {Ws}. /{Pi} | Average Consistency {λ} | Consistency Index {CI} | Consistency Ratio {CR} |
| 0.320 | 0.106 | 3.011 | 3.039 | 0.019 | 0.037 |
| 0.790 | 0.260 | 3.033 |
| 1.946 | 0.633 | 3.072 |

Table 18: Consistency Check for Protect Against Roll-Over

Table 18 shows an example of a consistency check for one of the team’s engineering characteristics. It uses the listed variables above and calculates the {CR}. The values of {CR} vary depending on the values of the variables and the engineering characteristic. The value of {CR} is to be expected to be below 0.1. The value listed in the table above is 0.037, which means it is within the target range. This process is repeated for all engineering characteristics. None of the {CR} were above 0.1. Therefore, they are all within the target range.

A drawing of a blue hat on top of a white object

Description automatically generated

**Final Selection**

The completion of the binary pairwise comparison, house of quality, pugh charts, and analytical hierarchy process, resulted in a final selection of the design concept, “Roll Cage Chassis.” The choice was derived from the analytical hierarchy process and having the highest alternate value. This concept is considered to have the strongest qualities that satisfy the customer requirements and critical functions. The roll cage chassis will be most similar to a tube frame chassis as seen on most racecars to protect against collisions, roll-over, support weight of components, and for overall structural integrity. It will consist of welded tubes placed in the most appropriate position for the most optimal structural integrity. Team 503 considered this to be one of the strongest concepts going into the process and was in agreement with the conclusion found from the concept selection process.

## 1.7 Spring Project Plan

|  |  |  |  |
| --- | --- | --- | --- |
| **Team 503 - Formula 1/10th Vehicle TopHat** |  |  |  |
| **Spring 2024 Project Plan** |  |  |  |  |
|  |  |  |  |  |
| **Tentative Date** | **Milestone** | **Tasks** | **Description** | **Asignee** |
| January | Rapid Prototyping | Convert CAD to STL | Ensure dimensions/parameters are appropriate | Aaron |
| Prepare 3D Printer | Send to FabLab or personal printer. Select material. | Aaron |
| Assemble Prototype | Post-process prints, assemble with fasteners. | Aaron |
|  |  |  |  |  |
| January | Modify CAD Design | Review Design Requirements | Compare targets and metrics with prototype performance | Kyle |
| Discuss Problem Areas | Assess issues with current design | Team |
| Refine CAD | Address problems by fixing CAD model | Adam |
|  |  |  |  |  |
| January | Improved Prototype | Refine Model Based on Previous Error | Use performance of past prototype to improve working model | Ja'Quan |
| Redesign Model if Needed | Based on failures of prototype, rework any model parts that perform poorly | Alex |
| Simulate Loads | Perform a load simulation using a stress-analysis software | Kyle |
| 3D print prototype | Repeat Rapid Prototyping Steps | Aaron |
|  |  |  |  |  |
| January | Test Prototype | Load Testing in X, Y, Z | Apply loads to physical prototype from all directions | Ja'Quan |
| Collision Test | Crash the car and observe what breaks | Ja'Quan |
| Roll-Over Test | Perform a turn at top speed and observe roll stability | Ja'Quan |
| FEA Analysis | Use a simulation software to analyze loadcases | Alex |
| User-Handling Test | Handle the prototype roughly and observe what breaks/what is unergonomic | Adam |
|  |  |  |  |  |
| February | VDR4 | Condense Previous Work | Condense previous presentations for sponsor and advisor into key points | Adam |
| Summarize Current Work | Discern important information into key points for sponsor/advisor | Kyle |
| Create Presentation Powerpoint | Insert important information into powerpoint format. Add visuals. | Team |
| Overlook Rubric | Compare work produced with requirements in the asignment rubric | Ja'Quan |
| Submit VDR4 Powerpoint | Finalize and submit presentation on Canvas | Alex |
| Practice Presentation | Create scripts/key points and run through presentation as a group | Aaron, Alex, Ja'Quan |
| Present Presentation | Perform presentation and answer questions the advisor and TA's have | Aaron, Alex, Ja'Quan |
|  |  |  |  |  |
| February | Update Bill of Materials | Determine Main Components | Select key components from successful prototype design | Alex |
| Vet vendors | Contact vendors for part availability/cost | Adam |
| Record Changes | Take note of any changes from vendors | Adam |
| Intitial Order | Submit initial parts order to vendors | Adam |
|  |  |  |  |  |
| February | Finalize CAD Drawings | Create CAD Drawings | Draft a final CAD drawing for final design | Adam |
| Annotate Dimensions | Annotate dimensions on CAD drawing | Alex |
| Create Part Numbers | Assign part numbers to individual components | Ja'Quan |
| Create CAD Assembly for Reference | Assemble all parts in CAD software for computer modeling | Adam |
| Export to PDF | Create a PDF of final CAD assembly | Kyle |
|  |  |  |  |  |
| February | Machining and Fabrication | CAD files provided to Machine Shop | Send CAD file to Machine Shop for manufacturing | Aaron |
| Provide Material to Machine Shop | Supply Machine Shop with materials from vendors | Adam |
| Receive Status Update on Machined Parts | Check with Machine Shop on manufacturing progress | Aaron |
|  |  |  |  |  |
| February | Assembly | Look over CAD Models | Refer to CAD model before assembly | Alex |
| Examine Machined Parts | Inspect machined parts for defect | Aaron |
| Put together all components | Assemble components into the design | Kyle |
|  |  |  |  |  |
| March | Testing | Load Testing in X, Y, Z | Apply loads to physical prototype from all directions | Ja'Quan |
| Collision Test | Crash the car and observe what breaks | Kyle |
| Roll-Over Test | Perform a turn at top speed and observe roll stability | Adam |
| FEA Analysis | Use a simulation software to analyze loadcases | Alex |
| User-Handling Test | Handle the prototype roughly and observe what breaks/what is unergonomic | Aaron |
|  |  |  |  |  |
| March | VDR5 | Condense Previous Work | Condense previous presentations for sponsor and advisor into key points | Aaron |
| Summarize Current Work | Discern important information into key points for sponsor/advisor | Kyle |
| Create Presentation Powerpoint | Insert important information into powerpoint format. Add visuals. | Team |
| Overlook Rubric | Compare work produced with requirements in the asignment rubric | Adam |
| Submit VDR4 Powerpoint | Finalize and submit presentation on Canvas | Adam |
| Practice Presentation | Create scripts/key points and run through presentation as a group | Kyle, Adam |
| Present Presentation | Perform presentation and answer questions the advisor and TA's have | Kyle, Adam |
|  |  |  |  |  |
| April | Senior Design Day | Outline Previous Work | Discuss work done in previous presentations | Team |
| Outline Current Work | Discuss work done since prior presentations | Team |
| Prepare Demonstration | Set up demonstration of design capabilities | Team |
| Submit VDR6 Powerpoint | Submit presentation on Canvas | Kyle |
| Practice Presentation | Create scripts/key points and run through presentation as a group | Team |
| Present VDR6 | Perform presentation and answer questions the advisor and TA's have | Team |
| Prepare Poster | Lay out and prepare visuals for poster | Team |
| Create Elevator Pitch | Draft short summary of our project and what it does | Team |
| Practice Elevator Pitch | Create scripts/key points and run through presentation as a group | Team |
| Present Poster | Present poster and answer questions on Senior Design Day | Team |
| Network with Industry Professionals | Form relationships with and send follow up contact to Industry Representatives | Team |
|  |  |  |  |  |
| April | Finals | Prepare for Finals | Study and get enough sleep | Team |
| Take Finals | Take all final exams | Team |
| Pass all Finals | Perform Outstandingly | Team |
|  |  |  |  |  |
| May | Graduation | Prepare Cap and Gown | **GRADUATE** | Kyle, Alex, Adam, Ja'Quan |
| Practice Graduation Walk | Kyle, Alex, Adam, Ja'Quan |
| Graduate on May 4, 2024 | Kyle, Alex, Adam, Ja'Quan |

# Chapter Two: EML 4552C

## 2.1 Spring Plan

### Project Plan.

### Build Plan.

# Appendices

# Appendix A: Code of Conduct

**Mission Statement**

Team 503’s mission is to create a collaborative and efficient group environment by encouraging communication and contribution at every possible opportunity. Our team aims to not only create an optimized “work-horse” but to also cultivate friendships and comradery. Each opinion will be heard, valued, and taken into consideration. Each contribution will be accepted, welcomed, and amended if necessary. Most importantly, Team 503’s mission is to work together to become successful engineers one day in the future.

**Team Members and Roles**

**Aaron Hastie - Fabrication Engineer**

As fabrication engineer, Aaron will focus on the methods required to produce prototypes and design iterations. He will work closely with the materials and design engineers to ensure the designs produced meet the high-quality standard. As an ISTJ personality type, Aaron is geared toward controlling efficient processes with a well-planned step-by-step approach. This enables him to ensure quality manufacturing processes are implemented to produce physical designs in an efficient manner.

**Adam Imamura - Materials Engineer**

As a materials engineer, Adam is responsible for researching, testing, as well as comparing specific materials for the project. He will be researching various metals and polymers to find the most cost-friendly and most efficient material for the project. He will also be testing as well as comparing similar materials to find the highest quality standard. He will be collaborating with the design engineer, for further information about the needs of the ideal material(s). As an ISTJ personality type, Adam is devoted to duty. As an introverted thinker, Adam often shows sympathy and empathy through actions rather than feelings. This enables him to focus on the material process through individual study/research as well as progress in a timely manner.

**Kyle Lozano – Robotics and Coding Engineer, Point of Contact**

Kyle is responsible for the middleware and software components of the design project. This includes the integration of sensors, cameras, computers, microcontrollers into a single system and having them collaborate with one another. Kyle will be responsible for any part of the project that will require the coding, implementation, and control of robotic systems.

**Alex Soriano - Design Engineer**

Alex is responsible for developing and refining designs including tolerances necessary for fabrication of parts. Tasks include Computer-aided design, assemblies, and sub-assemblies. For fabrication, this will require the necessary detailed drawing of individual parts. As an ENFJ personality type, he will assist in coordinating and mediating the collaboration in the team.

**Ja’Quan Young - Test Engineer**

As the test engineer, Ja’Quan is responsible for ensuring the quality and reliability of any potential design. He will create a plan that outlines the testing strategy, objectives, and testing scenarios and environments. He will collaborate with the design engineer and the sponsor to perform user acceptance testing ensuring the design meets the requirements and specifications. As an ENTJ personality type, Ja’Quan will aid the team in the innovative and iterative design steps.

**All Team Members**

These roles will change, and each member will accept different responsibilities as they arise for the duration of the project. These additional roles will be identified and assigned by the project team as needed. Each member understands this and is willing to accept that their role may change in name or in definition. The quality of work produced is of the foremost importance over individual roles.

**Methods of Communication**

Team 503’s methods of communication will primarily be through Microsoft Teams. Methods of communication include messaging, uploading files and documents for the project, and utilizing calendars for meetings, assignments, and time conflicts. In case of further communication such as emergencies, team 503 has exchanged phone numbers. Phone numbers will be used for immediate communication with either all team members, or individual team members for further discussion. For sponsor communication, email will be utilized for scheduling meeting times, further assistance, and potential conflicts.

**Dress Code**

Meetings with our sponsor and presentations will require business professional attire for all members. RASLab black or blue polo shirt, black slack or chino trousers, and brown shoes. Scheduled meetings with academic advisor will be presented with casual attire.

**Attendance Policy**

Meeting locations will typically be held at the FAMU-FSU College of Engineering. Other locations outside of the FAMU-FSU College of Engineering will be acceptable. For extensive work on the project, members will be utilizing the senior design lab. If needed, the members will be able to use the Center for Advanced Power Systems lab room for more focus and testing.

All members are encouraged to attend meetings with other team members to discuss, review, progress, and assist with the project. In the event where (a) team member(s) cannot attend a meeting, the attended team member(s) need to inform the absentee(s) about what was discussed. All team members are highly encouraged to meet on Wednesday from 12:30pm to 2:15pm, labeled as the “weekly meeting”. The weekly meeting is for team members to give updates on individual progress, as well as discuss, review, progress, and assist with the project. In the event where (a) team member(s) cannot attend the weekly meeting, the same procedure applies with a regular meeting as discussed above.

All members are required to attend meetings where sponsors are present. Furthermore, all members are required to take notes and minutes during the meeting to verify and understand what was discussed. In the event where one member cannot attend the sponsor meeting, all other members will discuss with the absentee what was discussed. In the event where 2/3 of the team are absent from the sponsor meeting, there will be a rescheduled sponsor meeting as soon as possible followed by an email informing the sponsor about the change. If a team member needs to be absent for a sponsor meeting, they need to notify the rest of the team at least 1 hour before the scheduled time.

**Member Discourse**

Should discourse begin to foster among group members, time will be allocated for the members to express their concern in an environment that encourages growth and collaboration rather than an impediment to progress. If this proves not beneficial to the group other methods, such as conferring with Dr. McConomy, will be utilized to smooth over any issues should they arise thereon.

**Code of Conduct Amendments**

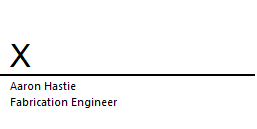
Should the Code of Conduct need to be amended, a unanimous agreement must be reached between the group members before the amendment is added.

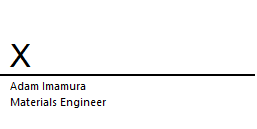
**Statement of Understanding**

By signing below, you acknowledge that you have read the documented code of conduct and will adhere to the guidelines specified.

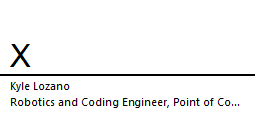
A black and white image of a star

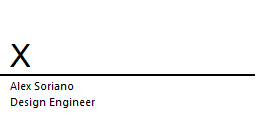
Description automatically generatedA black and white photo of a letter

Description automatically generated

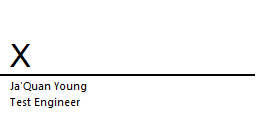


A black background with a black square

Description automatically generated with medium confidence



A black letter on a white background

Description automatically generated

# Appendix B: Functional Decomposition

# A screenshot of a computer Description automatically generatedAppendix C: Target Catalog

**Table 1: Targets and Metrics of Critical Functions**

|  |  |  |  |
| --- | --- | --- | --- |
| **System** | **Critical Functions** | **Target** | **Metric** |
| Movement | Limits Body-Roll | ±5 [deg] | Rotation Angle |
| Clears Maximum Turn Radius | ±30 [deg] | Steering Angle |
| Structure | Limits Height | 18 [cm] | Height |
| Supports Weight of Components | 12[N] | Weight |
| Withstands Forces from Crashes | 150 [N] | Force |
| Dampens Component Vibrations | Ns/m | Damping Coefficient |
| Allows for Rotation About All Axes | 360 [deg] | Rotation Angle |
| Utilization | Allows for Easily Accessible Input/Output Ports | 5 [cm] | Port Clearance |
| Protection | Protects Against Collisions | 150 [N] | Force |
| Protects Against Roll-Over | 20 [N\*m/N\*m] | Static Stability Factor |
| Non-Function Targets | Vehicle Dimensions | 26 [cm] | Wheelbase |
| 20 [cm] | Total Width |
| 31.3 [m/s] | Maximum Speed |
| 1.44 [kg] | Subframe Mass |
| 3.6 [kg] | Vehicle Mass |
| ±30 [deg] | Steering Angle |

**Appendix D: Concept Generation & Selection**

**Concept Generation List**

Adam’s Ideas

1. A modular chassis with multiple universal housing chambers to fit components in
2. A car that has cable chambers to organize cords, cables, and wires.
3. A car that has protective shielding on sensitive components to protect from outside forces
4. A car that has a chassis with rounded ends to reduce stress points in the corners
5. A lightweight chassis design that reduces downforce on the car
6. A car with emergency braking in case of failure
7. Create fail-safe system for software as well as hardware
8. Ventilation system to affect heat dissipation as much as possible
9. Detachable chassis that allows components to be easily accessible for switching and replacing
10. Magnetic fastened battery housing unit to be easily replaceable

Kyle’s Ideas

1. Sliding Component Tray Chassis that incorporates sliding trays that can hold various components can be adjusted to different positions and angles.
2. Centralized Electronics Hub Chassis that houses the computer, LiDAR, and other sensors for easy maintenance.
3. Streamlined Aero Chassis Design that reduces drag and optimizes airflow.
4. Cable Management Channels Chassis Design for wire organization.
5. Adjustable Telescopic Sensor Pole Chassis Design to extend or retract sensor height.
6. Carbon Fiber Chassis design to reduce weight and increase rigidity.
7. Quick Release Shell Chassis Design for quick access and maintenance to internal components.
8. Low Center of Gravity Chassis Design to limit the height of the center of gravity.
9. Recessed Camera Housing Chassis Design for camera protection.
10. Adjustable Weight Distribution Chassis Design to balance the vehicle and optimize handling.

Aaron’s Ideas

1. Maintain a low-profile chassis like a racecar. This will reduce the frontal area and keep aerodynamic drag forces lower.
2. Implement a moving mass inside the chassis to change the center of mass of the car. This allows the car to make tighter turns by keeping the force distribution on the inner and outer wheels closer to 50/50 during a turn.
3. The layout of the chassis will have layers based on the needed access and functionality of the components. Components that do not need to be readily accessed can be placed on a lower, less accessible tier of the chassis. Components that need to be readily accessible will be placed on a higher tier, or on an accessible section of a lower tier along the outside.
4. Use a fixed mast to mount the LiDAR and other sensors in a location appropriate for their use. Minimize the height of the rest of the chassis. This will lower the center of gravity and keep the overturning moment of the car lower during a turn, which will keep the force distribution on the inner and outer wheels more even.
5. Implement the motherboard of the CPU as a structural component in the chassis. This will reduce the weight of the chassis as less structural support will be needed.
6. Use a skirt around the vehicle with a fan to create low pressure under the vehicle. This acts inversely to a hovercraft to create a somewhat constant static downforce on the car and keep it stuck to the ground better.
7. Glass Cannon: create an extremely light chassis that is optimized for mass minimization.
8. Optimize chassis strength and survivability. Maximize the ability to survive in a crash.
9. Use biomimicry in elements where aerodynamic drag reduction and structural rigidity are most important.
10. Increase the ground clearance to allow for further roll angle of the vehicle body.

Ja’Quan’s Ideas

1. Use tubular space frames made from strong yet light material to increase strength and decrease weight
2. Integrate with the suspension to ensure responsiveness
3. Innovating on the advanced aerodynamics inspired from the Honda NSX by way of their inspiration from the F-16 fighter jet.
4. Incorporate a more streamlined to enhance downforce
5. Lowering the ground clearance to optimize handling
6. Stiffen the chassis to enhance overall rigidity and handling
7. Incorporate electronic stability control to increase handling
8. Redistribute the weight evenly above the wheels to optimize sharp turns
9. Use insulation materials to vibration
10. Modularize the chassis so that variations of the car can be created

Alex’s Ideas

1. Apply a “cable harness” approach similar to full-size vehicles to maximize space
2. Mounting or contact points contain rubber or closed cell foam to minimize vibrations
3. Create a sway bar component to reduce the body roll of vehicle
4. Push quick release components that require replacing or constant access
5. If carbon fiber is not used, consider a high strength plastic to maintain a good power to weight ratio
6. For components, create a roll cage preventing damage beyond structure
7. Purchase shorter cables for unnecessary lengthy cables
8. At maximum high-speed collision, best case is crunch points to reduce collision effect on major components and dampening the vibration caused
9. Aside from aerodynamic use, direct air through body ducts to components releasing excess heat with outlets to remain applying downforce
10. Create a tear drop design to reduce drag

**Morphological Chart Variations (10 each)**

Kyle: Screwed Down

1. Screwed Down, Uniform Mounting Holes, Fully Rigid Construction, Multiple Springs, Limit Straps
2. Screwed Down, Magnetic Fasteners, Crumble Zone, Damping on Fasteners, Increase Spring Stiffness
3. Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increase Spring Stiffness
4. Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Multiple Springs, Increase Spring Stiffness
5. Screwed Down, Uniform Mounting Holes, Rely on Subframe Bumpers, Dampening on Fasteners, Increase Spring Stiffness
6. Screwed Down, Uniform Mounting Holes, Fully Rigid Construction, Damping on Fasteners, Reduce Center of Gravity
7. Screwed Down, Hook and Loop Fasteners, Fully Rigid Construction, Multiple Springs, Increase Spring Stiffness
8. Screwed Down, Magnetic Fasteners, Soft Body Energy Absorption, Vibration Supression Pendulum, Bump Stops
9. Screwed Down, Slot & Pin, Fully Rigid Construction, Cushioning, Limit Straps
10. Screwed Down, Magnetic Fasteners, Rely On Subframe Bumpers, Cushioning, Limit Straps

Adam: Welded Variations

1. Welded Chassis, Slot & Pin, Crash Detection and Avoidance/Protection, Cushioning, Bump Stops
2. Welded Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Tune Natural Frequency of Chassis, Limit Cornering Force
3. Welded Chassis, Slot & Pin, Rely on Subframe Bumpers, Tune Natural Frequency of Chassis, Limit Cornering Force
4. Welded Chassis, Studs, Rely on Subframe Bumpers, Tune Natural Frequency of Chassis, Limit Cornering Force
5. Welded Chassis, Magnetic Fasteners, Crash Detection and Avoidance/Protection, Tune Natural Frequency of Chassis, Limit Cornering Force
6. Welded Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Multiple Springs, Limit Cornering Force
7. Welded Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Cushioning, Limit Cornering Force
8. Welded Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Damping on Fasteners, Limit Cornering Force
9. Welded Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Tune Natural Frequency of Chassis, Bump Stops
10. Welded Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Tune Natural Frequency of Chassis, Increase Spring Stiffness

Ja’Quan: Adhesive Variations

1. Adhesive Chassis, Uniform Mounting Holes, Soft Body Energy Absorption, Multiple Springs, Limit Straps
2. Adhesive Chassis, Uniform Mounting Holes, Crumple zone, Multiple Springs, Limit Straps
3. Adhesive Chassis, Uniform Mounting Holes, Fully Rigid Construction, Tune Natural Frequency of Chassis, Bump Stops
4. Adhesive Chassis, Slot & Pin, Rely on Subframe Bumpers, Tune Natural Frequency of Chassis, Limit Cornering Force
5. Adhesive Chassis, Studs, Rely on Subframe Bumpers, Tune Natural Frequency of Chassis, Limit Cornering Force
6. Adhesive Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Multiple Springs, Limit Cornering Force
7. Adhesive Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Cushioning, Limit Cornering Force
8. Adhesive Chassis, Magnetic Fasteners, Rely on Subframe Bumpers, Damping on Fasteners, Limit Cornering Force
9. Adhesive Chassis, Magnetic Fasteners, Crash Detection and Avoidance/Protection, Vibration Suppression Pendulum, Increase Spring Stiffness
10. Adhesive Chassis, Hook and Loop Fasteners, Fully Rigid Construction, Vibration Suppression Pendulum, Increase Spring Stiffness

Alex: Riveted

1. Riveted, Uniform Mounting Holes, Soft Body Energy Absorption, Multiple Springs, Limit Straps
2. Riveted, Uniform Mounting Holes, Crumple zone, Multiple Springs, Limit Straps
3. Riveted, Uniform Mounting Holes, Rely on Subframe Bumpers, Multiple Springs, Limit Straps
4. Riveted, Studs, Crumple zone, Dampen on Fasteners, Reduce Center of Gravity
5. Riveted, Uniform Mounting Holes, Crumple zone, Dampen on Fasteners, Reduce Center of Gravity
6. Riveted, Studs, Crumple zone, Multiple Springs, Reduce Center of Gravity
7. Riveted, Studs, Crumple zone, Cushioning, Reduce Center of Gravity
8. Riveted, Magnetic Fasteners, Rely on Subframe Bumpers, Multiple Springs, Limit Cornering Force
9. Riveted, Magnetic Fasteners, Rely on Subframe Bumpers, Cushioning, Limit Cornering Force
10. Riveted, Magnetic Fasteners, Rely on Subframe Bumpers, Vibration Suppression Pendulum, Limit Cornering Force

Aaron: One Piece

1. One piece chassis, slot and pin component mounting, Crumple zone, vibration damping on fasteners, reduced center of gravity.
2. One piece chassis, magnetic component mounting, crash detection and avoidance, tuned chassis frequency damping, bump stop and limit strap roll reduction.
3. One piece chassis, hook and loop component mounting, soft body energy absorption, cushioning for vibration damping, roll reduction via limiting cornering force.
4. One piece chassis, mounting studs for components, Crumple zone, vibration damping on fasteners, increased spring stiffness to limit body roll.
5. One piece chassis, uniform mounting adapters for components, reliance on driveline subframe bumpers for crash protection, bump stops to limit body roll.
6. One piece chassis, slot and pin component mounts, fully rigid construction, vibration damping on fasteners, reduction of center of gravity to limit body roll.
7. One piece chassis, hook and loop component fasteners, reliance on driveline subframe bumpers for crash protection, tuned natural frequency of chassis for vibration damping, limit straps for body roll limiting.
8. One piece chassis, uniform mounting adapters for components, soft body energy absorption for crash protection, cushioning for vibration damping, limited cornering force for roll reduction.
9. One piece chassis, mounting studs for components, Crumple zone for crash protection, dampening on fasteners for vibration damping, reduced center of gravity for roll reduction.
10. One piece chassis, hook and loop fasteners for components, crash detection and avoidance, pendulum for vibration suppression, increased spring stiffness for roll reduction.

**Concept Generation Tables**

**Table 2: Morphological Chart**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Functions | Solutions | | | | |
| 1 | 2 | 3 | 4 | 5 |
| Attachment | Screwed Down | Welded | Adhesive | Riveted | One Piece |
| Modularity | Uniform Mounting Holes | Slot & Pin | Studs | Magnetic Fasteners | Hook and Loop Fasteners |
| Crash Protection | Fully Rigid Construction | Soft Body Energy Absorption | Crumble Zone | Rely on Subframe Bumpers | Crash Detection and Avoidance/Protection |
| Dampens Vibration | Multiple Springs | Cushioning | Damping on Fasteners | Tune Natural Frequency of Chassis | Vibration Suppression Pendulum |
| Limit Body Roll | Limit Straps | Bump Stops | Reduce Center of Gravity | Limit Cornering Force | Increase Spring Stiffness |

**Table 3: Medium Fidelity Concepts**

|  |  |
| --- | --- |
| **Concept #** | **Description** |
| 2 | A car that has cable chambers to organize cords, cables, and wires. |
| 17 | Quick Release Shell Chassis design for quick access and maintenance to internal components. |
| 19 | Recessed Camera Housing Chassis Design for camera protection. |
| 22 | Implement a moving mass inside the chassis to change the center of mass of the car. This allows the car to make tighter turns by keeping the force distribution on the inner and outer wheels closer to 50/50 during a turn. |
| 53 | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increase Spring Stiffness. |

**Table 4: High Fidelity Concepts**

|  |  |
| --- | --- |
| **Concept #** | **Description** |
| 12 | Centralized Electronics Hub Chassis that houses the computer, LiDAR, and other sensors for easy maintenance. |
| 55 | Screwed Down, Uniform Mounting Holes, Rely on Subframe Bumpers, Dampening on Fasteners, Increase Spring Stiffness. |
| 61 | Roll Cage Chassis |

**Concept Selection Tables & Figures**

**Figure 1: Rating Factor Explanation**

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**Table 5: Customer Requirements and Engineering Characteristics**

|  |  |  |
| --- | --- | --- |
| # | **Customer Requirements** | **Engineering Characteristics** |
| 1 | Strong and Resilient | Limits Body Roll |
| 2 | Defined Mechanical Metrics | Clears Maximum Turn Radius |
| 3 | Improved Vehicle Handling | Limits Height |
| 4 | Each Production is Identical | Supports Weight of Components |
| 5 | Ease of Access to I/O and Battery | Withstands Forces from Crash |
| 6 | - | Dampens Component Vibrations |
| 7 | - | Handles Rough Treatment |
| 8 | - | Allows for Easily Accessible I/O Ports |
| 9 | - | Protects Against Collisions |
| 10 | - | Protects Against Roll-Over |
| 11 | - | Ground Clearance |
| 12 | - | Influences Fluid About Body |
| 13 | - | Generates Downforce |

**Table 6: Binary Pairwise**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Customer Requirements** | **1** | **2** | **3** | **4** | **5** | **6** | **Total** |
| 1. Strong and Resilient | - | 1 | 1 | 1 | 1 | 1 | 5 |
| 2. Defined Mechanical Metrics | 0 | - | 1 | 1 | 1 | 1 | 4 |
| 3. Each Production is Identical | 0 | 0 | - | 0 | 1 | 1 | 2 |
| 4. Improved Vehicle Handling | 0 | 0 | 1 | - | 1 | 1 | 3 |
| 5. Modularity of Components | 0 | 0 | 0 | 0 | - | 0 | 0 |
| 6. Ease of Access to I/O and Battery | 0 | 0 | 0 | 0 | 1 | - | 1 |
| Total | 0 | 1 | 3 | 2 | 5 | 4 | n - 1 = 5 |

**Table 7: House of Quality**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Engineering Characteristic | | | | | | | | | | | | | | |
| Improvement Direction | | - | - | - | - | - | - | - | - | - | - | - | - | - |
| Units | | deg | deg | cm | N | N | N | deg | cm | N | N\*m/N\*m | cm | m/s | N |
| Customer Requirement | IWF | #1 | #2 | #3 | #4 | #5 | #6 | #7 | #8 | #9 | #10 | #11 | #12 | #13 |
| #1 | 5 | 1 |  | 1 | 9 | 9 | 3 | 9 | 3 | 9 | 9 | 1 | 1 | 1 |
| #2 | 4 | 3 | 3 | 9 | 1 | 1 |  |  |  |  |  | 3 | 1 | 1 |
| #3 | 3 | 9 | 9 | 9 | 3 |  | 1 |  |  | 3 | 9 | 9 | 3 | 9 |
| #4 | 2 |  |  |  |  |  |  |  |  |  |  |  |  |  |
| #5 | 1 |  |  |  |  |  |  | 3 | 9 |  |  |  |  |  |
| Raw Data  (572) | | 44 | 39 | 68 | 58 | 49 | 18 | 48 | 24 | 54 | 72 | 44 | 18 | 36 |
| Relative Weight | | 7.7 | 6.8 | 11.9 | 10.1 | 8.6 | 3.1 | 8.4 | 4.2 | 9.4 | 12.6 | 7.7 | 3.2 | 6.3 |
| Rank Order | | 7 | 9 | 2 | 3 | 5 | 13 | 6 | 11 | 4 | 1 | 8 | 12 | 10 |

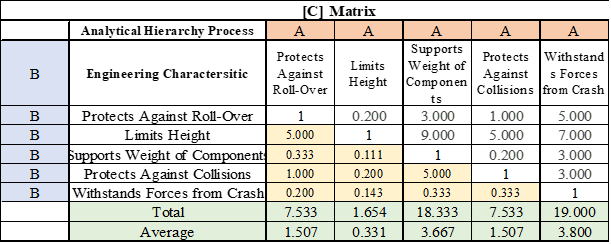
**Table 8: Pugh chart Open-Source Vehicle Model Datum**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| x | | Concepts | | | | | | | |
| Engineering Characteristics | [F1TENTH Open Source Vehicle Model](https://f1tenth.org/build) | #2 | #17 | #19 | #22 | #53 | #12 | #55 | #61 |
| Protects Against Roll-Over | - DATUM - | + | S | + | + | + | S | + | + |
| Limits Height |  | - | - | - | S | - | - | - | - |
| Supports Weight of Components |  | S | S | + | S | + | S | + | + |
| Protects Against Collisions |  | S | - | + | S | + | S | + | + |
| Withstands Forces from Crash |  | S | - | + | S | + | + | + | + |
| Total Pluses |  | 1 | 0 | 4 | 1 | 4 | 1 | 4 | 4 |
| Total Satisfactory |  | 3 | 2 | 0 | 4 | 0 | 3 | 0 | 0 |
| Total Minuses |  | 1 | 3 | 1 | 0 | 1 | 1 | 1 | 1 |
|  |  | Datum | No | Yes | No | Yes | No | Yes | Yes |

**Table 9: Pugh chart Cable Organizer Chamber Chassis Datum**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  | Concepts | | | |
| Engineering Characteristics | Cable Organizer Chamber Chassis | #19 | #53 | #55 | #61 |
| Protects Against Roll-Over | - DATUM - | + | + | + | + |
| Limits Height | S | S | S | S |
| Supports Weight of Components | S | + | + | + |
| Protects Against Collisions | + | + | S | + |
| Withstands Forces from Crash | + | S | S | + |
| Total Pluses | 3 | 3 | 2 | 4 |
| Total Satisfactory | 2 | 2 | 3 | 1 |
| Total Minuses | 0 | 0 | 0 | 0 |
|  |  | Yes | Yes | No | Yes |

**Table 10: Initial Comparison [C] Matrix**



**Table 11: Normalized [C] Matrix**

A screenshot of a computer screen

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**Table 12: Consistency Check**

A screenshot of a table

Description automatically generated

**Table 13: [Pi] Matrix**

A screenshot of a computer

Description automatically generated**Table 14: Alternative Value Matrix**

A close-up of a list of words

Description automatically generated

**Table 15: AHP EC [C] Matrix for Protect Against Roll-Over**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **[C] Matrix for Protect Against Roll-Over** | | | | | |
|  | **Analytical Hierarchy Process** | **A** | **A** | **A** |  |
|  |  | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | Recessed Camera Housing Chassis | Roll Cage Chassis | **Average** |
| **B** | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | 1 | 0.333 | 0.200 | 0.511 |
| **B** | Recessed Camera Housing Chassis | 3.000 | 1 | 0.333 | 1.444 |
| **B** | Roll Cage Chassis | 5.000 | 3.000 | 1 | 3.000 |
|  | **Total** | 9.000 | 4.333 | 1.533 | 4.956 |
|  | **Average** | 3.000 | 1.444 | 0.511 |  |

**Table 16: AHP EC norm[C] Matrix for Protect Against Roll-Over**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **norm[C] Matrix for Protect Against Roll-Over** | | | | | |
|  | **Analytical Hierarchy Process** | **A** | **A** | **A** |  |
|  |  | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | Recessed Camera Housing Chassis | Roll Cage Chassis | **Design Alternative Priorities {Pi}** |
| **B** | Screwed Down, Magnetic Fasteners, Fully Rigid Construction, Damping on Fasteners, Increased Spring Stiffness Chassis | 0.111 | 0.077 | 0.130 | 0.106 |
| **B** | Recessed Camera Housing Chassis | 0.333 | 0.231 | 0.217 | 0.260 |
| **B** | Roll Cage Chassis | 0.566 | 0.692 | 0.652 | 0.633 |
|  | **Total** | 1.000 | 1.000 | 1.000 | 1.000 |

**Table 17: Consistency Check for Protect Against Roll-Over**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Consistency Check | | | | | |
| Weighed Sum Vector {Ws} = [C]{Pi} | {Pi} | Cons = {Ws}. /{Pi} | Average Consistency {λ} | Consistency Index {CI} | Consistency Ratio {CR} |
| 0.320 | 0.106 | 3.011 | 3.039 | 0.019 | 0.037 |
| 0.790 | 0.260 | 3.033 |
| 1.946 | 0.633 | 3.072 |

# Appendix A: APA Headings (delete)

# Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

## Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

### Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

#### Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

##### Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

See publication manual of the American Psychological Association page 62

# Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 1 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.



Figure 1. Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table   
The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

|  |  |
| --- | --- |
| Level of heading | Format |
| 1 | **Centered, Boldface, Uppercase and Lowercase Heading** |
| 2 | Flush Left, Boldface, Uppercase and Lowercase |
| 3 | Indented, boldface lowercase paragraph heading ending with a period |
| 4 | Indented, boldface, italicized, lowercase paragraph heading ending with a period. |
| 5 | Indented, italicized, lowercase paragraph heading ending with a period. |

# References

**There are no sources in the current document.**