PROVE Primary Battery Structure
Scope of Work

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Written By:
Soren Barclay
sbarclay@calpoly.edu
Ryan Yu
ryu18@calpoly.edu
John Burkhart
jdburkha@calpoly.edu
Andy McCormick
anmccorm@calpoly.edu

Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
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Prepared For:
Caleb Erlenborn
PROVE Project Manager
cerlenbo@calpoly.edu

Abstract:

Prototype Vehicles Laboratory (PROVE Lab) is constructing a battery electric vehicle that needs to meet specific requirements with range and safety being the two most critical specifications. The primary battery structure is one of the most critical parts of the vehicle and must be able to support the vehicle's ability to reach its range requirement while keeping the battery cells secure and the occupants safe in the event of an emergency. The needs of stakeholders were considered in the scope so that engineering principles can be used to create a satisfactory product.

To help generate ideas, many ideation techniques were used along with technical research into product data and engineering standards. Other existing designs were listed as a source of comparison with the current product and to show potential solutions to problems and constraints that this project faces. A Quality Function Deployment (QFD) house of quality was used to compare data from existing products to stakeholder needs and engineering principles. So far, a CAD structure has been created on Siemens NX, which helps determine dimensional constraints. The battery structure is at risk of being damaged by heavy loads from crashes and thermal shocks from electrical failure. Therefore, the structure will need to be strong enough to support the stability of the lithium-ion battery cells contained. It also must be able to remove heat through an air circulation system.

This Scope of Work will define all essential goals of this project as well as how this project will be organized over a long period of time. It will also outline how work on the project will be conducted and how the team will be scheduled.

Contents

1. Introduction

The Prototype Vehicles Laboratory is constructing an electric car called “Mila” whose goal is to have a range of over one thousand miles on a single charge. To achieve this record-breaking range, PROVE Lab needs a way to integrate approximately 6480 lithium-ion batteries of model 21700. The solution to this problem is for our team to design a primary battery structure that houses and protects the batteries from mechanical and thermal loads.

The primary benefactor of this project is PROVE itself, but there are numerous people within the club that are being considered, such as the PROVE project manager, the technician, the driver, and the manufacturer. The battery structure will be designed to suit all their needs by being as safe, constructable, and accessible as possible. The team working on this project includes Soren Barclay, Andy McCormick, Ryan Yu, and John Burkhart—all of whom are experienced members of PROVE Lab.

This report will outline the specific needs of each benefactor, the qualitative and quantitative requirements the vehicle must meet, and the schedule this project will follow. The background section discusses the sponsor’s needs, and preliminary research and information that will guide our design. The project scope will discuss the expectations of our team and what we want to accomplish in the coming months. The objectives section covers our problem statement, specifications and constraints that will drive our design. The project management section will outline our technical approach to complete this design challenge and the major milestones.

2. Background

Since beginning this project, we have reached out to the members of the Prototype Vehicle Laboratory to better understand the existing systems, and the need for a primary battery structure. We spoke extensively with the project manager to best understand the project requirements. Since then, we have remained in close contact with PROVE throughout the iterative process. The following information is summarized in the sponsor wants and needs in section 3.2.

The PROVE endurance vehicle, aims to break the one-thousand-mile world record for distance traveled on a single charge. The safe storage of the vehicle's batteries is paramount. Thermal runaway events can occur from circuitry issues, mechanical deformation, or high operating temperatures [1]. For this reason, the primary purpose of the primary battery structure must keep the battery cells within their rated load and temperature.

Secondarily, the primary battery structure must meet size and weight requirements. PROVE Lab is setting out to break the endurance record. For this reason, we will optimize weight while satisfying the safety requirements. Our team is considering using a carbon fiber structure. This will reduce the weight of the structure without sacrificing strength. However, there are several manufacturing and cost considerations that we must explore to determine if this is a feasible option.

2.1 Commercial and Experimental Primary Battery Structures

There is ample existing research on existing battery structure designs. For example, Tesla has a patented battery structure that features multiple modules to house battery cells in the vehicle's wheelbase [2]. The structure insulates the battery cell and improves temperature regulation. Toyota's has a patent on a primary battery structure stored in the wheel base of a vehicle. The outer shell utilizes steel as a likely material [3]. The Proterra inc. uses a similar method of a battery pack housed in the floor of the vehicle [4]. Additionally, Subaru designed a "battery support structure" housed in the floor of the vehicle [5]. These patents expose important design considerations such as mitigating battery deformation and regulating temperature.

However, each of these existing designs use the floor of the chassis as an integrated primary battery structure. Our sponsor has defined that battery must exist in the back half of the car. As a result, we must build a structure that is not integrated into the floor of the car. This requirement provides an opportunity to utilize a nonconventional structure. A burgeoning area of research is the usage of honeycomb structures. Honeycomb structures are useful as low-density structures that allow for excellent resistance against transverse deformation from axial loads. This structure could allow the battery structure to withstand heavy loads while minimizing weight [6].

2.2 Mechanical Loading of Lithium-ion Batteries

Understanding the strength of batteries is an essential key input into how we design our pack. It is essential that we avoid a thermal runaway event, and thus the batteries must not experience mechanical failure. Batteries are complicated structures that fail differently depending on charge, temperature, etc. Data on experimental failure given different failure modes (i.e. bending, axial, etc.) clarifies this requirement [7]. Additionally, it is necessary to understand Battery failure is a coupled model where the thermal model, impacts the battery performance, which in turn affects the mechanical model. Experimental failure results given different temperature and state of charge further clarifies the failure of batteries [8].

2.3 Battery Cooling systems and safe operating temperatures

Batteries in electric vehicles tend to overheat quickly due to current draw and imperfections in circuits, which can cause short circuits and even fires. While this risk is not as great in the Mila due to its small size and relatively low power demands, a system to remove heat from the battery structure will be necessary.

A simple design would be to use an air-cooling system with an input fan and some output vents. According to one paper [9], there are many methods to improving an air-cooled system, such as using two output vents on each side of the structure or using staggered winglets and fins. These solutions would improve the structure's ability to remove heat from the structure by convection.

More complex solutions also exist, as discussed in [10], Ming Shen and Qing Gao proposed a refrigeration cooling structure for larger electric vehicles. This battery thermal management system, (BTMS) is a potential solution for the structure's heat problem, which could cause severe damage to the car if left unchecked. This solution may be more powerful than necessary, but understanding other systems will help in developing an effective cooling system for the batteries.

Overall, a large cooling system will likely be unnecessary for the Mila, which will not likely experience high electrical demands, but it is still important to control the temperature of the battery to optimize efficiency and prevent overheating.

2.4 Chassis Integration

The Mila's chassis has already been constructed, and there are several methods to integrate the batter structure to it. Current options include using steel plates and tubes to connect the boxes to the chassis. These support structures should keep the structure firmly in place while absorbing loads from a crash. Another consideration is that carbon fiber cannot be directly attached to the structure due to corrosion risks, so a buffer material such as fiberglass must be used.

3. Project Scope

Project scope defines the needs and the desired functionality of our project. The primary function of the battery structure is to keep the batteries securely fastened to the chassis in all load cases while preventing individual battery cells from thermal runaway to do mechanical loading. This function is derived from the stakeholders need to protect the driver in all modes of operation.

3.1 Boundary Sketch

Figures 1 and 2 below show which parts of the car and chassis our team can modify and the space we must work with. The battery boxes, in their current arrangement, are shown in figure 2 which our design must fasten to the chassis.

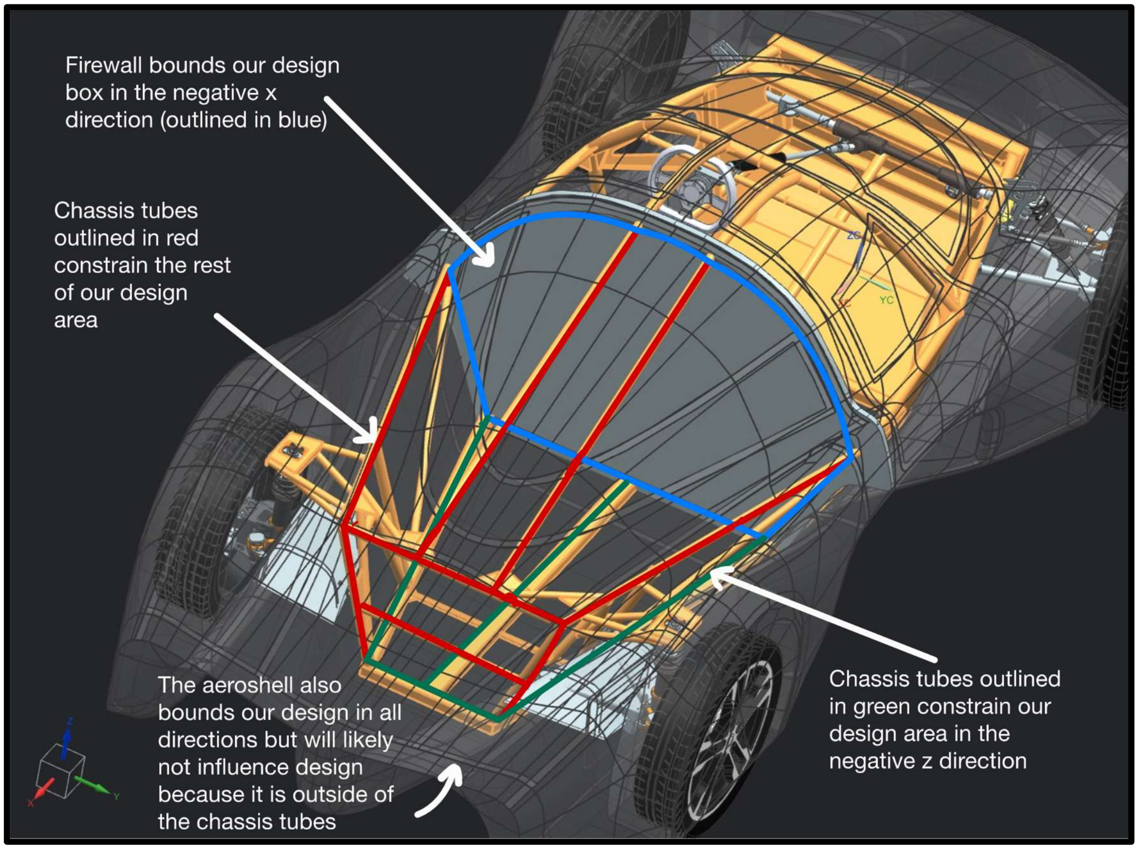

Figure 1: The illustrated figure above, taken from the PROVE CAD documentation [12] shows the physical geometric constraints to our design must adhere to. The chassis tubes (outlined in red and green) combined with the firewall (outlined in blue) create a bounding "box". Our design must fasten the battery boxes shown below in figure 2 to the chassis tubes outlined above while staying within the bounding box. In addition to the chassis tubes, our design must also maintain a clearance of xx inches with the Aeroshell. (translucent / gray) The design can modify the chassis tubes i.e., by welding but should not degrade the structural integrity of the chassis. [PROVE Doc]

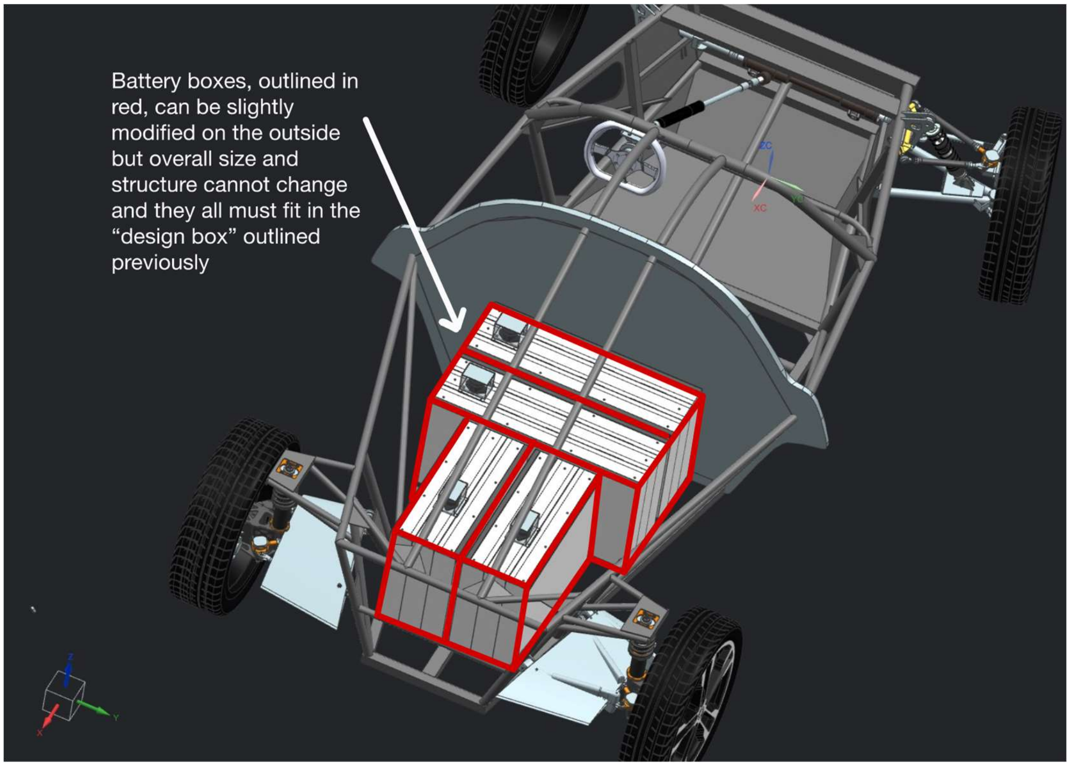

Figure 2: The figure above, taken from the PROVE CAD files [12], illustrates the 5 battery boxes currently designed. Our design can slightly modify the exterior and arrangement of these boxes, but the overall structure and size must stay the same. These 5 boxes must be mounted to the chassis illustrated in figure 1 above while staying in the bounding box. Additionally, we must allow for an additional smaller battery box to be added should the users desire another battery box. We will include the battery boxes and battery cells in our simulations/analysis to get a better look at what is happening to the individual battery cells with different load cases.

3.2 Stakeholders' Wants and Needs

The primary stakeholder in our battery structure design is our sponsor, PROVE, within which the specific stakeholders can be broken down to: Manufacturers, Technicians, and Drivers. Since PROVE is an engineering organization our group started with a complete list of engineering specifications our structure must adhere to which will specifically be addressed in Table 1. Additionally, the car for which this structure is designed is not intended for commercial use or large-scale production which significantly reduces our design constraint and amount of end users. The following needs have been identified using stakeholder interviews and analyzing the PROVE requirements [10].

From the manufacturing perspective, our design must be manufacturable by students on the team as specified in the provided requirements [10]. Our team is especially lucky to have been members of PROVE for years such that we have extensive knowledge of our manufacturing capabilities. Along these lines, the battery structure must be cheap / within PROVE's means to construct. We have a great understanding of the current stock and composites at our disposable, and any additional materials should be minimized for cost. In addition to in house manufacturing, the integration of the battery structure must be doable by members of PROVE who did not directly participate in its design. PROVE has a fast member turn around and this design shouldn't be too complicated that only the original members to design it can manufacture and integrate it.

From a service / technician perspective, the battery structure must be easily serviceable by PROVE members without excessive tool requirements as specified in the PROVE requirements [10]. In order to tune the electronics system, the batteries will need to be regularly accessed and possibly modified. The batteries should be easily serviced with only two members; however, removing the batteries will require a crane. Additionally, the battery structure design should not be excessively complicated so that future PROVE members will have difficulty servicing it.

The driver of "Mila" possesses the most critical needs. First and foremost, the driver needs safety. In the event of a crash the battery structure should prevent thermal runaway due to battery cell mechanical abuse as well as protect the driver from impact with the batteries/battery boxes. The battery structure should also minimize load transmitted to battery cells in the event of normal driving encounters i.e., a 3g bump, moose test, or intense breaking. The vehicle is expected to have a normal operating speed of 35 miles per hour, so the structure must be stable at that speed. In normal run cases, the battery structure should also allow enough air circulation to prevent battery overheating and failure.

The goal of "Mila" is to maximize the vehicle's range. To align with this goal, the weight of our design must be minimized although this is not a driving design requirement. These needs will be discussed quantitatively in subsequent sections.

3.3 Functional Decomposition

The primary function of the primary battery structure is to keep the battery boxes mounted to the chassis. SAE standard J2929, [13], illustrates the minimum requirements of a battery system for the system to be usable in an electric vehicle. As specified in SAE J2929, the batteries must remain operable in the event of nominal vibrations, a crash, and a battery drop for up to an hour after the event to prevent injury to the driver. As seen in [14] and [15], the maximum allowable force an individual 21700 cell can take is about 5000lb of stress which equates to about 0.16 inches of deflection before a short circuit occurs and thermal runaway begins. The battery structure's primary function is to prevent cells from seeing these loads under the aforementioned load cases.

In addition to preventing battery failure due to mechanical loading, the battery structure also must provide adequate heat dissipation to keep batteries operating at their optimal temperature. SAE standard J3073, [16] illustrates the importance of different battery thermal management systems and the results they have on the operation and safety of the vehicle. An investigation of the 21700 Li-Ion cells, [18], indicates cells should discharge at an optimal temperature of 105 F. Slightly Exceeding this temperature will have little effect on the performance and safety of the vehicle. However, significant temperatures can cause catastrophic failure of the battery system. The battery structure must provide enough circulation to maintain battery temperatures of 105 F. It is unlikely that heating will be necessary to reach this temperature, but cooling may be necessary to prevent thermal runaway.

Additionally, [13] specifies the battery structure must be puncture resistant. As investigated in [17], road debris can significantly damage the battery pack and cause thermal runaway very quickly. Therefore, materials must be chosen that possess strong impact strength. The vehicle's outer shell, the Aeroshell, will have a layer of Kevlar to prevent intrusion, however, this requires redundancy considering the catastrophic failure should the batteries be punctured.

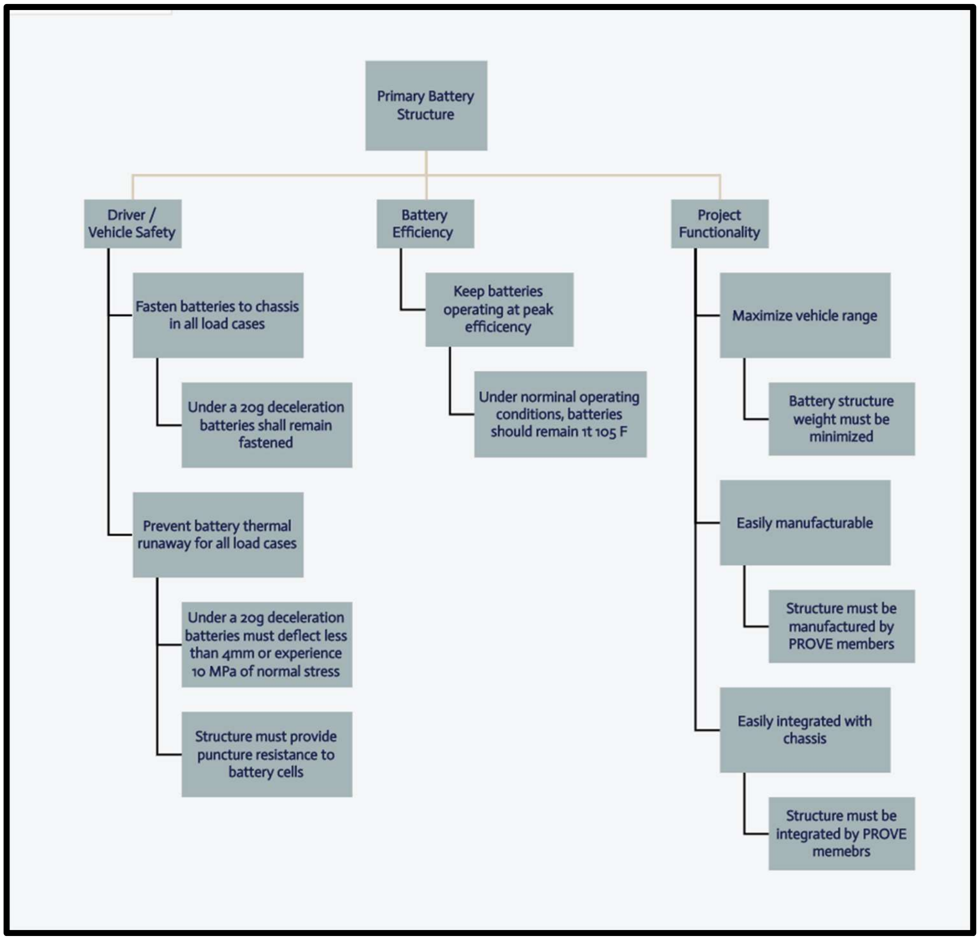

Figure 3: Graphical representation of the battery structure functional decomposition. The overall battery structure functions are provided vehicle and driver safety, maximize battery efficiency, and promote the PROVE project functionality. Each of these functions has been broken down into more specific functions with quantitative measurements.

3.4 Final Deliverables

Our team plans to deliver a working and tested full size battery structure come Spring 2023. We will integrate our structure with the chassis and with the battery boxes should they be available. We will also provide ample documentation regarding our design decisions and process, in addition to detailed manufacturing and servicing documents. Should our team fail to manufacture the final structure by the end of the year we will provide PROVE with an extensive manufacturing and integration plan such that it can be completed by any other member of PROVE.

4. Objectives

4.1 Problem Statement

The Cal Poly Prototype Vehicles Laboratory's "Mila" requires a structure to safely house the lithium-ion battery boxes while addressing the vehicle's range requirements, loads, and packaging constraints because the Mila needs to safely achieve a range of at least one thousand miles.

4.2 QFD Process

The needs of the stakeholders ("Who" section) were evaluated using a house of quality, located in appendix B. The house of quality compares customer requirements ("What" section) with engineering specifications ("How" section) to help understand design needs and how to solve them. This structure also displays the correlation between engineering specifications to help streamline the process development. The house of quality also compares existing products ("Now" section) to our own design, using a numbered scale from one to five to determine how effectively a current product has met customer requirements. The final section ("How Much" Section) lists numerical requirements, their importance, and how they compare to current products.

4.3 Engineering Specifications

Table 1: This is a list of specifications the car. Some requirements are qualitative (yielding) and will be determined by later tests. Others are qualitative based on existing dimensions of the car.

Specification	Specification Description	Requirement	Tolerance	Risk	Compliance
1	Operational Battery Temperature	105° F	Max	L	T
2	Battery Structure Weight	100lbs	Max	H	A
3	Physical Size/ Dimensions (Trapezoidal Shape)	50'' Long 22'' Wide (Base 1) 36'' Wide (Base 2) 20'' Tall	Max Max Max Max	M	A
4	Manufacturability	Under 2 months	Max	M	A
5	Manufacturing Cost	$10000	Max	H	A
6	Vehicle Crash Test - Deflection	1mm	±0.1''	H	A
7	Vehicle crash test - Battery box ultimate strength	FOS of 2.0	±0.5	M	A
8	Vehicle crash test - Battery cell yielding	5000lb	±50lbs	L	A

Risk of meeting Key: (H) High, (M) Medium, (L) Low

Compliance Key: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

The engineering specifications are explained below:

1. Operational Battery Temperature The safe operating temperature of the batteries is 105° F, so this is the maximum temperature of the structure. The vehicle is not expected to become too cold to operate, but the structure should be thermally insulated to protect against hot weather.
2. The battery structure must be able to remove heat through air circulation. The battery structure's weight is essential because if the structure is too heavy, the car's range will be compromised. This means that the weight of the battery structure is one of the most crucial specifications, and this will affect other specifications.
3. The dimensions (listed above) are based on the chassis of the car, which the battery structure must fit. The base is trapezoidal, giving us more room to configure a battery structure to how we see fit.
4. The battery structure should be manufactured in under 2 months, which should be plenty of time to construct and install the structure.
5. The cost must be below $10,000. This one is a high-risk cost because cost overruns are common in project like these, especially given the cost of the cells, and manufacturing. The budget is subject to change however, and costs can be reduced by having project members perform manufacturing themselves.
6. The battery structure deflection is critical because it is necessary to reduce internal damage to battery cells and other components.
7. The battery structure must have a reasonable factor of safety for its ultimate strength. More information of the forces sustained by the vehicle and the dimensions of the structural components are needed, but a factor of safety of 2.0 is reasonable for the project that is being constructed.
8. The battery cells are designed to handle up to 5000lbs of force before critical damage is sustained. The battery structure should be able to handle most of the force, which means this is not a high-priority specification.

5. Project Management

In order to generate the best battery structure, we must ensure that all of the design specifications are satisfied and optimized. Our overall design approach will follow design for structural integrity, thermal analysis, and cost/manufacturability. Listed below are the various aspects that will go into our approach:

5.1 Design Considerations

Our main design considerations comprise of design for structural integrity, manufacturability, thermal effects, and weight. For structural integrity we must define all our expected loads and battery placement and boundary conditions (e.g. mounting locations). From there we would define what failure mode will drive our design (e.g. stiffness). To design for these failure modes, we will use factors of safety of 1.2 to yield and 1.5 to ultimate failure (subject to change depending on sponsor needs). Since one of our primary objectives is to protect the batteries, we must also consider whether our batteries will fail on a cell level (e.g. inertial loads on the front row of cells) or battery box level. To design for thermal loads, we must consider the effects of thermal runways. This means ensuring that there is adequate cooling through the system. We would need to design ducts with inlets and outlets optimized for cooling. To design for the weight specifications, we must select a material with a high strength-to-weight ratio (e.g. carbon fiber or aluminum). If we can't achieve a working design, we would need to select a stronger and/or stiffer material. We also will use our results from finite element analysis to remove any excess material that do not contribute to our load paths.

5.2 Analysis

To satisfy our design specifications, we must perform appropriate analysis. For our structural specifications, we will perform finite element analysis with accompanying hand calculations to validate our results. One method [21] describes a finite element model of a battery structure with five bending and compression loads acting on a homogenous battery structure. This process will help simulate how the structure will act under collision loads.

To further ensure the integrity of our results, we must use appropriate software for the type of analysis and mesh our parts with appropriate element types. In addition to static analysis, we may also consider explicit FEM solvers to model dynamic loading and nodal analysis. To satisfy our thermal requirements we may consider performing free convection analysis and transient analysis while accounting for worse case weather conditions. To evaluate the effectiveness of our ventilation system, we may consider using computational fluid dynamics (CFD).

With all these design considerations, we may rank the importance of each design aspect and allocate our time and efforts accordingly. Because of our current skillset and project timeline, we may need to reduce the extent of our analysis. (eg. CFD, thermal analysis, FEM meshing with anisotropic composite behavior)

5.3 Deliverables

Deliverable	Description	Due date
Scope of work	Describes how goals will be achieved	10/19/22
Generate preliminary design	1st design of the battery structure will be created	10/26/22
Perform initial analysis	The design will be analyzed with computer simulations and mathematical calculations	11/7/22
Conduct design changes	The Preliminary design will be improved and formalized based on results from the initial analysis	11/16/22
Preliminary Design Review	The design will be presented and discussed with the sponsor, coach, and other engineers	11/15/22
Conduct PDR design changes	The design will be updated based on feedback from the Preliminary Design Review	11/29/22
Test design	The design will be validated with either a prototype or a computer simulation/FEA analysis	1/17/23
Interim Design Review	The design will be overviewed with the team prior to CDR	1/24/23
Critical Design Review	Updated design will be presented and scrutinized by the sponsor, coach, and other engineers	2/14/23
Make final iterations	Final changes to the design will be made based on data from the critical design review.	2/21/23
Finalize bill of materials	A list of materials needed to complete the project will be finalized.	3/1/23
Fabrication	Fabricate all parts and integrate into the “Mila”	5/19/23
Final Design Review	The final edition of the design will be presented to the sponsor, coach, and other engineers	6/9/23

Table 2: This table outlines the major deliverables and tasks that the team will accomplish

Leading up to our first preliminary design review there are various tasks we must complete per our Gantt chart (see appendix C). The first of which is brainstorming housing architypes and select three via a decision matrix. We will then perform preliminary analysis to determine the best architecture to build our structure with. Once we have a preliminary architecture, we must validate our material selection and optimize our design per our engineering specifications.

6. Conclusion

We are tasked with designing the primary battery structure for PROVE Lab's electric endurance vehicle. The primary purpose of this structure is to fasten the large battery boxes to the steel frame chassis. This document serves to outline the specifics of the problem we are facing. In the future, we will reference the Scope of Work to verify we are solving the correct problem PROVE Lab wants us to solve. We also outlined relevant previous solutions to this problem that will prove useful when ideating viable solutions.

Most importantly the battery structure must protect the driver in normal conditions and in extreme circumstances. The nominal load cases have been determined from provided PROVE requirements and include a 3g bump, moose test (swerve test), and vibrations. The batteries should function nominally under all these conditions. The structure must also be puncture resistant and prevent thermal runaway due to mechanical loading in the event of a crash. In the coming weeks, we will be working on developing many solutions to the problem through ideation and will have a preliminary design review in early December illustrating our best solution and preliminary model / analysis. We would appreciate confirmation that the scope of work provided is in line with what PROVE would like us to accomplish.

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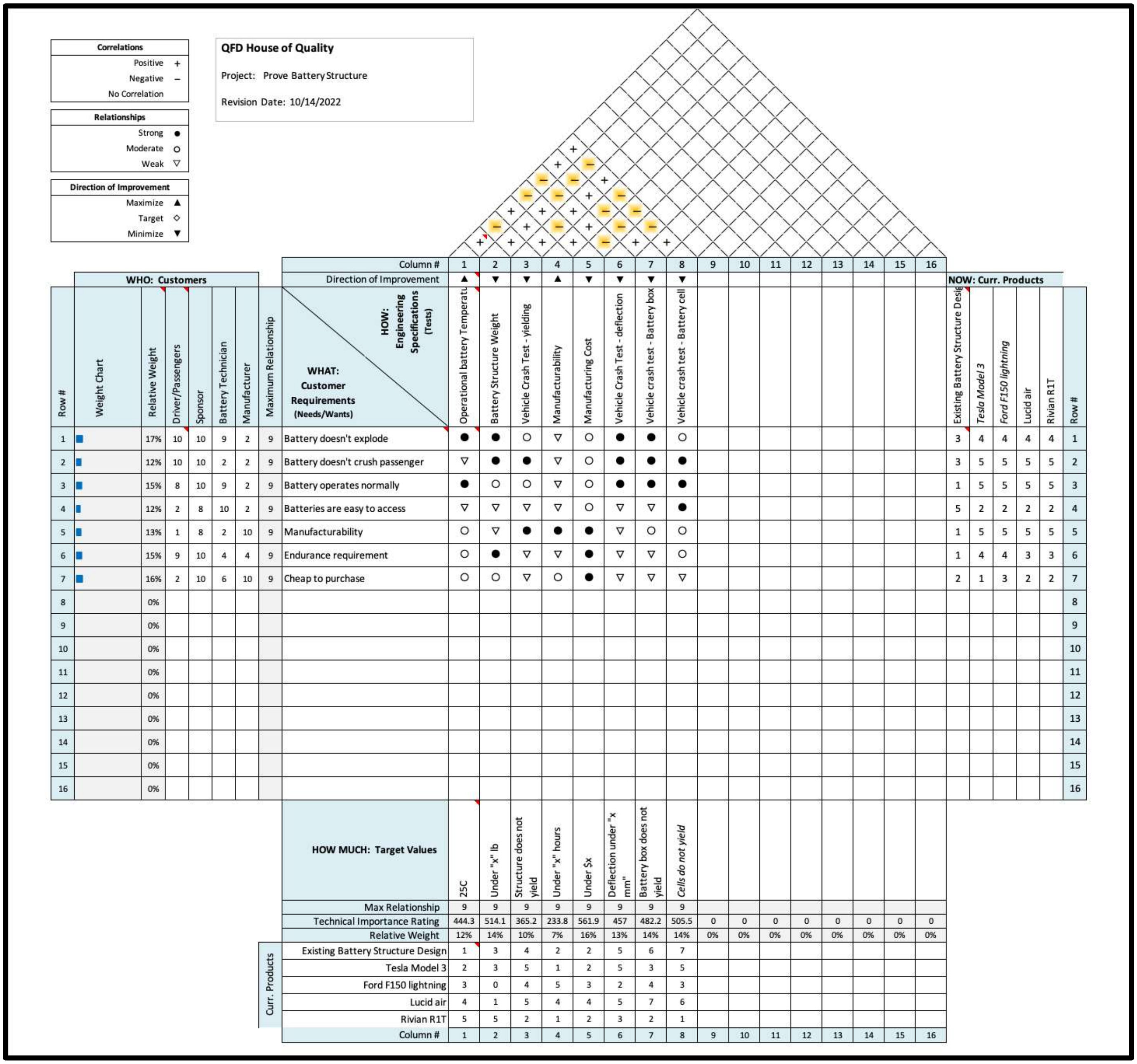
Appendix A: House of Quality



Correlations
Positive +
Negative –
No Correlation

Relationships
Strong ●
Moderate ○
Weak ▽

Direction of Improvement
Maximize ▲
Target ◇
Minimize ▼

QFD House of Quality

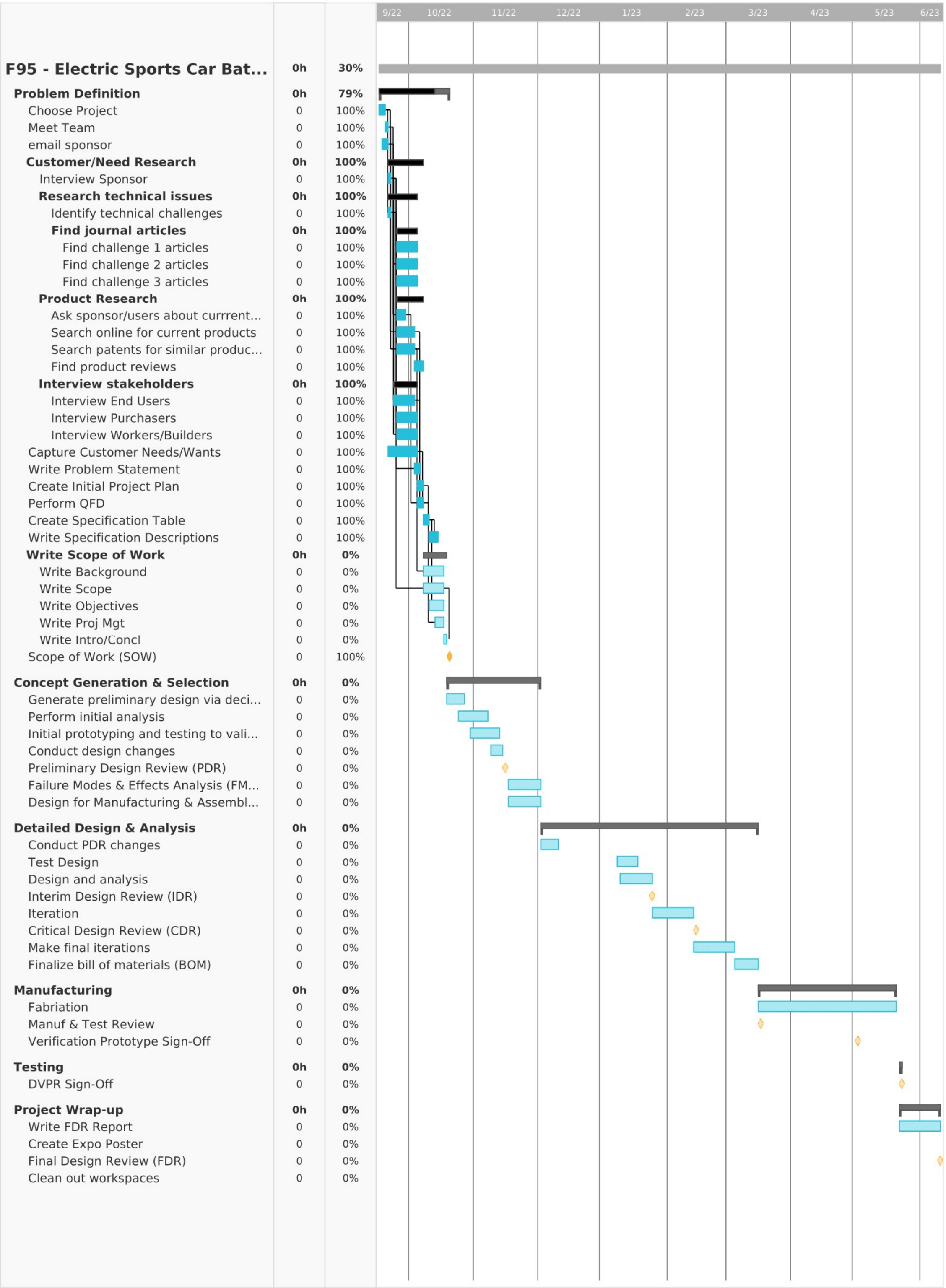
Project: Prove Battery Structure

Revision Date: 10/14/2022

								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
	WHO: Customers							Direction of Improvement	▲	▼	▼	▲	▼	▼	▼	▼									NOW: Curr. Products					
Row #	Weight Chart	Relative Weight	Driver/Passengers	Sponsor	Battery Technician	Manufacturer	Maximum Relationship	HOW: Engineering Specifications (Tests) WHAT: Customer Requirements (Needs/Wants)	Operational battery Temperatu	Battery Structure Weight	Vehicle Crash Test - yielding	Manufacturability	Manufacturing Cost	Vehicle Crash Test - deflection	Vehicle crash test - Battery box	Vehicle crash test - Battery cell									Existing Battery Structure Desig	*Tesla Model 3*	*Ford F150 lightning*	Lucid air	Rivian R1T	Row #
1	■	17%	10	10	9	2	9	Battery doesn't explode	●	●	○	▽	○	●	●	○									3	4	4	4	4	1
2	■	12%	10	10	2	2	9	Battery doesn't crush passenger	▽	●	●	▽	○	●	●	●									3	5	5	5	5	2
3	■	15%	8	10	9	2	9	Battery operates normally	●	○	○	▽	○	●	●	●									1	5	5	5	5	3
4	■	12%	2	8	10	2	9	Batteries are easy to access	▽	▽	▽	▽	○	▽	▽	●									5	2	2	2	2	4
5	■	13%	1	8	2	10	9	Manufacturability	○	▽	●	●	●	▽	○	○									1	5	5	5	5	5
6	■	15%	9	10	4	4	9	Endurance requirement	○	●	▽	▽	●	▽	▽	○									1	4	4	3	3	6
7	■	16%	2	10	6	10	9	Cheap to purchase	○	○	▽	○	●	▽	▽	▽									2	1	3	2	2	7
8		0%																												8
9		0%																												9
10		0%																												10
11		0%																												11
12		0%																												12
13		0%																												13
14		0%																												14
15		0%																												15
16		0%																												16

	HOW MUCH: Target Values	25C	Under "x" lb	Structure does not yield	Under "x" hours	Under $x	Deflection under "x mm"	Battery box does not yield	*Cells do not yield*								
	Max Relationship	9	9	9	9	9	9	9	9								
	Technical Importance Rating	444.3	514.1	365.2	233.8	561.9	457	482.2	505.5	0	0	0	0	0	0	0	0
	Relative Weight	12%	14%	10%	7%	16%	13%	14%	14%	0%	0%	0%	0%	0%	0%	0%	0%
Curr. Products	Existing Battery Structure Design	1	3	4	2	2	5	6	7								
	Tesla Model 3	2	3	5	1	2	5	3	5								
	Ford F150 lightning	3	0	4	5	3	2	4	3								
	Lucid air	4	1	5	4	4	5	7	6								
	Rivian R1T	5	5	2	1	2	3	2	1								
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix B: Gantt Chart



F95 - Electric Sports Car Bat...	**0h**	**30%**
Problem Definition	**0h**	**79%**
Choose Project	0	100%
Meet Team	0	100%
email sponsor	0	100%
Customer/Need Research	**0h**	**100%**
Interview Sponsor	0	100%
Research technical issues	**0h**	**100%**
Identify technical challenges	0	100%
Find journal articles	**0h**	**100%**
Find challenge 1 articles	0	100%
Find challenge 2 articles	0	100%
Find challenge 3 articles	0	100%
Product Research	**0h**	**100%**
Ask sponsor/users about currrent...	0	100%
Search online for current products	0	100%
Search patents for similar produc...	0	100%
Find product reviews	0	100%
Interview stakeholders	**0h**	**100%**
Interview End Users	0	100%
Interview Purchasers	0	100%
Interview Workers/Builders	0	100%
Capture Customer Needs/Wants	0	100%
Write Problem Statement	0	100%
Create Initial Project Plan	0	100%
Perform QFD	0	100%
Create Specification Table	0	100%
Write Specification Descriptions	0	100%
Write Scope of Work	**0h**	**0%**
Write Background	0	0%
Write Scope	0	0%
Write Objectives	0	0%
Write Proj Mgt	0	0%
Write Intro/Concl	0	0%
Scope of Work (SOW)	0	100%
Concept Generation & Selection	**0h**	**0%**
Generate preliminary design via deci...	0	0%
Perform initial analysis	0	0%
Initial prototyping and testing to vali...	0	0%
Conduct design changes	0	0%
Preliminary Design Review (PDR)	0	0%
Failure Modes & Effects Analysis (FM...	0	0%
Design for Manufacturing & Assembl...	0	0%
Detailed Design & Analysis	**0h**	**0%**
Conduct PDR changes	0	0%
Test Design	0	0%
Design and analysis	0	0%
Interim Design Review (IDR)	0	0%
Iteration	0	0%
Critical Design Review (CDR)	0	0%
Make final iterations	0	0%
Finalize bill of materials (BOM)	0	0%
Manufacturing	**0h**	**0%**
Fabriation	0	0%
Manuf & Test Review	0	0%
Verification Prototype Sign-Off	0	0%
Testing	**0h**	**0%**
DVPR Sign-Off	0	0%
Project Wrap-up	**0h**	**0%**
Write FDR Report	0	0%
Create Expo Poster	0	0%
Final Design Review (FDR)	0	0%
Clean out workspaces	0	0%