PROJECT NOTEBOOK

FORMULA SOCIETY OF AUTOMOTIVE ENGINEERS - ELECTRIC VEHICLE
ECE419/420

PROJECT MANAGERS: SAM CASAUS, DAVID SHAPIRO, LUCAIS MARTIN, SALVADOR LAMBERT AND JESSICA SMYTH

AADESH NEEL
ALEJANDRO RUIZ
BRANDON LEE
CYRUS STEPHENS
JOSHUA ATENCIO
KENDRIC ORTIZ
MIKE CHU
NATHAN HINES
SETH JOHANNES
ZONGLIN LI

UNIVERSITY OF NEW MEXICO
SCHOOL OF ENGINEERING

SPONSOR: CHARLES FLEDDERMANN
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ALBUQUERQUE, NM 87131

4/24/2020

FINAL REPORT

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4/21/2020

1 OVERVIEW

1.1 Executive Summary

The UNM Lobo Motorsports program desired to create an Electric Vehicle (EV) prototype so that future students could take an improvised, rules compliant Electric Vehicle to the annual Formula SAE (FSAE) competition. Future students will design and develop a competition ready vehicle with the foundation of our EV prototype. To reduce time, cost, and labor we used the existing 2014 Internal Combustion car and converted it into an EV prototype without affecting the chassis. The research for this project started in 2018 and continues to this day.

This team consists of 11 students majoring in computer and electrical engineering. Aadesh Neel is an electrical engineer with a track focus in electromagnetics. Alejandro Ruiz is a computer engineer with a track focus in software. Brandon Lee is a computer engineer with a track focus in software. Cyrus Stephens is an electrical engineer with a track focus in controls. Jessica Smyth is an electrical engineer with a track focus in materials and devices. Joshua Atencio is an electrical engineer with a track focus in electromagnetics. Kendric Ortiz is an electrical engineer with a track focus in electromagnetics. Mike Chu is a computer engineer with a track focus in software. Nathan Hines is an electrical engineer with a track focus in electromagnetics. Seth Johannes is an electrical engineer with a track focus in electromagnetics. Zonglin Li is an electrical engineer with a track focus in electromagnetics. Professor Charles Fleddermann sponsored our project and Gene Kallenbah mentored our project and provided the highest technical guidance.

Our team accomplished the design and layout phase of the project circuit schematics. We were also able to define a parts list of the components we needed. Unfortunately, due to COVID-19 we were unable to manufacture and test the circuit boards. This greatly devastated the team and caused a huge setback in our goals but we know the work we finished will still set a strong foundation and prepare next year students to develop the desired rules compliant electric vehicle.

1.2 Abstract

Development of a Formula SAE Electric Vehicle is a significant design and production challenge. The members of this team worked on different sub-systems of the vehicle including, but not limited to, tractive system battery, motor controller, motor, data acquisition, logging, display, battery management, battery charger, power distribution, controls, brake system, tractive system, acceleration system and relay controls. Our team gained tremendous amount of experience in real-world engineer as building a vehicle from scratch would provide. We learned circuit design, troubleshooting systems, high voltage safety, engineering ethics, high level management and teamwork.

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4 PROBLEM DESCRIPTION

<u>BMS I/O (Nathan Hines)</u>
This project is addressing the problem of communication between the high voltage BMS (Battery Management System) and the low voltage controller systems of the FSAE Electric Vehicle. In order to comply with the FSAE rules, we need to have these systems isolated. However, we need these systems to communicate to maintain safety.

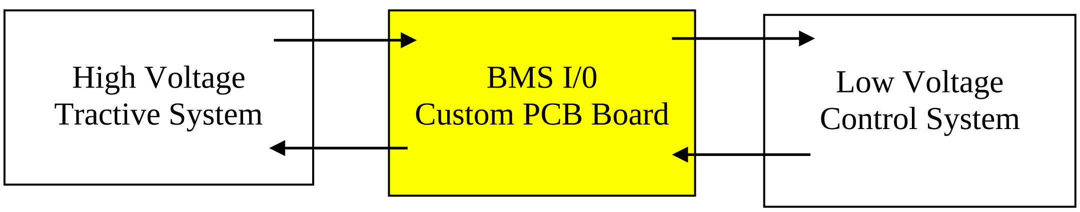

Figure 1: Two-way communication between the High and Low Voltage Systems through the BMS I/O Custom PCB Board.

<u>Isolation Relay Control (Nathan Hines)</u>
This project is addressing the problem of controlling the high voltage isolation relays via the low voltage controller system. The isolation relays are meant to cut power from the high voltage batteries to the high voltage motor controller, effectively turning off the high voltage tractive system. This is important to maintain safety.

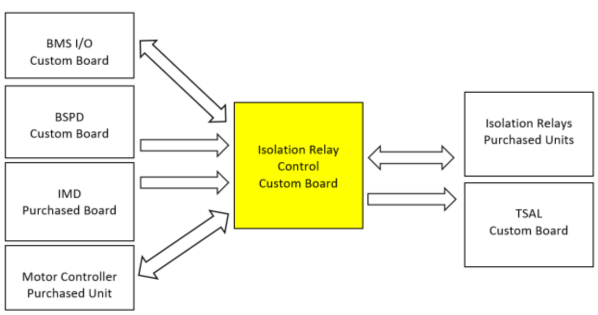

Figure 5: Communication from low voltage system to the Isolation relays through the Isolation Relay Control Board.

<u>Accelerator Pedal Position Sensor (Cyrus Stephens)</u>
Need to communicate the actuation of the accelerator pedal to the motor, so the car can move forward. Need to do this in a way that is safe, redundant, and meets the rules of the Formula Society of Automotive Engineers (FSAE) Electrical Vehicle (EV) competition.

Tractive System Active Light (Aadesh Neel)

The tractive system active light is a status light that is attached to the chassis and is clearly visible to all observers around the vehicle. The purpose of the light is to safely report the status of the tractive system. The light can report three possible scenarios:

- Off (light is off)
- Tractive system is not connected to high voltage (green)
- Tractive system is connected to high voltage and car is ready to move (flashing red)

Since the TSAL is a high voltage system, the high voltage and the low voltage must be isolated from each other, as per the rules of FSAE. This complicates the system from a simple switch circuit.

Brake System Plausibility Device (Kendric Ortiz and Seth Johannes)

The BSPD board is a standalone circuit, it must be designed and manufactured to comply with FSAE 2020 EV rule book, section EV.8.2 as part of the SHUTDOWN circuit. The Shutdown Circuit consists of at least two (2) Master Switches, three (3) Shutdown Buttons, the Brake Over Travel Switch, the Insulation Monitoring Device (IMD), the Inertia Switch, the Brake System Plausibility Device, all required interlocks and the Accumulator Management System (AMS) per rule EV.8.2.2.

The BSPD (EV.8.6) is a standalone nonprogrammable circuit must be used on the vehicle such that when braking hard (without locking the wheels) and when a positive current is delivered from the motor controller (a current to propel the vehicle forward), the AIRs will be opened. The BSPD must comply with the following

A) The current limit for triggering the circuit must be set at a level where 5 kW of electrical power in the DC circuit is delivered to the motors at the nominal battery voltage.
B) The action of opening the AIRs must occur if the implausibility is persistent for more than 0.5 sec.
C) The circuit must also include open/short circuit detection for sensor inputs such that the Shutdown Circuit is opened.

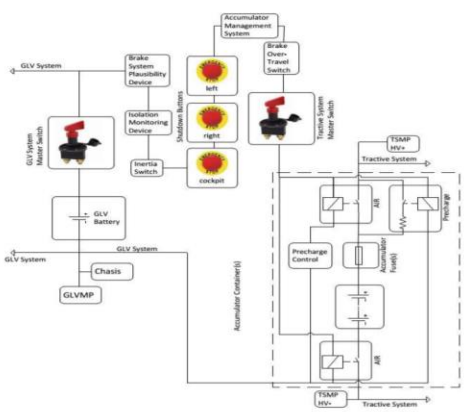

Figure 11: BSPD high level schematic.

Power Distribution and Control (Zonlin Li and Jessica Smyth)

This subsystem consists of the wiring for the power control and measurement signals for all the components, circuit breaker, fuses, relays, switches and displays. The High Voltage Disconnect and high voltage cabling outside of the battery box are included in this subsystem.

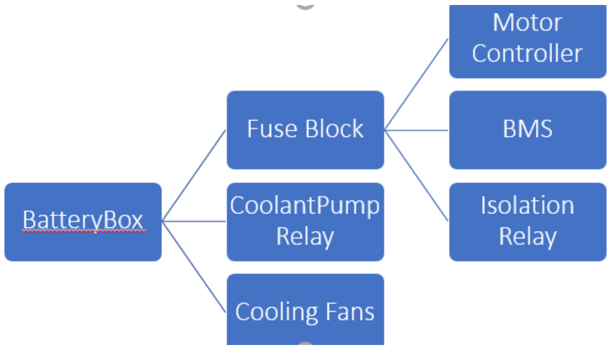

Figure 13: High-level overview of Battery Box connections.

Data Acquisition, Logging and Displays (Mike Chu)

Whenever a vehicle is operational, a great deal of data is constantly being generated. Information including but not limited to the motor temperature, motor operational status, isolation relay status, coolant temperature, and battery temperature can help detect faults as well as aid in the optimization of the car. If there is a fault in the automobile, data acquisition is one of the first systems with the ability to detect it. but a system needs to be in place in order to do so. Yellow blocks on Figure 16 below designate areas within the scope of the data acquisition, logging, and display project.

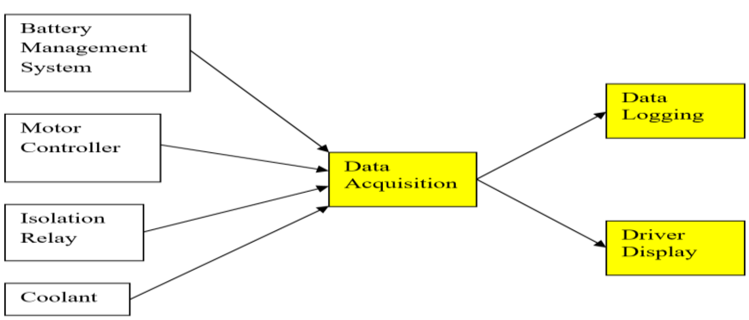

Figure 16: System context diagram of the Data Acquisition system.

Motor Controller and Motor (Brandon Lee)

Regarding modern cars, motors need some kind of controller to integrate the electrical inputs from the lights, battery, pedals, and so on. As a computer engineer, I was tasked to program the motor controller so it could accelerate, deaccelerate, and limit the speed of the car for safety. The other computer engineers on the team and I had to solve multiple steps to this, find out how to power the controller up, understand how to install the software, determine the connections for the motor controller and the computer used, then picking our values to match our requirements.

Figure 17: PMDX100 Motor Controller.

Battery Management System (Joshua Atencio)

This project is addressing the problem of controlling charging and discharging of the batteries.

Battery Charger (Alejandro Ruiz)

Electric vehicles, as the name suggests, run on electricity instead of the more common internal combustion vehicles that rely on fuel. This means that our FSAE EV car would rely on many batteries. but once the batteries run out of energy, then what can we do? This is why we needed a battery charger that can recharge these batteries. However, if the batteries were too charged, then we would be dealing with a dangerous and expensive situation since these are batteries could explode. So the battery charger must be programmed to only charge up the batteries a certain amount, enough to give power to the car for a long amount of time, but not enough were we could damage and possibly break the batteries.

5 PROGRESS TOWARD A SOLUTION

BMS I/O (Nathan Hines)

We have decided to make six custom BMS I/O PCB boards, one for every one of the BMS boards. This will allow us to communicate with each of the BMS boards individually, as well as allow us to link the BMS boards together allowing them to communicate with each other.

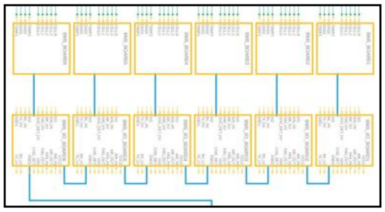

Figure 2: Layout overview of BMS I/O as it relates to BMS and Low Voltage Systems.

Since this is just one board design that will be copied six times over, we assigned this project to just one person in FSAE (Nathan Hines). It was his job to design and manufacture and test the BMS I/O boards as well as assemble them on the FSAE Electric Vehicle.

Using the Eagle: Student Edition software, we were able to fully design the schematic and board layout for the BMS I/O boards.

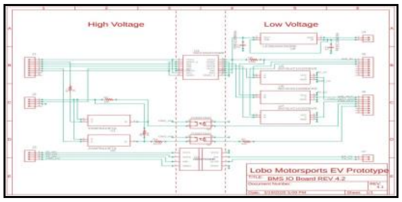

Figure 3: Schematic layout of the BMS I/O board.

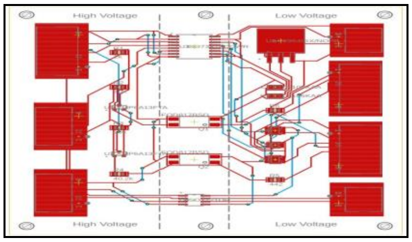

Figure 4: Final design layout of the BMS I/O board.

We designed the board to have fastening connectors (to maintain contact points during the vibrations of driving) and 4-40 screw points for mounting (to securely fasten the board to the vehicle).

We have not been able to purchase the board or its subsequent electrical components, therefore we are not able to perform physical testing of the boards and components or are we able to physically mount the boards on the vehicle.

This inability to produce a physical copy of the circuit boards has limited the teams' overall goal of making a running vehicle. However, our primary goal was to design a prototype vehicle and we have finished the design process. This will allow the future FSAE teams to use our designs to more quickly design future vehicles and to better understand what their design requires.

Had we been able to manufacture the physical boards, we would have verified its capabilities using a low voltage power source and a multimeter.

<u>Isolation Relay Control (Nathan Hines)</u>

We have decided to manufacture a custom PCB board for controlling the isolation relays. This will allow us to easily control the relays through one signal to them, controlled by the inputs of the entire low voltage system into this control board.

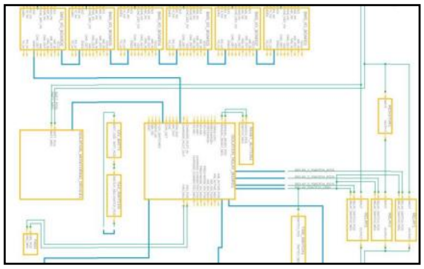

Figure 6: Layout overview of Isolation Relay Control as it relates to the other systems.

We assigned this project to one team member (Nathan Hines), who was enough to get the design and layout done for this complicated board. It was his job to design and manufacture and test the Isolation Relay Control board, as well as assemble it onto the FSAE Electric Vehicle.
Using the Eagle Student Edition software, we were able to fully design the schematic and board layout for the Isolation Relay Control board.

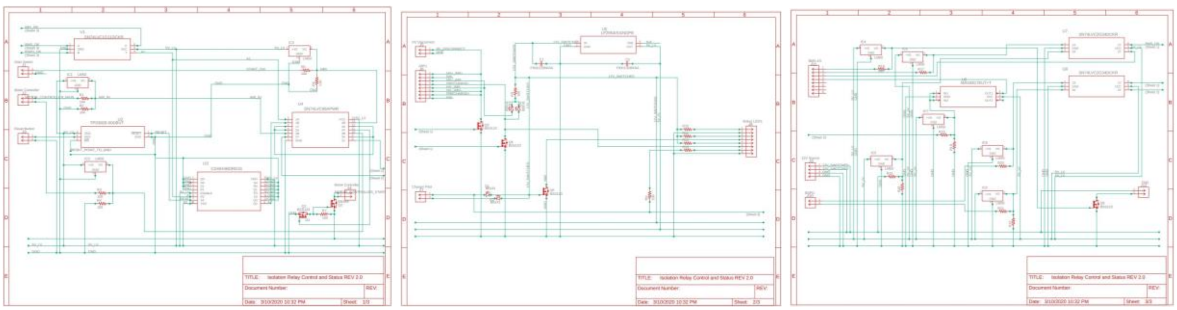

Figure 7: Schematic Layout Page 1-3 of the Isolation Relay Control board.

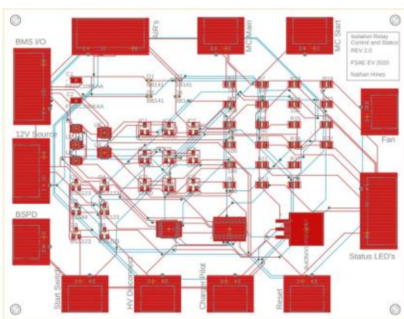

Figure 6: Final Design layout of the Isolation Relay Control Board.

We designed the board to have fastening connectors (to maintain contact points during the vibrations of driving) and 4-40 screw points for mounting (to securely fasten the board to the vehicle).
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Had we been able to manufacture the physical boards, we would have verified its capabilities using a low voltage power source and a multimeter.

Accelerator Pedal Position Sensor (Cyrus Stephens)

All initial design work is complete. Starting last summer, a design was considered that utilized two separate electrical sensors with differing and opposed gains, to ensure a correct output reading reached the motor. We selected a Corvette accelerator pedal as it had the redundant sensors we needed, and we were able to test and confirm that the pedal and sensors worked properly. Once we knew the specific gains of our pedal outputs, we were able to design the circuit such that, as long as the sensors were working properly, we would get two effectively equal outputs that would send a drive signal to the motor. If the outputs were not within 10% of each other's value for greater than 10 ms at a time, the circuit would interrupt the output to the motor and force a manual restart of the system. At this point, we believe the current design should meet all requirements in the problem description and the FSAE rules, however physical assembly and testing is impossible at this time.

Tractive System Active Light (Aadesh Neel)

The TSAL is a hybrid low voltage and high voltage system. As a result the TSAL is separated by an electronic component known as an isolator which is in the middle of the board and is known as U2. At another point in the circuit, we also need 5 Volts to power a comparator on the high voltage side and the low voltage, which I will discuss later. Because of this 5V requirement, we also have a transformer, known as T1 transforming voltage into 5V and is also located in the middle of the board. The board has 4 mounting holes on it for mounting. It is also worth noting that the low voltage side and the high voltage side do not share grounds

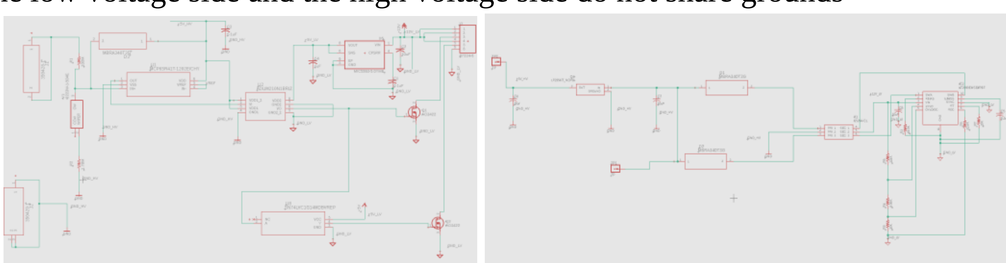

Figure 9: TSAL Circuit design Sheet 1-2.

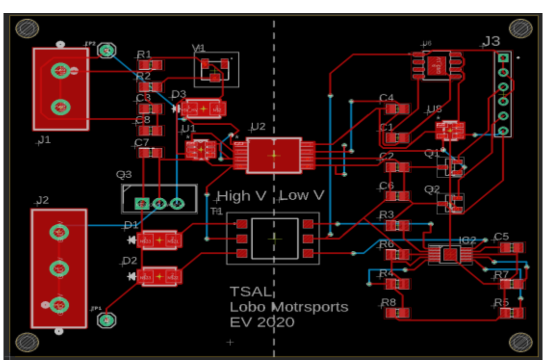

Figure 10: TSAL PCB layout.

High voltage side:

- Resistors, known as R#, are included to properly control the voltage
- Capacitors, known as C#, are included for frequency filtering
- Diodes, known as D#, are included for over current protection
- Two connectors are included. J1 is the input from the tractive system and J2 is the ground
- Two test points, known as TP#, are included for the bench test
- A varistor, known as V1, is attached to vary the resistance at a specific point and get the right voltages at the test point
- A comparator, known as U1, is included to compare a signal to a reference and output a signal to the isolator to communicate with the low voltage system. This is powered by the 5V from the transformer.
- An AC/DC converter, known as Q2, is included to change the AC back to DC.

Low voltage side:

- Resistors, known as R#, are included to properly control the voltage.
- Capacitors, known as C#, are included for frequency filtering.
- A connector is included, known as J3, that goes out to each light and ground.
- Two transistors, known as Q1 and Q2, are included to properly switch between the lights that are on depending on the voltages taken from the system.
- An inverter, known as U8, is included to get the proper voltage for one of the transistors.
- A DC/AC converter, known as IC2, is included to allow the transformer to work.
- A linear voltage regulator, known as U6, is required to regulate the voltage signals.

<u>Brake System Plausibility Device (Kendric Ortiz and Seth Johannes)</u>

Our standalone BDPS circuit is designed (Hand drawn after 2 revisions)

Revision 1.) change of parts and additional parts added

Revision 2.) additional parts added to generate correct voltage source.

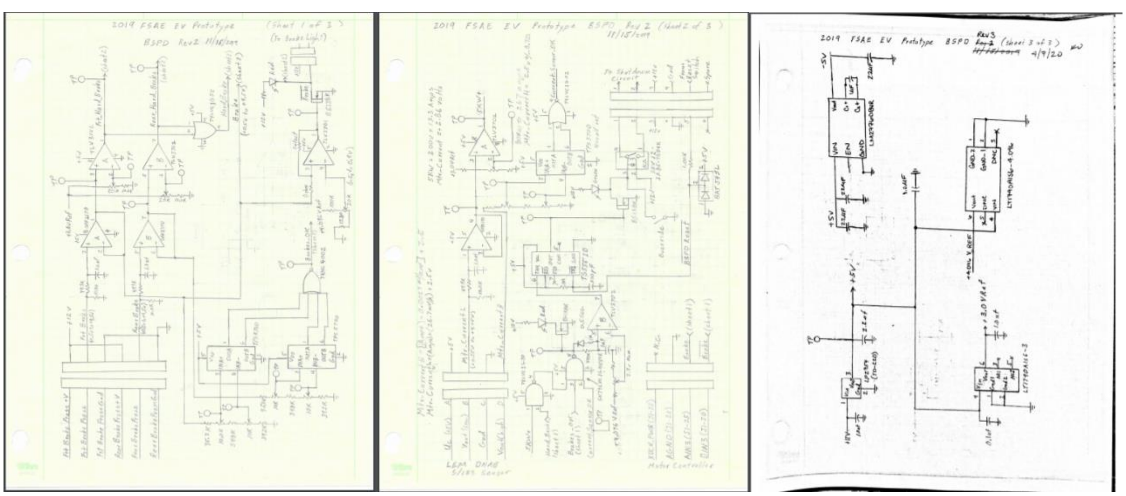

Figure 12: BSPD Hand drawn schematic.

Power Distribution and Control (Zonlin Li and Jessica Smyth)
There are multiple choices for the Fuse Block and Battery. For future convenience our decision is to use the battery same as the IC cars. Since that type of battery requires specific charger for safety. The Fuse Block our first choice was 8 ways block there we can have serval extra terminals for other uses. However, the 8ways blocks were out of stocks we have to pick the 6 ways and change the schematics.

Figure 14: 6-way fuse block.

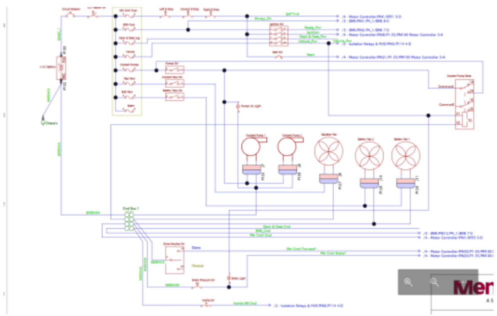

Figure 15: Low Voltage VeSys Schematic.

The software we used to develop our schematic is VeSys. The design meets requirements that the overall system will provide a power supply to each low voltage terminal. First, we managed the materials needed then all the parts were ordered and we started to estimate the wiring cost and predicted the physical position of each circuit board. Once the boards were finished and tested, we could wire them into the system. We had to make several changes to the schematics since the fuse block only came with a negative busbar. Therefore, the extra busbar was redundant and can be cut off. For verification purposes we have serval LED lights that could verify the connections. The wiring harness was tested using a multimeter before its final application to the system.
The only iteration we had was the BMS. Originally, we did not plan to purchase a BMS for the control system. The BMS order came in around January and we altered our new schematic. A huge impact on our system was due to the COVID-19 virus. The virus caused our shop to shut down and nobody could continue working on the vehicle. Since the software we were using was

only available at the shop and the shop is closed, the schematics needed to be fixed for the fuse block bus bar and the 6-way fuse block.

Data Acquisition, Logging and Displays (Mike Chu)

Throughout development, we went through two main phases based on our primary information sources, the coolant, isolation relay, motor controller, and battery management system. Since the coolant and isolation relay had alternative methods available to signal their status, we focused mainly on gathering data from the motor controller and battery management systems. Our motor controller, the RMS PM100 as well as the old BMS system, both output data through the RS232 serial communication protocol. To capture this, our plan was to use the analog pins on an Arduino Mega to process the incoming signals and then relay them to the logging and display functions. However, due to challenges with the old BMS system and the battery charger, we ultimately decided to switch to using OrionBMS instead, which directly interfaces with the motor controller allowing us to pull data from only one source using their provided software.

Motor Controller and Motor (Brandon Lee)

For us to work toward our solution, we had to take everything step by step. Starting with understanding the software and the connections for the motor controller. Reading up on the datasheet and user manuals, as well as getting help from Gene gave us an adequate understanding of the hardware and software. We would meet up and discuss on how we would get the motor controller connected to the computer and voltage source. Once we had the controller connected, we would download and test the software needed. Now at this point, we were constrained on what we could input into the motor controller because we needed the actual motor to work, which required the batteries to be charged, which required our BMS and battery charger to be working with the utmost confidence.

Battery Management System (Joshua Atencio)

We decided to purchase an Orion BMS board for controlling the charging and discharging of the batteries. This will allow us to easily control the relays through the BMS I/O custom board and to manage the charge/discharge level of the batteries. At first, we had chosen to use the Energus Power Solutions Battery Management System, however this decision was changed due to the fact that we would have to use multiple BMS boards that could not communicate with each other and charger compatibility.

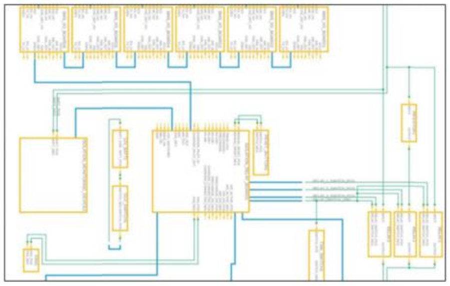

Figure 20: Layout overview of BMS as it relates to the other systems.

We assigned this project to one team member (Joshua Atencio), who was enough to get the battery profile and initial wiring diagram. It was his job to create the wiring diagram and battery profile using the Orion software and to physically assemble the BMS. Using the Orion Software, we were able to create an initial wiring diagram and battery profile. We have not been able to perform physical testing of the BMS or complete the most up-to-date wiring diagram. The inability to implement the BMS in the actual vehicle limited the final goal of a running electric vehicle, and our goal of a working battery management system. However, we were able to select a feasible battery management board that future FSAE teams can work from.

Battery Charger (Alejandro Ruiz)

To try and solve our problem, all the computer engineers would meet up to discuss our plans to program the battery charger. We would start by figuring out a way to wire the charger so that we could safely turn it on and off from a distance. This was done by wiring a switch to the charger so that, even if it was on, no current would pass through unless we flipped the switch. We would also use extension cables so that we could test the battery charger outside. Our next plan would be to write up a test plan so that we would all be on the same page on what we can do to test our program. Once we would get to actually testing the battery charger, we would document what we found so that we could say for sure that it worked, or it didn't work.

6 CONSTRAINTS

The main constraint to finishing an electric vehicle prototype was the start of COVID-19 which took a toll on our project stating in March. This virus shut down our machine shop where we built upon our vehicle, our University, and the manufacturing shops. This is the main reason we did not produce our physical circuit boards. The next constraint was how many people were involved in this project to begin with. Our team had to constantly communicate with the mechanical engineering leaders working with the Internal Combustion car, not to mention all the faculty managers including R. Jordan, B. Evans, G. Balakrishnan, G. Kallenbach, C. Fleddermann, and J. Russell. We also had several student managers not in ECE420 including Sam Casaus, David Shapiro, Salvador Lambert, Lucais Martin and Andrei Fratain. This project was extremely over-managed and caused confusion in our project. Since this was the very first year an electric vehicle prototype was designed at UNM the ECE and MechE departments were unorganized integrating this vehicle into an ECE420 senior design project.

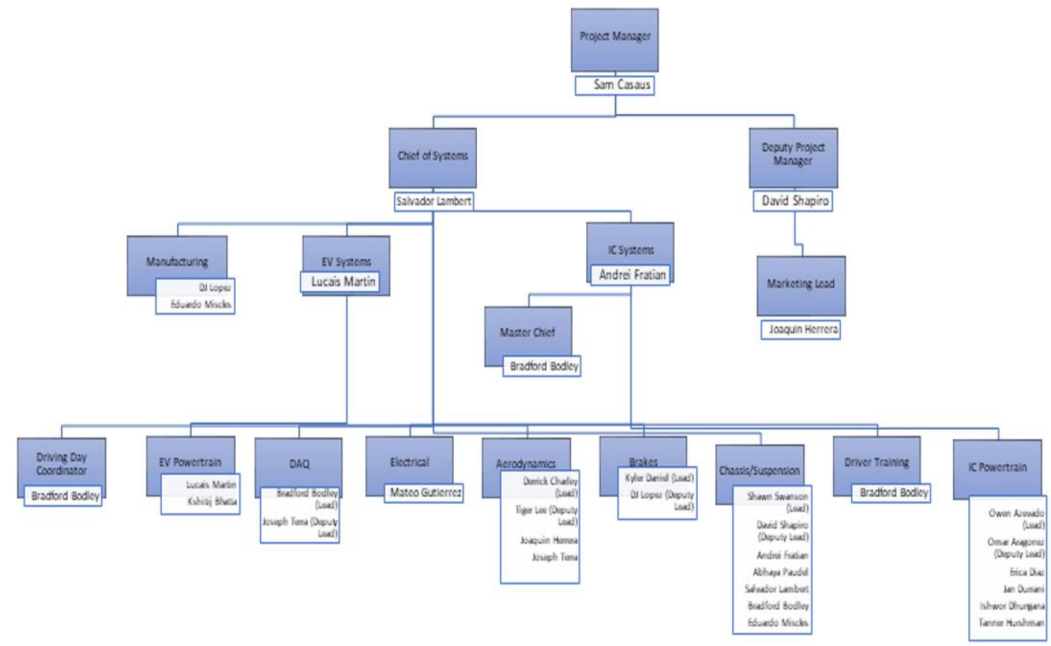

Figure 19: Org chart of FSAE.

7 BUDGETS

Our team raised a total of $20,000 by dedicating several weekends at fundraising events like Concourse De Soleil, and other community outreach events. The ECE department sponsored our project, and we also received funding from a private donor.

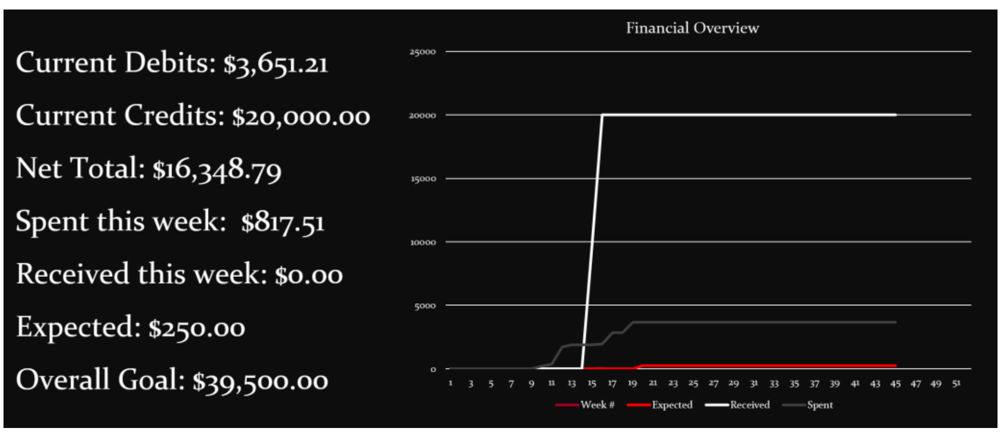

Figure 18: Financial overview of Electric Vehicle.

8 WORK SCHEDULE

Our Gantt Charts are very detailed and adding screenshot to this report would make them blurry and unreadable. Therefore, there are linked in References. As seen in the Gant Chart, we were able to accomplish the design and layout phase of the project. We were also able to define a parts list of the components we needed. We were unable to manufacture and test the circuit boards.

9 PERSONNEL INTERACTIONS

9.1 Teamwork

Team Members	Responsibilities
Aadesh Neel	Tractive System Active Light
Alejandro Ruiz	Battery Charger
Brandon Lee	Motor Controller and Motor
Cyrus Stephens	Acceleration Pedal Position Sensor Interface
Gene Kallenbah (Mentor)	Technical Guidance
Jessica Smyth, Zonglin Li	Power Distribution and Control
Joshua Atencio	Battery Management System
Kendric Ortiz, Seth Johannes	Brake System Plausibility Device
Lucais Martin, Jessica Smyth	Managerial Organization, Weekly Meeting
Mike Chu	Data Acquisition, Logging and Displays
Nathan Hines	BMS I/O, Isolation Relay Control

Table 1: Team Member Responsibilities

9.2 Mentorship

Our entire team was mentored by Gene Kallenbah for most of the technical work. He was an essential for the design process and had key insights that would have been useful if we had gotten to the manufacturing phase. The team members have spent an hour or so with him every other week to discuss the project. He was also our high voltage safety trainer, a key step for us was taking his safety course. We were also mentored by the three instructors of the senior design class. They have helped us in managerial organization and engineering safety/ethics.

10 SUMMARY & CONCLUSIONS

Because our goal is a prototype version of the vehicle, we have met all our goals except the manufacturing of the actual components. We have been able to complete the schematics, board layouts, netlists, and bill of materials. If not for the COVID-19 pandemic, we would have been on track to completely manufacture and finish this project on time.

The future FSAE teams will be able to use our designs for their vehicles and be able to make a competition ready vehicle.

11 DISCUSSION

Our team in general believes our UNM ECE courses were useful in preparation for our final senior design project. We had a good background in basic circuit design, engineering software, documentation, programming, and troubleshooting systems. The Senior Design course helped guide us in staying organized with all of the design documentation needed for a project of this scale. We learned how important the teamwork aspect is in a project with so many people involved.

Throughout the process of this project, we have learned basic engineering practices such as design and safety. We have taken a university high voltage safety course, university lead engineering ethics discussions, and we have seen firsthand how management and teamwork are so closely intertwined in the success of the project.

We have also seen how the schedules on a project of this size can change due to outside sources and the shifting of parallel projects. Because this FSAE team project is ran in parallel with other sub-projects, the schedule would be shifted due to those other sub-projects even if this project was on schedule. Every sub-project would be affected by the other sub-projects. A project of this size needed good management strategies.

If we could do this project over again, I would have run it through the electrical engineering department, and had Gene Kallenbach be our technical mentor through the entire process. His career experience was needed for a design of this scale. I would have also used less peer managers, there doesn't need to be five student managers and one student team member.

12 ACKNOWLEDGMENTS

Our team would like to thank Gene Kaltenbach for his mentorship and guidance through the entirety of this project. He was an essential and invaluable member of the FSAE teams and all of our work. We would also like to thank the University of New Mexico for their financial support of this project. Without their financial support, this project would have never gotten off the ground for us or for future students. We would like to thank the leadership role that the mechanical engineer, Lucais Martin, has played. He has been an enormous help to not only this sub-group but also to the entire FSAE team. Finally, we would like to thank the three instructors of the Senior Design class that this project is affiliated with: Ramiro Jordan, Ganesh Balakrishnan, and Bradley Evans. Without your guidance and expertise, we would not be able to accomplish as much as we have and I'm sure we wouldn't be able to accomplish as much as we will in our future engineering careers.

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UNIVERSITY OF NEW MEXICO
LOBO*MOTORSPORTS* 2020
ELECTRIC VEHICLE

SYSTEMS REQUIREMENT DOCUMENT

FINAL DRAFT

The main objective for the 2020 **LOBO***motorsports* (LMS) Formula SAE electric vehicle system is to perform consistently and reliably under all realistic racing conditions while conforming to all rules and requirements. The vehicle will be required to operate under multiple system limitations defined as: rules and regulations of the competition, operating limits of the tires, subsystem integration, feasibility, and overall reliability of the vehicle systems. We will be competing in the Formula SAE Electric competition in Lincoln, Nebraska, with a goal to pass technical inspection and to compete in each of the static and dynamic events for the electric vehicles.

SYSTEM LIMITATIONS

Rules and Regulations: The team will design each system under the guidelines and restrictions of the 2020 Formula SAE and 2020 Formula SAE Electric Rules.

Tire Capability: All subsystems will consider the limitations of the tires and will perform within them.

System Integration: Each subsystem will be designed such that they integrate with adjacent systems in order to obtain a performance capable of competing in all events and able to be maintained.

Schedule: The vehicle system will be designed in a manner which is within the limitation of the schedule. All deadlines including documentation, manufacturing, and competition deadlines shall be met.

Cost: The vehicle will be designed within the cost limitations set by the amount of donations received from sponsors. The budget for each subsystem will be designated as per the amount of funding received.

SYSTEM PERFORMANCE

The vehicle will be designed to pass technical inspection and compete in every static and dynamic event. The ultimate goal is to design, manufacture, and test a completely reliable vehicle that can consistently perform well under all racing conditions. The system will need to be designed and tested in such a way all performance data is gathered and measured accurately to allow for design validation and component adjustment prior to competition. The team will use legacy data and past knowledge to build upon the prior LMS19 prototype EV.

During the design phase, reliability will be top priority, efforts will be taken to minimize weight, but not at the expense of performance reliability. An overall vehicle weight goal will be implemented. However, the majority of efforts will be placed in ensuring the car is rules compliant and able to compete in the full endurance dynamic event. Additionally, the 2020 vehicle will be designed with a rear weight bias to maximize the performance of the vehicle with respect to longitudinal and lateral acceleration.

In order to meet the competition goal of passing the technical inspection and competing in every event, the following system parameters must be met for the design. Car parameters include: sustained lateral acceleration, longitudinal acceleration, braking acceleration, and a power to weight ratio. The system goal of 1.5g's in skidpad, a 0.9g longitudinal acceleration, and braking acceleration of 1.68 g's will ensure a competitive car able to compete in the top 10. A projected power output from the motor of at least 70 kW (93.9 HP), and a weight goal of no more than 550 lbs allows the system to achieve a minimum power to weight ratio 0.17. This value is within the typical range for the electric vehicles brought to competition and, in conjunction with the other parameters, will aid in the car's ability to compete within the top 10.

To do well in dynamic event scoring, adjustability at the track will be implemented to better prepare the system for longitudinal or lateral acceleration along with improving the capabilities for single runs or maintaining consistent handling over long runs. Each driver will be given options to adjust different handling parameters of the car to suit their preferred driving styles while improving the vehicle's performance in the dynamic event it will be competing in. An example would be a driver changing the amount of brake bias or anti-roll bar stiffness.

FORMULA SAE.

Electric 2017 Overall Results

Place	Car Num	Team	Penalty	Cost Score	Presentation Score	Design Score	Acceleration Score	Skid Pad Score	Autocross Score	Endurance Score	Efficiency Score	Total Score
1	202	Univ of Pennsylvania	-20	83.0	75.0	120	100.0	71.2	125.0	275.0	94.0	923.2
2	206	Massachusetts Inst of Tech		69.6	70.4	110	61.6	70.9	120.8	265.8	88.4	857.5
3	211	Universidade Estadual de Campinas		69.2	64.3	135	97.8	75.0	122.7	10	92.4	666.5
4	205	Missouri University of Science and Tech		82.6	63.0	70	91.4	55.9	111.9	11	100.0	585.8
5	237	Univ of Washington		60.0	66.6	100				252.3	97.9	576.8
6	210	Univ of Calif - Davis		68.3	43.5	70	62.0	46.3	50.2	11	95.0	446.4
7	220	Virginia Tech		79.2	57.4	100			54.4	4		295.0
8	221	Univ of Wisconsin - Madison		68.8	71.7	150						290.5
9	208	California Polytechnic State Univ-SLO		64.3	70.6	110						245.0
10	217	Univ of Kansas - Lawrence		60.1	65.6	100						225.7

Table 1: FSAE 2017 Lincoln Electric Results

FORMULA SAE.

Electric 2018 Overall Results

Place	Car Num	Team	Penalty	Cost Score	Presentation Score	Design Score	Acceleration Score	Skid Pad Score	Autocross Score	Endurance Score	Efficiency Score	Total Score
1	223	Carnegie Mellon Univ	-10	74.5	71.2	90	81.6	61.3	98.1	240.0	92.9	799.6
2	234	McGill Univ		69.7	68.2	130	97.3	64.8	101.0	144.4	96.8	772.2
3	205	Univ of Washington		57.2	71.3	140			86.9	275.0	91.4	721.7
4	208	Univ of Wisconsin - Madison		66.9	66.2	150	58.9	62.9		46	96.8	548.3
5	202	Massachusetts Inst of Tech		76.0	57.7	100	100.0	70.7	125.0			529.4
6	217	Georgia Institute of Technology		91.2	54.6	60			52.1	121.2	97.6	476.7
7	225	Purdue Univ - W Lafayette		57.1	39.9	70	93.1	75.0	117.8	1		453.9
8	203	Universidade Estadual de Campinas		71.8	70.2	100	92.2					334.3
9	230	Montreal Polytechnique		77.9	48.7	50				8	100.0	284.6
10	232	Univ of Manitoba		55.5	59.3	50				9	94.8	268.7

Table 2: FSAE 2018 Lincoln electric results

As seen in Table 1 and 2, finishing all events at competition will secure a top ten finish based on 2017 and 2018 results.

SYSTEM ADJUSTABILITY AND SERVICEABILITY

Each appropriate system will be designed to be repeatedly adjustable and serviceable. Ease of adjustability is of high importance for the LOBOmotorsports team to achieve our goal of driver comfort and ease of drivability. On site ease of adjustment will allow the LOBOmotorsports team to adapt to the track conditions at Lincoln or Michigan as well as adjusting the car response for the different drivers and their preferences at competition. Ease of adjustability will allow our team to also tune the car for different weather conditions such as wet vs dry and hot vs cold. Different surfaces also play into how cars handle. Asphalt vs concrete surfaces have different grip effects on the tires which can be taken advantage of by ease of adjustability in the tires, brakes, and suspension. An easily tunable car will also allow the team to take advantage of chassis tuning at driving days and training engineers for adjusting the car at competition. Ease of serviceability will be important to the LOBOmoto8rsports team in maintaining the car in top running condition as well as giving us the ability to easily fix oversights that might appear in testing. In order to maximize ease of serviceability, the battery pack must be able to be completely removed within 30 minutes; this includes removing any car components that must be removed before the battery pack could be removed. The goal of ease of adjustment and serviceability is to improve the overall performance and reliability of the car.

SYSTEM INTERFACE AND ERGONOMICS

The team will focus on creating a comfortable and highly functional environment for the driver, providing controls that are accessible and easy to operate. The cockpit will be designed such that adequate comfort will be maintained throughout all events, particularly the endurance event. The pedal assembly, seat, belts, and headrest will be designed to give ease of adjustment for all individuals ranging from the 5th percentile female up to the 95th percentile male. The steering wheel must also be removable to facilitate easy entrance and exit of the cockpit. Adjustability of different subsystems will be made readily available for each driver to customize the vehicle parameters to comply with their size, weight, and preferences.

APPENDIX A SUBSYSTEM PERFORMANCE

AERODYNAMICS

The goal of LMS 2020 Aerodynamics team is to provide performance, efficiency, and reliability such that the vehicle finishes all dynamic events and potentially become a top 10 finisher at the competition. LMS 2020's plan is to iterate on LMS 2019's design while researching techniques to improve performance and efficiency. The iterative process is intended to increase the coefficient of lift and decrease the coefficient of drag for the car. LMS 2018's design currently is achieving coefficients of lift and drag of 2.18 and 1.04 for their design. These values represent the minimum requirements of the 2020 aerodynamics package pending 2019's final values. The 2020 Aerodynamic subteam will maintain a similar design to the 2019 Aerodynamics package while attempting to increase performance.

The goal for frontal area is a decrease of 5% from the 2019 car. The goal for the drag coefficient is to achieve a value of less than 1.00. The goal for the coefficient of lift will be a designed value of greater than 2.24. The coefficients of drag and lift are for 2018's design is 1.04 and 2.18 respectively; 2017 had coefficients of lift and drag of 0.94 and 2.05.

In regard to reliability, the goal is to increase rigidity of each component on the car while minimizing each components weight. We will also produce spare parts for damage prone components, such as the front wing, to ensure that aerodynamic performance is maintained throughout testing and competition.

In conclusion, the aerodynamic package is a major factor to the vehicle's performance. Although we would like the upmost performance from the system, we also do not want to sacrifice reliability and structural integrity for the risk of failing in dynamics events. Therefore, a balance between performance, weight, and reliability will be found.

BRAKES

The brakes system should not fail during competition and should not limit the capability of the car from the tire capabilities. Previous LMS teams have failed at or before competition causing detrimental consequences to the performance of the car. The car's brake system shall be designed with a sufficient factor of safety as a measurement of reliability. The brake system should ensure ergonomics for various drivers such that all drivers can comfortably provide the required force to lock all four wheels and have a pedal gain such that the applied force is adequately amplified. The brake system should not be the limiting factor in the capability of the car. The brake system will be designed such that its capability is greater than that supplied by the tires.

First, the LMS 2020 car is required to simultaneously lock all four wheels after a prescribed acceleration distance. All four tires should be able to lock simultaneously without an excessive applied force. The force required to lock all four tires shall be no more than half the weight of the 95th percentile male. The 95th percentile male weighs about 216 pounds. Therefore, the required force shall be no more than 108 pounds.

Second, the brake system shall be designed to have a safety factor of 1.5 or greater for all components. The factor of safety for each component should be a measure of the ratio of the maximum capability of the component to the expected loads on the component as a function of the component material. This provides a metric to the reliability of the brake system and promotes the success of the team in all events, especially the endurance event. Brake components are commonly rated for a maximum hydraulic pressure of 1000psi given from the manufacturer. As such, the brake system should not exceed 650psi such that the hydraulic system has a factor of safety of at least 1.5.

Third, the brake system should have a minimum pedal gain of 4.8. Pedal gain is a ratio of the applied force to the bias bar to the force applied by the driver. This goal is reasonable as previous LMS teams have achieved close pedal gains.

Lastly, the brake system should be more capable than the maximum capability of the tires. Given that the brake system can withstand a greater braking acceleration than that of the capability of the tires, it is safe to assume that the brake system will not limit the braking acceleration. LMS 19 members reported a coefficient of adhesion calculated from their tires of about 1.6 g's. The LMS 2020 car shall have a braking acceleration equivalent to the maximum capability of the tires at ideal conditions. The LMS 2020 car shall have a minimum braking acceleration of 1.6 g's under ideal road, environment, and power conditions.

CHASSIS

The 2020 chassis team will design and manufacture a steel tube spaceframe chassis for the electric vehicle which integrates well with all other subsystems. We will utilize the 2019 chassis as a baseline engineering model and will closely follow FSAE rules in order to meet their requirements. The primary goal will be to build a chassis that will fit the regulation templates and obtain the maximum strength as well as rigidity of the frame. We will also build the chassis with ergonomics in mind to ensure driver comfort is not compromised. Effective communication with the suspension, drivetrain, and brakes sub-teams in the early design stages will be critical to ensure the best position of nodes to guarantee maximum function of the vehicle.

A secondary goal for the 2020 chassis team will be to build an EV chassis that supports the amount of torsion that the electric motor provide and does not compromise the structural integrity or rigidity of the frame. While keeping the overall weight in mind, the chassis design should not exceed 90 pounds. The 2020 EV chassis will be built stiff enough to be considered a rigid member to facilitate and simplify the suspension analysis.

Finally, the 2020 chassis team will complete the fabrication of the EV chassis within the deadline set by the overall project. This deadline will be Thanksgiving break. This is so each subsystem can properly incorporate their components in a timely manner to be able to make adjustments as needed.

DATA ACQUISITION

A data acquisition system will be implemented to verify design parameters set by each individual sub team allowing for a check on whether the LMS2020 team has reached its design requirements. The amount and type of data accumulated will be determined during design in order to create an accurate G-G diagram of the car's capabilities. In addition, the data system will be available to a minor extent in the cock-pit tachometer, water temperature gauge, battery voltage, etc.- and to its full extent via computer track side providing real time data on the car's current performance for example, data pertaining to lateral and horizontal G forces, slip angle, yaw rate, suspension kinematics, tire temperature, engine parameters, and driver inputs will be logged and accessible for interpretation. Data collected will be used as a check and balance system for the car in order to optimize its performance with respect to its weakest subsystem.

Lastly, the system will be able to provide feedback for those training to be drivers allowing for the driver instructor to identify weaknesses and act accordingly. Once capable drivers are driving the car the system will be used to optimize the given driver's performance and motor tune for the best results when competing at competition.

POWERTRAIN

The powertrain subsystem will be responsible for the power generation and transmission from the motor to the wheels. This subsystem consists of two main parts: The motor and the drivetrain. The goal of the electric motor is to produce power of at least 70 kW (93.9 HP) and the goal of the drivetrain is to reliably transfer the produced power from the motor to the wheels with minimum losses.

One of the defining attributes of the car is the power-to-weight ratio. This is a simple ratio that allows you to compare the performance of two vehicles without the need for technical explanation or engine design. Using an estimated maximum weight of 550lbs and a motor with the proposed power output we get a minimum power-to-weight ratio of 0.17HP/lb which, based on the results of the 2017 and 2018 Lincoln electric results, will insure a competitive car during the 2020 competition. To achieve the highest possible power-to-weight ratio, we will consider the weight of the subsystem to be a priority, but not at the expense of overall performance, reliability of the powertrain or safety of the team. A motor controller will be utilized to maintain a consistent, reliable power curve for the electric motor. The motor controller will also ensure a proper balance between motor performance and motor temperature.

The drivetrain of the subsystem will be able to handle the instantaneous peak torque created by the electric motor with minimum power losses. It will be optimized to achieve a maximum vehicle velocity for the acceleration event and operate in the peak RPM range set by the 80kW power limitation for the electric motor. A planetary gearing system will be utilized to implement a two speed transmission system. This will ensure a higher top speed and reduce stall torque limits.

Motor components will be judged based on their ability to increase the performance of the vehicle compared to the effect they have on the total weight, reliability of the system and safety of the team. The motor and components will be designed to operate at an optimum temperature for power delivery and motor safety. Ease of maintenance will be considered when designing this sub-system to ensure reliability.

Tire analysis on multiple tire options was conducted, and revealed that a maximum of 0.90 G's of longitudinal acceleration can reliably be obtained for a range of driver weights. Therefore in order to achieve the system goal to perform within the maximum capability of the tires, the powertrain will support the vehicle system to achieve a lateral acceleration of at least 1.5 G’s and a longitudinal acceleration of at least 0.90 G’s.

LOW VOLTAGE

The low voltage system of the electric vehicle consists of the electrical systems not considered part of the tractive system. Low voltage will be responsible for powering the battery sensors, data acquisition sensors, notification lights, and the ready to drive sound. This system will be designed separately from the high voltage system in order to protect the sensors from drawing too much current or voltage.

The low voltage system will be completely isolated from the high voltage system, and will be monitored by an Insulation Monitoring Device (IMD) rated at 500 ohm/volt. A single 12 V battery or equivalent cell based design can be used to power this system, as the components will not require more than this. The battery will be easily accessible and occupy a minimum amount of space. This will improve maintenance of the system in the event that the battery should need replacement and will also reduce the weight put on the car by the power supply.

ACCUMULATOR (BATTERY)

The batteries for the LMS20 electric vehicle will not operate above the maximum allowed voltage of 600V. Considerations for the current and voltage limitations of the motor controller and motor will be made to prevent damage to these components from the batteries. We will design an arrangement of the batteries that maximizes allowed voltage using the least amount of battery cells to conserve both weight and cost. Additionally, factors that may affect performance, such as heat, will be considered in design in order to maximize the efficiency of the batteries.

Another important objective of the entire high voltage system on the 2020 Electric Vehicle is to ensure a safe design for driver and crew. All electric vehicle rules will be adhered to as set forth by the FSAE 2019-2020 rules and safety will be a main priority when any work is done involving the high voltage or tractive system. All persons working on the vehicle in any respect will have proper training and safety equipment at all times. Another way we will maintain safety is to have a minimum of 2 people working on the vehicle when any work or maintenance is done on the car. Proper storage and maintenance will help to keep all batteries, motors and motor controllers in proper functioning order, but routine inspections will also ensure the safety and quality of any parts we will be using on our vehicle. This will be achieved by having a separate EV maintenance area in the FSAE shop. Persons not working directly on the EV will be required to maintain a minimum distance from the vehicle.

SUSPENSION

The goal of 2020 suspension team will be to design and build a system that maximizes the capabilities of the tires through effective load transfer. The system will be designed to maximize performance. This will be achieved by prioritizing the anti-roll bar and steering in design and analysis. These goals will be quantified by comparing the lateral G force acceleration achieved in the skidpad event of the top 10 Lincoln times between 2014 and 2017. By achieving a specific, steady state, lateral G force of 1.5 in the skidpad event, increased cornering performance in the autocross and endurance events will also be achieved.

The 2020 suspension team will also push research of material properties and the feasibility of implementing alternative materials into future systems. The goal is to maximize performance and drop weight while making the system easily adjustable to the driver.

To obtain these benchmarks, we will maintain an emphasis on realistic timetables and deadline delivery. Working closely with the data acquisition team and drivers will allow us to properly test and tune our system. Suspension aims to have an easily tunable system that meets the requirements of the track and each individual driver.

TIRES

The capabilities of the vehicle are largely limited by the performance characteristics and properties of the tires. Based on prices, values of longitudinal and lateral acceleration from the tire consortium data, we will use the same tires as the IC vehicle.

APPENDIX B SUBSYSTEM DESIGN

AERODYNAMICS

The equations that were used to calculate the performance characteristics of the aerodynamic package of the car are shown below.

Equivalent Downforce Production:

$$D_z = {}^1/_2 \rho A_{front} C_l V^2$$

Assuming the air density and car velocity are the same, the only variables than can be changed are the front area of the car and the coefficient of lift. The LMS 2016 car achieved a 1.94 coefficient of lift, and assuming a track width of 50" front and 48" rear, the LMS 2018 car is 5% smaller than the LMS 2016 car, therefore, the coefficient of lift must be improved to maintain the same performance. This calculation is shown below.

$$A_{18}C_{18} = A_{16}C_{16}$$
$$A_{18} = 0.95A_{16}$$
$$0.95A_{16}C_{18} = A_{16}C_{16}$$
$$C_{18} = 1.0526C_{16} = 1.0526 \times 1.94 = 2.05$$

Maximum Allowable Coefficient of Drag:

To ensure that the car is limited by the power of the engine instead of the drag of the car, there is a maximum coefficient of drag that can be allowed. This calculation is shown below.

$$C_x = \frac{2 \times P_{max}}{1.25\rho V_{max}^3 A_{front}}$$
$$P_{max} = 48\ hp \times 550 \frac{ft * lb}{s * hp} = 26400 \frac{ft * lb}{s}$$
$$V_{max}^3 = 75\ mph \times 5280 \frac{ft}{mile} \times \frac{1\ hour}{3600\ s} = 110 \frac{ft}{s}$$
$$\rho = 0.0023769 \frac{lbm}{ft^3}$$
$$A_{frontal} = 12.6\ ft^2$$
$$C_x = \frac{2 * 26400}{1.25 * 0.0023769 * 12.6 * 110^3} = 1.06$$

Skid Pad Analysis:

8

$$\mu(W + D_z) = \frac{m * V^2}{r}$$

$$\frac{V^2}{r} = \frac{\mu}{m}(W + D_z)$$

$$D_z = \frac{1}{2}\rho C_l A_{front} V^2$$

$$G's = \frac{\mu}{W}(W + 0.5\rho C_l A_{front} V^2)$$

$$G's = \frac{\mu}{1 - \frac{\mu}{W}(0.5\rho C_l A_{front} r g)}$$

$$G's = \frac{1.4}{1 - \frac{1.4}{610}(0.5 * 0.0023769 * 1.74 * 12.6 * 28.05 * 32.17)} = 1.480$$

POWERTRAIN

One of the defining attributes of a race car is the power-to-weight ratio. This is a simple ratio that allows you to compare the performance of two vehicles without the need for technical explanation or engine design. As per the rules, the electric motor is limited to a maximum of 80 kW(107.28hp) for performance. Using the available results from the 2017 Formula SAE Electric competition at Lincoln, typical weights of vehicles are in the 600 pound region. Assuming that this includes the driver weight, as indicated in several entrants' data sheets, an assumed weight of about 500 pounds, car only, seems reasonable.

Using these numbers, the optimum power to weight ratios for a typical electric vehicle in the competition are:

$$\frac{P}{W} = \frac{107.28\ hp}{550\ lbs.} = 0.195 \text{ (100\% efficiency)}$$

$$\frac{P}{W} = \frac{107.28\ hp}{550\ lbs.} * 0.9 = 0.176 \text{ (90\% efficiency)}$$

Our design assumes that our maximum power output will be 80.0 kW (107.28HP), similar to the performance of an internal combustion vehicle in the FSAE Lincoln competition, of which much of the design has been based. Running through similar calculations, our theoretical lowest performance of 70kW (93.9HP) is:

$$\frac{P}{W} = \frac{93.9\ hp}{550\ lbs.} = 0.170 \text{ (100\% efficiency)}$$

$$\frac{P}{W} = \frac{93.9\ hp}{550\ lbs.} * .9 = 0.154 \text{ (90\% efficiency)}$$

These values are reasonable, being similar to the 2019 EV prototype.

APPENDIX C COMPONENT DESIGN

DESIGN PHILOSOPHY

Based on the nature of competition, LMS should design the vehicle system to the ultimate tensile strength (UTS) rather than yield strength. This gives the overall ability to maximize performance of the vehicle so it finishes competition yet competes at the highest of standards. This is done by determining the worst possible load that a component would see for even a small range of time.

The static load factor is multiplied by 1.5 in order to determine the dynamic load factor, which is then used to calculate the worst case load (see Appendix C). The safety factor of the vehicle system will be based on the UTS and is defined as follows:

$$SF_{UTS} = \frac{\sigma_{UTS}}{\sigma_{Worst\ Case}}$$

To remain competitive while still maintaining the structural integrity of the vehicle system, components will be designed to UTS.

An example of the worst possible load a component can experience would be if the car was braking, downshifting, and entering the corner such that the only corner of the car that was in contact with the racing surface is the right front corner. This would cause the whole car to transfer all dynamic and static loads to the right front components. To calculate the worst case maximum force, it can be done as follows:

The static load factor is multiplied by 1.5 in order to get the dynamic load factor,

$$n_{Static} = 1.5$$

$$n_{Dynamic} = 1.5 * n_{Static} = 1.5 * 1.5 = 2.25$$

From there, the maximum possible load, in this case the whole weight of the car, is then multiplied by the dynamic load factor to achieve the worst possible load. In this case the maximum expected load is approximately 600 lbs. or about 2.7 kN. Thus,

$$F_{Worst\ Case} = n_{Load\ Factor} * F_{Max\ Expected} = 2.25 * 2.7 = 6.075\ kN\ or\ 1350\ lbs$$

The components should be designed in a way that based on the Finite Element Analysis (FEA), the maximum stress in a component is based on $F_{Worst\ Case}$ which gives $\sigma_{Worst\ Case}$ in the analysis of the component. In order to make sure no component fails, yielding is allowed as long as our stress concentrations meet the following criteria:

$$\sigma_{Worst\ Case} \leq \sigma_{UTS}$$

The safety factor will be based on the ratio of Worst Case Stress to Ultimate Tensile Stress as follows[6]:

$$SF_{UTS} = \frac{\sigma_{UTS}}{\sigma_{Worst\ Case}}$$

SYSTEM COST AND MANUFACTURABILITY

System components will be designed with the principles of Design for Manufacturability (DFM) in mind. Components will be prioritized based on scheduling, capabilities, and financial needs. Technical engineering drawings will conform to the standards set by ASME Y14.5M – 2009 in order to reduce cost and more easily communicate design intent. Technical engineering drawings will be completed and reviewed internally in the case that a component must be manufactured externally.

APPENDIX D

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PROJECT SCHEDULE

FORMULA SOCIETY OF AUTOMOTIVE ENGINEERS - ELECTRIC VEHICLE

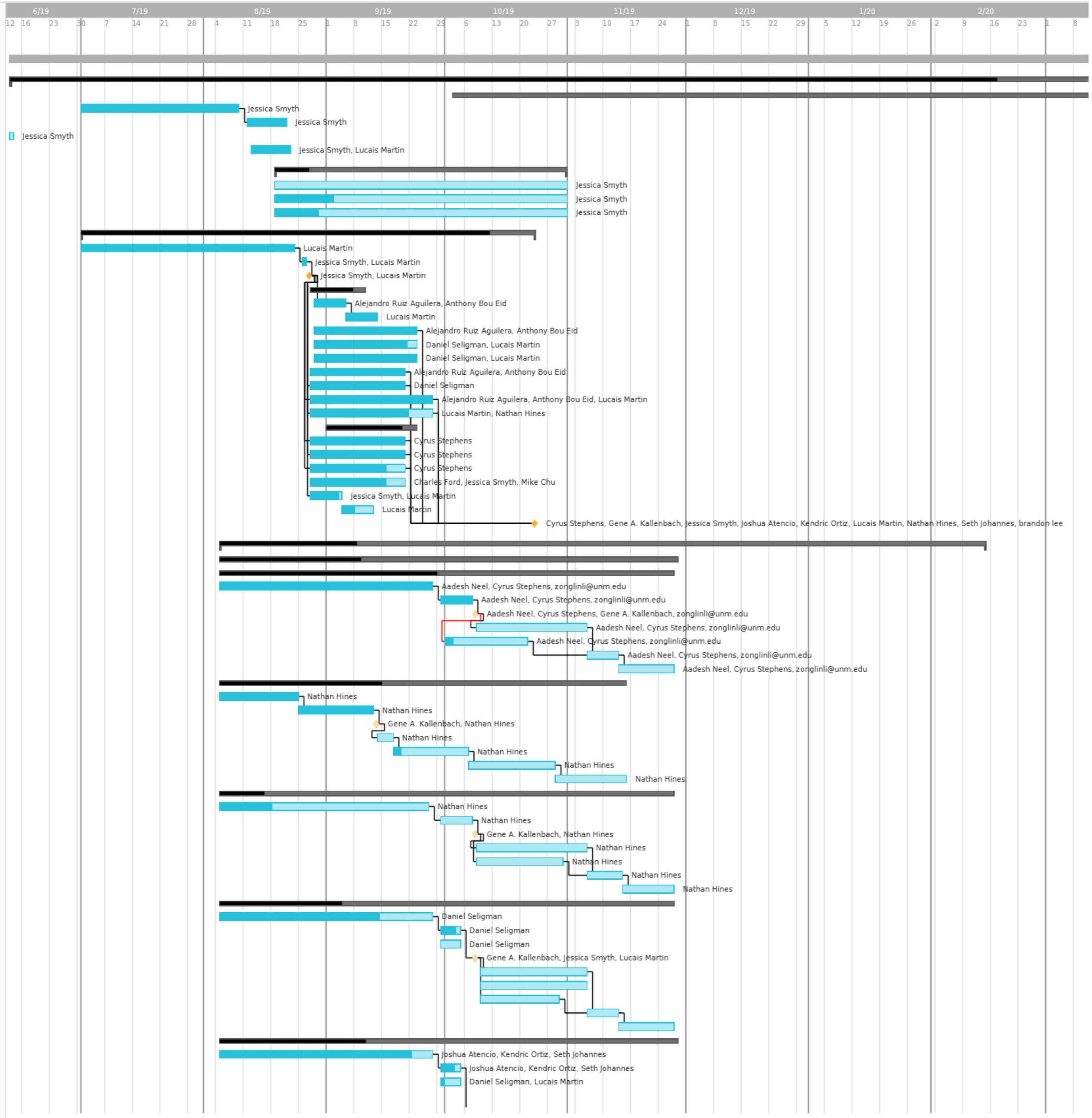
PROJECT MANAGERS: SAM CASAUS, DAVID SHAPIRO, LUCAIS MARTIN, SALVADOR LAMBERT AND JESSICA SMYTH

AADESH NEEL
ALEJANDRO RUIZ
BRANDON LEE
CYRUS STEPHENS
JOSHUA ATENCIO
KENDRIC ORTIZ
MIKE CHU
NATHAN HINES
SETH JOHANNES
ZONGLIN LI

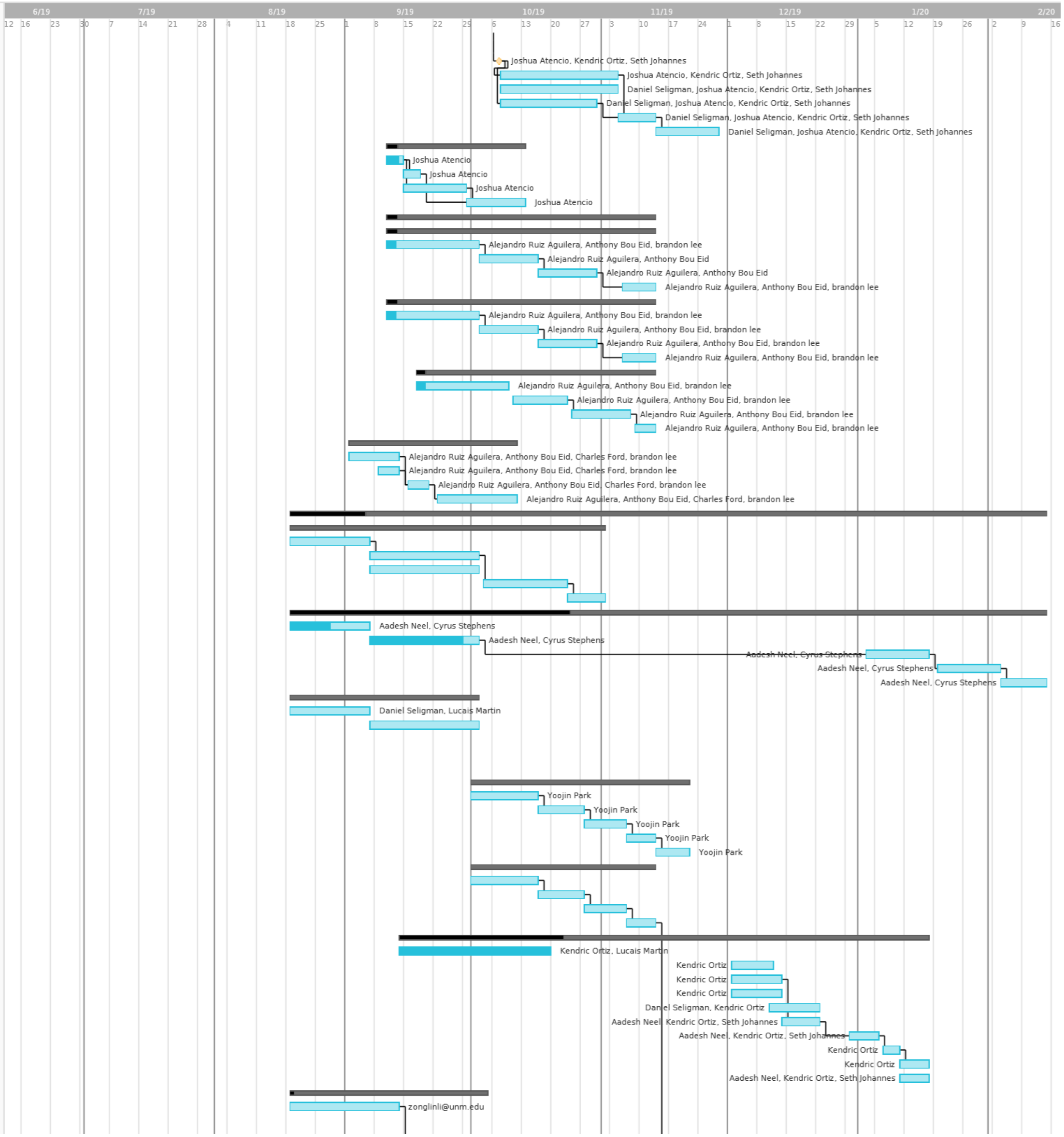
UNIVERSITY OF NEW MEXICO
SCHOOL OF ENGINEERING

SPONSOR: CHARLES FLEDDERMANN
UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NM 87131

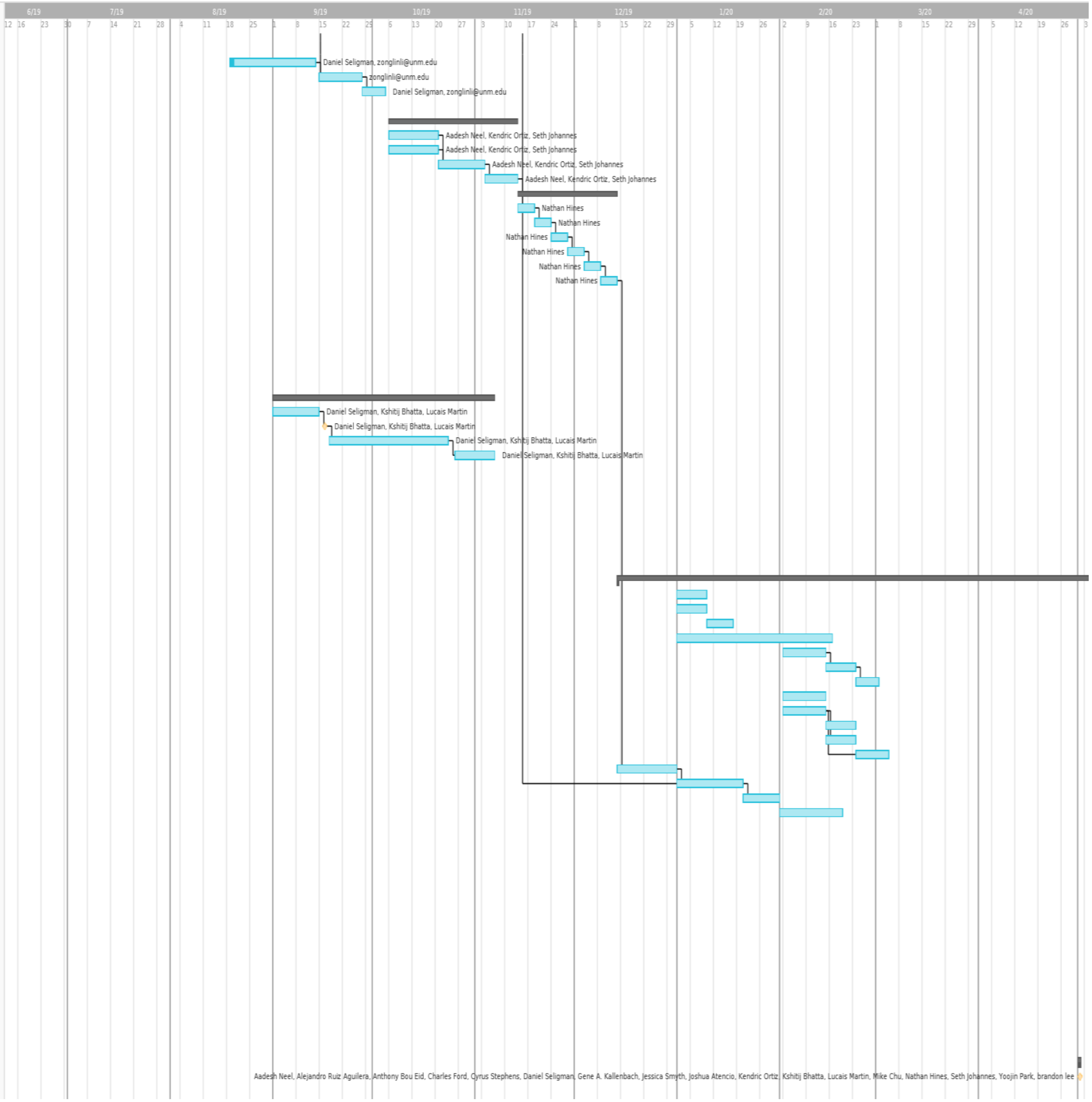
LMS 2020 EV Prototype	start	end	0h	32%
Project Management	06/13/19	04/08/20	0h	83%
FSAE Deadlines	10/03/19	04/08/20	0h	0%
Resource Determination	07/01	08/09	0	100%
Resource Allocation	08/12	08/21	0	100%
Status Reviews	06/13	06/13	0	0%
Parts Inventory	08/13	08/22	0	100%
Documents	08/19/19	10/31/19	0h	12%
Electrical Systems Officer and Elect...	08/19	10/31	0	0%
Electrical System Form	08/19	10/31	0	20%
Failure Modes and Effects Analysis	08/19	10/31	0	15%
System Design	07/01/19	10/23/19	0h	90%
Design Concept	07/01	08/23	0	100%
Design Concept Review	08/26	08/26	0	100%
Design Concept Completed	08/27	08/27	0	100%
Electrical Power/Energy Design...	08/28/19	09/10/19	0h	78%
Major Component Selection	08/29	09/05	0	100%
Major Component Purchase	09/06	09/13	0	100%
Electrical System Diagram	08/29	09/23	0	100%
Subsystem Space Allocation	08/29	09/23	0	90%
Weight Budget	08/29	09/23	0	100%
Aero Design & Analysis	08/28	09/20	0	100%
Chassis Design & Analysis	08/28	09/20	0	100%
Drivetrain Design & Analysis	08/28	09/27	0	100%
Cooling/Thermal Design & Analysis	08/28	09/27	0	80%
Cooling/Thermal System Design	09/01/19	09/23/19	0h	84%
Suspension Design & Analysis	08/28	09/20	0	100%
Brakes/Wheels Design & Analysis	08/28	09/20	0	100%
Cockpit & Safety Design & Analysis	08/28	09/20	0	80%
Instrumentation & DAQ	08/28	09/20	0	80%
Test Equipment Identification	08/28	09/04	0	90%
Test Equipment Purchase	09/05	09/12	0	40%
System Design Review	10/23	10/23	0	100%
Subsystem Design, Build,Test	08/05/19	02/14/20	0h	18%
Custom Electronics	08/05/19	11/28/19	0h	31%
Tractive System Active Light ...	08/05/19	11/27/19	0h	48%
Design	08/05	09/27	0	100%
Layout	09/30	10/07	0	100%
Review	10/08	10/08	0	0%
Fabrication	10/09	11/05	0	0%
Procure Parts	10/01	10/21	0	10%
Assembly	11/06	11/13	0	0%
Bench Test	11/14	11/27	0	0%
Battery Mgmt Sys (BMS) I/O	08/05/19	11/15/19	0h	40%
Design	08/05	08/24	0	100%
Layout	08/25	09/12	0	100%
Review	09/13	09/13	0	0%
Fabrication	09/14	09/17	0	0%
Procure Parts	09/18	10/06	0	10%
Assembly	10/07	10/28	0	0%
Bench Test	10/29	11/15	0	0%
Isolation Relay Control & Stat...	08/05/19	11/27/19	0h	10%
Design	08/05	09/26	0	25%
Layout	09/30	10/07	0	0%
Review	10/08	10/08	0	0%
Fabrication	10/09	11/05	0	0%
Procure Parts	10/09	10/30	0	0%
Assembly	11/06	11/14	0	0%
Bench Test	11/15	11/27	0	0%
APPS Decode & Motor Control	08/05/19	11/27/19	0h	27%
Design	08/05	09/27	0	75%
Layout	09/30	10/04	0	75%
Housing Mechanical Design	09/30	10/04	0	0%
Review	10/08	10/08	0	0%
Circuit Board Fabrication	10/10	11/05	0	0%
Housing Fabrication	10/10	11/05	0	0%
Procure Parts	10/10	10/29	0	0%
Assembly	11/06	11/13	0	0%
Bench Test	11/14	11/27	0	0%
Brake System Plausibility Dev...	08/05/19	11/28/19	0h	32%
Design	08/05	09/27	0	90%
Layout	09/30	10/04	0	70%
Housing Mechanical Design	09/30	10/04	0	20%



Review	10/07	10/07	0	0%
Circuit Board Fabrication	10/08	11/04	0	0%
Housing Fabrication	10/08	11/04	0	0%
Procure Parts	10/08	10/30	0	0%
Assembly	11/05	11/13	0	0%
Bench Test	11/14	11/28	0	0%
BMS	**09/11/19**	**10/13/19**	**0h**	**8%**
Document Review	09/11	09/14	0	70%
Software Download	09/15	09/18	0	0%
Test Cable Fabrication	09/15	09/29	0	0%
Bench Test	09/30	10/13	0	0%
Motor, Motor Controller, & Mot...	**09/11/19**	**11/13/19**	**0h**	**4%**
Battery to Motor Controller	**09/11/19**	**11/13/19**	**0h**	**4%**
Harness Electrical Design	09/11	10/02	0	10%
Location & Mounting	10/03	10/16	0	0%
Harness Build	10/17	10/30	0	0%
HV Insulation Test	11/06	11/13	0	0%
Motor Controller to Motor	**09/11/19**	**11/13/19**	**0h**	**4%**
Harness Electrical Design	09/11	10/02	0	10%
Location & Mounting	10/03	10/16	0	0%
Harness Build	10/17	10/30	0	0%
HV Insulation Test	11/06	11/13	0	0%
Resolver	**09/18/19**	**11/13/19**	**0h**	**4%**
Harness Electrical Design	09/18	10/09	0	10%
Location & Mounting	10/11	10/23	0	0%
Harness Build	10/25	11/07	0	0%
HV Insulation Test	11/09	11/13	0	0%
Mtr Controller Software	**09/02/19**	**10/11/19**	**0h**	**0%**
Procure EV Laptop	09/02	09/13	0	0%
Application SW Install & Test	09/09	09/13	0	0%
Comm Bus Fab & Test	09/16	09/20	0	0%
Mtr Cntr Base Configuration	09/23	10/11	0	0%
Low Voltage Harness	**08/19/19**	**02/14/20**	**0h**	**10%**
Power Distribution	**08/19/19**	**11/01/19**	**0h**	**0%**
Component Location & Mounting	08/19	09/06	0	0%
Harness Electrical Design	09/07	10/02	0	0%
Harness Location & Mounting	09/07	10/02	0	0%
Harness Build	10/04	10/23	0	0%
Harness Test	10/24	11/01	0	0%
TSAL Lights	**08/19/19**	**02/14/20**	**0h**	**37%**
Component Location & Mounting	08/19	09/06	0	50%
Harness Electrical Design	09/07	10/02	0	85%
Harness Location & Mounting	01/03	01/17	0	0%
Harness Build	01/20	02/03	0	0%
Harness Test	02/04	02/14	0	0%
Ready to Drive (RTD) Annunci...	**08/19/19**	**10/02/19**	**0h**	**0%**
Component Location & Mounting	08/19	09/06	0	0%
Harness Electrical Design	09/07	10/02	0	0%
Harness Location & Mounting	-	-	0	0%
Harness Build	-	-	0	0%
Harness Test	-	-	0	0%
Dash & Status LEDs	**10/01/19**	**11/21/19**	**0h**	**0%**
Component Location & Mounting	10/01	10/16	0	0%
Harness Electrical Design	10/17	10/27	0	0%
Harness Location & Mounting	10/28	11/06	0	0%
Harness Build	11/07	11/13	0	0%
Harness Test	11/14	11/21	0	0%
GLV Main Harness	**10/01/19**	**11/13/19**	**0h**	**0%**
Harness Electrical Design	10/01	10/16	0	0%
Location & Mounting	10/17	10/27	0	0%
Harness Build	10/28	11/06	0	0%
Harness Test	11/07	11/13	0	0%
HV Battery Charger	**09/14/19**	**01/17/20**	**0h**	**31%**
Purchase	09/14	10/19	0	100%
Interlock Design	12/02	12/11	0	0%
Harness Electrical Design	12/02	12/13	0	0%
Housing Design	12/02	12/13	0	0%
Component Location & Mounting	12/11	12/22	0	0%
Harness Location & Mounting	12/14	12/22	0	0%
Harness Build	12/30	01/05	0	0%
Harness Test	01/07	01/10	0	0%
HV Insulation Test	01/11	01/17	0	0%
HV Battery Charge Procedure	01/11	01/17	0	0%
Tractive System Monitoring Poi...	**08/19/19**	**10/04/19**	**0h**	**2%**
Electrical Design	08/19	09/13	0	0%



Task	Start	End	Hours	%
Mechanical Design	08/19	09/13	0	5%
Build	09/15	09/27	0	0%
Test	09/28	10/04	0	0%
Instrumentation & DAQ	-	-	0h	0%
Battery Segment Simulator	10/06/19	11/13/19	0h	0%
Electrical Design	10/06	10/20	0	0%
Mechanical Design	10/06	10/20	0	0%
Build	10/21	11/03	0	0%
Test	11/04	11/13	0	0%
BMS & BMS I/O Segment Bench...	11/14/19	12/13/19	0h	0%
Segment 1 Assembly & Test	11/14	11/18	0	0%
Segment 2 Assembly & Test	11/19	11/23	0	0%
Segment 3 Assembly & Test	11/24	11/28	0	0%
Segment 4 Assembly & Test	11/29	12/03	0	0%
Segment 5 Assembly & Test	12/04	12/08	0	0%
Segment 6 Assembly & Test	12/09	12/13	0	0%
HV Battery	-	-	0h	0%
HV Battery Assembly & Test Proc...	-	-	0	0%
Iso Relay, Relay Control, and Har...	-	-	0	0%
Cell Installation	-	-	0	0%
BMS, BMS I/O and Harness Install...	-	-	0	0%
Battery Discharge Test	-	-	0	0%
Battery Charge Test	-	-	0	0%
Battery Hand Cart	09/01/19	11/06/19	0h	0%
Design	09/01	09/14	0	0%
Review	09/16	09/16	0	0%
Build	09/18	10/23	0	0%
Test	10/26	11/06	0	0%
Energy Meter	-	-	0h	0%
Purchase	-	-	0	0%
Location & Mounting	-	-	0	0%
Harness Design	-	-	0	0%
Harness Build	-	-	0	0%
HV Insulation Test	-	-	0	0%
Energy Meter Box	-	-	0	0%
System Integration	12/14/19	05/20/20	0h	0%
Brake Subsystem Install	01/01	01/09	0	0%
Low Voltage Harness Installation	01/01	01/09	0	0%
Dash & Status Indicator Installation	01/10	01/17	0	0%
Brakes Bleed, Balancing and Static ...	01/01	02/16	0	0%
Brake Press. Senors to BSPD/BSE Ca...	02/02	02/14	0	0%
APPS and APPS Decode Installation	02/15	02/23	0	0%
APPS to APPS Decoder Calibration &...	02/24	03/01	0	0%
Brakes, APPS to BSPD Calibration &...	02/02	02/14	0	0%
Motor Controller, Motor and Harnes...	02/02	02/14	0	0%
HV Insulation Test	02/15	02/23	0	0%
Motor Controller to Motor Test	02/15	02/23	0	0%
Motor to Drivetrain Test	02/24	03/04	0	0%
Battery Installation	12/14	12/31	0	0%
Battery to LV System Test	01/01	01/20	0	0%
Battery to Drivetrain End to End Te...	01/21	01/31	0	0%
TSAL and RTD Installation & Test	02/01	02/19	0	0%
Aero Installation	05/08	05/15	0	0%
Vehicle Ready to Drive	05/20	05/20	0	0%
System Test	-	-	0h	0%
Driver/Cockpit Checks & Template ...	-	-	0	0%
Status and Controls Static Tests	-	-	0	0%
IMD Test	-	-	0	0%
Insulation Measurement Test	-	-	0	0%
Start/Stop Test	-	-	0	0%
Acceleration Test	-	-	0	0%
Steering and Suspension Test	-	-	0	0%
Brake Test	-	-	0	0%
Brake Regeneration Test	-	-	0	0%
Energy Meter Test	-	-	0	0%
Rain Test	-	-	0	0%
Rules Compliance Review	-	-	0	0%
Completion	05/01/20	05/01/20	0h	0%
Car Complete	05/01	05/01	0	0%



Gantt Chart 1
https://www.dropbox.com/s/3seih8emhqgay9o/Project%2014%20Gantt%20Charts%201.pdf?dl=0

Gantt Chart 2
https://www.dropbox.com/s/j8rvk67o1l860kd/Project%2014%20Gantt%20Charts%202.pdf?dl=0

Gantt Chart 3
https://www.dropbox.com/s/t51vsfi8d1n0zna/Project%2014%20Gantt%20Charts%203.pdf?dl=0

MANPOWER & COST ESTIMATES

FORMULA SOCIETY OF AUTOMOTIVE ENGINEERS - ELECTRIC VEHICLE

PROJECT MANAGERS: SAM CASAUS, DAVID SHAPIRO, LUCAIS MARTIN, SALVADOR LAMBERT AND JESSICA SMYTH

AADESH NEEL
ALEJANDRO RUIZ
BRANDON LEE
CYRUS STEPHENS
JOSHUA ATENCIO
KENDRIC ORTIZ
MIKE CHU
NATHAN HINES
SETH JOHANNES
ZONGLIN LI

UNIVERSITY OF NEW MEXICO
SCHOOL OF ENGINEERING

SPONSOR: CHARLES FLEDDERMANN
UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NM 87131

14 DISCLAIMER

Please note that we are under the assumption that we need to list all costs for everything we need. As FSAE is a well-established program, we have a lot of the materials. We included cost information for both the total (for what we do and do not need to buy) and needed (for what we do need to buy), as established in their respective areas. Please note that we used the provided template for EC419 in making these tables. We kept as much information as possible from those tables as this was how this document and rubric were presented to us.

15 LABOR TYPES

Typical Labor Categories and Hourly Costs				
Task	Position Required	Hours Required	Hourly Rate	Total Wage
Design Wiring Harness	Wiring Engineer	40	$25.00	$1,000
Eagle Layout Schematics	Electronics Engineer	240	$35.00	$8,400
Purchasing Parts	Purchasing Professional	25	$15.00	$375
Testing	Test Engineer	300	$32.00	$9,600
Sponsor Marketing	Business Consultant	15	$15.00	$225
Powertrain	Mechanical Engineer	150	$42.00	$6,300
Total				$25,900

16 MATERIALS COSTS

Materials Cost		
Task	Materials	Cost
Low Voltage Wiring Harness	Wires and connectors	$1,400
High Voltage Wiring Harness	Wires and connectors	$1,500
Circuits	Custom PCB’s	$2,500
Dash	Controls (LED’s, switches, brake light	$100
Brakes	Sensors	$30
Driving	Pedal Box	$120
Motor	Drivetrain Belt	$60
Total		$5,710

17 EQUIPMENT COSTS

Equipment Cost			
Task	**Equipment**	**Type**	**Cost**
Batteries	EV Battery Charger	Purchase	$4,000
Power	Motor Controller Power Supply	Purchase	$60
Total			**$4,600**

18 SUMMARY OF COSTS

FSAE IC Electrical Manpower & Cost Summary	
Cost Category	**Estimated Cost**
Labor	$25,900
Materials	$5,710
Equipment	$4,600
Total Estimated Project Cost	**$36,210**

FUNCTIONAL SPECIFICATION

FORMULA SOCIETY OF AUTOMOTIVE ENGINEERS - ELECTRIC VEHICLE

PROJECT MANAGERS: SAM CASAUS, DAVID SHAPIRO, LUCAIS MARTIN, SALVADOR LAMBERT AND JESSICA SMYTH

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REVISION HISTORY			
Name	**Date**	**Changes**	**Version**

Table of Contents

1 Introduction

The Powertrain Section of the SRD says the following:

The powertrain subsystem will be responsible for the power generation and transmission from the motor to the wheels. This subsystem consists of two main parts: The motor and the drivetrain. The goal of the electric motor is to produce power of at least 70 kW (93.9 HP) and the goal of the drivetrain is to reliably transfer the produced power from the motor to the wheels with minimum losses. One of the defining attributes of the car is the power-to-weight ratio. This is a simple ratio that allows you to compare the performance of two vehicles without the need for technical explanation or engine design. Using an estimated maximum weight of 550lbs and a motor with the proposed power output we get a minimum power-to-weight ratio of 0.17HP/lb which, based on the results of the 2017 and 2018 Lincoln electric results, will insure a competitive car during the 2020 competition. To achieve the highest possible power-to-weight ratio, we will consider the weight of the subsystem to be a priority, but not at the expense of overall performance, reliability of the powertrain or safety of the team. A motor controller will be utilized to maintain a consistent, reliable power curve for the electric motor. The motor controller will also ensure a proper balance between motor performance and motor temperature. The drivetrain of the subsystem will be able to handle the instantaneous peak torque created by the electric motor with minimum power losses. It will be optimized to achieve a maximum vehicle velocity for the acceleration event and operate in the peak RPM range set by the 80kW power limitation for the electric motor. A planetary gearing system will be utilized to implement a two speed transmission system. This will ensure a higher top speed and reduce stall torque limits. Motor components will be judged based on their ability to increase the performance of the vehicle compared to the effect they have on the total weight, reliability of the system and safety of the team. The motor and components will be designed to operate at an optimum temperature for power delivery and motor safety. Ease of maintenance will be considered when designing this sub-system to ensure reliability. Tire analysis on multiple tire options was conducted, and revealed that a maximum of 0.90 G's of longitudinal acceleration can reliably be obtained for a range of driver weights. Therefore in order to achieve the system goal to perform within the maximum capability of the tires, the powertrain will support the vehicle system to achieve a lateral acceleration of at least 1.5 G’s and a longitudinal acceleration of at least 0.90 G’s.

1.1 Summary

We are designing, building, and manufacturing the electrical and mechanical subsystems of a formula-style electric vehicle race car.

1.2 Requirements

We have the following system limitations.

- *Rules and Regulations: The team will design each system under the guidelines and restrictions of the 2020 Formula SAE and 2020 Formula SAE Electric Rules.*

- *Tire Capability: All subsystems will consider the limitations of the tires and will perform within them.*
- *System Integration: Each subsystem will be designed such that they integrate with adjacent systems in order to obtain a performance capable of competing in all events and able to be maintained.*
- *Schedule: The vehicle system will be designed in a manner which is within the limitation of the schedule. All deadlines including documentation, manufacturing, and competition deadlines shall be met.*
- *Cost: The vehicle will be designed within the cost limitations set by the amount of donations received from sponsors. The budget for each subsystem will be designated as per the amount of funding received.*

18.1

1.3 Numbers

The team will use results of previous competitions to analyze the system performance of 10thplace finishes from 2014-2018. This data will be used to form a basis for performance goals. Table 1 shows the overall score of the 10thplace finish for Formula SAE Lincoln 2014-2018. Performance benchmarks will be obtained from looking at previous competition results to determine lateral, longitudinal, and braking g's.

	2014	2015	2016	2017	2018
Overall Point Score	719.0	619.6	661.8	686.0	615.7

Table 2 shows the 10th place event results for Formula SAE Lincoln for 2014-2018.

Event	2014	2015	2016	2017	2018
Design	110	107	110	110	100
Presentation	69.3	67.1	63.4	62.9	68.6
Cost	77.30	75.08	77.14	77.32	67.7
Acceleration	56.64	65.32	59.39	87.05	72.0
Skidpad	42.49	36.56	40.22	50.72	46.0
Autocross	130.49	120.97	133.85	95.45	76.7
Endurance	220.8	174.6	230.7	181.4	134.0
Fuel Efficiency	81.4	81.3	82.4	72.4	50.7

TABLE 2: LINCOLN EVENT RESULTS FOR 2014-2018

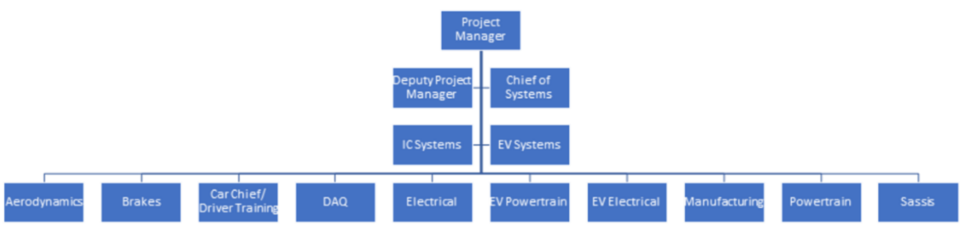
To maintain the feasibility of a top 10 finish, the vehicle will need to complete all stages of competition without fail. Reliability is key to achieving our goals due to the high point values awarded to endurance and efficiency. The vehicle will be designed to not give up reliability for performance or weight loss unless these values are increased sufficiently to merit such a risk.

In order to maximize dynamic event scoring, adjustability on the track will be implemented to optimize the system for longitudinal or lateral acceleration along with preferred driver settings. These adjustments must be able to be conducted live during the respective event.

LMS2020 recognizes that performance will be limited by the ability of the drivers. The car is being built with the concession that the average driver (less than three months of "seat time", training with the LMS2020 car, or other racing experience) will be behind the wheel, while also not neglecting adjustments for the experienced driver (three or more months of training) to optimize their performance. The car must not be the limiting factor. The performance of the system must be limited to the abilities of the driver.

1.4 Existing System

We service the older vehicles to learn more about the systems. We can learn lessons from previous vehicles. About 40 members work together under different subteams to build the car. The chain of command is shown below.



1.5 Terminology

Throughout the document

1.6 References

Please look at the roadmap document and the FSAE2020 Rules.

2 Functional Description

2.1 Use Cases

Formula Society of Automotive Engineers is an international collegiate engineering competition. For the compoetition, Students design, manufacture, evaluate, and race a formula style racecar according to rules. These standards help keep vehicles safe and ensure that the competition focuses on Engineering

The FSAE 2020 Competition will be in Fontana California June 17-20

2.2 User Community

UC-1: Race car Drivers: This community knows and has experience in driving race cars. They know the appropriate safety precautions to take and how to control the car in various conditions.

UC-2: Competition Drivers: These people are being trained by UC-1 and are learning how to drive the car. They have more ability than those without prior training.

UC-3: Team-members: This community may not have any experience driving a formula race car. They will be taught how to drive the car, how to shut it down and how to control it.

2.3 Administration Functions

N/A

2.4 Error Handling

Errors will be handled by the BMS boards. From those errors, our team will be able to locate and change those sensors or the appropriate wiring if necessary.

2.5 Security

There is no real security concern for our project. The ECU of the system is contained and is only modified and configured by our team.

2.6 Help

Design binders that describe how the car functions will be available. Team members that have the knowledge on how to operate it will also be present.

2.7 Printing

N/A

2.8 Interfaces

2.8.1 User

Ease of adjustability is of high importance for the LOBOmotorsportsteam to achieve our goal of drivability. On site ease ofadjustmentwill allow the Lobo Motorsports team to adapt to the track conditions at Lincoln as well as adjusting the car's response for the 6 different drivers and their preferences at competition.Additionally, having ease of adjustability will allow our team to also tune the car for different weather conditions such as wet vs dry and hot vs cold. Different surfaces also play into how cars handle; Asphalt vs Concrete surfaces have different grip effects on the tires which can be taken advantage of by ease of adjustability in the tires, brakes, and suspension. An easily tuneable car will also allow the team to take advantage of chassis tuning at driving days and training engineers for adjusting the car at competition. In order to maximize ease of serviceability, the battery and engine must be able to be completely removed within 30 minutes; this includes removing any car components that are in the way before the engine or battery.

The team will focus on creating an ergonomic and highly functional environment for the driver by providing controls that are accessible and easy to operate. Additionally, the cockpit will be designed such that adequate comfort will be maintained throughout all events, particularly the endurance event. The pedal assembly, seat, belts, and headrest will be designed for all individuals ranging from the 5th percentile female up to the 95th percentile male. The steering wheel must also be removable to facilitate easy entrance and exit of the cockpit. Adjustability of different subsystems will be made readily available for each driver to customize the vehicle parameters to comply with their size, weight, and preferences.

2.9 Boundary Conditions

We have the following system limitations:

- Rules and Regulations: The team will design each system under the guidelines and restrictions of the 2020 Formula SAE Rules.
- Tire capability: All subsystems must be designed such that they perform within the maximum capability of the tires.
- System Integration: Each subsystem will be designed such that they integrate with all subsystemsin order to attain a top 10 position at competition. The vehicle will be designed with ease of adjustment and maintenance in mind.
- Feasibility: The vehicle system will be designed in a manner that is within the limitationsofrules, tire capability, schedule,and cost.

2.10 Constraints

We must meet a schedule, budget, and present the features previously listed and in the Roadmap Document

2.11 Platforms

N/A

2.12 Internationalization

N/A

2.13 Performance

18.1.1

2.13.1 Capacity

Please see the SRD.

2.13.2 Response times

2.14 Portability

N/A

2.15 Expandability

N/A

2.16 Customization

N/A

2.17 Support & Maintenance

N/A

2.18 Configuration Management

2.19 Documentation

We will have design binders and poster presentations. Please see the Roadmap document for more information.

3 Approvals

We submit all documentation to the FSAE Project Manager (Sam Causas), and Dr. Russell before submission.

TEST PLAN
ELCON PFC5000 BATTERY CHARGER

FORMULA SOCIETY OF AUTOMOTIVE ENGINEERS - ELECTRIC VEHICLE

PROJECT MANAGERS: SAM CASAUS, DAVID SHAPIRO, LUCAIS MARTIN, SALVADOR LAMBERT AND JESSICA SMYTH

AADESH NEEL
ALEJANDRO RUIZ
BRANDON LEE
CYRUS STEPHENS
JOSHUA ATENCIO
KENDRIC ORTIZ
MIKE CHU
NATHAN HINES
SETH JOHANNES
ZONGLIN LI

UNIVERSITY OF NEW MEXICO
SCHOOL OF ENGINEERING

SPONSOR: CHARLES FLEDDERMANN
UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NM 87131

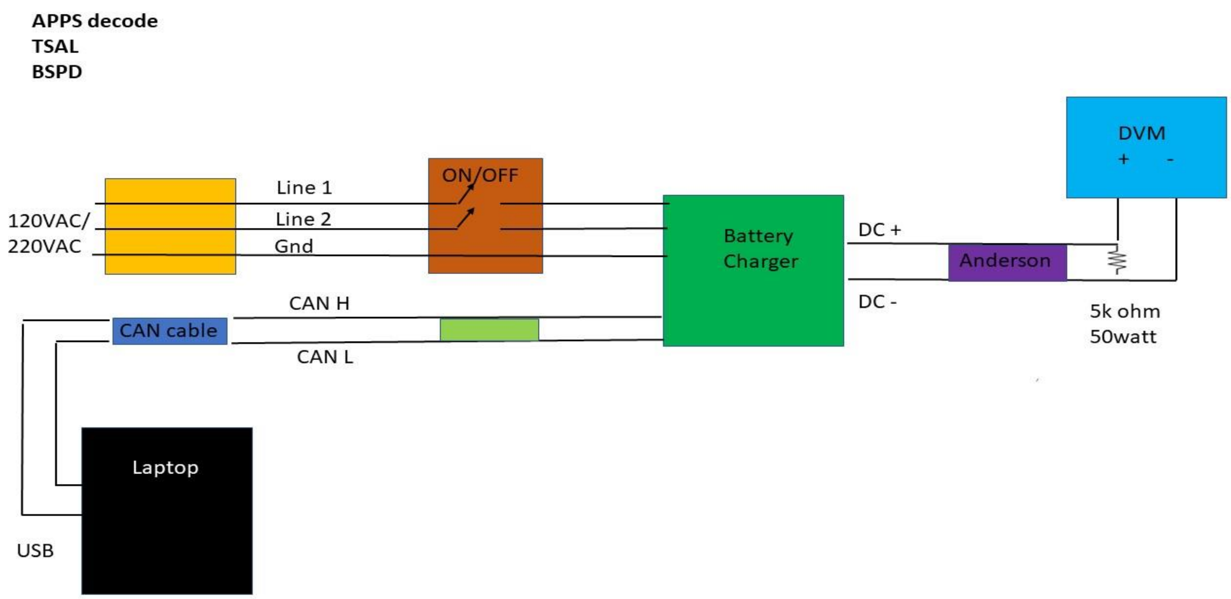
1. INTRODUCTION

Our battery charger is an Elcon PFC5000 that can be programmed to dispense a safe amount of current so that we can charge our lithium-ion batteries. We want to make sure that we can accomplish this and create an environment where we can test this without running the risk of harming ourselves with electrocution, or the risk of damaging the batteries.

2. OBJECTIVES AND TASKS

- Objectives
    - Verify the the battery charger input power connections are correct.
    - Verify the ability to transmit commands to the battery charger and receive information from the battery charger using the CAN bus.
    - Demonstrate the ability to control the output current and voltage of the battery charger.
- Tasks
    - Wire input switch and power plug to the battery charger. Test the connections using an ohmmeter or an insulation resistance tester prior to applying power.
    - Design and fabricate a test load for the battery charger. The test load will include a mating connector to the battery charger and provisions for attaching a voltmeter. Test the load with an ohmmeter prior to applying power.
    - Set up in a suitable location. This will include establishing the restricted entry boundary for high voltage work. This will require signage or a physical entry barrier (e.g. rope/tape)
    - Conduct initial power-up test
    - Conduct CAN bus communication test
    - Verify the ability to control the output current and voltage of the battery charger.

3. TEST CONFIGURATION



4. HARDWARE AND SOFTWARE REQUIREMENTS

- Windows computer with CAN bus control software.
- Elcon PFC5000 model TCCH 288-7.5*2 battery charger

5. ENVIRONMENT AND FACILITY REQUIREMENTS

- Electrical lab and a test bench with a non-conductive surface.
- 220 VAC, 60Hz, 23 amp power. (Note: If this is not available, 120VAC, 60Hz, 20 amp power can be used, but the output of the battery charger will be reduced.)
- Signage: Caution High Voltage sign
- Restricted Entry Boundary: Yellow Caution Tape and adhesive tape to secure it in place.

6. TRAINING

All personnel conducting the test must have received FSAE Electrical Safety Training

7. TEST EQUIPMENT

- Resistive Test Load with at least a 500VDC, 50watt, (0.1 amp) rating. The test load shall be designed such that no exposed high voltage is present when connected to the battery charger and voltmeter.
- USB to CAN bus interface
- Computer with CAN bus communication software.
- Cat III Digital Voltmeter with test leads

8. SAFETY EQUIPMENT

- Safety Glasses

- Long sleeve shirt
- For emergency use only: Insulated gloves if reaching inside the restricted entry boundary while circuit is energized.

9. RESTRICTIONS

Manipulation of energized circuits is not permitted. Power will be turned off and the voltage monitored to verify the voltage present is below 50VDC prior to manipulation of circuits.

10. ROLES AND RESPONSIBILITIES

A minimum of three people are required to conduct this test:

1. Person #1 Test Coordinator and Data Recording
2. Person #2 Test Operator operates computer and reads meter
3. Person #3 Test Safety ensures safe conduct of test and stands by power switch to turn off power in case of a malfunction

11. SCHEDULES

- Major Deliverables
    - Test Plan
        - Rough draft done by February 10th.
        - Final draft done by February 17th.
    - Test Cases
        - Test done by February 24th.
    - Test Summary Reports
        - Report done by February 28th.

12. RISKS/ASSUMPTIONS

- Risk and Mitigation:
    - High Voltage Work. Risk will be mitigated through the use of insulation to prevent exposed high voltage, signage, restricted entry boundary, properly rated test equipment,
    - Arc Flash: Risk will be mitigated by ohmmeter and insulation resistance checks prior to energizing circuit. No manipulation of energized circuit components is allowed except under emergency conditions.
- Assumptions:
    - The program can read the data from the battery management system.
    - We will be safe when testing

TEST PLAN
EMRAX 228 MOTOR

FORMULA SOCIETY OF AUTOMOTIVE ENGINEERS - ELECTRIC VEHICLE

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Trial 1: Hooking up the battery to the Motor Controller
Goal: This will be the first time we hook the 470V (400V nominal) to the motor controller. The motor controller will be programmed to run at 10% max voltage. Our goal is to ensure that we safely create a proper connection in order to successfully turn the motor. We will be able to check our 3-phase connections and programmatic application. We will also be able to test the input of the pedal to control speed via voltage.
General Safety: For our first trial run we will have the motor controller team in close proximity to the setup in proper PPE. See following section for proper PPE. The procedure will be carried out under the supervision of an individual trained in high voltage systems. More people may be present but should maintain a 10ft radius away from the main setup to prevent overcrowding and issues.
PPE:

- Gloves rated to Class 00
- Apron
- Face protection
- Close toed, thick soled shoes
- Insulated tools
- NO METAL JEWELRY

Procedure:
PART 1: Set Up Motor Controller and NDrive
For the first trial, we will run using the .urf file for the medium voltage Emrax 228 motor sent from Emrax. The parameters are set to the parameters Emrax uses to characterize their motors. The parameters may need to change slightly to make our system more efficient, but this will get us a good baseline.

STEP 1: Power on the motor controller

- Ensure switches to RFE and RUN (X1-T, X1-G) are all open
- Connect 12V battery to connection X1-D and X1-C
- Open NDrive (should be most recent version). Baudrate should be 115k. Attach the serial port connector
- Select correct COM port
- Check that NDrive sees controller. Indicated by Firmware number at the bottom of the NDrive

STEP 2: Connect Battery to the Controller (**CAUTION THIS STEP USES HIGH VOLTAGE***)

- All switches in the pre-charge circuit should be open
- The discharge (emergency off switch) should be closed. If it is open, close it for atleast 15 seconds to ensure any voltage in the motor controller is drained

- Open discharge (emergency off switch and connect the ground of the battery to the motor controller ground.
- The second switch closed is the switch connecting the positive terminal of the battery to the motor controller THROUGH A PRECHARGE RESISTOR.
- Once the precharge switch is closed, monitor the DC-BUS voltage under (Extra->Vdc-Bus) in NDrive. For our first connection we are only using a minimal voltage of 40V.
- Once the DC-Bus reads the equivalent of 36V (90% of our goal voltage), we will close the switch that connects the battery to the motor controller through the fuse. Once closed, open the precharge switch.
- THE SYSTEM IS NOW LIVE

STEP 3: Enable the Motor Controller

- RFE, Connection X1-T, acts as an ignition power and this will allow the motor to rotate.
- Once the RFE start switch is closed, we must determine if the phase lines to the motor (U,V,W) are correctly connected.

PART 2: Checking Proper Phase connection to Motor

1. Open NDrive and set I max pk to 10%
2. Set Speed 1 and Speed 2 at Pos-Reference to 120
3. Auto→Special Fuctions→ select [fn4] Phasing-Rotating
4. Press START
5. Wait 10 seconds
6. Switch on X1-G (Run-Enable) {this is the equivalent of our starter}
7. If working properly:
    - Motor will rotate 360 degrees in a clockwise direction
    - If any other behavior is seen, the motor phases are not connected properly
8. Open ‘RUN’ Switch (X1-G) so that the drive is turned off
9. On NDrive, record FB-offset. This is the new offset angle. Write this value into FB-Offset at the page settings and save to Eprom
    a. To save to eprom press Eprom-STORE 0 button

*****Motor Controller is now ready to accept command signals*****

PART 3: Configuring Analogue Input and Test Motor
****Leave I Max at 10% for ALL configurations****

1. Motor should still be off.
2. Set command mode to Analog Torque and Format to Cmd+ and offset to -1000
3. Set the mode 0 to +10V
   *** The NDrive doesn’t have 5V range so Im wondering if we will need a different potentiometer. ****

4. Turn potentiometer to max resistance. We should use a potentiometer to test the motor. We would need a potentiometer hooked up to a 10V supply. This would be connected to X1-J and X1-H
5. Monitor speed inside NDrive on Speed page at top left
6. Ain should be below 0 if resistance is at a max
7. Ain x scaled = (Ain in + Offset) * Scale **We might need this if we do use the pedal as an input.

*****If Ain is reading correctly in NDrive, the motor can now be turned on*******

PART 4: Using the potentiometer with the motor on

1. Set the potentiometer to 0. Double check Ain is below 0
2. Turn RUN switch (X1-G) to on
3. **Check all status signals**
4. If OKAY slowly turn the potentiometer. The motor should turn in the clockwise direction.

PART 5: Disconnecting the battery

1. Make sure RFE switch is open before disconnecting for 1 second.

CHARACTERIZATION REPORT

FORMULA SOCIETY OF AUTOMOTIVE ENGINEERS - ELECTRIC VEHICLE

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Revision History:

Version	Revision Date	Description	Author

Contents

19 OVERVIEW

19.1 Executive Summary

The purpose of this characterization report is to briefly summarize which features of our electric vehicle prototype met design specifications and which did not. Previously, before the pandemic our design specifications involved a bench test, a driving test, system integration and system assembly. Unfortunately, due to social distancing rules we did not meet those specifications because our shop got shut down, we were not allowed on campus and we were not allowed to work together on the vehicle any longer. Specifications we did meet include programming the battery charger and circuit schematics and layouts that control different parts of the car including the batteries, tractive system, acceleration pedal, and brakes.

19.2 Characterization Summary

Test Table – Not applicable.

20 PURPOSE

The purpose of the electric vehicle prototype is to create a foundation vehicle for future students to improve upon and take to competition. Future students would create an electric vehicle that is FSAE rules compliant and compete against several other universities in dynamic and static events. This vehicle provides students with real world engineering experience since they fundraise, design, improve, build, and test a running electric car.

20.1 Reference Documents

Emrax 228 Test Plan
https://www.dropbox.com/s/1i6826ubbphg92u/Test%20Plan.docx?dl=0

Elcon Test Plan
https://www.dropbox.com/s/pnrzujjk25ykb4t/Elcon_TestPlan_Rev1.pdf?dl=0

Eagle - Software Rules Check
https://www.autodesk.com/products/eagle/blog/design-rule-check-pcb-layout-basics-3/

FSAE Rules

https://www.dropbox.com/s/u9woz9dgrfia0gi/FSAE_Rules_2020_V2.pdf?dl=0

21 SCOPE

The team met all the specifications for our circuit board designs to comply with the Eagle software rules and layout. These boards include the Brake System Plausibility Device Schematic, Isolation Relay Control Schematic, Battery Management System Input/output Schematic, Tractive System Active Light Schematic, and Acceleration Pedal Position Sensor Schematic.

22 TEST CASE RESULTS

The team did not record test results derived from our test plans. Due to the coronavirus pandemic our electric vehicle shop got shut down and we were no longer allowed to go near our vehicle. This pandemic started at the end of the semester, around the same time our team planned on performing our test runs.

22.1 Test Cases

22.1.1 System Function

N/A

22.1.2 Functional Capability

N/A

22.1.3 Performance Capability

N/A

23 SUMMARY AND CONCLUSIONS

23.1 Demonstrated Capabilities

The BMS I/O, Isolation Relay Control, APPS, Tractive System Active Light, and Brake System Plausibility Device describe overall capabilities of the electric vehicle prototype.

Overall deficiencies of our vehicle include the system integration, system assembly, and driving test.

The BMS I/O custom circuit board provides electrical isolation between the low voltage electronics and the TinyBMS boards. It is necessary for the distributed BMS architecture used on the competition vehicle. It consists of digital isolators and optoisolators along with some logic that allows the six TinyBMS boards to be daisy-chained together to form a complete BMS for the entire battery array. Each TinyBMS board requires a matching BMS I/O board so a total of six BMS I/O boards are required. This board has both high voltage and low voltage components.

The Isolation Relay board combines signals from the BMS, BSPD, IMD, APPS Interface and Battery Charger and implements the logic that controls the Isolation Relays. The Isolation Relays are the main relays that connect the battery high voltage to the Motor Controller. If any faults occur, the Isolation Relays are opened to disconnect the battery. The Isolation Relays are also used during battery charging to disconnect the battery from the charger when balancing the cells or when the charge process is complete. This board also drives status LEDs mounted on the battery box.

The APPS custom circuit board converts the signals from the Accelerator Pedal Position Sensor (APPS) into the desired voltage levels for the Motor Controller. The APPS is a dual sensor device. This board monitors both signals to verify their integrity. If a fault condition exists, it will trigger the Isolation Relay Control board to shut down the vehicle.

The Tractive System Active Light (TSAL) is a custom circuit board that monitors the high voltage at the connection between the battery box and the Motor Controller. If the voltage is less than 60VDC, a green light is illuminated on the top of the vehicle. If the voltage is 60VDC or greater, a red flashing light is illuminated on top of the vehicle. Because this circuit board has both high voltage and low voltage elements, is required to operate from less than 60VDC up to 600VDC, and must minimize the drain on the high voltage battery when the low voltage is shut down, it is one of the more challenging designs.

The Brake System Plausibility Device (BSPD) is a custom circuit board that monitors the outputs of the brake sensor signals to determine if a fault has occurred. It also monitors the power being supplied to the Motor Controller in conjunction with the brake sensors to determine if “hard braking” is occurring simultaneously with application of the accelerator pedal. If so, a fault is declared. If either fault condition occurs, a signal is sent to the Isolation Relay Control board to remove power from the vehicle.

23.2 System Deficiencies

System Assembly - Assemble all subsystems and install into the vehicle. This would involve a substantial amount of wiring. This effort includes all the mechanical components, final mounting of subsystems to the vehicle and installation of all wiring harnesses. The system assembly is a deficiency of our prototype.

System Integration – This includes both static and dynamic tests on the assembled vehicle. Some tests can be completed prior to a fully assembled vehicle whenever the required subsystems have been installed although since we did not install our circuit boards, we could not integrate them together.

Driving Test - These tests are accomplished with the vehicle at the test track and a driver in the cockpit but since the vehicle is not running, we could not test drive it.

23.3 System Refinements

System refinements included redesigning circuit board based on resistor, capacitor, voltage, and current capacities. These refinements took place with the help of Gene Kallenbach. Redesigning circuits were a result of each circuit board's different specifications and rules in Eagle that did not originally comply. After refinements, the Eagle software allowed for circuit schematics to be transferred as layouts.

23.4 Recommendations and Estimates

If it were not for the coronavirus pandemic our system deficiencies including system integration of circuit boards, system assembly and driving tests would not be deficiencies. Our team was on track to deliver an electric vehicle prototype that would run on the track so the only way our team could have mitigated this issue is if we set our deadlines several months earlier than expected.

Design Documentation found in System Design Review
https://www.dropbox.com/s/d1wv7incka1ig26/L20_EV_SDR.pptx?dl=0