Autonomous Aircraft Rescue Firefighting Vehicle

Speedfest 2022 Charlie Div. Team 2

Team Fax

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Abstract

Aircraft fires are dangerous and can get out of control quickly. Due to the size of modern day aircraft, they can hold a large amount of fuel. This leads to a larger and hotter fire, one in fact that may be difficult for humans to approach. To decrease the risk of human life the implementation of autonomy to firefighting vehicles might be the solution.

In this article, one will find the complete background, design and manufacturing processes, as well as future plans for this concept to become a reality. A team of eight engineering technology students have put together ideas, experience and effort to propose a hopeful execution for the Autonomous Aircraft Rescue Firefighting Vehicle. One will find throughout this paper that many types of data have been collected, analyses have been run, and investigative research conducted. Programming, wiring, welding, machining, and testing are among several things that have contributed to the progress of this project. Over the course of ten months, amongst complexities and successes, Team Fax is attempting to solve this real-world problem of dangerous aircraft fires. To demonstrate this concept at a scaled size, the team has competed in the Oklahoma State University 2022 Speedfest Competition. The competition required the AARFF vehicle to navigate a course of cones based on GPS locations as well as locating and extinguishing a type A jet fuel fire.

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1 Introduction

1.1 Background

Aircraft fires are unpredictable, burn very hot, and can be deadly to firefighters. Because the fires are liquid-fueled fires and there is a large amount of the fuel present in the fuel tanks of the plane; there can be flare ups and explosions. Due to the danger of aircraft fuel fires researchers are working on a safer system to suppress these fires.

1.2 Problem

An autonomous system with the ability to extinguish the fuel fires without putting itself into compromising situations, this is the problem to be solved. The Autonomous Aircraft Rescue Firefighting Vehicle (AARFF) is one possible solution. This vehicle removes human firefighters from close proximity to the fire keeping them safer. It will also suppress the fire without creating any additional problems for itself or for rescue workers.

1.3 Overview

A user focused overview of the AARFF system follows. Before launch, the system is programmed with GPS coordinates to map the specific path to the fire. This would be used to keep the vehicle on taxiways or to strictly avoid the paved areas. Once the system is loaded with the navigation and fire GPS points, it is ready for launch. When placed into autonomous mode the vehicle will navigate through the GPS points, extinguish the fire, and return to base. Once the vehicle is back, all the system needs to run again are new coordinates and a refill of the extinguishing agent.

2 Description of Design Alternatives, Methodology, and Calculations

2.1 Design Features

2.1.1 Mechanical Design Features

2.1.1.1 Body

The body is laser cut from .125 inch thick ABS plastic. ABS plastic was selected due to its ability to withstand heat and stress while still being easily worked. Once the body panels are cut they will be fastened to the chassis using ⅜ inch bolts and sealed with Flex Seal to ensure it is water tight.

2.1.1.2 Chassis

The chassis is fabricated of 1 inch by .125 thick square tube of aluminum 6061-T-6. The joints are to be welded to provide stiffness. The chassis made of 6061-T-6 will allow the chassis to be lightweight and rigid

2.1.1.3 Steering

The steering system is used to turn the front tires either left or right to direct the vehicle in the direction it needs to go. This will be done using a 360° continuous rotation servo motor that will be directly attached to the mounting plate for the suspension and an aluminum plate with hole for tie rods will be attached to the servo horn. This will then push and pull two tie rods that will be attached to either front wheel allowing the car to move left and right while in motion. A spreader bar was also attached but later deemed unnecessary.

2.1.1.4 Suspension

The suspension system is important to keep the car stable as it travels across varied terrain. This will be done by using a double A arm system that utilizes an upper and lower A arm. This allows more control by allowing flexibility between the weight of the car and the varied terrain. The more controlled stability will allow for easier maneuvering between obstacles and allow a more accurate deployment.

2.1.1.5 Mission System

The Mission System refers to the extinguishing system. The extinguishing agent is a three percent aqueous film forming foam (AFFF). The final mixture is made by combining three percent AFFF concentrate and ninety-seven percent water. This will be premixed and added to the foam tank on the AARFF vehicle. The tank has a 20 oz capacity.

There is a 1.2 GPM diaphragm pump that will pump the mixture out of the tank, through the tubing, and out the nozzle. There are two Venturi nozzles in the tubing, one in the beginning of the tubing and one in the end of the exterior aluminum tubing. This will help to aerate the extinguishing agent and increase the effective area of deployment. There is one more major component to the mission system.

To increase the distance between the vehicle and the fire when the agent is deployed the nozzle and aluminum tubing is extended twelve inches away from the vehicle by a linear actuator. The linear actuator can be viewed in Figure 1 below.

Figure 1.

2.1.1.6 Drivetrain

The drivetrain is the main source of movement and power for the vehicle. It spins the back axle which in turn rotates the wheels The drivetrain uses a belt drive with a motor pulley and an axle pulley. The motor spins the motor pulley which in turn spins a larger axle pulley and spins the whole back axle which propels the car forward. The motor that was chosen is a Flipsky 6384 brushless electric motor, these motors are primarily used for electric skateboards. The max power of the motor is 4000 watts and 95 amps, and 9Nm of max torque. The motor will have an adapter on the shaft for the motor pulley with 16T. In the shaft connected to the tires will have a aluminum gear drive of 48T and rubber timing belt, the gear ratio will be 3.3:1

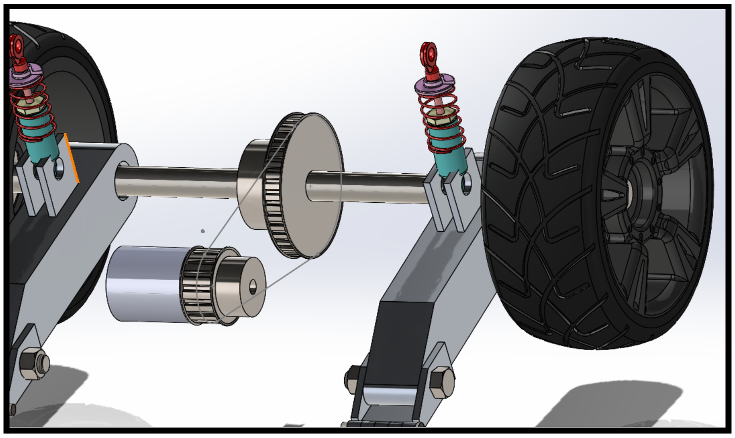


Figure 2.

2.1.2 Electrical Design Features

2.1.2.1 Power Network

The system will be powered by a six cell Li-Poly battery. This battery provides DC voltages from ~4V to ~22V in approximately 4V steps. This will break down into three different power buses, ~5V, ~12V, ~22V. The 5V bus will power all 5V components that do not receive their power from the controllers. The 12V bus will power all 12V components such as the MyRio and Motor controllers for the pump and boom. The 22V bus will power the drivetrain motor. For a complete list, find Figure 30 in section 6 Appendix. These connections are mostly made through the interconnect printed circuit board (PCB). For details of the interconnect PCB see section 2.3.1.3. The few connections that are not made through the interconnect board are also covered in that section.

2.1.2.2 Data Network

The data network is made up from connections between components that share information. There are four different protocols used throughout the system: pulse width modulation (PWM), inter-integrated circuit (I2C), universal serial bus (USB), and universal asynchronous receiver-transmitter (UART). This network's connections are mostly made through the interconnect printed circuit board (PCB).

For details of the interconnect PCB see section 2.3.1.3. The few connections that are not made through the interconnect board are also covered in that section.

2.1.2.3 Navigation

The electrical design features for the navigation system were meant to be arranged in such a way that does not interfere with the functionality of the mechanical system of the vehicle. This being said, these features were also designed to be efficient, effective, and to add an aesthetic appearance. With both of these ideas in mind, the team decided to include in the navigation external electrical design, one Slamtec RPLiDAR sensor. This specific LiDAR sensor was chosen because of the durability and field of view. The location of this sensor can be seen as shown in Figure 3 below, indicated by the white arrow.

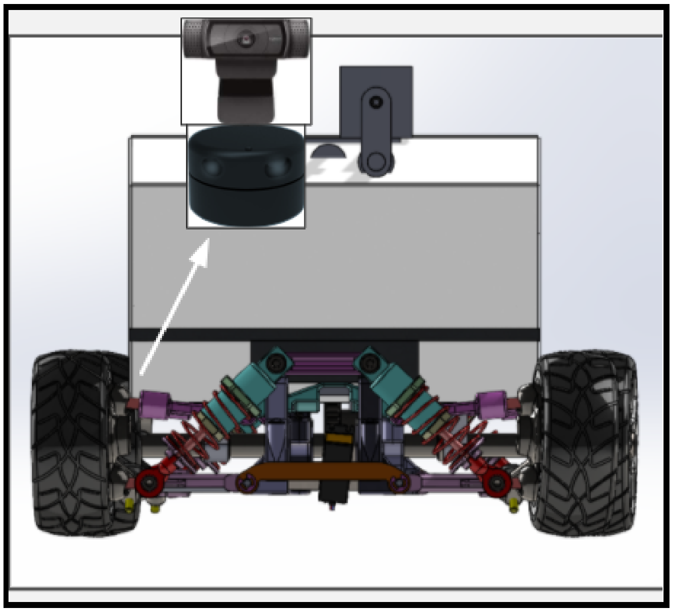


Figure 3.

The LiDAR sensor will transmit obtained data to the Raspberry Pi controller and from there transmit the data to the electrical system's main controller, the National Instruments (NI) myRIO. Also connected to the myRIO, will be the internal electrical components. Included in the navigation internal electrical design will be the 9 DOF BNO055 Gyroscope/Compass/Accelerometer sensor, and the BN-880 GPS module. Because these sensors do not need to scan or see the surroundings of the vehicle, it was decided that the most logical location for them would be inside the vehicle, protected from the elements. It was decided by the team that with these design features for the navigation electrical system, the requirements needed from an electrical standpoint could be best met.

2.1.2.4 Obstacle Avoidance

For obstacle avoidance, an RPLiDAR A1M8 360 degree LiDAR was used. It gets its information from the surroundings in two measurements, the angle from the sensor to the datapoint in degrees and the distance to that point from the sensor in millimeters. The sensor is oriented so that 0 degrees is straight ahead. To decide how the vehicle should move based on this data, two different sections of code are used. The first determines where each point is in terms of various priority zones, and the second determines how the vehicle should move based on the results of the first section.

2.1.2.5 Object Tracking

The object tracking software comes into play during the cone and fire zones of the course. The objects, the cones and the fire, need to be identified and located by the camera in order to navigate the car accordingly. When a cone is detected the vehicle will use the information gained by the camera to navigate through the slalom course of cones. When in the fire zone the camera will identify the fire and the vehicle will move directly towards it. After the camera system detects that the car is within range of the fire

2.1.2.6 Mission System Control

The control of the mission system consists of two sections. Controlling the extending boom via the linear actuator, and controlling the flow of the fire extinguishing agent. The mission system controls are quite simple and rely on information from the other systems to know when to operate.

The boom and pump are both powered by motor controllers that the MyRIO toggles. When inside the fire zone the boom will extend to full and hold there until it starts to return to base. At that time the boom will fully retract. The pump will be turned on when it is within range of the fire. After the agent is dispensed the pump will turn off.

2.2 Computation Supporting Design

2.2.1 Mechanical Calculations

2.2.1.1 Chassis Calculations

The chassis calculations were followed from the rubric given to us at the start of the semester. The main points that needed to be followed was a 22 inch wheel base. The body was based on an older model and has been remade using aluminum instead of steel to cut down on weight. This was achieved using 1”x1”x.125” 6061 aluminum and reduced the weight by about 50%. An impact test in ANSYS was also done to calculate if the frame would withstand a crash into a solid object (such as a wall) at maximum speed. Show in the figures and table below are the results for total deformation.

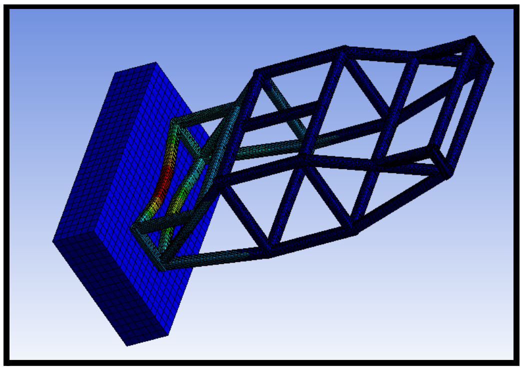


Figure 4.

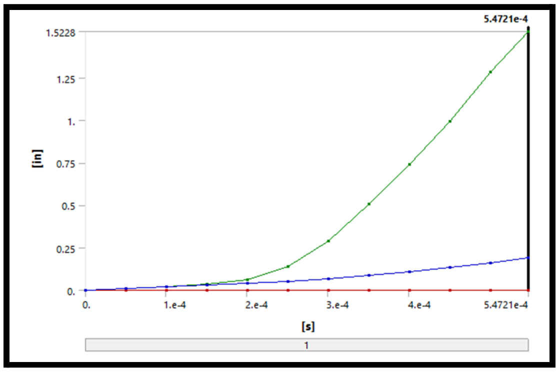
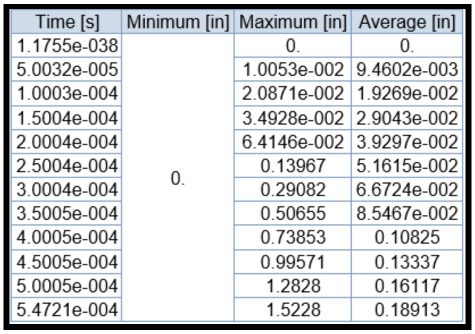


Figure 5.



Time [s]	Minimum [in]	Maximum [in]	Average [in]
1.1755e-038	0.	0.	0.
5.0032e-005		1.0053e-002	9.4602e-003
1.0003e-004		2.0871e-002	1.9269e-002
1.5004e-004		3.4928e-002	2.9043e-002
2.0004e-004		6.4146e-002	3.9297e-002
2.5004e-004		0.13967	5.1615e-002
3.0004e-004		0.29082	6.6724e-002
3.5005e-004		0.50655	8.5467e-002
4.0005e-004		0.73853	0.10825
4.5005e-004		0.99571	0.13337
5.0005e-004		1.2828	0.16117
5.4721e-004		1.5228	0.18913

Figure 6.

2.2.1.2 Steering Calculations

The tests that were run for steering was to see if the servo would be able to handle turning the tires. This was done by taking the known 35 kg-cm servo and finding out how many kilograms it can move. Since this was directly connected the servo had to be able to turn the whole front of the car (roughly 40 lbs). The other calculations that were done were stress tests of the ball joint that the tie rods will connect to. These tests were conducted at 20 kg after finding out the needed force to move the tires was 8.77 N and gave us a factor of safety greater than 2.

2.2.1.3 Suspension Calculations

The tests on the suspension include stress, buckling, and fatigue. The amount of weight the system can hold is calculated using. F = Kx+FD V where K is the spring stiffness, x is the contact depth of spring, or compression, and FD is the damper strength , and V is the speed at which the spring is compressing/decompressing. This is a good way of observing the strength of the suspension in a static environment. But the suspension system is a very dynamic system and requires the pieces to move together in harmony. $Fcf = (\frac{MV^2}{r})$ and $Fcp \geq \mu Mg$ were used to calculate the centrifugal force and stiffness needed of the system when cornering. To determine the lateral load transfer due to acceleration is used with the following equation.

$WF = A\gamma(\frac{W}{tf})[\frac{(H*K\phi F)}{((K\phi F+K\phi R)+\frac{b}{l}*ZRF)}]$ and the longitudinal load transfer is calculated using

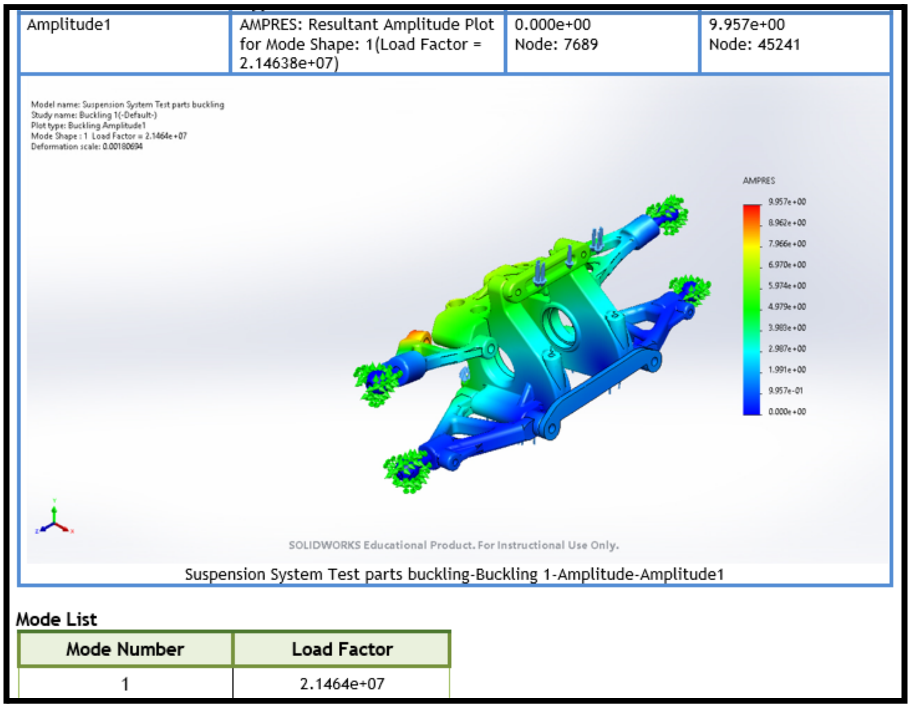
$$\text{LLT} = \frac{A*h}{t}$$

These equations help to understand what the system can withstand while it is in motion. The other very important calculation is the factor of safety. Using von Mises stress equation

$$\sigma v = \sqrt{\frac{1}{2}[(\sigma 1 - \sigma 2)^2 + (\sigma 2 - \sigma 3)^2 + (\sigma 3 - \sigma 1)^2]}$$

The car has a factor of safety of two. The tests performed were run using 100 lbf , which is more than twice the weight of the car.

The suspension components are made out of aluminum 1060 alloy. The yield strength of the material is 2.7*10^7 N/m^2 and tensile strength is 6.89 *10^7 N/m^2. Solidworks only runs tests in SI units. At the weight of 100 lbf there were no distorted elements in the system. Within this amount of weight the components will hold up with no issues of being anywhere near the tensile or yield limits.



Amplitude1	AMPRES: Resultant Amplitude Plot for Mode Shape: 1(Load Factor = 2.14638e+07)	0.000e+00 Node: 7689	9.957e+00 Node: 45241

Model name: Suspension System Test parts buckling
Study name: Buckling 1(-Default-)
Plot type: Buckling Amplitude1
Mode Shape : 1 Load Factor = 2.1464e+07
Deformation scale: 0.00180694

Suspension System Test parts buckling-Buckling 1-Amplitude-Amplitude1

Mode List

Mode Number	Load Factor
1	2.1464e+07

Figure 7.

2.2.1.4 Drivetrain Calculations

Approximately 10 N-m of torque to have the vehicle start to move from a cold start. The motor was rated max torque of 9 Nm for the transmission the gear ratio 3.2/1 by taking the driven gears teeth (48) over the driving gear (15). From there the torque supplied by the transmission can be determined with the following equation

$$.\frac{n_1}{n_2} = \frac{T_1}{T_2}$$

$$\frac{n_1}{n_2} * T_2 = T_1$$

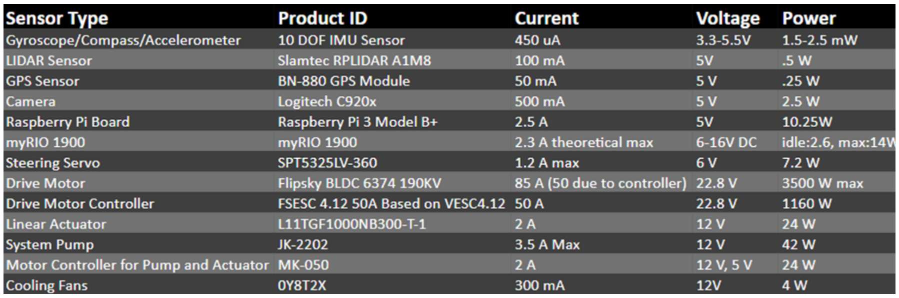
$$3.2 * 8Nm = 25.6Nm$$

Theoretically, with half power, the car should have more than enough torque to have the car start rolling from a cold start. The belt length was calculated by 1/2 C1 + 1/2 C2 + 2d. With C being circumference of each pulley and d being distance between the pulleys, 2 x distance because the belt is essentially a circle so the top distance and a bottom distance.

2.2.2 Electrical Calculations

2.2.2.1 Power Network Calculations

The power network draws all of the system's power directly from the battery. The wattages, voltages, and currents of the major components are listed below in Figure 8.



Sensor Type	Product ID	Current	Voltage	Power
Gyroscope/Compass/Accelerometer	10 DOF IMU Sensor	450 uA	3.3-5.5V	1.5-2.5 mW
LIDAR Sensor	Slamtec RPLIDAR A1M8	100 mA	5V	.5 W
GPS Sensor	BN-880 GPS Module	50 mA	5 V	.25 W
Camera	Logitech C920x	500 mA	5 V	2.5 W
Raspberry Pi Board	Raspberry Pi 3 Model B+	2.5 A	5V	10.25W
myRIO 1900	myRIO 1900	2.3 A theoretical max	6-16V DC	idle:2.6, max:14W
Steering Servo	SPT5325LV-360	1.2 A max	6 V	7.2 W
Drive Motor	Flipsky BLDC 6374 190KV	85 A (50 due to controller)	22.8 V	3500 W max
Drive Motor Controller	FSESC 4.12 50A Based on VESC4.12	50 A	22.8 V	1160 W
Linear Actuator	L11TGF1000NB300-T-1	2 A	12 V	24 W
System Pump	JK-2202	3.5 A Max	12 V	42 W
Motor Controller for Pump and Actuator	MK-050	2 A	12 V, 5 V	24 W
Cooling Fans	0Y8T2X	300 mA	12V	4 W

Figure 8.

2.2.2.2 Navigation Calculations

Of the required calculations for the navigation system, finding the bearing angle and the distance between two gps coordinates were the bulk of the mathematics. Beginning with the distance formula $[sin^2(\frac{\Delta Lat}{2}) + [cos(CLat) \cdot cos(XLat)] \cdot [sin^2(\frac{\Delta Lon}{2})] = a$. $atan2(\sqrt{a}, \sqrt{1 - a}) = c$. (3958.8)(c) = distance between two GPS coordinates in miles. To find the bearing angle take $\Delta Lat = \frac{ln(tan(\frac{XLat}{2} + \frac{\pi}{4})}{tan(\frac{CLat}{2} + \frac{\pi}{4})}$ and $\Delta Lon = |(CLon - XLon)|$ and finally $\theta = atan2(\Delta Lon, \Delta Lat)$ (Ramírez-Cortés).

See section 2.5.1 for further explanation and information regarding these calculations.

2.2.2.3 Obstacle Avoidance Calculations

The code for obstacle avoidance is split into two sections. The first gets how many points are in each predefined zone and the second decides how the car should move given that information.

The first section of the code records how many data points the LiDAR observes in given pre-defined zones. Zone 1 contains all points within 1 meter of the sensor within 90 degrees on either side , Zone 2 contains all points between 1 and 2 meters from the sensor within 45 degrees on either side, Zone 3 contains all points between 2 and 4 meters from the sensor within 30 degrees on either side, and Zone 4 contains all points further than 4 meters from the sensor within 20 degrees on either side. It also records whether the point is to the left or right of the 0 degree line, so the program could be stated to have 8 zones, 4 on each side. For simplicity, the zones were titled with their left/right orientation, then their distance zone: L1, R1, L2, R2, L3, R3, L4, R4.

The second section of the code takes these values and determines how the car turns. First, it adds all of the points on the left and right within zones 1-3, then if both values are over 30, the program decides that the path is completely blocked. Failing that, the program then reads the information for zone 1. If there are more points in L1 than R1, it turns right. If not it turns left. If there are no points in zone 1, it goes to zone 2 and so on until it finishes reading zone 4. If there are no points in any zone, it determines that there is no obstacle.

The code related to these functions is provided in the Appendix.

2.2.2.4 Mission System Calculations

2.2.2.5 Mission Electrical Calculations

The mission electrical calculations involved a variety of things. Mission had the Raspberry Pi, motor controllers, actuators, and servos. Mission also had technical calculations inside of the programs. These were things like color selections, servo speed and movements, and boxing for object avoidance.

The first calculation for the mission electrical involved programming for capture size. The imported image was generically too large for the Raspberry Pi. Instead of resizing the image, the team decided to import the image as a 640p by 480p image. This allowed the Raspberry Pi to process the image at the correct size and at a much faster speed. The second calculation was the upper and lower threshold for the colors the camera needed to track. Since the color the team was tasked to track is orange, the correct color calculations were (0, 125, 80) for the lower threshold and (10, 255, 255) for the upper. In OpenCV these calculations are entered as Blue Green Red. The correct shades of these colors give the team the most desirable orange spectrum. The bounding rectangle was a built-in function of OpenCV that gave the team a current position. Using that current position the program compared it to the left and right most bound for the servo. If it didn’t meet the bounds the program increased it by 0.005 until the bound of 0.980 or -0.980 was reached.

The second calculations for the mission electrical involved physical limitations. These limitations included voltages and current needs. The boom and pump system need a 5A motor controller. The Raspberry Pi needs a 2.5A, 5V this is so it will be able to run the camera and servo.

2.3 Assembly Drawings and Schematics

2.3.1 Circuit Diagrams and Schematics

2.3.1.1 Power Circuit

Shown here in Figure 9 is the schematic of the power network. All power connections can be seen here. To see the connections in a list view please see Figure 30 in the appendix, section 6.

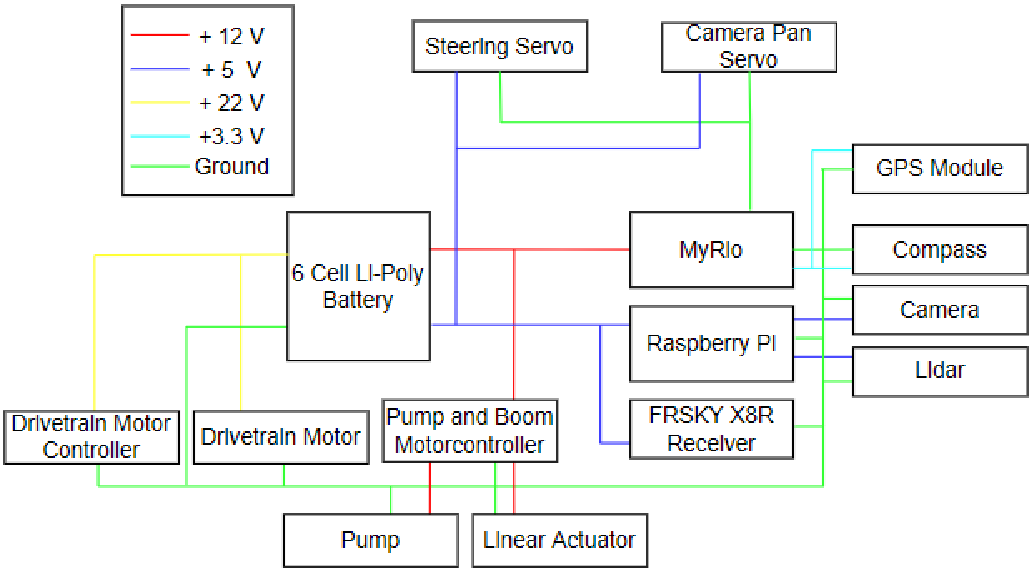


Figure 9.

2.3.1.2 Data Network Circuit

Shown here in Figure 10 is the schematic of the data network. All data connections can be seen here. To see the connections in a list view please see Figure 30 in the appendix, section 6.

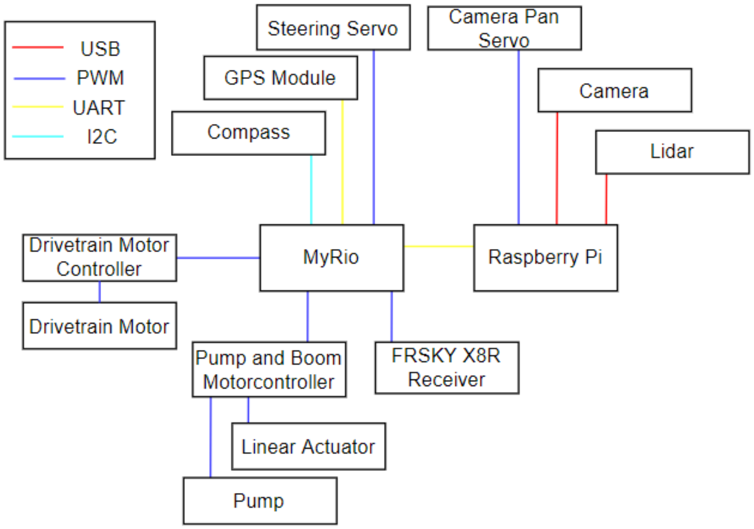


Figure 10.

2.3.1.3 Interconnect Printed Circuit Board

The Interconnect PCB is a single layer PCB made to simplify the connections across the AARFF system. This board is a collection of ribbon cable connectors that allow for a robust and reliable interconnect system that is more efficient and dependable than a large amount of dupont connectors. In section 6 Appendix there are pictures, Figures 31 and 32, of the IC Board schematic and PCB used for the connection of all electronics. Also included in the Appendix, section 6, there is a spreadsheet that shows all connections in the system in Figure 33. Note, while most of these connections in Figure 33 are through the interconnect PCB not all are.

2.3.2 Mechanical Assembly Drawings

2.3.2.1 Complete Assembly

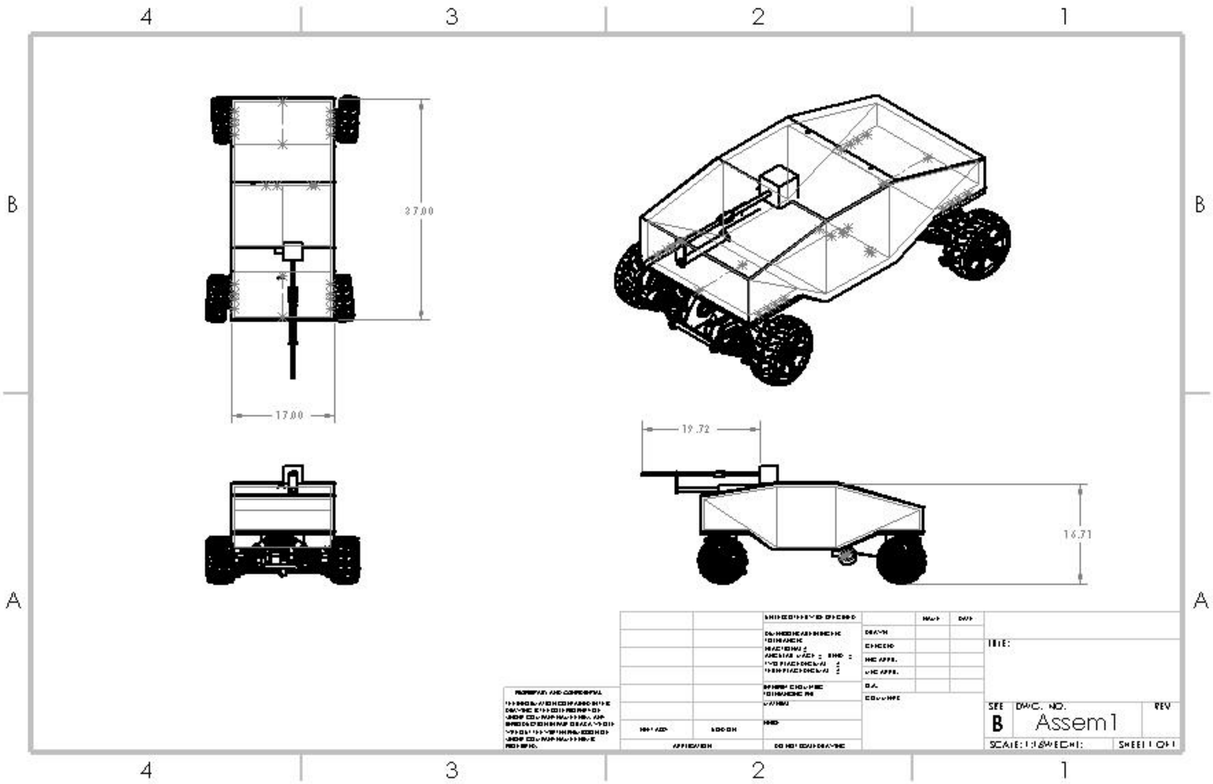


Figure 11.

2.3.2.2 Body

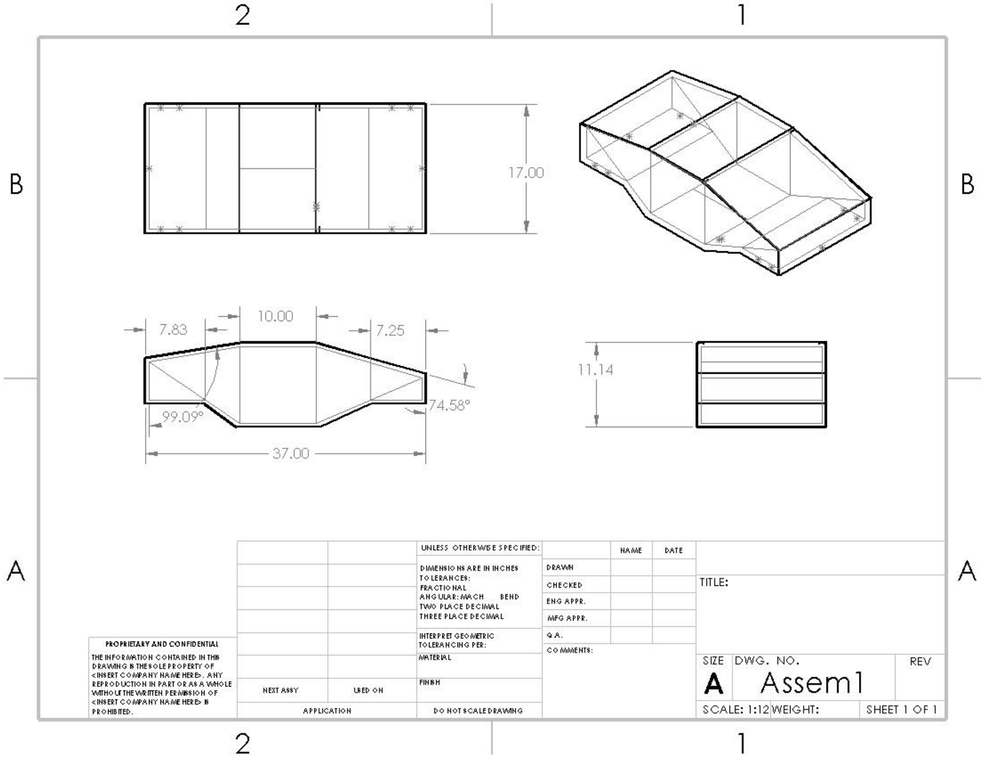


Figure 12.

2.3.2.3 Chassis

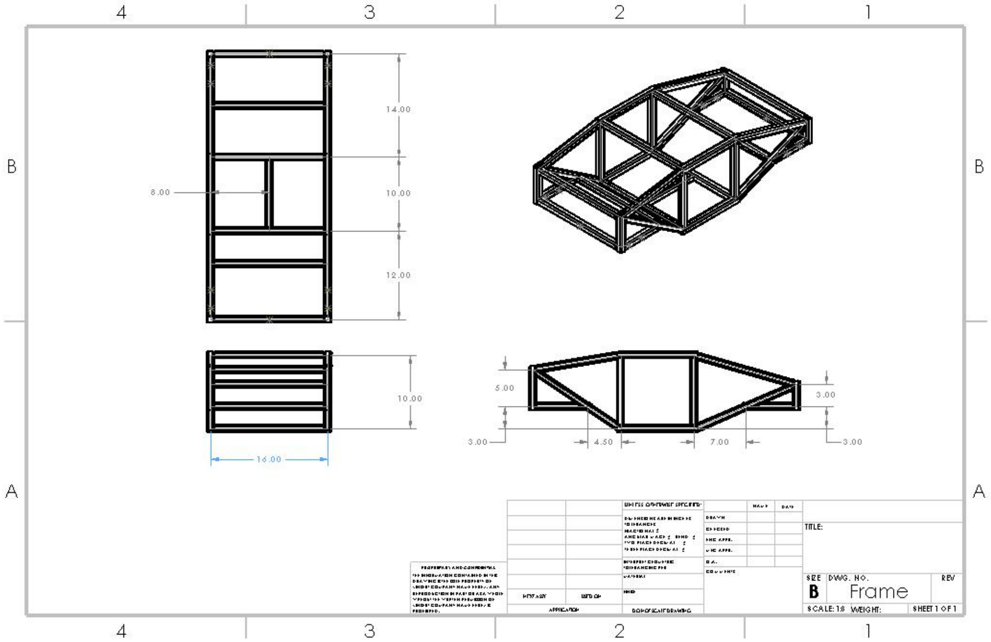


Figure 13.

2.3.2.4 Steering

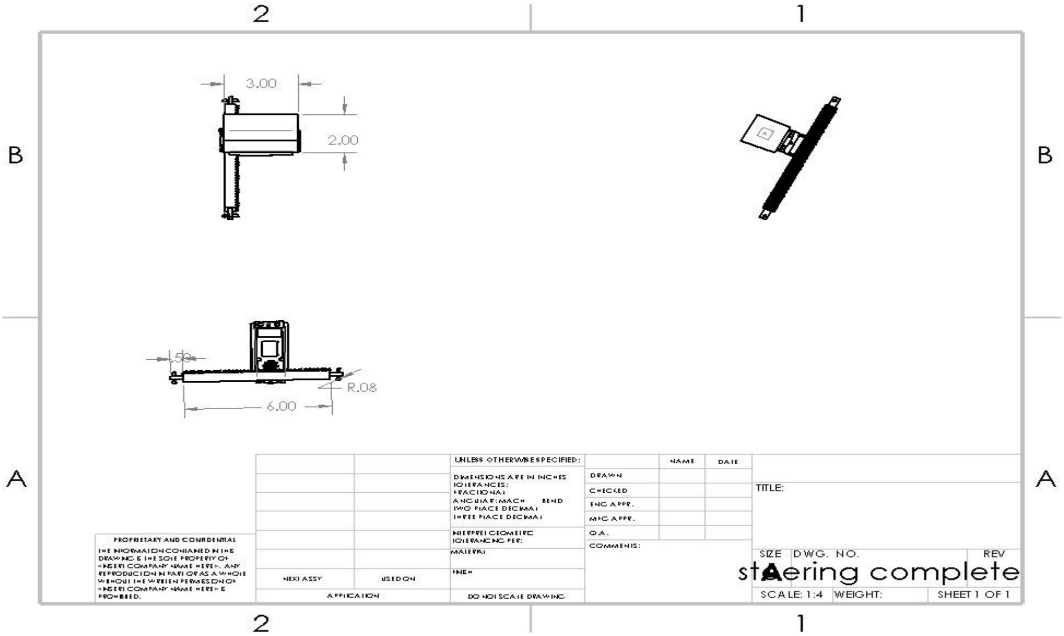


Figure 14.

2.3.2.5 Suspension

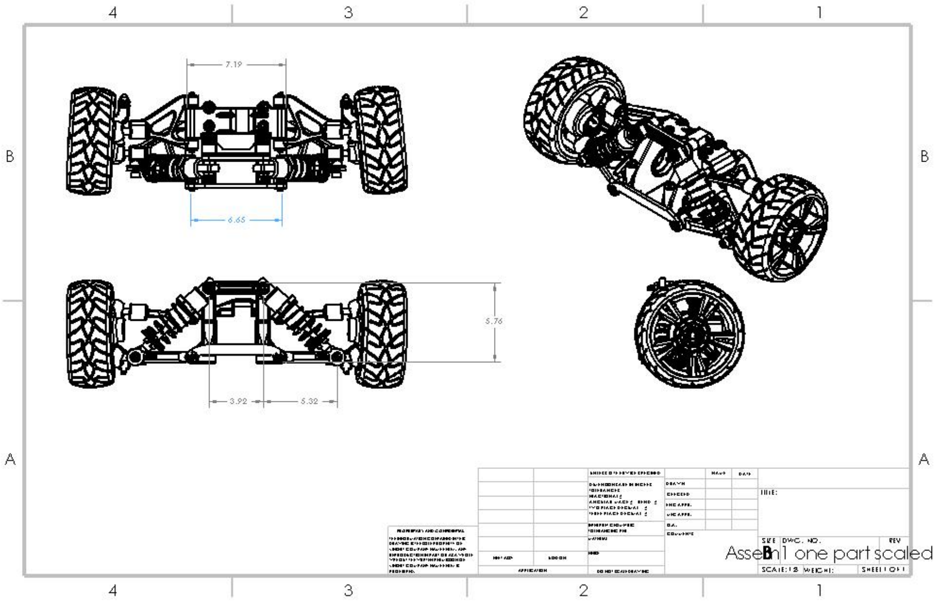


Figure 15.

2.3.2.6 Mission System

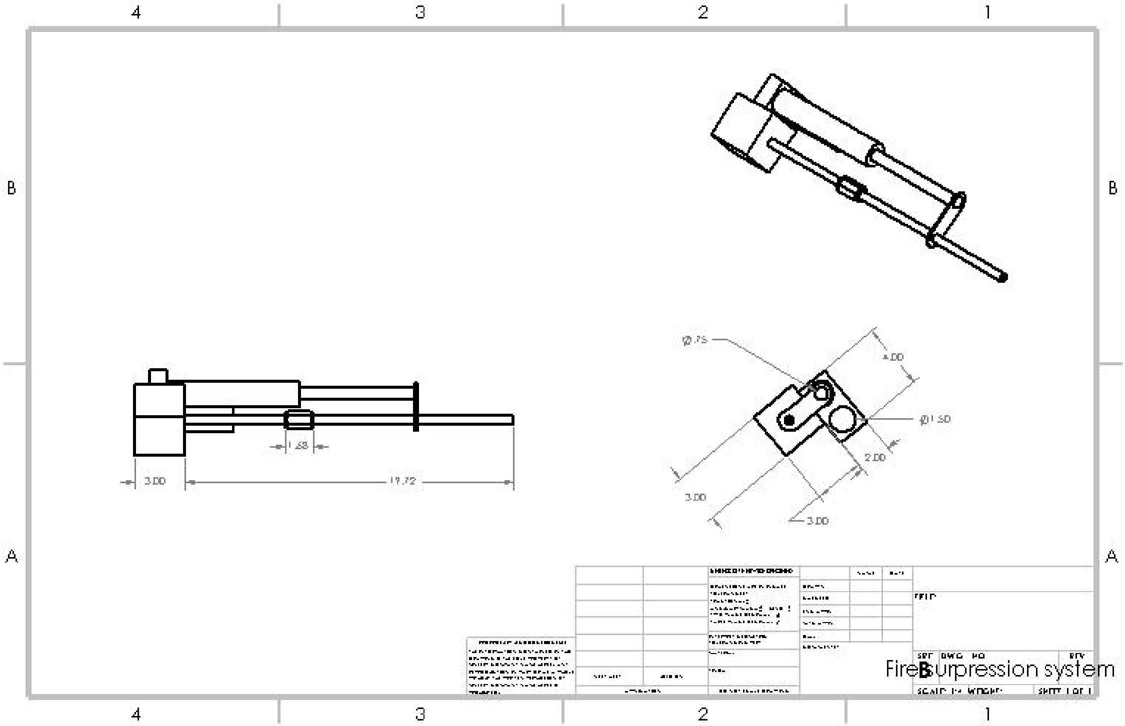


Figure 16.

2.3.2.7 Drivetrain

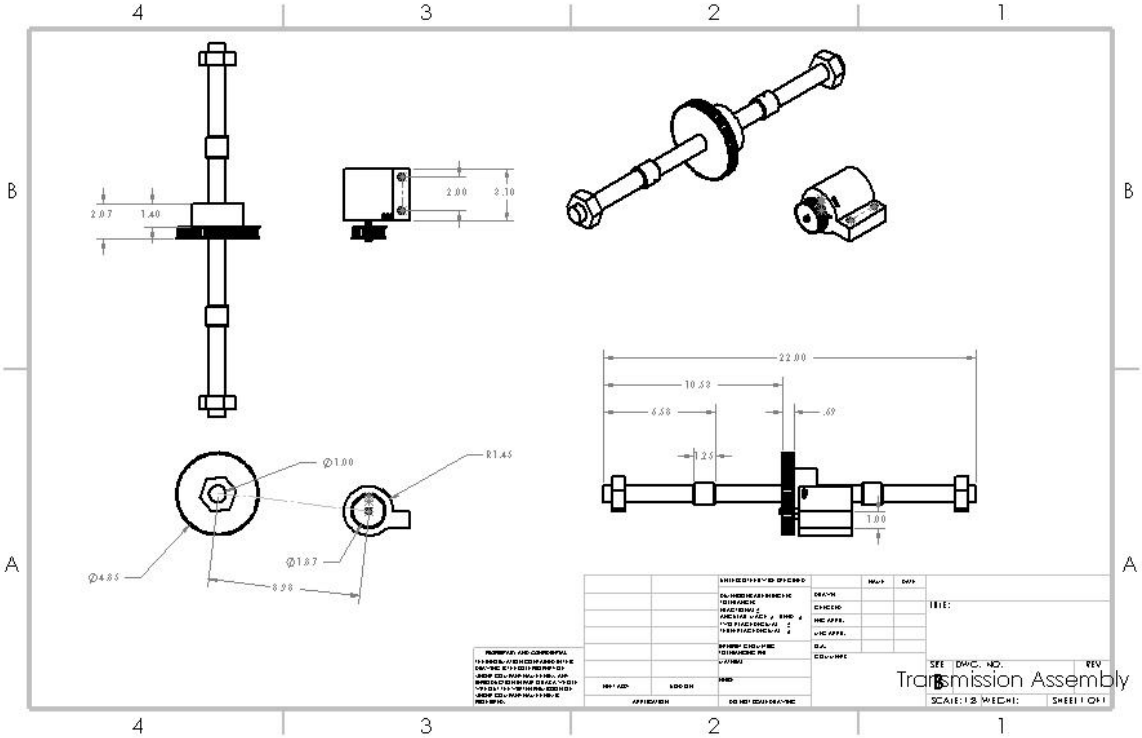


Figure 17.

2.4 Mechanical Construction Details

2.4.1 Body

The body has been laser cut from ABS plastic and attached to the frame using self tapping metal screws. The plastic will be coated in flex seal to provide a waterproof seal. The top part will have an access port that will allow for ease of access to both the extinguishing system and navigation components, while allowing components a weather proof cover.

2.4.2 Chassis

The chassis was planned to have been fabricated in the Design and Manufacturing Lab. One of the properties of aluminum 6061-T6 is that it is weldable compared to other alloys of aluminum. The procedure to construct the frame of the chassis is to first create a technical drawing from the solidworks model. Then a cold circular saw will cut the tube to the correct dimensions given in the model. To fix these cut parts of the tube together they will be welding using Tungsten Inert Gas (TIG) welding process using an alternating current welder. This task was outsourced for quickness and easability.

2.4.3 Steering

The steering system was a simple steering system that was a servo attached to two tie rods. The servo was put in a mount as shown in Figure 20 and mounted underneath the car directly to a mounting plate for the suspension system. After this a small aluminum plate was cut and press fitted onto the servo horn. This plate had multiple holes put into it to fit the tie rods ball ends. With this the tie rods needed to be manufactured for the main point the correct lengths were not offered by the shops. These were made with ¼ in aluminum bars that were threaded and tapped on both ends. On end had to be left handed threads and the other right handed threads so the bar when twisted with shorten or lengthen. This was attached to the ball joints two ball joints on either side of the tie rod and the tie rod mounted to the servo plate and the wheels completing the steering system.

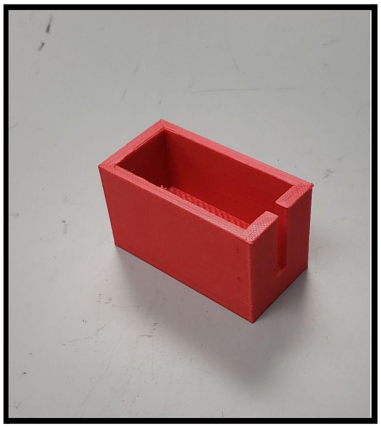


Figure 18.

2.4.4 Suspension

The suspension system is made of an aluminum alloy. The 4 main components on the suspension are the top and bottom A arm, the side plate, and the knuckle. These components are aluminum alloy and the hub will slide into the plastic wheel of the tire. The suspension is then mounted directly to the frame of the car via an aluminum plate. The front suspension will have the steering components attached in the middle underneath the car. The rear suspension will be a hybrid leaf spring design using pistons and allowing for room for the updated belt drive and have the drive shaft running into the hubs on either side while the knuckles connect the shaft and hubs to the suspension and rest of the car.

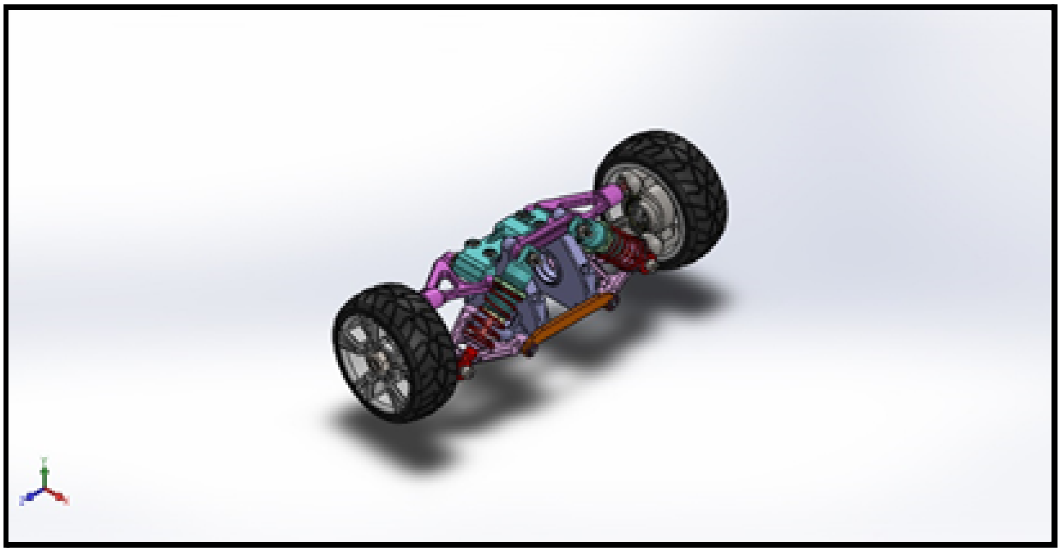


Figure 19.

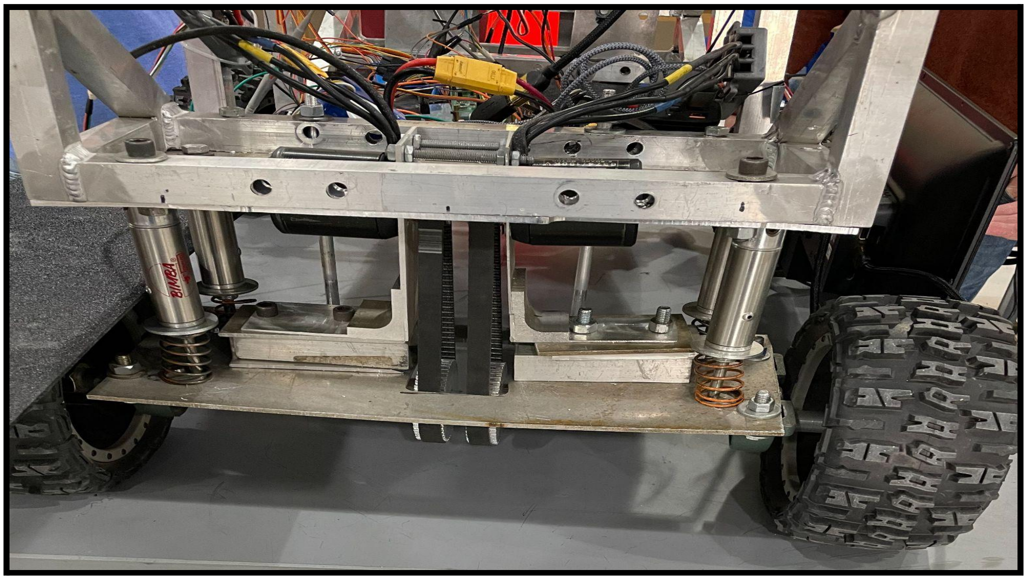


Figure 20.

2.4.5 Mission System

The mission fire extinguishing system is made of 6 components. The fire retardent reservoir, pump, rubber tubing, aluminum tubing, and two Venturi nozzles, one at the top of the aluminum tubing and one at the exit. The reservoir is tucked into the middle of the car. The rubber, flexible, tubing is then used to connect to the pump and runs up to the top of the car where the tube fits into the first Venturi nozzle and into the aluminum tubing and terminates at the end into a second Venturi nozzle that is used to help aerate the spray and allow for the foam to form and extinguish the fire.

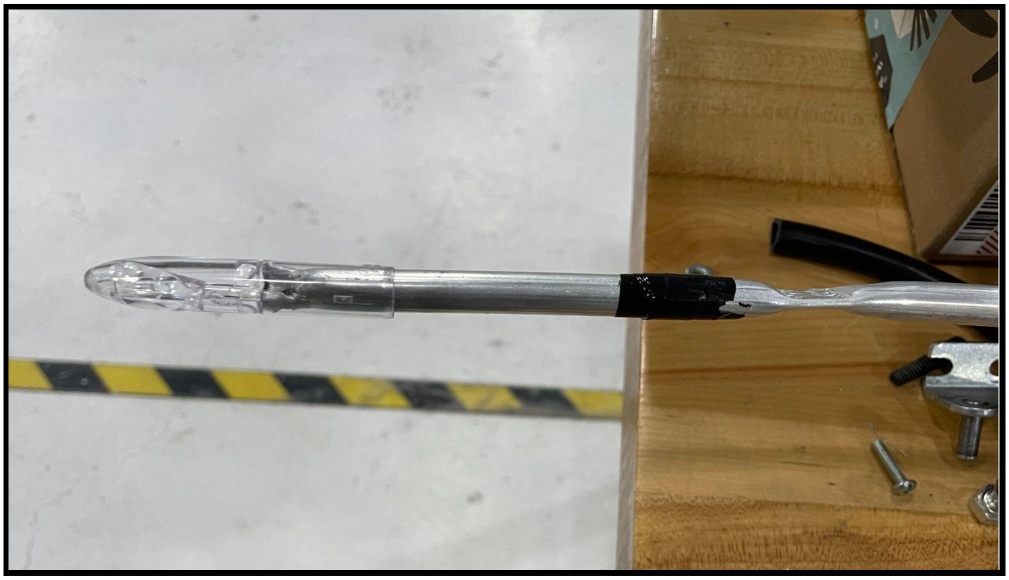


Figure 21.

2.4.6 Drivetrain

The drive train was determined to be a belt driven drive train. The first order of business was to determine the length of the belt. The belt needs to be long enough to move the gears, yet not too long as to have excess slack. The first order was to calculate the radius of each gear. Once the belt had been properly sized for length the pitch of the teeth was determined. A

With these results the overall belt length can be determined

$$belt\ length = c * 2 + \frac{c1}{2} + \frac{c2}{2}$$

The next calculation is to determine the torque that is generated to give the car forward motion

Tc= $\frac{Fa*r1}{1000*n}$

Fa= m*g*u

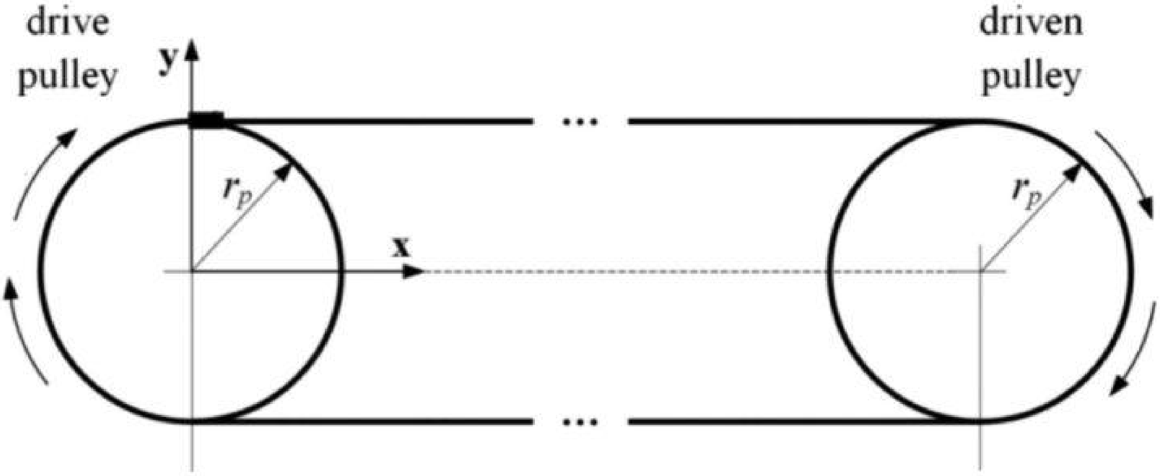


Figure 22.

Next calculating the amount of torque required for acceleration

Ta = Tc + Tac

Tacc = Jt *α

For angular acceleration was determined with the equation:

Jt= Jm +Jc +Jp1 +Jp2 +Jt

3 Manufacturing and Testing Plan

3.1 Manufacturing Plan

3.1.1 Mechanical Assembly

The overall assembly will be done in five major steps. There are five major mechanical subsystems of the car. The extinguishing system, suspension, steering, drive train, and body. Many of these components are intertwined. The steering will attach to the suspension with the servo for the steering and the rack and pinion on the side plate and knuckles that connect to the wheel hubs. Similarly, the drive train will have its driveshaft running through and connecting together with the suspension at the wheel hubs on either side of the vehicle and all will connect to the frame with the plate that attaches all three components to the car. The fire extinguishing system will have the reservoir that fits in the middle of the car and runs over the top. It will be connected to the frame using made to fit metal straps that will hold the linear actuator and extinguishing shaft in place. This will leave enough room for the electrical components room to fit in place.

3.1.1.1 Body Manufacturing Plan

The main function of the body is to protect the integrity of the electronics inside of it. The body of the vehicle will be made of ABS plastic panels which will be cut on a laser cutter. This will allow for fine, straight cuts to be made. There will be an access hatch made with two hinges for ease of access to the inside. The abs plastic will be connected to the aluminum tube of the frame with self tapping metal screws.

3.1.1.2 Chassis Manufacturing Plan

The chassis was welded by a third party. One of the properties of aluminum 6061-T6 is that it is weldable compared to other alloys of aluminum. The procedure to construct the frame of the chassis is to first create a technical drawing from the solidworks model. Then a cold circular saw will cut the tube to the correct dimensions given in the model. To fix these cut parts of the tube together they are welding using Tungsten Inert Gas (TIG) welding process using an alternating current welder. The electrode used will be 3/32 2% Ceriated tungsten and the shielding gas will be 100% pure Argon. The filler metal will be ER4043 which is 5% silicon alloy.

3.1.1.3 Steering Manufacturing Plan

Starting at the top the servo will be mounted between the side plates in a specially 3D printed mount that will hold it steady as it turns the metal plate attached to it will turn left and right. This plate will then move left and right pushing and pulling on either tie rod making the car turn left or right. The tie rods in question will be manufactured out of a simple aluminum bar with left hand threads on one side and right hand threads on the other side. Ball joints were ordered online to make the manufacturing process a bit easier. The ball joints were then connected to the plate on the servo and the holes located at the wheels.

3.1.1.4 Suspension Manufacturing Plan

The suspension will be mounted using a flat plate that will be attached directly to the frame. The top and bottom A arms are attached to a knuckle that then attaches to the wheel hub. The front suspension is connected to the steering components with the rack and pinion seated in the middle between the 4 A arms that will allow for turning. The rear suspension is a hybrid leaf spring design that allows for the drivetrain to fluctuate with suspension allowing for constant tension in the belt. The drive shaft will run through the middle and connect on each side to the wheel hubs. The assembly will be ready for testing once the tires are mounted to the wheel hubs.

3.1.1.5 Mission System Manufacturing Plan

The mission extinguishing system is to be mounted to the frame on the top of the car. The fire retardent reservoir will be in the center of the car lower toward the ground and run up using flexible rubber tubing that will connect the pump and reservoir to the extinguisher shaft. The shaft begins with a Venturi nozzle at the beginning of the aluminum tubing and terminates with a second Venturi nozzle. The system is fastened to the frame using 1 inch metal straps that can be cut and bent to fit.

3.1.1.6 Drivetrain Manufacturing Plan

Two motors are required to provide the necessary torque to drive the vehicle. Using a belt drive requires that the motors move with the frame, as such the motor mounts are attached to the suspension plate. The mounts are manufactured from a pair of aluminum brackets milled down to the required dimensions. Belt tension is achieved by carefully positioning holes and shimming the bottom of the mount. The aluminum gear with 48T will be press fit to the driven axle, combined with the 15 teeth on the driving axles will provide a gear ratio of 3.3 to 1.

3.1.2 Electrical Assembly

3.1.2.1 Wires and Electrical Boards

Tidiness is essential when it comes to the electrical assembly. It can become very problematic if there is a clutter of wires going every which direction, which also causes confusion and chaos. One of the disadvantages to having an untidy electrical assembly is the unnecessary complications added to the troubleshooting process. It can also be hazardous to users because of the possibility of electrical shocks and fires. Knowing this, it was crucial for the team to make sure the wiring assembly to the electrical boards is neat and simple to understand which wire is going to which component. Most of the connections will be made through the interconnect PCB, detailed in section 2.3.1.3.

3.1.2.2 Migration of Electrical Systems

All of the electrical systems will need to be moved from the test car over to the new AARFF vehicle. The majority of components will be mounted into a 3D printed box to increase the weather resistance. The components that need to be mounted in a specific location will have their own mounting locations. Two main components that will be mounted in special locations are the lidar sensor and the camera. The LiDAR sensor will mount onto the top front of the car byt screwing into the body with the built-in standoffs. The camera and pan system will mount directly behind the LiDAR sensor. The servo of the pan system will slide into a 3D printed mount shown below in Figure 25.

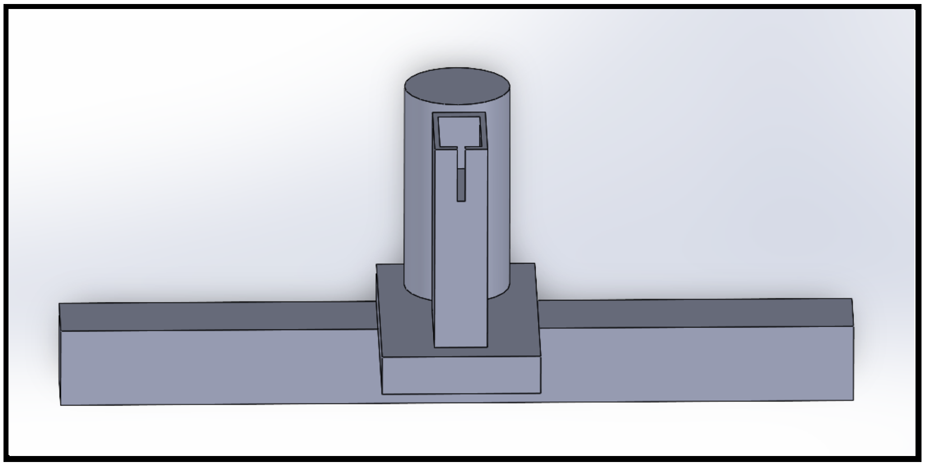
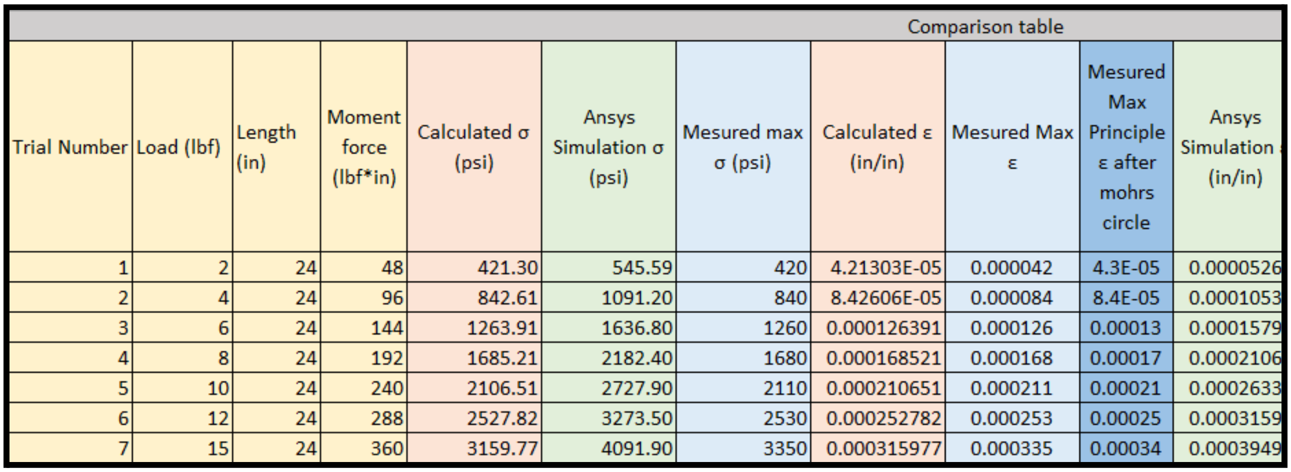


Figure 23.



Comparison table

Trial Number	Load (lbf)	Length (in)	Moment force (lbf*in)	Calculated σ (psi)	Ansys Simulation σ (psi)	Mesured max σ (psi)	Calculated ε (in/in)	Mesured Max ε	Mesured Max Principle ε after mohrs circle	Ansys Simulation (in/in)
1	2	24	48	421.30	545.59	420	4.21303E-05	0.000042	4.3E-05	0.0000526
2	4	24	96	842.61	1091.20	840	8.42606E-05	0.000084	8.4E-05	0.0001053
3	6	24	144	1263.91	1636.80	1260	0.000126391	0.000126	0.00013	0.0001579
4	8	24	192	1685.21	2182.40	1680	0.000168521	0.000168	0.00017	0.0002106
5	10	24	240	2106.51	2727.90	2110	0.000210651	0.000211	0.00021	0.0002633
6	12	24	288	2527.82	3273.50	2530	0.000252782	0.000253	0.00025	0.0003159
7	15	24	360	3159.77	4091.90	3350	0.000315977	0.000335	0.00034	0.0003949

Figure 24.

4 Electrical Design, Assembly, and Software Description

4.1 Navigation and Obstacle Avoidance

4.1.1 Functional Block Diagram

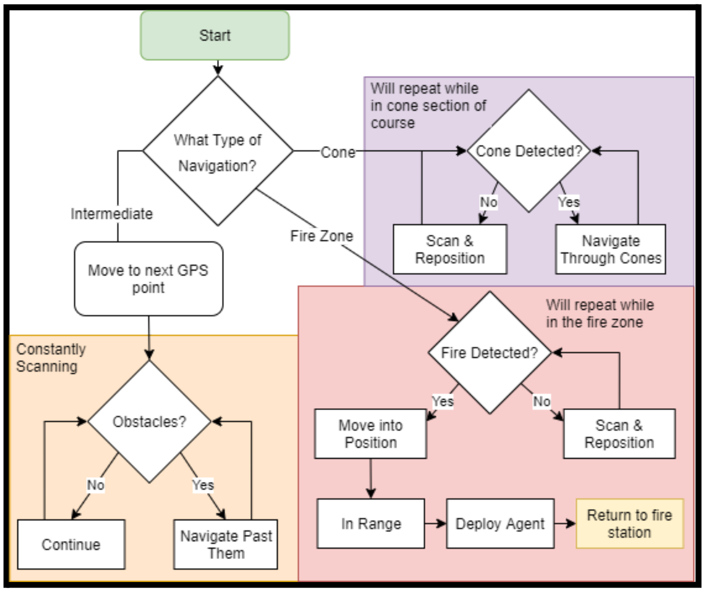


Figure 25

4.1.2 Circuit Diagrams and Schematics

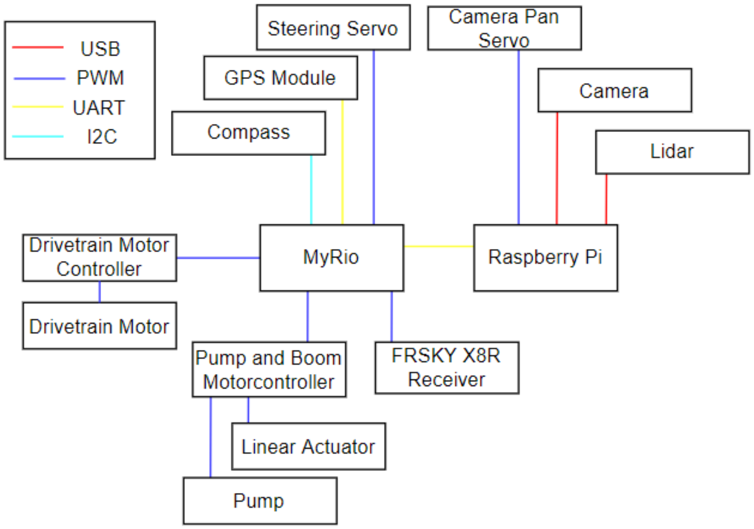


Figure 26

4.1.3 Software Description

4.1.3.1 MyRIO - LABVIEW

The GPS has been interfaced in LABVIEW, retrieving the current coordinates in longitude and latitude down to 7 decimal places. Using these coordinates, and the given coordinates, the code can determine the distance and bearing to the given point. By taking the $[sin^2(\frac{\Delta Lat}{2})\ +\ [cos(CLat) \cdot cos(XLat)] \cdot [sin^2(\frac{\Delta Lon}{2})]$ and assign that to variable “a,” and take the $atan2(\sqrt{a}, \sqrt{1\ -\ a}\ )$ and assign that result to “c.” The distance is then found by multiplying the radius of the earth (in miles) by c; (3958.8)(c) = distance between the two GPS coordinates, d (Figure 27) .The bearing angle between the two points is found first by finding the change in latitude and longitude between the car and the given points. $\Delta Lat\ = \frac{ln(tan(\frac{XLat}{2}+\frac{\pi}{4})}{tan(\frac{CLat}{2}+\frac{\pi}{4})}$ and ΔLon = |(CLon - XLon)|. After getting the change in latitude and longitude the bearing angle is found θ = atan2(ΔLon , ΔLat) (Figure 28).

The boom and pump are programmed within the manual and autonomous navigation indoors states. Using the MyRio’s PWM function, setting the duty cycle to 100% to maximize the speed of the boom, the vehicle will drive until 0.3 meters away from the fire (located by the camera mission system) and extend 45 seconds prior to arriving to the destination and extinguish; after the solvent is fully dispersed the car will return for solvent refill.

The navigation software has also been programmed using the graphical programming language, Labview. While receiving data from the GPS, LiDAR, and other sensors, the AARFF has several methods of determining what the next task is. When powered on, the car begins in an idle state to prevent any accidental autonomous driving and may be initialized by the user controller. After the idle switch is flipped, there are 3 options of states to choose from by a 3-stage switch on the controller: manual, autonomous navigation indoors, and autonomous navigation outdoors. While in any state, the user may enable the stop or kill switch to disable the vehicle immediately for any safety reason for users or the vehicle, as well as if the car is flipped, it will automatically enable this stop state until re-initialized by the user.

Beginning with the manual state, the car may be controlled using the Taranis Q X7-FrSky controller whether it may be to change states or using the joysticks to enable a pulse width logic to control the steering (90° left or right) or enable the throttle (forward or reverse). Along with driving, the user can change states, extend the boom, enable the pump, and stop the car entirely. When switched to the autonomous navigation indoors state, the MyRio receives a string from the Raspberry Pi giving directions to turn left, right, go straight, or stop if completely blocked. While autonomously navigating it can be switched to auto nav outdoors, manual, or stop if needed at any time, and when the gyroscope reads a 90° change, the car will shut off autonomously.

Finally, for autonomous navigation outdoors, the system will still avoid obstacles with the same method as indoors, however when given the “no obstacle” string from the raspberry pi, the car will pick up the coordinates implemented into the code before deployment. Once within 5 feet of each coordinate, the car will move to the next inputted point. Whilst driving, the compass determines the angle of the car heading- relative to true North- and compares with the bearing relative to the current coordinate the car is attempting to arrive at. If the error is greater than -5°, but less than 5°, the car is on the right path and will drive straight. Once the car has an error angle greater than 5° or less than -5°, the car will turn left or right accordingly until within the ±5° window to go straight. **(Figure 2.5.1.3)**

Upon arriving at each coordinate, the system will call for the camera to detect the cone locations and use the same obstacle avoidance and error angle logic to maneuver between the cones until the final coordinate is reached. Once all coordinates are successfully concluded, the camera will scan for a fire, the auto nav system will proceed until .3 meters (12 inches) from the fire and deploy the boom and pump system automatically to extinguish the fire and return to the home location (Ramírez-Cortéz).

4.1.3.2 LiDAR

The specific LiDAR sensor that the team will be using for the task at hand will be the Slamtec RPLiDAR A1M8 360 Degree LiDAR with a range of 12 m. This sensor will be used to gather a 2D mapping of the surroundings of the AARF vehicle, for the purpose of object detection and avoidance. A LiDAR sensor uses a laser to scan an area while finding the precise distances of found objects to create the shape of the area scanned. LiDAR sensors do this process promptly, for the convenience of and ease for the user. In the case of this project, with the goal being autonomous, this expedition process will be for the efficiency of the myRIO controller.

Another advantage of having this particular LiDAR sensor is that it will be on a spinning motor, providing for a 360 degree field of view. Seeing behind the vehicle, at this point is unnecessary, however, the function is there if needed. This Slamtec LiDAR, for one rotation, can be configured for a 2-10 Hz sample rate with 0.2 cm distance resolution and 1 degree angular resolution. The utilization of the Slamtec LiDAR sensor will aid significantly in the process of object detection and avoidance (Adafruit, 2021).

4.2 Mission System

4.2.1 Functional Block Diagram

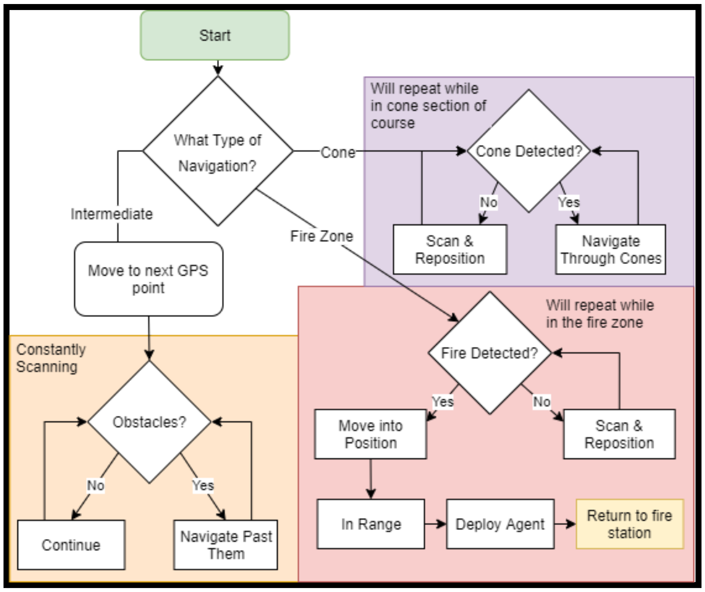


Figure 27

4.2.2 Circuit Diagrams and Schematics

A Raspberry Pi-4 was used for interfacing the LIDAR and camera. The programming was done using the Python programming language, due to that being the language the team was most familiar with. The libraries used were adafruit-circuitpython-rplidar for controlling and retrieving information from the lidar, serial for controlling communications between the

Raspberry PI and My-RIO, and openCV for getting information from the camera. The code for operating the lidar is modified from the code provided by Adafruit, which is linked in the appendix.

4.2.3 Software Description

Object tracking is handled through OpenCV. OpenCV is an open-source library that is used for a variety of vision applications. OpenCV has also been used in machine learning and image processing. OpenCV can be found in several applications including object detection and recognition, autonomous cars, surveillance, and object tracking. This makes the OpenCV library the best fit for the application. Another advantage of this library is the ability to integrate it with other libraries such as NumPy. The OpenCV library is supported by many applications such as Python, C, C++, and Java. The reason OpenCV is useful in object tracking is because it has a number of pre-built algorithms built in explicitly for tracking. Since the most widely documented form of OpenCV was python based, the team selected python to code the object tracking in.

After the installation of OpenCV onto the Raspberry Pi the team had to import specific libraries to enable OpenCV to work correctly. The team then set boundaries and limitations for the color spectrum and boxing area. These are used to track only orange objects of a certain mass. This was done to limit false tracking, that information was then passed on to the pan system for sweeping until the camera could detect an object. This enables the camera to not only track an object but search for one as well. The hardware requirements for the object tracking included a Raspberry Pi, a Logitech webcam, a pan and tilt servo controlled mount, and peripherals for coding. For the Raspberry Pi, it will require at least 2.5A, 5V power supply.

5 Testing

5.1 Mechanical Testing

For testing procedures the starting point will be with the body. The welds will be tested to make sure they can hold up under the weight of the body and the rugged conditions it will be put under. The next subsection that will be tested will be the suspension system and that will be tested on the car along with the steering and the drivetrain, as those three subsystems work in conjunction with one another. The extinguishing system will be tested off the car in a standalone test so as to not affect the car or sensitive components. This will be a simple test to make sure the pump runs correctly and there are no leaks within the connections.

The strength of the aluminum tubing was tested in a report done by one of the team members. A 1” inch by .125” inch thick square tube of aluminum 6061-T-6, was subjected to pure bending and a torsional and bending force. In the bending trial, the tube was set in a cantilever, and a rosette strain gauge was placed at the top of the fixed end. 7 different weights were then tested, each 2lbs heavier than the last. For the second trial, the square tube was put under a torsional load and bending load with the same increasing loading starting with 2lbs and adding an additional 2lbs for each sequential trial. Lastly ANSYS was used for the finite element analysis. Results are shown below. This analysis allowed us to prove that the square tube purchased was rigid enough to handle the loads in a real work driving scenario

5.1.1 Body and Chassis

To test the body a series of solidworks tests were performed. For our frame which was made of aluminum 6061 T-6. A strain gauge was used on a 2 foot section of the same material and a series of weights were placed in a torsion test and Mohr’s circle calculation performed. The car weighed approximately 73 lbs.

Torsion							
Data	**Load lbs.**	**M**	**σ**	**ε**	**Ch1**	**Ch2**	**Ch3**
1	5.511	63.377	760.54	0.0008	31	48	1
2	7.11	81.765	981.21	0.001	37	52	-1
3	8.711	100.18	1202.2	0.0012	48	57	-3
4	10.311	118.58	1423	0.0014	58	64	-8
5	11.911	136.98	1643.8	0.0016	67	73	-14
6	13.511	155.38	1864.6	0.0019	70	79	-17
7	15.111	173.78	2085.4	0.0021	95	93	-25
8	16.711	192.18	2306.2	0.0023	122	135	-36

9	18.311	210.58	2527	0.0025	134	154	-48
10	19.911	228.98	2747.8	0.0027	151	162	-63

Table 1.

The series of weights used were realistic for what our car would encounter on the racetrack at SpeedFest with the approximate weights being from 5.5 lbs to 20 lbs. This would encompass the car with all the electronic and AFFF fire retardant on board. The behavior was observed and recorded. Of course aluminum 6061 has a Young's Modulus of 69 GPA or 10,000 ksi and the weakness appeared to be in the welded sections.

5.1.2 Mission System

The mission system was physically tested with approximately 5 tests. The original design with the fan nozzle at the end was determined to not be able to aerate the foam well enough for it to be effective, and Venturi nozzle was determined to be the solution to add enough air for the AFFF to foam properly. After about 5 tests the solution was determined to be the use of two Venturi nozzles at the beginning and terminating end of the aluminum tubing. This eliminated the need for canned air and allowed for enough air and pressure for the solution to successfully extinguish the fire.

5.1.3 Steering

The testing for the steering came from mainly manual testing. This was done by hooking up the system and having live tests. With this we concluded that the original servo that we had was not powerful enough so we upgraded that. We finally ended up with a 55 kg-cm motor which worked fine.

5.1.4 Drivetrain

The drivetrain was tested first in solidworks to correctly test and measure the different gears and belts. After this the drivetrain assembly was put together and mounted on the car. The main testing like the steering was on the floor with the electronics connected to it. This was texted while the car was in motion. Other than having to tighten the belts and adjust the rear end to better align it it did not need much testing.

5.2 Electrical Testing

5.2.1 Mission Testing

In order to test and calibrate the mission electrical systems there will be multiple tests of both the mission system and the object tracking. To test the object tracking and communication efficacy the car will be set to follow orange objects as well as moving around them. To test the mission system there will be multiple fire extinguishing attempts to allow for fine tuning of the extinguishing system.

5.2.2 Navigation Testing

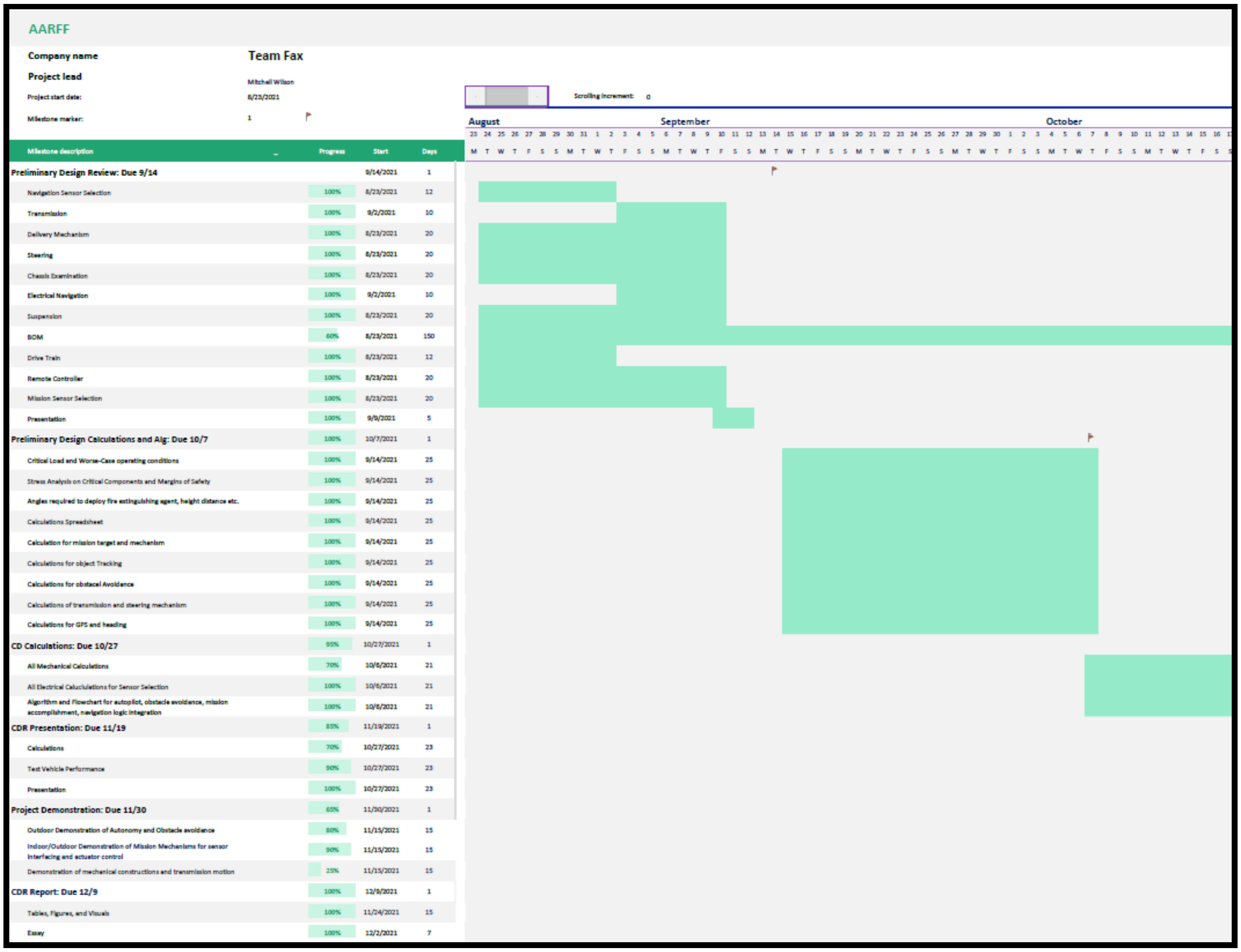
The navigation portion of this project is embodied by copious amounts of testing and tweaking to adhere to the constraints listed. Essentially the indoors navigation is a test for the outdoor navigation logic to allow the AARFF to avoid obstacles as it finds the coordinates inputted. To test the obstacle avoidance, it is as simple as placing the prototype AARFF and letting it avoid walls and people walking in front of it. As more and more tests and tweaks were done, a more defined code can be compiled to account for different distance ranges for obstacles and adjusting the lidar's angle of preponderance.

6 Project Cost and Schedule

6.1 Schedule Reflecting Project Activities

6.1.1 Gantt Chart Planned

Shown here is Table 1. This is the Gantt chart that was planned at the beginning of the semester. Due to the nature of school and assignment deadlines the team was forced to stay close to this schedule.



AARFF

Company name Team Fax

Project lead Mitchell Wilson

Project start date: 8/23/2021

Milestone marker: 1

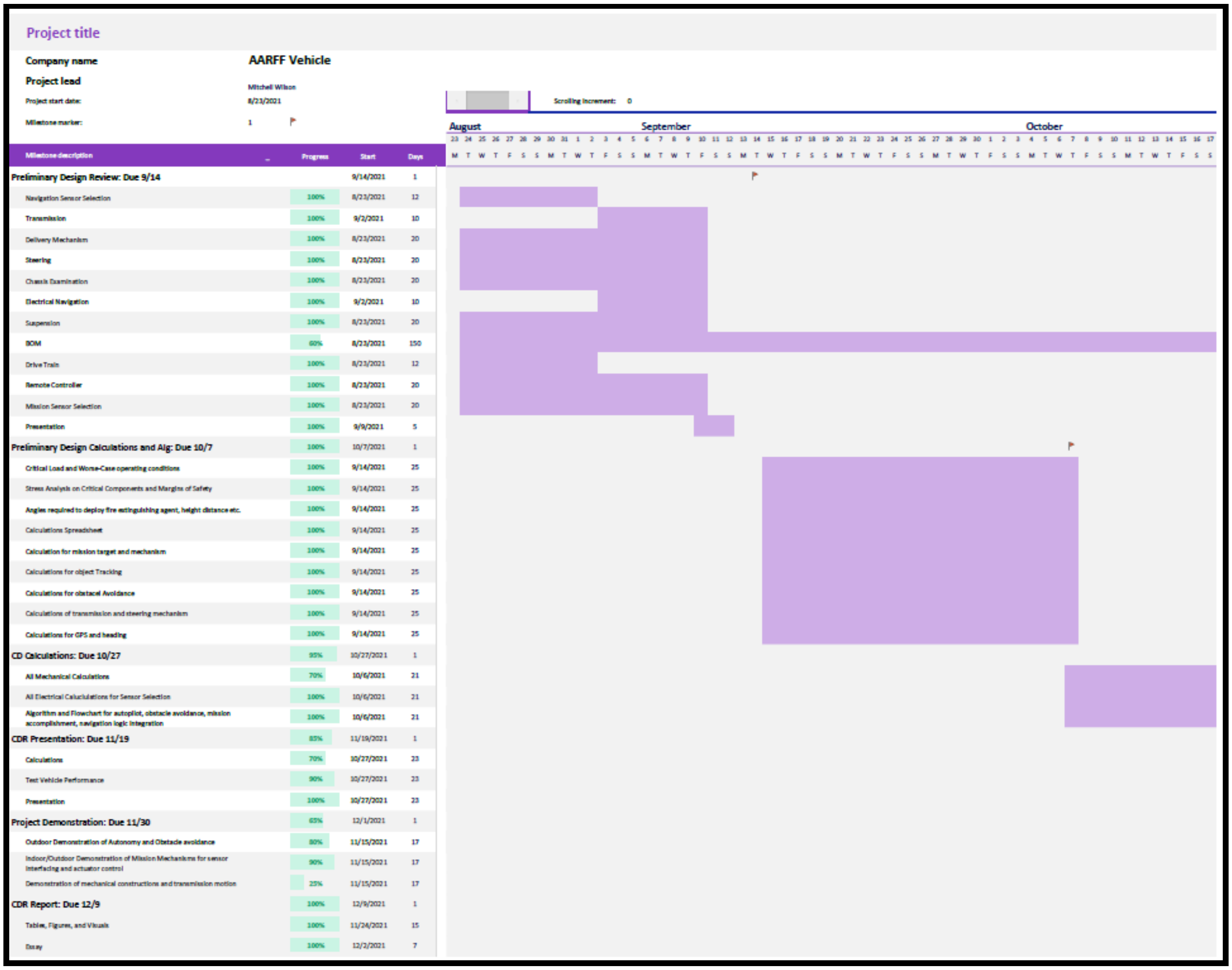
Scrolling increment: 0

Milestone description	Progress	Start	Days
Preliminary Design Review: Due 9/14		9/14/2021	1
Navigation Sensor Selection	100%	8/23/2021	12
Transmission	100%	9/2/2021	10
Delivery Mechanism	100%	8/23/2021	20
Steering	100%	8/23/2021	20
Chassis Examination	100%	8/23/2021	20
Electrical Navigation	100%	9/2/2021	10
Suspension	100%	8/23/2021	20
BOM	60%	8/23/2021	150
Drive Train	100%	8/23/2021	12
Remote Controller	100%	8/23/2021	20
Mission Sensor Selection	100%	8/23/2021	20
Presentation	100%	9/9/2021	5
Preliminary Design Calculations and Alg: Due 10/7	100%	10/7/2021	1
Critical Load and Worse-Case operating conditions	100%	9/14/2021	25
Stress Analysis on Critical Components and Margins of Safety	100%	9/14/2021	25
Angles required to deploy fire extinguishing agent, height distance etc.	100%	9/14/2021	25
Calculations Spreadsheet	100%	9/14/2021	25
Calculation for mission target and mechanism	100%	9/14/2021	25
Calculations for object Tracking	100%	9/14/2021	25
Calculations for obstacel Avoidance	100%	9/14/2021	25
Calculations of transmission and steering mechanism	100%	9/14/2021	25
Calculations for GPS and heading	100%	9/14/2021	25
CD Calculations: Due 10/27	95%	10/27/2021	1
All Mechanical Calculations	70%	10/6/2021	21
All Electrical Caluclulations for Sensor Selection	100%	10/6/2021	21
Algorithm and Flowchart for autopilot, obstacle avoidance, mission accomplishment, navigation logic integration	100%	10/6/2021	21
CDR Presentation: Due 11/19	85%	11/19/2021	1
Calculations	70%	10/27/2021	23
Test Vehicle Performance	90%	10/27/2021	23
Presentation	100%	10/27/2021	23
Project Demonstration: Due 11/30	65%	11/30/2021	1
Outdoor Demonstration of Autonomy and Obstacle avoidance	80%	11/15/2021	15
Indoor/Outdoor Demonstration of Mission Mechanisms for sensor interfacing and actuator control	90%	11/15/2021	15
Demonstration of mechanical constructions and transmission motion	25%	11/15/2021	15
CDR Report: Due 12/9	100%	12/9/2021	1
Tables, Figures, and Visuals	100%	11/24/2021	15
Essay	100%	12/2/2021	7

Table 2.

6.1.2 Gantt Chart Actual

Table 2 below is the gantt chart that most closely follows the team progress. Due to the nature of school and assignment deadlines the team stayed close to the planned version of this chart. The main difference is the Nov. 30 deadline, Project Demonstration, was moved back to Dec. 1. A larger version of this table is located in section 6 Appendix.



Project title

Company name **AARFF Vehicle**

Project lead Mitchell Wilson

Project start date: 8/23/2021

Milestone marker: 1

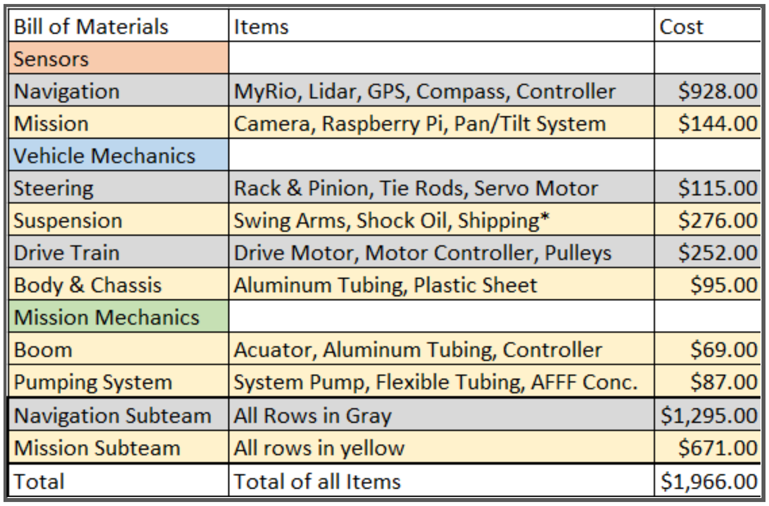
Milestone description	Progress	Start	Days
Preliminary Design Review: Due 9/14		9/14/2021	1
Navigation Sensor Selection	100%	8/23/2021	12
Transmission	100%	9/2/2021	10
Delivery Mechanism	100%	8/23/2021	20
Steering	100%	8/23/2021	20
Chassis Examination	100%	8/23/2021	20
Electrical Navigation	100%	9/2/2021	10
Suspension	100%	8/23/2021	20
BOM	60%	8/23/2021	150
Drive Train	100%	8/23/2021	12
Remote Controller	100%	8/23/2021	20
Mission Sensor Selection	100%	8/23/2021	20
Presentation	100%	9/9/2021	5
Preliminary Design Calculations and Alg: Due 10/7	100%	10/7/2021	1
Critical Load and Worse-Case operating conditions	100%	9/14/2021	25
Stress Analysis on Critical Components and Margins of Safety	100%	9/14/2021	25
Angles required to deploy fire extinguishing agent, height distance etc.	100%	9/14/2021	25
Calculations Spreadsheet	100%	9/14/2021	25
Calculation for mission target and mechanism	100%	9/14/2021	25
Calculations for object Tracking	100%	9/14/2021	25
Calculations for obstacel Avoidance	100%	9/14/2021	25
Calculations of transmission and steering mechanism	100%	9/14/2021	25
Calculations for GPS and heading	100%	9/14/2021	25
CD Calculations: Due 10/27	95%	10/27/2021	1
All Mechanical Calculations	70%	10/6/2021	21
All Electrical Caluclulations for Sensor Selection	100%	10/6/2021	21
Algorithm and Flowchart for autoplot, obstacle avoidance, mission accomplishment, navigation logic integration	100%	10/6/2021	21
CDR Presentation: Due 11/19	85%	11/19/2021	1
Calculations	70%	10/27/2021	23
Test Vehicle Performance	90%	10/27/2021	23
Presentation	100%	10/27/2021	23
Project Demonstration: Due 11/30	65%	12/1/2021	1
Outdoor Demonstration of Autonomy and Obstacle avoidance	80%	11/15/2021	17
Indoor/Outdoor Demonstration of Mission Mechanisms for sensor interfacing and actuator control	90%	11/15/2021	17
Demonstration of mechanical constructions and transmission motion	25%	11/15/2021	17
CDR Report: Due 12/9	100%	12/9/2021	1
Tables, Figures, and Visuals	100%	11/24/2021	15
Essay	100%	12/2/2021	7

Table 3.

6.2 Costs of the Design

6.2.1 Bill of Materials

For the complete bill of materials (BOM) see table table in section 6 Appendix. Shown here in Table 3 is a condensed BOM. This bill of materials contains items that the instructor already had available.

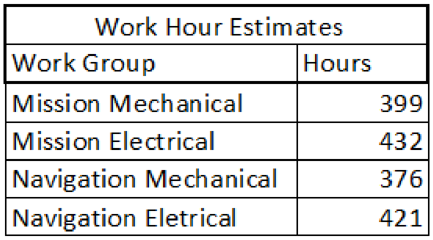


Bill of Materials	Items	Cost
Sensors		
Navigation	MyRio, Lidar, GPS, Compass, Controller	$928.00
Mission	Camera, Raspberry Pi, Pan/Tilt System	$144.00
Vehicle Mechanics		
Steering	Rack & Pinion, Tie Rods, Servo Motor	$115.00
Suspension	Swing Arms, Shock Oil, Shipping*	$276.00
Drive Train	Drive Motor, Motor Controller, Pulleys	$252.00
Body & Chassis	Aluminum Tubing, Plastic Sheet	$95.00
Mission Mechanics		
Boom	Acuator, Aluminum Tubing, Controller	$69.00
Pumping System	System Pump, Flexible Tubing, AFFF Conc.	$87.00
Navigation Subteam	All Rows in Gray	$1,295.00
Mission Subteam	All rows in yellow	$671.00
Total	Total of all Items	$1,966.00

Table 4.

6.2.2 Work Hour Totals

The estimated amount of work hours broken down into subteam is listed below in table 4. Most work groups had a similar amount of estimated work hours.



Work Hour Estimates	
Work Group	Hours
Mission Mechanical	399
Mission Electrical	432
Navigation Mechanical	376
Navigation Eletrical	421

Table 5.

7 Project Results and Conclusions

7.1 Results

The results experienced with the car's performance were a little mixed. The car did not perform as well as possible in some aspects, and performed well in other aspects. The mission system ended up working well to extinguish the fire, although not as fast as an extinguisher, the overall weight and space saved using the AFFF system gave the car more flexibility and room for electrical systems.

The bigger frame and heavier suspension made the car a little more on the heavier side. The aluminum frame was important in keeping the weight to a minimum. A steel frame could have potentially hindered the ability of the motor to push the car forward by making the car weigh too much for that size motor. The need to add another motor was quickly realized and with the design of the car, the addition was fairly painless to add.

The overall design was originally intended to mimic more sport utility vehicles that utilize bigger tires and a arm independent suspension and these aspects made the car weigh more than was originally anticipated. The idea of the track being in a field and not on pavement directed the original design to this off road design, yet these adjustments added weight to the car and with the increased size of the frame, the car was quite a bit more heavy than team 1.

With all these issues of heavier weight, the overall ground clearance became an issue for the ability of the car to maneuver successfully. The heavier shocks caused the front to be heavier than the rear end and the overall stance of the car made the adjustment of the height of the shocks and position they attach to the car an issue. These were the very first problems encountered in the manufacturing of the vehicle.

After adjusting for the weight and the stance of the car, the added second motor, the rear end suspension needed to change from wishbone to a hybrid leaf spring design that would allow for the motors and belts to move with the rear suspension. This was needed to keep the tension of the belts constant. This also added the need for the motor mounts to be adjusted to a system that would attach directly to the suspension so as to act as one bigger unit.

These were relatively minor adjustments needed to get the car to successfully travel and drive freely, yet they took time to make and apply to the car and design. Once these changes were made, the car would travel fairly trouble free. The weakest point in the car was the steering; in particular the connection of the steering to the servo. The aluminum parts of the steering arms did not adhere very well to the plastic of the servo holder. This was the part that broke at the track.

The results of how everything worked out on the track, the conclusion drawn was that the steering ultimately needed to have a motor instead of a servo. The problems with the strength of the servo and the difficult connection issues could have been averted using a motor.

7.2 Conclusion

The team worked on this project for 30 weeks. During that time, Team 2's version of the AARFF has come to life in design. There have been complete mechanical and electrical designs that are backed up by calculations and tests. Electrical and mechanical systems have united completely to produce what is shown in the Figures below. By the ides of Feb. 2022 the vast majority of the AARFF vehicle was mechanically assembled. In late February, the electrical and control systems were integrated into the new chassis and body and tests for various systems were underway. By April, the vehicle was ready for the annual Speedfest competition. The remaining time before the competition was spent on additional needed testing and calibration. Team Fax was very excited for the success in assembly and testing with both mechanical and electrical systems integrated, and anticipated great success at the Speedfest 2022 competition.

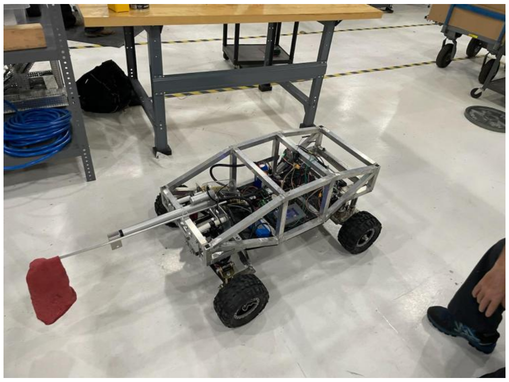


Figure 28.

Figure 29.

7.3 What Was Learned

7.3.1 Mission Mechanical

One of the biggest lessons taught this semester was to always have a plan B. Some components of this project would work in theory but not in reality. The need for this is exasperated by the fact that sometimes some parts are very hard to obtain. In this instance, it is important to have a plan B that can be utilized if this occurs.

Another very important lesson is the allocation of team members. Having one person on a critical part can result in a failure. It is important to have two or more people working together as a team so that if something happens while designing, the task still gets completed. Working together as a team also helps bring better, more efficient, solutions to challenges at hand.

7.3.2 Mission Electrical

The mission electrical team learned about programming with python primarily and some with labview. Raspberry Pi experience was also gained. The largest gain of experience was with OpenCV and video processing. Having no experience with this before now the team enjoyed learning how to manipulate and control based on images and video feed. The mission electrical team also got experience in motor controls and interfacing sensors.

7.3.3 Navigation Mechanical

What was learned from this semester was to communicate between your team members regularly to attain the most up to date information possible so as to avoid errors down the road. The team also learned to do the work early and fix the small mistakes as they appear. Another thing that was learned while in the field is while something may work for a little bit you need to look at the sustainability and how long it will hold up while in the field. This includes increased tests on all the systems within the mechanical part.

7.3.4 Navigation Electrical

One of the most important things that the navigation electrical team learned was how to interface the Raspberry Pi and myRIO. Codes for the specific instructions for the tasks that needed to be done were used, however this was not easy. This took many research attempts online and reaching out to other resources such as professors. However, the team endured and accomplished a significant amount of work that will greatly benefit the project. Because of this, experience in the Python and LABVIEW programming languages were also learned.

Regarding the Python programming language, one of the most important things that the team learned was how to read the libraries and interpret what the functions actually do, rather than rely on sample code. This greatly helped when the team had to troubleshoot errors in the code whose cause was not readily apparent.

7.4 Overview of Lessons Learned

One of the biggest lessons learned from this project is the importance of teamwork. The ability to build a project this ambitious is impossible to do without the aid of the team. The biggest challenge that the team faced was coordinating the schedules of each member so that work could be commenced.

The manufacturing of the individual parts also would take more time than expected. Minor adjustments would mean a full day of manufacturing and tearing down of the car to just change the smallest of things. This took most everyone by surprise. The ability to change something on a whim was not something that could be easily achieved on this project.

The importance of communication was also highlighted during this project. The communication between the navigation team and mechanical team was another hurdle the team had to overcome to successfully complete the car in time. The electrical team would be handicapped by the mechanical side and communication between the teams was less than optimal at the start of this second semester.

Once a couple of milestones were missed and the team was behind, did the communication and schedule issues start getting resolved as forward momentum was achieved. The complexity of the project and the need to rely on other team members made for a bit of a learning curve that had to be overcome. The biggest lesson was the need for communication and ability to rely on team members for completion of component

8 References

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9 Appendix

(2.2.2.3)

```
def process_data(data):
    global max_distance
    L1 = 0
    L2 = 0
    L3 = 0
    L4 = 0
    R1 = 0
    R2 = 0
    R3 = 0
    R4 = 0
    for angle in range(360):
        distance = data[angle]
        if distance > 0:                  # ignore initially ungathered data points
            max_distance = max([min([5000, distance]), max_distance])
            #Determine number of points in ranges
            if (distance <= 1000 and distance > 100): #between 10 cm and 1m
                if (angle < 90):
                    R1 += 1
                elif (angle > 270):
                    L1 += 1
            elif (distance <= 2000 and distance > 1000): #between 1m and 2m
                if (angle < 45):
                    R2 += 1
                elif (angle > 315):
                    L2 += 1
            elif (distance <= 4000 and distance > 2000): #between 2m and 4m
                if (angle < 30):
                    R3 += 1
                elif (angle > 330):
                    L3 += 1
            elif (distance > 4000): #over 4m
                if (angle < 20):
                    R4 += 1
                elif (angle > 340):
                    L4 += 1
    # determine car movement
    if (R1+R2+R3)>30 and (L1+L2+L3)>30:
        path_blocked()
    elif (R1+L1)>0:
        if L1>R1:
            turn_right()
        else:
```

```
        turn_left()
elif (R2+L2)>0:
    if L2>R2:
        turn_right()
    else:
        turn_left()
elif (R3+L3)>0:
    if L3>R3:
        turn_right()
    else:
        turn_left()
elif (R4+L4)>0:
    if L4>R4:
        turn_right()
    else:
        turn_left()
else:
    no_obstacle()
```

Figure 30.

(2.5.1)

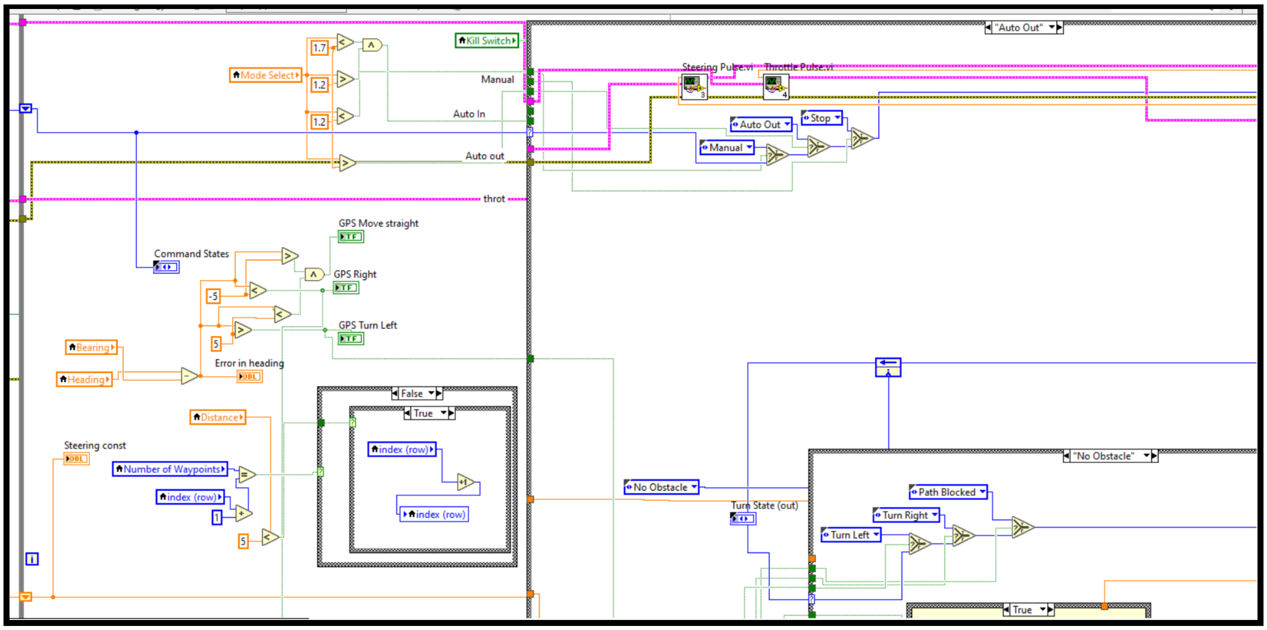


Figure 31.

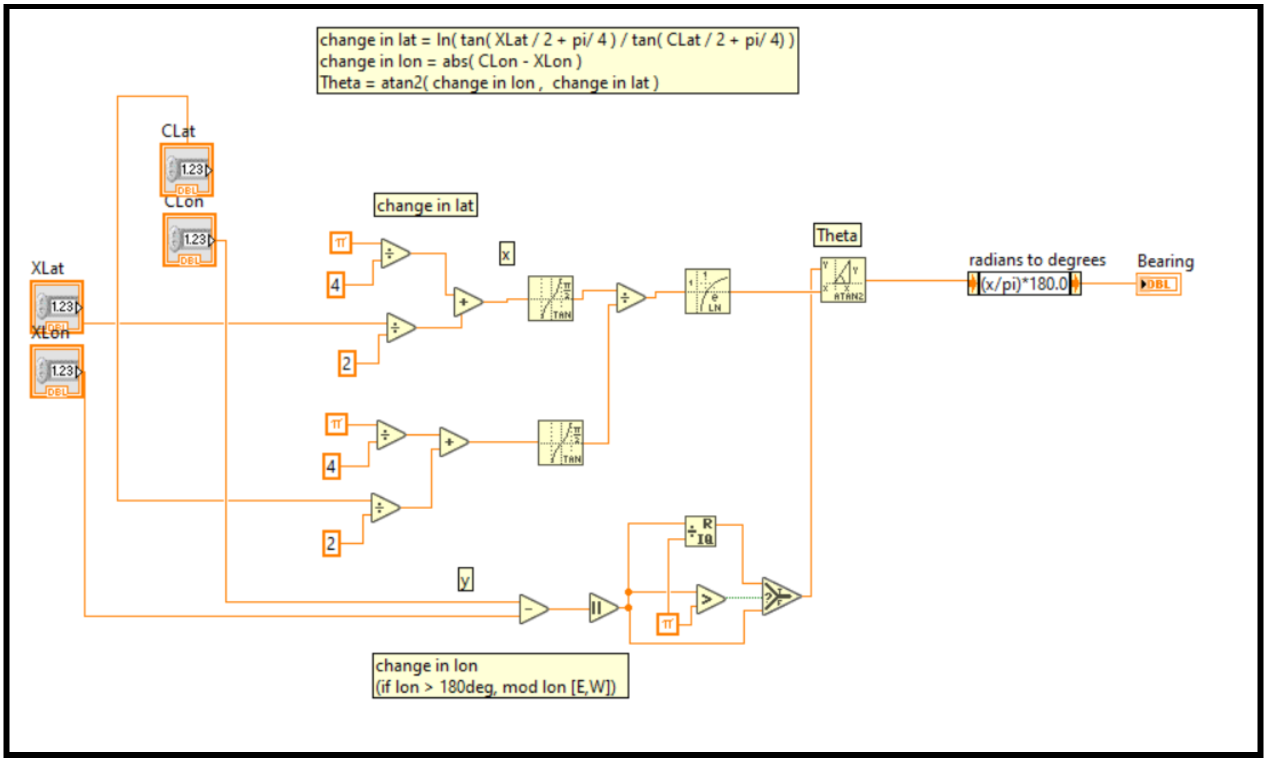


Figure 32.

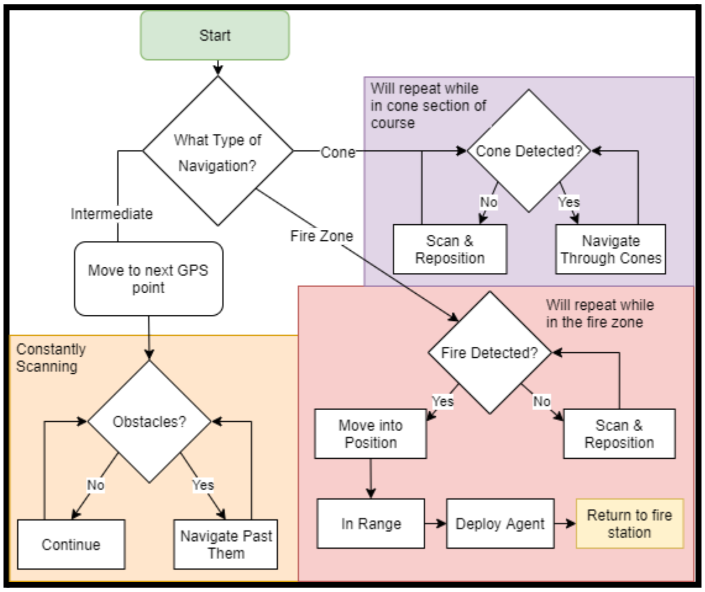


Figure 33.

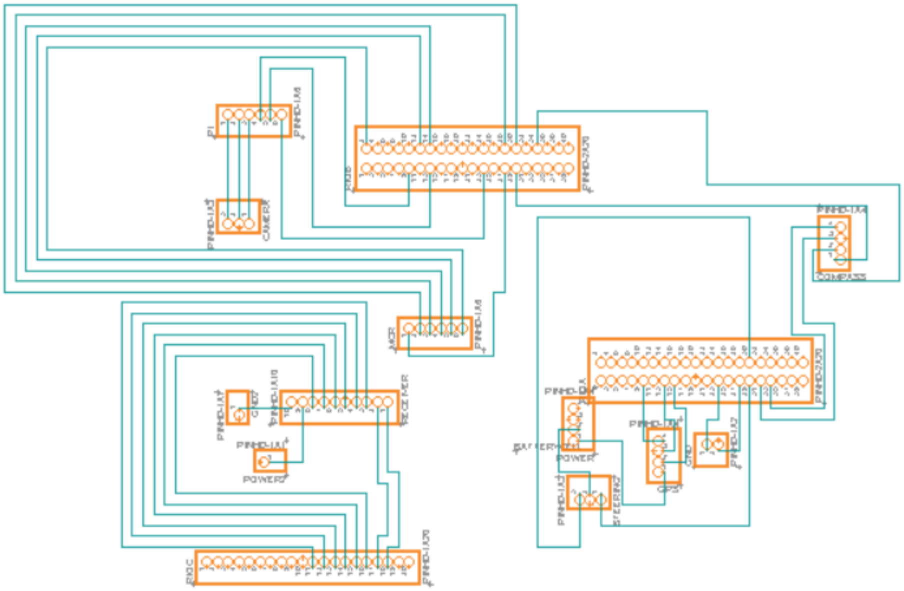


Figure 34.

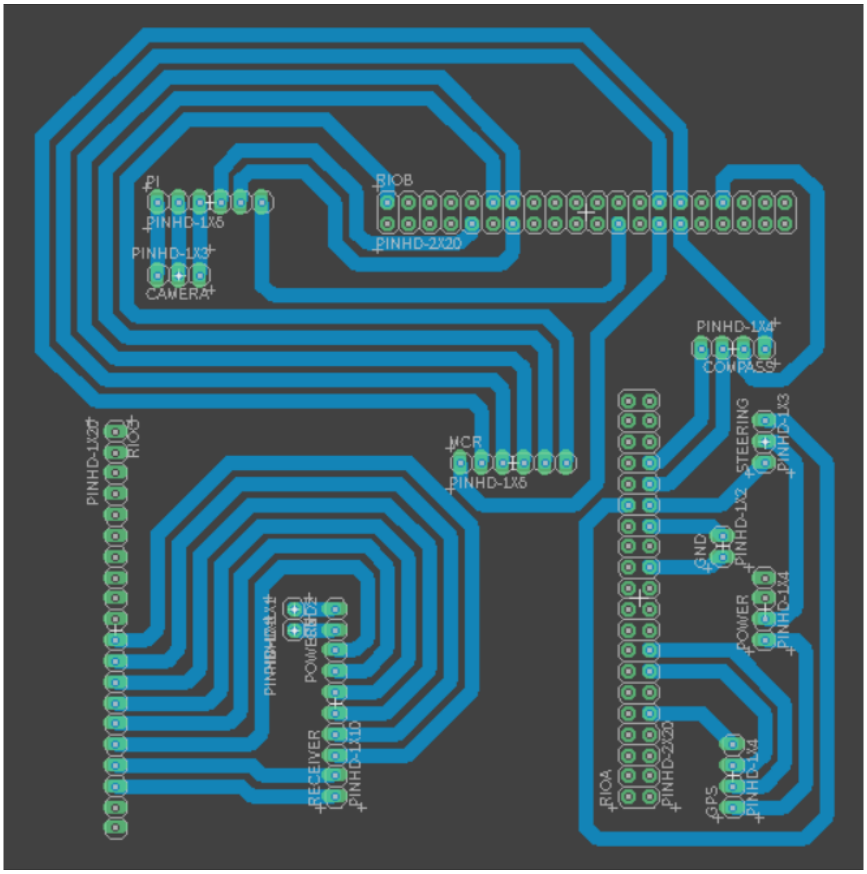
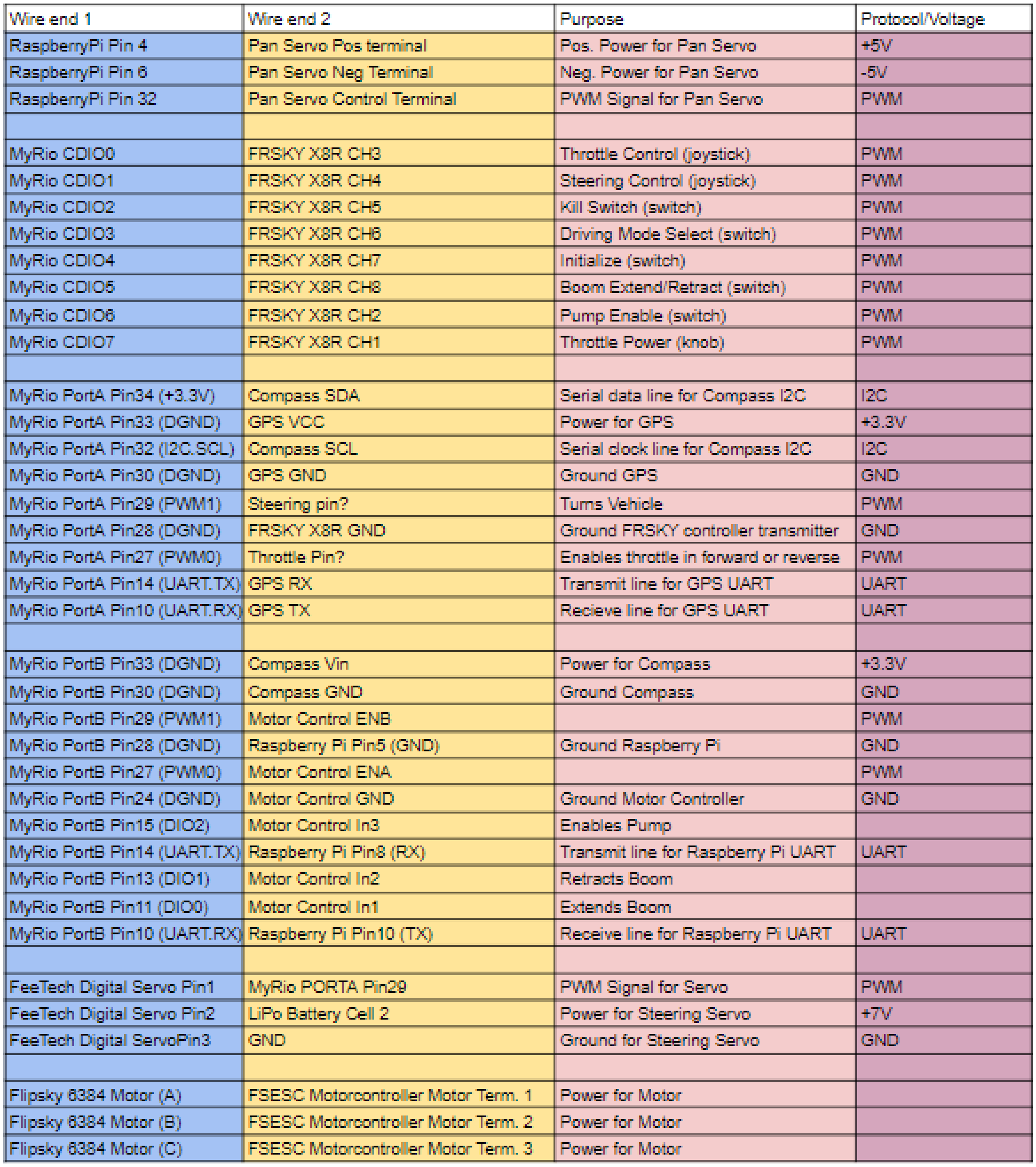
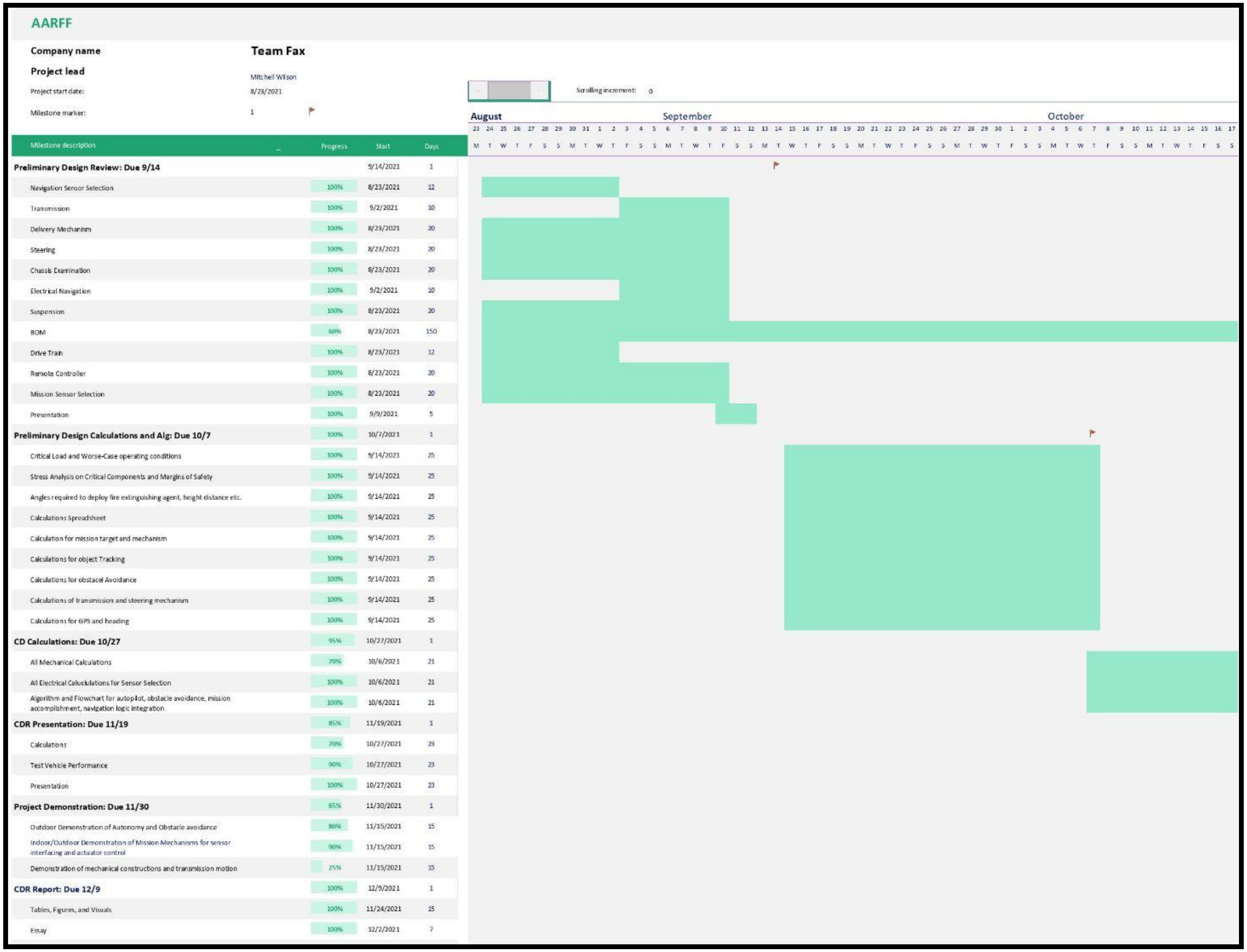


Figure 35.



Wire end 1	Wire end 2	Purpose	Protocol/Voltage
RaspberryPi Pin 4	Pan Servo Pos terminal	Pos. Power for Pan Servo	+5V
RaspberryPi Pin 6	Pan Servo Neg Terminal	Neg. Power for Pan Servo	-5V
RaspberryPi Pin 32	Pan Servo Control Terminal	PWM Signal for Pan Servo	PWM
MyRio CDIO0	FRSKY X8R CH3	Throttle Control (joystick)	PWM
MyRio CDIO1	FRSKY X8R CH4	Steering Control (joystick)	PWM
MyRio CDIO2	FRSKY X8R CH5	Kill Switch (switch)	PWM
MyRio CDIO3	FRSKY X8R CH6	Driving Mode Select (switch)	PWM
MyRio CDIO4	FRSKY X8R CH7	Initialize (switch)	PWM
MyRio CDIO5	FRSKY X8R CH8	Boom Extend/Retract (switch)	PWM
MyRio CDIO6	FRSKY X8R CH2	Pump Enable (switch)	PWM
MyRio CDIO7	FRSKY X8R CH1	Throttle Power (knob)	PWM
MyRio PortA Pin34 (+3.3V)	Compass SDA	Serial data line for Compass I2C	I2C
MyRio PortA Pin33 (DGND)	GPS VCC	Power for GPS	+3.3V
MyRio PortA Pin32 (I2C.SCL)	Compass SCL	Serial clock line for Compass I2C	I2C
MyRio PortA Pin30 (DGND)	GPS GND	Ground GPS	GND
MyRio PortA Pin29 (PWM1)	Steering pin?	Turns Vehicle	PWM
MyRio PortA Pin28 (DGND)	FRSKY X8R GND	Ground FRSKY controller transmitter	GND
MyRio PortA Pin27 (PWM0)	Throttle Pin?	Enables throttle in forward or reverse	PWM
MyRio PortA Pin14 (UART.TX)	GPS RX	Transmit line for GPS UART	UART
MyRio PortA Pin10 (UART.RX)	GPS TX	Recieve line for GPS UART	UART
MyRio PortB Pin33 (DGND)	Compass Vin	Power for Compass	+3.3V
MyRio PortB Pin30 (DGND)	Compass GND	Ground Compass	GND
MyRio PortB Pin29 (PWM1)	Motor Control ENB		PWM
MyRio PortB Pin28 (DGND)	Raspberry Pi Pin5 (GND)	Ground Raspberry Pi	GND
MyRio PortB Pin27 (PWM0)	Motor Control ENA		PWM
MyRio PortB Pin24 (DGND)	Motor Control GND	Ground Motor Controller	GND
MyRio PortB Pin15 (DIO2)	Motor Control In3	Enables Pump	
MyRio PortB Pin14 (UART.TX)	Raspberry Pi Pin8 (RX)	Transmit line for Raspberry Pi UART	UART
MyRio PortB Pin13 (DIO1)	Motor Control In2	Retracts Boom	
MyRio PortB Pin11 (DIO0)	Motor Control In1	Extends Boom	
MyRio PortB Pin10 (UART.RX)	Raspberry Pi Pin10 (TX)	Receive line for Raspberry Pi UART	UART
FeeTech Digital Servo Pin1	MyRio PORTA Pin29	PWM Signal for Servo	PWM
FeeTech Digital Servo Pin2	LiPo Battery Cell 2	Power for Steering Servo	+7V
FeeTech Digital ServoPin3	GND	Ground for Steering Servo	GND
Flipsky 6384 Motor (A)	FSESC Motorcontroller Motor Term. 1	Power for Motor	
Flipsky 6384 Motor (B)	FSESC Motorcontroller Motor Term. 2	Power for Motor	
Flipsky 6384 Motor (C)	FSESC Motorcontroller Motor Term. 3	Power for Motor	

Figure 36.



AARFF

Company name **Team Fax**

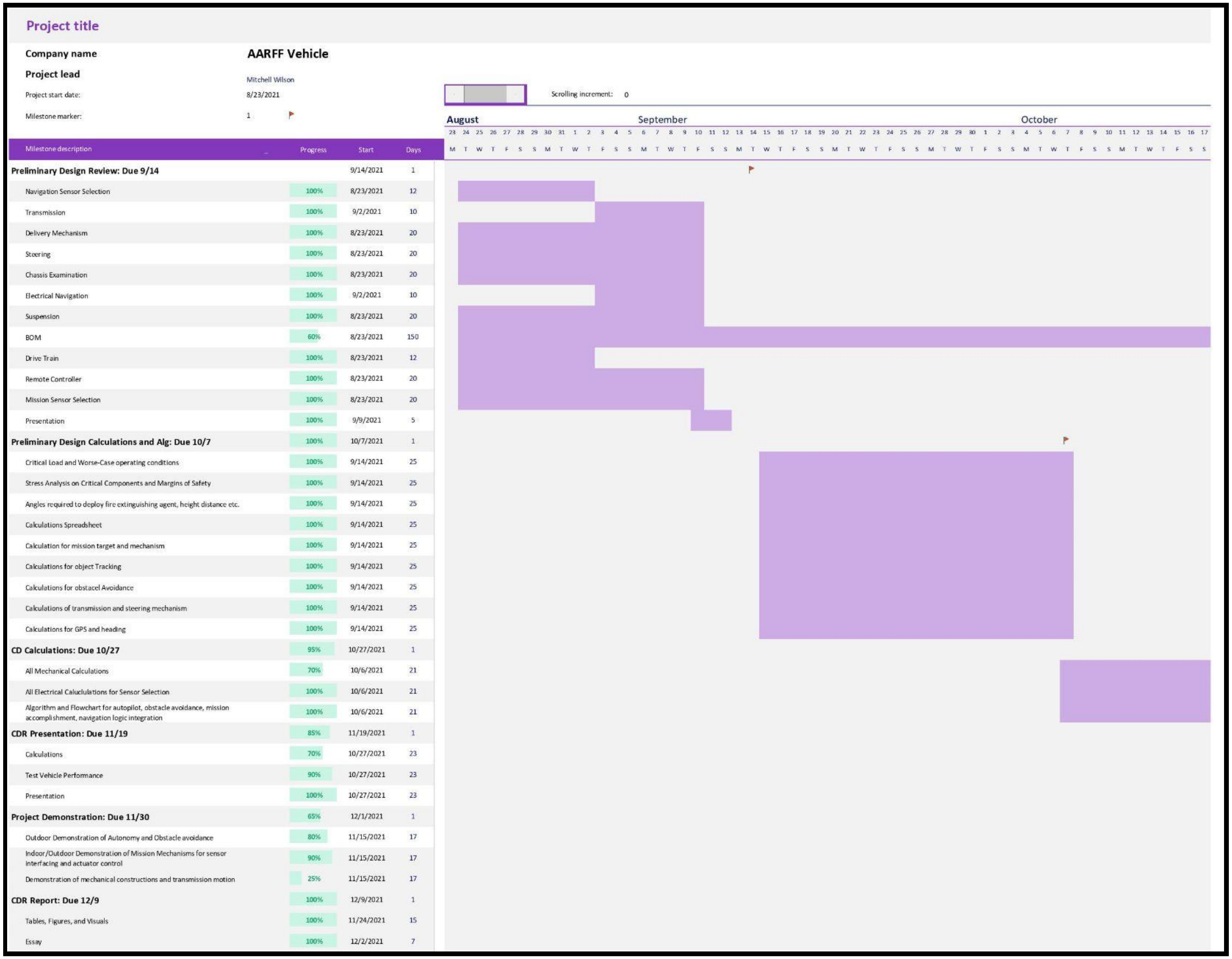
Project lead Mitchell Wilson

Project start date: 8/23/2021

Milestone marker: 1

Milestone description	Progress	Start	Days
Preliminary Design Review: Due 9/14		9/14/2021	1
Navigation Sensor Selection	100%	8/23/2021	12
Transmission	100%	9/2/2021	10
Delivery Mechanism	100%	8/23/2021	20
Steering	100%	8/23/2021	20
Chassis Examination	100%	8/23/2021	20
Electrical Navigation	100%	9/2/2021	10
Suspension	100%	8/23/2021	20
BOM	60%	8/23/2021	150
Drive Train	100%	8/23/2021	12
Remote Controller	100%	8/23/2021	20
Mission Sensor Selection	100%	8/23/2021	20
Presentation	100%	9/9/2021	5
Preliminary Design Calculations and Alg: Due 10/7	100%	10/7/2021	1
Critical Load and Worse-Case operating conditions	100%	9/14/2021	25
Stress Analysis on Critical Components and Margins of Safety	100%	9/14/2021	25
Angles required to deploy fire extinguishing agent, height distance etc.	100%	9/14/2021	25
Calculations Spreadsheet	100%	9/14/2021	25
Calculation for mission target and mechanism	100%	9/14/2021	25
Calculations for object Tracking	100%	9/14/2021	25
Calculations for obstacel Avoidance	100%	9/14/2021	25
Calculations of transmission and steering mechanism	100%	9/14/2021	25
Calculations for GPS and heading	100%	9/14/2021	25
CD Calculations: Due 10/27	95%	10/27/2021	1
All Mechanical Calculations	70%	10/6/2021	21
All Electrical Caluclulations for Sensor Selection	100%	10/6/2021	21
Algorithm and Flowchart for autopilot, obstacle avoidance, mission accomplishment, navigation logic integration	100%	10/6/2021	21
CDR Presentation: Due 11/19	85%	11/19/2021	1
Calculations	70%	10/27/2021	23
Test Vehicle Performance	90%	10/27/2021	23
Presentation	100%	10/27/2021	23
Project Demonstration: Due 11/30	65%	11/30/2021	1
Outdoor Demonstration of Autonomy and Obstacle avoidance	80%	11/15/2021	15
Indoor/Outdoor Demonstration of Mission Mechanisms for sensor interfacing and actuator control	90%	11/15/2021	15
Demonstration of mechanical constructions and transmission motion	25%	11/15/2021	15
CDR Report: Due 12/9	100%	12/9/2021	1
Tables, Figures, and Visuals	100%	11/24/2021	15
Essay	100%	12/2/2021	7

Table 5.



Project title

Company name **AARFF Vehicle**

Project lead Mitchell Wilson

Project start date: 8/23/2021

Milestone marker: 1 🚩

Scrolling increment: 0

Milestone description	Progress	Start	Days
Preliminary Design Review: Due 9/14		9/14/2021	1
Navigation Sensor Selection	100%	8/23/2021	12
Transmission	100%	9/2/2021	10
Delivery Mechanism	100%	8/23/2021	20
Steering	100%	8/23/2021	20
Chassis Examination	100%	8/23/2021	20
Electrical Navigation	100%	9/2/2021	10
Suspension	100%	8/23/2021	20
BOM	60%	8/23/2021	150
Drive Train	100%	8/23/2021	12
Remote Controller	100%	8/23/2021	20
Mission Sensor Selection	100%	8/23/2021	20
Presentation	100%	9/9/2021	5
Preliminary Design Calculations and Alg: Due 10/7	100%	10/7/2021	1
Critical Load and Worse-Case operating conditions	100%	9/14/2021	25
Stress Analysis on Critical Components and Margins of Safety	100%	9/14/2021	25
Angles required to deploy fire extinguishing agent, height distance etc.	100%	9/14/2021	25
Calculations Spreadsheet	100%	9/14/2021	25
Calculation for mission target and mechanism	100%	9/14/2021	25
Calculations for object Tracking	100%	9/14/2021	25
Calculations for obstacel Avoidance	100%	9/14/2021	25
Calculations of transmission and steering mechanism	100%	9/14/2021	25
Calculations for GPS and heading	100%	9/14/2021	25
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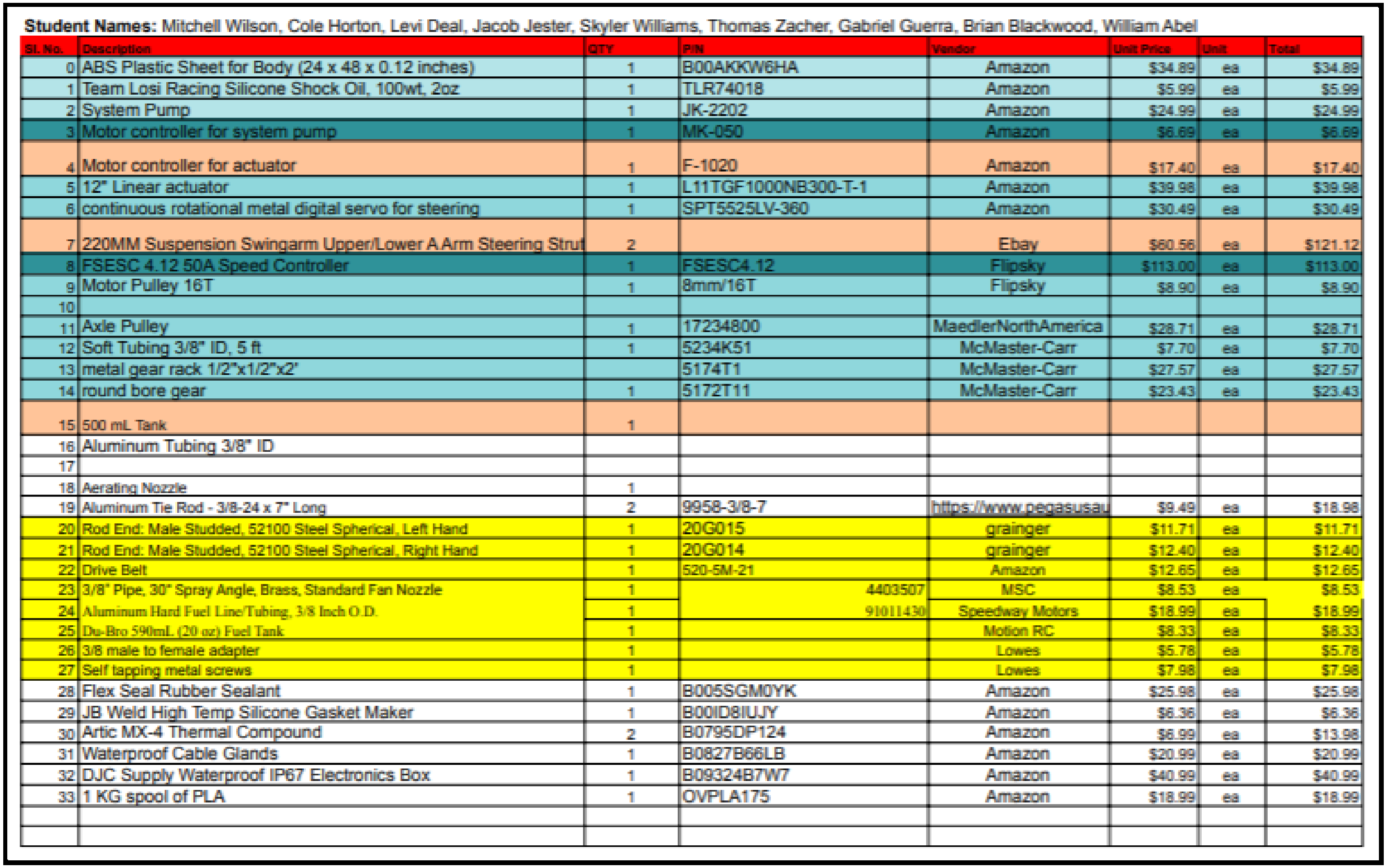
Presentation	100%	10/27/2021	23
Project Demonstration: Due 11/30	65%	12/1/2021	1
Outdoor Demonstration of Autonomy and Obstacle avoidance	80%	11/15/2021	17
Indoor/Outdoor Demonstration of Mission Mechanisms for sensor interfacing and actuator control	90%	11/15/2021	17
Demonstration of mechanical constructions and transmission motion	25%	11/15/2021	17
CDR Report: Due 12/9	100%	12/9/2021	1
Tables, Figures, and Visuals	100%	11/24/2021	15
Essay	100%	12/2/2021	7

Table 6.



Student Names: Mitchell Wilson, Cole Horton, Levi Deal, Jacob Jester, Skyler Williams, Thomas Zacher, Gabriel Guerra, Brian Blackwood, William Abel

Sl. No.	Description	QTY	P/N	Vendor	Unit Price	Unit	Total
0	ABS Plastic Sheet for Body (24 x 48 x 0.12 inches)	1	B00AKKW6HA	Amazon	$34.89	ea	$34.89
1	Team Losi Racing Silicone Shock Oil, 100wt, 2oz	1	TLR74018	Amazon	$5.99	ea	$5.99
2	System Pump	1	JK-2202	Amazon	$24.99	ea	$24.99
3	Motor controller for system pump	1	MK-050	Amazon	$6.69	ea	$6.69
4	Motor controller for actuator	1	F-1020	Amazon	$17.40	ea	$17.40
5	12" Linear actuator	1	L11TGF1000NB300-T-1	Amazon	$39.98	ea	$39.98
6	continuous rotational metal digital servo for steering	1	SPT5525LV-360	Amazon	$30.49	ea	$30.49
7	220MM Suspension Swingarm Upper/Lower A Arm Steering Strut	2		Ebay	$60.56	ea	$121.12
8	FSESC 4.12 50A Speed Controller	1	FSESC4.12	Flipsky	$113.00	ea	$113.00
9	Motor Pulley 16T	1	8mm/16T	Flipsky	$8.90	ea	$8.90
10							
11	Axle Pulley	1	17234800	MaedlerNorthAmerica	$28.71	ea	$28.71
12	Soft Tubing 3/8" ID, 5 ft	1	5234K51	McMaster-Carr	$7.70	ea	$7.70
13	metal gear rack 1/2"x1/2"x2'		5174T1	McMaster-Carr	$27.57	ea	$27.57
14	round bore gear	1	5172T11	McMaster-Carr	$23.43	ea	$23.43
15	500 mL Tank	1					
16	Aluminum Tubing 3/8" ID						
17							
18	Aerating Nozzle	1					
19	Aluminum Tie Rod - 3/8-24 x 7" Long	2	9958-3/8-7	https://www.pegasusau	$9.49	ea	$18.98
20	Rod End: Male Studded, 52100 Steel Spherical, Left Hand	1	20G015	grainger	$11.71	ea	$11.71
21	Rod End: Male Studded, 52100 Steel Spherical, Right Hand	1	20G014	grainger	$12.40	ea	$12.40
22	Drive Belt	1	520-5M-21	Amazon	$12.65	ea	$12.65
23	3/8" Pipe, 30° Spray Angle, Brass, Standard Fan Nozzle	1	4403507	MSC	$8.53	ea	$8.53
24	Aluminum Hard Fuel Line/Tubing, 3/8 Inch O.D.	1	91011430	Speedway Motors	$18.99	ea	$18.99
25	Du-Bro 590mL (20 oz) Fuel Tank	1		Motion RC	$8.33	ea	$8.33
26	3/8 male to female adapter	1		Lowes	$5.78	ea	$5.78
27	Self tapping metal screws	1		Lowes	$7.98	ea	$7.98
28	Flex Seal Rubber Sealant	1	B005SGM0YK	Amazon	$25.98	ea	$25.98
29	JB Weld High Temp Silicone Gasket Maker	1	B00ID8IUJY	Amazon	$6.36	ea	$6.36
30	Artic MX-4 Thermal Compound	2	B0795DP124	Amazon	$6.99	ea	$13.98
31	Waterproof Cable Glands	1	B0827B66LB	Amazon	$20.99	ea	$20.99
32	DJC Supply Waterproof IP67 Electronics Box	1	B09324B7W7	Amazon	$40.99	ea	$40.99
33	1 KG spool of PLA	1	OVPLA175	Amazon	$18.99	ea	$18.99

Table 7.