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SAFER: Search and Find Emergency Rover

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SAFER: SEARCH AND FIND EMERGENCY ROVER

By

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Abstract

When disaster strikes and causes a structure to collapse, it poses a unique challenge to search and rescue teams as they assess the situation and search for survivors. Currently there are very few tools that can be used by these teams to aid them in gathering important information about the situation that allow members to stay at a safe distance. SAFER, *Search and Find Emergency Rover,* is an unmanned, remotely operated vehicle that can provide early reconnaissance to search and rescue teams so they may have more information to prepare themselves for the dangers that lay inside the wreckage. Over the past year, this team has restored a bare, non-operational chassis inherited from *Roverwerx 2012* into a rugged and operational rover with increased functionality and reliability. SAFER uses a 360-degree camera to deliver real time visual reconnaissance to the operator who can remain safely stationed on the outskirts of the disaster. With strong drive motors providing enough torque to traverse steep obstacles and enough power to travel at up to 3 ft/s, SAFER can cover ground quickly and effectively over its 1-3 hour battery life, maximizing reconnaissance for the team. Additionally, SAFER contains 3 flashing beacons that can be dropped by the operator in the event a victim is found so that when team members do enter the scene they may easily locate victims. In the future, other teams may wish to improve upon this iteration by adding thermal imaging, air quality sensors, and potentially a robotic arm with a camera that can see in spaces too small for the entire rover to enter.

Acknowledgements

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Chapter 1: Introduction

1.1 Background and Motivation

In disaster situations, when civil structures such as buildings and bridges collapse, it is often dangerous for search and rescue teams to enter the wreckage to search for trapped victims and survivors. Earthquakes, hurricanes, fires, or simply structural failure can cause the collapse of these structures, and search and rescue teams are employed to enter the wreckage of actively collapsing buildings to find survivors and casualties alike. It goes without saying that these teams face great risks in their work; the nature of the job is to find victims within the failing structures before further harm can befall the victims, or the rescue team members. The motivation of this project is to reduce the risk that these brave men and women must take during their search.

If, instead of immediately sending a human into the rubble of a collapsed structure, a remote-controlled rover would be sent to perform a preliminary search, the rescue team would be able to avoid unnecessary risk. By sending a live video feed back to the team, the rover could help assess the current layout of the rubble and determine the location of any survivors without requiring a rescue team member to enter the structure uninformed. The driving concept behind this rover is that, while a machine is not an inexpensive product, it is infinitely less precious than a human life; in a worst-case scenario, the rover can be considered expendable in comparison to a disaster responder. A search and rescue rover could help rescue teams save lives while protecting the lives of the team itself. We aim to create a rover, SAFER: *Search and Find Emergency Rover*, to assist the search and rescue team members in these situations.

Santa Clara University is not new to the search and rescue rover scene. Known most recently as *Roverwerx 2012*, the basic design of SAFER has been employed and modified since its origin in 2001. Each design team slightly changed the design goals of the rover, but the end product by the years end has not been reliable since the original. Knowing this, this team placed a large emphasis on creating a usable product that can be improved upon rather than reinvented in the future.

1.2 Review of Field Literature

In the article “Development of Robotic Vehicle in the Intermediate Category Suitable for Deployment in Rough Terrain,” [1] a different approach is taken to address a similar issue of rough terrain and rescue. A remote controlled vehicle is posited, but instead of a tracked system, this vehicle uses 6 legs with a wheel at the end of each. Unlike a tracked system, this 6-legged system is touted for its flexibility; the legs allow the rover to navigate rugged terrain, but the wheels at the end of each leg allow movement in all directions, and high-speed mobility on smooth terrain such as a paved road. These are all ideas that could be taken into consideration for the design of SAFER, but due to the nature of our project, in which the base rover already exists with a tracked system, the logistics of developing a 6-legged mobility system place the idea outside the scope of feasible possibilities.

The article also details the “human-machine interface” designed for the rover system. It mentions the wide range of system functionality necessary for controlling the 6-legged rover, and the processes and items implemented in the controller device. These include, but are not limited to, a monitor with 3D glasses, and microphone and headset allowing immersive feedback from the rover's intel-gathering process. The article even mentions a "voice interface" with the controller system [1]. SAFER's 360 degree view camera with live feed comes equipped with a microphone application. In theory, the operator could use the microphone capability of the camera to communicate with potential survivors to inform them that help is coming or delivering any other necessary information.

The article entitled "Teodor: A Semi-Autonomous Search and Rescue and Demining Robot" discusses a robotic rover system designed for search and rescue situations as well as land mine detection for "humane demining" in war zones [2], such as mobility on rough terrain and resistance to the elements. The article proposes that the ideal solution to rough terrain is to use a tracked system for movement, which is fortunate for us as the rover in our possession already uses such a system. The resistance to dust and dirt appears to occur primarily through a chassis that protects the electronic components of the Teodor rover, which is also present on SAFER, though potentially in need of modification in the future to completely prevent dust from collecting on the electronic components. A third ideal the article proposes is precise movement of the rover, at a low speed of 3km/h, which is about 2.7 ft/s. The purpose for the Teodor rover is to maneuver carefully in a field of active explosive devices. This can also be applied to SAFER, as hasty movement through a crumbling environment could potentially trigger further collapse.

In "A Knowledge Based System Prototype for Robot Assisted Urban Search and Rescue" by John Biltch and Ruth Maurer, the importance and many advantages of using robots for Urban Search and Rescue operations are discussed [3]. This article discusses key issues in the application of robotic systems to urban search-and-rescue activities and discusses the development of a system to increase the effectiveness and efficiency of search rovers and robots. Biltch and Maurer focus primarily on mini-robots for urban search and rescue applications because they can fit into very small areas where humans cannot, as well as unstable spaces that are too dangerous for search and rescue members to enter. Miniature robots are an asset to search and rescue teams because they have a largely reduced footprint, they are more or less immune to hazards, and there is great flexibility in their design.

In "Designing Search and Rescue Robots Towards Realistic User Requirements," by Daniela Doroftei, the focus is more geared towards the mechanical challenges and constraints of an unmanned vehicle [4]. The difficult terrain of various search and rescue environments poses a difficulty for the rovers. Often, it is difficult to design a rover that can navigate the difficult terrain as well as a search and rescue team member. This papers shows how the designs of certain rovers are customized to fit a certain search and rescue environment. Doroftei also mentions the importance of working with the customer throughout the process to ensure the best and most effective rovers.

"Rescue Robotics," by Annellen and Alexander Simpkins outlines the development of urban disaster robots in a Japanese context [5]. Being near a major fault line, Japan often experiences earthquakes, and tsunamis. The authors focus on the requirements of the robots and on the social impact that they have on Japanese society. The impact these robots have on search and rescue operations are also discussed. Some of these impacts include fast, efficient, and risk-free means of searching and keeping members of the team out of harm's way while surveying the scene. The design and planning process of researchers is also discussed in this article to help readers better understand how useful and helpful robots are in search and rescue operations, though they offer no examples of specific robots that are used.

An article by Hassan, John, Munir, and Salim discusses the design of a chassis frame for an all-terrain vehicle. The discussion uses a finite element analysis program for its explanations, and has plenty of information about static design concerns when it comes to the possible loads on the chassis of a rover or unmanned vehicle [6]. This article is particularly informative to our project because at its core, the chassis is the literal framework of our rover. Because of this, the chassis needs to be designed to a high standard so that it will be able to handle any situation it enters.

"Speed Control of a DC Motor Using PD and PWM Controllers," written by Mikova, Virgala, and Kelemen, discusses the abilities and limitations of controlling a set of DC motors with PD (Proportional Derivative) controllers and PWM (Pulse Width Modulation) controllers [7]. While SAFER is not meant to be autonomous as in the article, understanding the transfer functions of each control scheme and their respective advantages will be important when designing systems for the rover.

1.3 Review of Existing Systems

Before beginning work on the rover, research was conducted on other rovers with similar uses to SAFER already on the market. The four rovers found comparable to SAFER include the PackBot EOD 510, the Urbot Man-Portable Robotic System, the Foster-Miller Talon, and the Foster-Miller Solem. All four of these rovers have specifications close to the targets that we aim for SAFER to achieve. Table 1.1, is a table of the collected specifications for each of the four rovers that were focused on when designing and building SAFER. The most important specifications are speed, weight, battery life, and cost. A more detailed list of all the benchmarking results for each of the four other rovers is included in Table 2.2.

1.3.1 PackBot EOD 510

The PackBot EOD 510 from iRobot is a very versatile rover and can easily and effectively navigates through difficult terrain, which is ideal, especially for urban search and rescue operations (Figure 1.1). The PackBot climbs stairs, rolls over rubble, and navigates through narrow passages [8]. The PackBot has a top speed of 5.8 miles per hour. The PackBot is also extremely portable, weighing only 24 pounds and easy to transport; one person can easily carry the rover. Along with the portability, the rover is also quite easy to use because it is controlled with a game-style controller for a familiar interface for the operators. The battery life of the PackBot is up to 4 hours, so a full search and rescue operation can be completed per charge. Additionally, the PackBot EOD 510 is equipped with real-time video, audio, and sensor data along with the flexibility of adding more sensors depending on the application. Unfortunately, all of the additional sensors and high quality batteries make the PackBot quite expensive, costing between $100,000 and $200,000, which makes it difficult for search and rescue teams to afford.

Figure 1.1: PackBot EOD 510 [9]

1.3.2 Urbot MPRS

The Urbot MPRS, or Man-Portable Robotic System has similar capabilities to the PackBot EOD 510. The Urbot MPRS was initially intended to be used to identify IED threats, but is versatile enough to be used for search and rescue operations as well. This rover can also navigate through difficult terrain (Figure 1.2). The Urbot MPRS is also remote controlled with a camera attached and has headlights for better visibility. This rover operates both upside-down and right side up, which is a great advantage, especially when the rover is used in collapsed structures and needs to navigate through difficult terrain. The Urbot MPRS has a slower speed of 1.7 miles per hour, which is slower than the average speed of a walking person. This can be a problem because it is important that the rover be able to get to any potential survivors quickly enough for the use of the rover to be more efficient. The Urbot MPRS weighs 65 pounds, so the rover is light enough for one person to carry it and portable. The battery life of this rover is 2-3 hours per charge, so the rover can be deployed, complete a search and rescue mission, and then return all on one charge. The Urbot MPRS costs $70,000, again, this expensive price makes it difficult for many search and rescue teams to afford these reconnaissance vehicles to increase the efficiency of their search and rescue operations [10].

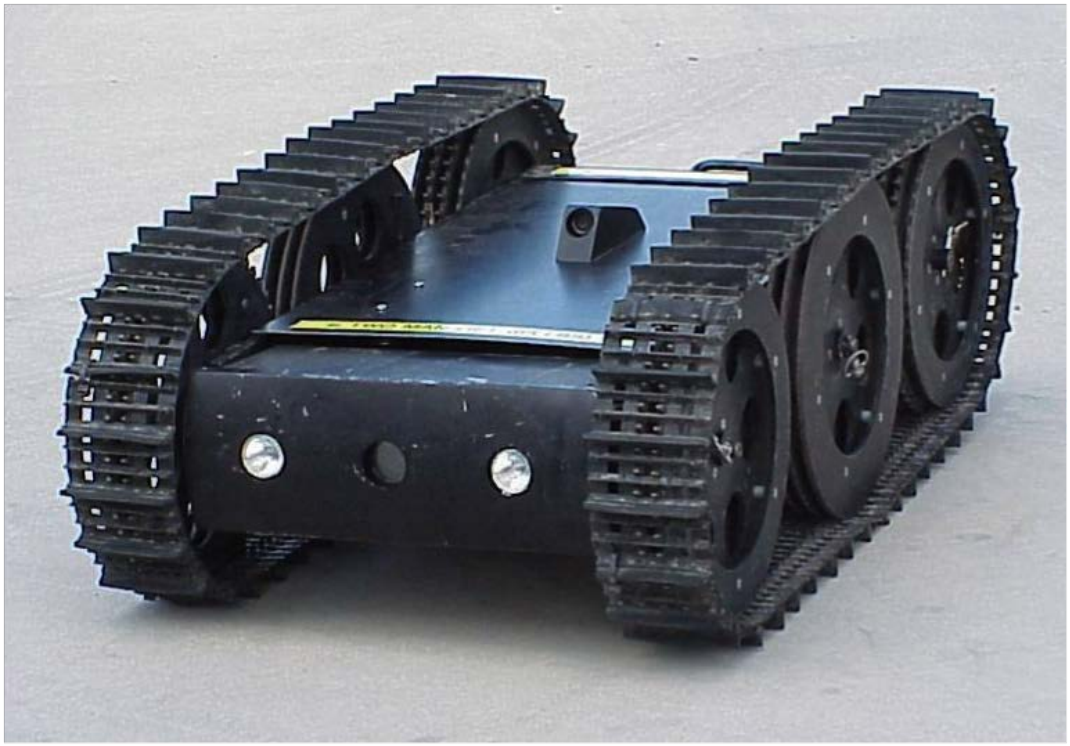

Figure 1.2: Urbot MPRS (Man-Portable Robotic System) [11]

1.3.3 Foster-Miller Talon

The Foster-Miller Talon is marketed as a “durable, quick, and easy to use” rover [12] (Figure 1.3). This rover is versatile and can operate in “all terrain conditions” [12]. This rover has the capability to carry up to 45 kilograms, drag up to 77.11 kilograms, and tow up to 340 kilograms [12]. This is unique to this rover because the previously mentioned rovers, the PackBot and Urbot do not have that capability. The Talon has a top speed of 4 miles per hour. The Talon weighs 85 pounds. This heavier weight is due to the extra features this rover has, including a robotic arm; which can lift up to 9 kilograms; and 7 cameras for impeccable visibility. The Talon has a battery life of up to 4 hours per charge, so a full search and rescue mission can be completed with each charge. The Talon pricing starts at over $60,000, too expensive for many search and rescue teams to afford.

Figure 1.3: Foster-Miller Talon [13]

1.3.4 Foster-Miller Solem

The primary use for the Foster-Miller Solem is search and recovery. The secondary desired use for the Solem is to clear paths for rescue crewmembers to get to victims [14] (Figure 1.4). The Solem has a speed of only 1.1 miles per hour, which is about a mile per hour slower than the average walking person, which is a target speed for search and rescue vehicles. The Solem only weighs 33 pounds; its lightweight is due to the simple design it utilizes. The battery life of the Solem is only 1 hour per charge, which is about an hour too short, likely making it difficult to complete a full search and rescue operation per charge. The Foster-Miller Solem costs up to $60,000, which is too expensive for most search and rescue teams to afford.

Figure 1.4: Foster-Miller Solem [15]

1.3.5 Benchmarking Results

There are many search and rescue unmanned vehicles already on the market. Four examples of unmanned vehicles similar to SAFER already on the market include, the PackBot EOD 510 (Figure 1.1), the Urbot MPRS (Man-Portable Robotic System) (Figure 1.2), the Foster-Miller Solem (Figure 1.3), and the Foster-Miller Talon (Figure 1.4). All four of these rovers are all relatively small, remote controlled, unmanned vehicles that navigate through difficult terrain on two sets of tracks. Table 2.1 provides a breakdown comparison of all the specifications for each of the four rovers. There are many similarities because these four rovers are all used in search and rescue operations. The PackBot was used during 9/11 to search for survivors, and the Urbot, Solem, and Talon are all used by the military. For that reason, the Urbot, Solem, and Talon all use military grade batteries that allow for significant mission duration, between 1 and 4 hours. Table 1.1 displays major specifications for these rovers with the most important target specifications highlighted in green.

Table 1.1: Benchmarking Results

Specification	PackBot EOD 510	Urbot MPRS	Solem	Talon
Manufacturer	iRobot	Military Funded	Foster-Miller	Foster-Miller
Height (in)	7	13	8	11
Length (in)	27-35	34	20	34
Width (in)	16-20.5	21	14.5	22.5
Weight (lbs)	24	65	33	85
Speed (max) (mph)	5.8	1.7	1.12	4
Angle of Climb (^{0})	60			Stairs:43 Side Slopes: 45
Price ($US)	100K-200K	70K	60K	min: 60K
Maintenance Cost ($US)		1500 (for batteries)		
Power Source	BB-2590/U Lithium Ion Rechargeable Batteries (x2)	Nickel Metal Hydride Military Batteries	Nickel Metal Hydride Military Batteries(x4)	Lithium Ion Batteries
Battery Life (hrs)	4	2	1	4
Communication	Digital Radio (2.4-4.9 GHz)	Wireless Ethernet	Fiber optic, cable, &/or RF	RF
Software	iRobot Aware 2			
Ease of Use	Yes, game-like controller	Yes, game-like controller; minimal training	Yes	Yes
Portable?	Yes, 1 person can deploy easily	Yes, but heavy	Yes	Yes
Navigate Tough Terrain?	Yes	Yes	Yes	Yes
Remote Controlled?	Yes	Yes	Yes, but safety tether	Yes
Real-Time?	Yes	Yes	Yes	Yes
Sensors?	Optional	Optional	Optional	Optional

The most important features of all four of these rovers are the lengthy mission duration, the weight, wireless and remote controlled, the ability to navigate through uneven and unstable terrain, and the real-time camera feedback. It is important for a search and rescue rover to have a lengthy mission duration, or long battery life per charge, because it would be counterproductive if a battery charge did not last long enough to complete a search and rescue mission. If the batteries died while the rover was still in the building, it would be a waste of time and energy to go in and retrieve it, especially when there are survivors still in danger. Additionally, the rovers are not very light; they weigh between 24 and 85 pounds. It would be difficult for one person to carry one of the larger rovers alone. The weight of the rover is important to consider because the heavier it becomes, the less portable the rover is. Also, the heavier it is, the more current and torque it takes to power and move the rover, which takes more from the batteries, leading to a shorter mission duration. Wireless and remote control capabilities are essential as well, because this allows for the members of the search and rescue teams to stay out of harm's way for as long as possible until they locate survivors. Rather than search and rescue team members needing to risk their safety looking for survivors, sending in the rover, controlled by a team member, will save lives. Because SAFER will likely be used in urban search and rescue operations, it will be important for the rover to be able to navigate over rubble and collapsed building. As seen with the market research, it seems tracks are the most effective and stable for this application because the tracks allow for increased traction as opposed to wheels. Finally, a live-feed camera is necessary for the rover to be effective in helping search and rescue team members. All four of the rovers already on the market have live-feed cameras so the operator can see what is happening on site immediately.

1.4 Project Statement of Goals and Objectives

The basis for this project is an existing remote-controlled rover that has been inherited from the Robotics Systems Lab at Santa Clara University. In previous years, other senior design groups at Santa Clara University have worked on this rover, which originated as a design project in 1999. Since that time it has been noted that, with each iteration of the design, the rover fell out of function once the design group responsible graduated and left the university; as we received it, the base rover was in a non-functioning state. Therefore the first objective for this project was to restore basic function to the rover such that it can be powered on, controlled remotely, and run continuously without overheating or mechanical failure. Most importantly, we must ensure that the rover is in a condition in June of 2016 that will allow its continued function and future improvements after our departure. This will include creating a user manual to be left behind with SAFER, so future teams can quickly pick up how SAFER works and improve upon our design. If this goal can be achieved, we can consider our project a moral success, but additional functionality is necessary to extend the rover's use into search and rescue.

Beyond basic mobility, the next goals for the project center on navigation. The rover will be operated remotely, mainly within collapsed buildings and tunnels where it is not immediately visible to the operator. Therefore a camera system is necessary not only to judge where the rover is going and what surrounds it, but also to identify victims within the structure or assess the stability of the structure itself. A main camera situated on the top of the rover's chassis with 360-degree rotation capability is used to stream live video feed back to a remote device, such as a phone or tablet at the temporary command center where the operator can remain a safe distance away from the structure. Along with the camera, headlights are necessary for the operator to have strong visibility, even when the rover is in dark places.

Additional functionality goals, which are secondary to mobility and navigation, included an infrared camera, a robotic arm attachment, and dispensable signal beacons. An infrared camera would allow for enhanced visibility in dark areas and assist in identifying victims or even hotspots potentially present in the rubble of a building. Combined with a three-degree-of-freedom robotic arm to hold this camera, vision could be provided around corners or through smaller areas where neither the rover nor a human being could fit. When a victim is located, a signal beacon will be dropped from the rover. This beacon will give off a glow or flashing light and make a loud sound, all in order to assist the follow-up rescue team to navigate to the appropriate location in a more efficient manner. These goals were set to enhance the rover's functionality in search and rescue operations, but due to time and budget constraints, only the signal beacon dispenser system was implemented.

As an end goal, the team was hoping to be able to test the finished rover at NASA's Ames research center where there is a facility designed for testing rovers such as this one in a simulated collapse environment, which would have allowed for a more accurate gauge of the success of the rover. Again, due to time limitations, this goal was not achieved as the rover was not deemed ready for that level of intense testing.

Chapter 2: System Overview

2.1 System Requirements and Customer Needs

We conducted market research to learn more about rovers similar to SAFER. These results included the Packbot (Figure 1.1), the Urbot MPRS (Man-Portable Robotic System) (Figure 1.2), the Talon (Figure 1.3), and the Solem (Figure 1.4). The benchmarking results combined with an interview with Lane Woolery, a Battalion Chief with the San Diego Fire Department, and the specifications from the *Roverwerx 2012* project and we were able to collect a solid start to what potential customers are looking for. Ease of use is one of the most important aspects of SAFER. For the Packbot, Urbot, Solem, and Talon, ease of use was mentioned when describing all of them. Lane Woolery, from the San Diego Fire Department, said that the rover would need to assist any personnel present by effectively reducing risk from the mission without slowing it down [16]. Therefore, SAFER must be as simple to operate and use as possible. If the rover is too difficult to operate, then search and rescue members will waste time trying to operate the vehicle, rather than using it to help them find and rescue more survivors. The rover also needs to navigate through difficult and uneven terrain. Again, from the market research, all four of the rovers can easily navigate through difficult terrain so they can be of assistance in collapsed structures and will not get stuck. From the photos Lane Woolery sent (Figures 2.1, 2.2, and 2.3), it is clear that the rover would need to navigate over and through crumbled concrete. Battery life is another important aspect to consider. The battery needs to last long enough go into a collapsed structure, look for and find survivors, and then come back to the operator. It would be extremely inconvenient if SAFER died when it was still in the collapsed structure, because it will not be a light rover, so it would be difficult to carry out. We aim to keep the weight of the rover as low as possible, however, the bare bones of the rover with no extra components (i.e. motors, batteries, electronics, controllers, etc.) is 76 pounds, so keeping SAFER at a weight that is competitive with the other rovers already on the market would be difficult and not likely. Finally, we aim to keep the cost of SAFER well below that of the other four rovers researched to make the rover more affordable to more search and rescue teams. Table 2.1 displays the main specifications and requirements we will be focusing on based on our market research, interview, Project Design Specifications (PDS), and team preference.

Figure 2.1: Search and rescue team members are searching through rubble from a collapsed building to find potential survivors [16].

Figure 2.2: The aftermath of a collapsed structure; search and rescue teams getting ready to go in to search for survivors [16].

Figure 2.3: Search and rescue team members begin to enter the unstable structure to find survivors [16].

Table 2.1: Customer Needs

Primary Goals	Battery Life (hrs)	2
	Weight (lbs)	100-150
	Size (in)	30x24x16
	Ease of Use	Yes, game controller
	Wireless	Yes, Xbee
	Navigate Tough Terrain	Yes, tracks
	Camera	Main; Live feed
Secondary Goals	Speed (ft/s)	3
	Infrared Camera	Yes
	Robotic Arm	Yes, 3 DOF
	Price ($)	3000
	Headlights	Yes
Tertiary Goals	Water Tolerant	Yes, entire rover
	Roll Cage	Yes
	Signal Beacons	Yes
	Flip back over	Yes

2.2 System Sketch

Figure 2.4 illustrates an anticipated scene for the use of SAFER. At the right side of the figure is a collapsed concrete structure with an opening for the rover (top-center) to enter. At the bottom of the figure is a temporary “command center” from which members of the rescue team can tele-operate the rover. A controller device is attached to a laptop to input commands to the rover, and the laptop both sends these control signals to the rover and receives video feed from the rover. Other potential cameras and sensors can also transmit data to the command laptop for monitoring.

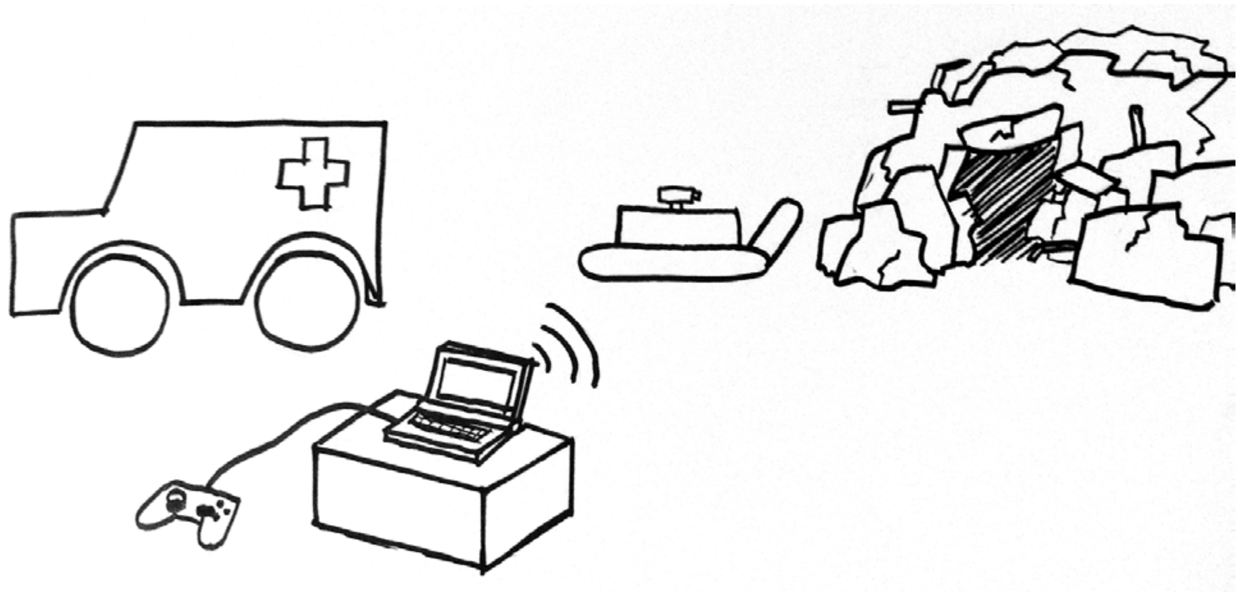

Figure 2.4: Cartoon sketch of rover and command center at a disaster site. Not to scale.

2.3 System-Wide Component Block Diagram

Figure 2.5 is a functional diagram showing the connective relationships between the rover’s main subsystems. In the top right of the figure, the operator interfaces with both the remote control and the laptop. The controller sends signals to the camera and the DC motor controller, causing the camera to rotate as well as the main motors to turn the ground tracks, and the actuating arm motor to adjust the angle of the arm tracks. The motors, DC controller, and the batteries that provide power to them all reside within the chassis of the rover, while the tracks and camera remain external to facilitate mobility and provide vision of the rover’s surroundings respectively.

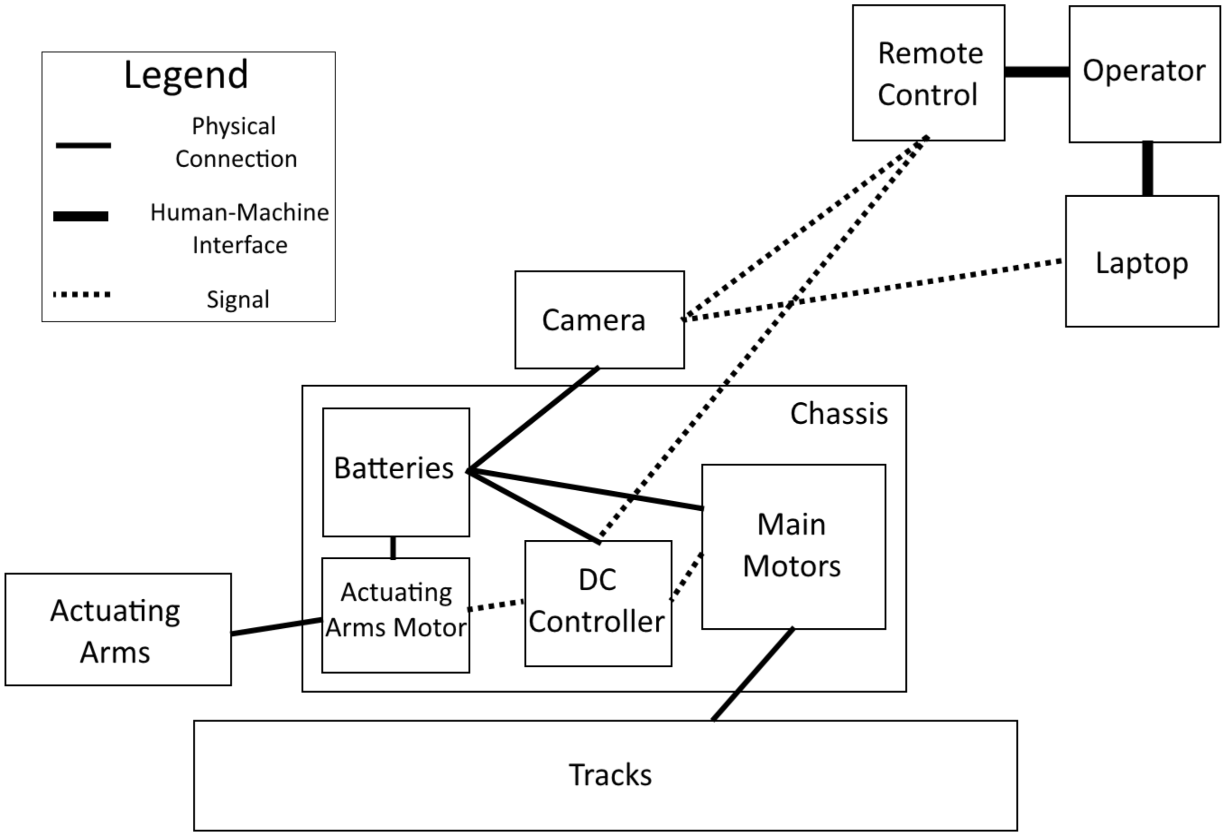

Figure 2.5: Functional diagram of the rover's main subsystems. Not to scale.

2.4 Functional Analysis

There are many implemented functions for this robot in order for it to operate at our desired performance. A series of mechatronic-based aspects within SAFER's control system has been selected in order to achieve the specific goals of each part.

Two AmpFlow E30-400 DC Motors operate the main tracks of the robot. These motors surpass our desired specifications for operation. For the rover's continuous tracks, it is important to select DC motors that can produce enough power in order to sufficiently transfer enough power to drive the tracks safely and effectively. Therefore, these specific motors, at a torque of 93.75 lb-in and 2.1 horsepower are ideal. However, there is one major problem that needs to be monitored. The stall current for these motors is 63 Amps. This high stall current could cause overheating and potentially even permanent damage to batteries or wires that are not intended to supply such a high current. To avoid any possibilities of electrical failures, we turn to the DC motor controller.

In order to control these motors, we are using a AX2550 DC motor controller, which has a current limiter to prevent this stall current from being reached. Additionally, this motor controller is useful for gathering information such as feedback voltage, efficiency, encoder position analysis, etc. All of this information can be analyzed through the Arduino programming software.

In order to communicate with the DC motor controller and operate the motors, along with everything else, an Arduino Mega microprocessor is used. This type of microprocessor is necessary for this rover because of the many implemented electrical components require enough analog and digital pins to operate and to transfer data. The Arduino Mega has 53 digital pins and 16 analog pins, which are enough to include all of SAFER's devices. With the specific libraries for this DC motor controller implemented into the code, these motors are controlled and analyzed for its feedback data.

Additionally, this microprocessor controls a high-torque stepper motor installed on the front of the rover, which controls the angle of the climbing tracks. A stepper motor was chosen for this application due to its precise angle adjustment system.

All of these mechatronic applications are linked back to a computer, which displays windows for the data from the motors. In order to remotely operate all systems, a FlySky FS-i6 with 2.4 GHz receiver remote controller was used because it has enough buttons and joystick movement in order to precisely control all of SAFER's systems. The right joystick, which is spring loaded, controls the driving directions of the rover as a whole. The left joystick is not spring loaded and controls the angle of the climbing tracks. The fact that the left joystick is not spring loaded is an advantage because it allows for a more precise control of the climbing tracks angle, as the angle of the joystick corresponds to the angle of the tracks themselves. This will allow the user to be able to familiarize him or herself with this controller in order to operate SAFER with precision and comfortability.

Chapter 3: Subsystems

There are several subsystems that needed to be taken into consideration for the building of this rover. Once the "big picture" was established of what SAFER needed to accomplish, the focus was shifted to the details of how each of those aspects will come to fruition.

3.1 Chassis

The chassis is simply defined as the compartment that houses all the internal electronics. It sets the framework for what the rover will become. There are two main concerns that must be taken into consideration when designing the chassis: the space required by the internal parts and the amount of protection they require.

Since the rover needs to be portable as possible, it is imperative that the design of the chassis must be wary of that. At the same time, the trade-off is that there must be enough room inside to house all the electronics needed for each subsystem. Additionally, the chassis must not be too heavy, or else it will start affecting other subsystems in a negative way.

3.2 Drive System

The drive system is a broad subsystem, and consists of several smaller subsystems, namely the tracks, the drive train, the drive arms, and the motors. Because this is such a large subsystem, it is broken into smaller subsystems to explain the entirety. Figure 3.1 shows the connections from the batteries, to the motors, to the gearboxes, to the tracks on the rover.

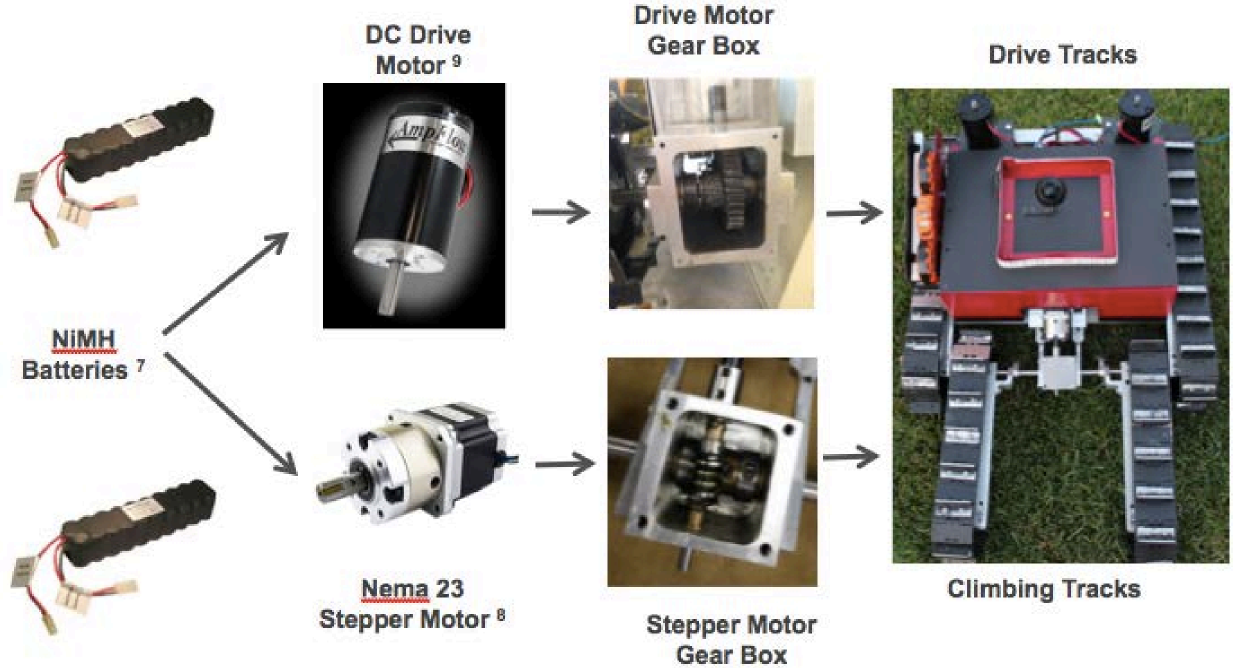

Figure 3.1: This is a visual aid to show the connection between each of the components in the drive system.

3.2.1 Drive Tracks

For the purposes of the SAFER project, the tracks will refer to the way the rover interfaces with the terrain. This subsystem could take the form of wheels or legs, but because much of the mechanical system was already constructed by previous design teams and the decision to use tracks fits with SAFER's purpose, so the original design was retained. Additionally, the original tread design greatly simplifies the motor system, which is discussed in subsequent sections.

3.2.2 Drive Train

The drive train refers to the system used to transfer mechanical power from the motors to the tracks. Interestingly enough, the tread design mentioned above is also a part of this subsystem. The motors are used to turn a worm drive system in the gearbox that both increases the torque ratio and turns the vertically oriented rotation of the motors into a horizontally oriented rotation that drives the rear axles. When those rear wheels turn, the rotational energy is transferred to the front axle through the tracks. This part of the system must be reliable and easily repaired, as this will be among the most stressed parts of the mechanical design.

3.2.3 Climbing Tracks

The drive arms are the two arms attached to the front axle that can be angled upwards or downwards. The tracks on the drive arms are driven by the main drive train, but the angle of the arms, which ranges from +90° to -90°, are controlled by a stepper motor mounted on the front of the rover that turns a shared axle between the two arms. This system is what allows the rover to climb up hills and steps. The main requirement of this system is the ability to support the weight of the rover when it is being used to climb up or down obstacles. This includes being powered by a motor strong enough to provide the torque necessary to lift the front end of the rover, and being made of a material strong enough to support that weight. Issues with this design are discussed in sections 4.1, 4.2.8, 4.2.9, and 5.1.

3.2.4 Motors

The motors are the electrically powered components that convert the electrical energy into rotational mechanical energy. Based on early calculations it was determined that the output torque after the gearbox needed to be about 25 lb-in, and the operating power would need to be approximately 1 HP at the upper limit of expected operation. In addition, a DC motor was considered ideal since it is relatively simple to install and easily provides the power necessary to drive a rover of this weight.

The team purchased a total of three motors for the SAFER project, two (Figure 3.2) AmpFlow E30-400 DC motors, and one (Figure 3.3) NEMA 23 Stepper Motor with a 4:1 planetary gearbox from StepperOnline. The two DC motors are used to power the left and right sides of the drive system, and the stepper motor is used to adjust the angle of the climbing tracks.

Figure 3.2: AmpFlow E30-400 DC Motor [17]

Figure 3.3: NEMA 23 Stepper Motor with 4:1 Planetary Gearbox [18]

The AmpFlow motors can each provide 93 in-lb of torque, which is plenty more than the 25 in-lb we calculated. The spreadsheets for both the AmpFlow and stepper motors can be found in Appendix A10.

3.4 Electronics

The final subsystem is the electronic components that power the mechanical systems. Like the drive system, this is a large subsystem that consists of further relevant subsystems, namely the camera, the batteries, the control system, and the data transmission system.

3.4.1 Camera

SAFER has been equipped with a top-mounted 360° camera that will provide a live video feed to the operator. This will allow the operator to pilot the rover without a direct line of sight to it. Figure 3.4 is an image of the camera mounted on the rover and Figure 3.5 is what the view from the camera looks like. The operator can manipulate this view by scrolling on the screen of the mobile device to focus on certain angles in the entire view, like in Figure 3.6. A significant design constraint for the camera is the range of the Wi-Fi signal the camera comes equipped with. The range is marketed as a 200-foot distance, however, when we tested this, the image quality decreases as the distance between the rover and the operator approaches 200 feet. Additionally, the 200-foot range is unobstructed, if there is a building or wall in between the rover and the operator, the image quality is also compromised. Obviously, this is an issue for SAFER, especially considering high image quality is necessary for the operator to accurately assess the potentially dangerous area and search for survivors all from a safe distance away. Our initial thought to remedy this issue was to utilize a signal booster to enhance the signal from the camera, unfortunately, this is not possible with the signal the 360Fly uses. While the strength of the signal became an issue with the camera, it also has many positives. SAFER runs on tracks that cause a significant amount of vibrations and movement when operating, because of all the vibrations, we were worried the video feed from the 360Fly would be difficult to make out with all the shaking. Initially, we thought we might need to design and implement a damping system to stabilize the feed. Fortunately, the 360Fly has an internal system that damps and stabilizes the live feed. This was a hugely positive aspect to the camera because it kept the live video feed stable and easy to see. The camera sends the live video feed as well as any recorded data to a mobile device such as an iPad or iPhone. It can connect simply by downloading the 360Fly App and hooking up to the camera's Wi-Fi signal. This is another great feature of the 360Fly because it allows the operation to be portable, this way the operator does not have to be stuck in one position hooked up to a laptop, the mobile device and RC controller can easily be taken wherever the operator needs to be. The simplicity of the available App keeps SAFER easy to use and works to increase the efficiency of search and rescue operations.

Figure 3.4: 360Fly Camera mounted on top of the chassis on SAFER.

Figure 3.5: 360-degree view from the 360Fly camera mounted on SAFER.

Figure 3.6: View from the 360Fly camera on SAFER to focus on the ground in front of SAFER.

3.4.2 Batteries

The batteries are what provide the electrical power for SAFER. There was much debate within the team regarding what kind of batteries to use, as there were many design constraints that clashed with each other. First, the most important design constraint was energy density, which needed to be high enough to power the rover for at least two hours. Secondary constraints were the weight of the batteries and the cost. Through preliminary calculations, it was estimated that the batteries would need to have a capacity of about 20 Ah at 24 V.

The final decision was to buy two 24V NiMH Battery Packs from AA Portable Power Corp. Figure 3.7 shows the batteries mounted in the chassis of the rover. NiMH batteries have a high energy density nearing that of lithium ion batteries, but are much safer to use and are also less expensive. The battery packs have a capacity of 10 Ah with a maximum discharge rate of 30A, and they each weigh 8 lbs.

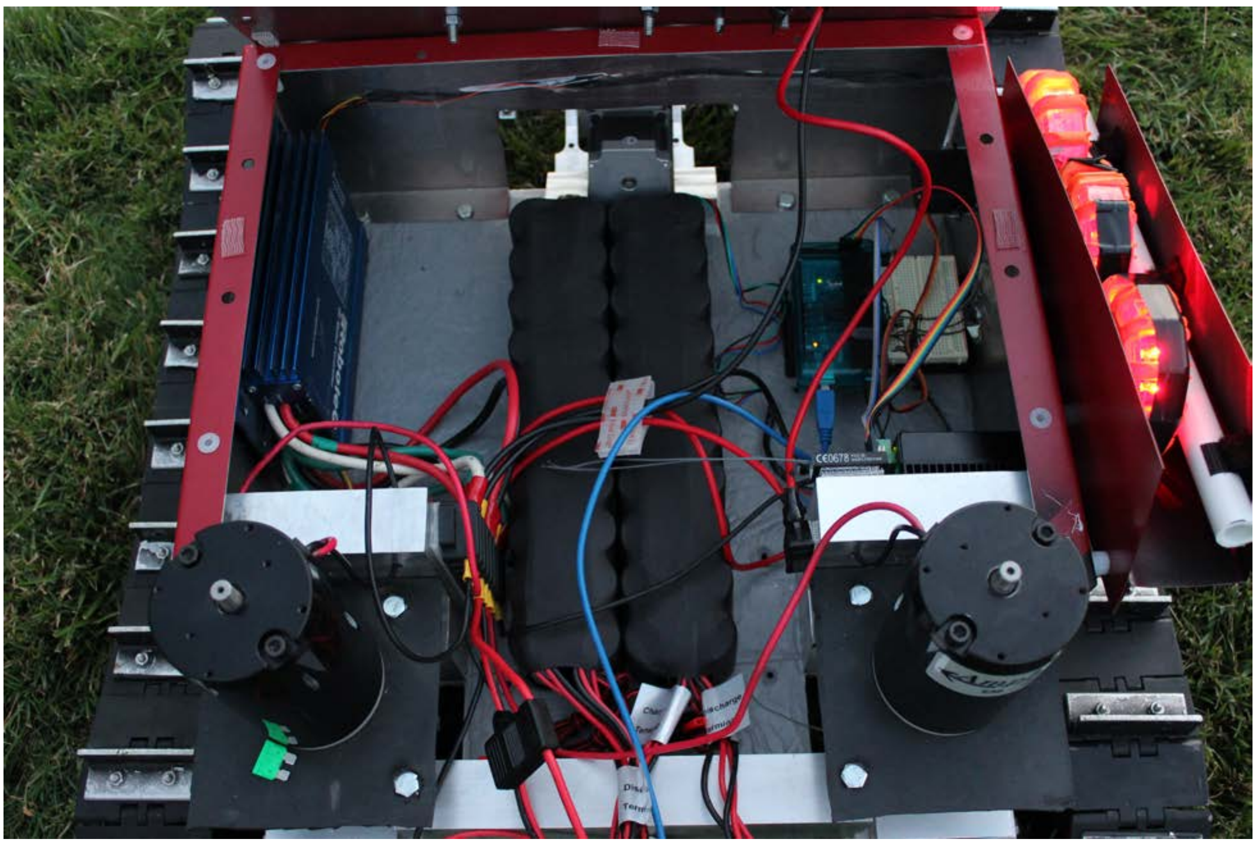

Figure 3.7: The two NiMH battery packs are in the center of the chassis.

3.4.3 Control System

The control system refers to the components that control the way the rover behaves. This includes the DC motor controller, the microprocessor, and the physical controller that the operator(s) will be using. At the recommendation of secondary advisor Dr. Kitts, the original motor controller (RoboteQ AX2550) was retained. He explained that it is a quality controller that has many safety features and provides a quality interface between the microprocessor and the motors. The microprocessor serves as the interface between the user and the motor controller.

The main concern was it needed to be small and easy to program, as this team did not have any computer engineers in the group. We decided to go with the Arduino Mega, as it satisfies both of those requirements and one of our team members is already familiar with its workings.

3.4.4 Data Transmission System

The data transmission system is the means by which the user will wirelessly send commands to the rover. The transmission system requires a long range and must be operational in disaster situations. Initially Wi-Fi was considered, but after some research it was determined that Wi-Fi would not work for disaster situations. Radio was determined to be the best data transmission medium, more specifically the XBee family of products, as radio does not require any outside equipment to reliably communicate, and it theoretically has sufficient range for the purposes of operating SAFER from a range of no more than half a mile in collapsed structures.

3.4.5 Signal Beacon Dispenser System

SAFER employs the use of three flashing beacons that can be dropped in the event it encounters a trapped survivor. The system uses three emergency beacons with variable flashing patterns combined with a slanted dispensing track with a servo-controlled gate at the end of the track. One beacon can be dropped at a time off the side of the rover to indicate to the search and rescue team members the locations of survivors. Figures 3.8, 3.9, and 3.10 are images of the beacons and the dispenser.

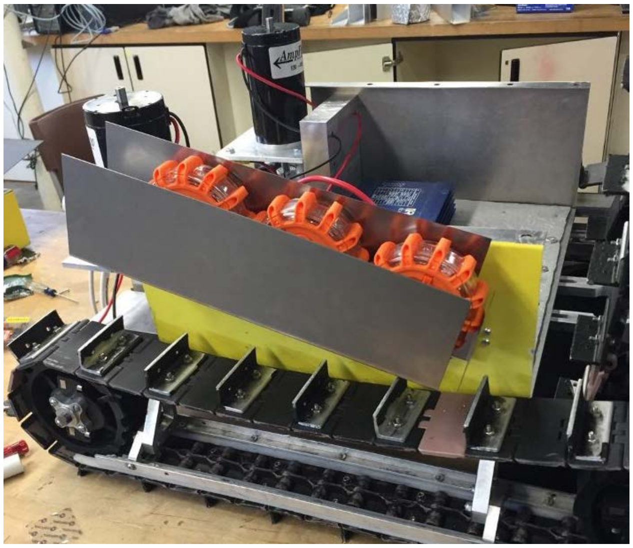

Figure 3.8: Side view of the beacon dispenser on the rover. The three beacons flash red lights when turned on to alert search and rescue members to the victims' locations.

Figure 3.9: Beacons loaded up in the dispenser. The PVC pipe supports the beacons so they can exit the dispenser smoothly and consistently.

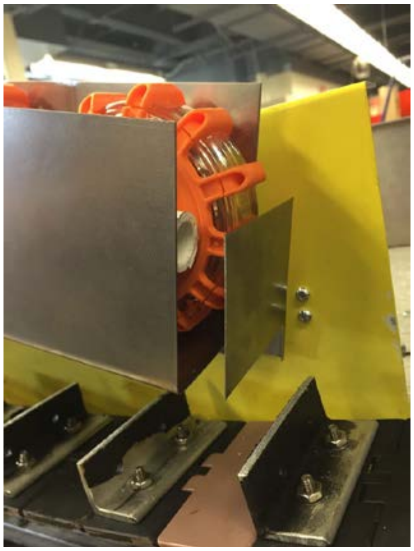

Figure 3.10: A servomotor controls the beacon dispenser door. When the operator wants to dispense a beacon, the servomotor flips the door down and back up again to prevent more than one beacon from being dispensed at once.

Chapter 4: System Integration, Tests, and Results

4.1 System Integration

SAFER consists of three overarching systems and subsystems within those two groups. The mechanical system consists of the drive tracks, the two drive motors, and stepper motor, the climbing tracks, the two NiMH batteries, and the chassis housing. The control system consists of the motor controller, the Arduino Mega coding platform, the RC controller, and in part the batteries as well, as they power the entire rover. The last system is the sensor system, which consists of the 360Fly camera and the mobile device to go along with that and the signal beacons.

The mechanical subsystems are all integrated in a fairly straightforward manner. The two 24V NiMH batteries power the three motors on SAFER. The two 24V DC motors are the main drive motors and run the tracks, both the main drive tracks as well as the climbing tracks. The NEMA 23 stepper motor also gets power from the batteries and they (theoretically) control the angle of the climbing tracks. The chassis houses all the components for the rover, including the batteries, the NEMA 23 stepper motor, as well as the control system components.

The control subsystems begin with the communication between the Arduino Mega and the motor controller. The motor controller controls the two main drive motors and there is a separate controller for the NEMA 23, both of which use Arduino to communicate. Next, the RC controller communicates with the motor controllers so the user can simply move SAFER in a user-friendly manner.

Lastly, the sensor subsystems are integrated into the entire rover. The 360Fly camera is mounted on top of the chassis for the best visual coverage of SAFER's surroundings. The 360Fly camera has its own rechargeable battery and wireless signal, so aside from being mounted on the chassis, it is not integrated into either of the other systems. The signal beacons are dispensed from the side of the rover and a servomotor controls their release. The servomotor overlaps into the control system because it is power by the NiMH batteries and is also controlled with the Arduino Mega.

Overall, all the subsystems on SAFER integrate smoothly and seamlessly to produce a functioning rover with capabilities to serve as a reconnaissance tool to aid search and rescue teams.

4.2 Tests and Results

Table 4.1 is the experimental protocol that we followed to test and verify that we met the desired values for each of the categories below that were all determined in our customer needs list and project design specifications.

Table 4.1: Experimental Protocol

Evaluation	Location/ Time	Equipment	Accuracy	Trials	Expected Outcome	Assumptions	Man-Hours
Top Speed	Engineering Quad, 5/5 1pm	Stopwatch, Tape Measure	0.25 ft/s	5	2 ft/s	Level Ground, Fully Charged Batteries, speed=distance/time	2
Battery Life	Engineering Quad, 5/5,5/7,5/8 2pm	Stopwatch	1 min	3	1.5 hours	Batteries Fully Charged to Begin, Level Ground, Constant Load	8
RC Controller Range	Engineering Quad, 5/6 1pm	Tape Measure	1 ft	2	500 ft	Some Obstructions	3
Camera Range	Engineering Quad, 5/6 1pm	Mobile Device, Tape Measure	1 ft	3	200 ft	No Obstructions	3
Weight	Machine Shop, 5/2 3pm	Scale	1 lb	5	125 lb	Full Rover, All Components Installed	2
Size	Machine Shop, 5/2 3pm	Tape Measure	1 in	2	24"x20"x16"	Climbing Tracks in Upright Position	1
Ground Clearance	Machine Shop, 5/2 3pm	Tape Measure	1 in	2	2 in	Rover on Level Ground, All Components Installed, Constant Load	1
Approach Angle	Engineering Quad, 5/16 1pm	Bench, Protractor	5 deg	2	90 degrees	Assume Bench is Perpendicular to Ground	1
Descent Angle	Engineering Quad, 5/16 1pm	Bench, Protractor	5 deg	2	90 degrees	Assume Bench is Perpendicular to Ground	1

4.2.1 Top Speed

To measure top speed, a set distance will be marked out on an even surface. One team member will pilot the rover at it's top speed through that distance (ensuring it has enough time to accelerate before reaching the starting line) while another will use a stopwatch to time how long the rover takes to move from the start line to the finish line. That set distance will be divided by the time to calculate the velocity of the rover for 5 trials.

Table 4.2 shows the results of all five trials completed to measure the top speed of the rover. To get these results, we timed the rover going over a distance of 6 feet once it hit its top speed, meaning we did not begin timing right as the rover began to move. The speed was then calculated from the times by dividing each measurement by 6 feet. The average top speed of the rover is 2.84 feet per second, which is in the target top speed of 2 to 3 feet per second.

Table 4.2: Top Speed Results

Trial	Time (sec)	Speed (ft/s)
1	2.23	2.69
2	2.26	2.65
3	2.17	2.76
4	2.11	2.84
5	2.28	2.63
Average Speed		2.72

4.2.2 Battery Life

Battery life will be measured by one team member while another is driving the rover on level ground for as long as possible until it becomes immobile. That exercise will be timed 3 times.

Table 4.3 shows the results for the three trials done to test the battery life. The average battery life was 115 minutes, which is about 1.92 hours. However, we realized that this test is not entirely accurate, as the length of the battery life would vary depending on what purposes the operator was using SAFER for. For example, if the rover was running on top speed the entire duration of the test, the batteries would likely not last more than about 1-1.5 hours. However, if the rover remained idle for long periods of time, then the batteries would likely last longer than the average, likely closer to 2.5-3 hours. During the testing, we found it difficult to operate the rover at a constant speed, we did not run the rover at top speed for the entirety of the tests, rather varied the speed. Additionally, during the testing, we occasionally stopped the rover to check to make sure nothing was overheating, as these tests were the first time we ran the rover for such long periods and wanted to ensure everything was operating correctly and safely. Therefore, it can be concluded that the battery life of SAFER falls between 1 and 3 hours and varies based on the speed as which SAFER is operated at, as well as how consistently the SAFER is being driven.

Table 4.3: Battery Life Results

Trial	Time (min)
1	130
2	116
3	100
Average Time	115

4.2.3 RC Controller Range

One team member driving the rover as far away as possible will measure the wireless range of the remote controller. Another team member will measure the distance that the rover is able to travel with a tape measure. This test will be performed 2 times.

Table 4.4 shows the results of the two distance tests we did to see how far the connection between the rover and the RC controller would reach. Again, this table is a bit misleading because there is such a large difference between the two tests. The differences are because for the first test, there were not any buildings in the way, the rover was by the SCU Library, and the operator walked away towards Palm Drive and eventually was standing near Franklin Street on the other side of campus. This distance according to the SCU Campus Map and Google Maps is about 0.2 miles, which is 1056 feet [19]. That was a very impressive distance, more than double what we were expecting to achieve. For the second test, we wanted to see if the RC controller would still connect if there were a larger obstruction, like a building, between the controlled and the rover. While the rover was still at the SCU Library, the operator walked into the Engineering Quad. The operator was still able to control and move the rover, however, with a larger obstruction, the connection was spotty and not as reliable as an unobstructed test. It can be concluded that with relatively minor obstructions, such as trees, the RC controller will still connect with and control the rover from a distance of 1056 feet, or 0.2 miles. However, when there is a larger obstruction, the connection is not nearly as reliable, so a safe distance is about 350 feet.

Table 4.4: RC Controller Range Results

Trial	**Distance (ft)**
1	1056
2	350
Average	703

4.2.4 Camera Range

The range of the 360Fly camera signal will be measured by one team member driving the rover as far away as possible and another team member monitoring the iPad or iPhone live feed. This test will be conducted assuming there are no major obstructions between the rover and the team member with the mobile device. This test will be conducted 3 times.

Table 4.5 shows the results of the three trials conducted to test the range of the 360Fly camera. Similar to the results of the RC controller tests, the camera tests are a bit misleading. The first two trials were done with zero obstructions between the camera and the operator. Under these simple conditions, the range is 205.5 feet. However, if any obstruction, such as a wall is introduced, the quality of the camera feed decreases dramatically almost immediately, and after 15 feet, the connection is lost.

Table 4.5: Camera Range Results

Trial	Distance (ft)
1	203
2	208
3	15
Average	142

4.2.5 Weight

Weight will be measured using the large scale in the machine shop. The rover must be fully assembled with all components mounted in their final positions.

Table 4.6 shows the results of the 5 trials conducted to measure the total weight of the rover. The average weight of the rover is 118.2 pounds, which is well under the target weight of less than 150 pounds. The actual weight is also under the expected weight of 125 pounds. This is a huge accomplishment because the staring weight of the rover with no additional components was 74 pounds, and we assumed maintaining a low weight would be difficult and was always a consideration when selecting motors, batteries, and other parts for the rover.

Table 4.6: Total Weight Measurements Results

Trial	Weight (lb)
1	118
2	119
3	117
4	118
5	119
Average	118.2

4.2.6 Size

Two team members will each use a tape measure to measure all outside dimensions of the rover. For length, tracks will be in the upright position, but height will assume climbing tracks are not upright. The rover must be fully assembled with all components mounted in their final positions.

Table 4.7 shows the results for the size of the rover. It was not expected that the size would change very significantly from the beginning of the year because we did not modify the overall size of the rover; we kept the basic skeleton of the rover. So, the average size of SAFER is 24”x19.5”x15.5.”

Table 4.7: Total Size Measurements Results

Trial	Length (in)	Width (in)	Height (in)
1	24	20	16
2	24	19	15
Average	24	19.5	15.5

4.2.7 Ground Clearance

Two team members will each use a caliper to measure from the ground to the lowest point on the chassis. The rover must be fully assembled with all components mounted in their final positions.

Table 4.8 shows the results of the ground clearance between the bottom of body of the rover and the ground. Again, because we did not modify the height of the rover at all, we did not expect this measurement to be any different from the previous team, *Roverwerx 2012*. The ground clearance between the bottom of the body of SAFER and the ground is 2 inches.

Table 4.8: Ground Clearance Measurements Results

Trial	Height (in)
1	2
2	2
Average	2

4.2.8 Approach Angle

A team member will drive the rover up one of the benches in the Engineering Quad. Assuming the benches are perpendicular to the ground, then the rover will climb a 90-degree angle. This test will be repeated 2 times. If the rover is able to climb the bench, then it can be assumed that the rover can achieve a 90-degree approach angle, however, if the rover cannot climb the bench, then an alternative, less steep, obstacle will need to be used.

Unfortunately, we did not do this testing because we were unable to get the climbing tracks operational. The stepper motor we selected should have had enough power and a high enough holding torque to support the climbing tracks and move them. However, the specifications for this motor were incorrect on the vendor site, so in reality, the stepper motor we selected does not have nearly enough holding torque to move or even support the climbing tracks. Therefore, the approach angle of SAFER is zero degrees because it cannot climb at all.

4.2.9 Descent Angle

A team member will drive the rover off one of the benches in the Engineering Quad at Santa Clara University, assuming the rover passed the above test. If the rover is able to climb down the bench, perpendicular to the ground, then it is safe to assume that the rover can also achieve a 90-degree descent angle. However, if the rover is unable to climb down the bench, then an alternative obstacle will need to be used.

The descent angle of SAFER is also zero degrees for the same reason stated above in section 4.2.9; the stepper motor is incapable of moving and supporting the climbing tracks.

Chapter 5: Team and Project Management

5.1 Project Challenges and Constraints

Over the course of this past year, there were a variety of project challenges and constraints we encountered. In the beginning of the year we had a slower start because there was some difficulty gaining access to the previous group's thesis, *Roverwerx 2012*. Other project challenges included back orders no parts, putting us behind schedule, incorrect specifications from vendors, budget when selecting the new batteries and motors, and other slight modifications that came along with the updated motors and batteries.

When the DC drive motors were first ordered, the vendor informed us week later that there was a back order, obviously this set us behind schedule by a week because we had to re-order the motor from a different vendor. Along with the new motor, meant a modification of the motor mount. The existing motor mounts were too short and had to be raised up an inch to accommodate the motors with a longer shaft. The longer shaft was a constraint and we had to ensure that the modified mount still retained its structural integrity. Along with the high torque motors, we needed to select a battery that could power the rover safely and effectively. Both motors are 24V DC motors, so the battery also had to be 24Vs. This was a difficult constraint to fulfill because high power batteries are quite expensive. We initially went with two 12 Volt DC lead-acid batteries. We could not use these batteries because lead-acid batteries emit a toxic gas when in operation, and they would not produce enough power to support the full rover and all its components [20]. Two 24V nickel-metal hydride batteries were selected instead because they are much safer and do not emit any toxic gases and with each being 24Vs, they provide more power to the rover. The stepper motor selected to control the climbing tracks was labeled with the incorrect specifications on the vendor site. This was a major project challenge we faced because the NEMA 23 stepper motor that we chose did not have a high enough holding torque to move or support the climbing tracks. We discovered this inconsistency in specifications far too late to order a new motor, about 2 weeks before the end of the project. Unfortunately, due to this oversight on we were not able to give SAFER climbing capability, and therefore were not able to complete our baseline design for SAFER to be an all-terrain vehicle and navigate through difficult obstacles and uneven ground.

Additionally, during one of our first longer tests, we had a wire overheat and melt. The wire that was compromised was an 18-gauge wire that was initially used only for testing purposes, all of which were less than one minute in duration. Unfortunately, we forgot to replace this wire with a heavier gauge for the longer tests and the wire got too hot and began to melt. There was no significant damage to any other components in the rover and we replaced all the wiring in the rover with 12-gauge wire to ensure this problem did not occur again. Lastly, when we were working on the rover, somehow the two discharge terminals on one of the batteries touched and ruined the battery. We are still unsure how this happened, both terminals had protective coverings provided by the manufacturer and no one or anything was tugging or pulling on the wiring on the battery to cause the protective covers to remove and the terminals to touch. Unfortunately, we did have to replace this battery, but there was enough of a buffer in the budget and schedule for this not to set us back too far. Overall, we did not face too many challenges or constraints and were able to complete the majority of our baseline design with the exception of the all-terrain aspect of SAFER.

5.2 System Issues

SAFER has many different subsystems, each of which presents its own unique challenges. The subsystem requiring the most research and decision-making was the drive system. Fortunately, the tracks and drive arms were not of concern, because they were already functional, leaving the main decision points as the motor and battery selection as well as possibly modifying the gearbox for better and more efficient torque multiplication.

The torque output was determined to be the most important factor in designing a gearbox. Alternatives to the current design that were examined were a worm gear setup similar to the one that already exists, a spur gear setup, and a helical gear setup for the gearbox. When putting all of the parameters into the decision matrix for gearbox selection (Appendix A3.1, A3.2), the best performing setup was without question the helical gear setup. However, when associating time spent on design and building of the new gearbox setup, it was determined that no new setups would give enough of a performance advantage to justify the amount of time it would add to the project. Therefore, the decision was made to reuse the current gearbox, and simply find a motor that would meet the design requirements instead. One safety concern of the gearbox is the exposed gears as seen in Figure 5.1.

Figure 5.1: The existing gearbox with the exposed gears, posing a safety risk.

If the gear teeth shear during use, it could be shot out of the gearbox, which could be dangerous to any survivors in proximity to the rover. Additionally, if any debris such as small rocks or other harmful objects get inside the gearbox, they could get jammed in the gears and stall the motors or even cause damage to the gears. To solve this, a cover plate on each exposed end of the gearbox was installed. This modification will not only prevent material from being ejected from the gearbox, but will also prevent debris from getting caught in the gears and causing damage during use. Additionally, each gearbox was greased with standard grease to ensure adequate lubrication and smooth operation.

Like the gearbox, the torque output was also determined to be the most important criteria in motor selection, thus kicking off research into the best motor for the constraints of our application (including price). The calculated requirements for the motors assumed an overall weight of roughly 200 lbs where the torque from the motors would be multiplied through the 30:1 gear ratio of the current gearbox. This meant that the torque output of the motor would need to be a minimum of 25 in-lb to climb up a near-vertical incline. These assumptions are conservative enough to incorporate a factor of safety. Although not as important as torque, the speed of the output shaft was an important consideration as well to ensure that SAFER could hit the speed requirement of 2-3 ft/s. It was calculated that the speed of the output shaft must be greater than 6900 rpm for 3 ft/s, but since 3 ft/s is on the higher end of the range, there is a bit of leeway in the shaft rotation speed. These calculations are outlined in Appendix A4. The most important tradeoffs are between the motor output, price, and size. There were many motors that could meet or exceed the output required, but were either too costly to work in our budget, or were too large and would require heavy modification of the chassis to accommodate them. Finally, the best motor was determined to be the Amp Flow E30-400 motor for its superior combination of performance and price. This motor has a stall current of 63 Amps which can present a safety concern if the motor tries to draw more current than the batteries can supply. Fortunately, the DC motor controller can limit the amount of current sent to the motors, which will prevent catastrophic failure as a result of this high stall current. Additionally, the motor circuits will be fused to prevent damage to the electronics or harm to people around the rover.

The most important parameters to consider for battery selection were voltage output and current output, followed by weight. This kicked off research for batteries. Initially, since the motors required a 24V power source, the ideal battery was also 24V. However, after preliminary research, the 24V batteries were initially determined to be out of the price range for this project. Therefore, 12 Volt batteries were also researched because they can easily be wired in series to create one 24V battery at a fraction of the price. Once the motors were selected, the current requirements for the batteries were selected to match those of the motors, namely, 3.1 Amps of continuous current at the minimum. Since this value is a “load-free” current, the minimum current requirement was bumped up to 10A so that the proper amount of current can be supplied when the motors are under load. To satisfy these requirements while simultaneously keeping the cost down, we initially decided to use a pair of 12V lead acid batteries to be wired in series to simulate a 24V battery. While these batteries came at an excellent price, the safety concerns were not fully considered in using these batteries. During operation, lead acid batteries emit fumes that are very toxic which is quite counter-productive for a machine that should be saving people. Additionally, these lead acid batteries cannot be tipped without leaking acid, which again presented a major safety risk that was counter-productive for our application. Lastly, at 12.5 lbs each, these batteries would add major weight to the rover, cutting down battery life and maneuverability [21]. All things considered, the lead acid batteries were returned and instead, after more thorough research, replaced with two AAPPC Nickel Metal Hydride 24V battery packs. These batteries supply 24V and 30A each with a 10Ah capacity and a weight of only 8 lbs each [22]. While significantly more expensive than the previous lead acid batteries, it was a worthwhile investment for weight savings and the elimination of any safety concerns regarding the batteries. Additionally, with the use of two 24V batteries rather than 2 12V batteries, there is much more freedom for configuration of the wiring, allowing for each drive motor to be able to draw from its own battery and increasing the capability of the rover by increasing each motor’s power availability.

5.3 Design Process

The design process for SAFER has not been focused so much around new design, rather updating the existing design of the rover to best suit a search and rescue application. The main aspects of the rover that needed updating were the motors and batteries. The existing motors from *Roverwerx 2012* were far too small; they were simple scooter motors and only produced 11 in-lb of torque. Based on the calculations in Appendix A4, it was calculated that SAFER would need 25 in-lb of torque. The motor to power the climbing tracks at the front of the rover was also missing from the *Roverwerx 2012* project, so we needed to pick a stepper motor to power the tracks. Once the motors were selected, batteries with enough power were necessary to reach the battery life goal of at least 2 hours. Once the motors and batteries were selected, it became clear that the existing chassis needed to be redesigned a bit to enclose all the components. The old motors are shorter than the new DC motors so the drive motor mount needed to be redesigned to accommodate the longer shaft. The stepper motor mount for the climbing tracks also needed to be modified because the existing mount is at a 20-degree angle. The stepper motor is longer than the old motor and extends into the front of the chassis. Because the mount is at an angle, a slanted support and an L bracket were used to install the stepper motor. The *Roverwerx 2012* team put the batteries in the tracks. Unfortunately, this will not be possible for our team because the batteries are larger and we felt more comfortable with them in the chassis for added protection and to prevent any possible risk they might face outside the rover.

Our design process began with brainstorming and thesis review of the *Roverwerx 2012* thesis [23]. This was an important step because it allowed us to get a solid idea of what state the rover was in before we began to narrow down what we needed to change or update. After the initial brainstorming process, we conducted some market research and customer analysis. This was an important step because it allowed us to further define our customers' needs and the aspects of SAFER to focus most on to be an effective search and rescue vehicle. Next, we developed specifications for the rover, including specifications for the torque, battery life, and speed; more specifications can be seen in the Project Design Specifications, Appendix A1. After all the specifications were determined, we began researching motors and batteries to fit the specifications required. The final decisions for the motor and batteries were ordered, and testing and coding began before installing the components in the rover. The initial testing was important because we wanted to ensure we were able to communicate to the motors with the Arduino Mega and DC motor controller and the batteries were powering everything correctly. Once all the initial coding was finalized, additional coding was done to encode everything to the RC controller to achieve the ease of use of SAFER we set at the beginning of the year. Alongside the testing, we brainstormed design ideas for the modified motor mounts, both for the two main drive DC motors and the stepper motor for the climbing tracks.

With new motors, the motor mounting design needed to be modified to accommodate the longer output shaft of the new motor. In order to accomplish this, the existing motor mounting plate was simply raised by one inch to allow for clearance between the output shaft of the motor and the shaft of the worm drive in the main gearbox. To accomplish this, three Aluminum sleeves were machined for each motor mount plate, and using longer bolts, the plates were bolted in as before but featured a higher mounting height for the motors. To ensure that this design was structurally sound, a Finite Element Analysis was performed on the assembly under maximum load conditions, and the part proved to be safe. With a maximum von Mises stress of 924 psi, the steel bolts and aluminum spacer and mounting plate would easily be able to handle any stresses encountered during operation. Both the assembly drawing and the FEA results are displayed in Figures 5.2 and 5.3. Other designs were examined as well such as reworking of the original mounting blocks, but the amount of time and money that a major rework of that nature would cost was determined to be too high.

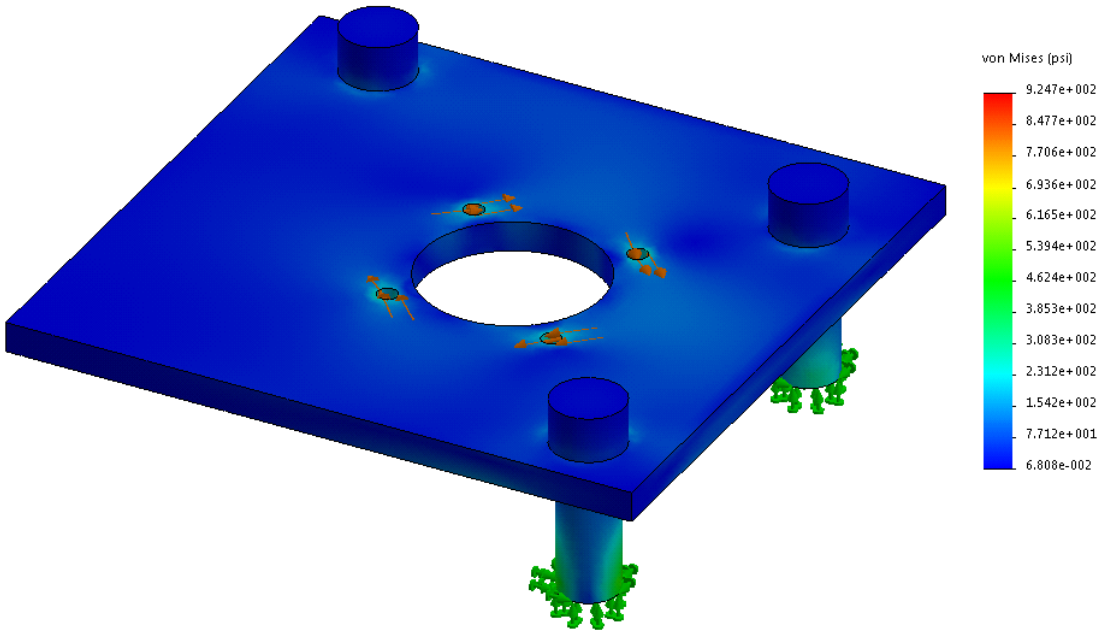

Figure 5.2: Results of the FEA analysis done on SolidWorks to assess the structural integrity of the modified motor mount. The points of highest stress concentration are at the bases of each of the spacers and the screw holes on the plate. These stresses are minimal, less than *5.394e2* psi.

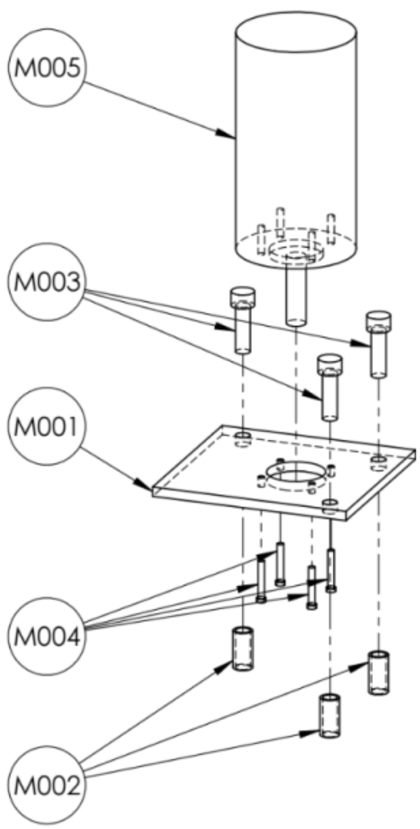

Figure 5.3: Exploded view drawing of the modified part.

The most important parameters for the stepper motor selection were determined to be torque and weight. Assuming a weight of 200 lbs for the rover and using the length of the climbing tracks, it was determined that the stepper motor would need to output 1800 oz-in of torque into the front climbing tracks gearbox. Speed of the shaft is important because the faster the shaft speed, the faster the climbing tracks could move up and down, therefore making the rover more time-efficient, which is important in the time-sensitive field of search and rescue. Originally, we decided to use a NEMA 34 stepper motor that outputs 1841 oz-in of torque. While this motor easily meets the conservative torque requirement, it weighed almost 12 lbs, and was so large that packaging inside the chassis was made difficult [21]. This motor was returned and replaced with a much lighter and smaller NEMA 23 stepper motor with a 4:1 integrated gearbox. This motor, while rotating much more slowly, claimed an output of over 2800 oz-in of torque and weighed a scant by comparison 3 lbs [21]. This motor seemed to give a much stronger output with a fraction of the weight of the previous motor, satisfying both main design parameters.

Like the drive motors, the new stepper motor required a new mounting system for it to work with the existing gearbox, which lies at a 21-degree angle from the base of the chassis. A couple of possible designs were examined to solve this problem. The first design was a bracket to be fabricated out of sheet metal, which would raise the motor to the correct height and angle for attachment to the gearbox. This design was analyzed using FEA and determined to be far too weak to withstand the maximum loading it would be subjected to. The next design was to use a standard NEMA 23 L bracket with a spacer plate mounting it to the chassis at the correct height and angle. The NEMA 23 bracket was rated to be able to handle the loading, and the 2023 Aluminum that the spacer block was made out of provided more than enough strength to keep the motor steady and in place. The final design can be seen in Figure 5.4 and 5.5. With only a small hole cut in the front wall of the chassis, this system proved to be strong, compact, and easy to manufacture.

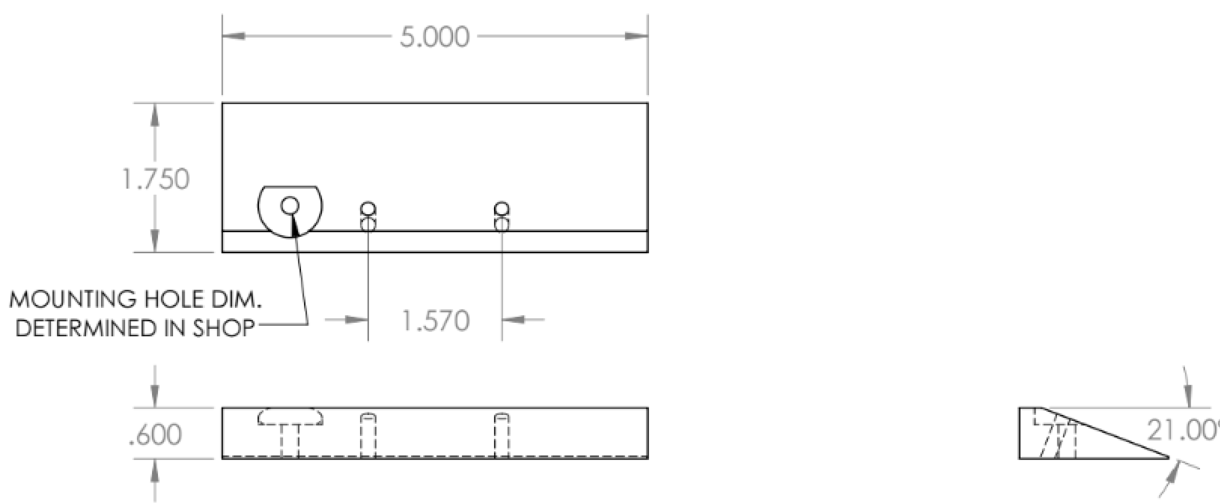

Figure 5.4: The spacer block for the NEMA 23 stepper motor to align with the gearbox on the rover.

Figure 5.5: Standard NEMA 23 L-Bracket [24]

5.4 Discussion of Timeline

Throughout the course of the year, we fell behind schedule a few times. We had a slower start than we initially planned for because we had difficulty locating the thesis from the *Roverwerx 2012* group. This was an issue because it prevented us from starting work on the rover, as we did not know what state the rover was left in and did not want to do any harm to the existing rover. Once we found the thesis, it was in the archives, which meant we could not check it out and had to do all the thesis review in the archives. While this was not a huge problem, it was a slight inconvenience, especially because we could not make any copies of the report. Once we were able to collect all the information from the thesis, we were well on our way to determining next steps and identifying the parts to update and replace. Other reasons for falling behind schedule at times included backorders of a few of our parts, the most significant one being the main drive motors. Twice, we were given incorrect specifications from the vendor on a few of our parts. This set us back behind schedule a few times because we additional time attempting to get these components to work with SAFER, when in reality; they would not because we had the incorrect specifications. Another timeline issue we encountered as a team was poor meeting attendance. While these meetings are not directly on the Gantt chart, people showing up late or not at all wasted a lot of time. Time was wasted when people show up late, while other team members either waited for people to show up or begin without them. Once people show up late, everyone has to stop to update the tardy team members on what they missed. On top of that, when not everyone shows up to meetings, it is difficult to keep everyone on the same page and future meetings often consisted of recaps from previous meetings with poor attendance. Of course, occasionally things came up and people could not make every single meeting, but meetings were scheduled at the beginning of the fall quarter because team members said they were available and could make these meeting times. Table 5.1 is a simplified version of the timeline for this project, a more detailed timeline and Gantt chart for the entire project is included in Appendix A5.

Table 5.1: General Timeline:

Task	Deadline
Select and Order Drive Motors and Batteries	1 November, 2015
Control DC Motors with Control System	1 December, 2015
Hardwire Motors and Batteries to Rover	1 January, 2016
Control Rover with RC Controller	15 January, 2016
Mount Camera	1 February, 2016
Select and Order Stepper Motor	10 February, 2016
Install Stepper Motor	17February, 2016
Finalize and Install Modified Chassis	1 March, 2016
Incorporate Signal Beacons	1 April, 2016
Fine Tune Control System	18 April, 2016
Testing	10 May, 2016

5.5 Discussion of Budget

The budget for SAFER was $3,000; all of these funds were received from the Santa Clara University School of Engineering. We finished well under the budget at just over $2,000. Table 5.2 is the budget, including all expenses for SAFER throughout the year, and is also included in The main expenses were the batteries, motors, and camera. One problem we came across in regards to the budget was the batteries. Many of the batteries we researched were quite expensive, and way outside our predicted and awarded budget. Initially, we settled on two, 12 Volt Lead Acid batteries because many of the other batteries we researched were too expensive. Unfortunately, we needed to return the lead acid batteries and spend more on safer batteries because of the health risks the toxic gases prose when the lead acid batteries are in operation. One of the most expensive items for the project was the DC motor controller, fortunately, the project before us, the *Roverwerx 2012* group, used a DC motor controller as well, that is in perfectly good condition, so we re-used that to save some funds. Overall, we were able to stay within budget very easily and were able to purchase all necessary items for SAFER.

Table 5.2: Budget

Category	Description	Cost
Drive System	24 V DC Motor (x2)	$262.18
	24 V NiMH Battery (x3)	$803.67
	Battery Charger	$64.99
	Motor Driver	$78.98
	Stepper Motor	$152.96
Electronics	Arduino Mega	$34.58
	Logitech Controller	$19.78
	RC Controller	$59.99
	Mega Case Enclosure	$7.99
	Batter Enclosure Holder	$7.04
	Performance Batteries	$8.99
	Speed Control Battery	$8.54
	Multimeter	$13.37
Sensors	360Fly Camera	$434.99
	Signal Beacons	$26.97
	Servo Motor	$19.48
	LED Lights	$45.59
Miscellaneous	Sheet Metal	$40.95
	Screws	$1.28
	Shaft Coupler	$11.98
	Shaft Collar	$45.14
	Black 12 Gauge Wire	$8.99
	Red 12 Gauge Wire	$8.99
	Terminal Wing	$9.99
	Rubber	$66.01
	Paint	$17.48
	Fuses (30 A)	$10.98
	Wires, Connectors	$15.53
	Wires, Splicer	$26.07
	Total	$2,313.48

5.6 Cost Analysis

The budget (Table 5.2) consists of parts and costs needed need for the prototype. The initial goal for SAFER was to design and build a search and rescue rover, with no intention of it being used in the field; this iteration was built for testing purposes. There is a possibility that SAFER could be a prototype for any number of potential customers where the final budget of the search and rescue rover would be more expensive than the costs for the prototype. The batteries would need to be higher grade and quality in order to improve the battery life for longer mission durations to increase the number of survivors SAFER can locate. Many of the other search and rescue rovers on the market use military grade batteries, which are far too expensive for our budget and the scope of this project. If SAFER were to become a product that is used in search and rescue missions often, then higher quality tracks would need to be installed. The two DC motors on SAFER draw more than 30 amps whenever the rover goes up an incline. This is an issue because the batteries cannot produce more than 30 amp hours of current. As a safety precaution, we implemented 30 amp fuses for each battery to ensure the motors did not overdraw from the batteries. A much more powerful and effective battery would need to be purchased if SAFER were to be used for anything other than testing, and even to test for search and rescue purposes, a better battery needs to be chosen. This improvement will drive the cost of SAFR up by at least a few hundred dollars. While the tracks SAFER has right now are fine, the “feet” on the tracks are very loud when the rover is in operation and creates a significant amount of vibration. While tracks are the best way to go for SAFER to increase the traction the rover would have when navigating over difficult terrain, the tracks SAFER currently uses are more than a decade old and it would be beneficial to upgrade and replace them. Additionally, for SAFER to have climbing capabilities the stepper motor needs to be replaced because the holding torque is not high enough to move or support the climbing tracks. Our overall budget is representative of an overall prototype, but is an underestimate for a search and rescue rover to be used in real search and rescue operations rather than just testing.

5.7 Risk Mitigation

Risk mitigation was an important aspect of this project because we wanted to ensure we took every safety precaution to prevent any possible hazard. As was mentioned before, the main drive motors draw more than the allowed 30 amps from the batteries when driving over any sort of incline. To ensure the motors did not overdraw from the batteries, we included 30 amp fuses between each battery and its respective motor. This proved to have a positive effect because when we were doing some testing, the fuses blew. Additionally, every time we tried to have SAFER go up a slight incline, the fuses blew as well. Another safety precaution we took was upgrading all the wiring in the rover to 12-gauge wire. Some of the wires were 18-gauge, which as mentioned before caused problems and a safety hazard. Other wires were 14-gauge, which we still felt were a little too small. The entirety of the chassis of SAFER is metal and there are a lot of components, wires, batteries, controllers, etc., that we housed in the chassis that should not be touching bare metal. If something were to go wrong, all the current, voltage, and metal all together could have been catastrophic. To eliminate this safety risk, we lined the base of the chassis is a rubber foam platform to separate the electrical components from the metal base of the chassis. We did not have any issues with the components touching any metal. Risk mitigation for this project mostly focused around ensuring all the electrical components of the rover were evaluated and measures were taken to eliminate any potential for a safety hazard.

5.8 Team Management

The structure of this six person mechanical engineering team consists of two main leaders. Elizabeth McMahon was the team leader and assigned tasks to team members related to course assignments and other less technical tasks. Charles Lewis was the most knowledgeable of robotics on the team, so he was a designated leader involving the technical tasks. He assigned tasks such as parts research, Arduino tutorials, and manufacturing tasks and requirements. With such a large team, it was best to divide up the work and assign one or two team members to focus on a task each week. This system worked well in some cases where team members would finish their assigned tasks on time. At times, however, tasks were not finished on time which delayed other aspects of the project, putting it slightly behind schedule each time.

A team of six members also provides a fair amount of issues and challenges to overcome, the first being meeting times. It was quite difficult to find times when six people are available. Initially, full team attendance was required to most team meetings. However, as the project progressed and assignments could be broken down into subsystems and smaller groups of tasks, full team attendance was not necessary for every team meeting. For example, a sub-team designated to researching a motor to control the climbing tracks typically had meetings of their own, and updated the rest of the team as it was necessary. Nonetheless, meeting attendance still remained important and the management approach for remedying this issue was not always successful. As the year progressed, attendance and responsiveness from team members declined, which led to a lot of frustration and less than ideal team dynamic. At times, tasks and assignments were not being completed by the designated deadlines. The consequences of not showing up to meetings and not completing tasks on time were not in place. In order to ensure the whole team was on the same page, each member evaluated both themselves and all five other team members anonymously. The team thought this would be helpful for everyone's concerns to be heard and because it was anonymous, the team dynamic would not suffer as a result.

The anonymous evaluation seemed to improve individual's performance and attendance. It was effective for each person to see what the rest of the team appreciated from them and also what they thought they should improve. It was also helpful for each person to evaluate themselves to better see how not responding to emails or completing tasks on time is frustrating to the team and sets the whole team back behind schedule. Overall, the team management approach had been successful. For the most part, team members responded well to the tasks they are assigned and often volunteered for most tasks and complete them on time.

Chapter 6: Business Plan

6.1 Abstract

SAFER, which stands for Search and Find Emergency Rover, is a search and rescue rover aimed to increase the efficiency of search and rescue operations and decrease the risk that search and rescue team members currently face in their profession. SAFER is equipped with remote control capabilities so operators can remain a safe distance away from the disaster situation. SAFER drives on tracks and has additional climbing tracks for navigating through and over difficult terrain. SAFER has a very limited market, it is not something many people would purchase, rather search and rescue teams throughout the country could purchase SAFER to help their teams. There are already a variety of rovers similar to SAFER, however, SAFER combines the most appropriate aspects of these other rovers to be best applicable for search and rescue purposes. To market SAFER, word of mouth and conventions will be most effective. If a few search and rescue teams begin with SAFER, then they can talk with other search and rescue teams and it will spread from there. Due to the limited market, SAFER will be a built-to-order product. It does not make much sense to mass-produce SAFER because there could be the possibility that each customer would want certain sensors or batteries on SAFER. Additionally, to begin, there will not be too many teams purchasing SAFER and it makes more sense to offer a more custom service. Due to the custom service we will offer, SAFER will cost $5,000 with a 2 year warranty protecting against manufacture defects.

6.2 Introduction and Background

SAFER, Search and Find Emergency Rover, is a tool that can be used by Search and Rescue teams both domestically and in other countries that will act as an early reconnaissance tool for the teams. It will deliver usable data to the teams so that they may have a better idea of the conditions of a collapsed structure so that they can adequately prepare themselves before jumping into what could be potentially an extremely dangerous situation. This rover is designed in conjunction with a search and rescue team and is designed for all urban search and rescue teams in mind. It is intended to be simple to use so that any member of a team can pilot the rover, requiring little special training or special personnel. While there are a few great rovers on the market with a similar purpose, SAFER aims to take a large portion of the market with a superior price point.

6.3 Goals and Objectives

The company manufacturing SAFER would be aimed at aiding the search and rescue community and helping to ensure that the brave men and women of the teams can stay as safe as possible in what is usually a very unsafe situation so that they may be able to return home to their families at the end of a long day of saving lives. We hope to work in conjunction with Search and Rescue teams so that we may cater to their needs and produce the best possible product for the best possible price and ensure that they stay safe and that victims may stay safe as well.

6.4 Key Product Technology

SAFER is a remotely operated rover that can provide useful reconnaissance to the Search and Rescue teams so that they may enter situations more prepared. This vehicle is constructed using high strength aluminum ensuring durability and ruggedness over any terrain. Utilizing two sets of aggressive tracks (one fixed and one articulating), this rover has the traction to traverse any terrain you can throw at it and has enough torque to climb a vertical wall. With climbing tracks that can articulate 90 degrees in both the positive and negative directions as well as a low center of gravity, the angle of approach and the angle of descent of this vehicle are incredibly high. The limits of what SAFER can do are extremely difficult to reach during normal search and rescue operations, making this vehicle the perfect solution to keeping our men and women of the search and rescue community safe.

6.5 Potential Markets

The main market for vehicles such as SAFER are obviously search and rescue teams across the world. Currently, there are many similar products on the market and have been fairly successful in that market. In order to become a leader in this industry, SAFER will first be sold to departments with lower funding because of our much lower price point. These departments will no doubt be impressed with the performance of SAFER and the low cost, and we can use the positive impression as a starting point for demonstration and eventually move up into the other municipalities. SAFER can make the search and rescue rover accessible to most teams across the nation and even the world by offering a capable rover at an unbeatable price.

6.6 Competition

As mentioned in Chapter 1 about the existing technologies, there are already many unmanned vehicles on the market. These vehicles are all used in a variety of situations, one being search and rescue. All four have comparable speeds, weights, battery life, and costs. However, the four rovers already on the market all cost upwards of $60,000. This is much too expensive for many search and rescue teams to afford. In order to compete effectively in the market, SAFER will be significantly cheaper than all the rest. With a budget of only $3,000 this year, all of the mechatronics were purchased with money to spare. This included all components to bring a bare chassis up to a fully functional rover with multiple subsystems. The estimated cost of the chassis components are $1,000 for the raw aluminum necessary for the base and drivetrain mounting hardware as well as the gears and tracks. Assuming another $1,000 in machining labor for these relatively simple parts puts the total cost at under $5,000. SAFER still maintains a competitive speed of 3 feet per second, a battery life of up to 2 hours and only costs $5,000 per rover to produce, allowing for a profit margin while still coming in far under the price of the competition. With future work to be done, a decrease in the weight will also keep SAFER competitive when it comes to weight and portability.

6.7 Sales and Marketing Strategies

One of the best ways to get word out about new products is at conventions. SAFER could be displayed and demonstrated at search and rescue conventions around the country. With the help of enthusiastic salespeople with a passion for saving lives, we can surely reach new customers around the country and build a solid customer base for our rover. After the sale of SAFER, the rover can be delivered to wherever specified. Shipping costs may be high, but will still come in at far less than competitive products.

6.8 Manufacturing Plans

In the early stages of production, SAFER will be a built-to-order product. With the design finalized and the wrinkles ironed out, the physical duplication of the finalized design should be relatively straightforward. Turnaround time from order placement to delivery could be as short as a month if mass production machining methods are used for parts and if there is a strong relationship with parts suppliers. Certain components can be manufactured ahead of time and stored to reduce production time such as all the aluminum pieces, nuts and bolts, etc. The machining of parts can be outsourced to a local machine shop, while final assembly can be completed at a company-owned warehouse somewhere centrally located to the market. Over time, multiple warehouses and manufacturing facilities can be added and machining can be transferred to these locations once the company takes off.

6.9 Product Cost and Price

It is realistic to predict that SAFER would sell at a cost of about $10,000. As explained in Section 6.6, this year's budget of $3,000 allowed restoration from a bare chassis to a working machine. With another estimated $2,000 in raw materials and machining, the total cost is estimated to be $5,000. Selling for $10,000 would allow many lower budget search and rescue teams to afford SAFER while still providing a large profit for the production team. This combined effect will target a segment of the market that has not been tapped into by other products and allow more rovers to be sold, compensating for the lower price.

6.10 Service and Warranties

SAFER will be backed by a full manufacturer warranty for hardware and software issues relating to design or manufacturer error for 2 years. Things that will be covered are limited to: Chassis integrity and durability, mechatronic systems, batteries, motors, motor controllers, software, camera, sensor malfunction. Warranty will not cover: attempting to modify software outside of manufacturer's specifications, scratches, burns, or other damage as a result of operator negligence on a mission.

6.11 Financial Plan

To begin, we will need about $20,000 to purchase raw materials, batteries, motors, cameras, sensors, and machine time. Initially, we plan to manufacture about 4 rovers so that we can market the product and begin selling SAFER to spread the word to increase sales. With each rover costing about $5,000 to produce, $20,000 should be sufficient enough to begin. As of right now, we do not have a source for the starting $20,000. To find investors for this money, we will talk to search and rescue teams throughout the country.

Chapter 7: Engineering Standards and Realistic Constraints

7.1 Economic

Adhering to the budget given for this project was an important constraint throughout the design process. Not only was this necessary to ensure completion of the project, but also to make SAFER cost effective for hypothetical mass production. Additionally, SAFER needs to be priced competitively for the target market. All existing technologies have higher price tags, making the target market for them a well-endowed search and rescue team such as the United States Armed Forces. Since SAFER is aimed at smaller markets, the pricing needs to put it in reach of smaller, lower budget teams.

7.2 Environmental

When choosing materials for our design, we should make sure that we choose materials that are long lasting, repairable (rather than replaceable), and environmentally safe. For example, rather than using lead acid batteries to power the subsystems, NiMH batteries were used because they do not carry the same environmental risk as lead acid batteries [20]. NiMH batteries can be tipped, tilted, and shaken without emitting any toxic fumes or liquids, making them the safer and more environmentally friendly choice.

7.3 Sustainability

SAFER fits within Santa Clara University's mission of sustainable engineering. By reusing many of the existing chassis components from *Roverwerx 2012*, SAFER reduces waste associated with manufacturing and making new parts. All scraps from manufactured parts were recycled so as to reduce landfill waste and harmful effects on the environment. Additionally, all of the hardware is made out of Aluminum which does not corrode and will have a longer life cycle which further reduces waste from replacing parts. SAFER is also powered by electricity which has a lower overall impact on the environment than other methods of propulsion.

7.4 Manufacturability

If SAFER is ever mass produced, this constraint will be among the most important. Creating a cost effective design with simple components can more easily be replicated and manufactured for a lower cost. To accomplish this, all manufactured components have been designed as simply as possible and off-the-shelf standard parts have been used as much as possible to keep machining cost as low as possible. Using off-the-shelf parts also allows for cross shopping to get the best price on comparable parts, which will help lower the cost of production.

7.5 Health and Safety

In order to ensure safe manufacturing, all team members completed a safety training course before operating any manufacturing machinery. Use of a mill, lathe, and other light fabrication tools are necessary for manufacturing many of the parts used for SAFER, so ensuring proper training for all personnel involved in fabrication is essential. To ensure safe operation of

SAFER, all operators must be trained in maneuverability of the rover so that they may have basic knowledge of the inner workings of SAFER in the event there is an issue. Additionally, since there is a slight delay between user input in the controller and actual motion of the rover that increases with distance, operators need to know how to control safely from a far distance. All components were designed and chosen with safety as a high priority. For example, the batteries are safe to operate near trapped survivors because they are self-contained and do not emit any toxic gasses or liquids. Similarly, the gearboxes all have protective plates to keep debris out that could potentially jam the gears or ricochet out and potentially injure a bystander.

Chapter 8: Project Summary and Conclusion

8.1 Summary of Work

Over the course of the past year, the team sought to create a search and rescue rover. The motivation behind SAFER was to increase the efficiency of search and rescue operations and decrease the risk search and rescue team members face when in unstable structures looking for victims. The objective when designing SAFER was that it function consistently, navigate over difficult terrain, be remotely operated, have a top speed of 2-3 feet per second, a battery life of 2 hours, and have signal beacons, lights, a robotic arm, and a thermal camera. We accomplished many of these goals. SAFER is now functional due to the two 24V DC motors and two 24V NiMH batteries and the motor controller, which was re-used from *Roverwerx 2012*. SAFER is remotely operated using an RC controller and a 360Fly camera so the operator can see the rover's surroundings from a safe distance away from the area of concern. SAFER has a top speed of 2.72 feet per second, which is in the target range and comparable to the speed of a walking person; meaning SAFER will not slow down any operation to the point where a person could do it faster. SAFER's battery life per charge falls between 1 and 3 hours, so it is fair to say the battery life goal of 2 hours was met. Three signal beacons that flash bright red lights can be dispensed from SAFER to help search and rescue team members locate a survivor more efficiently. Very bright LED lights are attached to the top of the chassis on SAFER to enhance the visibility, especially in dark areas.

Unfortunately, the team was not able to give SAFER the capabilities to navigate difficult terrain, a robotic arm, or thermal camera. SAFER cannot climb or go up inclines due to the lack of power from the battery as well as lack of holding torque from the stepper motor. As mentioned before, the most affordable batteries were purchased, however the batteries are still not quite powerful enough because the motors draw more than 30 amps of current when trying to climb any sort of incline, which is above the capabilities of the NiMH batteries. Even if the batteries were not an issue, SAFER would not do well at navigating difficult terrain because the stepper motor chosen does not have enough holding torque to support and move the climbing tracks, rendering the climbing tracks stationary. Lastly, time and budget prevented addressing two reach goals: the robotic arm and thermal camera. The robotic arm was not accomplished due to schedule as well as budget constraints, and the thermal camera could not be purchased because the viable options were all outside our budget alone. Even lacking one baseline and two reach goals, SAFER is still considered a success. The main goal was getting SAFER to run again, which has been accomplished. The team hopes that SAFER will continue to run and future groups will take on SAFER for their Senior Design Projects in the future and more of these goals can be met.

8.2 Future Work

While SAFER was put into a working state and will continue to run after graduation in June, there is still plenty of room for improvements, updates, and future work to be done. These improvements and updates include higher power batteries, a new stepper motor with higher holding torque, the addition of a robotic arm and thermal camera, and weight reduction where possible.

8.2.1 Batteries

The NiMH batteries that were chosen are unfortunately not powerful enough to support the rover going over any incline. This is obviously an issue because SAFER is a search and rescue rover and cannot do its job effectively if a fuse blows every time it attempts to drive over some rubble or other obstacle. The NiMH batteries each have a maximum current output of 30 Amps and as it turns out, in testing it was found that the main drive motors each need more than that. As a safety precaution, a 30 Amp fuse was wired in series with each of the batteries to ensure we did not overdraw from them and to prevent any damage to them. During testing, we found that the fuse blew every time the rover attempted climbing any sort of incline. For this reason, it would be very beneficial for the rover to use higher quality batteries that can support and power the high current the two DC motors are trying to draw in order to navigate through difficult terrain.

8.2.2 Stepper Motor

As mentioned before, the vendor that supplied the stepper motor to power and control the angle of the climbing tracks did not provide accurate specifications. While they claimed a holding torque of about 20 N m, in reality it only has a holding torque of 1.24 N m. Unfortunately, this inconsistency was discovered after it had already been ordered, received, and installed. When the issue was realized after having trouble raising the climbing tracks, it was too late to find an alternative. While this may be an easy fix for a future team, it is an important one in order for SAFER to have climbing capabilities.

8.2.3 Robotic Arm

It was a reach goal to include a three degree-of-freedom robotic arm on top of the SAFER. This was to increase the versatility of the rover and perhaps include another camera on the arm to increase the visibility for the operator and make it possible to see inside very tight and difficult to reach spaces. Due to schedule and budget constraints, this goal was not achieved. Therefore, there is great opportunity for future work to be done on SAFER to include a robotic arm to make it better equipped to be an excellent search and rescue reconnaissance tool.

8.2.4 Thermal Camera

Along with the robotic arm, another goal was to incorporate an infrared or thermal imaging camera with SAFER. The idea behind a thermal imaging camera is to increase visibility of SAFER and to help identify where survivors might be, even when they are not visibility and buried under debris and rubble. Unfortunately, due to budget constraints and the high cost of thermal cameras, a thermal imaging camera was unable to be included on SAFER. However, the addition of a thermal imaging camera would increase the efficiency of SAFER and help search and rescue personnel determine which areas are unsafe to enter and even determine which survivors may need more immediate attention.

8.2.5 Weight Reduction

Weight reduction is also a huge opportunity for improvement on SAFER. Ideally, SAFER would weigh well under 100 pounds, closer to 70 or 80 pounds. Unfortunately, because the chassis of SAFER, with no added components weighs 76 pounds, once the motors, batteries, camera, wires, and controller were added, SAFER weighs 118 lbs. Some of the additional weight comes from the large blocks of aluminum that previous groups had used for extra support. It is not likely that all that material is needed structurally, and can likely be shaved down, or replaced with slimmer and lighter pieces, which is something that this team did not have the time to accomplish. Keeping SAFER as light as possible is important to ensure that the rover is portable so it can be taken to and from disaster sites easily.

8.3 Conclusion

SAFER, *Search and Find Emergency Rover* is a small, maneuverable vehicle that serves as a reconnaissance tool for search and rescue teams in the event of a collapsed structure. In such an event, the situation inside the collapse is completely unknown to team members. Before risking their lives entering the disaster scene, SAFER can enter and feed information back to the operators so that they may ensure the areas are safe before entering. Therefore, the rover must be functional, reliable, and rugged so that it may traverse rough terrain. A high-resolution 360-degree camera will be used as a means to send information wirelessly to teams who remain at a safe distance. The tele-operation of the vehicle must be efficient and precise to ensure maximal maneuverability. Once these systems all operate reliably, focus can be shifted to using a 3-degree-of-freedom robotic arm that uses an infrared hybrid camera to look inside small openings in rubble and locate survivors. In addition to the robotic arm, the rover will be able to use accurate signal location technology to inform the search teams where the victims may be.

Initial market research revealed a few key take-away points. First, the rovers currently on the market are lightweight. This is imperative to ensure maneuverability. Secondly, these rovers are all very expensive. With a minimum of $60,000 price for the rovers researched, the price point is very high for this market, making these rovers inaccessible to many teams.

Communication with potential customers revealed a list of key requirements that the rover must be able to meet. First and foremost, the vehicle must be easy to use. If an average search and rescue team member cannot use the rover easily, it will defeat the purpose of having it there in the first place. Additionally, it must maintain the same search speed as a human (2-3 ft/s); it has to be able to travel quickly enough that lives are not lost due to slow response time. In order to successfully complete a mission, the rover must be able to operate for two hours per charge so that it is able to not only survey the situation, but also return back to base afterwards. Since rough terrain is what the vehicle must be able to traverse, the torque output of the motor must be high enough that it may climb over any obstacles in its path. The calculated torque requirement based on a vertical incline and weight of 200lbs (both conservative estimates) was 25 in-lb of output.

Control of the rover is broken into two separate systems. The first system is the drive control system, which utilizes a RC controller to communicate wirelessly with an Arduino microcontroller and RoboteQ AX2550 DC motor controller to drive the AmpFlow E30-400 DC motors. The DC motors are both 24V motors with about 93 in-lb of torque and rotation of 5700rpm, ensuring that the rover will be able to climb anything thrown at it at speed.

Fortunately, the DC motor controller has an integrated current limiter to prevent the motors from drawing too much from the batteries and causing potentially catastrophic failure. As an additional precaution, the wiring incorporated fuses between each battery and their respective motors to ensure the motors do not draw too much current from the batteries that the batteries just do not have. The drive system will be powered via 2 24V NiMH batteries. Power is routed through worm gear and spur gear gearbox inherited from the previous design team to use this chassis. The gear ratio is 30:1, which will add even more torque multiplication for low speed maneuverability.

The project finished under budget at $2,313.48. The project also finished in time, however a little more time would have been helpful to fix a few problems encountered towards the end of our schedule. The main issue to be addressed is the NEMA 23 stepper motor with the incorrect holding torque. Given more time it would have been feasible to research and order an alternative stepper motor with the correct holding torque. The coding was close to completion for the NEMA 23, and would only need minor changes to accommodate a new motor.

In the end, SAFER meets the eight of the nine baseline design goals. SAFER is functional, remote controlled with a 360-degree camera with live feed capabilities. SAFER has a top speed of 2.72 feet per second (between 2 and 3 feet per second), a battery life between 1 and 3 hours (goal of 2 hours) and a final weight of 118.2 pounds (goal range of 100-150 pounds) and there are LED lights on top of SAFER for increased visibility under darker conditions. The only baseline goal we did not reach was the climbing capability and navigating difficult terrain due to the incorrect specifications of the NEMA 23 stepper motor. SAFER also accomplished one of the three reach goals. SAFER is equipped with three signal beacons that dispense from the side and flash bright red lights to help increase the speed at which a search and rescue member can locate a victim after SAFER has found them and moved on to find more.

There is plenty of room for improvements for SAFER, first being upgrading the NEMA 23 stepper motor. After that, if a budget allows, replacing the current NiMH batteries with higher quality batteries that have an output current greater than 30 amps to sufficiently power the two DC drive motors. Incorporating a robotic arm and thermal camera would be highly beneficial for SAFER because the robotic arm could be used to move rubble out of the way or off victims until search and rescue team members arrive. Additionally, a thermal camera would help increase the efficiency of searching for victims because the operator could quickly see if there was a warm body trapped in rubble or out of immediate sight.

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Appendix

A1: Project Design Specifications

Date: May 1, 2016
Datum Description: SCU *Roverwerx 2012*
Rev: 3

Elements/ Requirements		Parameters	
	Units	*Roverwerx 2012*	Target Range
Performance			
Top Speed	ft/s	2	2-3
Torque	lb-in	11	>25
Battery Life	hrs	0.5	2
Operating Temperature	F		32-150
Power	hp		1.5-2
Product Life	yrs	1	3-5
Wireless Range	ft	500	500-1000
Physical Properties			
Weight	lbs	200	100-150
Size	in	24x20x16	24x20x16
Safety			
Auto shut-off	N/A	None	Prevent Current Backflow
Batteries	N/A	Disposed of Properly	Recycle

A2: Budget

Category	Description	Cost
Drive System	24 V DC Motor (x2)	$262.18
	24 V NiMH Battery (x2)	$535.78
	Battery Charger	$64.99
	Motor Driver	$78.98
	Stepper Motor	$152.96
Electronics	Arduino Mega	$34.58
	Logitech Controller	$19.78
	RC Controller	$59.99
	Mega Case Enclosure	$7.99
	Batter Enclosure Holder	$7.04
	Perfromance Batteries	$8.99
	Speed Control Battery	$8.54
	Multimeter	$13.37
Sensors	360Fly Camera	$434.99
	Signal Beacons	$26.97
	Servo Motor	$19.48
	LED Lights	$45.59
Miscellaneous	Sheet Metal	$40.95
	Screws	$1.28
	Shaft Coupler	$11.98
	Shaft Collar	$45.14
	Black 12-Gauge Wire	$8.99
	Red 12-Gauge Wire	$8.99
	Terminal Wing	$9.99
	Rubber	$66.01
	Paint	$17.48
	Fuses (30 A)	$10.98
	Wires, Connectors	$15.53
	Wires, Splicers	$26.07
	Total	$2,045.59

A3: Decision and Prioritizing Matrices

Table A3.1: Priority Matrix for Gearbox Design

Project:	SAFER												
System:	Gear Box												
Date:	11/10/15												
	Criterion	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	SUM	FACTOR
1	Output Torque		1	0.5	1	1	0.5	1	1	0.5	1	7.5	5
2	Output Speed	0		0.5	1	0.5	0.5	1	1	0.5	1	6	3
3	Gear Ratio	0.5	0.5		1	0.5	0.5	0.5	0.5	0.5	1	5.5	4
4	Aesthetics	0	0	0		0	0	0	0	0	0.5	0.5	1
5	Diameter	0	0.5	0.5	1		0.5	1	1	0.5	1	6	4
6	Strength/Material	0.5	0.5	0.5	1	0.5		1	1	0.5	1	6.5	3.5
7	Input Torque	0	0	0.5	1	0	0		1	0.5	0.5	3.5	2
8	Input Speed	0	0	0.5	1	0	0	0		0.5	0.5	2.5	2
9	Safety	0.5	0.5	0.5	1	0.5	0.5	0.5	0.5		0.5	5	5
10	Size of Gear Box	0	0	0	0.5	0	0	0.5	0.5	0.5		2	3

Table A3.2: Decision Matrix for Gearbox Design

Design Project =	SAFER				System=	Gearbox			
	TARGET or								
CRITERIA	FACTOR	1 = Baseline		Worm Drive		Spur Gears		Helical Gears	
Time – Design	1	1		2		3		4	
Time – Build	1	1		5		5		6	
Time – Test	10	10		3		5		5	
Time Score	10		10		24.33		28.33		35.00
Cost – Prototype	190	$ 190.00		$ 265.00		$305.00		$400.00	
Cost – Production	1	$ 1.00							
Cost Score	10		10		6.97		8.03		10.53
Output Torque	5	3	15	4	20	3	15	4	20
Output Speed	3	3	9	4	12	5	15	4	12
Gear Ratio	4	3	12	3	12	2	8	3	12
Aesthetics	1	3	3	3	3	2	2	2	2
Diameter	4	3	12	3	12	2	8	3	12
Strength/Material	3.5	3	10.5	3	10.5	2	7	4	14
Input Torque	2	3	6	4	8	4	8	4	8
Input Speed	2	3	6	4	8	4	8	4	8
Safety	5	3	15	2	10	4	20	4	20
Size of Gear Box	3	3	9	3	9	3	9	3	9
	TOTAL		97.5		93.2		83.6		91.5
	RANK								
	% MAX		100.0%		95.6%		85.8%		93.8%
	MAX	97.5							

Table A3.3: Priority Matrix for Motor Selection

Project: SAFER
System: Motor
Date: 11/10/15

	Criterion	1	2	3	4	5	6	7	8	9	SUM	FACTOR
1	Output Torque		1	1	1	1	1	1	1	0.5	7.5	5
2	Output Speed	0		1	1	1	0.5	0.5	0	0	4	3
3	Size of Motor	0	0		1	0.5	0	0	0	0.5	2	2
4	Aesthetics	0	0	0		0	0	0	0	0	0	1
5	Diameter of Output Shaft	0	0	0.5	1		0.5	0	0	0.5	2.5	1.5
6	Horsepower	0	0.5	1	1	0.5		1	1	0.5	5.5	3
7	Current Draw	0	0.5	1	1	1	0		0	0.5	4	1.5
8	Voltage Draw	0	1	1	1	1	0	1		0.5	5.5	1.5
9	Safety	0.5	1	0.5	1	0.5	0.5	0.5	0.5		5	5

Table A3.4: Priority Matrix for Battery Selection

Project:	SAFER
System:	Battery
Date:	11/10/15

	Criterion	1	2	3	4	5	6	SUM	FACTOR
1	Weight		0	0	1	1	0.5	2.5	3
2	Voltage Output	1		1	1	1	1	5	5
3	Current Output	1	0		1	1	1	4	4
4	Size	0	0	0		1	1	2	2
5	Battery Type	0	0	0	0		0	0	1
6	Life	0.5	0	0	0	1		1.5	1.5

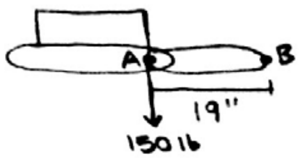
Table A3.5: Decision Matrix for Battery Selection

Design Project =	SAFER				System=	battery					
	TARGET or										DESIGN
CRITERIA	FACTOR	1 = Baseline		24V LIP		24V NIMH		Contender 12V		EXP12200 12V	
Time – Design	40	40		50		50		50		50	
Time – Build	70	70		60		60		60		60	
Time – Test	20	20		25		25		25		25	
Time Score	10		10		11.19		11.19		11.19		11.19
Cost – Prototype	100	$ 100.00		$ 265.00		$305.00		$400.00		$ 80.00	
Cost – Production	1	$ 1.00		$ 1.00		$ 1.00		$ 1.00		$ 1.00	
Cost Score	10		10		18.25		20.25		25.00		9.00
Weight	3	3	9	4	12	7.5	22.5	25.12	75.36	24.6	73.8
Voltage Output	5	3	15	24	120	24	120	24	120	24	120
Current Output	4	3	12	10	40	10	40	18	72	20	80
Size	2	3	6	140	280	37.2	74.4	280	560	273	546
Battery Type	1	3	3	5	5	3	3	2	2	2	2
Life	1.5	3	4.5	3	4.5	2	3	10	15	20	30
	TOTAL		49.5		452.1		251.5		828.2		851.6
	RANK										
	% MAX		5.8%		53.1%		29.5%		97.2%		100.0%
	MAX	851.6									

NOTE:
Baseline data is that of the *Roverwerx 2012* team's iteration of the rover.

A4: Detailed Calculations

Stepper Motor Calculations



Assume weight concentration is at point A to give conservative estimate. Conservatively estimate 150 lbs

Gear Ratio = 20 : 1

$$T = 150\,\text{lb}\,(19\,\text{in})\left(16\,\frac{\text{oz}}{\text{lb}}\right) = 45600\ \text{oz}\cdot\text{in}$$

$$T_{Final} = \frac{45600\ \text{oz}\cdot\text{in}}{20} = \boxed{2280\ \text{oz}\cdot\text{in required}}$$

Motor Calculations

Torque:

Assume rover weight = 200 lbs

Design for climb up 90° → front tracks may need

Gear Ratio = 30 : 1

Wheel Height in track ≈ 3 in

$$T = Fd = 200\,\text{lb}\,(3\,\text{in}) = 600\ \text{lb}\cdot\text{in}$$ After torque mult

$$\text{Necessary from motor} = \frac{600\ \text{lb-in}}{30} = \boxed{20\ \text{in-lb}}$$

Motor RPM Calculation

(G) Gear Ratio = 30:1

(D) Diameter of track wheel ≈ 3 in.

(S) Target Speed = 3 ft/s = 180 ft/m

(C) Circumfrence of wheel = $\pi D = \frac{\pi}{4}$ ft = 0.785 ft

After gearbox:

$$S = C(RPM)$$

$$RPM = \frac{S}{C} = \frac{180 ft/m}{0.785 ft} = 229.3 \text{ RPM}$$

Before gearbox

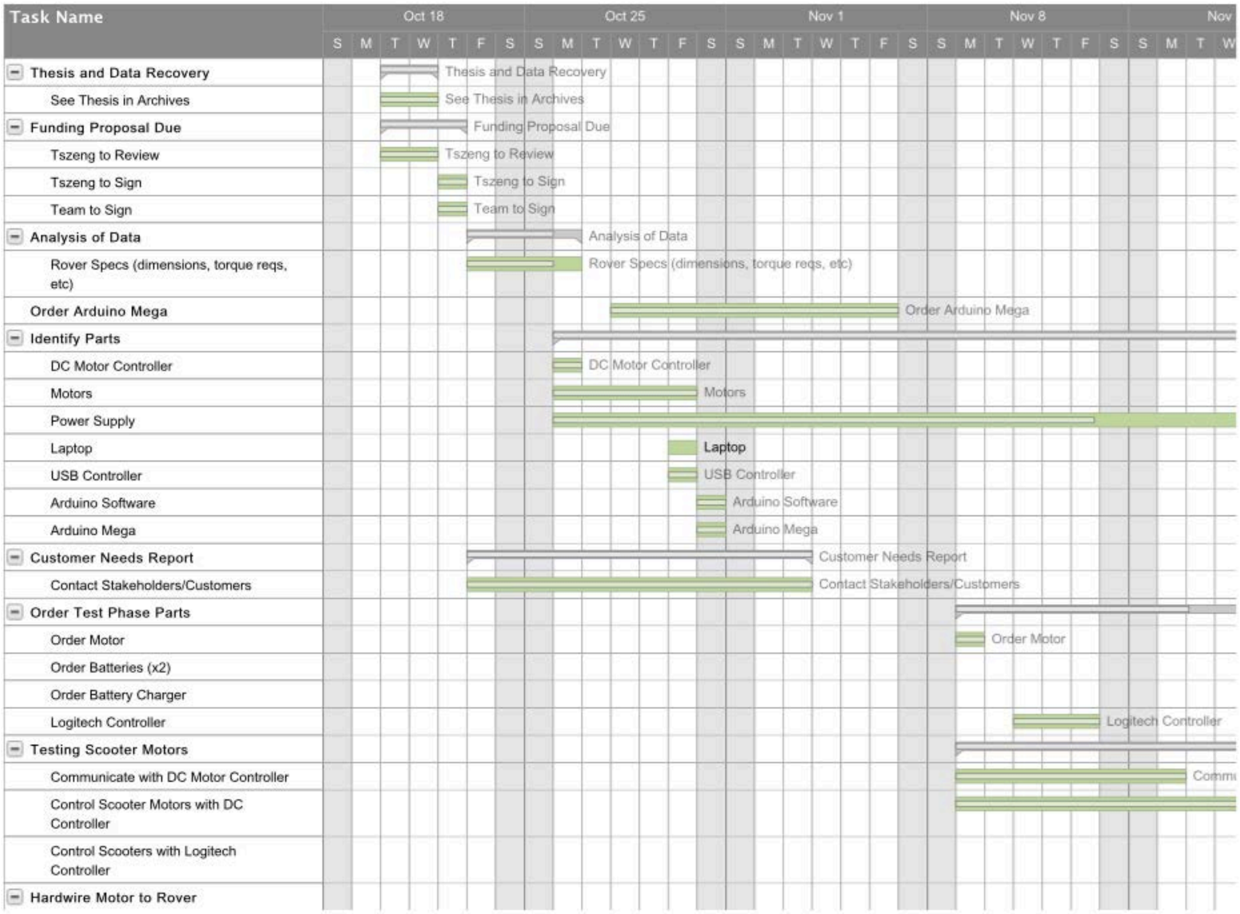
$$RPM_{in} \times G = RPM_{out}$$

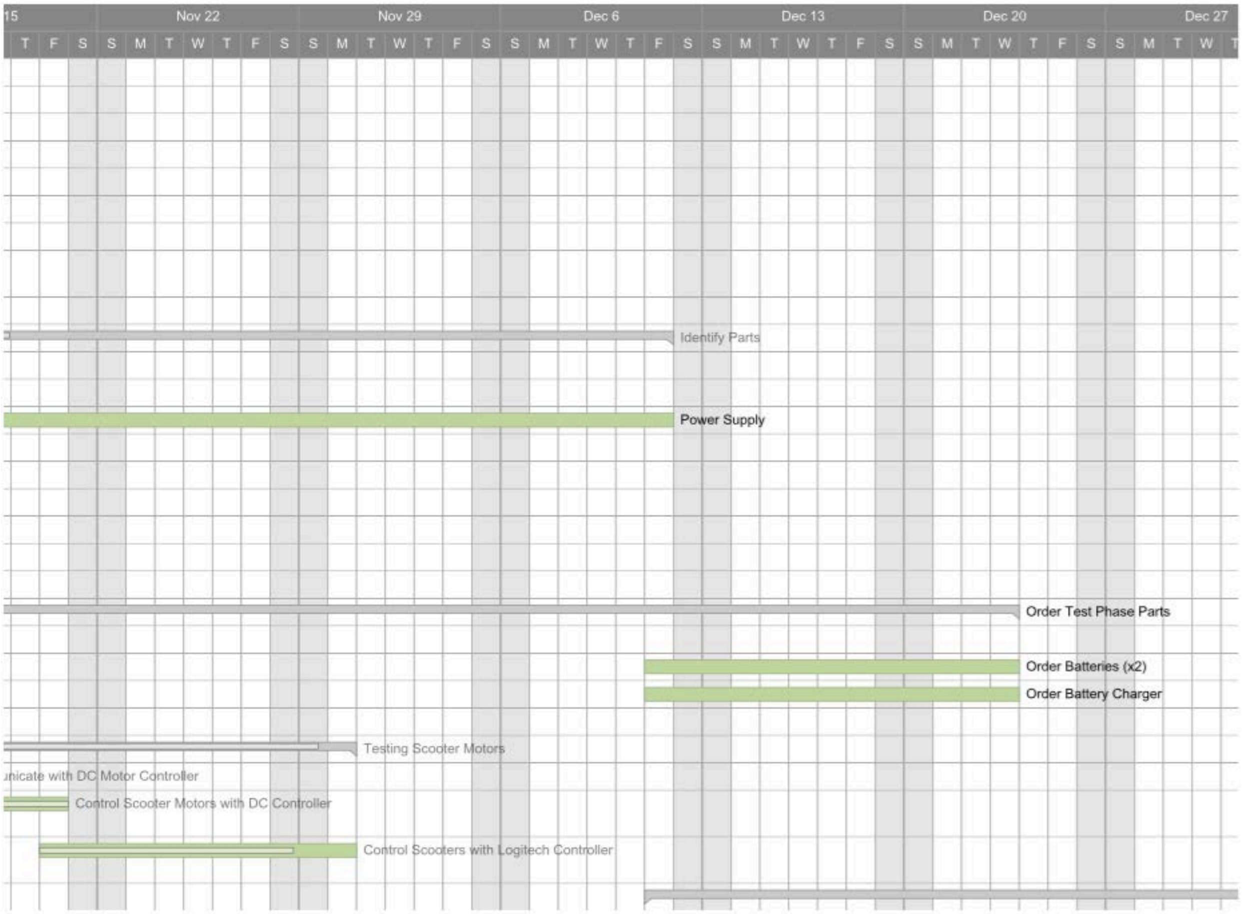
$$RPM_{in} = \frac{RPM_{out}}{G} = \frac{229.3 \text{ RPM}}{\frac{1}{30}} = \underline{6878.9 \text{ RPM}}$$

A5: Timeline

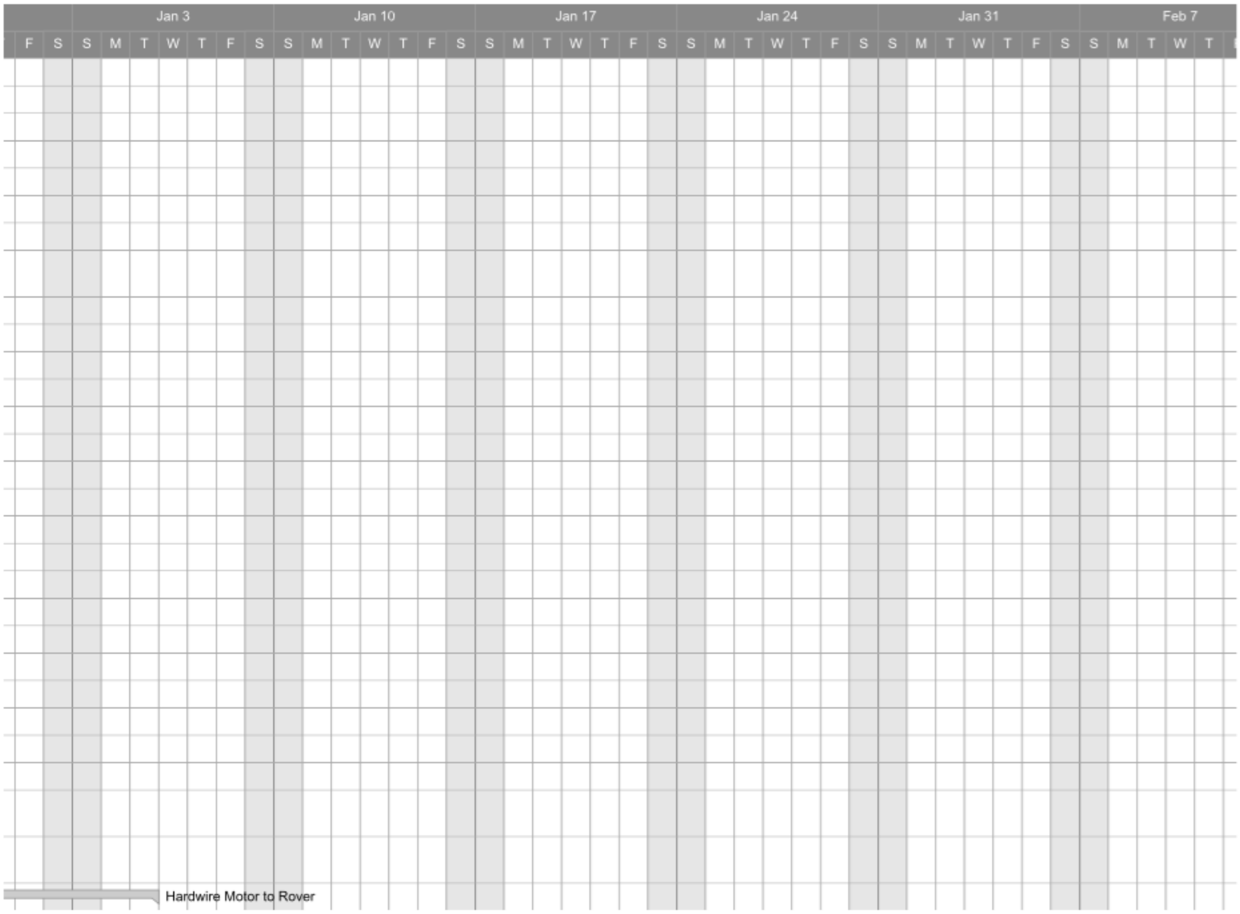
Task	**Deadline**
Select and Order Drive Motors and Batteries	1 November, 2015
Control DC Motors with Control System	1 December, 2015
Hardwire Motors and Batteries to Rover	1 January, 2016
Control Rover with RC Controller	15 January, 2016
Mount Camera	1 February, 2016
Select and Order Stepper Motor	10 February, 2016
Install Stepper Motor	17February, 2016
Finalize and Install Modified Chassis	1 March, 2016
Incorporate Signal Beacons	1 April, 2016
Fine Tune Control System	18 April, 2016
Testing	10 May, 2016

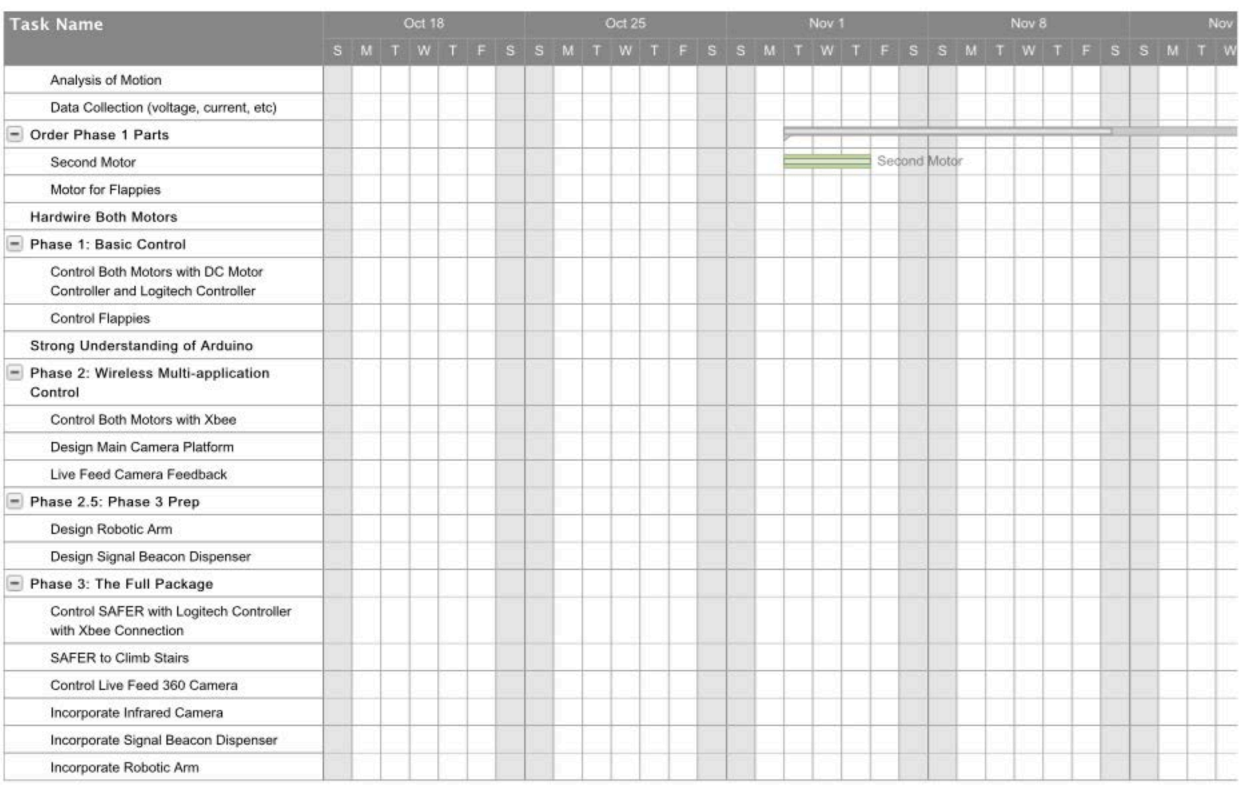
A6: Gantt Chart

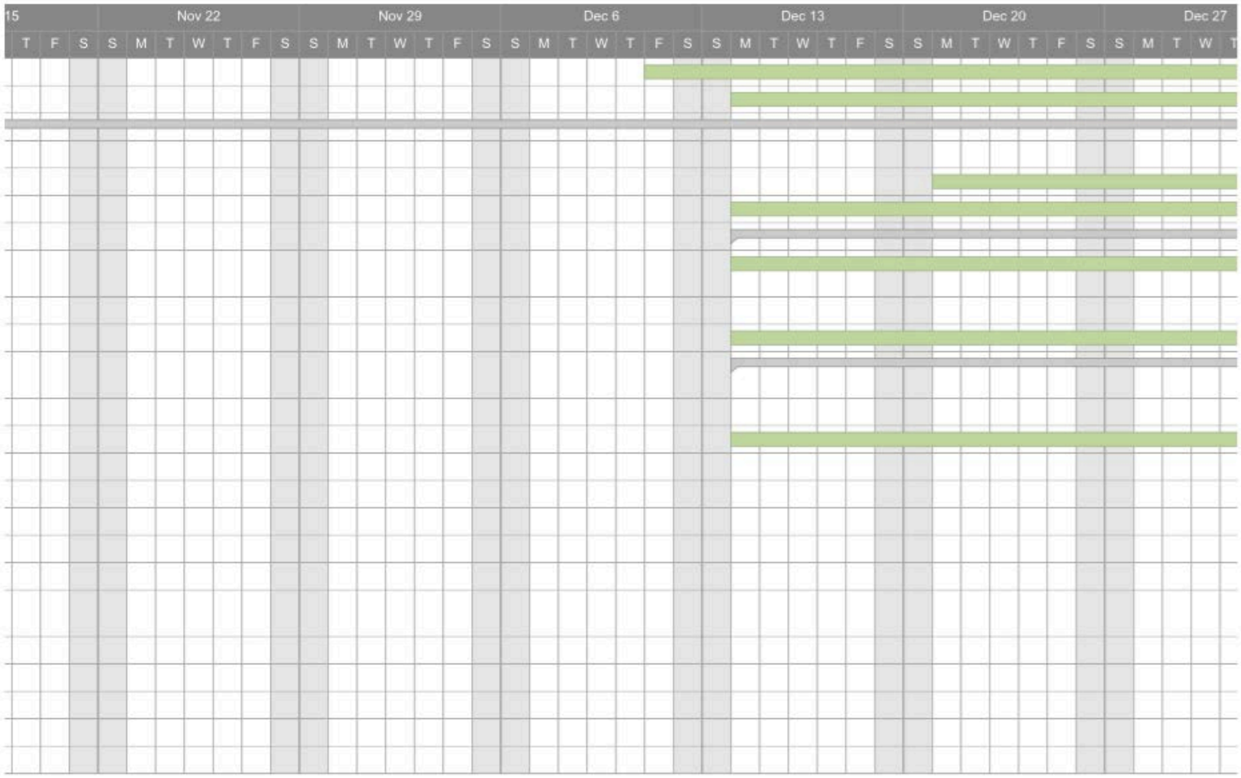




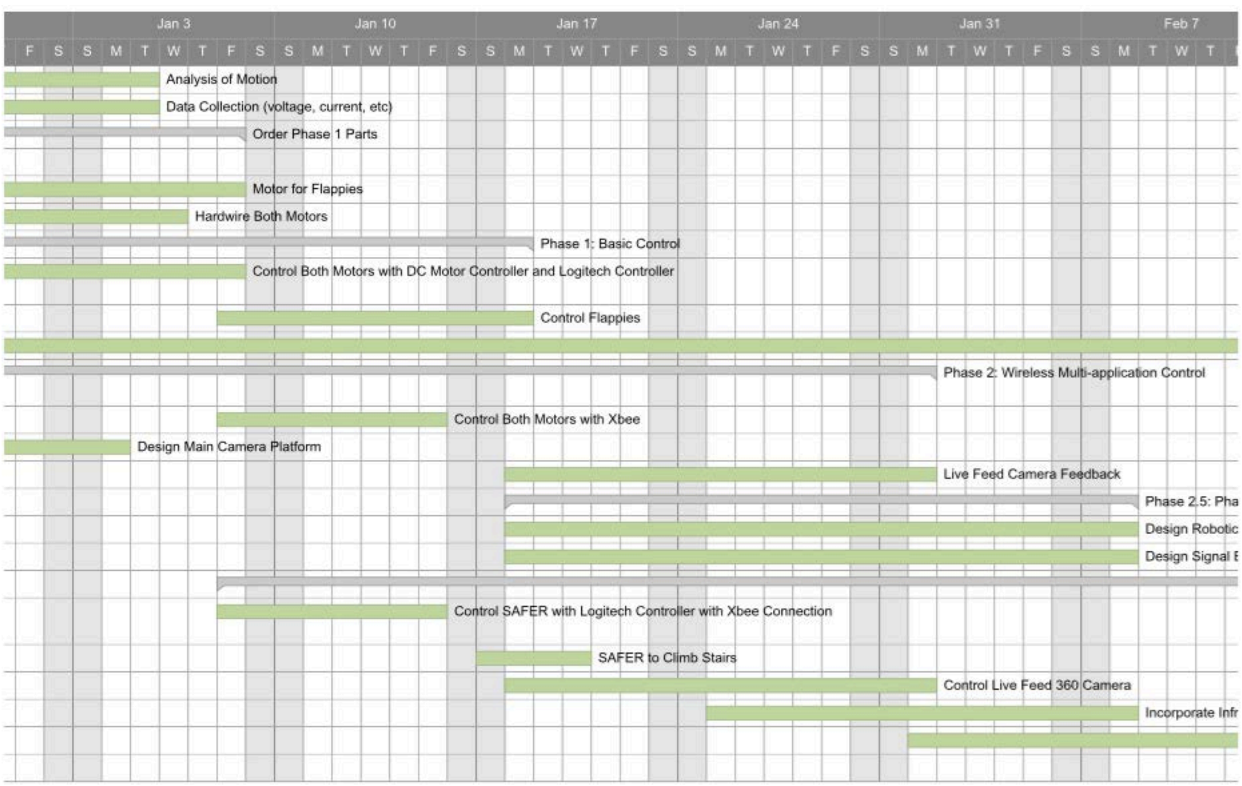
15
Nov 22
Nov 29
Dec 6
Dec 13
Dec 20
Dec 27
Identify Parts
Power Supply
Order Test Phase Parts
Order Batteries (x2)
Order Battery Charger
Testing Scooter Motors
unicate with DC Motor Controller
Control Scooter Motors with DC Controller
Control Scooters with Logitech Controller


Jan 3
Jan 10
Jan 17
Jan 24
Jan 31
Feb 7
Hardwire Motor to Rover

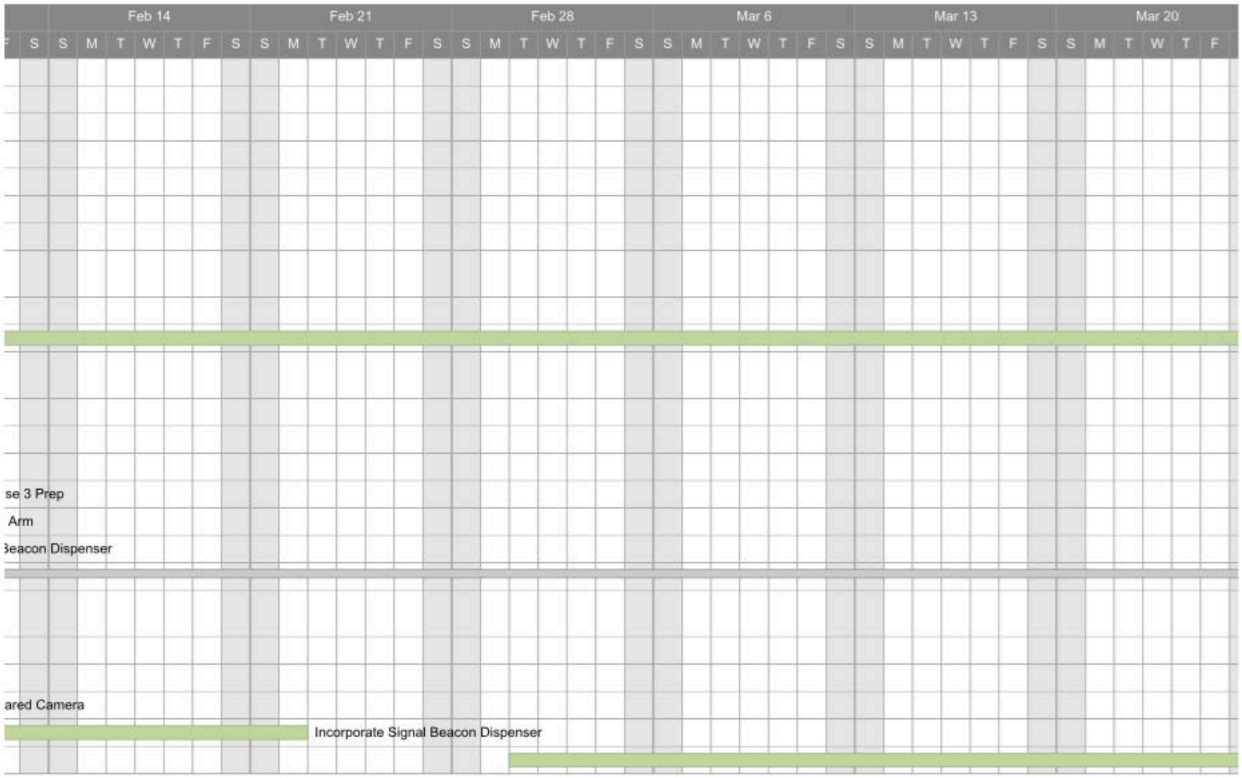

Task Name
Oct 18
Oct 25
Nov 1
Nov 8
Nov
Analysis of Motion
Data Collection (voltage, current, etc)
Order Phase 1 Parts
Second Motor
Motor for Flappies
Hardwire Both Motors
Phase 1: Basic Control
Control Both Motors with DC Motor Controller and Logitech Controller
Control Flappies
Strong Understanding of Arduino
Phase 2: Wireless Multi-application Control
Control Both Motors with Xbee
Design Main Camera Platform
Live Feed Camera Feedback
Phase 2.5: Phase 3 Prep
Design Robotic Arm
Design Signal Beacon Dispenser
Phase 3: The Full Package
Control SAFER with Logitech Controller with Xbee Connection
SAFER to Climb Stairs
Control Live Feed 360 Camera
Incorporate Infrared Camera
Incorporate Signal Beacon Dispenser
Incorporate Robotic Arm
Second Motor

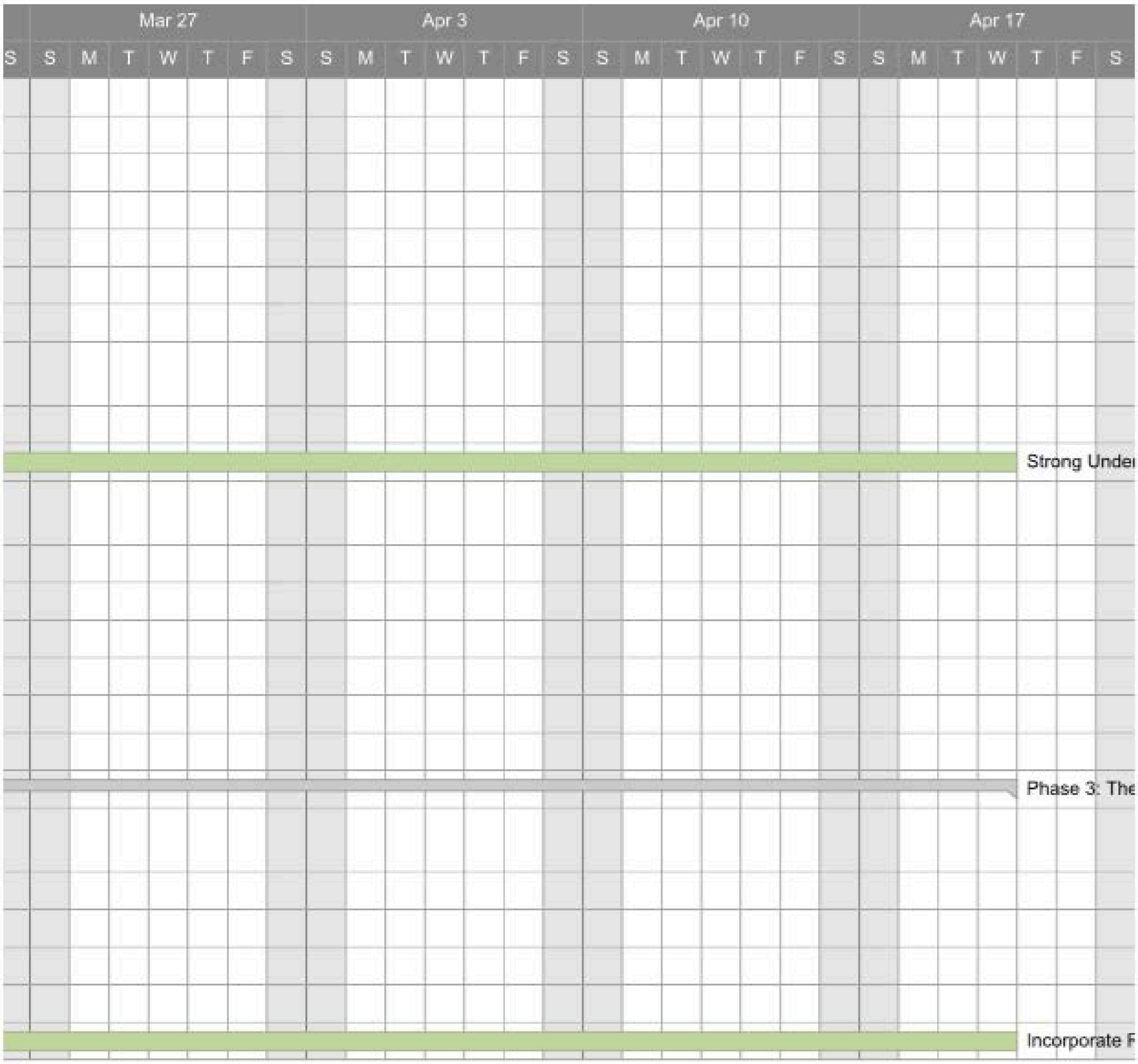


15
Nov 22
Nov 29
Dec 6
Dec 13
Dec 20
Dec 27



Jan 3
Jan 10
Jan 17
Jan 24
Jan 31
Feb 7
Analysis of Motion
Data Collection (voltage, current, etc)
Order Phase 1 Parts
Motor for Flappies
Hardwire Both Motors
Phase 1: Basic Control
Control Both Motors with DC Motor Controller and Logitech Controller
Control Flappies
Phase 2: Wireless Multi-application Control
Control Both Motors with Xbee
Design Main Camera Platform
Live Feed Camera Feedback
Phase 2.5: Pha
Design Robotic
Design Signal E
Control SAFER with Logitech Controller with Xbee Connection
SAFER to Climb Stairs
Control Live Feed 360 Camera
Incorporate Infr


Feb 14
Feb 21
Feb 28
Mar 6
Mar 13
Mar 20
se 3 Prep
Arm
3eacon Dispenser
ared Camera
Incorporate Signal Beacon Dispenser


Mar 27
Apr 3
Apr 10
Apr 17
S S M T W T F S S M T W T F S S M T W T F S S M T W T F S
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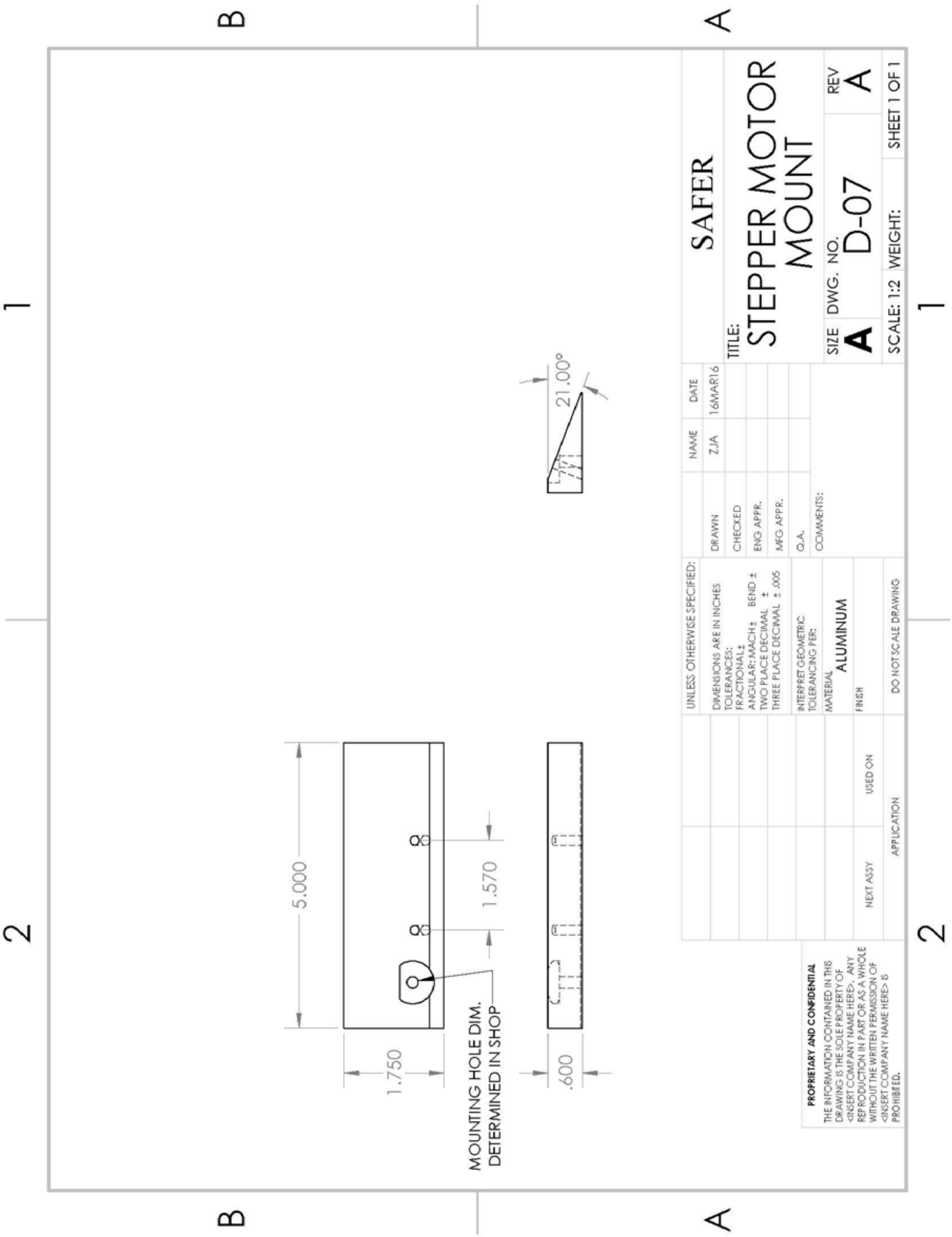
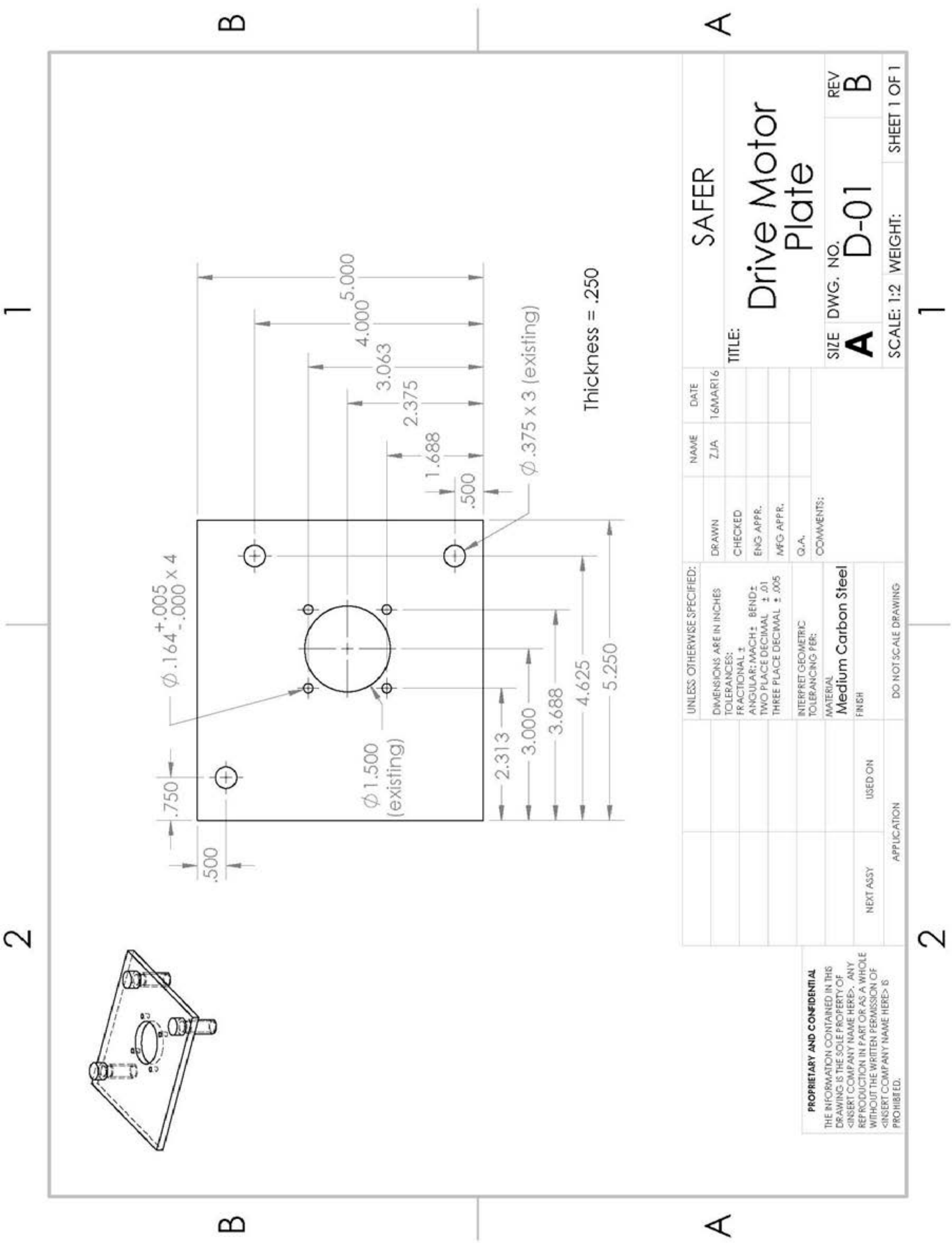
Phase 3: The
Incorporate

A7: Detailed Drawings

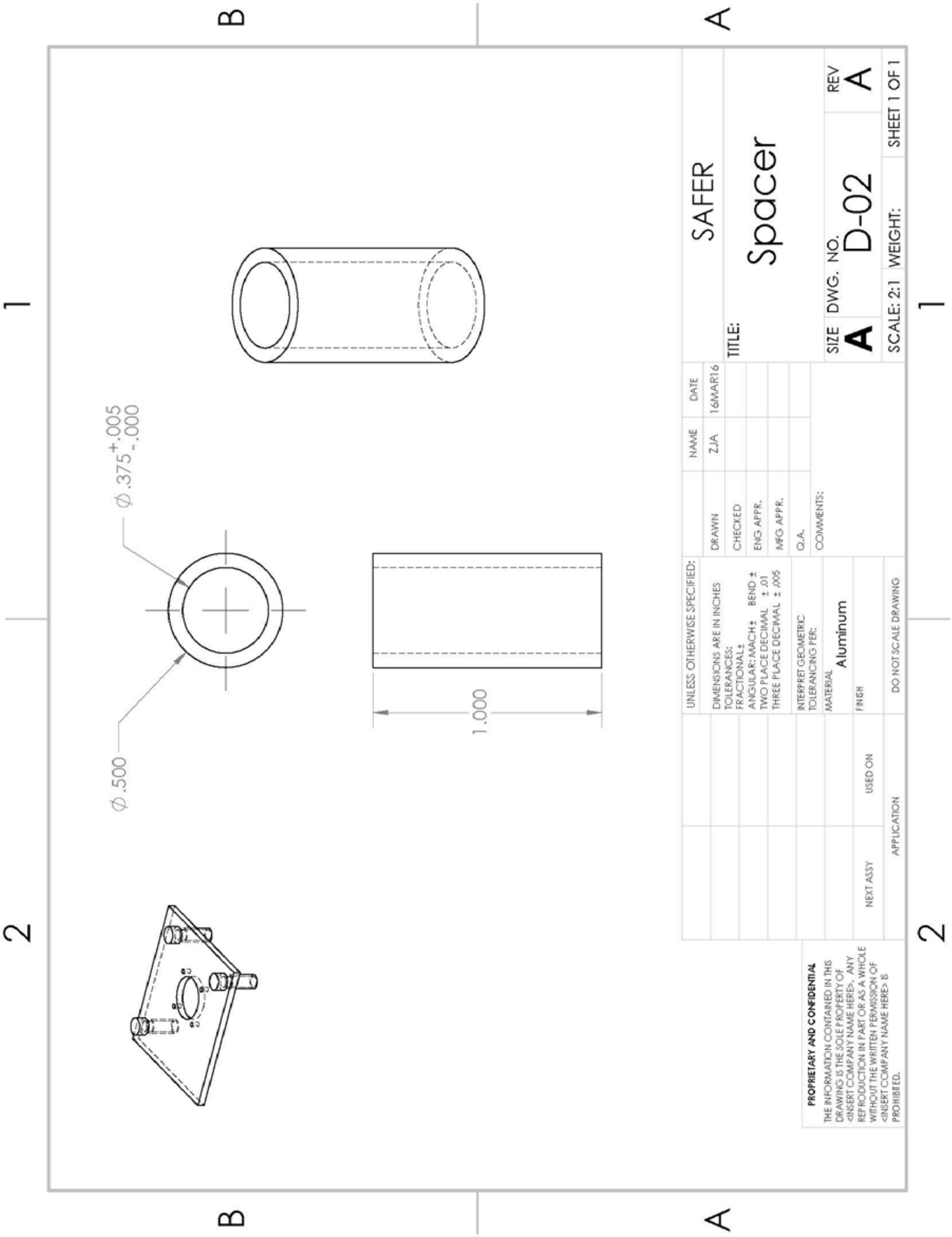
A7.1: Stepper Motor Mounting Angled Spacer



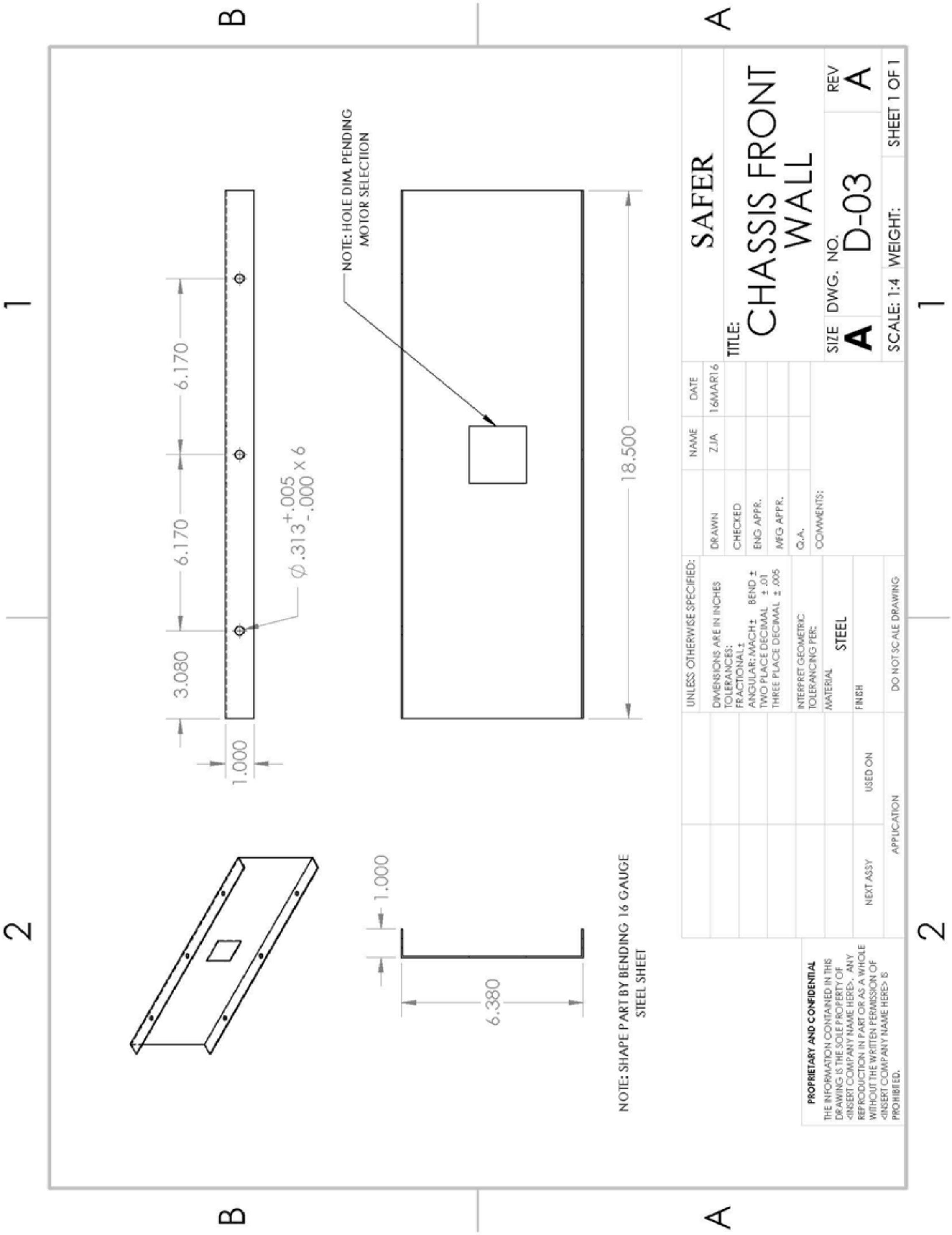
A7.2: Motor Mount Plate



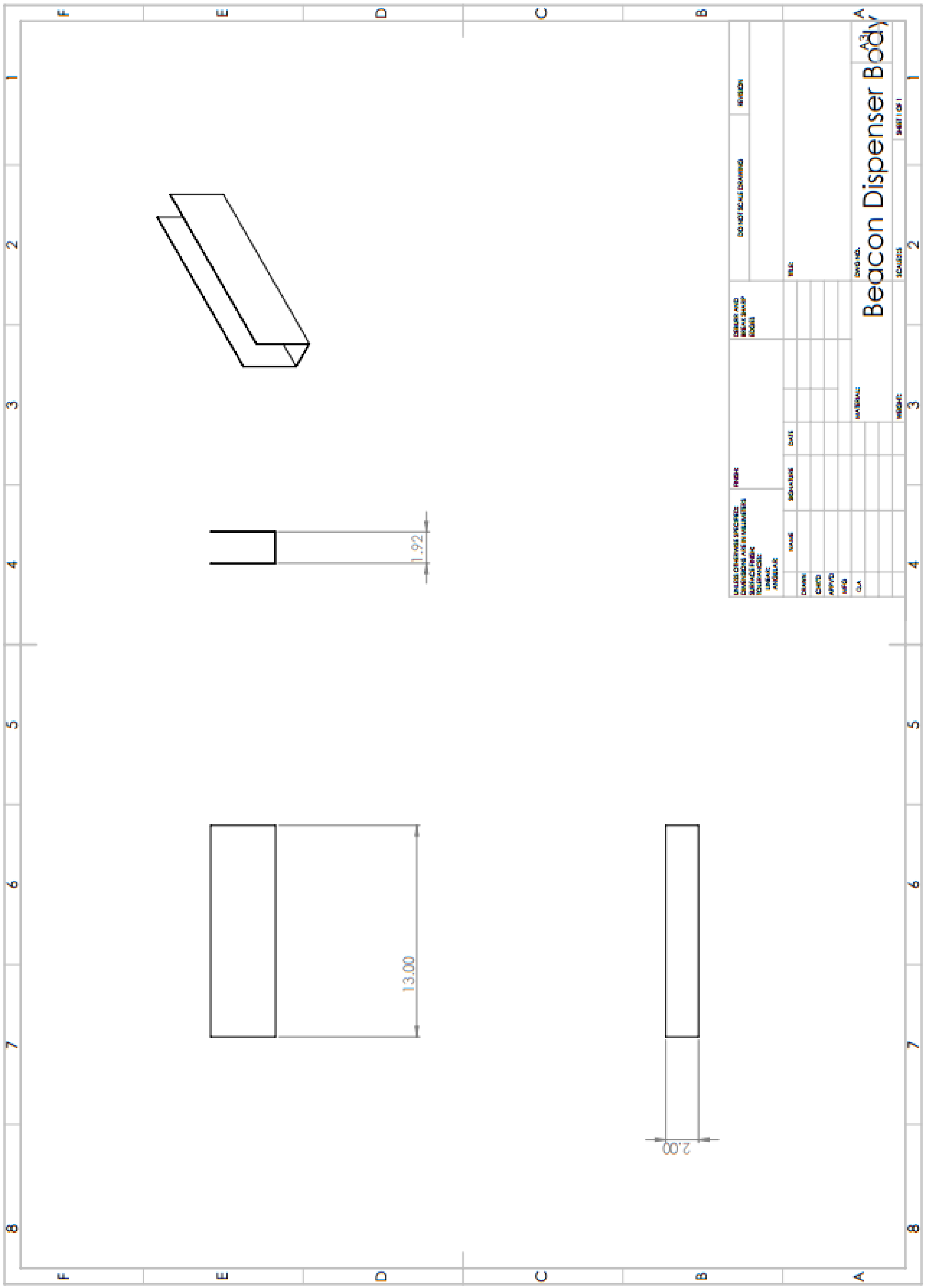
A7.3: Motor Mount Spacer



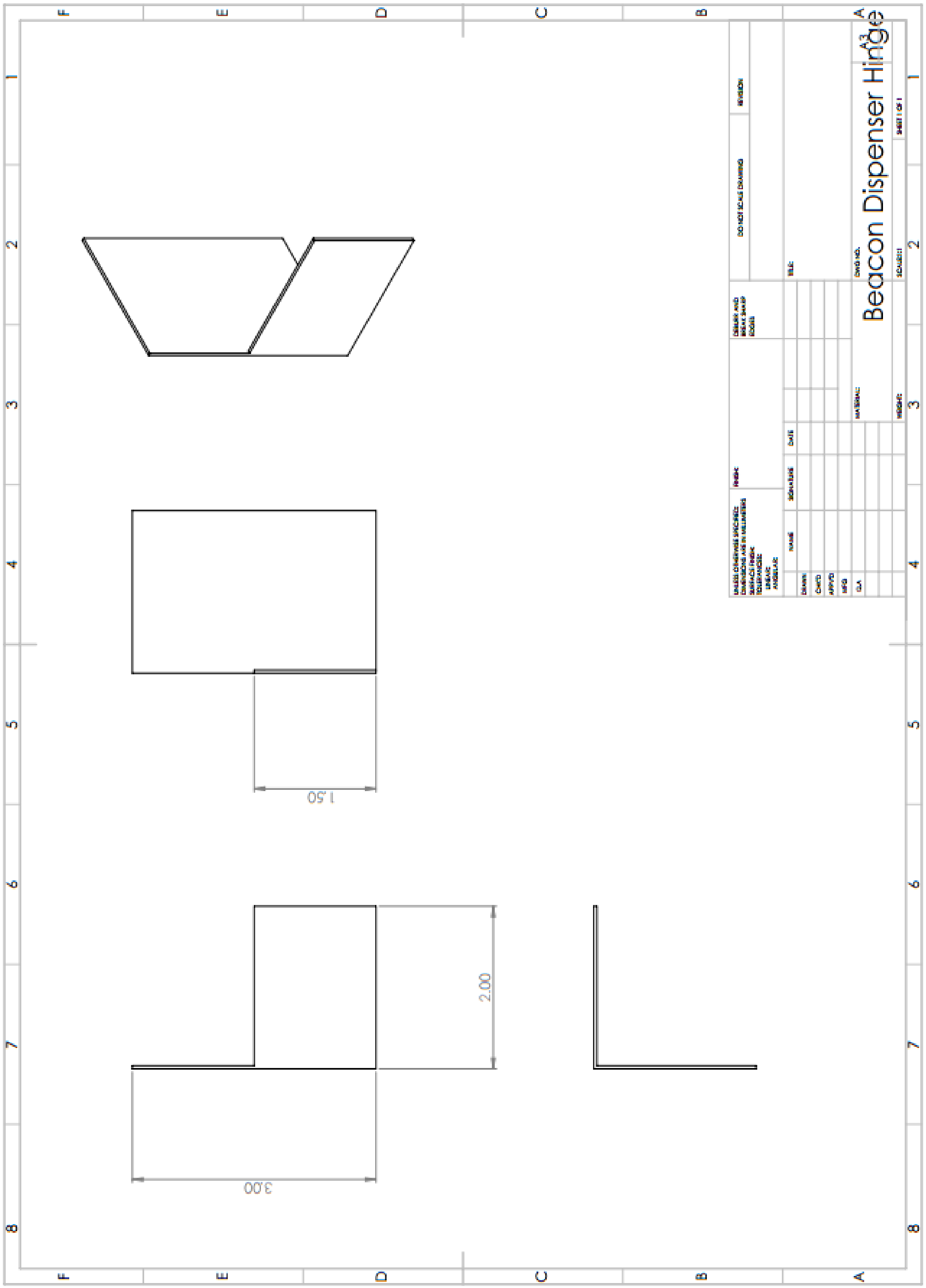
A7.4: Front Chassis Wall



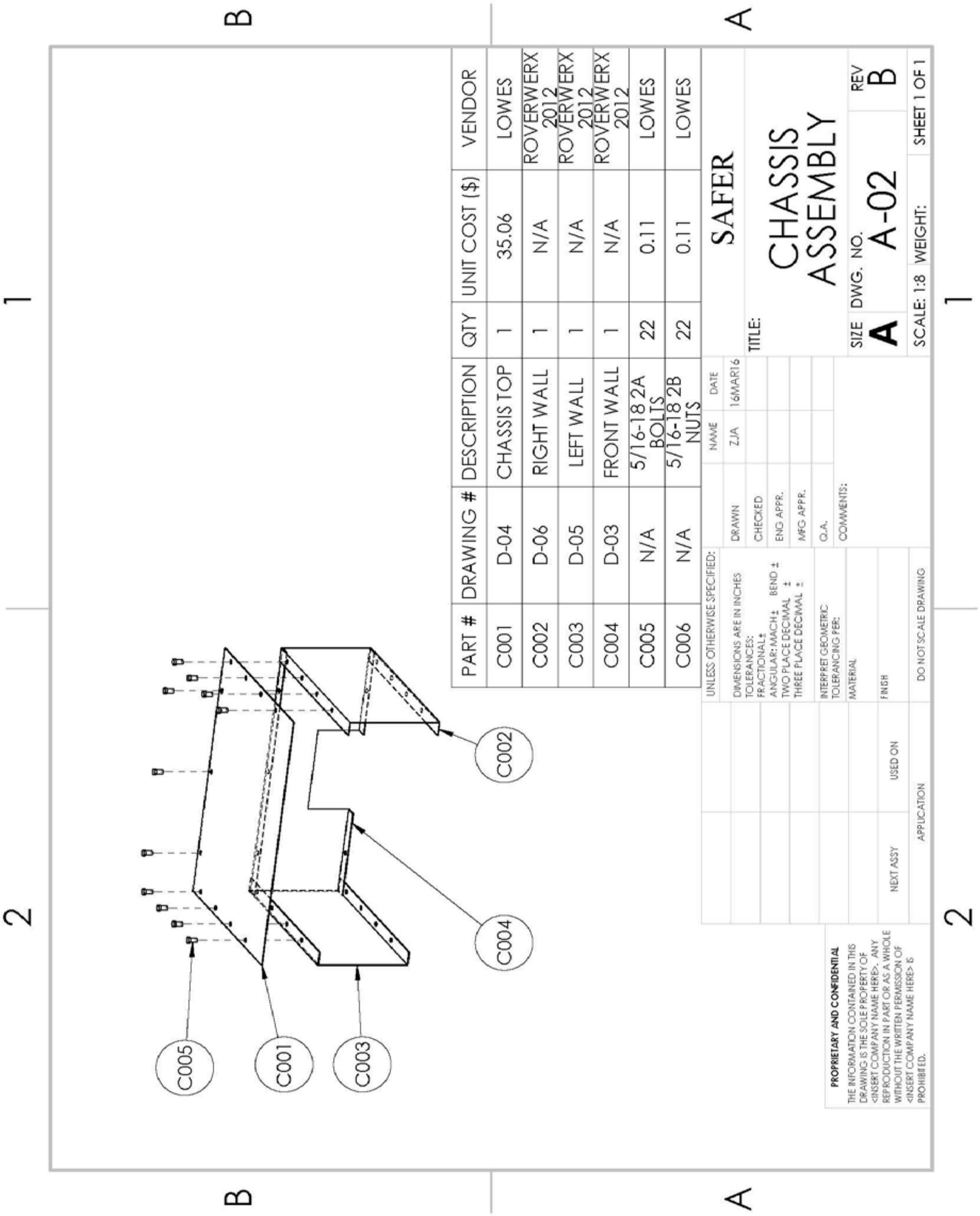
A7.5: Beacon Dispenser Track



A7.6: Beacon Dispenser Door

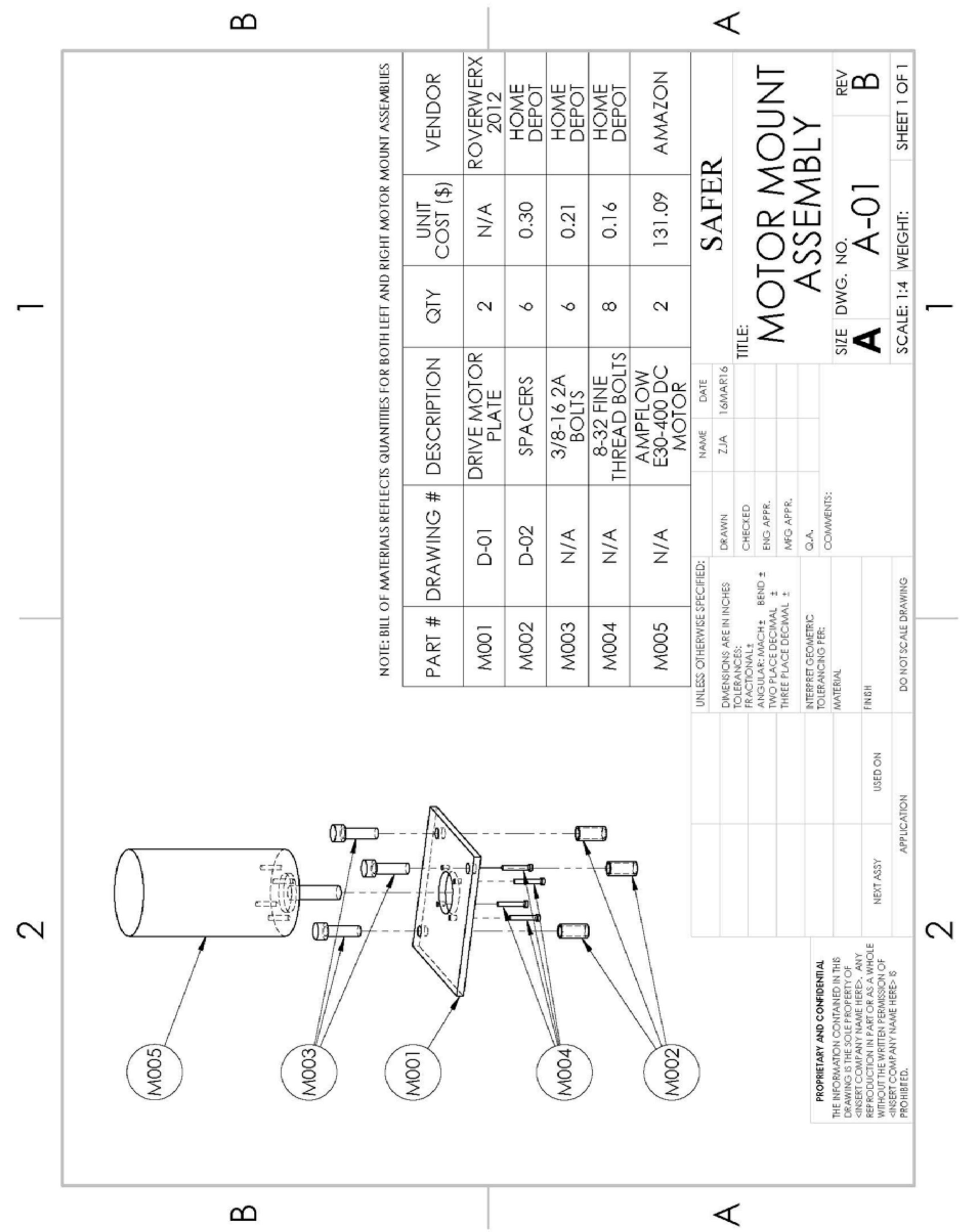


A7.7: Chassis Assembly



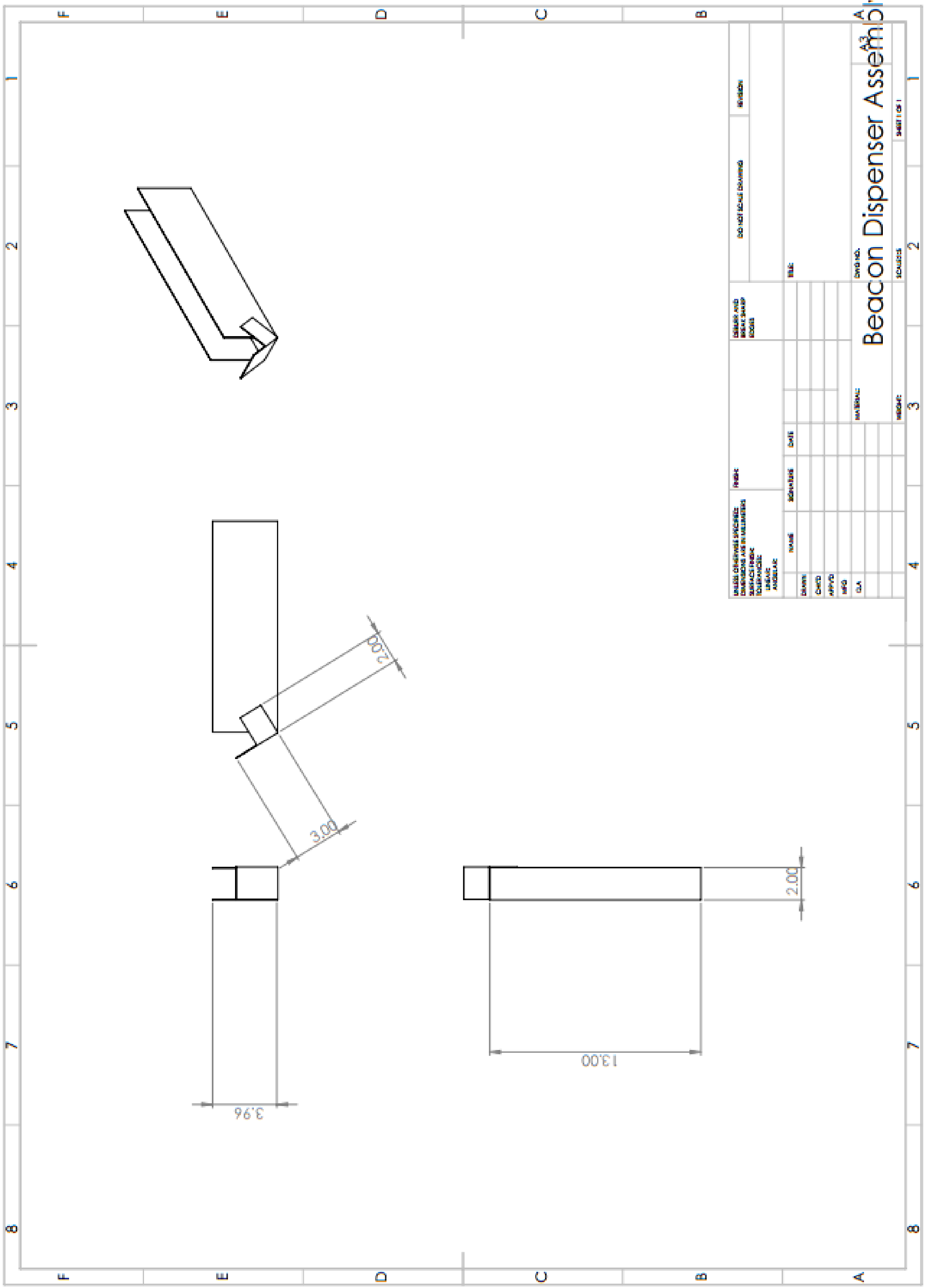
PART #	DRAWING #	DESCRIPTION	QTY	UNIT COST ($)	VENDOR
C001	D-04	CHASSIS TOP	1	35.06	LOWES
C002	D-06	RIGHT WALL	1	N/A	ROVERWERX 2012
C003	D-05	LEFT WALL	1	N/A	ROVERWERX 2012
C004	D-03	FRONT WALL	1	N/A	ROVERWERX 2012
C005	N/A	5/16-18 2A BOLTS	22	0.11	LOWES
C006	N/A	5/16-18 2B NUTS	22	0.11	LOWES

A7.8: Drive Motor Mount Assembly



PART #	DRAWING #	DESCRIPTION	QTY	UNIT COST ($)	VENDOR
M001	D-01	DRIVE MOTOR PLATE	2	N/A	ROVERWERX 2012
M002	D-02	SPACERS	6	0.30	HOME DEPOT
M003	N/A	3/8-16 2A BOLTS	6	0.21	HOME DEPOT
M004	N/A	8-32 FINE THREAD BOLTS	8	0.16	HOME DEPOT
M005	N/A	AMPFLOW E30-400 DC MOTOR	2	131.09	AMAZON

A7.9: Beacon Dispenser Assembly



A8: Code

```
/*
  SAFER Version 4

  (6/1/2016)
*/

#include <Servo.h>

/////////////////// RC Controller //////////////////

//Receiver Pins
const int chA = 43;
const int chB = 45;
const int chC = 47;
const int chD = 49;
const int chE = 52;
const int chF = 53;

//RC Signal Conditioning limits
/*
  | RCmin - RClowcenter - RClocalmin| | RCcenter | | RClocalmax - RChighcenter - RCmax |
*/

//RC Controller Values

const int RCmax = 1980;
const int RCmin = 1020;
const int RClocalmax = 1550;
const int RClocalmin = 1450;
const int RChighcenter = 1765;
const int RCcenter = 1500;
const int RClowcenter = 1235;
const int RCrange = RCmax - RClocalmax;
int Pivotlocalmax = RCcenter + 200;
int Pivotlocalmin = RCcenter - 200;
int PivotRange = RCmax - Pivotlocalmax;

//Initiating Arrays
long int ch[7]; //RC Channel Array
long int MotorValue[7]; //Motor Value Array
long int Percentage[7]; //Percentages Array


/////////////////// DC Motor Values //////////////////
```

```
//DC Motor Pins
const int LeftPWM = 11;
const int RightPWM = 12;

//Motor Signal Conditioning Limits
const int MotorForwardMax = 260;
const int MotorForwardMin = 190;
const int MotorBackwardMax = 80;
const int MotorBackwardMin = 180;

//Calculated Motor Values
int leftMotor = 0;
int rightMotor = 0;

//Secondary Motor Speed Control
int Radius = 0;
int ForwardRadius = 0;
int BackwardRadius = 0;
int SecondarySpeedControl = 0;

//////////////////// Stepper Motor ////////////////////

//Stepper Motor Pins
const int directionPin = 6;
const int stepPin = 7;
const int ENAPin = 5;

//Stepper Motor Step Constants
const int NumSteps = 1000; // steps
const int Speed = 600; // how fast the motor will "step"
const int StepperThreshold = 50;
const int Stepper90Degrees = 10000;
int StepperZeroDegrees;
int TargetStep;


//////////////////// Servo Motor ////////////////////

Servo beaconServo;

const int servoPin = 9;

//Servo Motor Position Values
const int servoOpen = 30;
const int servoClosed = 110;
```

```
int pos;

//////////////////// Initializing Pins ////////////////////

void setup()
{
  Serial.begin(9600);

  //Receiver Pins Setup
  pinMode(chA, INPUT);
  pinMode(chB, INPUT);
  pinMode(chC, INPUT);
  pinMode(chD, INPUT);
  pinMode(chE, INPUT);
  pinMode(chF, INPUT);

  pinMode(directionPin, OUTPUT);
  pinMode(stepPin, OUTPUT);
  pinMode(ENAPin, OUTPUT);
  digitalWrite(directionPin, LOW);
  digitalWrite(stepPin, LOW);
  digitalWrite(ENAPin, LOW);
}


////////////////////////////////////////////////////
//////////////////// Main Program ////////////////////
////////////////////////////////////////////////////

void loop()
{

  //Read Transmitter Values
  ch[1] = pulseIn(chA, HIGH);
  ch[2] = pulseIn(chB, HIGH);
  ch[3] = pulseIn(chC, HIGH);
  ch[4] = pulseIn(chD, HIGH);
  ch[5] = pulseIn(chE, HIGH);
  ch[6] = pulseIn(chF, HIGH);

  if (ch[5] < 1200)
  {
    SystemOff();
  }
  else
  {
```

```
if (ch[6] < 1100)
{
 CalibrationMode();
 StepperZeroDegrees = 0;
}
else if (ch[6] >= 1100 && ch[6] <= 1600)
{
 SecondarySystems();
}
else if (ch[6] > 1600)
{

 Serial.println(" | Primary Systems | ");

 //Motor Pins Setup
 pinMode(LeftPWM, OUTPUT);
 pinMode(RightPWM, OUTPUT);
 beaconServo.detach();

 FeedbackCorrection(ch, 4); //Correct RC Input Values
 MotorValueCalculation(ch, 4); //Calculate Values For Motor Output

 //Determining Type of Directional Drive
 if (ch[4] < Pivotlocalmin || ch[4] > Pivotlocalmax)
 {
  PivotDrive(ch, 4);
  Serial.print("Pivot");
 }
 else
 {
  if (ch[2] > RCcenter && ch[1] == RCcenter)
  {
   StraightDrive(ch, 4);
   Serial.print("Forward");
  }
  else if (ch[2] < RCcenter && ch[1] == RCcenter)
  {
   StraightDrive(ch, 4);
   Serial.print("Backward");
  }
  else if (ch[2] > RCcenter && ch[1] < RCcenter)
  {
   ForwardLeftDrive(ch, 4);
   ForwardDriveCorrection(ch, 4);
   Serial.print("Forward_Left");
  }
```

```
    else if (ch[2] > RCcenter && ch[1] > RCcenter)
    {
      ForwardRightDrive(ch, 4);
      ForwardDriveCorrection(ch, 4);
      Serial.print("Forward_Right");
    }
    else if (ch[2] < RCcenter && ch[1] < RCcenter)
    {
      BackwardLeftDrive(ch, 4);
      BackwardDriveCorrection(ch, 4);
      Serial.print("Backward_Left");
    }
    else if (ch[2] < RCcenter && ch[1] > RCcenter)
    {
      BackwardRightDrive(ch, 4);
      BackwardDriveCorrection(ch, 4);
      Serial.print("Backward_Right");
    }
    else if (ch[2] == RCcenter && ch[1] == RCcenter)
    {
      Idle();
      Serial.print("Idle");
    }
  }
  //Outputing Values To Drive Motors
  if (ch[5] > 1500)
  {
    analogWrite(LeftPWM, leftMotor);
    analogWrite(RightPWM, rightMotor);
  }
}

//Types of Printing Cases

//PrintRCValues();
//PrintRCPercentages();
//PrintMotorValues();
//PrintMotorPercentages();
//PrintMotorPower();

//Reset All Array Values To Neutral Positions
for (int i = 0; i < 4; i++)
{
  ch[i] = RCcenter;
  Percentage[i] = 0;
  MotorValue[i] = 0;
```

```
    }

    //So The Control System Doesn't Freak Out
    delay(1);
  }
}


//////////////////////////////////////////////////////////////////////
/////////////////// Dual Motor Drive Methods ///////////////////
//////////////////////////////////////////////////////////////////////


//Corrects Raw RC Values
void FeedbackCorrection(long int* arr, unsigned int len)
{
  for (int i = 1; i <= len; i++)
  {
    if (arr[i] < RCmin) //Trim Noise From Bottom End
    {
      arr[i] = RCmin;
    }

    if (arr[i] < RClocalmax && arr[i] > RClocalmin) //Trim Noise To Dead-Band
    {
      arr[i] = RCcenter;
    }

    if (arr[i] > RCmax) //Trim Noise From Top End
    {
      arr[i] = RCmax;
    }
  }
}


//Forward drive motor value correction
void ForwardDriveCorrection(long int* arr, unsigned int len)
{
  for (int i = 1; i <= len; i++)
  {

    if (leftMotor < MotorForwardMin) //Trim Noise From Bottom End For Left Motor
    {
      leftMotor = MotorForwardMin;
    }
```

```
    if (rightMotor < MotorForwardMin) //Trim Noise From Bottom End For Right Motor
    {
      rightMotor = MotorForwardMin;
    }

    if (leftMotor > MotorForwardMax) //Trim Noise From Top End For Left Motor
    {
      leftMotor = MotorForwardMax;
    }

    if (rightMotor > MotorForwardMax) //Trim Noise From Top End For Right Motor
    {
      rightMotor = MotorForwardMax;
    }
  }
}


//Backward drive motor value correction
void BackwardDriveCorrection(long int* arr, unsigned int len)
{
  for (int i = 1; i <= len; i++)
  {

    if (leftMotor > MotorBackwardMin) //Trim Noise From Bottom End For Left Motor
    {
      leftMotor = MotorBackwardMin;
    }

    if (rightMotor > MotorBackwardMin) //Trim Noise From Bottom End For Right Motor
    {
      rightMotor = MotorBackwardMin;
    }

    if (leftMotor < MotorBackwardMax) //Trim Noise From Top End For Left Motor
    {
      leftMotor = MotorBackwardMax;
    }

    if (rightMotor < MotorBackwardMax) //Trim Noise From Top End For Right Motor
    {
      rightMotor = MotorBackwardMax;
    }
  }
}
```

```
//Calculates Percentages, Radius, and Motor Values For Driving Motors
void MotorValueCalculation(long int* arr, unsigned int len)
{
  for (int i = 1; i <= len; i++)
  {

    if (arr[i] >= RClocalmax) //For Filtered High Values
    {
      Percentage[i] = (arr[i] - RClocalmax) * 100 / (RCrange);
      MotorValue[i] = map(Percentage[i], 0, 100, MotorForwardMin, MotorForwardMax);
    }

    else if (arr[i] <= RClocalmin) //For Filtered Low Values
    {
      Percentage[i] = (arr[i] - RClocalmin) * -100 / (RCrange);
      MotorValue[i] = map(Percentage[i], 0, 100, MotorBackwardMin, MotorBackwardMax);
    }
  }

  Radius = sqrt((abs(Percentage[1] * Percentage[1])) + (abs(Percentage[2] * Percentage[2])));

  //Radius filter correction
  if (Radius > 100)
  {
    Radius = 100;
  }
  else if (Radius < 0)
  {
    Radius = 0;
  }

  //Radius calculations for secondary motor speed control
  ForwardRadius = map(Radius, 0, 100, MotorForwardMin, MotorForwardMax);
  BackwardRadius = map(Radius, 0, 100, MotorBackwardMin, MotorBackwardMax);
  SecondarySpeedControl = map(Percentage[1], 0 , 100, 0 , 35);
}


void Idle()
{
  //Turn Motors Off
  leftMotor = 0;
  rightMotor = 0;
}
```

```
void StraightDrive(long int* arr, unsigned int len)
{
  leftMotor = MotorValue[2];
  rightMotor = MotorValue[2];
}


void ForwardLeftDrive(long int* arr, unsigned int len)
{
  leftMotor = MotorValue[2] - SecondarySpeedControl;
  rightMotor = ForwardRadius;
}


void ForwardRightDrive(long int* arr, unsigned int len)
{
  leftMotor = ForwardRadius;
  rightMotor = MotorValue[2] - SecondarySpeedControl;
}


void BackwardLeftDrive(long int* arr, unsigned int len)
{
  leftMotor = MotorValue[2] + SecondarySpeedControl;
  rightMotor = BackwardRadius;
}


void BackwardRightDrive(long int* arr, unsigned int len)
{
  leftMotor = BackwardRadius;
  rightMotor = MotorValue[2] + SecondarySpeedControl;
}


void PivotDrive(long int* arr, unsigned int len)
{
  if (arr[4] < Pivotlocalmin) //Left Pivot
  {
    leftMotor = (map(Percentage[4], 0, 100, MotorBackwardMin, MotorBackwardMax));
    rightMotor = (map(Percentage[4], 0, 100, MotorForwardMin, MotorForwardMax));
  }
  if (arr[4] > Pivotlocalmax) //Right Pivot
  {
```

```
    leftMotor = (map(Percentage[4], 0, 100, MotorForwardMin, MotorForwardMax));
    rightMotor = (map(Percentage[4], 0, 100, MotorBackwardMin, MotorBackwardMax));
  }
}


////////////////////////////////////////////////////////////////////
/////////////////// Secondary System Methods ///////////////////
////////////////////////////////////////////////////////////////////


void SecondarySystems()
{
  Serial.println(" | Secondary Systems Activated | ");
  delay(1000);

  while (ch[6] >= 1100 && ch[6] <= 1600)
  {
    ch[2] = pulseIn(chB, HIGH);
    ch[3] = pulseIn(chC, HIGH);
    ch[5] = pulseIn(chE, HIGH);
    ch[6] = pulseIn(chF, HIGH);
    delay(50);

    if (ch[5] < 1200)
    {
      SystemOff();
    }

    if (ch[2] < 1000)
    {
      delay(500);
      ActivateBeacon();
    }

    beaconServo.detach();

    //Control Flippers
    //Flippers(ch[3]);

  }
}


/////////////////////////////////////////////////////////////////////////
/////////////////// Flipper Stepper Motor Methods ///////////////////
```

```
////////////////////////////////////////////////////////////////////////


void Flippers(long int arr)
{
  //Control Flippers
  FlippersFeedbackCorrection(ch[3]);

  int BeforeStep = 0;
  int AfterStep = 0;
  int Difference = 0;

  BeforeStep = pulseIn(chC, HIGH);

  if (BeforeStep < RCcenter)
  {
    BeforeStep = RCcenter;
  }

  delay(300);
  AfterStep = pulseIn(chC, HIGH);

  if (AfterStep < RCcenter)
  {
    AfterStep = RCcenter;
  }

  Difference = (AfterStep - BeforeStep);
  TargetStep = map(AfterStep, RCcenter, RCmax, StepperZeroDegrees, Stepper90Degrees);

  if (Difference >= (-1 * StepperThreshold) && Difference <= StepperThreshold)
  {
    digitalWrite(directionPin, HIGH);
    digitalWrite(stepPin, LOW);
    digitalWrite(ENAPin, LOW);
    Serial.println("Flippers Idle");
  }

  else if (Difference > StepperThreshold)
  {

    Serial.println("Flippers Rising");
    digitalWrite(directionPin, LOW);
    digitalWrite(ENAPin, HIGH);

    for (int distance = 0; distance < TargetStep; distance++)
```

```
    {
      digitalWrite(stepPin, LOW);
      delayMicroseconds(Speed);
      digitalWrite(stepPin, HIGH);
      delayMicroseconds(Speed);
    }

    digitalWrite(stepPin, LOW);
    digitalWrite(ENAPin, LOW);
    delay(10);
  }

  else if (Difference < (-1 * StepperThreshold))
  {

    Serial.println("Flippers Lowering");
    digitalWrite(directionPin, HIGH);
    digitalWrite(ENAPin, HIGH);

    for (int distance = 0; distance < TargetStep; distance++)
    {
      digitalWrite(stepPin, LOW);
      delayMicroseconds(Speed);
      digitalWrite(stepPin, HIGH);
      delayMicroseconds(Speed);
    }

    digitalWrite(stepPin, LOW);
    digitalWrite(ENAPin, LOW);
    delay(10);
  }

}


//Corrects Raw RC Values For Flippers
void FlippersFeedbackCorrection(long int arr)
{
  if (ch[3] < RClocalmax) //Trim Noise From Bottom End
  {
    ch[3] = RCcenter;
  }

  if (ch[3] >= RCmax) //Trim Noise From Top End
  {
    ch[3] = RCmax;
```

```
  }
}


//Activate Beacon System
void ActivateBeacon()
{
  Serial.println(" | Beacon System Activated | ");
  beaconServo.attach(servoPin);

  for (pos = servoClosed; pos >= servoOpen; pos--)
  {
    beaconServo.attach(servoPin);
    beaconServo.write(pos);
    delay(5);
  }

  beaconServo.write(servoOpen);
  delay(100);
  Serial.println("OPEN");
  beaconServo.detach();
  delay(100);
  beaconServo.attach(servoPin);

  for (pos = servoOpen; pos <= servoClosed; pos++)
  {
    beaconServo.attach(servoPin);
    beaconServo.write(pos);
    delay(5);
  }

  beaconServo.write(servoClosed);
  delay(500);
  Serial.println("CLOSED");
  beaconServo.detach();
  delay(1000);
}


////////////////////////////////////////////////////////
//////////////////// Calibration Mode ///////////////////
////////////////////////////////////////////////////////


void CalibrationMode()
{
```

```
Serial.println(" | Calibration Mode | ");
delay(1000);
/*
  Serial.println("Calibrating servo motor...");
  beaconServo.attach(servoPin);
  beaconServo.write(servoClosed);
  delay(500);
  beaconServo.detach();
*/
Serial.println("Calibrating stepper motor...");
delay(1000);

while (ch[6] < 1100)
{

  ch[3] = pulseIn(chC, HIGH);
  ch[5] = pulseIn(chC, HIGH);

  if (ch[5] < 1200)
  {
    SystemOff();
  }

  if (ch[3] > 1600)
  {
    Serial.println("Flippers Rising");
    digitalWrite(directionPin, LOW);
    digitalWrite(stepPin, LOW);
    digitalWrite(ENAPin, HIGH);

    for (int distance = 0; distance < 200; distance++)
    {
      digitalWrite(stepPin, LOW);
      delayMicroseconds(Speed);
      digitalWrite(stepPin, HIGH);
      delayMicroseconds(Speed);
    }
  }

  else if (ch[3] < 1400)
  {
    Serial.println("Flippers Lowering");
    digitalWrite(directionPin, HIGH);
    digitalWrite(stepPin, LOW);
    digitalWrite(ENAPin, HIGH);
```

```
      for (int distance = 0; distance < 200; distance++)
      {
        digitalWrite(stepPin, LOW);
        delayMicroseconds(Speed);
        digitalWrite(stepPin, HIGH);
        delayMicroseconds(Speed);
      }
    }

    else if (ch[3] >= 1400 && ch[3] <= 1600)
    {
      Serial.println("Flippers Still");
      digitalWrite(directionPin, LOW);
      digitalWrite(stepPin, LOW);
      digitalWrite(ENAPin, LOW);
    }
    digitalWrite(stepPin, LOW);
    digitalWrite(ENAPin, LOW);
    delay(100);

    ch[6] = pulseIn(chC, HIGH);
  }
}


void SystemOff()
{
  Serial.println(" | All Systems OFF | ");

  while (ch[5] < 1200)
  {
    ch[5] = pulseIn(chE, HIGH);
    pinMode(LeftPWM, INPUT);
    pinMode(RightPWM, INPUT);
    beaconServo.detach();
    digitalWrite(stepPin, LOW);
    digitalWrite(ENAPin, LOW);
  }
}


//////////////////////////////////////////////////////////////////
/////////////////// Printing Values Methods //////////////////
//////////////////////////////////////////////////////////////////
```

```
void PrintRCValues()
{
  Serial.print ("Ch1: ");
  Serial.print (ch[1]);
  Serial.print (" | ");
  Serial.print ("Ch2: ");
  Serial.print (ch[2]);
  Serial.print (" | ");
  Serial.print ("Ch3: ");
  Serial.print (ch[3]);
  Serial.print (" | ");
  Serial.print ("Ch4: ");
  Serial.print (ch[4]);
  Serial.print (" | ");
  Serial.print ("Ch5: ");
  Serial.print (ch[5]);
  Serial.print (" | ");
  Serial.print ("Ch6: ");
  Serial.print (ch[6]);
  Serial.print (" | ");
  Serial.println (" ");
}


void PrintRCPercentages()
{
  Serial.print ("Ch1: ");
  Serial.print (Percentage[1]);
  Serial.print (" | ");
  Serial.print ("Ch2: ");
  Serial.print (Percentage[2]);
  Serial.print (" | ");
  Serial.print ("Ch3: ");
  Serial.print (Percentage[3]);
  Serial.print (" | ");
  Serial.print ("Ch4: ");
  Serial.print (Percentage[4]);
  Serial.print (" | ");
  Serial.print ("Ch5: ");
  Serial.print (Percentage[5]);
  Serial.print (" | ");
  Serial.print ("Ch6: ");
  Serial.print (Percentage[6]);
  Serial.print (" | ");
  Serial.println (" ");
```

```
}


void PrintMotorValues()
{
  Serial.print ("Ch1: ");
  Serial.print (MotorValue[1]);
  Serial.print (" | ");
  Serial.print ("Ch2: ");
  Serial.print (MotorValue[2]);
  Serial.print (" | ");
  Serial.print ("Ch3: ");
  Serial.print (MotorValue[3]);
  Serial.print (" | ");
  Serial.print ("Ch4: ");
  Serial.print (MotorValue[4]);
  Serial.print (" | ");
  Serial.print ("Ch5: ");
  Serial.print (MotorValue[5]);
  Serial.print (" | ");
  Serial.print ("Ch6: ");
  Serial.print (MotorValue[6]);
  Serial.print (" | ");
  Serial.println (" ");
}


void PrintMotorPercentages()
{
  if (leftMotor > 185)
  {
    Serial.print ("Left: ");
    Serial.print (map(leftMotor, 190, 260, 0, 100));
  }
  else
  {
    Serial.print ("Left: ");
    Serial.print(map(leftMotor, 180, 80, 0, 100));
  }

  Serial.print (" | ");

  if (rightMotor > 185)
  {
    Serial.print ("Right: ");
    Serial.print (map(rightMotor, 190, 260, 0, 100));
```

```
 }
 else
 {
   Serial.print ("Right: ");
   Serial.print (map(rightMotor, 180, 80, 0, 100));
 }

 Serial.print (" | ");
}


void PrintMotorPower()
{
 Serial.print(" |  Left: ");
 Serial.print(leftMotor);
 Serial.print(" | Right: ");
 Serial.print(rightMotor);
 Serial.println(" ");
}
```

A9: User Manual

1. Introduction

SAFER uses an RC wireless teleoperated control system, which carries out a series of tasks. This user manual will cover the setup procedure, which is implemented before operating the rover along with the three different modes of controlling the rover.

2. Setup

Before operating the rover, safety and connectivity procedures need to be done to ensure that all electronic components are connected properly and working correctly.

a. Ensure that the climbing tracks are at a safe angle so they will not touch the chassis of the rover during operation.
b. The LED strip light switch must be turned off (top-half of the switch pushed in).
c. Inspect that all wires are connected in the breadboard, the motor controller, the Arduino Mega, the stepper motor driver, and the RC receiver.
d. Check the two fuse boxes to make sure that new, unbroken fuse have been installed. If not, install new fuses before continuing the setup.
e. Connect the batteries to the power terminal.
    i. Each battery consists of two wire boxes that contain a red and a black wire each.
    ii. The power terminal consists of two paths, each having 1 fuse box.
    iii. Pair the two wire boxes of each battery to the two wire boxes of each fuse box path of the power terminal.
    iv. For each pair, connect each wire box so the red wire of one connects with the red wire of the other box, and the black wire of one connects with the black wire of the other box. MAKE SURE THAT THE COLORS ALIGN. The first box connectivity will form a small spark – this is expected.
f. Once the batteries are connected, feel each component to make sure that nothing is warm. If any electronic component seems hot at this point, DISCONNECT THE POWER WIRES IMMEDIATELY.
g. Check to see if the DC AX2550 motor controller is blinking a red light, the RC receiver has a red light, and the stepper motor controller is illuminating a green light.
h. Turn on the battery pack under the Arduino Mega.
i. Flip all switches on the RC controller in the "up" position and the left joystick in the "down" position.
j. Turn on the RC controller.
    i. You should see the battery life of the RC controller and that of the RC receiver.
k. Turn the left main power switch OFF (down position) for now.
l. SHUTDOWN Procedure
    i. Turn the main power switch OFF
    ii. Turn LED strip switch OFF
    iii. Turn battery pack under the Arduino Mega OFF
    iv. Turn RC controller OFF
    v. Disconnect all four power wire boxes

3. Operation

a. Overview

Now that the rover is live, the RC controller can now be used to operate SAFER. At this point, there should be no power being used with the Arduino Mega in order to communicate with the electronic components. This is because the main power switch is in the OFF position. All controller modes will not work unless this switch is turned ON. This switch can be turned ON or OFF at any point during operation in order to temporarily turn the rover ON or OFF.

NOTE: Turning off the switch does not physically restrict the electronic components from receiving power. Although turned off, the components should still be checked for excessive heat. If at any point during operation, even if the main power switch is ON or OFF, an electronic component seems excessively warm, disconnect the power wires IMMEDIATELY.

b. Drive Mode

i. Overview

This mode is activated when the Mode Switch (right switch on the RC controller) is flipped to the top-most position. This mode only enables communication to the DC motor controller, which operates the drive motors. This mode does not operate any other component.

ii. Drive

In order to drive the rover, the right joystick on the RC controller is used. To drive the rover, start by pushing the joystick UP or DOWN to move the rover FORWARD or BACKWARDS respectively. While holding the joystick in the upward or downward region, turns can be made by moving the joystick to the right or left. This joystick also enables speed regulation – the farther the joystick position is from the center origin, the faster the rover will move.

NOTE: Due to the joystick algorithm, joystick positions directly along the X-axis of the joystick layout will not enable operation.

Pivot turns are made by using the X-axis of the joystick layout of the LEFT joystick on the RC controller. This joystick also enables speed regulation as previously described.

c. Secondary Systems Mode

i. Overview

The Secondary Systems Mode only enables communication with the stepper motor controller and the beacon delivery system. This mode does not operate the drive system.

ii. Climbing Tracks

The angle of the climbing tracks is governed by the LEFT joystick of the RC controller. During this mode, the X-axis of this joystick does not constitute any operation. The angular position of the climbing tracks is controlled with the non-spring-loaded positive Y-axis orientation of the joystick. The center of the joystick layout matches with the zero degrees position of the climbing tracks (parallel with the ground). The up-most joystick position matches with the 90 degrees position of the climbing tracks (perpendicular to the ground).

NOTE: At any joystick position where the joystick is in the negative Y-axis region will cause the climbing tracks to move to the zero degrees position.

iii. Beacon Dispenser

In order to operate the beacon system, the right joystick is used. While not operating the climbing tracks with the left joystick, hold the right joystick in the DOWN position for about half a second, then release. The beacon delivery system will then activate.

NOTE: While the beacon system is autonomously operating, no other controls are permitted.

d. Calibration Mode

i. Overview

In order to enter Calibration Mode, the right Mode Switch should be flipped to the down-most position. Once this happens, the program will run autonomously for about five seconds as it calibrates the RC connection and the Beacon System.

NOTE: If the Beacon System moves, this is to be expected as it is calibrating the Beacon System door to its origin position.

ii. Calibrating Climbing Tracks

After the Beacon System has been calibrated, the Calibration Mode will exit its autonomous calibration and will enable to user calibration. This part of the calibration process is to set the zero degrees position for the climbing tracks. For this, the user can use the right joystick of the RC controller to reposition the tracks to the zero degrees position. This mode allows the user to use the positive and the negative Y-axis of the right joystick layout to cause the climbing tracks to raise or lower. Once the climbing tracks are in the zero degrees position (parallel to the ground), flip the Mode Switch to either Drive Mode or Secondary Systems Mode.

A10: Senior Design Conference Presentation Slides

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SAFER
Search and Find Emergency Rover

Zachary Agustin, Charles Lewis, Elizabeth McMahon, Cameron Pierce, Pranav Pradhan, Michael Tamshen
Senior Mechanical Engineers

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Outline

- Problem Definition
- Existing Technologies
- Customer Needs and Goals
- Subsystems: Motors and Batteries
- Functional Analysis: Drive Control System
- Demonstrations
- Future Improvements and Conclusions

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Problem Definition

- S&R teams have few assessment tools
- Victims are often trapped in confined spaces
- Maneuverable rover to provide reconnaissance

Example of collapsed structure and confined and unstable spaces.[1]

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Existing Technologies

Talon [2]

Solem [4]

Urbot MPRS [3]

PackBot EOD 510 [5]

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Benchmarking Results

Specifications	PackBot EOD 510	Urbot MPRS	Solem	Talon
Speed (mph)	5.8	1.7	1.1	4.0
Weight (lb)	24	65	33	85
Battery Life (hrs)	4	2	1	4
Cost (USD)	100k-200k	70k	60k	>60k

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Customer Needs

- Ease of use
- Maintain speed comparable to walking human
- Battery life of at least 2 hours
- Climbing capability
- Lightweight

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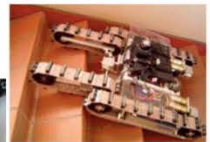
Baseline


2007 Rover [6]


Baseline Rover

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Project Design Specifications

Specifications	2012 Roverwerx	SAFER Targets
Top Speed (ft/s)	2	3
Drive Torque (in-lb)	11	96
Weight (lb)	200	
Battery Life (hrs)	0.5	1-3

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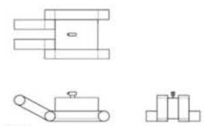
Team Goals

Baseline:

- Reliable Functionality
- High Torque Maneuverability
- Effective Remote Control Capability
- High-Resolution, 360° Camera with Live Feed

Reach:

- Accurate Location Technology
- 3 DOF Robotic Arm


Rover Schematic Drawing

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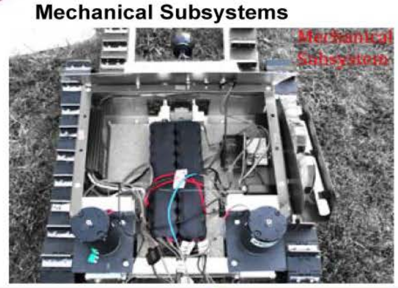
Mechanical Subsystems



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Mechanical Subsystems Overview



NiMH Batteries [7]

DC Drive Motor [9]



Nema 23 Stepper Motor [8]

Drive Motor Gear Box



Stepper Motor Gear Box

Drive Tracks

Climbing Tracks

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Gearbox Designs

- Most important parameter is torque multiplication
- Determined current gear box is best option
  - Manufacturing time for new design too long
  - 30:1 gear ratio
- Safety and Reliability
  - Shearing
  - Protective Plate


Drive Motor Gear Box

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Drive Motor Selection

- Torque output, price, and size most important criteria
- 25 in-lb required
  - Assume 200 lb and vertical approach
  - 2012 motors have 11 in-lb
- AmpFlow E30-400 selected
  - 93 in-lb torque
  - 5700 rpm
  - 2 hp
- Safety and Reliability
  - DC motor controller limits current

DC Drive Motor [9]

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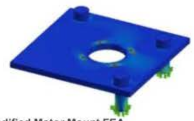
Drive Motor Mounting Assembly

- New motors warranted new mount design
- Spacers added to accommodate longer shaft
- Analysis indicates structural integrity


Modified Motor Mount FEA Results


Modified Motor Mount Drawing

Motor Installed with Modified Mount

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Stepper Motor Selection

- 2.8 Amp
- High Torque
  - 1800 oz-in required for 200 lb rover
  - 2832 oz-in supplied
- Run by separate driver
- 4:1 Gear Ratio
  - Slow movement for high articulation


Nema 23 Stepper Motor [8]

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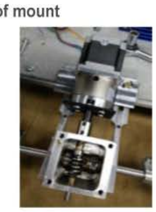
Stepper Motor Mounting

- New motors warranted redesign of mount
- Mounted at a 20° angle
- Made of 2024 Aluminum
- Standard NEMA 23 L-bracket
- 12 mm to ¼ in coupler


Stepper Motor Installed on Modified Mount

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Battery Selection

- Most important design criteria
  - Voltage output (24 V)
  - Current output (3.1 A)
  - Weight
- AAPPC NiMH Battery Pack (x2)
  - 24 V nominal voltage
  - 10 Ah capacity
  - 8 lbs
- Safety and Reliability
  - DC motor controller limits max discharge rate of 30 A

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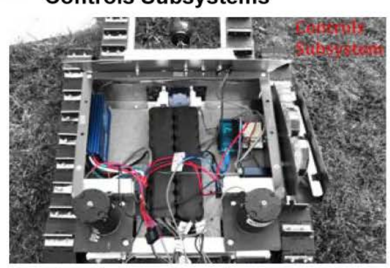
Controls Subsystems



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Drive Control Systems Overview

- RC to arduino to motor controller and stepper driver to respective motors

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Functional Analysis: Drive Control System

- FlySky FS-i6 with 2.4 Ghz Receiver
  - Left and Right Joysticks
- RoboteQ AX2550 DC Motor Controller
  - Dual H Bridge for dual motor drive
  - Internal sensors
  - Current Limiter
- AmpFlow E30-400 Brushed DC Motors
  - Current (no load): 3.1 A
  - Current (stall): 65 A
- Nema 23 Stepper Motor

Figure 19: Drive Control System Diagram

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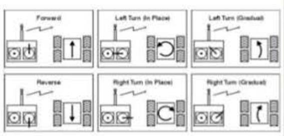
Functional Analysis: Drive Control System



FlySky Rover Controls

FlySky Remote Controller

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Signal Beacon Dispenser

- Flashing bright lights
- Indicate survivor location
- Controlled by servo motor

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Beacon Dispenser In Action

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Lights and Sensors

- Ultra-Bright LEDs
- Air Quality Sensors

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Video Of Use

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Operator View

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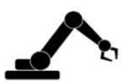
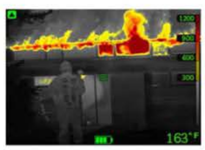
Future Improvements

- Robotic Arm
- Infrared Thermal Imaging
- Weight Reduction



Potential Robotic Arm



Infrared Camera View in a Fire

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Final Specifications

Specifications	2012 Roverwerx	SAFER Targets	SAFER Final Specifications
Top Speed (ft/s)	2	2-3	
Drive Torque (in-lb)	11	25	96
Weight (lb)	200	<150	
Battery Life (hrs)	0.5	2	1-3

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Goals Achieved

- High-Torque Maneuverability
  - High power DC motors
- Remote Controlled
- 360Fly Camera with live feed to mobile device
- Signal Beacons
- Top Speed

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Conclusions

- Baseline Design Near Completion
- Signal Beacons Complete
- Customer Needs Near Completion
- WHAT DID WE LEARN

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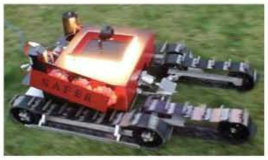
Conclusions

- Provide effective reconnaissance aid to S&R teams
  - Returns data to operator to safely assess surroundings
- Decrease number of injuries to S&R personnel
- Potential to revolutionize S&R process



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Acknowledgements

This project was made possible with the help of Dr. Christopher Kitts and the Robotic Systems Lab.

Special thanks to our primary advisor, Dr. Calvin Tszeng.

Thank you to the Santa Clara School of Engineering for funding this project.

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Thank you!

Questions?

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Reference Slide: Budget

Category	Item	Cost ($)
Drive System	AmpFlow E30-400 (x2)	262.18
	24 V NiMH Battery (x2)	518.33
	Battery Charger	64.99
	Nema 23 Stepper Motor	162.53
	Motor Driver	78.98
	Shaft Coupler and Collar	57.12
Control System	Arduino Mega	34.58
	RC Controller	59.99
	Mega Case Enclosure	7.99
	Battery Enclosure Holder	7.04
	Performance Batteries	8.99
	Multimeter	13.37

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Reference Slide: Budget (Continued)

Category	Item	Cost ($)
Sensors	Signal Beacons	
	360Fly Camera	434.99
	LED Lights	
Raw Materials	Weld Steel Sheet Metal (24"x24")	35.06
	Black 12 Gauge Wire	
	Red 12 Gauge Wire	
	Rubber	15.58
	Miscellaneous Parts	50.00

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