ECE Final Report

EE/COMPE 496A Senior Design

Team 14, Project 25: Rapid Deployment Runway Closure System

The Blockage Brigade

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Table of Contents

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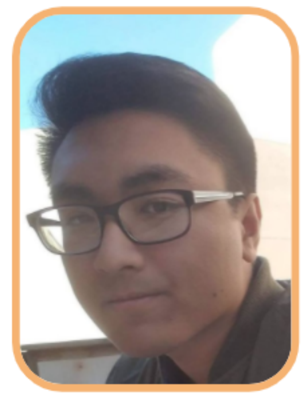

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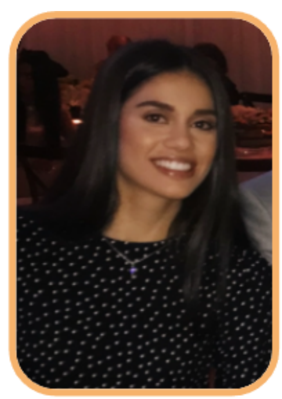

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System Description

Remote airstrip runways are likely to be influenced by unapproved use by external aircrafts which produces potential safety risks, blocks airstrips from use by other aircrafts and it also violates personal property. The existing solution to this problem is by spreading heavy debris like tires, material scraps, and barricades to create a somewhat physical barrier that planes would not be able to land over. This procedure is not only difficult and laborious, but also displays a degree of inefficiency. An illustration of this can be seen in figure 1. Transparently, even by producing a potential barrier for unauthorized aircraft landings, tires and other similar runway closures are risky if not cleared out in a timely manner.

Figure 1: Tire Runway Closure System

Therefore, the rapid deployment runway closure system is an inflatable device being developed to quickly deploy and retract to prevent the landing of unauthorized aircraft on remote airstrips by displaying the appearance of a barrier. The inflatable will be anchored and powered by an off-the-airstrip housing complex which contains the fan motor, the solar panel and control system. A simplistic design intended for one person to deploy the device and a method of quick retraction will be integrated. In case of an emergency, the aircrafts that need to land will land over the inflatable and will not suffer any significant damage. The inflatable will be lightweight and pose no risk to the aircraft while specifically being in desert-like environments. The runway deployment closure system would be helpful since it creates the same idea of a physical barrier without the threat of damage if an aircraft has to land on it. Another helpful element is that the system will eliminate the need for someone to perform heavy labor in setting up and clearing out the debris.

System Use Case and Test

The system will be able to operate when one single person on the runway places the rapid deployment closure system next to the runway. Then, the individual will manually turn on the system by flip opening the shield panel, verifying that the power switch is in the OFF position, verifying that the power LED is dim then switching the power switch to the ON position. After this, switching the PIN switch to the up (deploy) position and pressing the red button until completely recessed. The individual also verifies that the device deploys the inflatable material onto the runway evenly and consistently. When the inflatable is completely deployed after 3-5 minutes, the red button is pressed until it is in the original position to stop the fan/blower. To start the retraction process, switch the PIN switch to the down (retract) position. Verifying that the inflatable is being retracted back into the device evenly and consistently and within 180 seconds. Once the inflatable is completely retracted, switch the PIN switch to the middle (neutral) position. Finally, switch the power switch to the OFF position and verify that the power LED is dim (OFF).

The key components of this system are mainly lead acid battery, the solar panel, and the arduino uno. Through multiple trade studies and research, it was decided that the Powersonic 12

V battery will be the most efficient since lead acid batteries supply a system with stored power which is limited by weight. The trade study and its specifications can be seen in tables 1 and 2. For the solar panel, through research with multiple brands, it was decided that the 200W Rich Solar Panel will be most efficient because as most 200W solar panels are very similar, this one was more specifically due to it being the best one to be able to withstand high temperatures. The solar panel trade study can be found in tables 3 and 4 along with their specifications. Lastly, the team decided on the Arduino Uno microcontroller because of its operating voltage at 5 V and higher current to utilize the motor drive circuit that will be included in the system.

Trade Studies

Table 1: Battery Trade Study Breakdown

Criteria	1	2	3	4	5
Shelf Life (Months)	6 or less	7-12	13-18	19-24	25+
Nominal Capacity (Amps-Hours)	3 or less	4-6	7-9	10-12	13+
Maintenance Requirement	Monthly Maintenance	Quarterly Maintenance	Semiannual Maintenance	Annual Maintenance	No Maintenance
Cost ($)	401+	301-400	201-300	101-200	100 or less
Weight (lbs)	35+	30+	25+	20+	15 or less

Table 2: Battery Selection Trade Study

Criteria	Weight (%)	Power Sonic 12V 18AH Lead Acid Battery		Power Sonic 12V 40AH Lead Acid Battery	
		Rating	R•%	Rating	R•%
Shelf Life	25	3	90	3	90
Nominal Capacity	25	5	150	5	150
Maintenance Requirement	20	2	50	2	50
Cost	15	5	75	4	60
Weight	15	5	75	2	30
Total	100		440		380

Table 3: Solar Panel Trade Study Breakdown

Criteria	1	2	3	4	5
Cost	$300+	$270+	$240+	$210+	Under $210
Maximum Power Voltage	under 15V	16V+	17V+	18V+	19V+
Maximum Power Current	under 7A	8A+	9A+	10A+	11A+
Operating Temperature	0°F to 80°F	-10°F to 90°F	-20°F to 100°F	-30°F to 110°F	<-40°F to >120°F
Weight	30+ lbs	29+ lbs	28 lbs	27+ lbs	under 27 lbs
Size	2000+ in^2	1900+ in^2	1800+ in^2	1700+ in^2	1600 in^2 or less

Table 4: Solar Panel Selection Trade Study

Criteria	Weight (%)	Home Depot Grape Solar		Walmart Rich Solar		Amazon Newpowa		Renogy	
		Rating	R•%	Rating	R•%	Rating	R•%	Rating	R•%
Cost	20	3	60	4	80	5	100	2	40
Maximum Power Voltage	20	5	100	5	100	3	60	5	100
Maximum Power Current	20	3	60	3	60	5	100	4	80
Operating Temperature	20	5	100	5	100	3	60	5	100
Weight	10	5	50	5	50	4	40	5	50
Size	10	4	40	5	50	4	40	4	40
Total			410		440		400		410

Overall Final Design

In figure 2, the overall design is that of an aluminum tube frame with tabs welded to it for mounting of all the components. The chassis itself and its materials are just 9.4 pounds. However, the other components such as the gearmotors, heavy solid rubber wheels, stainless steel chain and solar panel do add up such that the 18 pound battery tips it over the 50 lb weight limit, therefore it becomes a 4th component that needs to be installed on site for single person system installation.

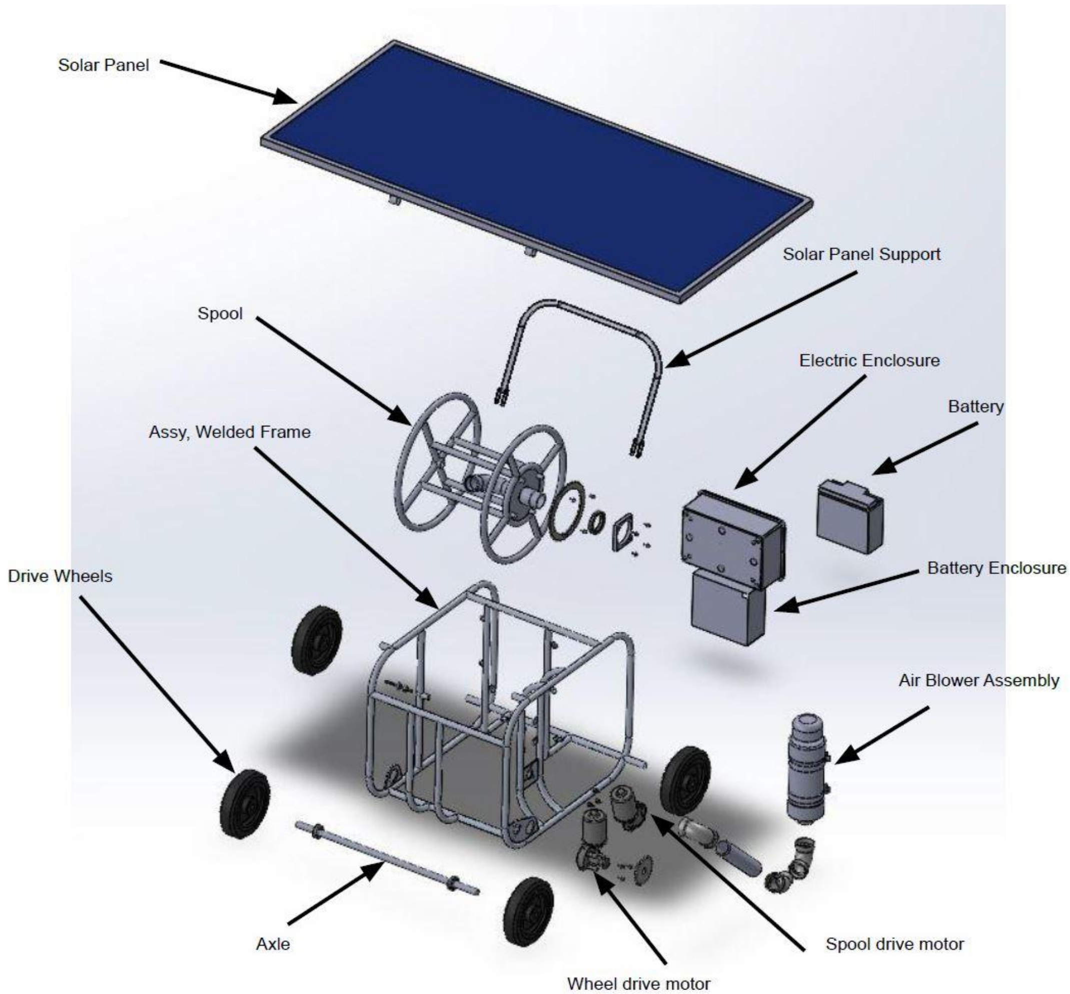

Figure 2: Whole System Exploded View

In figure 3, the system level diagram details the overall architecture and the interaction between the control unit and the various other components. The blue are the electrical components and the green are the mechanical components. Starting from the bottom up, the solar panel and battery power up the entire system. They are connected to the solar charge controller. The solar charge controller is basically to protect and automate the charging of the battery. Without a solar charge controller between the solar panel and battery, the panel will overcharge the battery by generating too much voltage for the battery to process which could seriously damage the battery. The solar charge controller detects when the battery's voltage is too low.

When the battery drops below a certain level of voltage, the controller disconnects the load from the battery in order to prevent the battery from being drained.

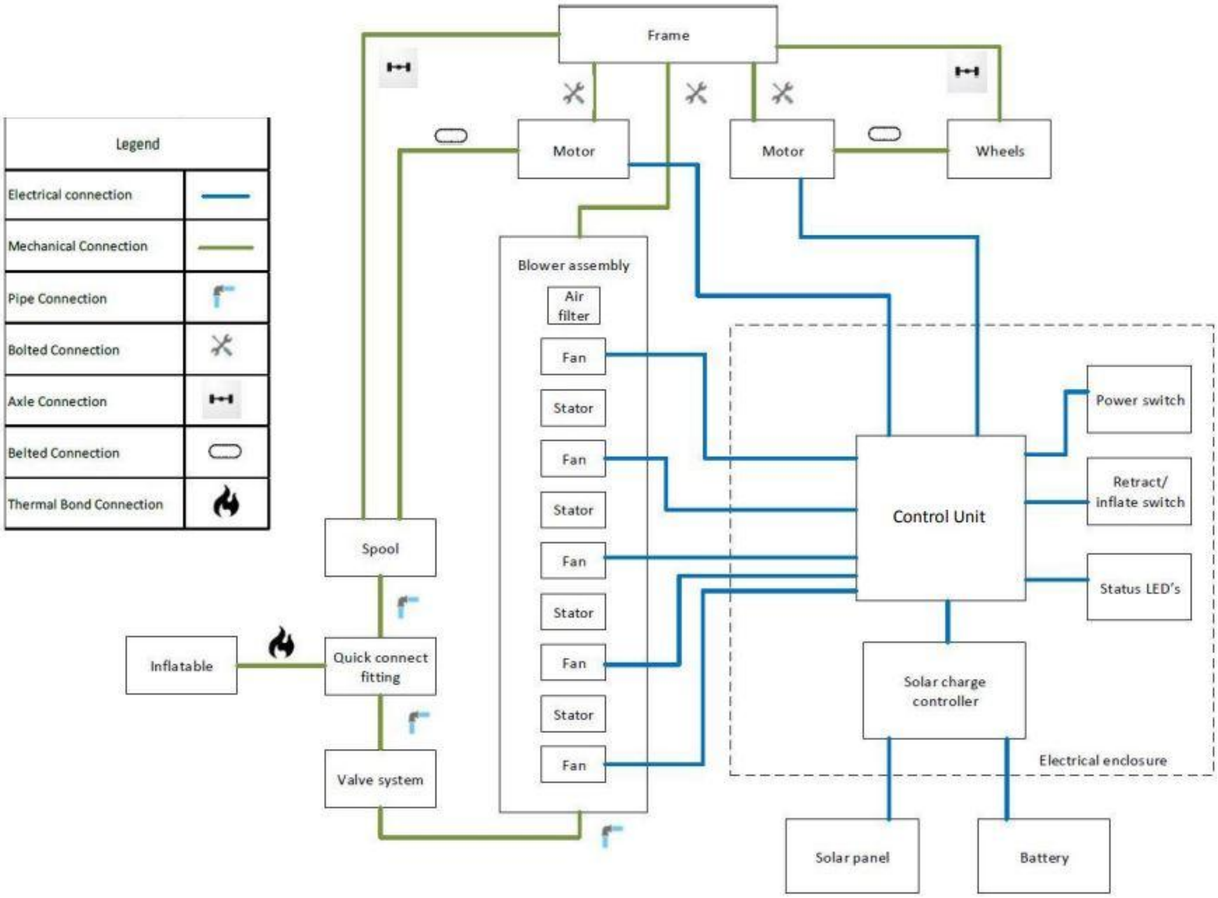

Figure 3: System Level Diagram

In figure 4 the controller utilizes an Arduino UNO as the brain, transistors driving relays to control the drive motors, and logic-level MOSFETs to drive the fans. The buttons, sensor inputs, and self-diagnostic fan rotation readings are handled entirely with the built in 25k ohm pull-up resistors, which are then pulled to ground by their respective input device with a current of 0.2mA.

Now for driving the fans, an IRF520N N-channel MOSFET was selected for the reason that it can be driven directly from the Arduino UNO to its 2-4V gate threshold voltage, and 4.5 amp current capability at 5V gate charge. The source/sink current from the Arduino is limited by a 470 ohm resistor to 10.6mA (peak), which results in a calculated 1.2 microsecond rise and fall time to reach 5V at the gate. With proper driving, this mosfet can achieve rise times of 23 nanoseconds, but because of the slow start feature of the fan eliminating inrush current, and the excessive 9.7 amp current rating of the mosfet, the 1.2 microseconds is sufficient to not cause heating of the MOSFET. In use, the MOSFET's VDS was measured to be 0.06 volts, giving a package power dissipation of 0.078 watts at 1.3 amp fan draw. As this power level does not require a heatsink, it gives the ability to simply socket the MOSFET for easy replacement, almost like you would a relay in a car.

Then, for driving the motors, a 2N2222a N-channel transistor rated at 600mA is used to trigger the coil of a standard automotive relay which draws 140mA. Both the relay coil and the motor loads have flyback diodes to protect their respective switching devices, and the transistor has a base current of 7mA to ensure it is fully saturated with its minimum gain of 100. The relays are socketed directly in PCB mount relay sockets to eliminate the mess of wiring that would otherwise occur, and can be seen in the prototyping section pictures. This eliminates at least 50% of the assembly time as soldering PCB connections is significantly faster than soldering wires, and eliminates many potential failure points in the form of broken wire or connections.

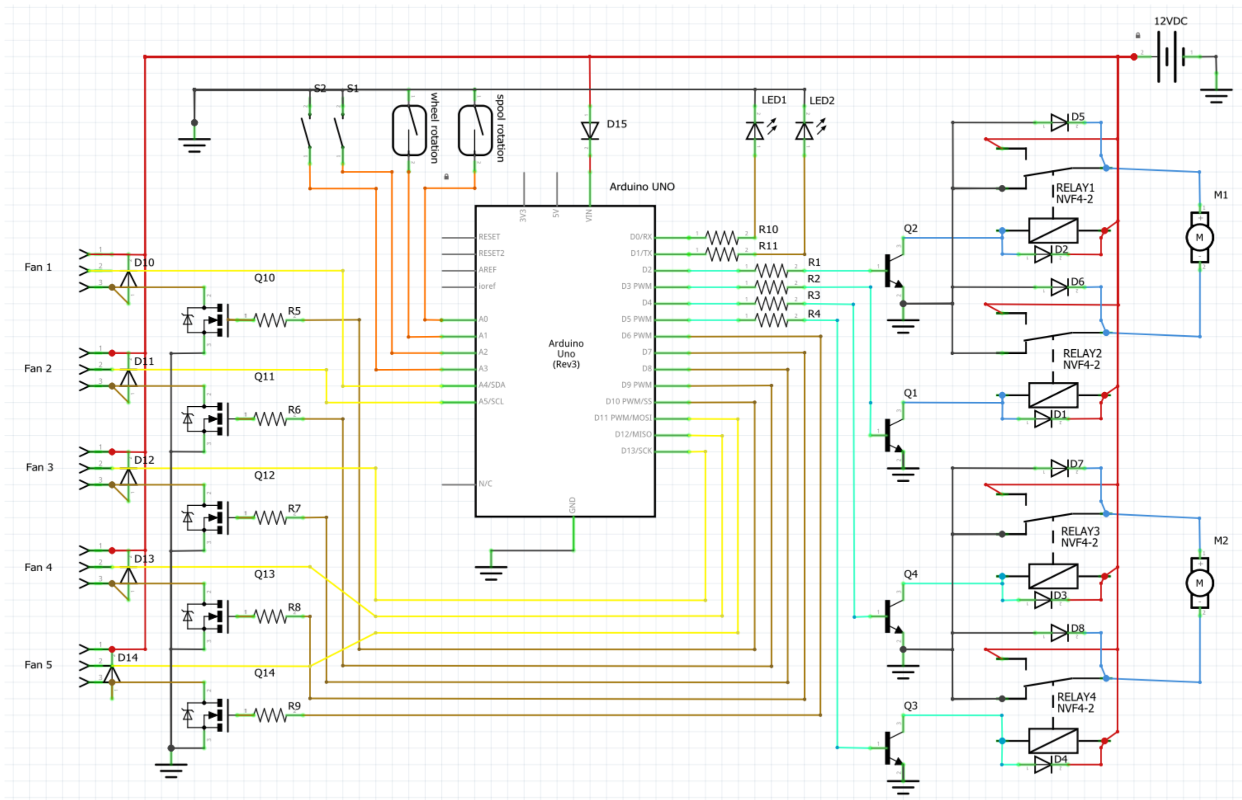

Figure 4: Controller Schematic

The basics of the diagram is that the inflation and deflation is based on time rather than a sensor measuring air pressure, as it could be unpredictable in gusty conditions. Another note is that distance will be measured by the number of pulses by the wheel sensor which triggers an interrupt pin, while fabric length deployed will be measured in the same way with the rotation of the spool. Both of these values will be user set when the system is first installed in location using the 2-button interface and status LEDs to confirm the progress through the learning process. Lastly, the Arduino code is still in the framework stage, but is expected to be completed at the same time as the PCB routing which is scheduled to be on January 21, 2022.

Key Technological Challenges and Strategies

Fan Motor and Circuit Power Dissipation Challenges and Strategies

Power dissipation in the original TIP120 transistors was calculated according to the graphs included in the datasheet. Since there is a 1.3 amp fan draw and an approximate 2V drop across the transistor at that load, the power output of 2.6 watts was too high to be dissipated without heat sinking, especially at the high ambient temperature that fan motor and circuit will be used at. As well as the fact this would result in the fans only having access to approximately 11.6 volts instead of 13.6 volts, when they are rated at 13.8 volts specifically for use with lead acid battery systems.

To address these issues, the switching device was changed to the commonly available, IRF520N, a MOSFET which can be driven directly from the arduino pins when done at relatively low frequencies. A current limiting resistor of 470 ohms was placed to limit peak current to 10 mA, and based upon the gate capacitance from the datasheet this should result in a turn-on and turn-off time of 1.2 microseconds. In practice, the mosfet was only 5 degrees celsius warmer than the ambient air temperature. This is backed up by the measured voltage drop being 0.06 volts, giving a package power dissipation of just 0.078 watts at 1.3 amps, no longer requiring any sort of heatsink and giving the fans full battery voltage.

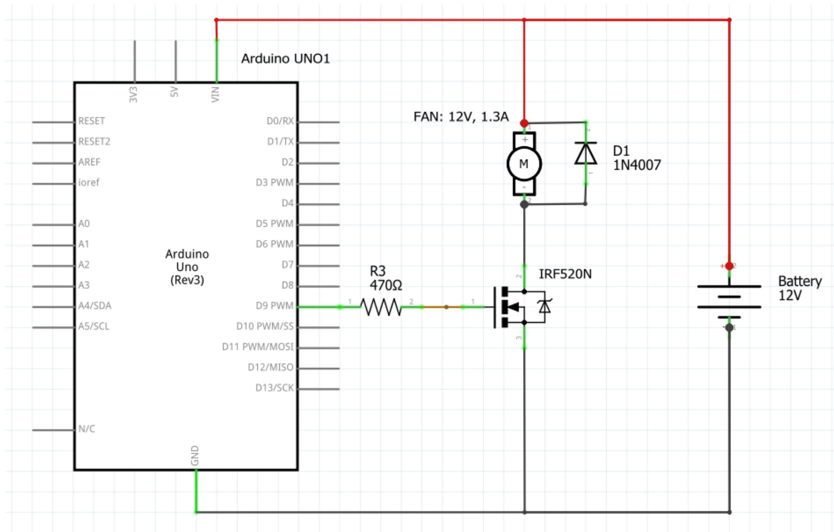

Figure 5: Fan Driving Circuit

Upon assembly of the lifespan testing prototype, issues encountered were that the fan does not draw its full current when faced down against a surface to avoid it flying away, and that the motor attempts to jump around when starting. To solve these problems a simple mounting plate needs to be created, and then lifespan testing can commence, which is later shown in the report in the prototyping section of the report.

PCB Challenges and Strategies

The Arduino will be inserted onto header pins upside-down, and receive 12V battery power from the Vin pin, to not use the barrel jack or USB port which could be disconnected by vibration. PCB mount sockets will be used for the motor drive relays to eliminate the vast majority of the crimped connections and reduce loose wiring in the electrical box. The PCB traces handling the high current for the drive motors will be overlaid with a solid copper wire and copious amounts of solder to decrease electrical resistance and therefore heating of the PCB. The PCBs will be professionally made by JLCPCB, who will provide 5 pcs of 6” x 6” double sided PCBs with 1oz copper for $13 with a 1-2 day turnaround time, and 3-5 day air shipping from China for $21.80. This decision was influenced by the success of other senior design teams who used JLCPCB and presented their projects at the Fall semester design day.

The fan MOSFETS are more than an order of magnitude below the power dissipation that would require heat sinking, and will simply be inserted into header sockets like the Arduino to make them easily user replaceable, as they could potentially be damaged in the event of elecro-static discharge into the harness outside of the electrical box if the fans are disconnected.

Also for driving the motors, a 2N2222a N-channel transistor rated at 600mA is used to trigger the coil of a standard automotive relay which draws 140 mA. Both the relay coil and the motor loads have flyback diodes to protect their respective switching devices, and the transistor has a base current of 7 mA to ensure it is fully saturated with its minimum gain of 100. The socketing of components eliminates at least 50% of the assembly time as soldering PCB connections to eliminate the mess of wiring that would otherwise occur. This eliminates at least 50% of the assembly time as soldering PCB connections is significantly faster than soldering wires.

Battery Challenges and Strategies

Protecting the battery from overheating due to desert climates such as ambient temperatures was one of main technological challenges during the development of our team; it is a key component that without, the whole system would not perform. As previously stated, Power Sonic’s 12V 18AH Lead Acid Battery is expected to be best suited for our expected temperature range. Making the right choice in components goes a long way to reaching our criteria however that is only part of the strategy for this challenge. A BMS (Battery management system) will also need to be included to help the battery reach the respective criteria. Battery management systems are critical in protecting the battery’s health and longevity but even more important from a safety perspective. Helps meet criteria of 5 year life span of device but does not help with temperature. To help with overheating the battery will be placed in a shaded location in the device to help mitigate impact of temperature.

Risk Analysis, Prototype Activity, and Results

Electrical/Computer Engineering Risk Table/Cube

Table 5: ECE Risk Table

Risk List			
Risk	**Description**	**Probability/ Likelihood**	**Impact**
1) Battery Failure	Since the battery will be operating in desert-like conditions,(i.e 48℃) it may overheat causing it to fail. As lead acid batteries absorb high heat, chemical activity in the battery accelerates. This will reduce the life of the battery at a rate of 50% for every 10℃ increase from 25℃. In order to reduce this from happening, a battery management system (BMS) can be used. Using a BMS can monitor and manage all of the battery's performance. Most importantly, it keeps the battery from operating outside of its safety margins (i.e calculates how much current can safely go in and come out without damaging the battery).	In the likelihood that the battery is dead or overheats due to environmental conditions, using a BMS can help with this risk. The probability of the risk occurring is estimated to be a 2.	After researching BMS, the impact this can have on the system is a 1.

2) Solar Panel Condition Issue	Since the Solar Panel would power up the battery. If it fails, the system would not function. In desert-like environments (i.e winds up to 95mph/80 knots), dust can build up and block sunlight which can negatively impact the solar electricity output.	The probability of the risk occurring is estimated to be a 3.	The solar panel is the main component for getting power to the system. This impact is a 4.
3) Solar Panel Durability	Over time, the solar panel will die down and eventually not work. If a solar panel is constantly in high temperatures (i.e over 25℃) then it will accelerate panel degradation. This means that a solar panel will lose its power output over time. Most of the solar panels degrade at a rate of about 0.5% every year which will generate around 12-15% less power at the end of their 25-30 year lifespan.	Since it is estimated for a solar panel to last 25-30 years, the probability would be a 1.	The solar panel's purpose is to charge the battery that is running the system therefore, if the solar panel dies down, the battery will continue to work and power the system. The impact is a 4.
4) Hardware/ Firmware Malfunction	Since the Arduino will use C code for managing the input and outputs of the system, there may be issues with the firmware/hardware that causes the system to not work correctly.	If the system deploys the inflatable when it is off rather than when it is on, there would be issues with either the firmware or hardware. The probability of the risk occurring is estimated to be a 3.	The Arduino is the main source for all the buttons and switches to function and communicate with the system. This impact is a 4.

5) System Interconnections	The PCB main electrical connector will have connections between the Arduino, motor, solar panel and battery.	Through soldering and screwing the components together on a PCB, we have to be careful on the 20+ wires in a monoblock connector since they're all identical and the need of counting the number of holes based on the diagram. The probability of the risk occurring is estimated to be a 2.	If the PCB had connections that were not correctly placed, the system would not operate correctly. This impact is a 4.
6) ESD Damage	There could be static shock in manufacturing especially if there are components that are outside the electrical box of the system.	In the likelihood that someone got electrostatic discharge damage from the system will just have a little shock. The probability of the risk occurring is estimated to be a 3.	The system would try to have most if not all the components inside the system and not have any exposed wiring, components, etc. to an individual. This impact is a 5.
7) Overheating	If the solar panel is not placed above the system, overheating could take place since it is going to be in a desert-like environment.	While electrical components most likely will not have a problem with the overheating, the battery will since it may go beyond the maximum temperature it could take. The probability of the risk occurring is estimated to be a 2.	If the battery does overheat due to the environment it is in, the system will not be able to operate. This impact is a 5

Risk Cube Before Prototyping

Likelihood

5					
4					
3				2,4	
2	1			5	
1				3	
	1	**2**	**3**	**4**	**5**

Impact

Figure 6: Risk Cube for ECE Risk Table

Risk Cube After Prototyping

Likelihood

5					
4					
3				2	6
2			4,5		7
1	1			3	
	1	**2**	**3**	**4**	**5**

Impact

Figure 7: Updated Risk Cube after Prototyping

Mechanical Engineering Risk Table/Cube

Risk Cube Legend			
General Risks		Technical Risks	
1	Material Supplier Risk	5	Inflatable Material Weakness Risk
2	Materials Delivery Delay Risk	6	Inflatable Detachment Risk
3	Not Adhering to Schedule Risk	7	Retraction Failure Risk
4	Covid Outbreak Risk	8	Motor Failure Risk
X	Material Budget Risk (Retired)	9	Fan Failure Risk
		10	Air Flow Irregularity Risk
		11	Circuit Component Failure Risk
		12	Battery Failure Risk
		13	Solar Panel Energy Insufficiency Risk
		14	System Connections Failure Risk

Table 6: Risk List Cube Legend

Current Risk Cube

Likelihood

5					
4				12	
3			2, 5	7, 8, 9, 10	13, 14
2			1, 3	11	
1			6		4
	1	**2**	**3**	**4**	**5**

Consequence

Figure 8: Current Risk Cube Before Mitigations

Current Risk Cube Mitigations Applied

Likelihood

5					
4					
3		2		12	
2		3	5	7, 8	13 ,14
1			1, 6	4, 9, 10, 11	
	1	**2**	**3**	**4**	**5**

Consequence

Figure 9: Current Risk Cube with Mitigations Applied

Table 7: Risk List with Mitigation Plans

Risk List				
	Risk Statement	C	L	Mitigation Method
1	If a materials supplier only sells our chosen material in bulk, then we might have to resort to a more expensive option or change the material entirely	3	2	If the team reaches out to material suppliers early on to see what buying conditions look like, we can have more time to find a new supplier or different material.
2	If delivery is postponed due to covid or other circumstances, then materials and prototype testing will be delayed	3	3	If we plan to order early and utilize in store components as much as possible, we can increase the time we have to make purchase adjustments and avoid waiting for deliveries all together.
3	If the team does not adhere to the established gantt chart timeline, then there will be less time for device testing.	3	2	If we set rigid schedule timelines and collectively enforce them, we can make sure deadlines are met and device defects can be solved if they arise.
4	If the school is required to go virtual due to a covid outbreak, then in person project time will be eliminated & access to campus resources will be limited	5	1	If the team creates a covid action plan to establish project time and find exterior shops to allow for essential facility use, the negative effects of the lockdown will be diminished.

5	If the inflatable experiences a point of weakness ruining the air tight system, then the overall intended function of the device will be mostly lost.	3	3	If the inflatable material is extensively researched for strength properties and UV resistance, we will be better equipped to create an airtight system resistant to defects.
6	If the inflatable's connection to the spool and motor detaches, then it will not inflate and will lose intended functionality.	3	1	If the team researches optimal fastener options for the specifics of the device, then the probability of detachment can be minimized or eliminated.
7	If the retraction system fails, then the aircraft will be forced to land over the device and it will be required to be manually retracted	4	3	- If the prototype is tested to identify any mechanical weaknesses, the retraction system will be less likely to fail. - If the material is researched so that a light and safe choice is selected, then it will not damage the aircraft in the event of a forced landing.
8	If the motors fail to drive during operation, then the inflatable will not retract properly.	4	3	-If a prototype is tested extensively, then mechanical and technical issues can be foreseen. -If tests are conducted on the actual motor, then a better understanding of unknown issues can be timely addressed.
9	If the fans stop blowing air during operation, then air will not inflate the device.	4	3	-If the fans are researched for reliability and longevity, then the chance of failure will be minimized. -If the fans are tested in desert conditions, then their resilience and performance can be analyzed and improved if necessary.
10	If the air fans do not propel the air correctly into the inflatable, then power will be lost and the inflatable will not inflate.	4	3	If the team researches air flow in tubes, then the team can prevent air flow irregularities in the inflation channel.
11	If the electrical components experience failure, then most of the device's mechanical roles will lose functionality	4	2	If the team works with ECEs to determine temperature constraints of all components and prioritize using electrical components with high temperature ratings, then the integrity of the electrical system will be strengthened.
12	If the battery gives out from weather conditions or short circuits, then the system will have to function solely on solar power which may delay or inhibit functionality.	4	4	-If the team researches heat resistant batteries, then the battery will be better equipped for desert conditions. -If the team designs a shaded compartment within the device, then the battery could potentially escape direct sunlight temperatures.

13	If the solar panel does not generate the required energy demands, then the entire system will not function.	5	3	- If the team calculates, estimates, and tests energy demands of every energy utilizing component, then a better understanding of how much energy the system demands will be clear. - If climate data is considered to gauge weather patterns, then an energy income estimate will be available to manage power expectations.
14	If any system connections are compromised, then that connection's signal will disrupt the device's intended function.	5	3	-If the team verifies the soldering was done correctly and tests the connections, then the chance of connection failure will be minimized. -if the team applies a heat test to the connections, then we will have a better idea of how the connections might fare in hot conditions.

Prototype Activities/Results

For the team's first prototyping activity, the team decided to use an Arduino Uno to turn on and off a similarly rated motor and analyze the voltages and currents from the prototype. Shown below is the original prototype design where we used a 12V battery to power the Arduino Uno and motor by creating a motor drive circuit where a 1.5 kohm resistor was used going into the npn transistor through the base and would be able to turn on and off.

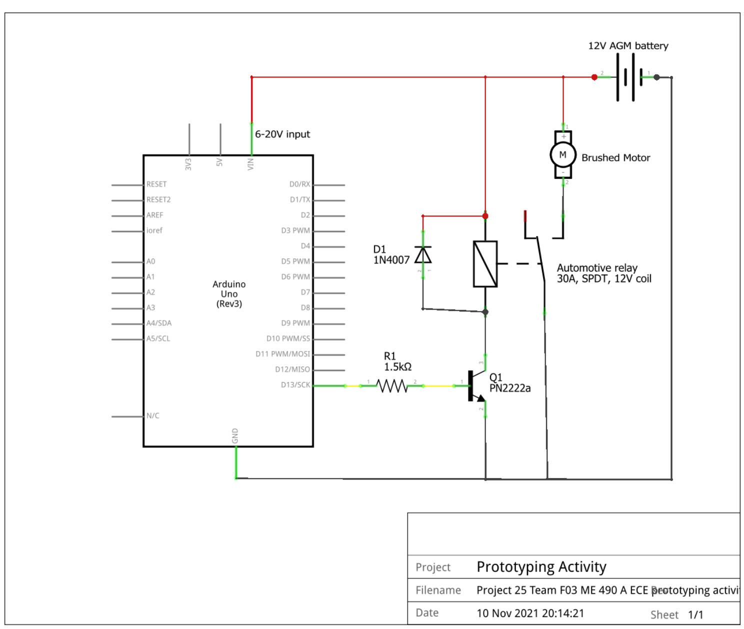

Figure 10: Schematic of the Prototyping Activity

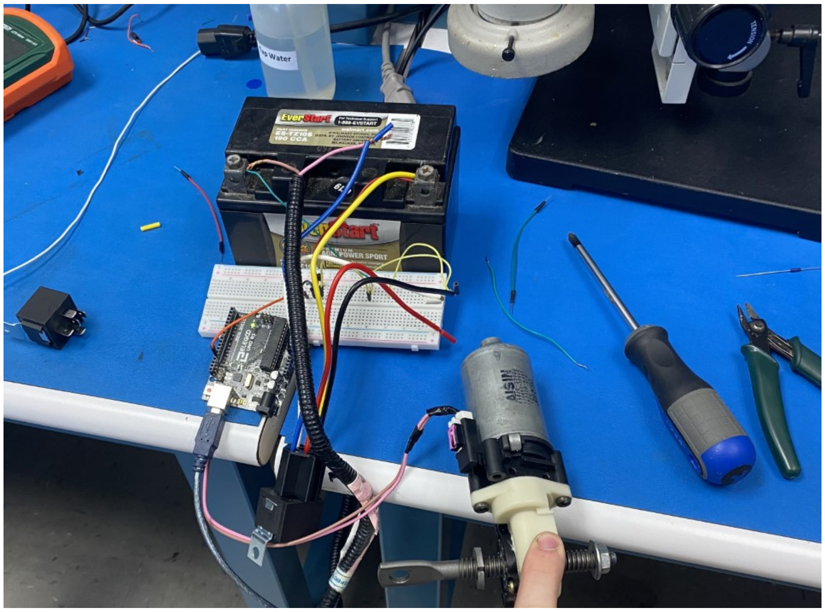

Figure 11: Test Setup for Prototype Activity

Based on the results from this prototype, the team noticed an inrush current on the relay coil which could be due to capacitances in the system such as a snubber circuit on the relay coil, and/or the transistor not being fully saturated for the inrush current and even extending the time period by limiting the current. The team also noticed that the transistor did not get hot to the touch and was well under the package thermal limits, which would be a maximum operating temperature of 150℃.

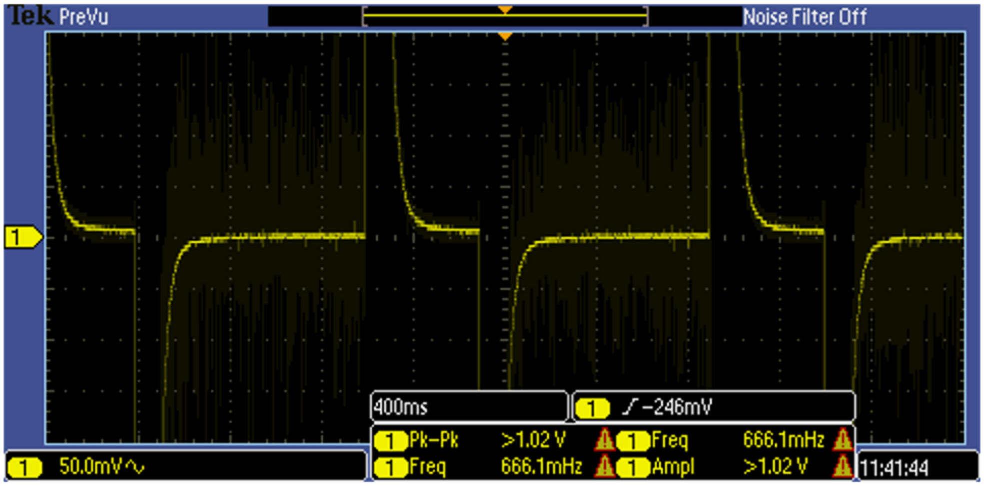

Figure 12: Oscilloscope Reading from the Collector of the Transistor

However, the team decided to create a new prototype where it would combine bidirectional motor control and fan control that would use a MOSFET rather than a transistor. Shown below is a part of the new prototype design that shows the fan driving circuit with a redesign of using a MOSFET.

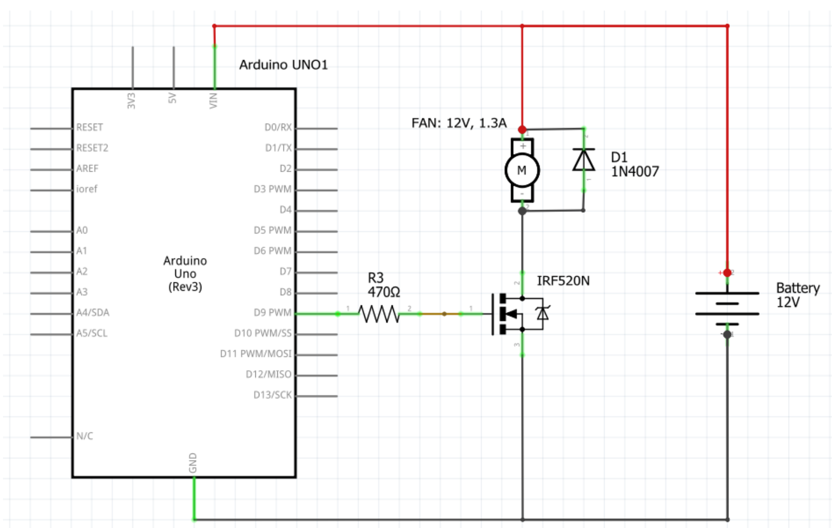

Figure 13: Fan Driving Circuit

When testing this prototype, it was measured that the voltage across the MOSFET drain and source pins was 0.06V and with the current of 1.3 amps, the total power dissipation would be

0.078W with an RDSON of 0.046ohms. As expected according to the datasheet, this does not require a heatsink since it is not overheating. The team also measured the current draw from the Arduino Uno at which came out to peak at 10.6mA through the 470ohm resistor and the charge time of 1.2 microseconds to charge the gate capacitance of the IRF520N MOSFET.

Then, a full bidirectional brushed motor driving circuit was created where this circuit was integrated into the lifespan test prototype. Based on the first prototype the team did originally, there was a long duration current spike, so in order to eliminate it the base current was increased on the 2N2222a transistor to 6mA. There is also a flyback diode protection of the relays to avoid contact arcing as indicated on the relay datasheet for motor driving applications. On the relay H-bridge, there was a dead time of 500 milliseconds to ensure that the previously activated relay was fully reset to its normally connected terminal before going in the opposite direction. 500 ms was chosen as it was a little over double the time when comparing the time specified in the datasheet.

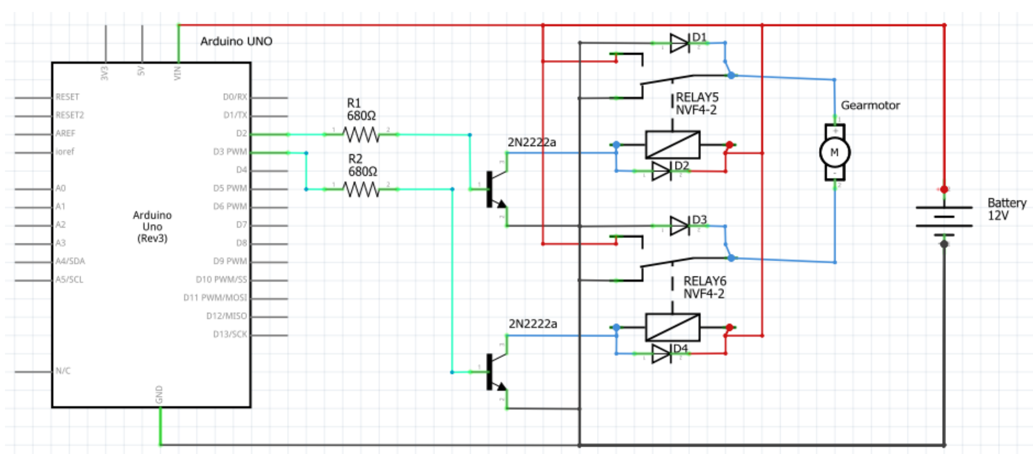

Figure 14: Bidirectional Motor Driving Circuit

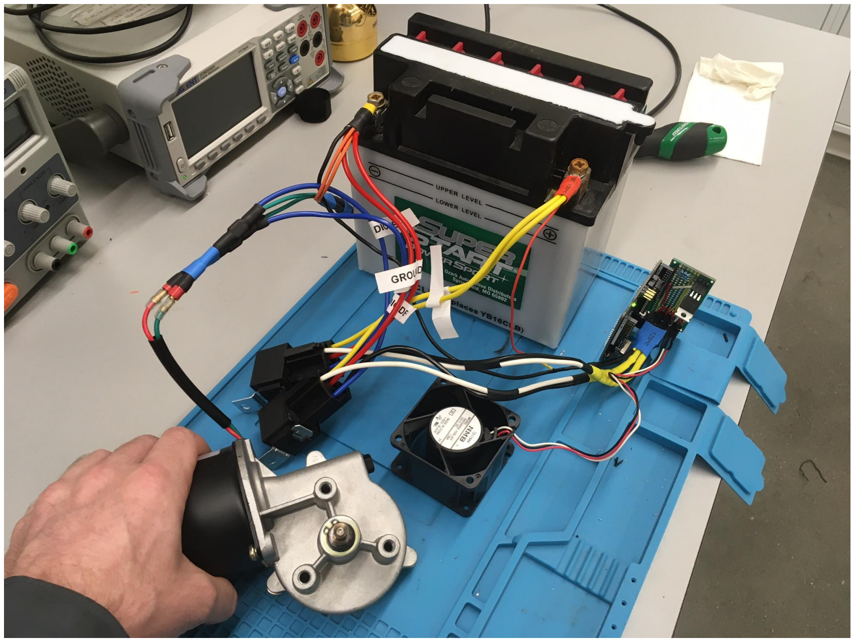

Figure 15: Prototype for Bidirectional Control and Fan Driving

An issue that the team encountered when assembling the lifespan testing prototype was that the fan was not drawing its full current when faced down on a surface and the motor moves around when it is starting. To fix these issues, the team mounted these items by creating a mounting plate and fixing them to the surface. Since the fan has a slow start feature and a long wind-down time for it to fully stop, the cycle time for the lifespan test was set at 10 seconds. In order to achieve the expected activation cycles of 2 uses per month for 5 years, the team will let the test run for 2400 seconds or 40 minutes in a 55℃ test chamber that has no airflow for each "lifespan". After leaving the prototype in the incubator, the team measured the MOSFET temperature reading to be at 60 degrees celsius and the temperature of the motor to be at about 65 degrees celsius, which are safe temperatures despite being in our worst case environment. The Arduino Uno has a maximum operating temperature of 85℃ and since the datasheet does not provide any derating curves for the inputs and outputs source and sink current limits, this becomes one of the important factors to be tested.

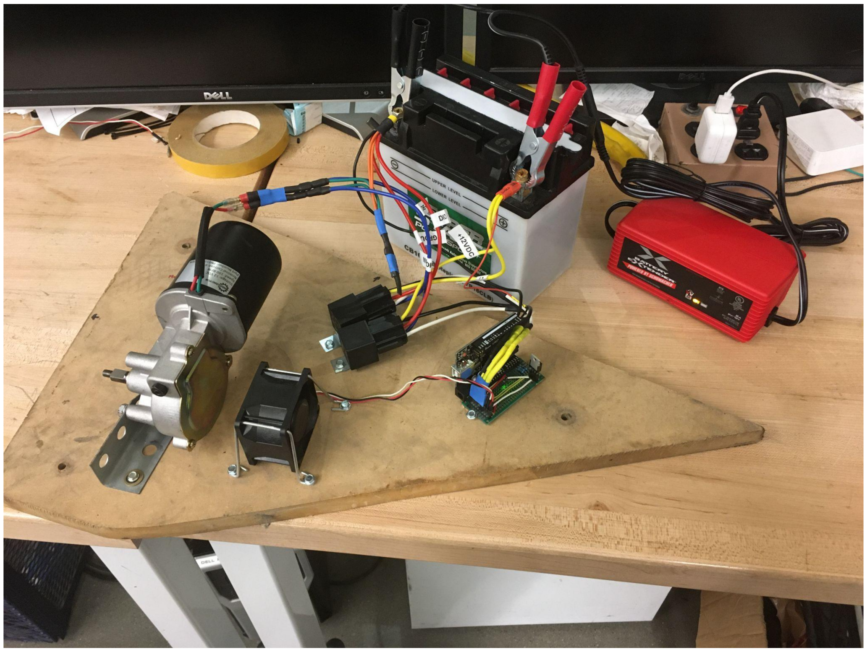

Figure 16: Prototype for Bidirectional Control and Fan Driving Used for Incubator

After doing the prototypes, our risks were moved such that for risk #1 (Battery Failure), we were able to test the battery in the incubator at 55 degrees celsius in the worst case environment and found that it was able to survive, so our risk got moved to impact 1 and likelihood 1. However, since it was in an incubator rather than in a real-life environment, this created a new risk as shown in Table 5 called Overheating because if the battery is not protected from direct sunlight in the desert, it would have a huge impact as shown in the risk table in Figure 7. The next risk, risk #4 (Hardware/Firmware Malfunction) and #5 (System Interconnections) and after doing these prototypes, the team found that when working with MOSFETs that they could easily be confusing in terms of figuring out where the drain and source are located. During the test, the team found that the MOSFETs died due to high soldering heat. So, based on the risk cube in Figure 7, the team was able to have the impact as a 3 and the likelihood of 2. However, if the team were to socket them, this may change the risk to a zero. Another new risk we encountered was ESD Damage where there could be static shock especially when there are electrical components exposed outside. For this risk, as shown in Figure 7, it's listed impact is at a 5, while the likelihood is at a 2.

Key Integration Activities

For key integration activities, there will be three tests that would lead up to finalizing the overall system as shown below in the figure.

1. Air Blower Controller Test: The team plans to have an air blower controller test that would occur over the Winter Recess until the end of January. For this test, the team would have a PCB made where a motor drive controller connected to the fans needed to inflate the inflatable and make sure enough current is being put through the five fans being used and is going at its fullest potential.
2. Switches and Sensor with Arduino Test: For this test, the team plans to have this test coincide with the Air Blower Controller Test where it would start over the Winter Recess until the end of January. In this test, the team would test the integration of the buttons/switches and well as the sensor inputs to the Arduino.
3. Motor Controller Test: The team then plans for a motor controller test that has a probable start date of middle/end of January to the end of February. In this test, the team will have two motors that are identical to each other, and they will be connected and be used for the system. One is a 50 rpm motor and the other is a 100 rpm motor, and it will be able to drive both motors for the winch/spool and the wheel. It will be necessary to analyze the speed of the motor and if it satisfies the team's expectations from the controller created. Currently, we are conducting a motor controller test, and are almost done with the testing for it and once the team has fully made a PCB, this test will be complete.
4. Full System Test: The team plans for a full system test after doing the air blower controller test and motor controller test starting the end of February to the end of March.

This test is where all of the ECE and ME components and circuits are put together to be tested and analyze how each area would react with each other.

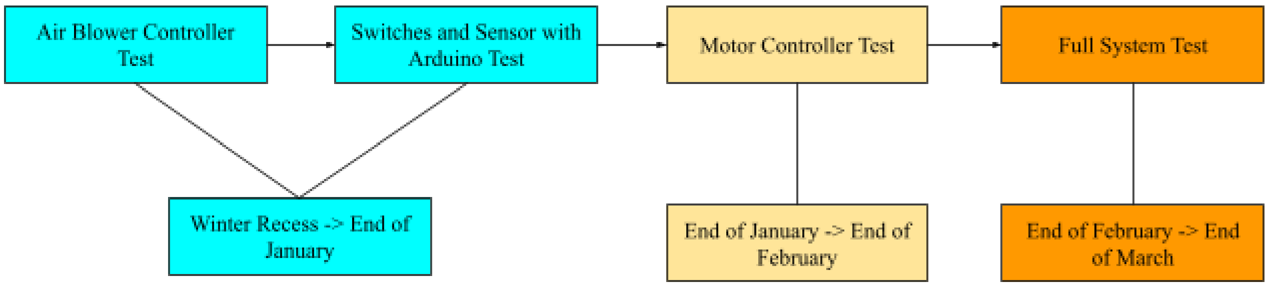

Figure 17: Key Integration Activity Breakdown

Work Breakdown Structure, Task List, and Schedule

In this section of the final report, the work breakdown structure, task list, and scheduling will be shown. Below is the work breakdown structure for the Rapid Deployment Runway Closure System.

Rapid Deployment Runway Closure System is shown in red to signify the project that is to be accomplished. Shown in orange are the electrical and computer engineering section. Showcased in that section are the three main parts coming from the electrical and computer engineering sides and are listed as the power storage for the battery and the solar panel that will be used and how it would be incorporated into the project as the main power sources and storing power so that the system could be used when the solar panel is inactive.

Next is the printed circuit board and motor drive design where the ECE team will build and create a PCB design of a motor drive in order to drive the motors, relays, Arduino Uno, etc… for the whole system to operate. Fortunately, the turnaround time from submitting the PCB file to getting the double sided PCBs back is just 4-7 days. Then is the embedded systems stage where all the Arduino coding would occur by implementing interrupts for the rotation sensing inputs and internal clocks for fan run time and H bridge timing.

Lastly, the mechanical engineering parts are shown in blue. The first part in their section is the air system where they would choose the appropriate fans needed to inflate and deflate the inflatable. The second part is the chassis where all the circuitry, motors, fans, inflatable, panel, and battery are contained in a manner safe from the desert-like conditions that would damage vulnerable components. Finally, the third part would be the inflatable and they would choose the material to make the inflatable and choose one where it would be noticeable from up in the air in an aircraft.

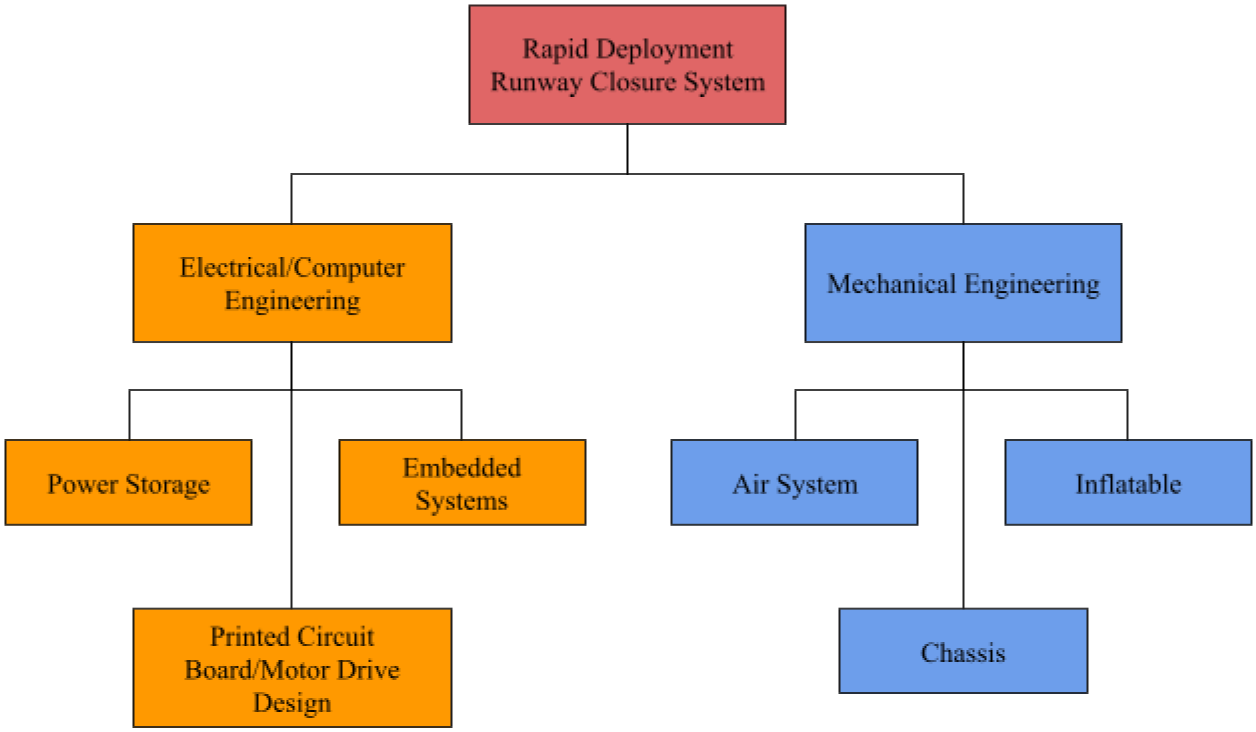

Figure 18: Work Breakdown Structure

The task list that the team intends to follow into Part B are:

1. Board Design/Arduino Coding (Winter Recess to Middle of January): For this task, the team will be designing the PCB with the electrical components, which Khalid is in charge of. Jomari and Marc will begin the process of developing the code for the Arduino Uno for the system and control panel.
2. Making the PCB (Middle of January to End of January): This task shouldn't take much time in that we will be making the PCB for the system and the EE side will be taking care of that part of the task and will continue to assist the ME team with any other needs. Within this time the team will finalize and debug the Arduino code and test parts of the code with each subsystem that is intended to prototype.

3. Assembly/System Testing (End of January to Beginning of March): This task is where all ECE and ME components that were designed and created are ready to be put all together and also continue testing and debugging when needed.
4. Senior Design Day (Beginning of May): Finally, the team should have 2 working systems and should be ready to put it on display for Senior Design Day.

By the beginning to middle of March, the team should have a fully operational Rapid Deployment Runway Closure System and since the team has more time between the beginning of March to Senior Design Day, the team plans to make another system since Mr. Benham requested the team to make a secondary system along with the first system.

Milestones for Part B:

1) Week 6: Hardware Readiness Report (End of February)
2) Week 8: Firmware Readiness Report (Mid-March)
3) Week 10: System Integration Test Report (End of March)
4) Week 11: ECE/ME System Integration Test Report (Beginning of April)
5) Week 13: Customer Sign Off (Mid-April)
6) Week 16: Final Report (Beginning of May)

With all the work breakdown structure, task list, and scheduling, a more in-depth plan could be seen through TeamGantt where all the ME and ECE scheduling for the entire project could be seen with all the breakdowns, dependencies, owners, etc. being displayed.

Cost and Financing

For the Rapid Deployment Runway Closure System, Mr. Benham gave the team a budget of $2500.00 and also would like for the team to create two to three of these systems within the budget provided. As of right now, the total cost for our system is at $1,205.36; if the team remains within this budget, they are able to make at least two of these systems for Benham Aviation Services.

Based on the ECE's costliest items, the most costliest items were the Arduino Uno, which sits at $23.00 from the Arduino Store, the Powersonic PS-12180HD-M5 AGM Battery from UPS Battery Center at $69.99, and finally the Rich Solar 200W Panel, that is crucial for this project, runs for $219.00 from Rich Solar. As of right now, the overall electrical total sits at $437.91.

In terms of the ME's costliest items, the team has 4 pieces of 6ft x 0.75'' OD x 0.125'' ID Tube for the framing of the system, which cost about $11.20 each for a total of $44.80. Next, there will be two motors being bought, a 6A, 12V, 100 rpm TENV Gearmotor for the winch/spool system and a 6A, 12V, 50 rpm TENV Gearmotor for the wheel system and both of these motors would cost $83.00 each. Lastly, the ME would have an 18 oz. per square yard PVC coated fabric, 61'' wide, sold by the yard to create the inflatable. It costs $8.95 per linear yard and the team plans to buy ten yards of the fabric bringing the total to $89.50. The overall cost for the ME's materials sits around at $767.45.

Table 8: Bill of Materials

Item	Quantity	Price Each	Total Price	Link
Frame:			total for system:	$100.31
6 ft x 0.75" OD x 0.125" ID Tube	4	$11.20	$44.80	online metals
SS strap for Air Blower Bracket	1	$10.31	$10.31	McMaster Carr
#8-32	2	6.05 (pack of 50)	$6.05	McMaster Carr
12" x 24" x 0.125" 6061-T6 aluminum sheet	0.5	$60.96	$30.48	McMaster Carr
M6x1.0 grade 8.8 15mm flange bolts	6	$0.16	$0.96	McMaster Carr
1" quick release pin	3	$2.17	$6.51	McMaster Carr
Winch/Spool system:			total for system:	$219.61
6 A, 12V, 100rpm TENV gearmotor	1	$83.00	$83.00	makermotor
8"x8"x0.188" 304SS sheet	0.67	$35.15	$23.55	McMaster Carr
12" x 24" x 0.125" 6061-T6 aluminum sheet	0.5	$60.96	$30.48	McMaster Carr
2.25"OD x 1.25"ID x 6"L 6061-T6 tube	1	$42.56	$42.56	McMaster Carr
#35 304SS chain, 10ft box	0.25	$74.97	$18.74	Nitro Chain
6910-2RS deep groove ball bearing	1	$11.44	$11.44	123bearing
608-2RS deep groove ball bearing	2	$0.87	$1.74	123bearing
5/16" shoulder bolt	1	$8.10	$8.10	McMaster Carr
Wheel system:			total for system:	$160.31
6 A, 12V, 50rpm TENV gearmotor	1	$83.00	$83.00	makermotor
8"x8"x0.188" 304SS sheet	0.33	$35.15	$11.60	McMaster Carr
Solid rubber wheel	4	$7.99	$31.96	Harbor Freight Tools
#35 304SS chain, 10ft box	0.15	$74.97	$11.25	Nitro Chain
3/4" ID sealed flange bearing	2	$2.55	$5.10	Amazon
3/4" 2024 aluminum shaft collar	2	$8.70	$17.40	McMaster Carr
Inflatable and Rig for			total for system:	$101.66

Manufacturing				
18 oz. PVC fabric, 61" wide, by the yard	10	$8.95	$89.50	TarpsNow
Vinyl plastic PVC Welding Nozzle Attachment	Already Have	1	$0.00	
Concrete Form Tube (8in diameter)	$7.60	1	$7.60	Concrete Tube
Metal Shelf Brackets (everbilt brand)	$2.28	2	$4.56	Shelf Bracket
Item	Quantity	Price Each	Total Price	Link
Air system:			total for system:	$185.56
Fans	5	$15.00	$75.00	NMB Technologies
#8-32 All Thread	1	$4.02	$4.02	McMaster Carr
#8-32 Nuts	8	3.46 (100 pack)	$3.46	McMaster Carr
4" S&D PVC Tube	6 in.	14.26 (10 ft)	$14.26	Home Depot
4" S&D PVC Caps	2	$2.92	$5.84	Home Depot
Air Filter	1	$35.00	$35.00	Northeastern Arborist
PVC Adapter made from Cast Nylon	1	$18.72	$18.72	McMaster Carr
Stator, 3D printed ABS	4	$0.00	$0.00	
Santoprene Rubber for Gaskets	1	$15.65	$15.65	McMaster Car
schedule 40 DWV 90 degree elbow 1.5"	3	$3.46	$10.38	McMaster Carr
schedule 40 DWV 45 degree elbow 1.5"	1	$3.23	$3.23	McMaster Carr
Electronics:			total for system:	$437.91
Apache 1800 waterproof case 8"x9"x4"	1	$12.99	$12.99	Waterproof Case
Arduino UNO	1	$23.00	$23.00	Arduino store
Bosch 0 332 209 151 relay	4	$3.09	$12.36	Rockauto
Powersonic PS-12180HD-M5 AGM battery	1	$69.99	$69.99	UPS battery center
1N4007 diode	14	$0.10	$1.39	Digikey
IRF520NPBF N-channel MOSFET	5	$1.00	$5.01	Digikey
PN2222a transistor	4	$0.10	$0.40	Digikey
ACS712 bidirectional 20 amp current	2	$5.64	$11.28	Digikey

sensor				
24 pin sealed connector pair (kit)	1	$60.00	$60.00	Digikey
Rich Solar 200w panel	1	$219.00	$219.00	Rich Solar
Relay Socket	4	$1.25	$5.00	Spemco
PCB	1	$17.50	$17.50	JLCPCB
	TOTAL:	$1,205.36		