SAN DIEGO STATE UNIVERSITY

ECE Hardware Readiness Report

EE/COMPE 496B Senior Design

Team 14, Project 25: Rapid Deployment Runway Closure System

THE BLOCKADE BRIGADE

The Blockage Brigade

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Executive Summary

In this hardware readiness report, the team has put together a detailed hardware design for the Rapid Runway Closure System. The hardware in this system consists of an Arduino Uno microcontroller based on the ATmega328P, a motor driving circuit, fan driving circuit and a fan diagnostic array circuit that utilizes one of the hardware interrupts. These elements have been designed and the key points of the design and a circuit walkthrough are included in this report. An original PCB design has been constructed for this system and is also included in the report. Also included in the hardware is a solar panel and a solar charge controller where the solar charge controller will be mounted to the PCB for a more simplistic layout. The hardware also includes blowers to inflate the barrier system. Lastly, All the electrical components, except for the solar panel, will be in-closed in a NBF-32016 Series Plastic Nema IP66 rated Box for environmental and weather proofing.

This report will show that the team is ready to procure parts and begin assembly and test. The supporting documentation includes the electrical design for the system along with details as to why certain components were chosen. Along with that, the schematic diagram, parts list, and the plan for testing the hardware prior to integrating with firmware are also included.

Electrical Design

Arduino Uno:

For the system, the team will utilize a microcontroller as the brain for the system, but more specifically an Arduino Uno, a procured component, which has a 16Mhz, 8-bit microprocessor. The Uno was selected because it has an operating voltage of 5V and higher IO current to simplify the driver circuits that will be in the system. The Uno can be powered by an external power supply that draws from the 12V-14V battery voltage. The Arduino Uno will be placed on the PCB such that it will sit on top and have its pins connected to their specific connections located on the PCB.

Fan Driver Circuit:

Driving the fans: A IRL520N N-channel MOSFET was selected for the reason that it can be driven directly from the Arduino UNO due 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 maximum 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, like you would a relay in a car.

Transistor Selection For Motor Drive Circuit:

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. 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. The transistors are going to be in parallel with each other to use the same IRL520N MOSFET as the fans in order to achieve 100% socketability and therefore zero active components soldered to the board for easy field repair.

Solar Charge Controller:

The solar charge controller is simply 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 also 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 over discharged.

Motor Driver Relay H-Bridge:

The Motor driver relay H- Bridge 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 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. Low ohm power resistors are used to tune which motor spins faster to keep tension on the inflatable.

Capacitor Selection:

For the selections of the capacitors, they are for when the voltage drops too low when the motors start up and draw very high current for a split second, which could reduce the board voltage to levels that would cause a brownout of the Arduino. Therefore, the capacitors act as a "battery" for the Arduino and the two hall effect sensors, which is fed through a diode so power can only go into the capacitors, Arudino, and sensors while making sure it does not go beyond that section of the circuit. The capacitors selected are rated for 25V, approximately double the typical operating voltage. In addition, higher temperature capable aluminum polymer capacitors were selected to better tolerate the desert-like conditions that traditional electrolytic capacitors.

Schematic Diagram and Walkthrough

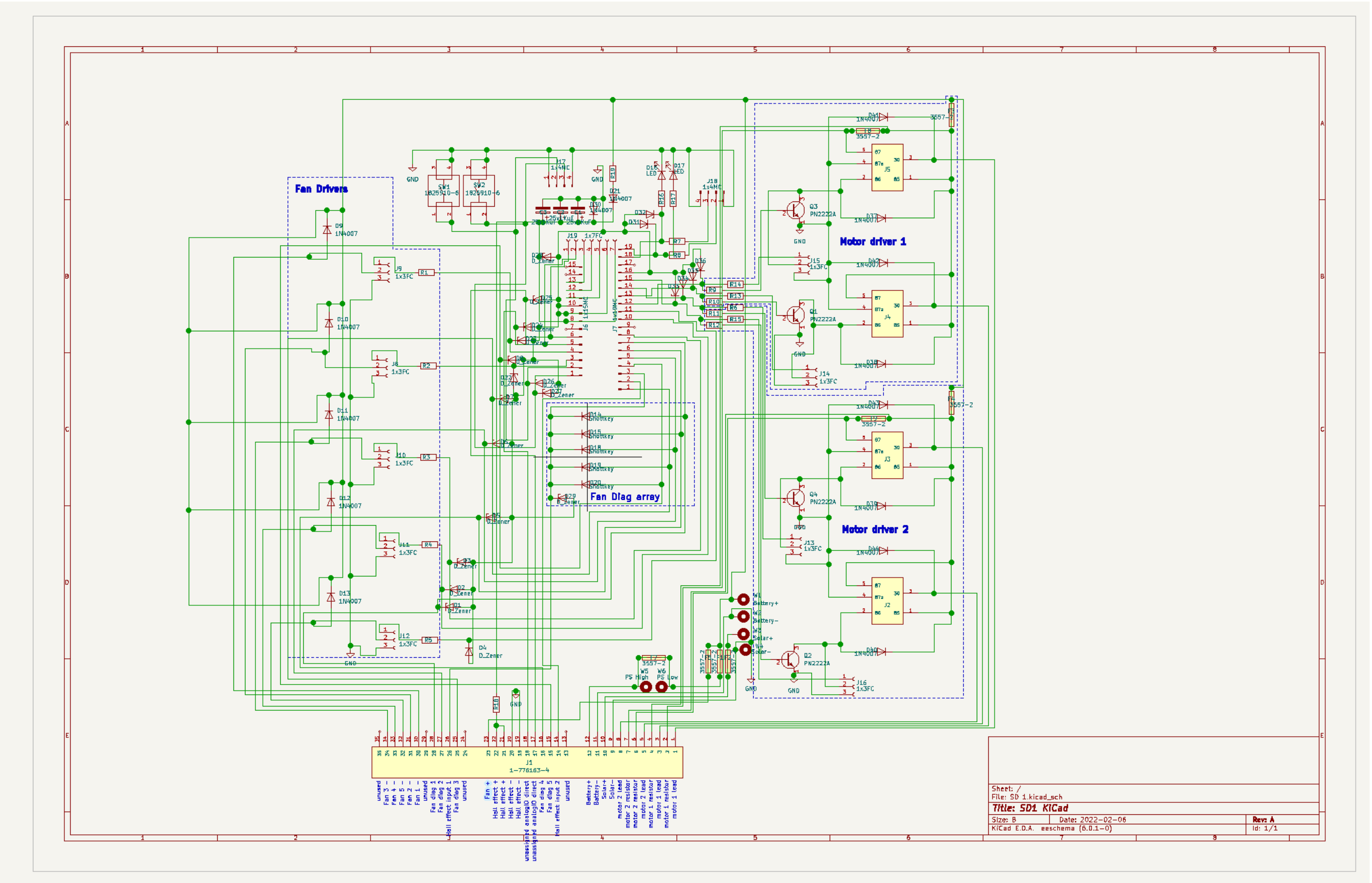

Figure 1: Schematic for the PCB Showcasing Each Component and Sections Such As Motor Drive One and Two, Fan Drivers, Fan Diagram Array, and Descriptions for the J1 Connector

The schematic design for the PCB is shown in the above Figure 1. There is a 12 volt input that comes in on pin 12 of the J1 Connector and goes through the jumper fuse, F7, or through pad W5 through an external power switch to pad W6 from there through fuse F1 for overcurrent protection. From there, there is a pad, W1, for the solar charger battery positive connection. Then it goes to the fuse, F3. It also goes from fuse F1 to fuse F3 for motor driver one and to fuse F4 for motor driver two to feed motor drive one. In addition, another path goes from fuse F1 through a diode, D21, to charge the capacitor bank that provides stable power for the Arduino Uno and other sensitive electronics; it also connects from fuse F1 to fuse F4 to feed motor driver 2 as well as to the 12V lines to all the fans. A fuse output wire was added F7 for all the fans this will get 5-10 amps fuse depending on the number of fans this is connected pin 23 on J1 connecter as fan +. On pin 10 of J1, there is the solar positive connection which then goes through fuse F2 to pad W3 for the solar positive connection. Then, pin 9 of J1 connects to pad W4 of solar charger negative connection. Next, pin 11 of J1 connects to pad W2 of the solar charger battery negative connection and also is ground for all components of the board.

The 12 volt input from the battery comes in on pin 12 of J1 connector and goes through the fuse F7 or through the pad W5 through an external power switch to pad W6; from there it would go through fuse F1 to power the 2 motor drivers through their own independent fuses, F3 and F4. For motor driver one, it has four resistors coming from two pins on the Arduino, R14 feeds pin 1 of a one by three female connector J15 for a MOSFET to be socketed into it. R9 then feeds the base of the Q3 Pn2222A transistor. Either of these can activate the relay attached to socket J5 by connecting pin 1 of J5 to ground which triggers the relay to turn on motor 1 in one direction by connecting pin 3 to pin 5 of the J5 socket. The power going through the J5 socket can either pass through a fuse F8 or have a connection to J1 pin 2 and pin 4 for connecting to an external power resistor to slow down the motor when J5 relay is activated. Pin 5 of the relay sockets are also connected to the 12V battery power, so connecting pin 4 and pin 5 provides 12V to pin 3 to drive the motor.

On the other relay for motor driver 1, there is no fuse connected. It is directly connected to the 12 volt battery positive power on pin 5 to pin 3 and that is connected to pin 3 of the J1 connector. In motor driver one, D41, D37, D42, and D38 are all anti-flyback diodes to prevent arcing on the relay contacts and to prevent voltage spike in the relay activating devices such as Q3 or the MOSFET in socket J14 or J15 or Q1. Motor driver two is the same where F4 provides overcurrent protection on the input power to the entire motor driver, arrangement socket J3 has fuse F9 as a jumper, or it goes to socket J1 pins 6 and 7 for an external power resistor. The relay in J2 is connected to 12-volt power and has the 4 diodes D43, D39, D44, and D40 for anti-flyback protection for the relay contacts and relay activating solid state devices.

For each fan driver, a digital IO pin passes through a resistor to pin 1 of Q1 by a one by three female connector which gets a MOSFET placed into it. Pin 2 of the one by three female connector is connected to pins 30-34 on the J1 connector in order for the fan negative wires to be connected too. Pin 3 on each one by three female connectors goes directly to ground. They each have an anti-fly back diode in between the input pin from connector J1 to the positive 12-volt wires in case of voltages generated by the fan once turned off D9, D10, D11, D12, and D13. Pins 28, 27, 25, 16, and 15 are used as fan diagnostics, these go to pins 4, 5, 6, 7, and 1 on the Arduino to read the status of the fan whether they are rotating, the fan pull or can sick current so the Arduino internal pull up resistor will be set to high and the fans will pull them down to low. In order to know when to read the fan diagnostic lines all of these are connected to pin 3 on the Arduino which is a hardware interrupt through schottky diodes so when one of the diagnostic pins goes low, it will also pull down pin 3 and that hardware interrupt will trigger a read of all 5 fan diagnostic pins.

Pins 2 and 3 of the Arduino are also connected to Pins 26 and 14 of the J1 connector and these are used with Hall effect sensors which also sink current when activated so when the cart is moving the pins will be used to count pulses of the moving devices to measure their progress. Switches S1 and S2 have one end connected to ground and the other end connected to header J17. These are pins 1 and 2 of a small connector of J6 so when switches are pushed, they will pull it to ground or to 0 volts so the Arduino will have the internal pull up resistor to high. Pins 1 and 2 of J6 also go to connector J17 which will be connected to external switches which will do the same task of pulling them to ground. To light the leds D15 and D17 the low ends are connected to ground and they pass through resistors R16 and R17 respectively and led D17 is connected to pin 19 of connecter J7 and led D15 is connected to pin 18 of J7 connector of the Arduino and these will be used to display diagnostic information.

The diodes in the vicinity of the Arduino D6, D7, D22-D28 and D33-36 are for static discharge and overvoltage protection where if a higher voltage is connected to the pins it will be shorted to ground through the diode and a fuse will blow quickly enough so the device is protected. These will be 6 volts Zener diodes so anything over 6 volts will get shorted to ground. Female connector J19 has 2 ground pins, a 5 volt, 3.3 volt, and capacitor storage sourced Vin pin for powering future expansion devices such as a radio transceiver if one were to be added. R19 is a low ohm resistor to limit the surge current into the capacitor that provides stable power to the Arduino and hall effect sensors. Pins 5 and 6 of connector J6 which connect to two unused analog pins of Arduino connect to pins 1 and 2 of J19 and pins 17 and 18 of connector J1 for the purpose of expansion.

Printed Circuit Board

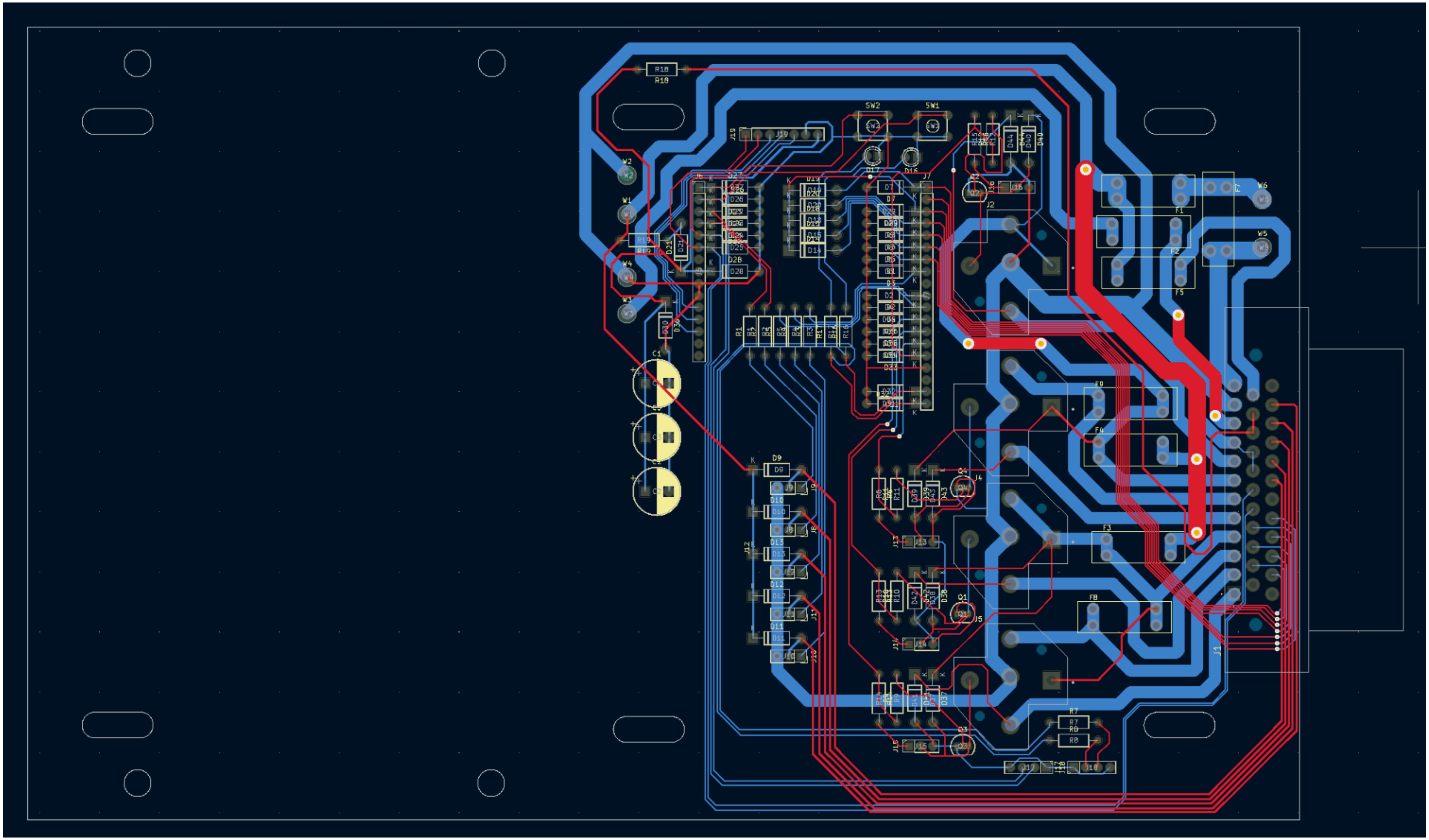

Figure 2: Circuit Side View of the PCB Showing the Traces and Wire Connections Between Components

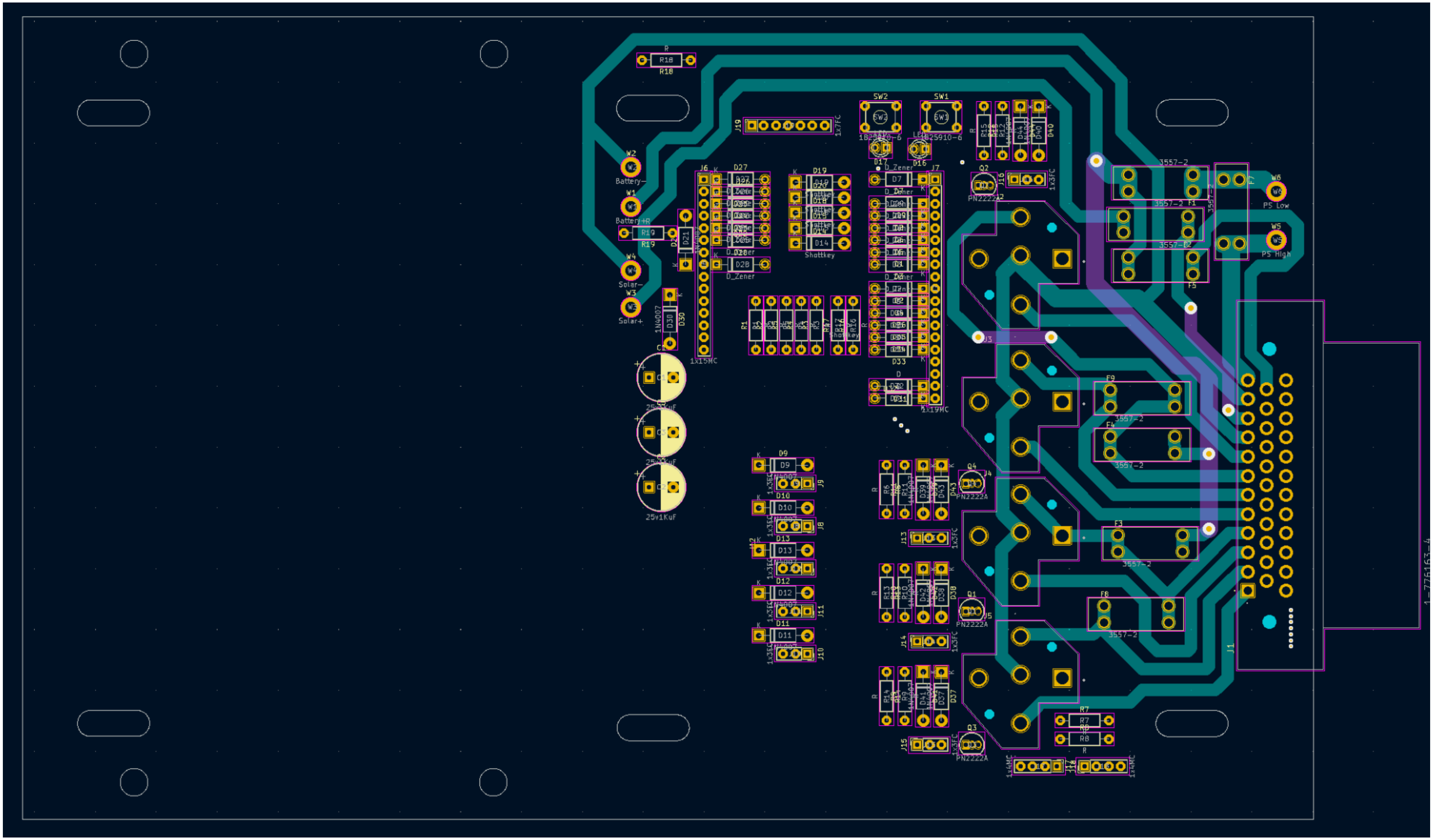

Figure 3: Component Side View of the PCB Showing the Traces and Components

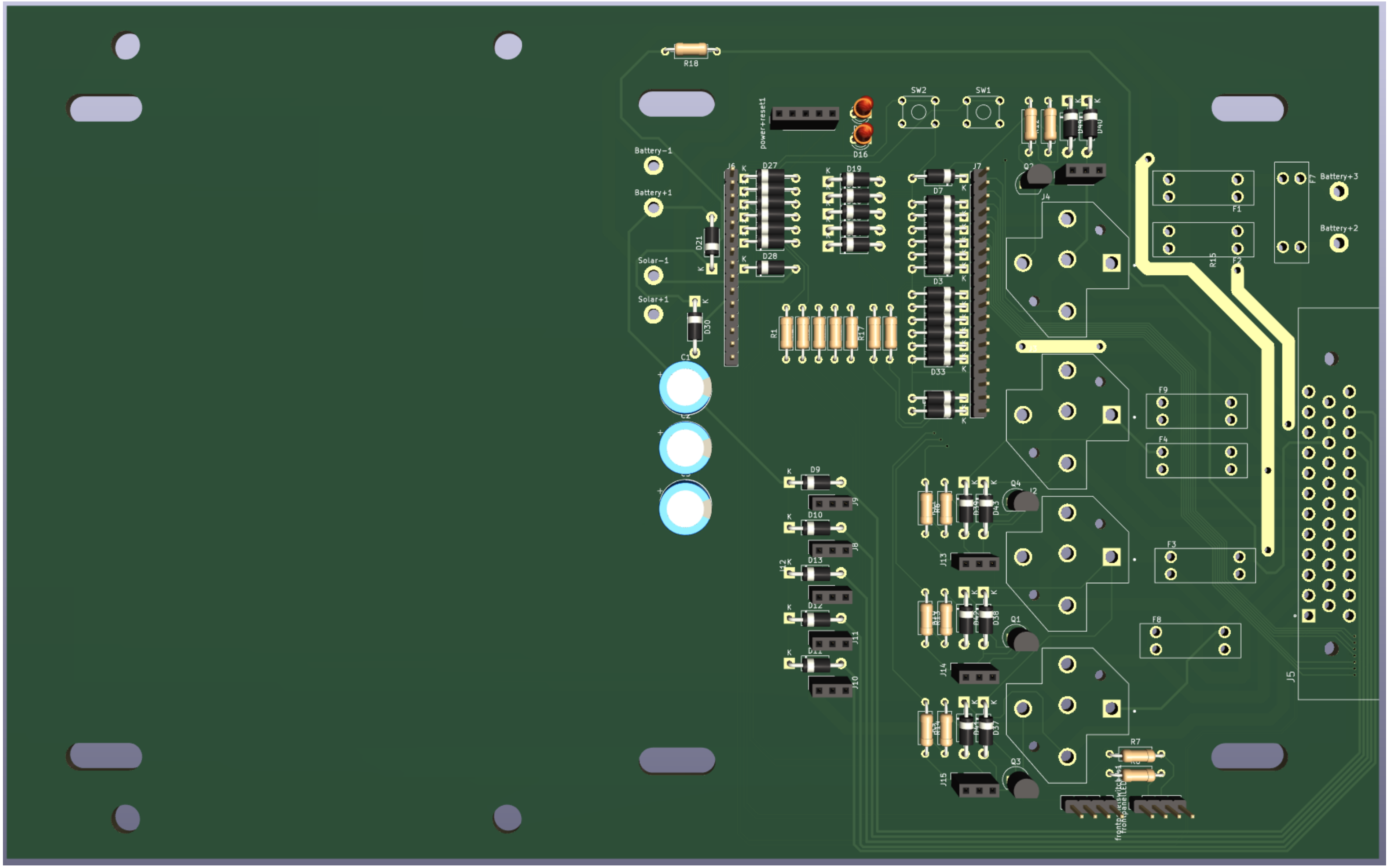

Figure 4: Front View 3D Model of the PCB Displaying All Components In Their Place

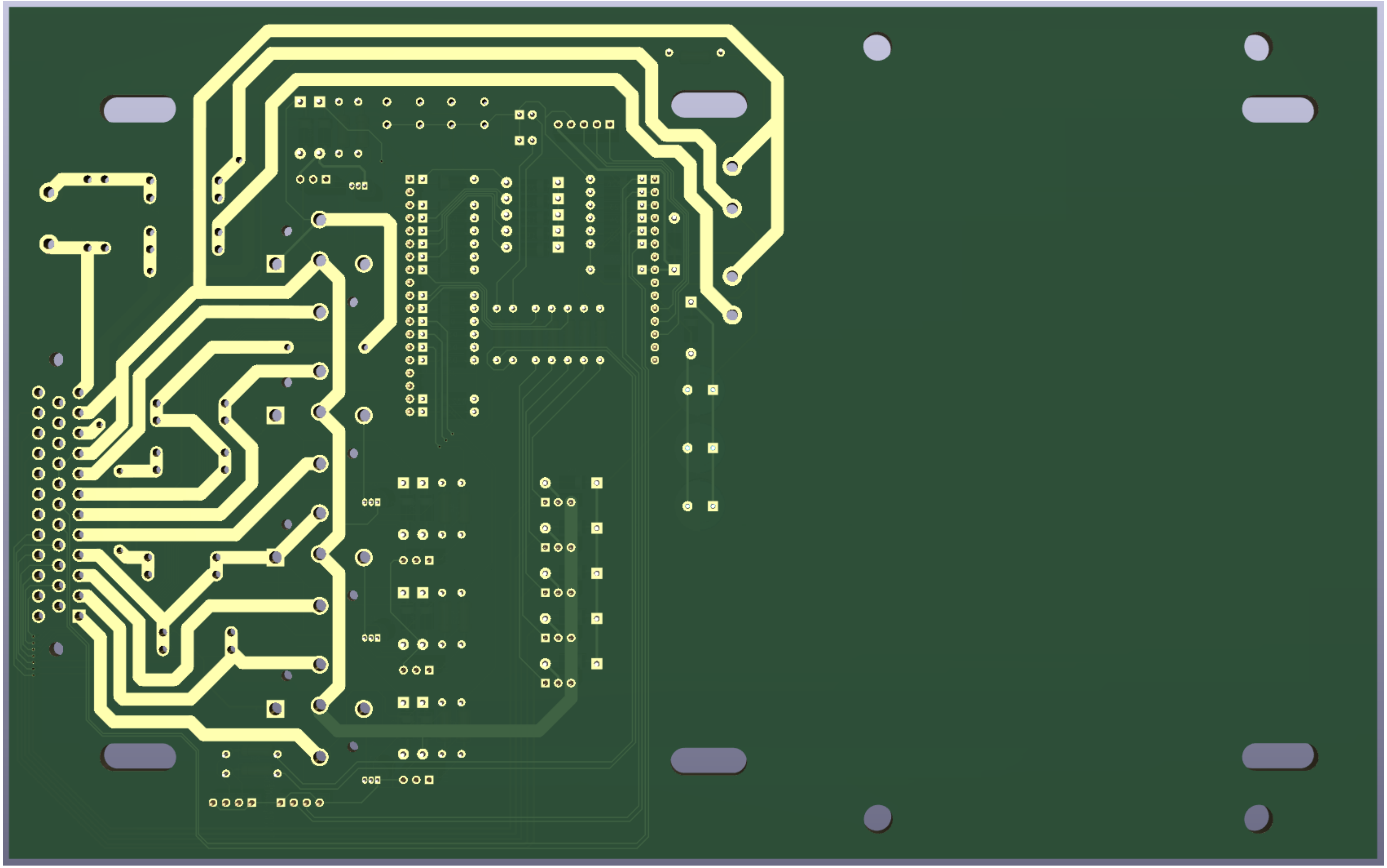

Figure 5: Back View 3D Model of the PCB Showing the Traces

Enclosure Details

Figure 6: Electrical Enclosure We Intend To Use Called the NBF-32016 Series Plastic Nema Box

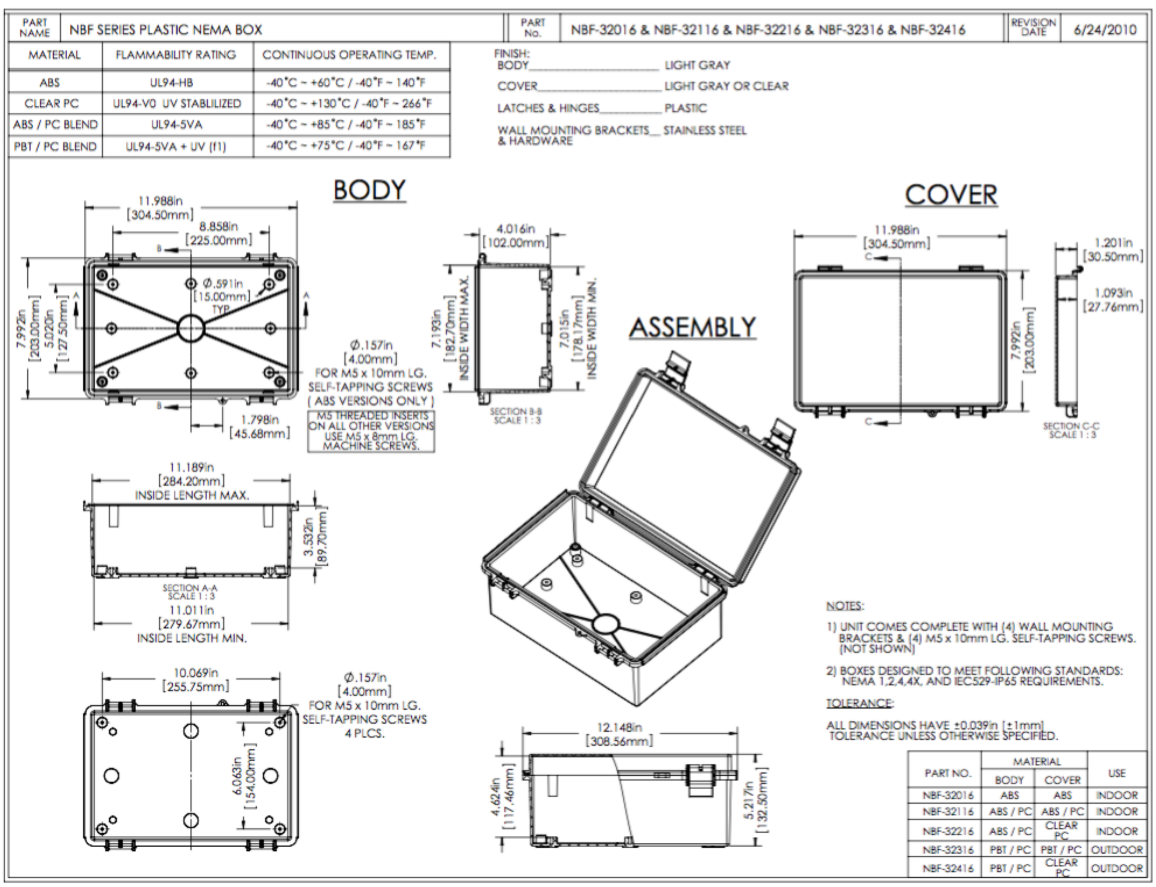

Figure 7: Electrical Enclosure Standard Showcasing the Cover, Body, and Assembly

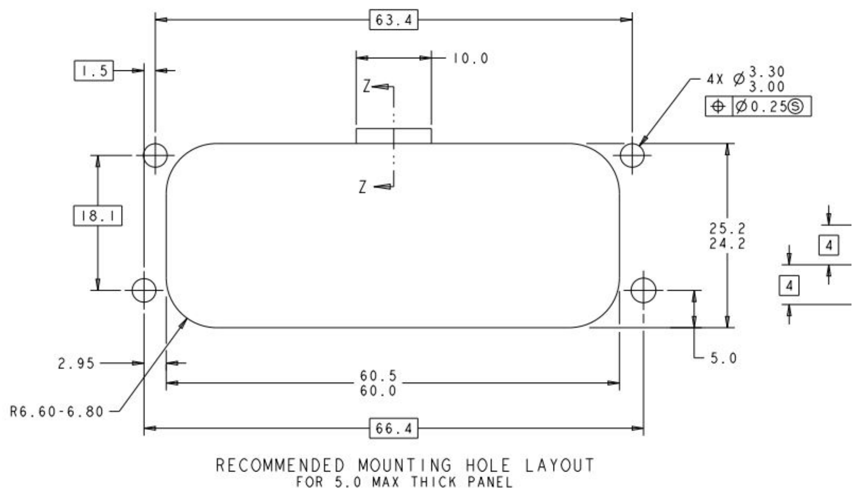

Figure 8: Hole Layout For Enclosure Where All The Wires From the J1 Connector Will Go Through

Shown above in Figure 6 is the schematic for the enclosure that is going to be used for the Rapid Deployment Runway Closure System. The enclosure that will be utilized is called the NBF-32016 Series Plastic Nema Box, manufactured by Bud Industries, and sold by Mouser Electronics for $25.80. Here is the link to the enclosure. Currently, the enclosure has been purchased and is waiting for the PCB to be completed in order to make modifications to the enclosure. The plan is to have a hole on the left side of the enclosure to allow for all the wiring to be connected to other components for the system. When oriented with the plug to the left, the USB port on the arduino will point up such that it will not risk falling out if we are logging data on a computer while it is driving around. In Figure 8 is the layout the ME's intend to use when cutting the hole on the enclosure..

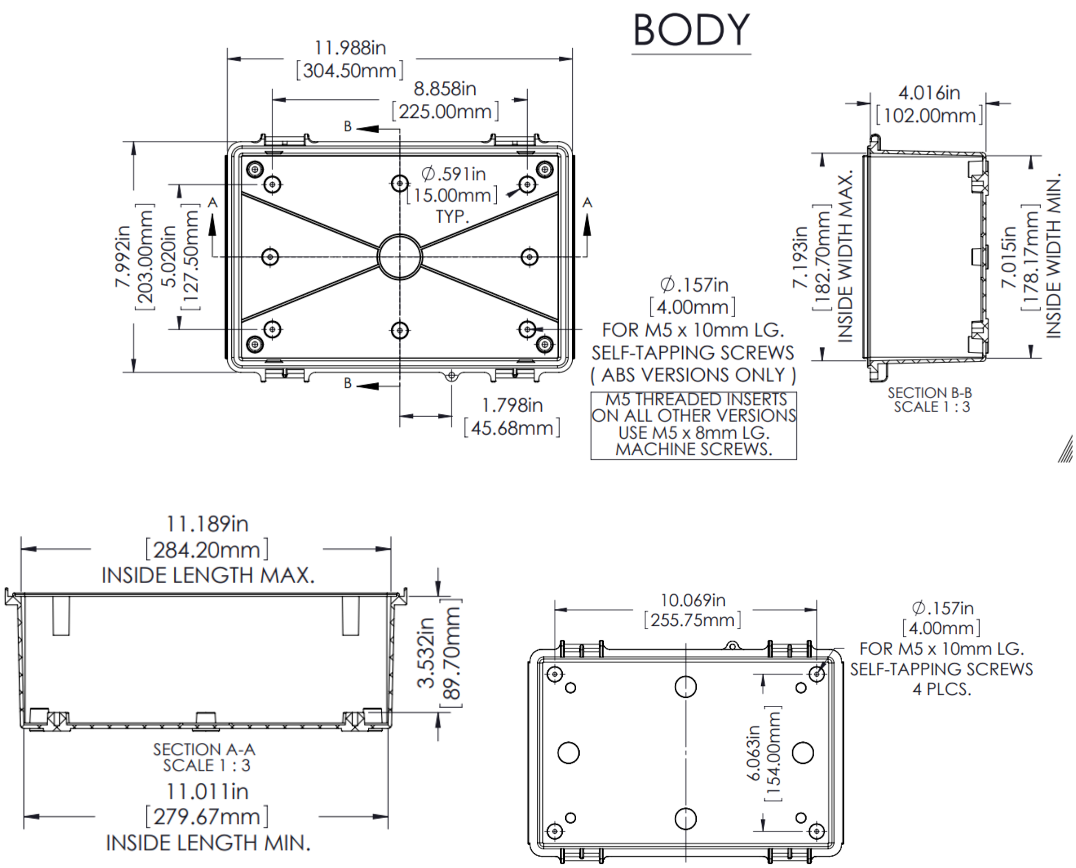

Figure 9: Electrical Enclosure Standard Showcasing the Body and All of its Dimensions

As shown in Figure 9, is the body of the enclosure. When looking at the enclosure at the top view, it will be 11.988 inches by 7.992 inches. When looking at the enclosure from a side view, it will be 7.193 inches by 4.016 inches. Finally, the front view for the enclosure will be 11.189 inches by 3.532 inches. Since the team plans to make a hole on the side of the enclosure for all the wires of the PCB to go to its respective elements, the ME team plans to make the hole 60.5 millimeters by 18.1 millimeters as shown in Figure 8.

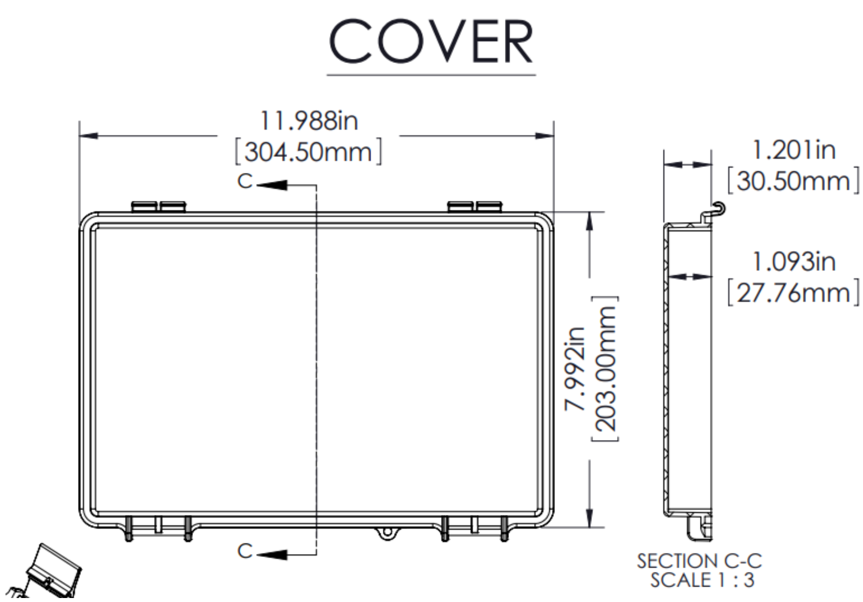

Figure 10: Electrical Enclosure Standard Showcasing the Cover and its Dimensions

In Figure 10, the cover for the enclosure will be 11.988 inches by 7.992 inches and from the side, it will have a height of 1.201 inches. The cover allows for both the PCB and the solar charge controller to be protected from environmental elements since the system will often be used in desert-like environments.

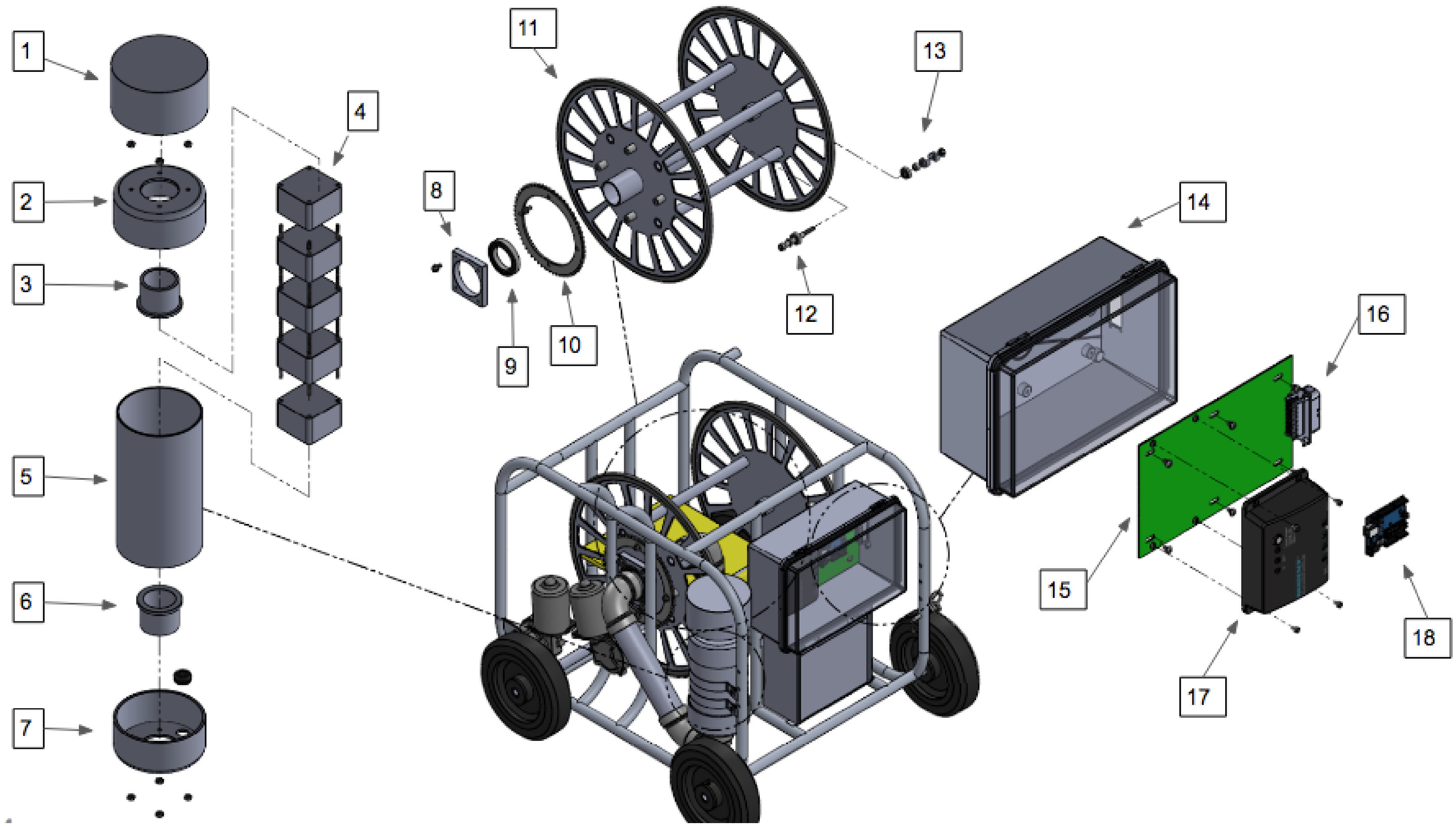

Figure 11: Total Enclosure Detail for the Rapid Deployment Runway Closure System

Part #	Subsystem	Components
1	Air Assembly	Air Filter
2		Endcap, Input Side
3		Reducer Bushing
4		Fans
5		Air Blower Tube
6		Reducer Bushing
7		Endcap, Output Side
8	Spool Assembly	Bearing Mounting Block
9		Bearing
10		Spool Drive Sprocket
11		Spool Assembly
12		Axle and bearing
13		Axle fasteners
14	Electrical Assembly	Electric Enclosure
15		Main PCB
16		Panel Mount Connector
17		Solar charge Controller
18		Arduino Uno

Table 1: Enclosure Details Table Showcasing Each Subsystem and Components

The overall enclosure/system and how the entire system is being housed can be shown through Figure 11 followed by a table that labels each element in Table 1. The electrical enclosure is shown as part #14, and allows for easy access just in case anything needs to be replaced or changed.

Wiring Diagram

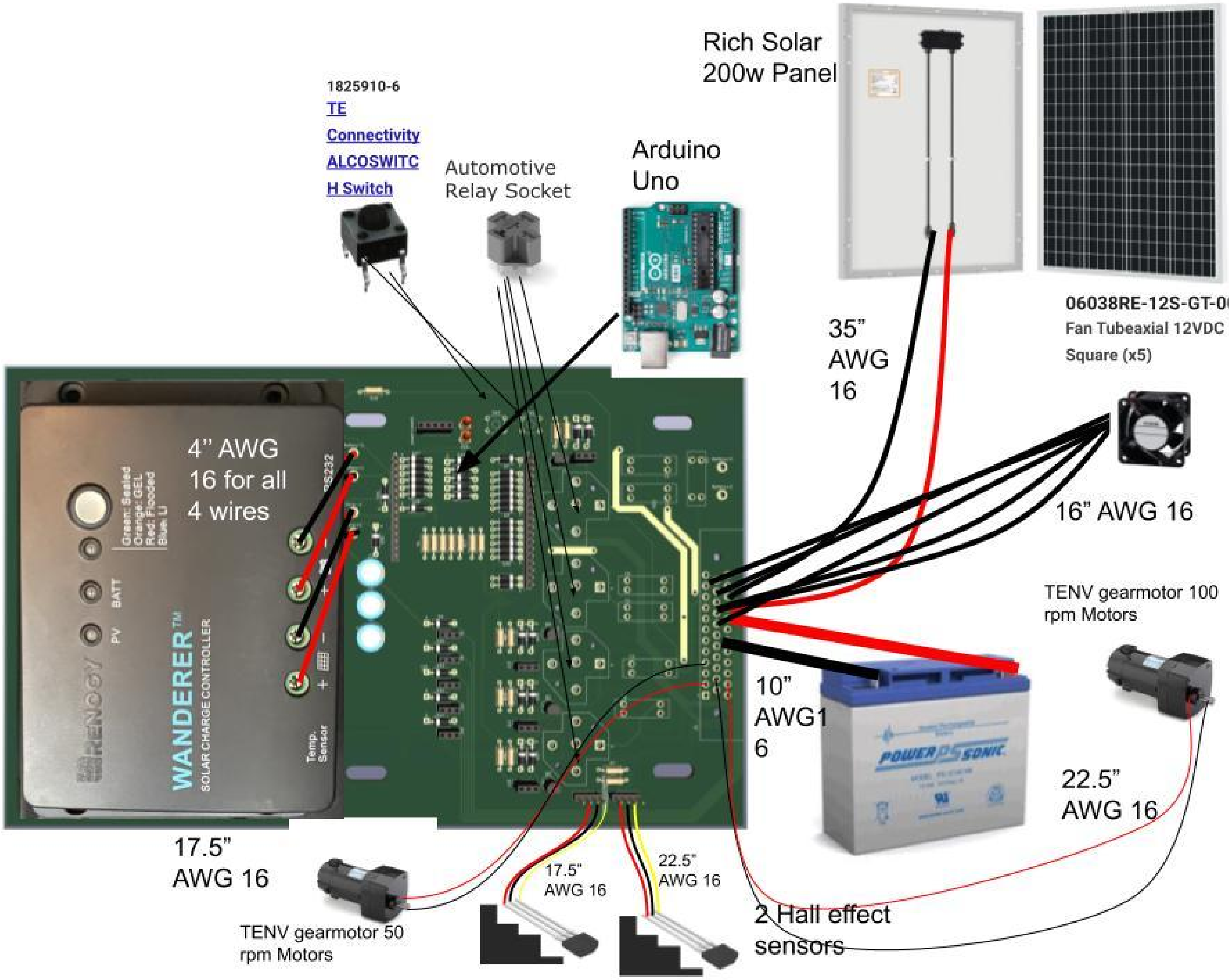

Figure 12: Wiring Diagram Showcasing the Wires and Lengths to Each Component (Red Wire = Positive, Black Wire = Negative (Except For Fans, Wires Represent Where Wires Are Connected to the J1 Connector), Yellow Wire = Signal)

Parts List

Quan.	Ref Des	Description	MFG P/N	DigiKey/link	Cost	Ext
4	R9,R10,R11,,R12	470 Ω, 1/4W Resistor	594-AC03W470R0J	Digikey	$0.57	$2.28 (Provided)
4	R1,R1,R3,R4,R5	680 Ω, 1/4W, Resistor	45F680E	DigiKey	$0.10	$0.40 (Provided)
1	Electrical Enclosure	NBF series IP66 ABS enclosure	563-NBF-32016	Mouser	$25.80	$25.80
1	Arduino Uno	Arduino UNO	7630049200050	Arduino store	$23.00	$23.00
4	RELAY1,RELAY2,RELAY3,RELAY4,	Bosch0332 209151 relay	0332209151	Rockauto	$3.27	$13.08
1	Battery	Powersonic PS-12180HD-M5 AGM battery	PS-12180HD-M5	UPS battery center	$69.99	$69.99
14	D9,D10,D11,D12,D13,D40,D44,D39,D43,D38,D42,D37,D41,D21	1N4007 diode	1N4007	Digikey	$0.10	$1.39
5	Q5,Q6,Q7,Q8,Q9	N-channel MOSFET	IRL520N	Digikey	$1.00	$5.01
4	Q1,Q2,Q3,Q4	PN2222A transistor	PN2222A	Digikey	$0.10	$0.40
2	SW1,SW2	PTS645SL50-2 LFS SPST momentary switch	PTS645SL50-2 LFS	Digikey	$0.17	$0.34
2	N/A	Allegro APS11700LUAA-0	APS11700LUAA-0PL	Digikey	$1.30	$2.60

Table 2: Rapid Runway Closure System Parts List Showing the Components Needed for the PCB Such As Resistors, Arduino, Transistors, Etc.

		PL Hall effect switch				
1	N/A	35 pin Ampseal panel connector, gold plated	1-776163-4	TE connectivity	sample	$0.00
1	Solar Panel	Rich Solar 200w panel	SKU RS-M200	Rich Solar	$219.00	$219.00
1	Solar-1,Solar+1,Battery-1,Battery+1	Renogy Wanderer Li 30 amp PWM charge controller	RNG-CTRL-WND30-LI -US	Amazon	$27.90	$27.90
4	RELAY1,RELAY2,RELAY3,RELAY4,	Relay Socket	BR05-PCB-1P	Spemco	$1.25	$5.00
1	N/A	PCB	N/A	JLCPCB	$17.50	$17.50
4	Fuse socket	Fuse holder blade 30A PCB	3557-15	Digikey	$1.22	$4.88
3	N/A	Wire	N/A	McMaster Car	$21.00	$21.00
1	Battery+1,Battery-1,Solar+1,Solar-1 MountingHole_Pad	5 pack solar panel mounts	8863T69	McMaster Carr	$6.11	$6.11
3	C1,C2,C3	1000 uF capacitor	A750MV108M1EAAE014	DigiKey	$1.08	$3.24

Table 2: Rapid Runway Closure System Parts List Showing the Components Needed for the PCB Such As Resistors, Arduino, Transistors, Etc.

Hardware Test Plan

Test Name	Supported Specificiation	Procedure and Equipment	Expected Results
Arduino Test Fit	Internal	Have the Arduino Uno connected on the connectors of the PCB and verify that the connections with the Arduino match with the ones on the PCB.	The Arduino should fit securely onto the PCB and should be routed properly between the PCB and the Arduino.
Solar Panel Test	External	Connect the solar charge controller to the battery and solar panel. First connect the battery then the solar panel in so that the solar panel can operate safely. Put the solar charge controller into “Li” mode with maximum voltage set to 13.6V per the battery specifications. Connect solar panel.	Make sure the solar charge controller charges to no higher than 13.65 volts to ensure maximum lifespan of the battery..
Power On Test	Internal	Remove relays from sockets. Place a 30 amp fuse as a jumper while connected to the lab power supply to turn on board. Monitor current flow as capacitor energy storage charges, and verify voltages at key points.	The capacitor bank inrush current should be limited to 5 amps peak. 12V power should be detected at pin 5 of all motor driver relay sockets, Vin of the arduino, Vin on connector J19, fan output wire, and both hall effect sensor pins on .

Table 3: Rapid Runway Closure System Hardware Test Plan Such As Arduino Test Fit, Solar Panel Test, Power On Test, Applied Coil Voltage Test, and Motor and Fan Capability Tests

Applied Coil Voltage Test For the Relays	Internal	Turn on the board with the relays out of the PCB, but have a resistor in the socket between the coil sockets and set all motors on high in the Arduino and measure the voltage across the relay. The resistor needs to be able to create a 140mA load from 12V.	Should be at least 10V, but could word down to around 7V. As the ambient temperature increases, the minimum trigger voltage changes.
Motor Capability Test	External	Connect both the 50 and 100 rpm motors to the PCB individually and then at the same time. The Arduino should be set on HIGH in order for the motors to run. Use the voltage power supply in the lab and set it to 12V to have the motor and Arudino run.	Should be able to have the motors run in either direction. Monitor the speed of the motors such that we should be hoping that it will be able to deploy the inflatable in 3-5 minutes.
Fan Capability Test	Part #4 on Table 1, External	Have the fans connected to the PCB and set on HIGH on the Arduino. Use lab equipment, such as the voltage power supply, to have the fans and Arduino run at 12V.	Make sure the MOSFET does not get too hot to the touch when the fans are turned on. Fans should be running at full power and be able to inflate the inflatable in about 3 minutes.

Table 3: Rapid Runway Closure System Hardware Test Plan Such As Arduino Test Fit, Solar Panel Test, Power On Test, Applied Coil Voltage Test, and Motor and Fan Capability Tests