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Personal Vacuum Assisted Climber

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PERSONAL VACUUM ASSISTED CLIMBER

by

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Approved:

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Abstract

The Personal Vacuum Assisted Climber (PVAC) system built in 2012 by the Ascending Aggies at Utah State University which was designed using vacuum motors to provide suction to pads to allow the user to climb various surfaces, needs to be further developed before being fully marketable. The current system does not have a user-friendly interface and is very loud (approx. 90 dB). These issues were addressed to answer the following question: how can the current PVAC system be optimized to decrease noise and produce a user friendly interface while maintaining current run time? To obtain the sound reduction desired it was decided to surround the motors with a hard plastic polystyrene case created by a vacuum forming process and then lined with sound-reducing convoluted foam. The motor exhaust was channeled through a single muffler out of the bottom of the case. This resulted in a sound reduction of over 20 decibels. The power system was improved with a new choice of 36 volt motors which could each be run off of only four batteries or an AC power supply through an inverter. The batteries used in this system increased run time by 50% and decreased the overall weight of the previous system by 8 lbs. This choice of motors was found to supply in excess the needed suction to support a 300 lb. person. A Pulse Width modulator was also installed to provide a control on Voltage output of the batteries to optimize the run time. A pressure gauge and Voltmeter were installed to provide a user interface with a display on the pads of the system showing the remaining battery voltage and pad suction pressure.

Acknowledgments

This project was undertaken by the Climbers senior design team from Dr. Wood's MAE 4800/4810 classes. I would like to personally thank Wes Elder, Zach Sims, Tyson Kesler, Preston Ford, Matt Palmer, Tyler Hunsaker, and Nick Lee for their hard work and dedication to making this project successful as integral parts of that senior design team. With their teamwork we have been able to meet the requirements set forth by our professors and customers for the PVAC system. I would also like to thank Dr. B.D. Wood and Dr. D. Magna for their role as design mentors throughout the development of this design project. Their guidance and input into the project has been crucial to the success of the PVAC system. Thanks is also due to Dr. Hansen and Rhet Astle. As our customers for the development of the PVAC system they were more than helpful in communicating their desires and where appropriate gave crucial advice and guidance in our development of the design of the PVAC system. Lastly I would like to thank the Air Force Research Laboratory for providing the funds for the project and their continued interest in the development of the PVAC system.

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1. Introduction to the PVAC system

The Personal vacuum Assisted Climber (PVAC) system was first designed and built in 2012 by the Ascending Aggies at Utah State University as part of the Air Force Research Laboratory's (AFRL) University Design Competition. The competition was to design a device that could get soldiers up a wall without the use of a grappling hook. More specifically the device had to be able to scale a 90 ft. structure, support 300 lbs., climb a variety of surfaces (glass, adobe, brick, etc…), climb faster than 12 ft/min, and fit inside a 3 cubic foot backpack.

To accomplish these requirements the Ascending Aggies team designed the PVAC system that works by the principle of a vacuum that holds the user to the climbing surface. The system is composed of a vacuum motor subsystem, power delivery subsystem, pad subsystem, foot support subsystem, and safety devices. The motor subsystem uses impeller based vacuum motors to provide suction to the pad subsystem through hoses. The power deliver subsystem was comprised of either an extension cord or Lithium Polymer (LiPO) batteries. The pad subsystem included an aluminum base, an outer fringe seal, friction strips, a pressure release, and a vacuum hose connection to the hose coming from the motors. The foot support subsystem included stirrups which were connected to a bracket on the pads. Finally the safety devices included a pressure gauge to determine when safe suction had been reached for climbing and a voltmeter to allow the user to determine if the batteries were providing the voltage required.

All these subsystems were made to fit into a backpack that the user would carry on their back, two pads that the user would hold in each hand, and stirrups into which the user stand in as they climbed the wall (figure 1). With the system now in position the user may ascend a climbing surface by attaching the pads to the wall in an alternating pattern by the suction provided by the motors. While one pad is stuck to the wall the user may use their legs to propel themselves upward, place the next pad on the wall, attach it to the wall by use of suction, step up to the side that is secured while releasing the previously attached pad from the wall, then repeat the process as the user ascends the wall.

Figure 1: PVAC system designed by the Ascending Aggies

The PVAC system developed by the Ascending Aggies took first place at the competition. However this system needed to be further developed before being deployed or marketed. As a result of the competition the AFRL provided a grant to USU to produce a production prototype that included a user-friendly interface, safety gauges, AC or DC power options as well as significantly reducing the noise. The Climbers team at Utah State University was assigned this task as their senior design project.

2. PVAC System Design Requirements

<u>The design requirements set forth by the customers are the following:</u>

- **Maintain current run time of 21 minutes.** The new design needs to perform equal to or better than the current design.
- **Add only 10 pounds of new weight.** As this system will be worn on the back of a person ascending a vertical surface, keeping the system under a manageable weight is critical.
- **Allow the backpack to run on batteries or an external power supply.** To allow for versatility and climbing in a variety of locations, the backpack will be able to run on battery power or some other external power supply.
- **Provide the user with the ability to monitor the motor vacuum pressure inside suction pads, and remaining battery life.** The user will be able to monitor the conditions inside the system to minimize risk.
- **Reduce the noise by 20 decibels.** For the comfort of the user and for stealth climbing, the noise will be reduced by 20 decibels.
- **Stay within a budget of $4,000.** The modifications made to the PVAC system will cost less than $4,000. This does not include any parts, supplies, or components on or used in the development of the current system.

3. Redesign and Results

At the onset of the project the team met together and brainstormed ideas. It was decided that due to the nature of the project the team would split into power and sound sub teams to accomplish the tasks. These sub teams then investigated solutions to the design requirements as outlined in the work breakdown structure shown in figure 2. The power sub team further investigated options of using other motors, batteries, and the possibility of using a logic controller to relay information of temperature, battery voltage, and pressure to the user. The sound sub team investigated solutions to the sound requirement through use of active and or passive noise cancellation methods. This section of the design report discusses the development of the design by component that were decided upon by the team. The section following this one presents the completed system as a whole.

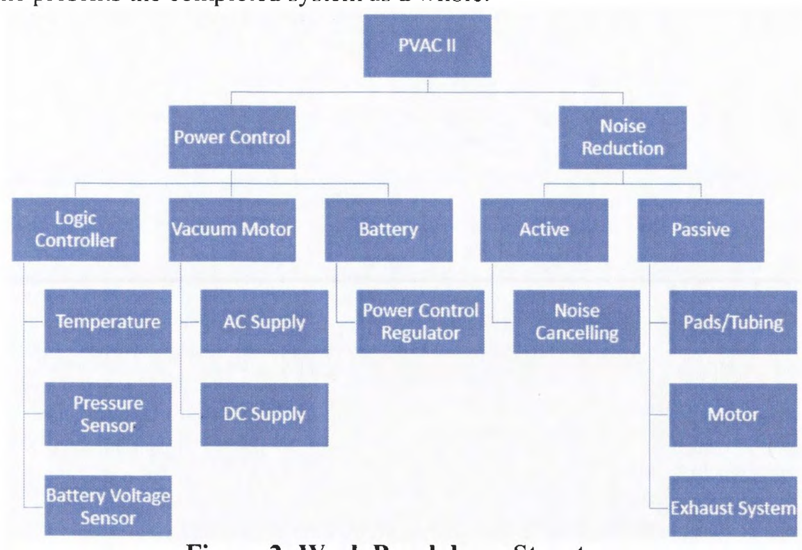


Figure 2: Work Breakdown Structure

3.1 Design Assumptions

In order to meet the design requirements, some assumptions were necessary. The assumptions made were that the user would be physically capable of operating the new PVAC system which could weigh up to 64 lbs., the climbing surface is smooth, climbing will be done in fair weather conditions, and the climber does not weigh more than 300 pounds.

3.2 Power System

3.2.2 Motors

The original PVAC motors were 3 stage brush motors that operated at 120 Volts. Further research was done and the best available motors found for this project are shown in trade study 1 of Appendix A. It was decided to use the 3 stage, direct current (DC), brush motors that use 36 volts and 15 amps. They are capable of providing a suction of 137 inH_2O, they weigh 7 pounds, and cost about $92 each. The suction provided by these motors were determined to be sufficient as explained in the testing section of this document. These new motors were chosen due to the lower voltage they are run on. This would allow for less batteries required for operation and would offset the weight addition from the sound system keeping the system under the required weight.

3.2.2 Pulse Width Modulator

To maximize run time, act as a power switch for the motors, reduce noise, and allow the user to control power consumption, it was decided that a pulse width modulator (PWM) would be used. Other options were ruled out by trade study 2 of Appendix A. The PWM selected runs the motors between 5% and 100% voltage, weighs 0.29 pounds, costs $15.35, and handles up to 20 amps and 60 volts. As shown in the test section these were found to be adequate for use with the batteries and with the inverter with one modification. The Inverter selected is not able to handle the pulse width modulators from each pad running at full capacity. To address this issue it was decided to put marks at which the operator would not be allowed to turn the pulse width modulators past when operating the system on the inverter.

3.2.3 Batteries

Various configurations of Lithium Polymer (LiPo) batteries were discussed to provide power to the motors as shown in trade study 3 of Appendix A. It was decided that Product 3 of that trade study would be used. This product consists of four Gens ACE 4000 mA-18.5V batteries. These batteries were connected as illustrated in figure 3. This configuration of wiring two in series and wiring those in parallel with another set of two in series provide 8 amp hours and 37 Volts. They weigh 4.6 pounds, cost $268, and last 31.5 minutes under normal operating conditions. Their use is justified in the testing section of this document.

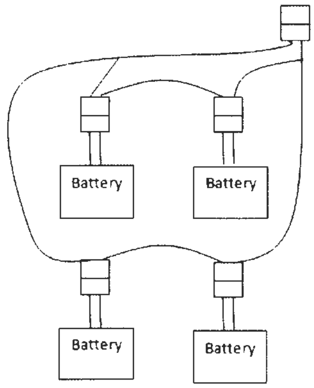


Figure 3: Battery Wiring Diagram

3.2.4 Inverter

The motors discussed above run off DC power. In order to operate using an external power supply from a generator or outlet, an inverter is necessary to change the power from AC to DC. The power inverter chosen is a Synqor product. It uses 1400 watts, provides 48 volts, weighs 2.6 pounds, and costs $910. One inverter powers both motors in the system.

3.2.5 Battery Connectors

Del City's weather pack connectors were chosen to connect the batteries to the pulse width modulator and motor. Each motor requires five 2-way weather pack connectors to be used to wire its four batteries. In order to wire these to the motor through the pulse width modulator two additional 4-way square weather pack connectors per motor are required. The complete wiring diagram is included in Appendix B.

3.2.6 Sensors

Originally it was thought that temperature sensors would be needed in addition to the power and pressure sensors. This was because of the configuration of the sound system. However as demonstrated in the testing section of this document the temperature was not an issue and therefore temperature sensors were not required. Before this was determined a Printed Circuit board was going to be used to regulate the display of LEDs on the surface of the pads to indicate the current power and temperature of the system to the user.

Since temperature sensors were not needed the idea of a circuit board and LEDs was done away with. It was determined to use a simple Cole-Parmer 0-100 inH_2O pressure gauge and a USA green waterproof small battery meter (8.5-90 Volts) voltmeter. The pressure gauge allows the user to know if the right amount of suction is being produced to keep them on the wall. The voltmeter allows the user to know if the correct amount of voltage is being provided by the power supply. Also by careful calibration of the batteries the voltmeter allows the user to know when the batteries are nearing the end of their charge.

3.3 Sound System

After preliminary research by the sound sub team it was decided to pursue passive noise canceling methods as opposed to active noise canceling methods. Upon further research is was decided to encase the motors with a polystyrene backpack lined with one inch convoluted foam with a muffler for the motor exhaust. The Plastic case and convoluted foam was chosen as a result of trade studies 4 and 5 respectively as illustrated in Appendix A. Preliminary sound testing was performed in the anechoic chamber at Utah State University to justify the design decision and further develop the idea.

Noise measurements were taken from the PVAC I system and compared to the PVAC II prototype. Noise absorbing foam was placed on the inside of the plastic case. The tests were performed with a short (12 inch) muffler and a long (24 inches) muffler. Noise measurements were taken from each side of the case from a distance of 1 foot and 3 feet while the pads were attached. The measurements in decibels were then averaged to get an overall noise measurement. The results are displayed in table 1. The preliminary tests show that a 20 dB reduction is possible with this system design. The following sections discuss the completed design.

Sound Reduction (dB)	Top	Bottom	Left	Right	Front	Back	Average
Previous Testing	92.0	93.0	89.2	93.0	92.4	82.1	90.3
Long Muffler	65.9	78.8	61.8	67.5	67.7	65.2	67.8
Short Muffler	66.5	74.8	64.8	68.2	68.6	65.9	68.1
Reduction (Short Muffler)	25.5	18.2	24.4	24.8	23.8	16.2	**22.2**

Table 1: Preliminary Sound Testing Results

3.3.1 Soundproof Case

The motors, batteries, and mufflers are contained inside a polystyrene plastic case lined with one inch sound reducing acoustic foam. The case was made by vacuum molding the polystyrene case. This was done in three sections. A top and bottom as shown in the drawing package in Appendix B are the same part. A side wall piece was made by heating along the bend lines and siliconing the ends together as explained in the manufacturing manual in Appendix D. The bottom was then fastened to the walls with rivets and the top was attached by three latches. This case manufactured in the university lab, costs approximately $250, weighs less than 3 pounds, and is airtight. The acoustic foam selected to reduce the sound is convoluted, high density foam. It has a density of 1.5 pounds per cubic foot, costs $2 per square foot, and is 1 inch thick. This soundproof case provides a noise reduction of 20.7 decibels as shown in the testing section of this report which meets the design requirement.

3.3.2 Exhaust Muffling

The majority of the noise comes from the vacuum motor exhaust system. A muffler is critical to reducing the noise. The muffler is also used in channeling exhaust gases out of the backpack. This is important because the motors expel heat through the exhaust which would otherwise have no outlet. To meet these requirements, mufflers were found that are made of economy PVC, cost $15 each, and weigh 0.5 pounds per foot. The economy PVC mufflers were chosen according to trade study 6 in Appendix A.

3.4 Interfaces

3.4.1 Backpack Interface

An Alice Pack Frame with Camo Straps was chosen to replace the original backpack frame. The sound case is secured to the backpack by the use of nuts and bolts. The motors were then secured to the backpack frame with seven inch hose clamps through slits in the back of the soundproof case. The batteries sit in the bottom of the backpack. All the wiring is wired into their components and out the top of the case to the pads through various holes drilled in the soundproof case as shown in the drawing package and explained in the manufacturing manual. The inverter is secured on the outside of the top cover of the soundproof case and covered with another polystyrene piece made by heating and bending.

3.4.2 Pad Interface

The backpack system is connected to the pads using hoses to allow for suction to the pads. It was decided that the wires would be wired through the inside of these hoses by drilling holes and siliconing the gaps left after wiring. To connect the hose to the suction area of the motor, basic plastic parts were found locally and in a vacuum part catalog. The selected hose adaptor fits a 2 inch vacuum hose and is connected to lightweight plastic fittings as outlined in the bill of materials. The plastic fittings are glued together and rigidly attached to the motor.

The hoses fit into the pads by locking into a connector secured on the pads. Wires from the hoses then go to the pulse width modulator secured on the pad by a plastic part made from a 3D printer that is secured to the pad. The voltmeter previously discussed is also mounted here on the pad. This arrangment is explained in the manufacturing instructions and specific parts are shown in the drawing package.

It is noted here that the production and design of the pads and leg straps which hang from the pads are the work of MS candidate Rhet Astle and are not discussed in detail in this document.

4. PVAC System Deliverable

The integration of the components previously discussed along with the pads and leg straps provided by Rhet Astle, a masters student at Utah State University, results in a complete, redesigned PVAC system. The complete cost for one fully operational power/sound system without the pads and stirrups is $1834.66. Outside of the costs of a PVAC system the development costs were $592.22. An operations manual on how to operate the PVAC system is included as Appendix E. The redesigned PVAC system meets the requirements set forth for this project. The fulfilment of the design requirements are justified by the testing section of this document. A brief summary of the design requirements and results are shown as a summary in table 2 below. Figure 4 on the following page shows a diagram of the system and its components. Each of these components except for the pads are diagramed in detail in Appendix B in the drawing package.

Description	Requirement	Goal	Results	Pass/Fail
Runtime	21 + min	30 + min	31.5 min	Pass
Weight	Less than 64 lbs.	Less than 54 lbs.	52.2 lbs.	Pass
Power Supply	External/Battery	N/A	Yes	Pass
Monitor System	Pressure & Voltage	N/A	Yes	Pass
Sound	20 dB reduction	40 dB reduction	20.6 dB Reduction	Pass
Budget	$4000	N/A	$2,570	Pass

Table 2: Table of Requirements, Goals, Results, and Whether the Requirement was met.

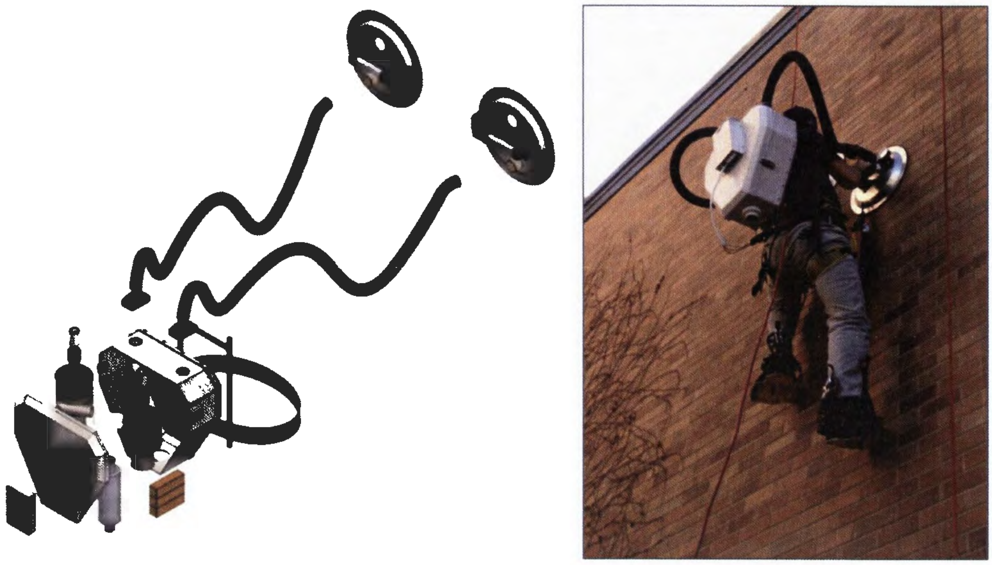


Figure 5: Diagram of complete PVAC system and Team Member Climbing a Brick Wall

5. Testing Justification Data

5.1 Suction Test

Description: The system needs to hold a total of 300 lbs. vertically on unpainted OSB wafer board. The test was performed by attaching the suction pads to a vertical piece of OSB wafer board and applying a load to the d-ring located in the bottom of the pad. OSB wafer board was chosen for the test because it has similar suction results as the brick on the EL building at Utah State University. The system is often demonstrated on this building. The load was static and slipping was determined by visually inspecting the pad for movement on the board. Total weight held by the pad at maximum suction was also tested.

Results: 400 lbs. of weight was found to be supported at a max suction of 84 inH_2O. The required weight of 300 lbs. was found to be supported by a suction of 60 inH_2O.

5.2 Weight vs. Suction Test

Description: Data about the weight and suction is very valuable because of the difference in user weight. This test was performed by attaching the pad to a vertical piece of un-painted OSB wafer board and then applying incrementing loads to the d-ring. OSB wafer board was chosen for the test because it has similar suction results as the brick on the EL building at Utah State University. The suction was then reduced until the pad slipped. Slipping was determined by visually inspecting the pad for movement on the board. The minimum suction needed to hold the weight was then recorded and displayed in the figure bellow.

Results: Figure 6 below shows the increase in the pressure at which the system will fail for the given weight of the user.

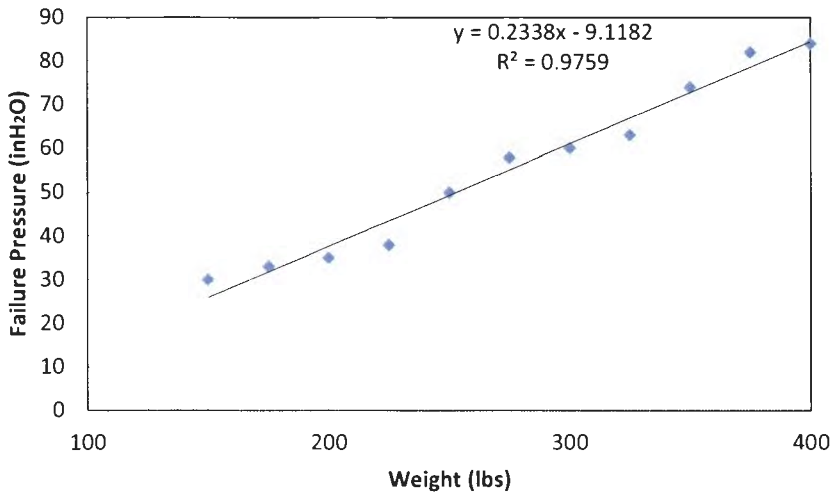


Figure 6: Vacuum Pressure vs. Max Weight before Slipping

5.3 Horizontal Suction Test

Description: This test was performed by attaching the pad to a horizontal surface and then applying a perpendicular load to the handle until the pad was pulled from the surface. The surface is independent of the results as long as 70 inH_2O can be reached when the load is applied.

Results: A maximum of 398 lbs. was found to be held by 70 inH_2O. The original suction was 80 inH_2O but it was reduced when the load was applied because the pads ability to seal on the surface was reduced.

5.4 Common Exhaust Test

Description: The motors were examined both individually and together to inspect for differences in suction due to a common exhaust. This test was performed by running one motor and attaching the pad to the surface. The suction was then monitored while the other motor was started up and attached as well.

Results: No difference in suction was noted during this test.

5.5 Power Consumption Test

Description: The power consumption of each component of the system was measured or researched through manufacture data

Results: Motors require 13.1 amps per motor on high during battery operation. This test was performed by measuring the current going into the motors when the PWM was set to a maximum while using batteries. Two volt meters were wired in parallel to perform this test. The Voltage Display was found to require .02 amps as given in the manufacturer's data. The PWM required .02 amps with 99% efficiency of PWM at max output as delineated in the manufacturer's data.

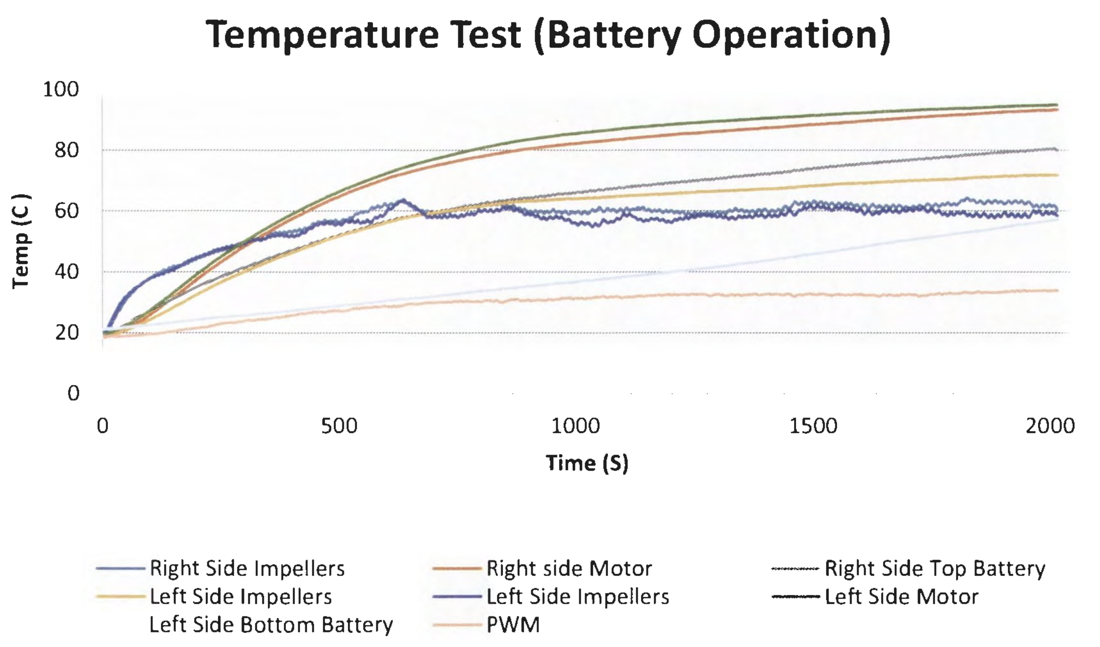
5.6 Temperature Test (Battery Operation)

Description: Temperature tests were performed to locate potential thermal overload locations. Tests were performed at ambient temperature (20 C) while the pads were alternated from suction to open approximately every 5 seconds for the life of the batteries. The motors were fully enclosed in the sound proof box and foam throughout the test. The pads were alternated to simulate a climbing condition. Thermal couples were placed in the following places. The thermocouples were accurate to 2.2 degrees Celsius.

Results: The results for temperature are shown below in table 3 and displayed in graph 1.

Thermocouple	Position	Max Temperature Reached (C)
Thermocouple 1	Right Side Motor Impellers	64.3
Thermocouple 2	Right Side Bottom Metal of motor	93.2
Thermocouple 3	Right Side Batteries (top battery)	80.5
Thermocouple 4	Ambient Temp in box	71.8
Thermocouple 5	Left Side Motor Impellers	63.8
Thermocouple 6	Left Side Bottom Metal of motor	94.9
Thermocouple 7	Left Side Batteries (bottom battery)	57.1
Thermocouple 8	PWM	34.0

Table 3: Battery Operation Max Temperature Results



Graph 1: Battery Operation Temperature Graph

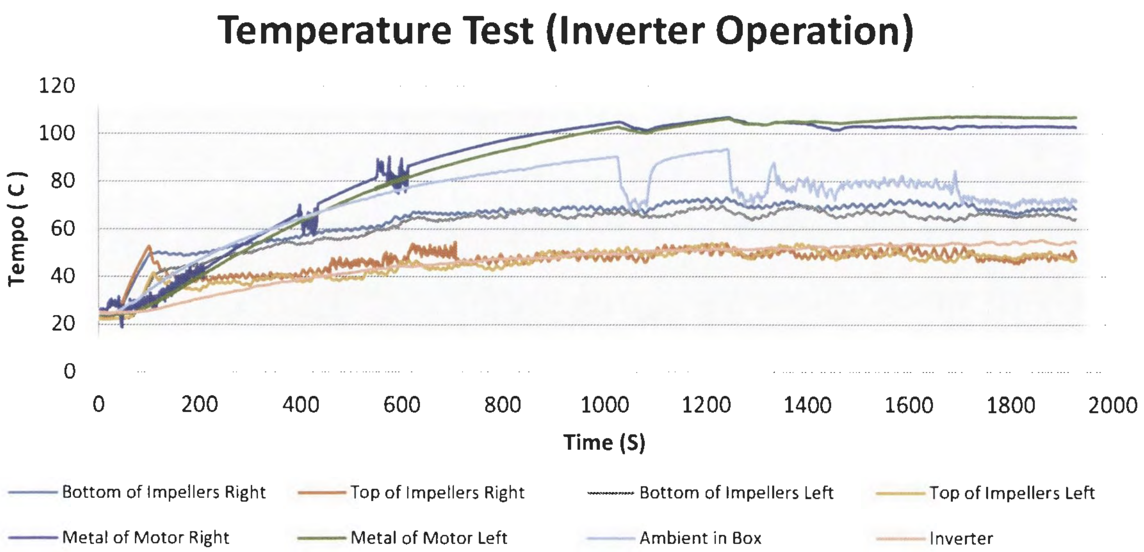
5.7 Temperature Test (Inverter Operation)

Description: Temperature tests were performed to located potential thermal overload locations during inverter operation. Tests were performed at ambient temperature (20 C) while the pads are alternated from suction to open approximately every 5 seconds for the life of the batteries. The motors were fully enclosed in the sound proof box and foam throughout the test. The pads were alternated to simulate a climbing condition. The inverter was mounted on the outside of the sound proof case. Thermal couples were placed in the following places. The thermocouples are accurate to 2.2 degrees Celsius.

Results: The results for temperature are shown below in table 4 and displayed in graph 2.

Thermocouple	Position	Max Temperature Reached (C)
Thermocouple 1	Bottom of Impellers Right	73.1
Thermocouple 2	Top of Impellers Right	54.4
Thermocouple 3	Bottom of Impellers Left	70.0
Thermocouple 4	Top of Impellers Left	54.2
Thermocouple 5	Metal of Motor Right	106.8
Thermocouple 6	Metal of Motor Left	107.2
Thermocouple 7	Ambient in Box	93.4
Thermocouple 8	Inverter	55.4

Table 4: Inverter Operation Max Temperature Results



Graph 2: Inverter Operation Temperature Graph

5.8 Thermal Cutoff Test

Description: Thermal cutoff will be tested and researched through manufacture data. The Thermal cutoff will be determined by placing the motor inside of the sound insulation and inside of an air tight box to simulate the sound proof properties. The motor inlet was covered and the vacuum pressure was monitored. The motor was turned on high for 33 minutes.

Results: No manufacture data was obtained and no thermal cutoff or failure point was found in the motor. The maximum temperature was monitored at various points is displayed below in table 5. Vacuum pressure was not affected at these temperatures.

Placement	Top of Impeller	Bottom of Impeller	Base of Impeller	Metal on Motor	Plastic on Fan
Max Temp (C)	**208.0**	191.9	169.1	161.4	156.0

Table 5: Thermal Cutoff Test Results

5.9 High Voltage Test

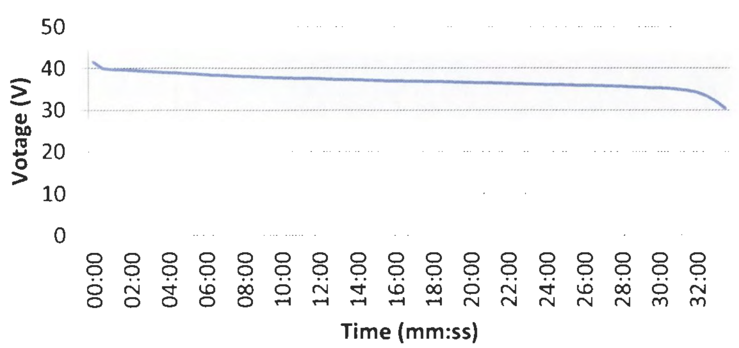
Description: Motors were tested to verify the effect of running them at 48 volts. This was done by wiring the motors to the 48 volt converted and allowing them to run for 35 minutes.

Results: A single motor was tested for 35 minutes and no damage or loss of suction was found after the test. The inverter was not able to supply enough current to run both motors at 48 volts for 35 minutes. The inverter was capable of supplying a maximum of 45 volts to both motors. Both motors were tested at 45 volts and no damage or loss of suction was discovered throughout the test. It is recommended that a maximum of 43 volts be supplied to each motor to prevent inverter overload.

5.10 Battery Profile and Discharge Test

Description: The battery voltage profile was collected over time while the motors were run on high and the pads were cycled from attached for 5 seconds to detach for 5 seconds to simulate a climbing situation. The voltage was measured with a volt meter and the time was recorded on a timer. The suction was measure using the vacuum gauge. The batter low voltage cutoff was researched through manufacture data to determine the discharge point that will damage the batteries.

Results: Minimum suction was reached at 34.6 volts. A minimum of 15 volts (30 volts in the system) should always be maintained in the batteries according to manufacture data. The battery voltage profile is shown in graph 3.



Graph 3: Battery Voltage Profile

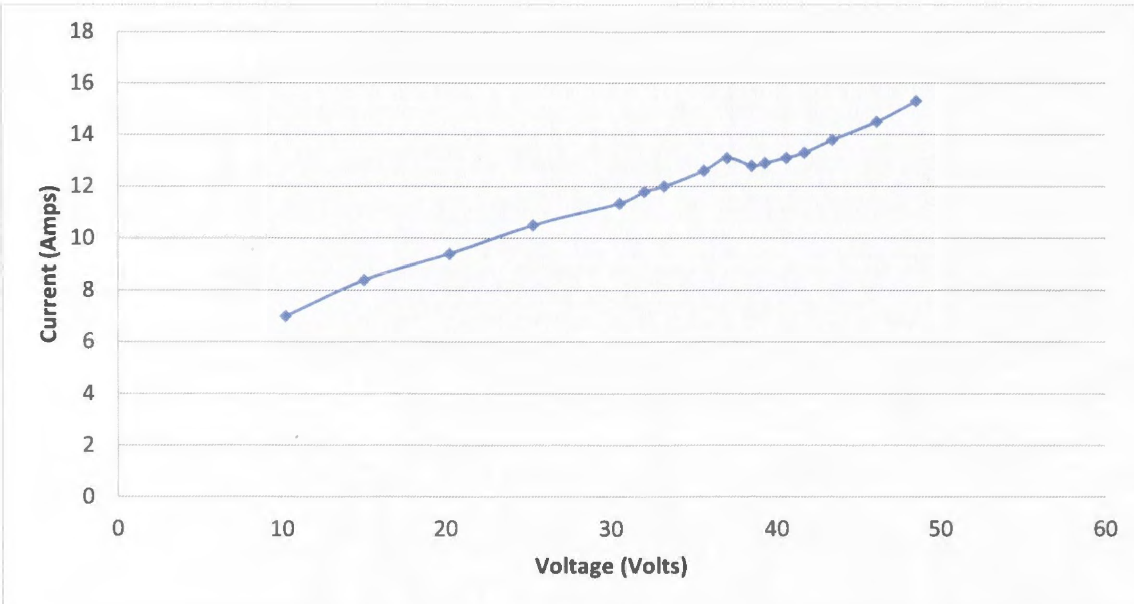
5.11 Voltage Current Suction Test

Description: The voltage going to each motor was tested while simultaneously recording the current going to each motor and the vacuum pressure while the pad was attached to a clean smooth surface. A sanded and sealed cement floor was used on this test. The cement floor performs similar to OSB wafer board for suction requirements.

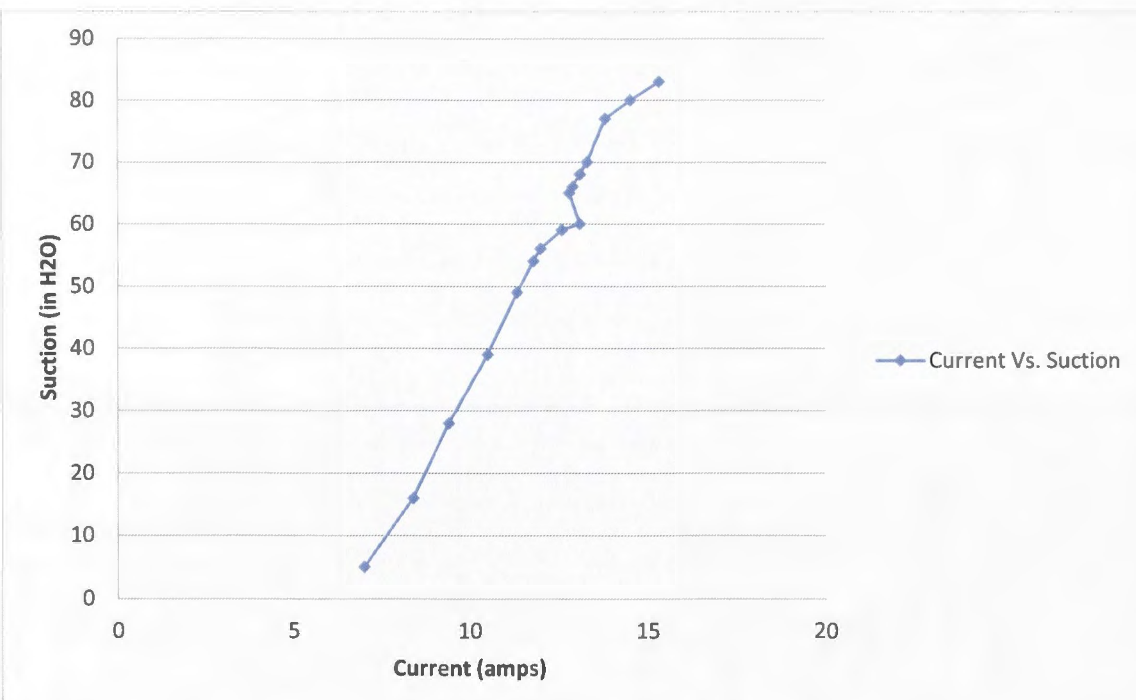
Results: The results for voltage vs current vs suction is shown in table 6. Voltage vs current, current vs suction, and voltage vs suction is shown in graphs 4, 5, and 6 respectively.

Voltage (Volts)	Current (amps)	Suction (in H_2O)
10.2	7.0	5.0
15.0	8.4	16.0
20.2	9.4	28.0
25.3	10.5	39.0
30.5	11.34	49.0
32.0	11.8	54.0
33.2	12.0	56.0
35.6	12.6	59.0
37.0	13.1	60.0
38.5	12.8	65.0 (reset pad)
39.3	12.9	66.0
40.6	13.1	68.0
41.7	13.3	70.0
43.4	13.8	77.0 (reset pad)
46.1	14.5	80.0
48.5	15.3	83.0

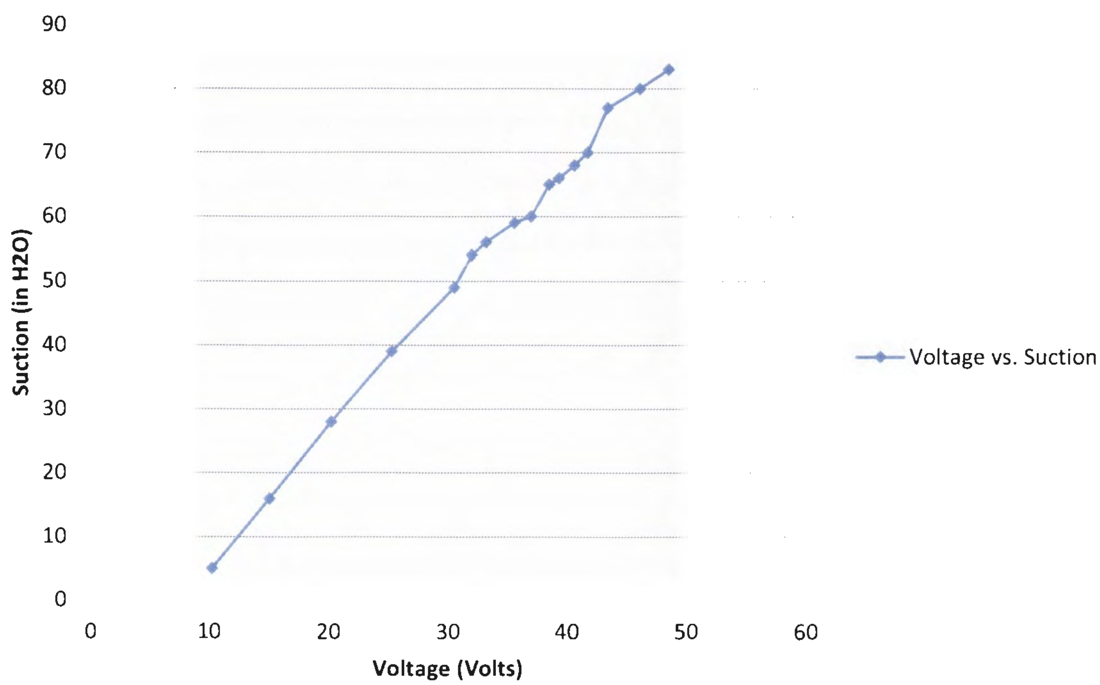
Table 6: Voltage vs. Current vs. Suction Table of Results



Graph 4: Voltage Vs Current Graph



Graph 5: Current vs. Suction Graph



Graph 6: Voltage vs. Suction Graph

5.12 Weight Test

Description: This test was performed in the SPL using a calibrated hanging scale. Components were weighed separately and individual weights were totaled. The backpack was weighed with eight batteries inside, while the pads, hoses, and foot straps were weighed separately.

Results: The calculation below shows how the total weight of the system was determined to be.

Backpack (w/ 8 batteries):	31.6 lbs. (25.6 lbs. with inverter)
Pads (together):	9.6 lbs.
Left hose:	2.4 lbs.
Right hose:	2.4 lbs.
Left foot strap:	2.6 lbs.
Right foot strap:	2.6 lbs.
Total weight:	51.2 lbs. (Total weight with inverter: 45.2 lbs.)

5.13 Runtime Test

Description: A runtime test measured the climbing time when the motors were on high with fully charged batteries. The batteries were considered dead when minimum suction could not be obtained. Minimum suction for climbing was determined to be 60 (in H20) which is the lowest suction where 300 lbs. can be held. The pads were cycled from attached to detach every 5 second to simulate climbing conditions. The pads were attached to clean smooth sealed cement which has similar vacuum pressure capabilities as OSB wafer board and the brick on the EL building at Utah State University.

Results: 31.5 min of safe runtime.

5.14 Inverter Test

Description: The inverter was tested for performance and for thermal overload. The first test consisted of the inverter being placed inside of the sound insulating box near the top next to the impellers. Thermocouples were attached to the motor and the inverter. The motors were run at 45 volts while the pads were cycled from attached to detach every 5 seconds to simulate climbing. The second test consisted of the inverter being mounted on the outside of the lid under a protective cover. The Inverter was open to ambient air at 20 °C in this test. The thermocouples and pad were placed in the same location and the motors were run at the same voltage. The test lasted for 30 min. Manufacture stated a thermal cut off at 125 °C at the PCB.

Results: During the first test the inverter shut off due to thermo-overload after 7.5 min at 109.3 °C. During the second test the inverter operated continuously for 30 min and reached 55.4 °C.

5.15 Electronics Test

Description: The battery voltage display will be compared to a Radio Shack volt meter provided by the SPL to ensure accuracy of the voltage being displayed

Results: The Radio Shack Volt meter is the same as the LED display.

5.16 Sound Testing

Description: Sound testing was performed in the anechoic chamber at Utah State University. The sound meter was pointed directly at the system and measurements were taken at 3 feet and 1 foot from all directions. The measurements were taken with the pads sucked and open from a smooth flat surface. The original system tested at an average of 91.6 decibels.

Results: Table 7 shows the results for the sound tests. Overall average of 70.9 dB was found for the system as a whole.

Sound Level (dB)	Top	Bottom	Right	Left	Front	Back
Attached 1 Foot	69.1	80	69.2	73.5	71.4	70.5
Attached 3 Feet	68.3	71	65.9	67.3	68.1	69
Free 1 Foot	69.5	80	71	72.8	71.8	74
Free 3 Feet	71.8	74.5	65	68.5	69	72

Table 7: Sound Testing Results

6. Conclusion

The PVAC system as redesigned by the Climbers at Utah State University is in compliance with all the requirements set forth by the customers Dr. Hansen and Rhet Astle. The system is now significantly quieter, lighter, and provides for an overall better quality climb than the previous system. This project in conjunction with the work from Master's student Rhet Astle will be presented to the Air Force Research Laboratory this summer.

Appendix A –Decision Matrices

The following matrices were used when choosing the major components of the system. A legend is provided below.

(green)	Exceeds Requirements	(yellow)	Meets Requirements	(red)	Does Not Meet Requirements

Trade Study 1: Motor Comparison. Motor 2 was selected

Requirement	Motor 1	Motor 2	Motor 3	Motor 4
Type	2 stage Brushless	3 stage	2 stage	2 stage
Suction (inH20)	86	137	113.4	104.6
Volts	36	36	120	240
Amps	17.7	17.9	9	5.5
Weight (lbs.)	10	7	unknown	unknown
Cost (each $)	586	92	150	216

Trade Study 2: Voltage Reduction Comparison: The Pulse Width Modulator was selected.

Requirement	Product 1	Product 2	Product 3
	Pulse Width Modulator	Variable Resistor	Switching Regulator
Reduce Power Consumption	Runs at 5% to 100%	Consumes Power	Reduces Power
Reduce Noise	X unknown	X unknown	X unknown
Less than 0.55 lbs.	0.29	0.51	0.10
Less than $25	20.38	14.82	2.13
Handles 20 A	40	3	3

Trade Study 3: Battery Selection Comparison. Product 3 was selected.

Requirement	Product 1	Product 2	Product 3	Product 4
	Gens ACE 5500-18.5	Gens ACE 5500-18.5	Gens ACE 4000-18.5	Gens ACE 4000-18.5
Amp Hours	5.5	5.5	4.0	4.0
Number of Batteries	4	6	4	6
Combined Amp Hours	11	16.5	8	12
Weight (lbs.)	6.58	9.87	4.63	6.95
Running Time (min)	33.6	50.5	24.5	35.7
Cost (total $)	268	402	268	402

Trade Study 4: Backpack Case Design Comparison. Product 4 was selected

Requirements	Product 1	Product 2	Product 3	Product 4
	Solid Grey	Gemstar	South-Pack	In-house
Purchase Requirement	20 units	1 unit	1 unit	1 unit
Less than $300	210	400 (quotable)	400 (quotable)	Approximately 250
Less than 5 lbs.	2.5	~ 8.0	~10.0	< 3.0
Air Tight	No	No	Yes	Yes

Trade Study 5: Noise Reducing Methods Comparison: Convoluted foam was selected.

Requirement	Product 1	Product 2	Product 3
	Acoustic Foam (convoluted)	Wall Blanket	Eggcrate Foam
Density (lbs./ft^3)	1.5	0.25	1.2
Cost ($/ft^2)	2-14	4.5-6	0.825 or 1.175
Thickness (in)	1 or 2	1	1.5 or 2.5
Max Temp. (°F)	250	250+	250
Noise Reduction Coefficient (NRC)	0.7 or 0.8	0.7	0.45 or 0.6
Flexibility	Easy to cut and shape	Difficult to manipulate	Easy to cut and shape

Trade Study 6: Exhaust Muffling Comparison: Economy PVC was selected.

Requirement	Product 1	Product 2	Product 3	Product 4
	Economy PVC	Industrial PVC	Rigid Noise Reducing	Intake
Cost ($)	15.00	37.00	12.97	9.95
Weight	0.5	0.5-1.0	0.3	0.5
Availability	1 week shipping	1week shipping	Local	1 week shipping
Effectiveness/ Reviews	Reduces high frequencies	Decrease in total noise	No difference in noise level	No reviews

Appendix B Drawing Package

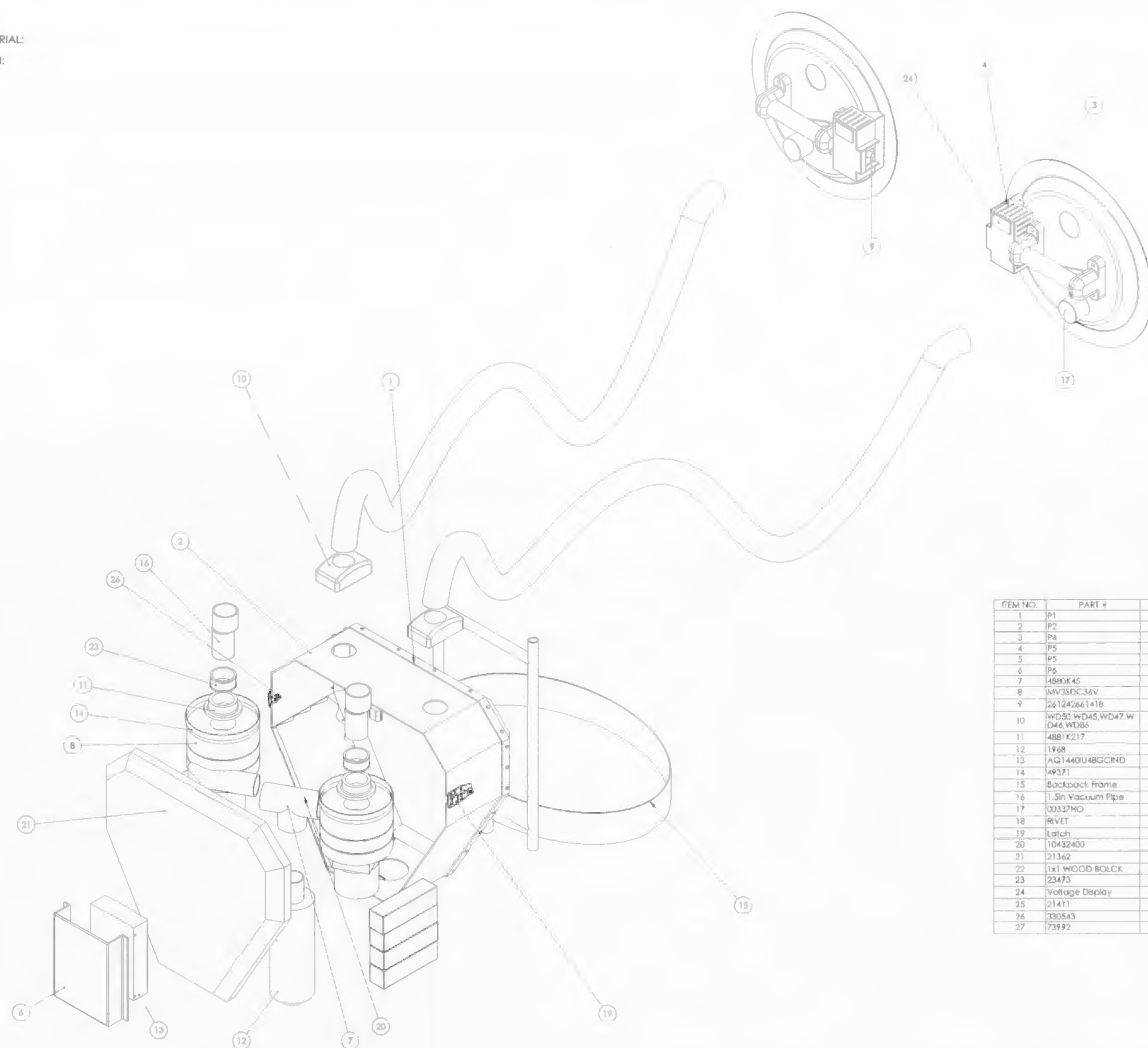
The Following Pages Contain the Drawing Package for the PVAC System

Drawing Order
Drawing 1: Assembly Package
Drawing 2: Backpack Lid
Drawing 3: Middle Section of Backpack
Drawing 4: Pulse Width Modulator Mount
Drawing 5: Pulse Width Modulator Cover
Drawing 6: Inverter Cover
Drawing 7: PVC Flanges
Drawing 8: Wiring Diagram
Table 1: Wiring Diagram Information Table

NOTES:

1. MATERIAL:
2. FINISH:

20



ITEM NO.	PART #	DESCRIPTION	Manufactuer	Location	Price	QTY
1	P1	LID OF BACKPACK				2
2	P2	MIDDLE SECTION				1
3	P4	PWM MOUNT				2
4	P5	PWM COVER				1
5	P5	PWM COVER				1
6	P6	Inverter Cover				1
7	4880K45	1.5" PVC Vacumn Tee		Wimmers	$2	1
8	MV35DC36V	Vacuum Motor	Kleen Pro Vacuum Supplies	www.kleenpro.com	$92	2
9	261242661418	Pulse Width Modulator		www.ebay.com	$14.99	2
10	WD50,WD45,WD47,WD46,WD86	Vacuum Hose Connector		www.power-flite.com	$22.36	2
11	4881K217	PVC Flanges		mcmaster.com	$10.92	2
12	1968	Small Muffler	Central Vacuum	www.centralvacuumstores.com	$15	1
13	AQ1440IU48GCIND	Inverter	Synqor	www.synqor.com	$854	1
14	49371	Hose Clamps		Lowes	$2.06	2
15	Backpack Frame	Backpack Frame		amazon.com	$36.99	1
16	1.5in Vacuum Pipe	1.5" Vacuum Pipe		Whimmer	$2.06	2
17	00337HO	Pressure Gauge	Cole Parmer	www.coleparmer.com	$53.32	2
18	RIVET	RIVET 1/8		Ipaco	$.25	23
19	Latch	Latch	Gate House	Lowes	$ 3.37	3
20	10432400	Convaluted Foam		www.soundproofcow.com	$58.22	1
21	21362	Battery 4000mA	Zippy		$	8
22	1x1 WOOD BOLCK	Wood Block				4
23	23473	Rubber Coupler w/ Hose Clamps		Lowes	$4.33	2
24	Voltage Display	Voltage Display		wwww.ebay.com	$19	2
25	21411	Pipe Insolation		Lowes	$1.64	2
26	330543	Fender Washer		Lowes	$	3
27	73992	ABS coupler		Lowes	$2.10	2

DIMENSIONS ARE IN INCHES

THIRD ANGLE PROJECTION

SOLIDWORKS 3D

Climbers

ASSY, PVAC

GROUP 8

GROUP 8

0001

A

DO NOT SCALE DRAWING

SIZE: D

4/1/2014

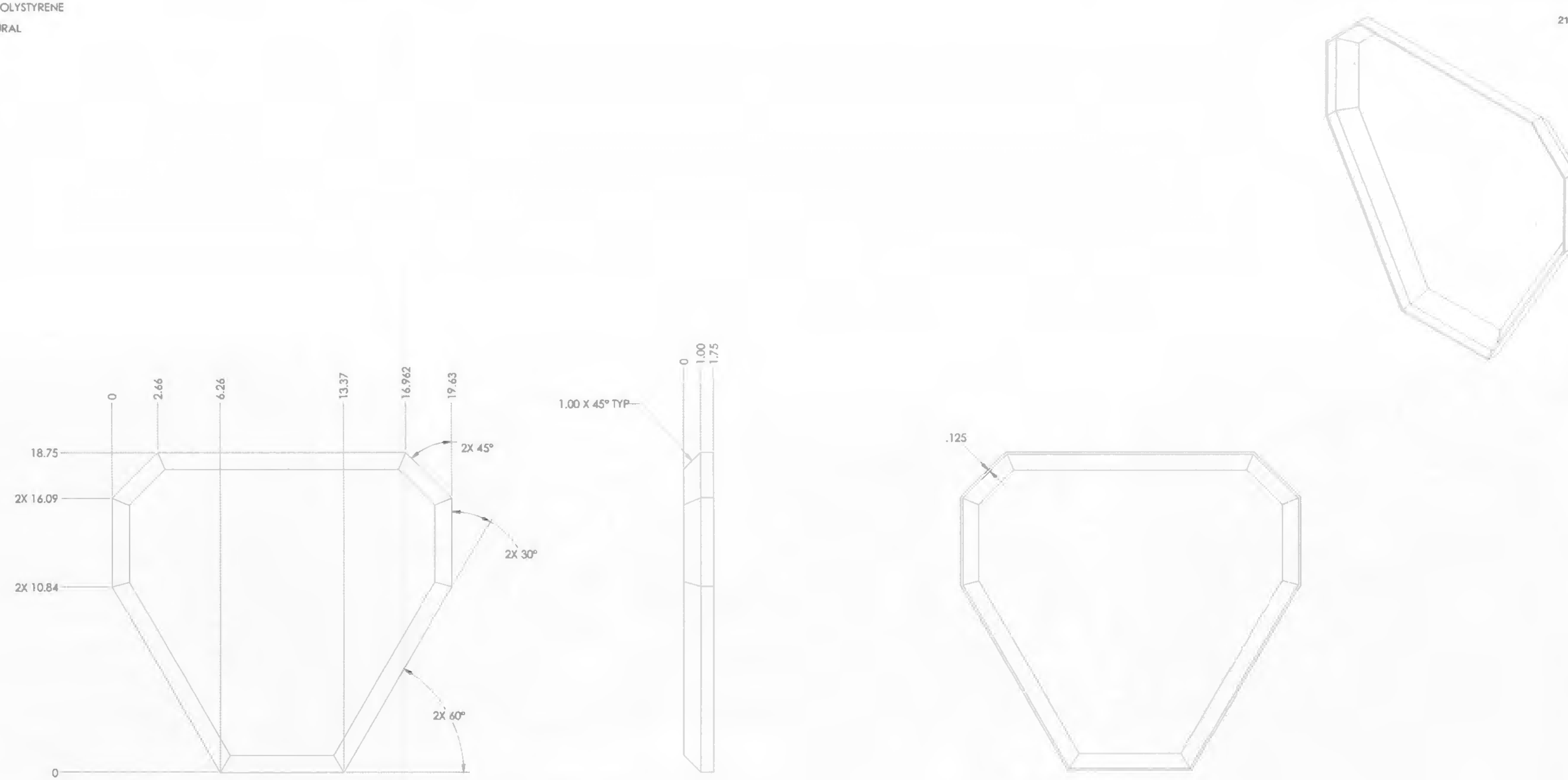
173.85

SHT 1 OF 1

NOTES:

1. MATERIAL: POLYSTYRENE
2. FINISH: NATURAL

REV.	ZONE	DESCRIPTION	DATE	APPROVED
A		INITIAL RELEASE		



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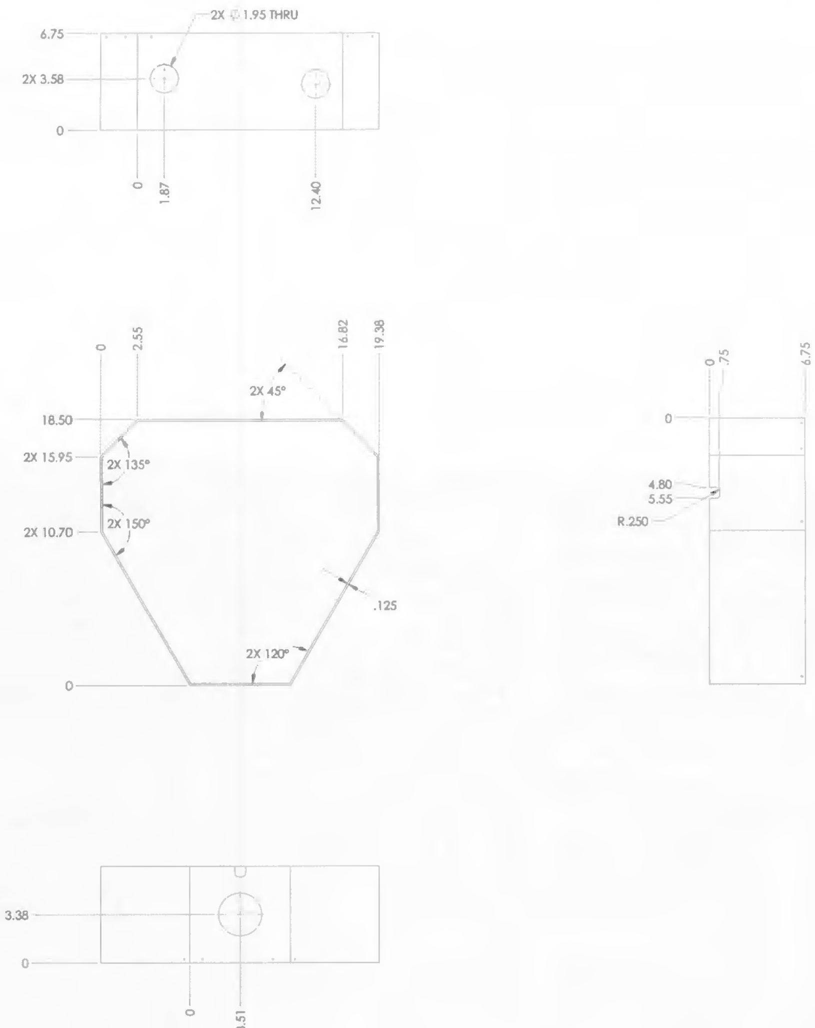
THIRD ANGLE PROJECTION		LID OF BACKPACK
SOLIDWORKS 3D		GROUP 8 / W.ELDER / 4/1/2014 — P1 — A
DO NOT SCALE DRAWING	SIZE D	1:66 — SHT 1 OF 1

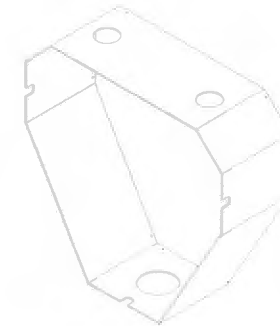
NOTES:

1. MATERIAL: POLYSTYRENE
2. FINISH: NATURAL

REVISIONS				
REV.	ZONE	DESCRIPTION	DATE	APPROVED
A		INITIAL RELEASE		

22





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THIRD ANGLE PROJECTION		MIDDLE SECTION
SOLIDWORKS 3D		GROUP B / W.ELDER / 4/1/2014 — P2 — A
DO NOT SCALE DRAWING	SIZE D	1:90 — SHT 1 OF 1

NOTES:

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2. FINISH: NATURAL

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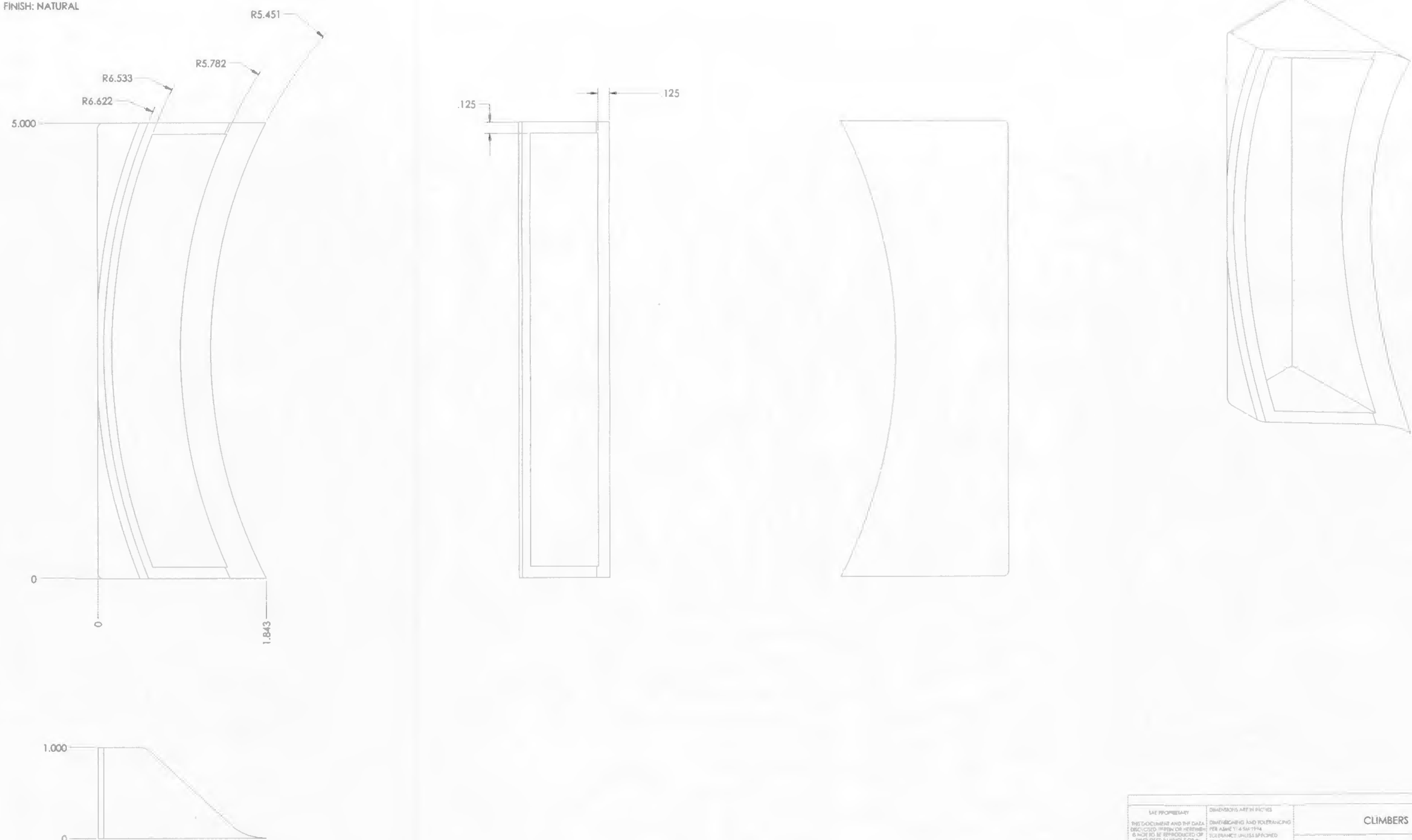
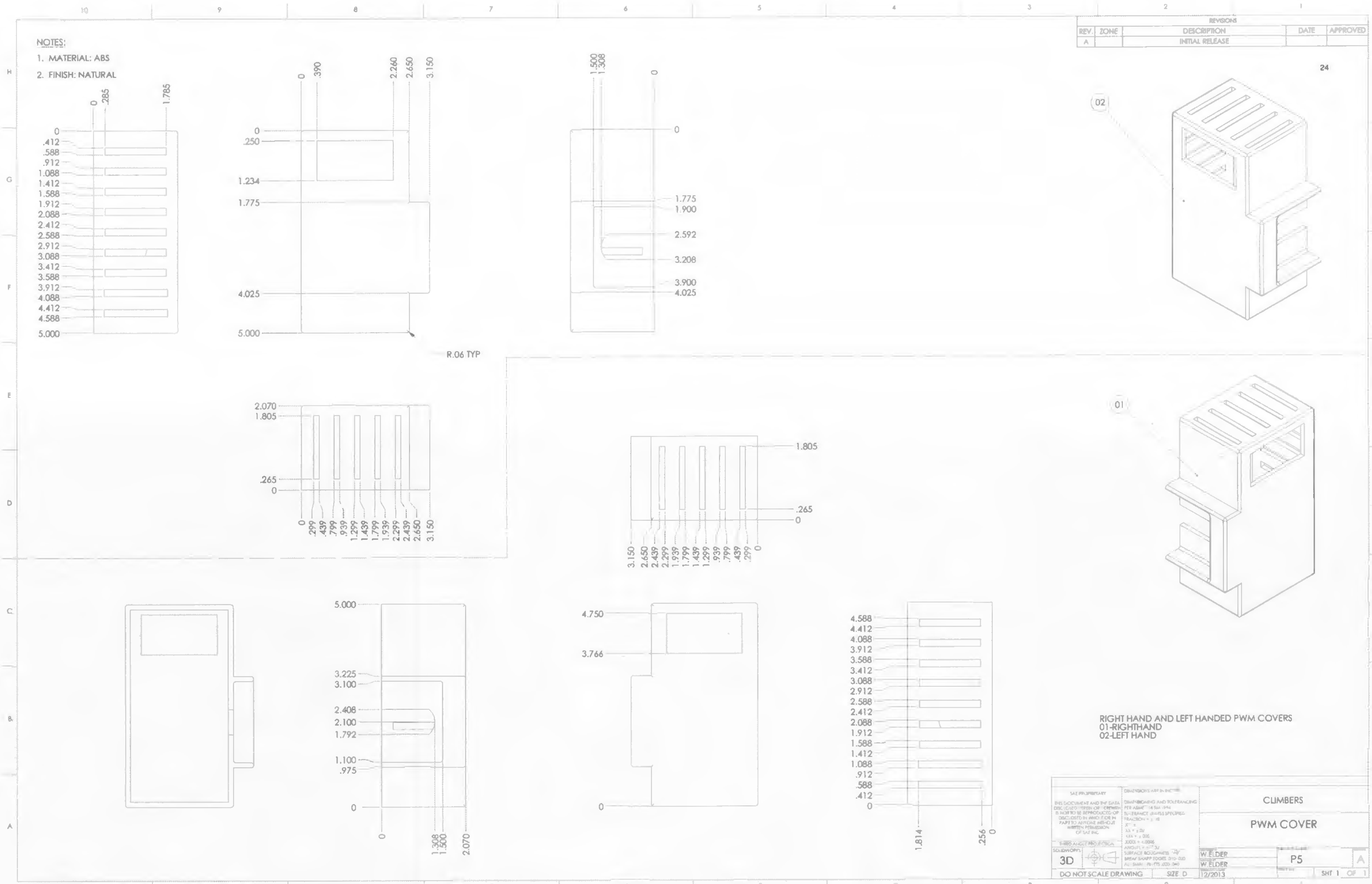
A		INITIAL RELEASE		

23



SAE PROPRIETARY	DIMENSIONS ARE IN INCHES DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994	CLIMBERS
THIRD ANGLE PROJECTION		PWM MOUNT
SOLIDWORKS 3D		W. ELDER W. ELDER
		P4
		A
DO NOT SCALE DRAWING	SIZE: D	12/2013
		SHT 1 OF 1



NOTES:
1. MATERIAL: ABS
2. FINISH: NATURAL
REVISIONS
REV. ZONE DESCRIPTION DATE APPROVED
A INITIAL RELEASE
24
02
01
R.06 TYP
RIGHT HAND AND LEFT HANDED PWM COVERS
01-RIGHTHAND
02-LEFT HAND
SAE PROPRIETARY
THIRD ANGLE PROJECTION
SOLIDWORKS
3D
DO NOT SCALE DRAWING
SIZE D
CLIMBERS
PWM COVER
W.ELDER
W.ELDER
12/2013
P5
A
SHT 1 OF 1

NOTES:

1. MATERIAL: POLYSTYRENE
2. FINISH: NATURAL

REVISIONS				
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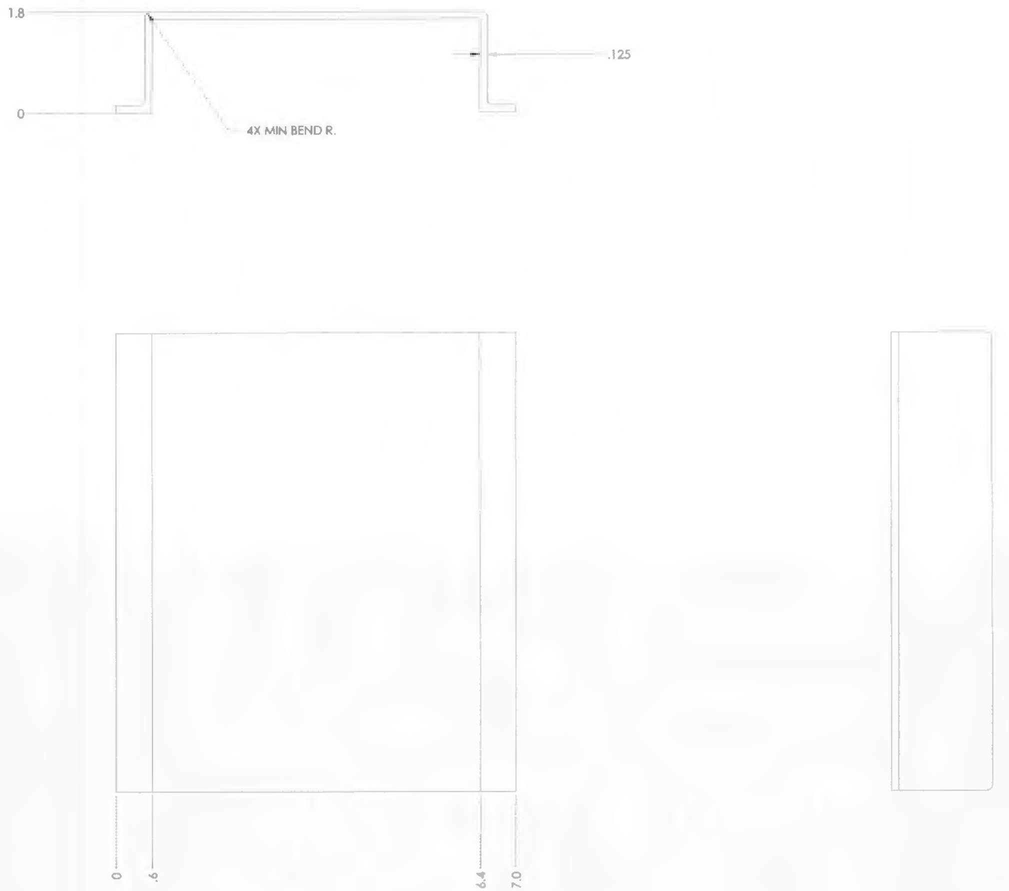
A		INITIAL RELEASE		

25



SAE PROPRIETARY	CLIMBERS
THIS DOCUMENT AND THE DATA DISCLOSED HEREIN OR HEREWITH IS NOT TO BE REPRODUCED OR DISCLOSED IN WHOLE OR IN PART TO ANYONE WITHOUT WRITTEN PERMISSION OF SAE INC.	Inverter Cover
DIMENSIONS ARE IN INCHES; DIMENSIONING AND TOLERANCING PER ASME Y14.5M-1994; TOLERANCE UNLESS SPECIFIED: FRACTION = ±1/8; X = ±.1; XX = ±.02; XXX = ±.005; XXXX = ±.0005; ANGLES = ±0° 30'; SURFACE ROUGHNESS; BREAK SHARP EDGES .010-.020; ALL SMALL FILLETS .020-.040	GROUP 8
THIRD ANGLE PROJECTION	W.ELDER
SOLIDWORKS 3D	P6 — A
DO NOT SCALE DRAWING — SIZE: D	4/14/2014 — 0.377 — SHT 1 OF 1

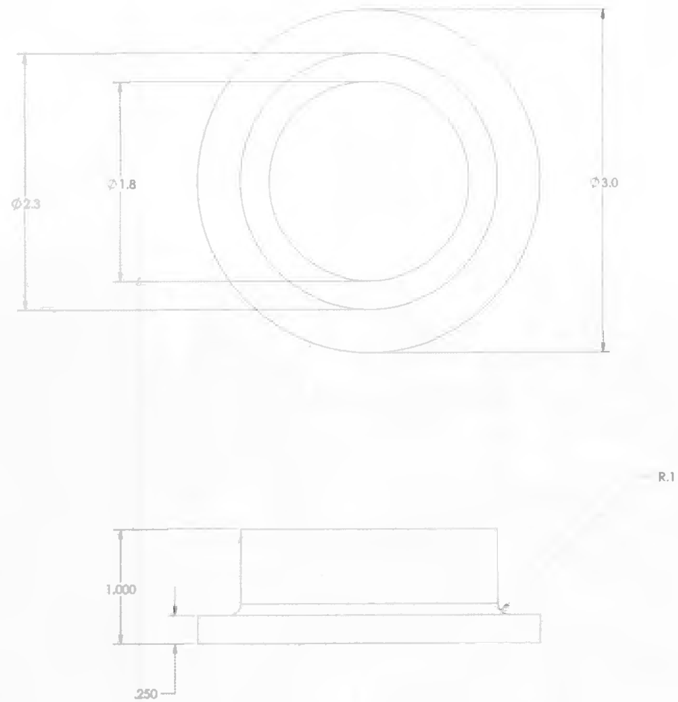
REVISIONS				
REV.	ZONE	DESCRIPTION	DATE	APPROVED
A		INITIAL RELEASE		

26

NOTES:

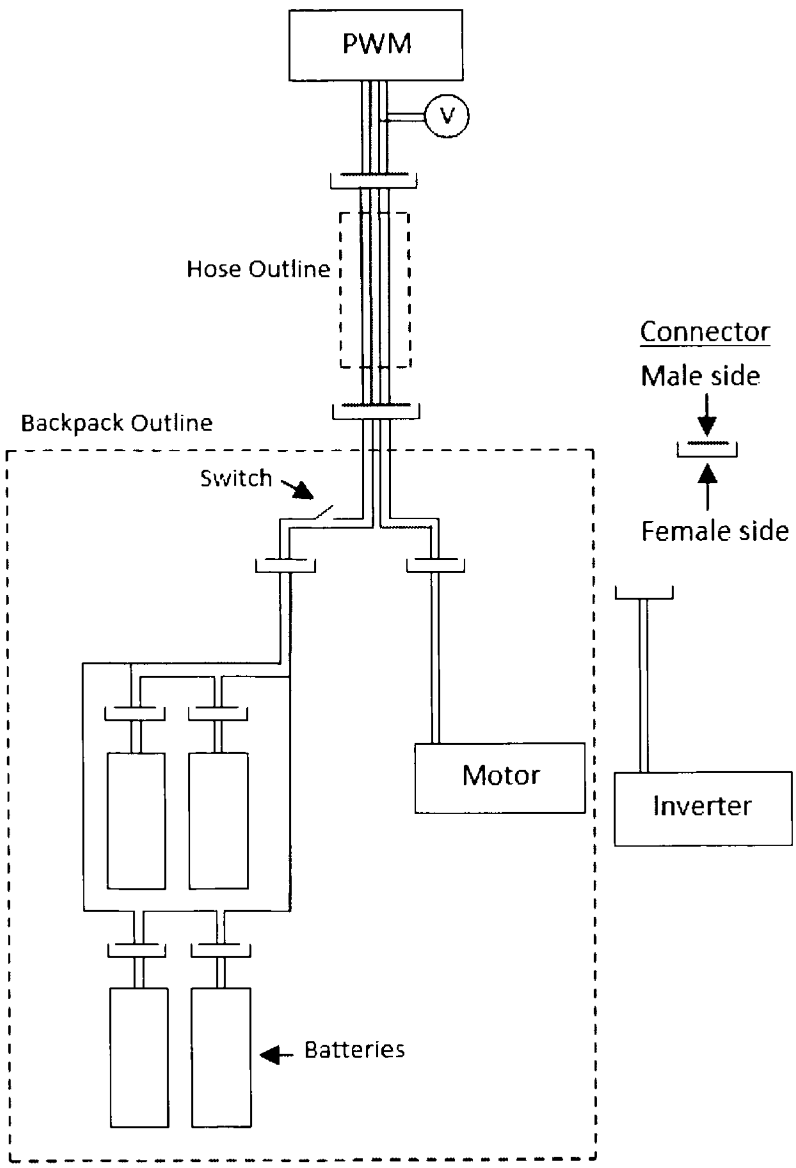
1. MATERIAL: ABS
2. FINISH: NATURAL

3. PURCHASE MCMASTER PART #4881K217 AND ALTER TO SPECIFICATIONS



SAE PROPRIETARY	DIMENSIONS ARE IN INCHES	CLIMBERS
THIRD ANGLE PROJECTION		PVC Flanges
SOLIDWORKS 3D		GROUP B / W.ELDER — P7 — A
DO NOT SCALE DRAWING	SIZE: D	4/1/2014 — SHT 1 OF 1

For the following wiring diagram Please see the key presented in Table 1 as to specific wiring.



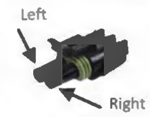
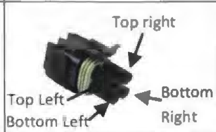
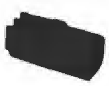
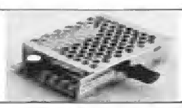
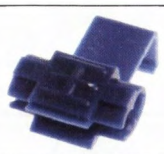
#	Diagram	Description: For all cases Positive (red wire) and Negative (black wire)
1		2 way male connector: Wire the positive always through the left and Negative through the right.
2		2 way female connector: Wired the same as 2 way male connector.
3		4 way male connector: Top left =Negative Motor, Top Right = Positive Battery, Bottom Left=Negative Power, Bottom Right, Positive Power.
4		4 way female connector: Wired the same as 4 way male connector.
5		Male terminal: Always Soldered to the wire put in the Female connectors.
6		Female terminal: Always Soldered to the wire put in the Male Connectors.
7		Pulse Width Modulator: from the left Positive to power, Negative to Power, Positive to Motor, Negative to Motor.
8		Hoses: With the hoses oriented vertically connecting to the pad at the top end, the wire from the left side proceeding clockwise, Negative Power, Positive Power, Negative Motor, and then Positive Motor. This should be the same for both ends of the hose where the wires come out while oriented in the same position as that described above.
9		Splice Connectors: used at all junctions of two wires needing to be spliced together.

Table 1: Wiring Key for wiring diagram

Appendix C Bill of Materials

Bill of Materials Template is divided into two sections. The first is the bill of materials for one backpack. The second is for materials purchased during the design of the backpack that is a onetime purchase.

1: Part List for One Complete Backpack

Part Number	Part Name	Quantity	Total Cost
261137583670	DC 9-60V 20A PWM Pulse Width Modulation	2	$29.98
MV3SDC36V	Replacement Motor 3 Stage For Scrubbers 36V	2	$197.32
AQ1440IU48GCIND	Inverter	1	$874
PLA08M7000/AA	Inverter Output Connector	1	$16.01
MS114N/AA	Inverter Output Contact	8	$13.84
DF22B-3S-7.92C	Inverter Input Connector	1	$17.58
DF22A-1416SC	Inverter Input Contact Hirose Power to the Board	3	$8.46
MOLEX 43025-0800	Inverter Controller Connector	1	$1.97
MOLEX 43030-0008	Inverter Controller Contact	1	$1.64
8139PT	Pico 8139PT Gauge 2 conductor Parallel Primary Wire 25' per package	1	$19.73
113443	BernzOmatic 1/8-lb Lead-Free Electronics Solder	1	$9.99
75004	16-14 Gauge grey Cavity seal	7	$16.59
75034	16-14 Ga Male Weather Pack Terminal	38	$8.36
75036	16-14 Ga Female Weather Pack Terminal	38	$8.36
75014	2-way Weather Pack Connector, Tower(female)	15	$8.85
75016	2-way Weather Pack Connector, Shroud(Male)	15	$6.3
75044	4 way square weather pack connector tower(female)	2	$1.54
75046	4 way square weather pack connector tower(male)	2	$1.34
906475	Weather Pack Removal Tool, Delphi	1	$2.77

450971	Hillman group 10 count wire splice connectors by box of 10	1	$1.76
75654	10-Amp Black Single Pole Light Switch	2	$8.9
Amazon1	Backpack frame (Alice Pack Frame with Camo Straps)	1	$36.99
21411	Frost King 1/2-in x 6-ft Foam Plumbing Tubular Pipe insulation	1	$1.64
8734K25	Easy-to-Machine Polystyrene Sheet, 1/8" thick, 40" x 72"	1	$136.33
44933	Arrow 3/16 in Aluminum Rivet (pack)	1	$1.98
113108	Latches (Gatehouse 2-3/4-in Zinc Draw Hasp)	3	$10.11
57851	Bolts and nuts for latches	3	$0.36
330543	Stainless Steel standard Fender Washers 7-count 3/16-in x 1-in	1	$1.98
58123	Blue Hawk 24-count #10 x 1/2-in zinc-plated standard flat washers	1	$1.24
4511	Premium Furring Strip 1x2x8	1	$0.97
58065	Blue hawk 20-count #10-24 zinc - plated standard hex nuts	1	$1.18
62096	Blue hawk 10 count 10-24x5/8 Round-head zinc-plated slotted drive machine screws	1	$1.18
49371	Hose Clamps 7 in x 7-7-1/2-in L Stainless Steel Adjustable Clamp	2	$3.96
9750	J-B Weld 0.85-oz Epoxy Adhesive	1	$5.98
47970	GE 9.8 oz Clear Silicone Window and Door Caulk	1	$5.92
91735A208	bolts for frames type 316 stainless panhead phillips machine screw 8-32nd thread 1.5 in length by box of 25	1	$8.75
DP8405NS Green	Acrylic Adhesive green 45 ml cartridge	1	$15.77
EPX 10/1	mixing nozzles	4	$13.56
90257A009	titanium hex nut, 8-32 thread, 11/32" width 1/8" height	1	$3.83
1968	Muffler Kit	1	$15

10432400	Convoluted Acoustic Foam Pad	0.5	$61.73
00337HO	Dry Gauge 25KPAV-100 1WV 1/4"	2	$106.64
WD45	Suction Coupler	2	$4.08
WD47	Spring	2	$0.32
WD46	Button	2	$1.36
WD86	Button Base	2	$2.26
73992	NIBCO 2-in Dia ABS Cleanout Adapter Fitting	2	$4.2
23952	Charlotte Pipe 2-in x 10-ft 0 PSI ABS DWV Pipe	0.25	$2.41
4881K217	Thick-Wall Dark Gray PVC Unthreaded Pipe Fitting, 2 Pipe size X 6" OD, Flange, Schedule 80	2	$28.44
23473	Rubber Couplers 2 in	2	$8.66
Wimmers1	T - Connector (Standardized central Vacuum size) 2"	1	$2.19
Wimmers2	8' section 2" pipe (Standardized Central Vacuum size)	1	$0.41
232593	Christy's 8 fl oz LO-VOC PVC Cement	1	$5.94
Ebay	USA Green Waterproof Small battery meter voltmeter 8.5-90v DC 2 wire	2	$76
156887	3M 1.88-in x 165-ft White Duct Tape	0.25	$1.745

2: One time use items purchased during the development of the design

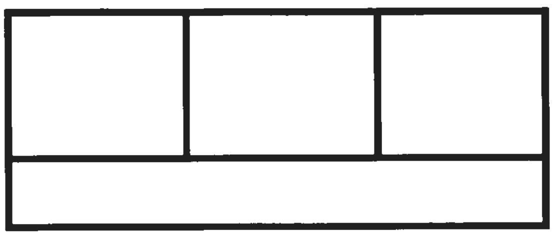
Part Number	Part Name	Quantity	Total Cost
72822	Dremel Fiber Cutting Wheel	1	$6.18
71810300	Binder Clip 8Pk LA	3	$13.47
071641391093	Sharpie metallic S	1	$5
74794	1/2 x48 x 96 Premium MDF board	2	$63.44
26420003	Random PVC Stuff	1	$14.18
06614	Stratford CT 06614 Zone-8 shipping of 3 lb 10.6 oz	1	$13.38

41150	Elmer's Carpenter's 16-oz Wood Glue Adhesive	1	$4.98
251041	Gator 8-Pack 220-Grit 9-in W x 11-in L Multi-Surface Power Sandpaper	1	$3.98
249463	Sylvania 8-pack 60-Watt A19 Medium Base Soft White Dimmable Incandescent Light Bulbs	1	$4.48
161710	M-D Building Products 0.6-in x 10-ft Brown EPDM Rubber Window Weatherstrip	1	$7.86
1030	2x3x96 Kiln-Dried Whitewood Stud	1	$1.98
1TA-49406	Chamfer 45 1/2 Shank	1	$10
4511	Premium Furring Strip 1x2x8	2	$1.94
313147	25-ft 14-AWG Stranded Red GPT Primary Wire	1	$4.96
313148	25-ft 14-AWG Stranded black GPT Primary Wire	1	$4.96
130751	2x6x10 top choice kiln-dried douglas-fir lumber	2	$6.52
17365	Grip-Rite 1-lbs #8 x 2 1/2-in Countersinking-head galvanized deck screws	1	$8.47
179709	USP 13/16-in x 3-1/2-in Mending Plate	8	$4.64
20027	Velcro 15'L x 3/4"W Black Universal Sticky Back Tape	1	$16.97
184582	Velcro 4'L x 2"W Black Industrial Strength Roll	1	$8.97
SQ122CUSTOM	Stratiquilt, Single Faced, 1" x4' x4' (Sound Proofing Blanket)	1	$122
4948	Long Muffler	1	$37.95
2786	Intake Muffler	1	$9.95
6084T28	Harsh Environment Low-Voltage DC Connector, 4 pole, 25 Amps	2	$41.08
70595K64	Harsh Environment molded Connector with Cable, Female Receptacle, 4 Poles, 15 Amps	2	$70.54
70595K61	Harsh Environment Molded Connector with cable, Male Plug, 4 Poles, 15 Amps	2	$102.54
22798	NIBCO 2-in Dia ABS Coupling Fitting	2	$1.8

Appendix D Manual for Assembly

This document is not intended to be stand-alone instructions on the manufacturing of the PVAC II, it is simply meant to suggest the order that things should be done and to give helpful hints throughout the process. In all phases of manufacturing, refer to drawings for correct dimensions, configurations, and clarifications.

<u>Plastic Sheet:</u>
The plastic comes in sheets 6x3 feet. These sheets should be divided into 3 pieces 24x25 inches, and a strip 6x1 feet according to the diagram below.



Note: It is important that the long, horizontal cut along the bottom be made first as the long strip will be used later on in the manufacturing process. The vertical cuts may be made in any order.

<u>Vacuforming Process:</u>

- Attach square piece to the wooden frame with six evenly spaced binding clips on each side
- Heat in oven preheated to about 330° F.
- Plastic should be heated until it sags about 4 inches which takes anywhere from 5-10 minutes.
- Suction should be turned on in vacuform box
- Quickly remove plastic from the oven and place on the vacuform box over the mandrel and hold in place until plastic solidifies (usually about 20 seconds). **Note:** If any webbing or defects arise, they can be pressed out within the first 5-10 seconds of the process by hand, with a heat gun, or machined out after the piece cools. If the defects are too severe, put the plastic back into the oven and try again.
- This process is to be done three per PVAC-II unit as the case requires two lids and a back.

<u>Lid and Back Trimming Process:</u> When the plastic sheet is removed from the mandrel and the wooden frame, it should look something like the picture below.

- Remove the extra plastic that sits parallel to the table surface leaving the edge to be a vertical flange. **Note:** The cut does not need to be exact as the edges will be ground off later.
- Draw a line along the inside of the flange marking an appropriate flange length of about one inch.
- Sand edges down to the line allowing the case to lie flat on a table, all of its edges flush with the table surface.
- Remove any webbing or other defects made while forming

Straight connection: Once a lid and a back piece have been made, a connecting piece is made to bridge the gap between the two.

- Cut plastic into a strip 8 inches wide, the length of the plastic sheet.
- Attach one side to the bottom of the mold and using a heat gun, heat the corners and form around until the strip wraps completely around.
- Cut a 2 inch hole in the center of the bottom face to allow for the muffler to come out, and two additional holes are cut in the top section as shown in the drawing for the hose adaptors.
- The two short edges are not attached to one another at this point in the process.
- Place the bottom inch of the piece inside the back piece, drill small rived guide holes, and drive rivets through both pieces every 1.5-2 inches around the piece. **Note:** A heat gun can be used to close the gap between the flange and straight connector piece where needed.
- Connect the short edges using epoxy and attach the modified hose adapter units to the top section.
    - The bottom part of the hose adapter units is curved so it should be ground down so that it lies flat on the top of the backpack.
- Drill small holes are also made to allow for wiring to leave the case and use silicone caulking to form a good seal.

Lid Attachment:

- Attach the clamps to the straight connection piece and the lid piece. The clamps are placed in the centers of the 3 long sides of the case using #10 pan head machine bolts and nuts.

- Inside the lid, a large washer is placed between two nuts.
- Cut a groove about ¾ inches wide and 1 inch deep in the straight connection piece for the lid bolts.
- Line the backpack with the acoustic convoluted foam, attaching it with double sided tape.
- Additional steps for inverter lid:
    - Drill holes at the top of the face of the lid to allow for the inverter and inverter shell to be attached
    - Plastic inverter shell is heated with a heat gun and bent around wooden pieces to match dimensions in drawing.
    - Attach inverter and plastic shell using appropriate screws and washers

<u>Motor Mounting:</u>

- Wrap the vertical parts of the frame in foam.
- Cut two slits for each motor in the back part of the backpack.
- Place a piece of the 1X2 wood between the motor and the backpack back and secure into place with hose clamps.
- Attach PVC T-joint to the exhaust ports on the motors, and attach muffler with the PVC adaptor piece to the other T-joint opening.
- Attach a modified PVC flange to the top of each motor and connect a modified rubber connection to the other end with hose clamps.
    - The modified flange is lathed down to match the dimensions on the drawing.
    - The modified rubber connection is cut in half.
- The other ends of the rubber connections are attached and clamped to the inside of the hose adaptor units.

<u>Electronics:</u>

- Wiring is done according to the wiring diagram in the drawing package.
- The connectors are assembled as follows.
    - Strip the end ½ inch of wire.
    - Solder wire into connector pin male/female.
    - Place a seal over the wire.
    - Place pin into black connector unit.
- Drill 4 holes at the each end of the hoses and run wires through the length of the hose
- Attach the wires at one end to the PWM/voltage monitor and attach the other end to the backpack.

Appendix E Operations Manual

Power Supply Set-up for PVAC 2014 System

Before initiating the set-up of the power supply make sure each PWM dial, located on each suction pad, and are turned to the off position (rotated completely counterclockwise).

Two options for power source

1) Batteries:
   a. Batteries are placed and connections are made inside motor casing
   b. There are 4 batteries per motor (8 total)
   c. Ensure all batteries are fully charged then properly attached to the PVAC system
   d. There are two wire connection systems used to combine the batteries in proper series and attach to each motor
   e. An analog flip switch is located at the head of the electrical connection for each motor (located inside the motor casing)
2) Converter:
   a. Converter is located outside the motor casing
   b. An extension cable is used to connect converter to external power supply which must keep a connection for the full climb.
   c. There is no cut-off on runtime with the converter.
   d. Connections of converter to motor- red wire

Warning: When installing power supply system make sure the connection of the PWM, located at base of external hose, is made with the electrical output of the motor casing before making connection to any power supply. In the case of the batteries first plug in the batteries and then use the analog on/off switch located within the motor casing to hook in the PWM without supplying power while doing so. In the case of the Inverter plug everything before installing the small red wire mentioned in the inverter manual.

Note: A red light will show on the PWM signifying that proper connection of the power supply has been made.

Equipping of the PVAC 2014 System

- Equipping the user to the PVAC is done by setting straps on shoulder and clipping the waist belt.
- User must be wearing a climbing harness
- The climbing harness will have two connections, one to each of the suction pads. Connection is made at the base of the suction pad onto a clip.
- Two foot hold stirrups are to be connected to the suction pads at the same clip located on the base of the suction pad.
- The stirrups can be adjusted to fit the height and preference of the user.

Operating the PVAC 2014 System for Climb

- Establish connection between the climbing surface and pads then turn the dial on the PWM until proper pressure and voltage are met as determined from the weight vs suction tests outlined in the previous document. A separate gauge for pressure and voltage is placed on each pad.
- To remove the pad from surface and begin climbing press on the pressure release valve with the thumb on the pad. As the valve opens pressure is released and pad can be repositioned.

- Once connection and pressure have been restored to a pad the user can then position his/her weight to that pad with use of the stirrup.
- The climber then ascends the wall by this alternating motion between pads.

Warning: Continue to monitor pressure and voltage throughout the climb to ensure they stay within proper levels. Decreases in either parameter will result in loss of suction.